ALCAN LABS
BANBURY

RECOLLECTIONS

1938 – 2003

CONTENTS

1. INTRODUCTION

Recollections is an attempt to record aspects of the life and work at the Banbury Laboratories from its beginning in 1938 until its closure in 2003. The story is told in a number of essays written by scientists and engineers who spent some or all of their working lives at Banbury. Some have recounted the technical work in detail whilst others included reflections on their own personal experiences. Together they describe many of the technical advances made at Banbury that contributed to Alcan's leading position as a global manufacturer and supplier of aluminium. But they also capture something of the spirit of the times and the relationships with the other Alcan Labs, the operating businesses and the academic world. The recollections come from individual memories rather than from archived records.

Hopefully any errors or omissions are minor. We cannot claim this to be a total picture or a totally accurate picture. More could have been written about many aspects of the Lab's life and work but much has been lost to time, especially from the early years, and not everyone felt they wanted or were able to contribute. We are grateful to all contributors however great or small the efforts involved, and have tried to indicate authorship where possible, but apologise if we have failed to acknowledge appropriately any particular contribution.

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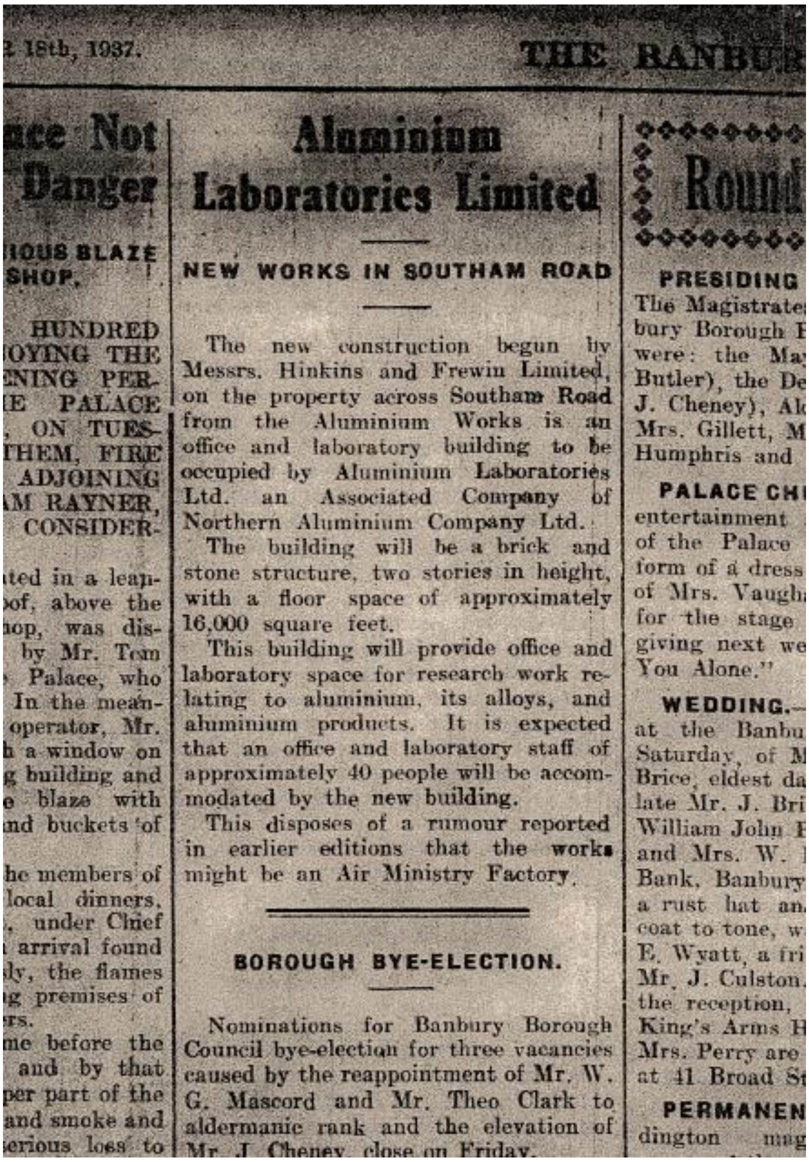
2. SEVEN DECADES

Peter Band

On the 18th of November 1937 the Banbury Advertiser was able to dispel rumours about a large building under construction opposite the Northern Aluminium factory on the Southam Road. It was not to be one of the Air Ministry's new shadow factories - part of Britain's urgent rearmament programme during those tense times - but rather a Laboratory Building for Aluminium Laboratories Ltd, an associate company of Northern Aluminium Ltd. Then the largest employer in town, Northern had been in Banbury since 1931, being the British manufacturing subsidiary of the Aluminium Company of Canada (Alcan for short) - itself a new company spun off in 1928 from the Aluminium Company of America (Alcoa).



Aluminium Laboratories Limited

NEW WORKS IN SOUTHAM ROAD

The new construction begun by Messrs. Hinkins and Frewin Limited, on the property across Southam Road from the Aluminium Works is an office and laboratory building to be occupied by Aluminium Laboratories Ltd. an Associated Company of Northern Aluminium Company Ltd.

The building will be a brick and stone structure, two stories in height, with a floor space of approximately 16,000 square feet.

This building will provide office and laboratory space for research work relating to aluminium, its alloys, and aluminium products. It is expected that an office and laboratory staff of approximately 40 people will be accommodated by the new building.

This disposes of a rumour reported in earlier editions that the works might be an Air Ministry Factory.

BOROUGH BYE-ELECTION.

Nominations for Banbury Borough Council bye-election for three vacancies caused by the reappointment of Mr. W. G. Mascord and Mr. Theo Clark to aldermanic rank and the elevation of Mr. J. Cheney, close on Friday.

Alcan comes to Banbury (The Banbury Advertiser 18.11.1937)

During Alcan's early years, technical support had come largely from experienced personnel provided by Alcoa, who had built the original Alcan plants and trained the Canadians in their use. However, when Alcan began to invest in new fabrication plants as outlets for its smelter ingot production, it became clear that the company would need to grow its own technical capability. For this purpose, Aluminium Laboratories Limited (ALL) was incorporated in Canada in 1937 to be the engineering, technical and research arm of the corporation. With its Northern Aluminium subsidiary in England faced with the prospect of a rapid expansion to supply strong alloy sheet, extrusions and forgings for the rearmament programme, a decision was taken to locate the company's first research and development operation on a greenfield site in Banbury across the Southam Road from the Northern plant.

Alcan Labs opens for business in 1938

Dr. Paul Haenni, a metallurgist with Alcan's European office in Geneva, was appointed the first director of research at Banbury. Other technical personnel were recruited to join a research team that was expected to comprise around 40 graduate scientists and engineers, with additional support staff. However, although the engineering group was soon producing plans for new rolling mills in India and Australia and a smelter in India, research work was barely underway before the outbreak of war. Research was curtailed and the laboratory building requisitioned for use by the Ministry for Aircraft Production and the Materials Licensing Board as a centre for the control of aluminium supply for the duration of the war. The technical resources required to support Northern's Banbury factory and, subsequently, the government-funded but Alcan-managed new plant at Rogerstone in Gwent, was transferred to an expanded technical group within Northern itself. Dr. Haenni moved to Canada and, in 1942, was appointed Director of Research of a new laboratory built adjacent to the rapidly expanding fabrication plant in Kingston, Ontario.

At the end of World War II the aluminium industry found itself with a massive surplus in capacity, having been expanded to many times its pre-war size to supply the demands of the allied air forces. It was during this turmoil that Alcan was to receive back the Banbury Laboratories from government control. In his letter of 28th December 1945, Robert Hamer, Secretary of ALL, advised that from 2nd January 1946, 'Aluminium Laboratories Ltd. would resume technical and engineering work at Banbury under the direction of Mr. P. W Rolleston, Vice President', and that 'Banbury would discharge the Aluminium Laboratories Ltd functions in Europe, starting with metallurgical engineering and fabricating research, patents, contracts, and technical sales service and development'. Branches of the engineering department and the mining and exploration departments were to be added later but it was subsequently decided to retain these groups in Montreal.

ALUMINIUM LABORATORIES LIMITED
(Incorporated in the Dominion of Canada)

LIMITED
MONTREAL FILE

Montreal, Que.

CABLES-ALULAB, MONTREAL
CANADA
1800 SUN LIFE BUILDING

ROUTED	DATE
J.W. McKee	JAN 4 '46
R. Redler	JAN 7 - 1946
A. Senchyna	
C.F. Taylor	JAN 8 '46
D. Casselman	25
W.A. Harvey	

28th December 1945.

RELEASED
JAN - 3 1946

Aluminium Secretariat Limited,
Box 6090,
Montreal.

On 2nd January 1946, Aluminium Laboratories Limited will resume technical and engineering work at Banbury, England, under the direction of Mr. P. W. Rolleston, a Vice-President of the company. The Banbury branch of the company will discharge Aluminium Laboratories Limited's functions in Europe and, at the outset, will be active mainly in the fields of Metallurgicall Engineering and Fabricating Research, Patents and Contracts, and Technical Sales Service and Development. It is planned that branches of the Engineering Department and the Mining Engineering and Exploration Department will be established at Banbury later. The initial technical staff will be comprised of members of Northern Aluminium Company, Ltd.'s research department which is to be discontinued as at 31st December 1945.

On the same date, Aluminium Laboratories Limited will take over the research work currently being carried on by the Aluminum Company of Canada, Ltd. General Technical Department at Arvida, Que., and for this purpose the majority of the members of the existing Arvida research staff will be transferred to Aluminium Laboratories Limited. Mr. H. L. Collins will be directly in charge of our Arvida branch.

Simultaneously, the research staff of our Kingston laboratory will be augmented by the transfer of several members of the Aluminum Company of Canada, Ltd., General Technical Department at Toronto and Kingston.

Also, on 2nd January, Mr. R. H. Rimmer will assume the position of Director of Research for Aluminium Laboratories Limited, succeeding Dr. P. M. Haenni who has been

Aluminium Secretariat Limited - 2 - 28th December 1945.

selected for other duties in Europe where he will take up residence in due course. Dr. Haenni will continue his direction of activities at the Kingston laboratory until arrangements are completed for his departure for Europe.

Mr. Rimmer, whose headquarters will be at Kingston, will be responsible for the research work at both the Kingston and Arvida branches of the company. However, until otherwise advised, correspondence with him in his new capacity should be directed to Aluminium Laboratories Limited, 1800 Sun Life Building, Montreal.

ALUMINIUM LABORATORIES LIMITED

R. D. Hamer - Secretary

RDH:GL:CM

Copy to:

Mr. P. W. Rolleston: Banbury

Dr. P. M. Haenni: Kingston

Mr. H. L. Collins: Arvida

Aluminium Limited: Montreal

Aluminium Fiduciaries Limited: Montreal

Aluminium Securities Limited: Montreal

Stand Corporation: Boston

Stand Corporation: New York

Stand Limited: London

Stand S.A.: Geneva

Aluminum Import Corporation: New York

L'Aluminium Commercial S.A.: Geneva

The Alma & Jonquieres Railway Company: Montreal

Aluminium Company of South Africa (Pty.) Ltd.: Johannesburg

Aluminium Meridional: Paris

Aluminium Works Limited: Montreal

Alcan Labs is back in business

Initially, staff for the Banbury Laboratory came from the research department of Northern Aluminium, which was discontinued. Gordon Field, who had directed the wartime technical work at Northern, took over the Laboratory following the untimely death of Patrick Rolleston. In his essay on 'Early Years" Nevill Turner recalls working on both sides of the road, firstly dealing with the short term demands of war time problems at Northern but moving on to peace time work, such as the major project of re-cycling scrapped aircraft into extrusions for pre-fabricated housing.

At the same time, the Kingston Laboratory was strengthened by personnel from the technical departments of the Toronto and Kingston Works and ALL took over the work of the Arvida (Quebec) Technical Department in the field of Bayer chemistry and smelting. A new R&D Laboratory was built at Arvida in 1948. With these moves Alcan had put in place the main technical components that were to serve the company for the decades ahead. The mandate for the laboratories required them to respond to the needs of the production plants and of the sales and marketing groups, whilst pursuing new opportunities for investigation on their own initiative. These objectives were never easily balanced to the satisfaction of all concerned.

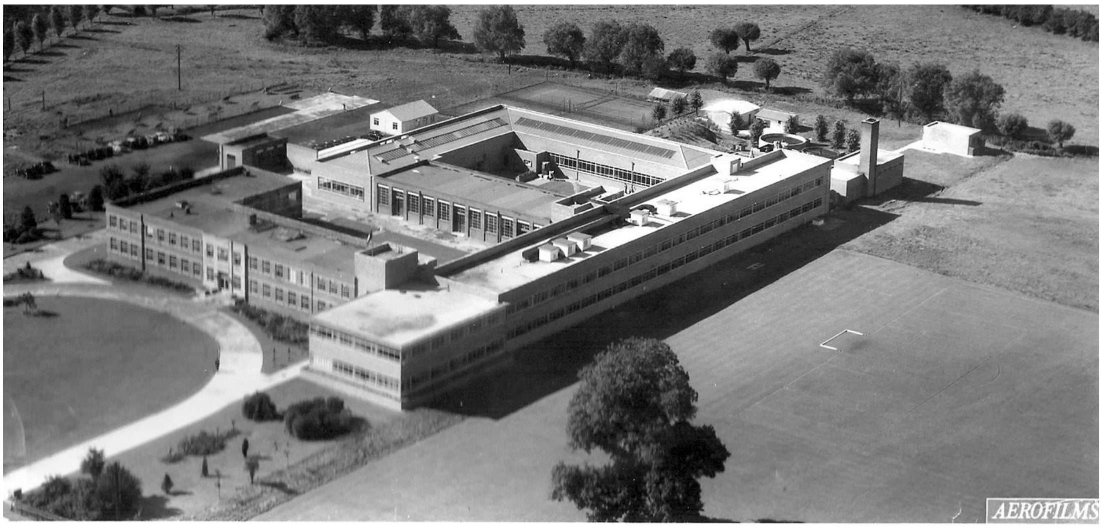
The industry's most pressing need was to identify and develop new peacetime applications for aluminium that would take up the excess capacity of the wartime smelters. After years of wartime austerity there was a demand for peacetime luxuries such as new consumer goods, more homes and better transport. Aluminium was in a good position to respond to demand - competitive materials were in short supply, the increased efficiency of the big smelters meant that the price of aluminium had come down over the war years and manufacturers had grown used to aluminium and the ways of using it. To address the new opportunities, teams were established in Labs, and in Northern's Sales Development Department, to encourage the use of aluminium and to provide authoritative advice, information and back up development. The importance of new product development was such that most of the projects undertaken by Labs were dictated by the needs of Sales Development, Northern's Central Technical Department and the Ingot Sales Group. Building, transport, household goods and electrical applications were the main markets for aluminium in the late 1940s. In Europe, especially in Switzerland and Scandinavia, there were a number of interesting uses of aluminium for the packaging of foodstuffs that had been developed during the war years. With this in mind, packaging was added to the list of target markets and Banbury Labs was given the task of investigating new opportunities. The approach taken is described by Alec Lovell in his essay 'The Development of Containers for Packaging', referring in particular to the aluminium drawn and ironed can that came to dominate the global beverage market. As Alec points out, the work was given impetus by a policy of recruiting specialists from the target market areas into both Labs and the Sales Development departments. In Alec's case his knowledge of the draw and iron process came from his wartime experience in the manufacture of brass shell cases - an example of the shift of resource and capacity from war to peacetime industry. The evolution of the beverage can - its alloys, the can alloy fabrication technology and the process of producing the can itself - has been an on-going process for over 60 years, driven primarily by economics. Whilst many organisations and countless scientists and engineers have contributed over that period to achieve the outstanding performance of the modern aluminium beverage can, the groundbreaking work in which Alec Lovell was a key player stands as an important milestone.

Another approach to packaging development arose from work initiated in Norway to exploit the potential of thin anodic films as a pretreatment for lacquering aluminium can material for food products. The paper by Eric Wootton and Jon Ball, 'Continuous Anodising', charts Banbury's long history with developments in the continuous anodising of coiled strip, initially for lacquered stock used for the packaging of fish and other food products, but adapted in the 1980s to the processing of lithographic sheet for the printing industry and in the 1990s for the cleaning and pretreatment of sheet for automotive applications. The work undertaken at Banbury led to the installation of continuous anodising lines for food can material in a number of Alcan's plants in Europe and South Africa and, subsequently, for lithographic plates and automotive sheet panels in Germany. The work was characterised throughout by the importance of close working relationships between the Laboratories' personnel and those of the operating companies, from the business CEO to those operating the equipment on the shop floor. Credit should always be given to the technical staff in the plants who took on trust the new, sometimes unusual, ideas presented by the scientists and engineers from R&D. In particular, the fulsome support of Peter Limbach and his colleagues at Alcan Deutschland made much possible.

Whilst the process of anodising aluminium had been in existence since the mid 1920s, it was the post war demand for better and more exciting building materials that led anodising to become one of the major enabling technologies behind the application of aluminium to both domestic and monumental buildings. Ted Short's paper on 'Conventional Anodising' describes a chapter of work starting in the early 1950s and continuing through the Labs history, not only in researching the fundamental science of anodising but also in the development of a series of processes that were exploitable globally and which provided Alcan with major new markets for its ingot, sheet and extrusion businesses. This story also highlights the importance of patenting the company's knowledge and the considerable value of licensing patented technology. Also in evidence is the close on-going co-operation that existed between the personnel of the Banbury and Kingston Laboratories - and sometimes sharp competition - and also the good relationships between Alcan's R&D operations and those of the associated Japanese companies, NLM and Toyal. It became a regular occurrence for personnel from NLM and Toyal to spend periods of time on secondment at Kingston and Banbury and, at a later date, for some Alcan personnel, including Phil Morris plus Nigel and Val Davies, to spend a year at the Japanese Laboratories.

At this time the market for consumer goods was growing fast but was often presenting difficulties. There were many problems to be solved including the phenomenon of razor streaks on the bright surfaces of coffee percolators and 'elephant's foot' or malformation of the base of pressure cookers. However, the most universal and vexatious problem was that of anisotropy - commonly known as earing - that occurs during the deep drawing of aluminium sheet. This was exacerbated by the post-war industry-wide move to the more efficient semi-continuous casting method for its ingot supply. Nevill Turner's talk 'Tackling the Problem of Anisotropy' describes how practical solutions were only found after the Lab scientists investigated the fundamental mechanism of the problem, and then collaborated in a joint effort with the Works technical personnel, who conducted production trials designed around the new understanding. This co-operative approach between plant and research personnel was to prove again and again to be the right way of deploying good science into the company's operations.

By the 1950s it was quite clear that the building in Banbury was far too small for ALL to undertake both the quantity and scope of the work needed and an expansion was approved. The extensions were completed in 1954, trebling the total floor space. A new two-storied north wing provided space for laboratories, offices and library, with a modular design that allowed flexibility in the utilisation of space. An additional single story experimental block, built around a courtyard, housed large-scale workshops for structural testing, metal casting, rolling and heat treatment, in addition to shops for anodising, welding, metal forming and testing facilities. Not only was Labs able to increase its capacity for work but also could now research more realistically the operational problems of Alcan's production units and simulate the conditions of manufacture by the company's customers.



The expanded facility in 1954

Expanding the use of aluminium in markets where structural integrity was of the utmost importance - transport being a good example - required the Labs to be equipped both with the personnel and the equipment to generate a greater understanding of the performance of alloys, product forms and structures under static and dynamic loading. This meant that more data and understanding was required for Labs to apply to commercially viable transport and structural engineering systems and, if necessary, to deal with problems and difficulties in the field. Applying aluminium alloys to structural applications also required Alcan's customers to be able to fabricate the material into final product forms. This could involve welding and other joining methods for which there was frequently inadequate knowledge and experience in the field. As a result, Labs played a major role in developing aluminium welding technology, establishing standards, spreading the knowledge and trouble-shooting if and when problems arose. Roy Woodward describes the work undertaken over several years by the Labs' engineers and metallurgists in his paper on 'Engineered Products'. Throughout this period, the Labs team made major contributions to the preparation of national and international standards, helped to understand phenomena such as metal fatigue and elevated temperature creep, and also supported the introduction of aluminium alloys into a wide range of engineering applications.

From 1950 until 1959 the Lab was under the direction of Robert Hamer, who had taken over from Gordon Field. Roy Woodward's letter to the editor of the Alcan retiree magazine Emeritus, 'Told like it was...', with its accompanying photograph of the besuited Banbury management team of 1954, captures the spirit of the age. At this time, the Laboratory was organised on a traditional departmental basis and it continued this way, with some modifications, until the 1980s. The research departments were based on established scientific and engineering disciplines, each with a head of department and staffed with suitably qualified and skilled scientists or engineers and technicians. In 1962, under the direction of Robert (Doc) Parker (1959-1972), the research organisation at Banbury comprised Metal Physics, Metallurgy, Chemistry and Casting in one Division, Physics, Packaging, Joining and Electrical in a second and Research and General Engineering in a third. Each Division was led by an Associate Director - the three Georges - George Forrest, George Gardam and George Stanford respectively. Separate departments dealt with Information Services, Patents and Contracts and Fabrication Technique. All were supported by Maintenance, Treasury and Office Services Departments. An outlying

Engineering Design Group was based in Geneva but reported to the Banbury Director.

The 1960s saw a major step change in research technology that was to affect almost every piece of work undertaken by Alcan's material scientists over the years to come. With the advent of electron microscopy, scientists were able to examine the finer details of material structures and surfaces and achieve a better understanding of the way in which these features controlled material properties. Two papers - 'The Electron Optics Story', by Mike Wheeler, David Moore and Mel Ball and 'Surface Analysis & Pretreatment' by Nigel Davies - describe how the new technologies revolutionised materials research. Banbury was an early user of a succession of new instruments - the electron probe microanalyser, transmission electron microscope (TEM), scanning electron microscope (SEM), electron spectroscope for chemical analysis (ESCA) and others. These technologies, supported by the growth of computer power, were to provide the quantitative information needed to make a succession of advances in all areas of alloy development, surface treatments and process innovation.

Throughout the life of Banbury Labs, the process of casting presented the scientists and engineers with myriad problems and numerous opportunities for technical advances. The 1960s was a time that brought together several important challenges to be met by a strong team of researchers with a new and well-equipped Casting Shop. In his paper 'Banbury Bed Filter' Peter Read describes the work undertaken at Banbury to develop a system for cleaning molten metal to render it suitable for products that are sensitive to inclusions - products such as anodising qualities, can stock, lithographic sheet and aircraft components. The system developed at Banbury was very successful and was readily scaled up to a full production size facility. Over the next decade, Banbury Bed Filters (BBF) were installed at Alcan plants around the world including Alunorf, Oswego, Kitts Green and Banbury. The system was transferred to Arvida for its application to Alcan's Smelter system, was up-engineered to the Alcan Bed Filter and remains a milestone in Casting Shop technology. In parallel to the filtration work, Banbury was fully engaged in addressing other casting issues that impacted upon the quality of the cast ingot - it is fully recognised by metallurgists that the quality of the ingot is fundamental to the quality of the finished product. In 'Casting at Banbury Labs', Gerry Lucas recalls the early years of his career working for the legendary Don Collins on a raft of issues that related to the quality of cast ingots and the productivity of direct chill casting. The considerable investment in a new enlarged Foundry in 1965 reflects the importance attached to the successful resolution of casting problems; the output of much of this work was embodied in the standard practices of Alcan casting technology over subsequent decades.

In his paper, "Electrical Division at Banbury Labs", Perry Bamji describes the research undertaken by the Division to investigate the potential for electrical and electromagnetic systems in the melting and casting processes for aluminium. Although the Division had been set up originally in the immediate post war years to support the growing use of aluminium in the electrical industry - in particular for transmission cables and associated fittings - a research group had been established to apply electrical technologies to other processes. Perry describes several innovations that led to commercial exploitation.

In the early 1970s Alcan decided to finance ideas promoted by Bill Baker for the development of improved twin belt casting technology – an alternative approach to ingot casting as a feedstock to sheet metal production. At this time Bill was the chief technical officer for Alcan U.K. and was an enthusiastic advocate of new technology for the operating companies. In 'Early Days of the Twin Belt Caster', Dave Bonney describes how he became involved in Bill's project. The early stages of the development was undertaken at Banbury and the basic principles of an operating system were established before Bill took the system to Oswego, NY, where a full scale operating unit was put into production. Although the Alcan Twin Belt Caster failed to meet its objective of providing a low cost route for can end stock alloys, a much enlarged operation at Alcan's Saguenay Plant, supplied by liquid metal from the Saguenay smelters, succeeded in achieving a robust and economical process for the production of wide foil and finstock re-roll for the whole of Alcan's North American low gauge and foil operations.

Alcan's considerable growth over the years since 1945, its expansion into new regions and businesses and external changes in business conditions, prompted the company to review its structure and organisation with the help of business consultants, McKinsey & Co. Effective from 1 January 1968, three new operating divisions were established to cover Alcan's global operations - raw materials, smelting and fabrication. Later in the same year, Aluminium Laboratories Ltd was renamed Alcan Research and Development Ltd, and the R&D resources were placed under the direct control of the line divisions; the Banbury Lab joining the fabrication division.

Also in 1968, Alcan acquired Delta Metal's 50% of James Booth Aluminium (JBA) in the U.K. - a company with a reputation for the manufacture of strong alloys for aircraft and defence industries - and completed a full merger of JBA and Alcan's U.K. operations by 1970. Hitherto, James Booth had relied largely on its own resources to develop its position in the aerospace market - albeit with some help from Kaiser Aluminium, the other party in combination with Delta Metal. However, with the Banbury Lab already engaged in developments of importance to Kitts Green, it became possible to increase R&D funding and Joint Development projects for the aerospace market. In his 'Strong Alloys Overview' Maurice Reynolds lists the main fields of development during this period both for aerospace and for military applications in fighting vehicles and military bridges. These programmes were characterised by close working arrangements between R&D and businesses involved in strong alloys. In particular, six monthly meetings to review technical strategy and joint progress were held between research personnel and the technical, production and marketing teams. In due course this interaction led to a decision for Alcan to investigate the options for lightweight aluminium lithium alloys.

Rationalisation of the Alcan UK and JBA operations led to the closure of the Banbury Sheet Mill, an action that provided the opportunity for Banbury Works to grow into the largest extrusion plant in Europe. Alcan acquired other U.K. businesses during the decade, including the pressure vessel manufacturer, Luxfer, and, significantly, made a major smelter investment at Lynemouth. Although Banbury was now presented with a wider portfolio of potential users of its R&D services, there were often problems in establishing programmes of joint work, usually for financial reasons. The need to develop closer working relationships between the R&D labs and the operating companies was well recognised within Alcan; one response being the appointment of Lab Directors from the ranks of plant management. In 1971, John Wilson became Director for Kingston Lab and in 1972 Richard Hartree, formerly Director of the Banbury plant, took over the same role at Banbury. In 'A Director's Perspective, 1972-1979', Richard describes some of the difficulties being experienced by Alcan in relating R&D to the needs of the operating units; in particular to the reluctance of some of the companies to pay for R&D that looked beyond their immediate problems. Consequently, as much as 20-25% of Labs activity was being devoted to short term Technical Assistance. In 1979 Richard Hartree moved on to international duties with Alcan in South America and the Pacific regions. For a short period, the Lab's Director was George Wistreich but ill health forced his resignation.

Whilst Alcanint was engaged in re-organisation, Alcan's European operations were undergoing major changes. In Germany, Alcan expanded its plant at Goettingen and acquired foil and foil-finishing plants at Ludenscheid and Berlin. But, most importantly, the company entered into a partnership arrangement with VAW, the German government-owned aluminium producer, to erect what was to become the largest aluminium rolling plant in Europe at Norf, near Neuss, on the left bank of the Rhine. The Norf plant commenced operations at the end of 1967 and enjoyed continuous investment in the most advanced productive capacity that became a characteristic of the German operations. The demands for support from the Norf rolling plant provided a major stimulus to the Banbury work on rolling technology. Commenced in the 1950s, a research effort had been devoted to creating a fundamental understanding of rolling processes with the aim of securing improvements to both product quality and process productivity. Ian Calderbank's paper, 'Rolling & Strip Process Engineering', describes the history of the work from its early focus on gauge control to improved strip flatness, strip profile, mill productivity and the finishing processes of levelling and slitting. Fundamental to this work was the successful development of computer based mathematical models that helped to provide both insight and a predictive capability. Essentially, all of Alcan's knowledge of the process of aluminium rolling was incorporated into the Alcan Rolling Model. By the 1980s the knowledge gained was used to set up the Alcan Rolling Course, designed to train Alcan rolling mill engineers and manufacturing professionals worldwide. In time, as the technology advanced, it became possible to develop on-line models that would be employed throughout the Alcan Rolling system, facilitating continuous improvement and establishing leading standards of rolling mill performance.

Mike Budd's paper, 'Lubrication', tells a parallel story, starting at Banbury in the 1950s, of research and development devoted to the lubrication requirements of metal deformation in rolling mills. Over a period of four decades a Banbury team of lubrication scientists and engineers developed a series of improved lubricants for hot, cold and foil rolling, methods for testing lubricant performance, systems maintenance and environmental compliance. In many cases the technology had to be tailored to the needs of specific plants and products, and frequently demanded liaison with lubricant suppliers. The paper also mentions two important aspects of the Lab's work that were not unique to lubrication but were common to most process activity. The first was the publication of in-house documents, known as Fabrication Memoranda, aimed at providing comprehensive guidance to operations personnel on specific areas of process and product technology. Secondly, events such as workshops and seminars were held between R&D and operations personnel to transmit new information around the group and to share best practice and experience between operations.

A change in Alcan policy in 1979 resulted in a re-grouping of the R&D resources into one unit, to be known as Alcan International Ltd (Alcanint). Ihor Suchoversky was appointed Vice President for research and operations technology - the first time that the term 'operations' had been included in the chief technical officers brief. Jeff Edington joined the company as director for Banbury after a career in university R&D in both UK and USA. Jeff came with a reputation in electron optics. Under his leadership the divisional organisation of the Banbury Lab was removed and replaced by a matrix structure that placed the scientists and engineers into 'silos', led by Principal Scientists. Programme Managers led each area of business related projects. The function of the Programme Manager was to deliver R&D results on time and on budget to the businesses or, in the case of corporate R&D, to the satisfaction of senior Alcan management. The Principal Scientists took responsibility for guiding the scientific performance of the programmes and maintaining the quality of the Lab's scientific capability, including maintaining relationships with appropriate universities and other external centres of excellence.

Charged with the responsibility of providing research and development group-wide, Alcanint was required to consult with the operating companies in order to establish both its annual budget and its priorities. As the operating companies met the cost of R&D, either directly or through a Group-wide levy, both the R&D budget and the programme priorities were to prove 'hot potatoes' at Alcanint's annual planning event, when the programme for the year ahead was thrashed out between the three main laboratories and the businesses. Programmes comprised three types of projects. Work undertaken to address specific needs of an operating company was described as a 'Joint Development Project' and was funded directly by the company concerned. Where the whole of a business stream - such as extrusion - was considered to be the beneficiary of the work, or where the research was aimed at providing fundamental understanding to support a number of Joint Development Projects, the term 'General Project' was used. The business stream, on the basis of individual company rated capacity, funded these projects collectively. Thirdly, project work of a long term nature, considered to be in the overall interest of Alcan's future - either for the existing businesses or for potentially new businesses - was funded at a corporate level, with a levy placed upon the whole company. These were described as 'Corporate Projects' and were to assume greater importance in the 1980s as Alcan sought to widen the scope of its business interests - the New Opportunities programme. Finally, a small proportion of the capacity of the laboratories was earmarked for 'Technical Assistance', to be provided at short notice, and to be charged by the hour, in response to immediate problems being experienced by the operating companies in their plants or in their markets. It was understood that the call for Technical Assistance (T.A.) took priority over other work and it was well appreciated by Labs staff that successful T.A. worked wonders for relationships with those otherwise reluctant to pay for R&D!

In 1982 Alcan merged its UK interests with those of the British Aluminium Company, creating a new wholly owned British Alcan. In addition to its portfolio of operating companies, British Aluminium brought into the Group a further well-established research centre at Chalfont Park. An immediate task for Alcan's research management, and, in particular for Jeff Edington, was the rationalisation of the activities of the two laboratories. Over time, this process resulted in a progressive closure of the Chalfont Park research operation and a transfer of some of its key personnel and unique programmes to Banbury. In particular, British Aluminium's research programme into aluminium lithium aerospace alloys had begun earlier than the work at Banbury and was further advanced. As a result, the two projects were merged under the leadership of Roger Grimes, Project Leader for the Chalfont work. His paper 'The Aluminium Lithium Development' recounts the extensive and complex programme of work undertaken, not only to develop high performance light weight alloys but also the herculean efforts to solve the problems of their manufacture. In particular, the difficulties and hazards of casting these reactive alloys led to new casting technologies and equipment, production versions of which were subsequently installed at Kitts Green. The research programme was discontinued in 1992 when Alcan sold its aerospace manufacturing businesses. Despite this disappointing end to a high profile programme, much of the knowledge gained from the Banbury work continues to be employed at Kitts Green and other companies that supply a growing demand for aluminium lithium alloys.

It was also in this period that Alcan began a serious effort to develop a new market for aluminium in the field of automotive structures. For decades the automotive industry had taken advantage of the low density and other attractive properties of aluminium alloys for the engine blocks, wheels and other castings of high end vehicles, and for decorative trim and, increasingly, for brazed radiators. The next objective was to convince the automotive industry to construct the total body structure from aluminium alloys. In his paper, 'The World Wide Alcan Automotive Program', Mike Wheeler describes Alcan's efforts in research, marketing and production to promote aluminium structures and closure applications. Both the Banbury and Kingston Labs were heavily committed to this objective, with Banbury primarily engaged with the concept of an adhesively bonded light weight sheet structure with structural stiffness and durability (AIV). This required the development of enabling technologies in surface pretreatments, lubricants, adhesive bonding and spot welding, as well as increased efforts in structural modelling and performance simulation. In due course the efforts were rewarded by the adoption of the technology by Jaguar - but thereafter the automotive industry favoured a more conservative approach, committing only to the use of aluminium sheet in closure applications (for example, doors). By the end of the 1990s Alcan ceased serious promotion of the technology. Another twenty years was to pass before the demands for increased fuel efficiency led to a strong growth in the application of AIV technology by Jaguar Land Rover and others.

In March 1985 at Alcan's annual meeting, the Alcan CEO, David Culver, re-stated the company's strategies to include the development of new market-related technologies in both existing and new fields and to make selective investment in non-aluminium sectors that were related to Alcan technical strengths. At the same time, technology programmes supporting existing businesses were to be focused strongly on operational productivity and product quality, meshing with new efforts in the operating companies to define and achieve global best practice. It was explained that the aluminium industry was reaching a period of maturity, with slowing growth and with products that were becoming commodities. The existing businesses were to streamline, become more efficient and to cut costs as cash cows, whilst technology would seek new opportunities for the corporation. At the Banbury Lab, work was set in motion to research new products in composites, aluminium air batteries, sol gels and the exploitation of anodic structures. The work on the aluminium lithium aerospace alloys and aluminium automotive structures were included in the portfolio for corporate funding as potential new fields for aluminium sales. To resource these programmes Alcanint set about recruiting large numbers of new staff, many of whom were professionals in fields previously unknown in the Labs. This was a period of lush pastures for Alcanint. During the 1980s, Alcan's R&D expenditure rose from U.S. $47 million in 1980 to U.S. $136 million in 1989, reflecting in part the effects of inflation and cost rises but mainly the strong effort to explore opportunities for new products from both established operations and for new businesses. Nigel Davies describes the period in his paper 'New Opportunities', giving his attention mainly to the work on exploiting separated anodic films as filtration devices and other scientific tools. He describes a series of successful new products developed by the programme and the establishment of a new manufacturing and sales business. Other major projects included the spray casting of high performance alloys, led by Dick Jordan, the search for opportunities using sol gels and efforts to develop and exploit batteries based on aluminium, under the leadership of Geoff Scamans.

The 1980s also saw a major expansion in the use of computer based mathematical modelling as a research tool, primarily for process development. Arguably, the availability of powerful computers and the technology of mathematical modelling represented as significant a step change in R&D capability as that experienced two decades earlier with the advent of electron optics. Of course, mathematical modelling had been employed in previous decades, as has already been explained in Ian Calderbank's history of process engineering, but in the 1980s the Lab was to acquire a mainframe computer on which to run not only in-house derived models, such as Alcan's rolling model, but also commercially produced software applied or adapted to a range of metallurgical processes. Also, the graduate scientists and engineers that were joining Alcan at this time were generally familiar with and, in some cases, highly competent in modelling methodology. Researching a subject with a mathematical model did not eliminate the need for physical scientific investigation - always required to validate and fine tune the model - but did provide a faster and cheaper route to a solution and sometimes provided insight difficult to obtain by other means. One of the projects at this time that exploited the new big computers was the exploration of the process of metal solidification during the casting process, as recorded by Laurens Katgerman in 'The PSICASO Story'. It is clearly apparent from Laurens' paper that the Lab projects did not operate in watertight compartments. We see casting model work being applied not only to an important operational problem at the Kitts Green plant but also into the New Opportunities field of Alcan Cospray metal-matrix composites, led by Dick Jordan. Laurens also records the close collaboration that existed between Banbury and Kingston in this field but also the co-operation between Banbury teams and the science departments of leading universities. PSICASO was not unique in promoting collaboration between Banbury and Kingston - it was frequently the case that projects benefitted from the skills and equipment that could be brought together in the two Labs (and often by staff transfers), although it must be admitted that elements of competition were not uncommon. Banbury's interaction with university scientists was always a strength that brought considerable benefits to the research programmes and provided Banbury with an on-going stream of potential recruits.

An important development at this time was the creation in Banbury of a core rolled product metallurgy project that would underpin with fundamental work the efforts of Joint Development projects being undertaken with the manufacturing companies. Ricky Ricks took charge of core metallurgy and, in many ways, shaped both the content of the research work and the relationships with the operating companies. Ricky explains the conception and development of the approach in his essay, 'Core Research and Development' and also describes the development of unique Plane Strain Compression equipment to simulate the processing of strip through multi-stand hot and cold tandem mills of the kind operated by Alcan in its major plants. The quality of the research and the capability of Banbury's equipment, plus the evolution of joint R&D/Business advisory groups resulted in significant advances being applied to the manufacturing processes.

At this time, Jeff Edington transferred to Kingston and subsequently took senior office as Alcan's Vice-President for Technology. Geoff was replaced at Banbury by John Hirschfield, an Englishman who had served Alcan many years at Kingston with a speciality in joining technology and as a divisional head. In 1990 John returned to Canada and was replaced by Mike Sporton, who joined Alcan from the Lucas Group.

Unfortunately, despite many technical successes, the overall commercial results from the New Opportunities portfolio were inadequate to justify the annual expenditure being committed. Certainly, the aim of achieving 15% of corporate revenue from New Opportunities was never at risk of being achieved. Consequently, in 1991 Alcan reversed out of its diversification programme and proclaimed the virtues of core competence in primary metal and rolled products. This decision presented Alcanint management with severe problems of downsizing the laboratory operations. Several of its more successful technology ventures were sold as going concerns and the associated R&D programmes closed down, with a consequential reduction in Lab staff numbers. Banbury Lab was now faced with a struggle for survival. With New Opportunities lost and the extrusion and aerospace businesses sold, the Lab was losing its customers. However, it had a number of strengths in terms of its high quality staff and a number of key programmes of value to the rolled product businesses. These included a first class rolled products metallurgy programme, a similar high quality programme supporting rolling process technology, unique knowledge and capability in surface pretreatments and lithographic sheet and a major play in automotive. Banbury also played host to a group of Alcan Chemicals R&D personnel led by Ken Evans, formerly located at Chalfont and a second group of Alumina specialists from Kingston. The job of re-organising the Banbury Lab operations fell to Rod Jones, who took over from Mike Sporton after serving the Lab as a Programme Manager and then as Programme Director. Rod describes this period in his essay, 'New Opportunities and Thereafter'.

One of the projects that blossomed after the demise of New Opportunities was a study led by newly arrived Paul Evans into the intermetallic phases formed between dendrites during the casting of aluminium alloy ingots - perhaps something could be done to influence phase formation and, thereby, improve the performance of fabricated products. In 'Solidification Research in the 1990s' Paul tells of the work undertaken at Banbury using fairly simple tailor-made laboratory equipment, supported by sound science, computer power and electron optics. The results proved the commercial value of good science and an ability to place it in the context of business needs and opportunities.

Although the process stages for the extraction of alumina from bauxite ore were supported by R&D undertaken at the Arvida R&D Centre in Quebec and at Kingston Labs, in 1989, Banbury was invited to provide a research team to assist the Aughinish operation in Ireland, and other plants, that required help in dealing with caustic corrosion problems. In his paper, 'Alcan Primary Raw Materials R&D Program: Banbury Labs 1989 – 2002', Chris Newton describes a decade of work devoted to critical process criteria, including process plant corrosion and heat transfer modelling. The story of this programme provides an insight into the high levels of collaboration and staff interchange that existed between the three Alcan Labs and production operations on several continents.

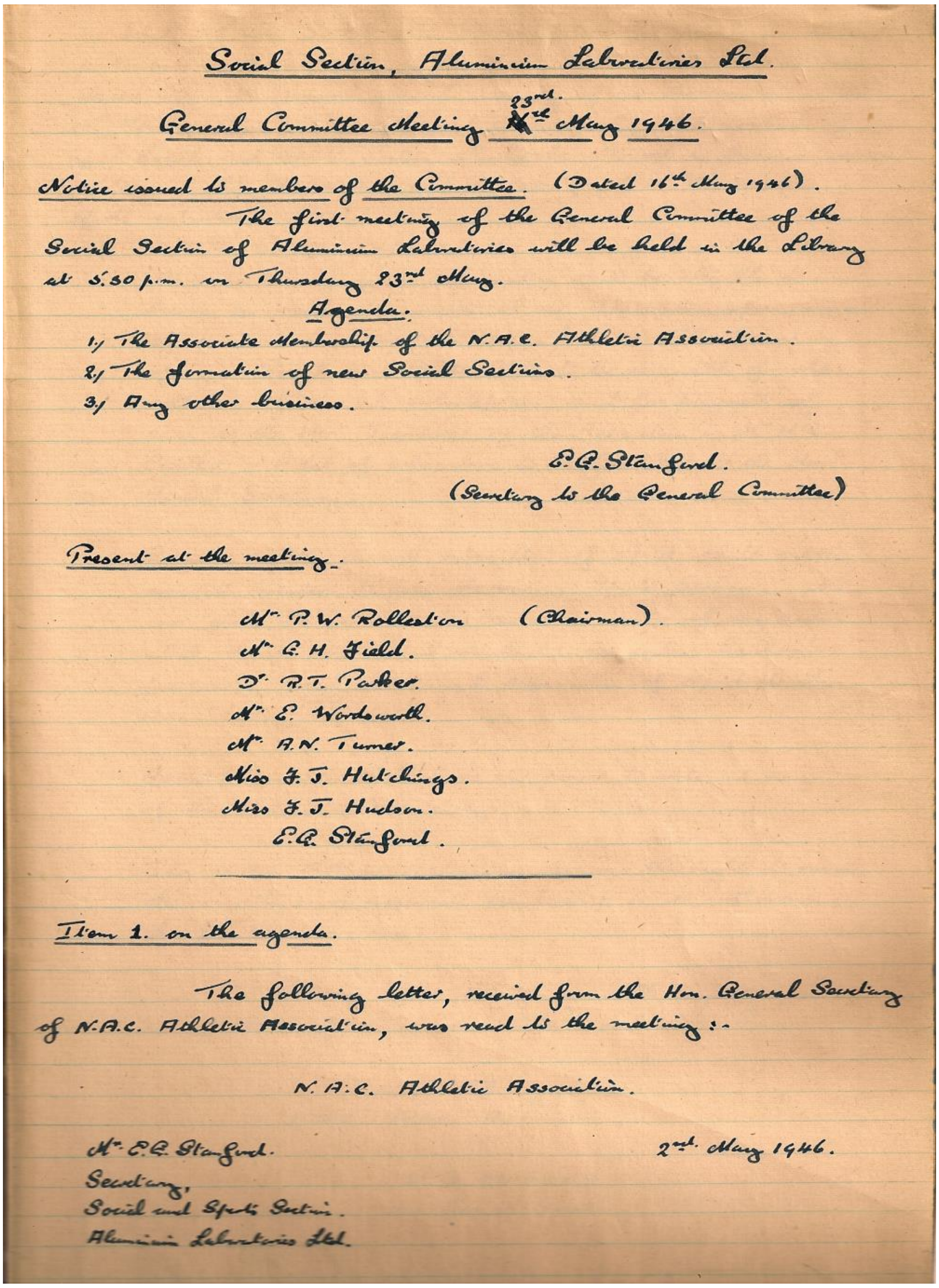
In 1999 Alcan startled the metals industry by attempting a three-way merger with its major European rivals - Pechiney of France and the Swiss company Algroup. Whilst each of the three companies had complementary strengths, there existed considerable areas of overlap, which offered the potential for substantial cost savings by surgery. The merger was blocked by the European Commission on the grounds of reduced commercial competition. However, in 2000, Alcan did acquire Algroup and a process of 'rationalising' the resources of the two companies began. The Banbury Lab was now joined with the Algroup R&D centre at Neuhausen in Switzerland to act as a pair under the management of Harald Jenny. Along with the lab at Kingston, the joint fabrication R&D resources were seen to be oversized and in need of reduction. It was clear that one of the R&D centres would be closed. Despite its strong connections to the Alcan global fabrication system and its depth in skills - demonstrated at a joint meeting of project leaders of the three Labs in Kingston in 2001 - Banbury was selected as the candidate for closure. The absence of dependent U.K. manufacturing operations and the relative ease of closing businesses in the U.K. no doubt had their influences. In 2002 Alcan announced its plan to close the Banbury Laboratory the following year. The story of its closure is covered by Peter Band in his paper 'The End of the Day'.

Over a period of sixty-five years the Banbury Laboratory set a standard for industrial research and made a number of major contributions both to its parent company and to the industry in general. These are largely covered by the papers included in this document, although many fields of endeavour are missing, being lost by time or oversight. The output of the Lab continues to be used by aluminium manufacturers the world over. In some cases its work was ahead of its time. The two postscripts written by Geoff Scamans on aluminium automotive structures and aluminium lithium alloys, respectively, show how the need for more fuel efficient transport systems has caught up with Banbury technology.

We have mentioned in passing another contribution of the Banbury Lab - its role as a source of trained and experienced technical personnel to the whole of the Alcan group. With its close relationships with British universities, Alcan was able to attract high quality scientific and technical personnel and, after service at Banbury, many accepted posts at Kingston and Arvida and in the operating companies in North America and elsewhere overseas. Mike Wheeler, David Moore, Phil Morris, Gerry Lucas, Mel Ball, Dave Bonney and others transferred permanently to North America and others such as Dick Jordan and Phil Enright were there on secondment. Several of the Kingston Lab directors came from Banbury including Jeff Edington, Paul Butler, Dick Daugherty and Peter Band.

Most of the essays contained in this document speak of specific technical fields of endeavour. Perhaps not enough is said about the way in which the research programmes were dependant upon able people operating support group such as the Workshop and Drawing Office, the Patents Group, Publications, Secretarial, Finance and, in more recent times, the I.T. support team. Similarly, an unmentioned happy aspect of the Banbury Laboratory was its social life. In the early years, the Sports and Social Club played an important role in the life of the Lab people - after all Banbury was a small town, personal transport was relatively limited and there were fewer other diversions in life. Sports teams, parties and fetes were well supported.

Alcan Labs Children's Christmas Party 1956



Social Section, Aluminium Laboratories Ltd.

General Committee Meeting 23rd. May 1946.

Notice issued to members of the Committee. (Dated 16th May 1946).

The first meeting of the General Committee of the Social Section of Aluminium Laboratories will be held in the Library at 5.30 p.m. on Thursday 23rd May.

Agenda.

1/ The Associate Membership of the N.A.C. Athletic Association.
2/ The formation of new Social Sections.
3/ Any other business.

E.G. Stanford.
(Secretary to the General Committee)

Present at the meeting.

Mr P.W. Rolleston (Chairman).
Mr G.H. Field.
Dr R.T. Parker.
Mr E. Wordsworth.
Mr A.N. Turner.
Miss F.J. Hutchings.
Miss F.J. Hudson.
E.G. Stanford.

Item 1. on the agenda.

The following letter, received from the Hon. General Secretary of N.A.C. Athletic Association, was read to the meeting :-

N.A.C. Athletic Association.

Mr E.G. Stanford.
Secretary,
Social and Sports Section.
Aluminium Laboratories Ltd.

2nd. May 1946.

Minutes of the first meeting of the Social Club 1946

In recent years company social activities became less important as life choices widened and, with personal transport available, many chose to live a distance from Banbury. Nonetheless, the closure of the Banbury Lab was felt by many as a family loss and residual social activities by the Sports and Social Club and the 30 Year Club continue to draw strong support. The disappearance of Alcan as an independent company has also done much to draw a final line under this period of enterprise, hard work and innovation.

3. DIRECTOR'S PERSPECTIVES

3a. Richard Hartree 1972-1979

My background

With a degree in metallurgy I joined Northern Aluminium Company in 1954 as a 'Graduate Trainee'. During my 'training' year I worked for 3 months in Laboratories on a canning related investigation. This was the protection of the interior of cans by anodising. It was an idea of Dr George Gardam and used high current density AC. I took it from the idea to the anodising of cans for field trials. It was not successful, or practical for industrial scale operation. In 1962 -64, after a year at the CEI, I was in Alindustries General Technical Department under Dr W (Bill) A Baker. Our offices were in Laboratories building. Through these two jobs I came to know quite a few Laboratories people and something of the organisation.

My Alcan career, starting in Northern Aluminium Co Ltd, included 5 years in the General Engineering Department at Rogerstone, 2 years in the Technical Department at Banbury Works, 3 years as head of Industrial Engineering in Banbury, 2 years in Alcanint: Montreal and 2 years as Works Manager at Banbury – during which the Sheet Mill was closed and 1200 people made redundant. Then I transferred to Alcanint Banbury Labs as Director. After leaving Labs in 1979 I was Area V-P Technology for Latin America based in Rio de Janeiro and then Regional V-P Technology for Alcan Pacific based in Vancouver. These roles gave me the opportunity to keep in touch with the R&D system. The Vancouver office closed in 1991 and I was 'early retired'.

Laboratories place in the Alcan world

My source for this is 'Global Mission' the official Alcan history by Duncan Campbell.
Aluminium Laboratories was chartered in Canada in 1937 as a subsidiary of Aluminium Limited and the building of Labs: Banbury commenced that year. In 1968 the name was changed to Alcan R&D.

In the 1970s Alcan's total R&D budget was 1 – 1.5% of total Sales. R&D was not a hugely important part of Alcan's activities.

In 1970 Aluminium Limited created three worldwide divisions one of which was Fabricating and Sales of which the management company was Alcan International in Montreal. Banbury (and Kingston) laboratories reported to the Alcanint Vice-President of Technology M G O'Leary. In 1975 Alcanint ceased to have responsibility for the Laboratories and Banbury 'came under' Alcan: London. In 1977 this changed to Alcan: Europe Geneva. Banbury returned to Alcan International in 1980. (I do not remember submitting Labs budget to London or Geneva for approval which I would have expected to do if Labs had really 'come under' them: it was always to Alcanint: Montreal.)

An important objective of these changes was to bring the Banbury and Kingston laboratories closer to the operating companies. In 1971 John Wilson of the Alcan Canada Rolled Products Division was appointed Director of the Kingston laboratory. My appointment in 1972, from Alcan Booth Extrusions Banbury Works Manager to Banbury Labs followed the same pattern.

In the 1970s it was very difficult to find suitable projects for joint work with the operating companies in the UK and Europe. In the UK the economic climate was depressing. The Alcan Booth merger and subsequent rationalisation were being 'digested' and commercial survival was the main preoccupation of management. The Kitts Green strong alloy aircraft plate business was the only one with which Labs had a strong, positive relationship. They knew how to work with us. The big sheet business based at Rogerstone was, to quite a large extent based on obsolete equipment and not suitable for technology advancing projects. The management of the MagSil extrusion business of Banbury and Skelmersdale placed their main emphasis on commercial matters, with little attention to process development and, for example, did/could not help to steer the 'interference colour' anodising project.

In Europe Labs had worked closely with the sheet operation at Goettingen over their lacquering line and, by the 1970s, the Works was technically self-sufficient. The new Alunorf sheet mill was half owned by VAW and hence not suitable for Alcan technology projects. The MagSil extrusion operations were technically quite strong and commercially saw no need for joint projects.

I realised that we were not achieving the kind of Joint Projects which Alcanint had hoped for.

Banbury Labs continued to provide Technical Assistance to all Alcan companies on request. It formed some 20-25% of Labs activity.

International Links with '50%' Alcan Companies

Nippon Light Metal (NLM) in Japan was a fully integrated aluminium business and had a R&D laboratory at Kambara, which was about the same size as Banbury. They had a programme for members of their staff to do 'two year' stints' at Kingston. We extended these to Banbury and also managed to place Alcan people in Kambara.

Indian Aluminium Company (Indal) was another fully integrated aluminium business and they wished to establish R&D facilities of their own. We created opportunities for their staff to do 'stints' in Banbury.

Endasa in Spain was in a similar position to Indal. We talked about mutual staff visits/exchanges but nothing came of it. I think Alcan got out of its connection with Endasa. I also went to ASV in Norway on a similar 'wild goose chase' which came to nought for similar reasons.

I felt that these 'wild goose chases' were a result of Alcan's wooliness about its relationship with its minority or 50% companies.

Staffing at Laboratories

The year before I came to Labs I had been involved with the redundancy of some 1200 people at Banbury Works. There was an expectation that I would make redundancies at Labs. After a few months of getting to know the place and the people I proposed to Mr O'Leary some 10 positions, and people, whom I believed should be made redundant. He accepted my proposal and it was implemented using terms based on those that had been used in Alcan Booth. Included was the Deputy Director and also the staff of the Fabricating Techniques Division which had previously reported to a, by then, defunct boss in Montreal. Soon after this Mr O'Leary told me that John Elton, the head of Alcan London, had told him that he felt it would be right for Labs to have a more general redundancy ('to share the pain' of Alcan Booth?) and a figure of 10% had been agreed. This was implemented on the same terms which, for long-service employees, gave an 'early retirement' option. Voluntary redundancies met the target.

The other side of this was that we should not recruit new research staff. Our most successful way of doing this was through our support for research programmes in universities. These gave us the opportunity to get to know post graduate students. We should/could not fail to make use of these opportunities for too long. By the mid 1970s we were recruiting good people.

A Reflection

I very much enjoyed my time as Director of Banbury Labs. The nature of the work, its people and its size (I could know first names and have a nodding relationship with everyone) made it a very pleasant job.

After I left there was a major new thrust in Alcan's R&D programme – to create Corporate projects to develop new science-based businesses which could earn high RoI (return on investment). The idea that these could significantly change Alcan's overall role was arithmetically ridiculous. I could not support it, was glad not to be a part of it.

A relevant recollection from just before I left in 1979 is of John Blade, following a British Deep Drawing research Group meeting, telling me that the British Leyland (or was it British Motor Corporation then?) representative asking if Alcan might be interested in joining the work they were doing on car bodies (it was their project which led to the experimental aluminium bodied Minis). I put the question to the management of the Rolled Product Division. They showed no interest. Subsequently this became one of Banbury's major Corporate projects, which led, some ten years later, to sales possibilities with Jaguar.

3b. Rod Jones 1997 - 2001

New Opportunities and Thereafter

I joined AlcanInt at Banbury in 1985 during a period of re-staffing and gradual consolidation with the British Aluminium Lab at Chalfont Park. My recruitment was to the rolling process team led by Peter Brooks and Ian Calderbank. The initial focus of my job was improvements to the Norf hot line. I soon realised that I had joined a strong team, which had the responsibility to develop and maintain Alcan's core technology in the rolling process area through the Alcan Rolling Model and the Alcan Rolling Course. The Model itself was managed with a high level of security – very much the crown jewels! The accuracy and integrity of the model was defended vigorously although I remember some consternation when the father of the model, Maurice Tulett, admitted that Pi in the model was 'about 3'.

I took the Rolling Course in Kingston during my first weeks. I must admit that my most vivid memory was some very late nights drinking Scotch with Ihor Suchoversky. This was my first indication of the culture within Alcan of very senior people spending the time to encourage staff at all levels to reach their full potential through training and career development.

Back in the Lab. it became apparent that the rate and level of recruitment driven by Jeff Edington was creating a revolution in the capabilities of AlcanInt, mainly to underpin the rapid expansion of the New Opportunities Programme. When I was promoted to Programme Manager Jeff's challenge to me was to keep the businesses quiet whilst the rest of the Lab got on with New Opps!

Alcan was not alone in this period in seeking to diversify away from low profitability, commoditised core businesses. Energy companies looked to move into the aluminium industry, the aluminium majors looked at other materials and loosely related markets. Over time most, but not all these efforts proved fruitless and certainly Alcan's attempt to use R&D as a route into new businesses operating in new markets with new products was largely unsuccessful and definitely a financial failure.

In time the focus of Banbury shifted back to support to the existing businesses. This took place progressively and coincided with my period as Programme Director of the Fabrication Programme. Most notable for me during this period was the effect of the legacy of New Opps on the Fabrication Programme. This consisted of the use of the highly qualified and diverse skills recruited for New Opps and now set against challenges in our core businesses together with the application of rapidly developing computer-modelling capabilities. With hindsight I see this period as the establishment of Banbury as a real centre of excellence for product metallurgy and process development for all our cast house and downstream processes. This, together with the funding mechanism of Joint Development and General Research managed through regular programme reviews with the businesses and AlcanInt, which had been established during Peter Band's period as Programme Director, formed the basis of a highly successful period of Banbury having a major and direct impact on business performance. This coincided with a period of Alcan investment in rolled product equipment and facilities which became almost the single focus in our manufacturing businesses. This required our support on a global basis and many of us spent considerable time in plants worldwide, not to mention all those long haul flights.

In addition to the programme above was a corporately funded project aimed at developing products for the automotive industry, which was performed across Banbury and Kingston Labs. The motivation for this programme was aimed at developing the next major market after the beverage can and essentially to keep the smelters running at capacity. If the downstream businesses could also take advantage through the supply of products this would be an additional advantage. This programme became the biggest single activity in the Lab over a number of years and took us into totally new areas of manufacturing technology, new relationships with automotive companies in both Europe and North America all of which required recruitment of many new skills. The appreciation of this programme from the businesses went through many ups and downs with much frustration at the slow rate of development of the market. Again we were not alone in this field – Alcoa, Alusuisse and Pechiney also had major automotive projects at this time. In reality probably only now, some 30 years on, has there been a real shift in the light weighting of automobiles and major volume of aluminium being used.

After a time in the Rolled Products business I returned to Banbury and became Lab Director during which period we operated a combined management team across the Banbury and Kingston Labs which highlighted our ability to recruit and maintain a high quality team at Banbury. Much of this was due to our investment in a strong scientific network with high quality universities both in UK and abroad. Our basic competencies and business links were strong, Alcan's investment in R&D remained reasonably constant through the economic cycle – things looked reasonable positive. One local issue occurred in the form of a serious fire in our main laboratory area. After much to-ing and fro-ing to Montreal and discussions with our insurance company we got the OK to rebuild which was a positive result. Alcan was however changing; in fabrication we were simplifying our business with a sharper focus on critical high volume plants. Assets in UK were closing or becoming less significant and efforts to seek consolidation across the industry were underway. The initial attempt to achieve a three-way merger between Alcan, Alusuisse and Pechiney was not successful but consideration of such moves brought consideration of the future shape of R&D in such industry structures into sharp focus. Probably from this point on the future of Banbury Lab became less certain and questioned.

Shortly after this the merger with Alusuisse went ahead and we had the task of working together with the Alusuisse Lab at Neuhausen. This marked the end of my direct responsibilities within the Lab as I moved to the new Engineered Products Division in Switzerland with responsibility for global automotive technology. A year or so later the closure of Banbury Lab was announced.

I will continue briefly with the further moves I made as it gives me the opportunity to look back at Banbury with a different perspective. I became VP Technology and Innovation in the Engineered Products Division firstly in Zurich, and then after the purchase of Pechiney, in Paris. This gave me responsibility for the labs at Neuhausen and the Pechiney lab at Voreppe. I worked on the spin-off of the ex Alcan rolling assets as Novelis, and after the sale of Alcan to Rio Tinto, the sale of Engineered Products to private equity, now known as Constellium.

So from the above perspective Banbury had a very strong scientific base and, uniquely, combined with a very real passion to ensure application of its output in the businesses. Its work ethic was also strong and exemplified by the acceptance that the job required travel and extended periods in plants. Strong links with universities and other centres of excellence meant that we could recruit top quality people internationally. This combination of skills and work ethic together with the old Alcan commitment to train and encourage people's development created a lab without peer. However this takes no account of geopolitical factors. The decline of UK manufacturing and especially that of Alcan's assets in UK, the concentration of the assets of our new partners in France, Germany and Switzerland and differing political attitudes eventually overwhelmed the excellence of Banbury. Probably also significant was the anticipation that people would move and hence that key skills could be protected.

So this brings me to my most positive reflection on Banbury Lab – the people. Regardless of the site closures and organisational changes both within Alcan and more generally in the industry you can see a Banbury diaspora made up of top quality technical people many in leadership positions. Many moved to Neuhausen, on to Kingston and now to Atlanta with Novelis; some to Neuhausen and Voreppe with what is now Constellium. Some stayed close to Banbury and formed successful spin-offs as Innoval and the testing team now as Westmoreland. Great people still doing great jobs.

4. RESEARCH

4a. The Early Years

Nevill Turner

In 1943, the main concerns of the Research Department of Northern Aluminium Company were mainly, but not entirely, concerned with problems associated with the war effort, and particularly those of the aircraft industry. Gordon Field was in charge of the Research Department, and the four senior staff were Bob Parker (metallurgy), George Forrest (engineering), George Stanford (physics) and Pat Murphy (chemistry). Our main contact with the plant was with E.G. Robinson who was in charge of the Technical Department.

As a very junior, new member of the metallurgical staff I was involved initially with problems in the manufacture of high-strength alloys used in aircraft construction. The Al-Cu-Mg series of alloys had been well researched earlier, although manufacturing difficulties such as coarse grain outer band and the peripheral cracking of extrusions were still encountered and were not understood until several years later.

The high-strength Al-Zn-Mg series of alloys, although in use, were still subject to development and caused severe problems in manufacture both during casting and in fabrication. At this time, before staff could be moved back to the building, which for the war period was occupied by the Ministry for Aircraft Production, and it became possible to take over the experimental equipment there, metallurgical work was largely confined to the study of microstructure and mechanical properties. Of particular concern to the aircraft industry was the premature cracking of spars in the direction perpendicular to the direction of extrusion caused by the presence of unidentified defects. Much work was carried out to identify the nature of these defects, which were revealed when the spars were machined from the extrusions. Their cause was ultimately revealed as being due to fragments of aluminium oxide and the presence of coarse particles of Al/Cr/Ti compounds, both of which were a function of the continuous casting process. (Kingston Laboratories made a significant contribution to determining how the intermetallic compounds were introduced into cast billet). The important part played by the presence of dissolved hydrogen in the metal was not recognised until later.

Other metallurgical work at this time, carried out in association with Northern's Handsworth foundry, concerned the production of aluminium pistons for tank engines (at a later date this became of interest to Aluminiumwerke: Nürnburg); and in the use of high magnesium aluminium cast alloys for structural parts of aircraft such as the Lancaster bomber (subsequently abandoned, very wisely, for civilian aircraft largely, I believe, as a result of work done in Banbury Laboratories).

I am much less familiar with the work of Divisions other than the Metallurgical at this time. Of great importance to the war effort, however, was the study of the fatigue characteristics of the high-strength alloys and of the techniques by which they were joined, by the Engineering Division; and particularly by the development of pre-stressing techniques in the assembly of aircraft wing spars, also by the Engineering Division. Also vital was the work of the Physics Division in their part in the development of ultrasonic non-destructive testing of aircraft parts.

The only large scale research programme of work not connected with the war effort being carried out during 1944/1945 was a study of the use of (mainly) aircraft scrap materials for commercial alloys for use in the production of sheet for prefabricated houses. This involved the production of clad sheet and its corrosion properties. Corrosion studies were also made of the Al-Mg alloys.

It must be remembered that at this time there were no computers (I brought my slide rule and log tables with me when I joined the company), no X-ray diffraction, no electron microscope, no microprobe analysis and its various developments, and the techniques of mathematical statistical analysis had not yet been applied to industrial problems in the aluminium industry. Some research which may be described as 'basic' had been carried out earlier – the age-hardening of Al-Cu-Mg alloys by George Hardy, and the 'modification' of Al-Si casting alloys by Bob Parker – but, to my knowledge, there was only one programme of work current in 1947. This was a study of methods for the determination of the hydrogen content of solid aluminium and its alloys. The vital significance of this work would only become apparent at a later date.

Tackling the Problem of Anisotropy - Nevill Turner.

Extracted from a talk given at the CEI, Geneva, in July 1958.

You probably know that, if you take a circular blank of aluminium sheet and with a punch and a die press it into a cup, then the rim will not be level but will contain protuberances, which we normally refer to as "ears". These ears are usually four in number and are symmetrically disposed. The earing problem hit the aluminium industry more or less simultaneously all over the world just after the war. The reason was that, during the war, very little commercial purity aluminium for deep drawing had been produced; most productive capacity having been devoted to the aircraft industry. During the war, however, a considerable technological change had occurred in the fabrication of aluminium. The older method of casting ingots into permanent moulds had been discarded and continuous casting had become more or les universal. When fabricators began to use continuously cast ingots to produce sheet for deep-drawing, they immediately encountered earing problems. Most factories went through the same stages: a period of intense activity when all production factors were varied together in an effort to alleviate the situation. The first reaction was that there was no sense to the problem at all but gradually, over a period of time, acceptable fabrication procedures were developed for particular products.

Two factors became apparent, however. Firstly that a separate procedure had to be laid down for each commodity which was obviously undesirable economically; and secondly that the solutions evolved in one Works were not applicable in another.

We went through three stages ourselves at Laboratories. We did not, in fact, find it very difficult to solve the problem as far as we were concerned and were able to produce high quality sheet on our experimental mill. We soon found, however, that it was quite impossible to transfer the technique from Laboratories to the Works, or indeed from Alcan to Northern Aluminium, or from Northern, Banbury to Northern, Rogerstone. We determined at Laboratories, therefore, that it was time we went away and taught ourselves something of the fundamentals of the earing phenomenon. This we did, and, for perhaps two years, were engaged in much theoretical work involving a fair amount of mathematics, X-ray back reflection and other techniques. At the end of this time, however, we felt that we knew just a little about what was going on and suggested that the time had come to get together again with the Works. A committee was therefore formed with a member of

Laboratories, a member of the Works and a member from Northern's Central Technical Department. From then on, all work at Laboratories and in the Works was planned and progressed by this committee.

The result was that, in the space of about a year, the earing problem was dropped from the top of Northern's list of difficulties to a position of considerably less importance. I wish to stress that this was not Laboratories doing. The experimental work was done by the Works but the fact that we understood something of the basic mechanisms involved enabled us to help the Works to plan the work systematically and economically and to ensure that the results obtained in one Works were applicable to another.

I think perhaps that this committee method of approaching a problem and applying the results of Laboratories, work is ideal.

Plane Strain Compression (PSC) Testing in the mid-1950s

4b. Core Research and Development (from the 80s)

Ricky Ricks

Nineteen eighty-six. Two years previously I had been given a staff position at the University of Surrey and it looked for the entire world that I would spend my life in academia. Alcan was a major sponsor of the research at Surrey and regular visits to

Banbury were the norm to meet with the likes of Dick Jordan who was then working on the aluminium – lithium programme. I was very pleased with the response from Alcan regarding the various research topics being sponsored and one day, whilst at Banbury I was offered a discussion with Jeff Edington, then Laboratory Director. I had known Jeff briefly at Cambridge before he left for the USA and always enjoyed discussing science and technology with him. However on this occasion I was in for rather a surprise: his agenda was to offer me a job. Life as an academic in Surrey was fun but for one thing – the salary. Guildford had London prices but no London allowance and living life on a shoestring was not particularly pleasant, so I accepted.

I actually started part-time so that when I joined full time I would "hit the ground running" (Jeff's words, not mine) and my role was to run a project of high temperature bonding and forming of the recently developed aluminium – lithium alloys known as Lital. This involved commuting to Germany and I sort of hoped that I might pick up some German in my time there, but it was not to be – all my German colleagues were far more interested in upping the standard of their English using me as a tutor.

After one year Alcan offered me the position of running a recently created project known as Sheet Metallurgy Research. At the time I knew nothing of the politics of Alcan having spent most of my first year in Germany. However I was soon made aware of the developing rift between Alcan operating companies and Alcan International, a rift that was not helped by the large research programme looking at anything to take Alcan out of aluminium at the suggestion of some highly paid consultants. In fact, with hindsight, I suspect Sheet Metallurgy Research was created to placate the operating companies. To get the project off the ground the previous project leader had investigated three topics of concern to operating companies in Germany and the UK. I should add that a sister project, with the same title, operated in Kingston to service the North American operating companies. This mode of operating the project seemed fine to get the project members some experience but didn't seem to me to be tackling the key issues of commodity sheet production, which should be the focus of Sheet Metallurgy Research.

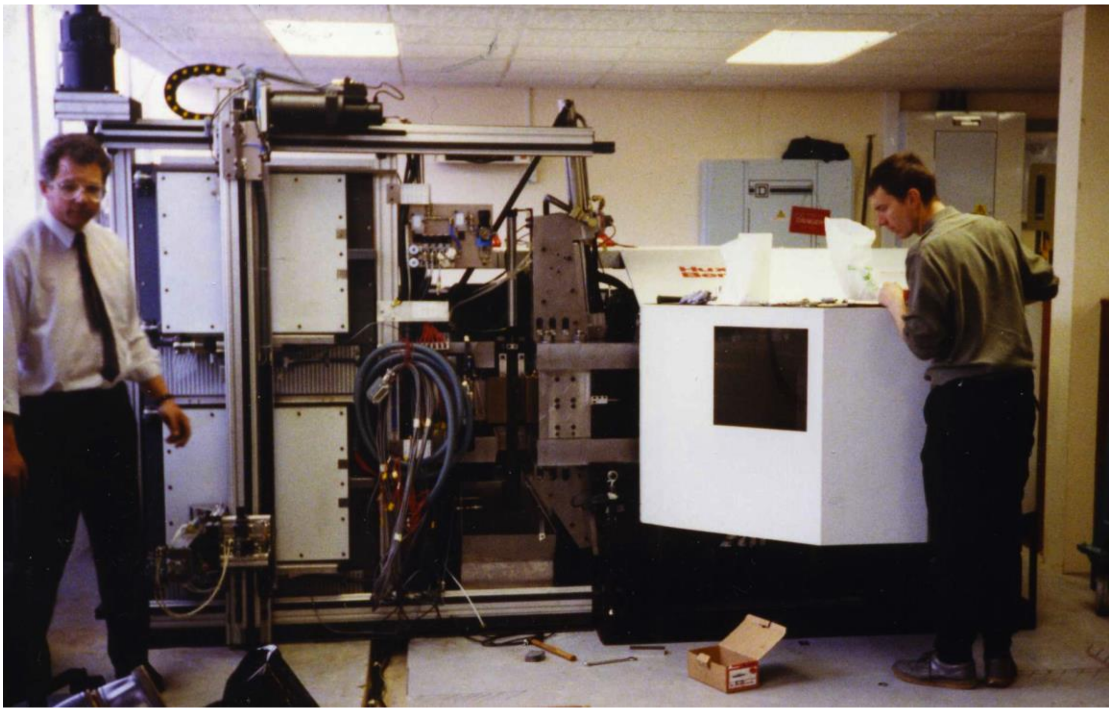
I did more travelling to Germany to meet the key players and soon befriended Dr Peter Limbach, then technology guru for Alcan Deutschland. Peter was a brutally honest character and was one of the main attackers of Alcan's "New Opportunities" research programme. It was not obvious that he and I would get on and there must have been a few senior members of the Banbury Laboratories who would think I might return in a packing case rather than British Airways! But we did get on, very well in fact, and I began to explain to Peter of my desire to create Sheet Metallurgy Research as a core science project, which would underpin the kind of work, it had done in the first year. Peter saw this as a good way to turn a small part of Banbury towards supporting the existing operating companies but also made the point that there was unfinished business in the research topics adopted. I suggested to Peter that those companies who would directly benefit from the research should be paying for it and to my surprise he agreed. And so began the model of Sheet Metallurgy Research being allowed to develop into a core science project and supporting, and being guided by, Joint Development Projects (JDPs) like a sun surrounded by its planets. This had another, unplanned for, benefit: each JDP needed a project leader and this provided an important means of developing the members of the original project.

Well, we must have been doing something right because the JDPs soon grew to be larger than the original project. We also had a lot of fun. Project review meetings became major events occupying a whole day and for reasons I've never questioned in my mind. It was always of the highest importance that everyone should be able to contribute into the discussion. It would not be unusual for more than twenty people to be discussing scientific issues and learning and contributing to this great debate.

I'm afraid the same could not be said for the sister project in Kingston which was withering slightly, and all because there was no Peter Limbach equivalent in North America to act as a sponsor. One alarming, yet with hindsight amusing, story I recall was from 1990. I remember the year easily because my son had been born that year and we all planned to go to San Sebastian in northern Spain to a conference on aluminium metallurgy. The fact that San Sebastian was a nice place on the coast had nothing to do with the popularity of this conference, honest, and of course we all used it as a means to take a short summer break with our wives and families. To my horror that same week was chosen by a delegation from North America to review the growing research in rolled product metallurgy with a view to cutting the central funding. So, to cut a long story short, I took my family out to Spain, stayed the Sunday night, flew back to the UK on the Monday, reviewed the research programme and flew back to Spain that evening. Once again, we had impressed our North American visitors to the extent that they started funding their own JDPs the very next year.

What Sheet Metallurgy Research did, once all the plant-focussed activities were dealt with in the JDPs, was left for us to decide. Many operations like annealing, forming, cold rolling, etc. could be successfully simulated in the laboratory and this simulation was the mainstay of our work. Simulation in the lab was very much cheaper than plant trials and was used extensively to design plant trials to maximise their effectiveness. Hot rolling was different and we had no way of simulating this stage of manufacture despite the fact that hot rolling mills are major pieces of capital so hot rolling trials were the most expensive of all. I was aware that certain Universities in the UK had done a lot of work looking at hot rolling of steel and the top academic in the field was Professor Mike Sellars at Sheffield University. A visit there confirmed that our chief competitor, Alcoa, had used the facilities at Sheffield and had retreated back to Pittsburgh to build their own. Mike Sellars was rather disappointed with the interaction he had had with Alcoa and wasn't at all sure Alcan would act in the same way. I managed to placate Mike and we started a project into simulating hot rolling using a technique called "plane strain compression" testing (PSC) which deforms metal in the lab in much the same way as rolling does in the plant, except on a much smaller scale.

The equipment at Sheffield was good, state of the art in fact. But what it could not do was simulate hot rolling in tandem mills. Tandem mills are three or four rolling mills operating in tandem, with the metal getting thinner, gathering speed and cooling down before finally being coiled ready for cold rolling. Tandem mills were the mainstay of commodity product production in Alcan and yet we had no way of simulating them. We had done quite a bit of equipment development with a prototype engineering company based near Cambridge and we began initial discussions with them on building a PSC tester which could simulate hot tandem mill rolling and these discussions eventually led to a design. One problem, the cost was going to be something like half a million pounds. Such was the success of the rolled products research programme by now that such a sum was eventually accepted by the Laboratory Management for inclusion in the next year's capital budget. It wasn't quite plain sailing after that but we did build our own PSC tester, it did work and we were able to simulate hot tandem mill rolling in the laboratory. It was, for me, the highlight of my career with Alcan and I can only just recall the party we threw at my house to celebrate this success of the whole team that did this development. We joined a pan European programme with three other aluminium companies and several Universities and our team felt immensely proud of our capabilities at Banbury compared to our rivals, all of whom sought to buy PSC testing facilities as soon as they could. As a footnote I should add that as the Banbury Laboratory was closed down in 2003 the PSC tester went to Imperial College in London who tried to adapt it for titanium research. It was never designed for the higher temperatures needed for processing titanium and the last I heard was that it was being cut up for scrap!



Ricky Ricks and Richard Keyte building the PSC test machine in the mid 1990s

The rolled products research model was rolled out to other areas, extrusion being the one I had direct involvement in. What we did, as a team, was to turn what seemed to be boring research topics into exciting scientific adventures and we had no difficulty attracting top academic interest in the major UK Universities. This again had a significant benefit: Alcan funded students could spend three years doing a doctorate and gaining experience at Banbury allowing Banbury to cherry pick the best as new recruits. This was the time I remember with the greatest fondness, with scientific discoveries happening regularly and how we built, in the UK, a tremendous science base, which Alcan benefitted from immensely.

The key word in this development was team. No one person dictated the research direction and although I was nominally project leader I knew fundamentally that it had to be a team-based approach: probably because I was aware that no one person could understand the complexities of aluminium metallurgy, certainly not me. But of course the success of the programme led to my promotion into Laboratory Management, lots more travel and a diminution in my involvement in science. But that’s another story: one that probably isn’t worth telling.

On hearing about the planned closure of the Banbury Laboratory I was sad and a bit angry that people, well divorced from technology, had chosen this path, seemingly without understanding what was being destroyed. It was without hesitation that I realised my time with Alcan was over and a life in consultancy beckoned. At the end of my time I was dabbling in topics unfamiliar to research laboratories, like knowledge management and competitive intelligence and I could see how the great minds of the staff at Banbury could be enormously beneficial if directed to these subjects. Now, as a consultant in the big, wide world these topics have enormous importance in my life and I'm thankful to Alcan for giving me all the training over the years.

One final thought. In our everyday work as consultants to the aluminium industry we are frequently having to resurrect topics of research which were on-going in Alcan ten or fifteen years ago and it is often with astonishment that we find the work published by Alcan all those years ago is still the latest understanding of that particular topic. This gives me a tremendous sense of pride of what had been achieved in Banbury and the small role I had in it. Like most commodity based aluminium companies, Alcan was losing the need for large, fully serviced, research facilities and I'm just thankful I joined the industry in time to participate in one of the best.

5. CASTING IN BANBURY LABS

5a. Gerry Lucas writes: -

The casting programme in Banbury Labs had several aims: to support ingot sales by providing expertise in shape casting (sand, low pressure and high pressure casting); to provide technology for major corporate initiatives (belt casting); to improve product quality by ingot microstructure control and defect elimination[1]; to find ways of reducing DC casting costs by reducing ingot scrap rates and increasing casting productivity; and – not least in the eyes of the other Lab programmes – to provide sample and trial quantities of development alloys and other materials. Perhaps the heart of the programme – and certainly its brain – was the understanding of solidification in casting, in particular of the development and consequences of cast microstructure, and of mechanical stresses, in various cooling regimes.

In 1963, when I was hired, the DC Casting section consisted of Don Collins as leader, Peter Sevier, Cliff Scales and Derek MacPherson. (I was hired because on interview I convinced John Clare that I already knew the meaning of the words ‘grain refinement,’ and George Gardam that I could translate the Latin on a two-shilling piece.) Don’s section inhabited a pokey little ‘lab’ in the extension between the main wing and the machine shop. Our equipment was an electric resistance furnace, which could melt metal but only just, and possibly the world’s smallest DC casting machine. And yet with these Don had already demonstrated some of the major principles of ingot shape control and the influence of differential cooling on ingot cracking.

Derek MacPherson and Cliff Scales with cast ingot

[1] See liquid metal filtration section.

Don Collins was a remarkable man. He knew DC casting to the point where he could think and feel like an ingot as it was being cast – the distribution of liquid metal, the chilling effect of the mould and the water curtain, the advance of the solidification front, the development of stresses because the central parts of the ingots solidified and cooled long after the outsides were cold. From this 'feel' Don went to paper, drawing sketch after sketch until he could think through, for example, the reasons why centre cracking was a continual problem in extrusion ingot casting. Then he would imagine a change in casting technique, or equipment, and test the idea on paper and in the lab. And, almost without exception, his ideas worked. Don's other virtue was always to write reports of exceptional clarity. The techniques he developed were not always adopted by the 'clients' in the operating companies (for reasons both good and bad), but they were proof of understanding. That understanding underpinned developments throughout Alcan's world.

When I entered the DC casting lab for the first time the team had just started casting a 9x24 inch ingot. Don was standing by a large manual water valve, looking at his watch and counting. Every few seconds he turned the valve 'on' and water hissed as it splashed onto the ingot. A few seconds more, a turn in the other direction – water 'off.' Repeated for about 10 minutes this was known as 'pulsed water to prevent butt curl.' Don later explained that the first layer of liquid metal poured into the mould solidified and contracted very quickly. The next layer then solidified and tried to contract but could do so only if it distorted the first layer to which it was now attached (or if the new layer cracked). Pulsing the water reduced the difference in the cooling and contraction rates between the layers – none became completely cold before the next started to contract – and allowed some relaxation of stress during the 'water off' periods. Back we went for the next trial. This time I got up close and watched the ingot. Sure enough, when the water was 'on' the butt curled up at the ends; when it was 'off' it visibly relaxed into a flatter shape. I was convinced. Delayed Quench (DQ) casting of cylindrical extrusion ingots was based on related principles. Usually, the outer band of such an ingot solidifies, cools and contracts long before the centre. When the centre does solidify, its contraction is prevented by the cold outer band. The resulting stress can cause the ingot to crack from top to bottom; the higher the casting speed, the worse the problem. In DQ casting the sub-mould water is reduced to the point where the outer part of the ingot just solidifies safely, but remains hot. A second water quench is applied at the point a foot or so below the mould where the centre is solidifying. Both centre and outer band contract together and cracking is prevented.

Cooling water distribution inside and below DC casting moulds must be controlled to cast ingots fast and to required quality standards. And yet, in the early 1960s, the principles of water distribution were often unknown in production casting plants, or were ignored. Gradually this changed; various engineering solutions were adopted but all incorporated the understanding the Lab programme had generated.

This is not the place to describe all the DC casting ideas we worked on but the list on the right will perhaps bring back some memories, smiles – and regrets. These ideas were not all tried in the old lab. In 1965 a new foundry building, with much better facilities, was opened. It brought all the (then) casting projects together under one roof. Brian Gillett's high-pressure die casting machine squatted ominously in the northwest corner. DC casting with three furnaces, including a three-ton 'giant,' occupied the east end. Next to the furnaces were two casting pits, one of which was of commercial size (well, it was if you ignored places like Norf, Oswego and the smelters). Low-pressure casting and various other equipment filled the rest of the space. We were, for a short time at least, like kids at Christmas, and we celebrated by setting two world records, one for DC casting speed (120 inches per minute; typical speeds were two to five ipm), the other for ingot 'thinness' (or more properly aspect ratio, 15:1). Neither technique was commercially practical but both removed barriers, which were mainly psychological – and they were excellent fun.

A principal focus of casting research was ingot microstructure control. Grain size and orientation, cell size and solute distribution controlled everything from ingot casting speed, scalp depth and homogenizing time to product performance (N.C. Joseph's bright anodized coffee pots will be a part of my nightmares to my dying day). Solidification rate and its variation through an ingot's thickness were controlling variables; another was 'grain refinement': the nucleation of many grains ahead of the advancing solid/liquid interface, usually by adding nucleant particles. When grain refinement worked as it should, the resulting grains were small and randomly oriented and macro-segregation was reduced. These were all good things but grain refinement itself was a chancy process. The commercial nucleants which were added to liquid metal before casting often introduced contaminants. And sometimes, mysteriously, they didn't work at all, and a batch of ingots would either crack or (worse still) be manufactured and sold, only to be rejected by the customer. Both these problems were largely solved by the Lab programme; the first by working with the grain refiner manufacturers to control the microstructure of their nucleants; and the second by limiting the boron content of metal coming from Alcan's smelters.

Pulsed water
Adjustable mould
Delayed Quench
Flexible mould
Short mould
Insulated mould
Hot mould
Electromagnetic mould
Bleed band control
High speed DC casting
Thin DC casting
Grain refinement by Ti/TiB2
Grain refinement by electromagnetic sump stirring
Rod grain refinement
Liquid metal cleanliness assessment (PoDFA, UPILM)
Electromagnetic furnace stirring

A new casting programme started in 1970 – Twin Belt Casting. Dave Bonney was lead metallurgist working under the leadership of Dr Bill Baker of Alcan UK; numerous other people throughout Labs Banbury contributed to the development.

Dave Bonney writes: -

I started work in Banbury in September 1969, just as Gerry Lucas was leaving. I believe that we overlapped by about a month but he was busy preparing for his transfer to Arvida, so I don't think we actually worked together. I spent the first year or so of my 3½ years continuing the work on high-speed DC casting and grain refining. Sometime during my second year we started working on both the drum caster and the twin belt caster. The principal behind the drum caster was to simplify the Hunter caster and cast horizontally. We spent a long time trying to modify the cooling rate and metal feed along with massive amounts of grain refiner to eliminate the very granular surface. This was due to nucleation and preferential growth of individual grains, which remained proud of the surface when the rest of the matrix solidified. We did not succeed. However our failure did result in marketing a product called **Granural**, when an architect visiting the extrusion plant across the road saw the sheet and decided he wanted to use it in the Beaulieu Motor Museum. I think that it was the only place that it was ever used.

A hive of activity in the casting shop

The twin belt caster was designed by Bill Baker to overcome some of the limitations of the Hazlett caster by better defining the casting cavity allowing production of sheet suitable for making cans. The original idea was to use magnetic chucks top and bottom with longitudinal cooling channels and Ryertex belt supports. For cooling water supply we used an old fire pump located by the water tank out back and a centrifugal return pump. One of the first challenging tasks was to balance the flow of the two pumps so that we didn't generate too much positive or negative pressure in the belt supports. In either case the result was water spraying everywhere. The initial trials resulted in a very well defined fine grain structure in areas of the sheet over the water channels and coarse grain structure over the Ryertex. To overcome this 'structural deficiency' we tried turning the water channel across the width but this resulted in chatter as the belts moved over the Ryertex. Eventually we turned off the magnetic chuck and relied on throttling back the supply pump to generate just enough negative pressure behind the belts to maintain contact with the supports. Again this worked well until the belts buckled, let in air and we lost the prime in the pump. The result was water spraying out everywhere usually followed closely by molten metal. There were a number of times when doing demonstrations for Bill Baker when I found myself surrounded by water and molten metal only to look up and find all of the visitors, who had been standing around watching, peering through the small windows of the foundry room doors – quite a comical sight.

We never did really succeed in eliminating the supersaturation and segregation but I guess there was enough success that Bill Baker moved to Oswego to work on the next prototype. I lost track of any further development when I moved to Arvida to work for Gerry so I really don't know how much of what we did ended up transferring to Saguenay Works. However, I do know that in my short 3½ years in Banbury I learned a lot about molten metal and casting that stays with me today. It was a great way to start my career.

5b. BANBURY BED FILTER

Peter Read

Introduction

In the 1960s it was becoming ever more obvious that the performance of many wrought products was being strongly influenced by the cleanness of the molten metal used to produce cast ingots and billets.

The quality of products such as lithographic and anodising sheet, bright trim, foils, can stock and thin-gauge drawn wire was adversely affected by the presence of impurities, notably oxides, carbides, borides, spinels and refractory particles from furnace linings. Consequently, molten metal cleanness and methods for improving it had been under consideration for some time.

Early attempts to filter molten metal using several layers of glass cloth in a metal frame (the underpour glass cloth filter, UGCF) had had only limited success in reducing film and gross oxides contamination.

There was clearly a need for a much more efficient molten metal filtration system and the work at Banbury Laboratories, summarised here, describes the experimental work and subsequent development of the Banbury Bed Filter into equipment suitable for use in production cast houses.

Early Experimental Work on Design Features

The initial development work, on a filter system based on depth filtration through a bed of refractory media, began with Peter Sevier carrying out a literature survey on packed bed filtration in other industries, notably the water industry. Peter subsequently emigrated to the U.S., where he still lives.

The flow of a fluid at low pressures through a packed bed is governed by the Darcy equation, in which the rate of flow is proportional to the pressure drop per unit length of packing. This simple equation, however, does not take account of the filter permeability, i.e. the packing characteristics of the filter medium.

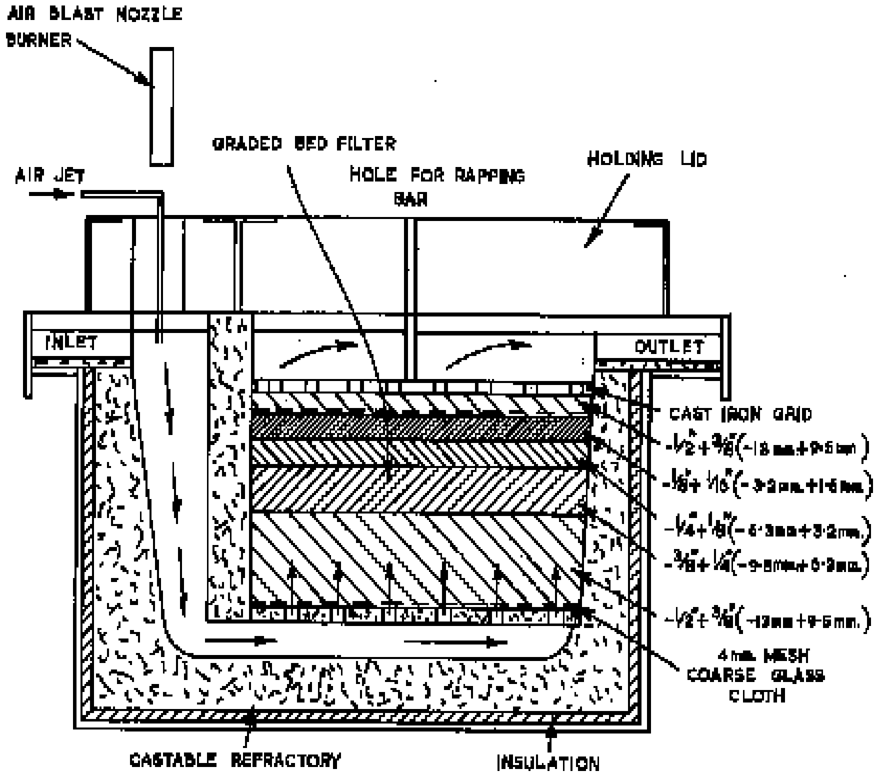
To utilise the Darcy equation in practical situations requires the characteristics of the filter bed to be experimentally determined. This was achieved by development of the more specific Kozeny-Carman equation.

This equation takes into account eleven factors including the rate of flow, porosity of the packed bed, pressure difference across the bed and the viscosity of the fluid, Although the Kozeny-Carman equation goes a long way towards determining the basic features of a packed bed filter, there were still other parameters which had to be determined before the design could be tested in a prototype filter.

The optimum arrangement of the packed bed layers and the most effective range of filter particle sizes was determined from a comprehensive series of water model experiments carried out by Chris Flint. These tests showed that a four-layer bed gave the best results using filter particles ranging in size from the coarsest (-1/2 inch to + 3/8 inch) to the finest (-1/4 inch to +1/16 inch) in a ratio of 4:2:1:1.

The design of the prototype filter is shown schematically in the figure on page 35.

Another important decision was whether the filter should be of an overpour or underpour type. Tests showed that underpour had several advantages. It tends to prevent the formation of oxides when the bed is first filled, the flow of metal upwards through the bed is more homogeneous, i.e. less chance of channelling, and the control of the metal against gravity makes for a more quiescent flow.



.**Graded Bed Filter Design**

First Production Trials

Banbury Works had a metal quality problem with F57S bright trim sheet. This material was used for washing machine lids in an anodised and dyed condition. Many of these lids exhibited a “fleck or comet tail” defect on anodising, which was found to be caused by large titanium diboride particles.

It was decided that this would be an ideal opportunity to test the bed filter in a production cast house.

The final design and construction of the filter was carried out in Alcan Laboratories with Brian Gillett heavily involved in its construction. As this filter would have to operate in an existing cast house, there were two other important factors to take into account, namely size of filter and provision of a driving head.

As filtration efficiency is strongly influenced by flow rate, the maximum flow rate must not exceed 0.5lb/sq.in./min. (0.035 kg/cm.sq./min.) and this factor largely dictates the overall area of the filter bed. The filter must take account of the maximum metal flow/minute which requires knowledge of the size of ingots being cast, the number of ingots and the casting speed for ingots of that size.

As metal passes through the filter, inclusions and oxides are removed from the metal and trapped within the filter media. This gradually increases the resistance to flow of the metal so that an increased pressure or head is needed to drive the molten metal through the filter at a constant flow rate. The increased head is most easily observable as the difference in level between the inlet and outlet metal heights. It is usual when designing a filter to make allowance for this driving head by ensuring that the inlet metal level can be up to 100mm (4in.) higher than the outlet level.

Use in Production Plants

After successful trials had been completed at Banbury Works on the F57S sheet, there was considerable interest in the use of the Banbury Bed Filter in other production plants within the Alcan group.

Arvida had constructed a filter based on design criteria supplied by Alcan Laboratories and Brian Gillett helped Horst Schinagl to commission it successfully.

A filter was used at Alcan Castings and Forgings, Handsworth, on a Properzi casting machine. The cast bar was drawn down to fine 0.5-mm gauge wire but the presence of inclusions in the cast bar caused many stoppages because of wire breaks.

The filter removed a substantial percentage of these inclusions so that the incidence of wire breaks was reduced by over 80%.

We co-operated with Frank Plata at Oswego to design the biggest filters at that time - weighing in excess of 2 tonnes. Peter Read helped Chris Kowceski to commission it.

Alcan Plate at Kitts Green had been operating a Kaiser ceramic tube filter, efficient but very expensive and with a short life. They too constructed a bed filter with assistance from Banbury. Brian Gillett and Peter Read worked many shifts with the casting crews as they gained experience in its use.

Eventually, it replaced the tube filter and was used as standard equipment on aircraft alloy products.

Alunorf showed interest in using a bed filter in the late 197Os and Peter Read co-operated with Dr. J. Lodde in the design and construction of a big bed filter for that plant.

A double chamber unit was designed for Endasa, Alicante. The first chamber was a conventional bed filter whilst the second was a degassing chamber constructed around a spinning nozzle unit. The spinning nozzle unit was designed and built at Banbury Laboratories with Gilbert Hill taking the lead role in producing it.

Photographs of this unit during its construction are shown in the figures on page 37.

The use of the Banbury Bed Filter in these production situations has led to some practical improvements on the original design. The use of kyanite (an alumino-silicate material) as the filter medium was discontinued because of the risk of silicon pick-up during long holding periods. It was replaced universally by crushed fused alumina, a totally inert product.

Improvements to heating arrangements have also occurred using either electric radiant heaters or immersion tube heaters. Levels of insulation have improved, as have the materials, moving away from Marinite to Micropore panels to minimise heat loss.

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Although this note relates specifically to the Banbury Bed Filter, it is clear that other companies, notably Pechiney, have gone down the same route and produced a bed filter which was uncannily like the Banbury version.

5c. RECOLLECTIONS OF BANBURY LABORATORY AND SOLIDIFICATION RESEARCH IN THE 1990s

Paul Evans

I arrived in Banbury in January 1991, having spent a couple of years as a post-doc at IBM in New York. My IBM work on the electrical properties of grain boundaries in semiconductors would not have made me an obvious choice as a new recruit for Alcan's R&D program (or "small r big D" as it was then branded). However my prior involvement in solidification of metals (including occasionally aluminium) during my research career in Cambridge stood me in good stead. In fact my former thesis supervisor had recommended I contact a certain Phil Enright of Alcan, on learning of my intention to apply for jobs back in the UK (since by all accounts he was a bit of a livewire, never short of an idea or ten). This I had duly done, and subsequently heard nothing for months. On a whim I decided to re-send the letter speculatively to the personnel department. Before I knew it, I was being whisked back for an interview, and sent down to Oxford to have my mental fitness probed by a bunch of industrial psychologists (whatever they were). Phil Enright it transpired had been in the midst of heading off to Kingston on secondment, and my original letter had obviously gone astray… or more likely lost in depths of Phil's legendary filing system! Anyway I managed to negotiate my way through a day of interviews, trying not to look too bemused when people kept talking about "DC casting". I sat racking my brains… direct current was all that came to mind. I wondered if they were talking about reduction, but fortunately resisted the temptation to voice that thought.

When I joined Alcan "New Opportunities" were the flavour of the month, and had resulted in a substantial expansion of the laboratory. I think I was just about the last new hire before the rot set in. The lab was bursting at the seams, with a hugely diverse array of research programs. Many of which seemed to have little or nothing to do with "conventional" aluminium as far as I could see. In fact I gradually became aware that this was not by accident, but rather by design. A strategy was being followed, investing Alcan's record ever profits into the development of whole new businesses, the holy grail being to find one (or more) which was counter-cyclical to the aluminium industry. In my youthful naivety, this seemed a very bold approach. As time would tell, it was actually a hopelessly naïve approach: I don't believe any of the scores of new opportunities ever made it to commercial fruition.

Whilst all the management sunshine was beaming on New Opportunities, there were still a few programs dealing with plain old aluminium. One such group, where I started my Alcan career, was focussed on DC casting (a quick perusal of a textbook after my interview had soon disavowed me of my misconceptions where "DC" was concerned). The bulk of the program, presided over by Laurens Katgerman, was focussed on modelling the process, pushing the then existing computer capabilities to their limits in their efforts to couple fluid flow to heat transfer with a solid to liquid transformation and an interesting surface boundary condition. Oh yes, and it also needed to be transient, and calculate stress development. My background had partly been in modelling rapid solidification, but on meeting the likes of Steve Rogers and Steve Flood, I realised they didn't really need much help from me! I also wasn't entirely sure where it was all supposed to be leading. Microstructurally, the output from the models seemed to be limited to a prediction of the size of dendrites across the ingot. Even with my limited exposure to wrought products, it wasn't entirely obvious why this was interesting. In fact given the amount of "heating and beating" most DC ingots were destined for, it was pretty questionable whether anything in the cast microstructure mattered at all. A point often made in those days with some eloquence by the Sheet Metallurgy Group.

There was however a small experimental project running as part of the DC casting program, which looked like being a vehicle which could deepen our understanding of controlling cast microstructures. And this was where I spent a large part of my time initially. There was already evidence that some aspects of the cast structure were significant: it wasn't the dendrites, but the stuff in between them, the intermetallic phases. Aluminium is able to form a bewildering array of compounds with alloying elements, and in the world of extrusion, and surface critical (for which read "value added") rolled products it was well known that getting the "wrong" phases in the cast structure would come back to haunt you downstream.

The traditional experimental approach involved casting DC slabs either in the Banbury foundry, or occasionally at a commercial production facility. This was a time-consuming business which usually meant that only a few alloys and conditions could be investigated, and with laboratory process conditions often far removed from large ingot casting. In spite of these limitations, there were some notable achievements using this methodology. One of the most eye catching related to a re-examination of the tolerance to impurities in AA5182, the can end stock alloy. At the time this was invariably a smelter alloy, with iron and silicon levels typically less that 0.1 wt.%. It was proposed to push these levels out to 0.2 or even 0.3%, which if successful, would allow a greater use of recycled scrap, and hence lower cost. The firm belief in the operating companies was that firstly it would be impossible to cast such ingots, and even if you could, they'd fall apart on the hot line. Nevertheless in a rare example of inter-lab cooperation, the ingots were duly cast in Arvida, shipped to Alunorf and rolled to final gauge. Then sent to Banbury for characterisation and testing. Finally they were sent to the Applied Material Centre to run on the end maker. Contrary to expectation, all the alloys were cast and rolled without a problem. And the final formability properties could be controlled by getting the balance of iron and silicon correct in the alloy, in order to select the correct intermetallic phase. The tolerance could certainly be relaxed to levels nearer 0.2%. Today AA5182 is cast in many remelts and is no longer considered to be uniquely a smelter alloy.

The trial described above lasted the best part of a year, and involved staff from three research centres, not to mention a casting plant and a rolling mill. All this was happening against a backdrop of increasing austerity in Alcan to which the research system was not immune. Alcan had moved from posting its biggest ever profit the year I arrived, to posting its biggest ever loss two years later. Suddenly "New Opportunities" were out, and "Core Competencies" were in. Which for Alcan meant smelting aluminium. And perhaps rolling it. But not extruding it, or shape casting it, or anything else. As the company tried to realign itself with the new strategy, business units and plants were closed or sold off, in the drive to achieve Full Business Potential (FBP). In the R&D system whole research programs shut down and the laboratory shrunk to less than half its size. All those left had one thing in common: they had actually touched aluminium during their Alcan research careers. Alcan emerged after a couple of years as a much leaner organisation, focussed on its core businesses (until it acquired a whole new rag tag of down stream businesses in the "merger" with Alusuisse a few years later!).

The only surviving element of the DC casting program in Banbury was the small experimental project focussed on Sheet Ingot Metallurgy. The whole modelling effort was terminated, and the competency transferred to Arvida. Laurens Katgerman had seen the writing on the wall and decamped back to the University of Delft. Steve Flood had also departed, seeing little room for advancement in a top-heavy structure. So I found myself running Sheet Ingot Metallurgy, closely tied to some product specific joint development projects mainly funded by Alcan Deutschland.

Given the financially straitened circumstances, I realised we needed to rethink the way we approached solidification research. The chances of running full-scale trials were very unlikely, and besides, it was such a slow process. Beyond that, there was the question of what exactly mattered in the cast microstructure. We could measure grain sizes and cell sizes *ad nauseam*, but so what? Dendrite sizes were known for decades to be simply a function of local cooling rate: and if nothing else, all the modelling work had shown that apart from the periphery of the ingot, this was pretty much dictated by the size of the ingot. Grain refiner additions had also gotten better and better, and their main function was understood as improving castability: provided the ingot was sound, the as cast grain size itself was largely irrelevant in most products (with a few notable exceptions). Besides, the full-scale trial described above had confirmed again the importance of getting the right intermetallic phases in some alloys. There were well established techniques to try and identify the intermetallic phases present by the use of various etches, but these were often unreliable, and the results were often found to be at odds with assessments of the same samples using electron optical methods.

So we needed a cleverer way of doing solidification experiments, and a more reliable way to interrogate the cast microstructure. The solutions to these two requirements came together at this point, and dramatically improved our ability to understand, and subsequently control cast microstructures.

In the height of the New Opportunities spend fest, a new Solidification Laboratory had been commissioned next door to the foundry. And sitting in the corner was a Bridgman growth furnace, originally ordered in a rush at the end of a financial year, to make use of a pile of unspent specific project costs (SPC), based on the principle of "use it or lose it". This was a very elegant controlled directional solidification device. It comprised essentially a vertical hot tube furnace, below which, and in very close proximity was a cold water bath. A long thin graphite crucible, filled with molten aluminium could be withdrawn from the furnace into the water bath. The really elegant thing about such a design is that within reason, the thermal gradient could be changed (by moving the water tank, or employing additional furnace elements), as could the growth speed (and being designed to operate in steady state, this equated to the velocity of the solid-liquid interface). And best of all, each experiment took about 10 or 15 minutes. Over the course of a few days, an impressive array of solidification conditions and alloy variants could be explored.

The Bridgman furnace had been designed by Steve Flood and Ian Hughes, building on their respective experiences with Prof. John Hunt (Oxford) and Prof. Howard Jones (Sheffield). There was only one problem: it didn't actually work. In fact when I had first arrived in Banbury, one of my initial tasks had been to work out what had gone wrong. I found John Worth and Ian Skiplorne tearing their hair out, unable to grow a single sample without the apparatus seizing up. As is usually the case, there wasn't one single thing wrong, but a host of errors had been incorporated by the engineering firm contracted to supply the equipment, no doubt in the haste to have it delivered before financial year end. We spent a good few months poring over the design drawings, measuring alignments, and slowly correcting all the flaws. Eventually, it ran smoothly and reliably. We even incorporated a computer based control system with a stepper motor, instead of the original design using a series of removable fixed speed motors. That allowed us to program in different speeds, or apply an accelerating or decelerating growth pattern into a single sample. So now we could recreate, controllably and reproducibly, on a small scale the thermal histories characteristic of a full-scale ingot. That met our first requirement.

Our second requirement was a means to characterise the intermetallic phases with the same degree of rigour and control. We soon realised that the scale of the intermetallics produced rendered the etching techniques very unreliable, whilst looking at the ratio of *e.g.* the iron to silicon concentration in the SEM or microprobe was no help when the phases were *e.g*. different binary compounds of aluminium and iron. Clearly the best way forward was to find a way to remove the intermetallics from the aluminium matrix. Various deep etching methods were tried, and we also looked at a method being used occasionally in Kingston which involved dissolving the aluminium in phenol, but we shied away from that for health and safety reasons. Finally we came across a method developed by the Norwegian research institute SINTEF in the 1980s. This entailed placing approximately a cubic centimetre sized sample of the alloy in an autoclave with anhydrous butanol, and holding at temperature for a couple of hours. The aluminium dissolved, leaving the intermetallics in suspension. The autoclave was then vented through a PTFE filter which collected all the intermetallics. The system was called SiBut, as a contraction of SINTEF and butanol.

We acquired such a system from SINTEF, and I can still recall the sense of amazement I felt when we first looked at the filtrate in the SEM, and began to fully appreciate the topological complexity of the intermetallic phases, forced to grow in the inter-dendritic spaces. A complexity barely hinted at when seen in section on an optically polished sample.

The original SiBut system seemed to comprise an awful lot of glassware. As the usefulness of the system became apparent, we decided to redesign it, replacing much of the glassware with stainless steel. The SiBut lab began to look less like a high school chemistry lab, and more like a chemical engineering plant! A lot of time and effort was devoted by Ged Flynn to make the whole process more robust. Within a couple of years, the facility was moved out of the control of the project, and incorporated in the analytical service group. The new design could process first 4, then 8 samples in parallel. This was required because the demand continued to grow, with the lab processing typically 300 or 400 samples a year. Putting a sample in for SiBut characterisation became a standard part of microstructural analysis, for cast samples, as well as from further down the process stream.

Why did it become so popular? Apart from facilitating the capture of some beautiful SEM pictures, the extraction and concentration of the intermetallics allowed their characterisation with an accuracy and a reliability which was previously unheard of. Intermetallics were examined from an original volume, which was many orders of magnitude greater than seen on the plane of polish. This concentration factor improved our analytical capability in the same way the PoDFA technique had improved our characterisation of inclusions in molten metal some decades earlier.

X-ray diffraction of the extractate was found to be the most reliable and unambiguous tool to identify which phases were present. We even used the Bridgman furnace to grow “standard” samples, designed to have an alloy composition and growth speed such that the sample only contained one type of intermetallic phase. From these standard samples, a whole range of 2 and even 3 phase mixtures were prepared. By comparing ratios of characteristic XRD peaks, calibration curves were developed, which allowed the phase fractions to be estimated in mixed structures. Andries Bosland and Jes Brown undertook a huge amount of very careful analytical development in this area in particular.

So now we had both an experimental technique that allowed us to explore rapidly a range of solidification conditions, and a means to characterise the intermetallic phase content reliably. As hinted above, the technique really came into its own when applied to surface critical products, probably best epitomised by lithographic (litho) sheet ingots. It was well known that litho had to be cast with strict control of factors such as the Fe/Si ratio in the alloy, the amount of grain refiner and the casting speed and temperature. If these parameters strayed outside of established ranges, a variety of defects began to appear. The most notorious was the so called “fir tree zone”. This usually showed up as dark etching region near the edge of the ingot, with a characteristic zig-zag interface in the casting direction. With an over-active imagination, the shape of the defect could be said to resemble a fir-tree. An ingot accidentally scalped through the fir tree zone resulted in customer rejects at final gauge due to streaking. Alcan Deutschland had developed the casting practice mainly using Scandinavian smelters, but was being increasingly pressured to use Alcan smelters. Every time this happened, the smelter invariably resented being told how to cast the alloy, which in their view was only pure aluminium anyway! It was very gratifying during this period to see the key players in Alcan Deutschland, notably Theo Rottwinkel, move from a position of complete scepticism that we in Banbury could possibly have anything to offer in terms of assessing litho ingots, to a position of complete reliance on our assessment. Before new smelter metal was allowed anywhere near a rolling mill, the phase distribution in the ingot was checked using the intermetallic extraction method, both in the cast state, and increasingly after homogenisation.

It had been known for a number of years that the cause of the fir tree zone was the formation of a particular metastable intermetallic phase in the region nearest the ingot surface, thought to be due to the higher cooling rate in this region. The phase was usually designated Al_mFe since there was ambiguity as to its exact stoichiometry ('m' was approximately 4). These intermetallics had been identified by some very painstaking transmission electron microscopy work in the 1980s by Skerpje at the University of Oslo and Westengen in Hydro. One of the first observations we made using SiBut was that the phase responsible for the fir tree zone also often reappeared right in the middle of the ingot. This of course is the most slowly cooled region, so we could immediately discount the idea that exceeding a critical cooling rate was responsible for the fir tree zone formation. However, what the edge and centre of the ingot had in common was that in both locations, the isotherms are horizontal: in other words the solidification speed is exactly the same as the casting speed. At intermediate locations, the local solidification speed is lower than the casting speed. This led us to think the key to fir tree formation was a critical interface speed, rather than a cooling rate.

So we had a hypothesis, and now we also had the perfect tool with which to put this to the test. We quickly made up some binary Al-Fe and ternary Al-Fe-Si alloys. We grew them over a range of speeds bracketing typical DC casting speeds and waited in anticipation to get the results back from SiBut and XRD analysis. What we found was not what we were expecting. We did see a gradual transition from the equilibrium phase (Al_3Fe) to a metastable phase (Al_6Fe) happening over a range of speeds. And we did see this transition being spread over a wider range of speeds as the silicon level increased. But we didn't see any evidence of the specific metastable phase responsible for the fir tree zone, Al_mFe. Even when growing at the fastest speed the machine was capable of (~120 mm/min), there was no evidence of the fir tree. We were solidifying aluminium at a litho composition at speeds (or cooling rates) far in excess of those required for fir tree formation in a DC ingot, and yet it was absent in our samples. What were we missing?

We were missing the obvious: litho ingots are always grain refined, and in our haste we had neglected to include grain refiner in the alloy make up (since as far as we were concerned the only reason for adding grain refiner was castability: not an issue in a Bridgman growth sample!). We quickly repeated the experiments with grain refiner: success! Now we found that the litho composition showed a sharp transition to the fir tree zone phase, Al_mFe at around 65mm/min: which agreed remarkably well with DC casting commercial practice. Clearly the presence of grain refiner was a key ingredient to form fir tree zones. At that stage we didn't know whether that was because it provided specific nucleation sites for the phase, or because the topology of the inter-dendritic regions in a grain refined mushy zone presented particular difficulties which the growing eutectic has to negotiate, and the fir tree phase was particularly adept at changing its growth direction. This of course didn't stop us registering a patent for litho cast without grain refiner, which allowed the use of DC casting speeds in excess of 70 mm/minute without forming a fir tree zone, rather desirable from a productivity point of view when most litho was conventionally cast at 50mm/minute.

We also discovered that as the silicon level in the alloy increased, this transition was brought to lower speeds. Clearly the fir tree phase was able to accommodate the silicon partitioned to the inter-dendritic regions, unlike the competing phases. Understanding that the critical speed was itself a function of silicon level in the alloy helped define boundaries for alloy development.

The same approach was then used to map out the effects of various trace elements on phases selection. All smelters generated their own characteristic levels of trace elements, depending on the source of pitch for the anodes for example. These comprised elements such as vanadium and nickel, often present at levels around 50-200ppm. Many of these elements were practically insoluble in solid aluminium, so naturally partitioned to the inter-dendritic liquid during solidification, reaching quite high local concentrations. Perhaps unsurprisingly, some of these trace elements were found to influence phase selection. Another thing to consider when a new ingot source was being considered.

Thinking about the events occurring during solidification, in particular the "path" on the phase diagram followed by the composition of the residual liquid as it became increasingly concentrated led us to think about how good were the phase diagrams we were using. Mostly we relied on the seminal publications by Phillips, who had worked for British Aluminium in the 1940s and 50s. Good as they were, it was generally accepted there were some contentious areas, undoubtedly related to the fact that analytical techniques open to Phillips were of necessity limited, and some elements were particularly slow diffusers in solid aluminium, and so some of the experiments he based his diagrams on may not have represented equilibrium. A European program ran in the 1990s, with participation from Banbury, Pechiney and Hydro, designed to deliver better phases diagrams for light metals. In Banbury, Havovy Cama led the way in bringing the output from this program back into the lab, and making it accessible to researchers. Of course one of the attractions of the modern approach was the ability to generate phase diagrams on demand, any isothermal section, or any isopleth. This allowed parameters from the phase diagram, such as partition coefficients, to be extracted, and incorporated in models predicting the evolution of the residual liquid composition during solidification, and hence the competition between phases forming from that liquid.

I said the modern approach to phase diagrams was attractive: that is provided you had the appropriate software package. It seems quite ironic that nearly 20 years on, as I now ply my trade as a consultant to the aluminium industry, given the exorbitant cost of software licences for phase diagram packages, we still rely on the seminal publication of Phillips. Which being a book is still very user friendly.

Towards the end of the 1990s, I had the opportunity to leave solidification, and move across to the rolling process group. Richard Hamerton took over the running of the solidification program, which continued to apply the techniques we had developed to a wider range of commercial alloys. Following the closure of Banbury, much of the equipment was transferred to Neuhausen. I know for a fact the Bridgman furnace was operational before Neuhausen itself closed. By then I had parted company from Alcan, but had a need to undertake some directional solidification experiments for a client, and was able to buy time on my old furnace. Thereafter, it was shipped out to Leoben University (Austria), where one of our old PhD students, Peter Schumacher, was now a professor. I fielded quite a few telephone calls as they went through the process of refurbishing the equipment. I believe it is still up and running.

Looking back, I am still impressed at the scope and the rigour of the body of solidification work undertaken in Banbury over the years. Much of it of course will never see the light of day, which is rather sad, as I am regularly reminded when I come across current journal articles in this area, just how far ahead of the game we were. But then that could also be said of a number of other areas of research in Banbury.

5d.THE PSICASO STORY

Laurens Katgerman, Principal Scientist (1984 -1992)

Background

My first encounter with Alcan and Banbury Labs was a visit after a Rapidly Quenched Metals conference in 1978 in Brighton. In Delft, we were doing research on rapid solidification and stir casting, and Alcan scientists Phil Enright, Ian Hughes, and Dick Jordan were working on the same processes. Researchers in casting and solidification mostly have a very broad view on liquid processing. I remember lively and creative meetings in the Pear Tree pub in Hook Norton or the Wine Vaults pub in Banbury. In the early 80's Phil and Dick came to Delft for a return visit. They both certainly still will remember this trip, because the night before they explored the Delft pubs and not being constrained by pub closing times, as in the UK, they had only a few hours sleep when they arrived at the Delft lab next morning. Not fully recovered from the previous night, they were hit by the opening question of Prof. Kievits: *"What is your opinion on the current state and development of the aluminium industry?"* It took the two young researchers quite a while to compile a coherent and comprehensive answer, but they bluffed their way out!

A few years later Banbury labs had a major reorganisation, Alcan 'merged' with British Aluminium and under the new lab director, Jeff Edington, Banbury labs started to recruit scientists at all levels. Early 1983 Phil Enright came to Delft to invite me to join Alcan to work in the solidification area. This was a complicated decision because I had to leave the academic world and my family had to change countries. As Alcan had no activities in the Netherlands, this would be a one-way transfer! However, a senior job in an industrial challenging environment was an offer that I could not easily refuse, and I joined Banbury labs in 1984. The original idea was that I would start working on rapid solidification processes. At that time, Alcan was setting out on a new strategy of diversification into new business opportunities. This was largely promoted by Hugh Wynn-Edwards, chief scientific officer of Alcan International and this strategy was fully supported by Alcan CEO David Culver. The 1984 mission statement said that the current core business of Alcan (primary metal and UBC sheet) only would be 25% of the activities in the years to come. Because of this strategy, projects on new materials and processes were largely promoted. One of these new processes was HMF: Hot Metal Feed. The HMF process was in the early 80's invented by Phil Enright, Ian Hughes, and Dick Jordan. In the HMF process, a high temperature concentrated aluminium alloy (e.g. Al-Zr) is squirted at high velocity into a molten aluminium bath at lower temperature. The liquid jet breaks up and due to the undercooling forms very fine intermetallics. The presence of these fine intermetallics in the final structure can largely improve the strength of aluminium alloys in particular at elevated temperatures.

When I started in 1984, the labs had no main computer for research activities like modelling. The on-going modelling work, mostly in the rolling area, was done on HP desktop type stand-alone computers (we have to realise that in 1984 PC's were not around; serious computing was done on mainframe computers like Digital VAX etc.). Nevertheless, a RFA to acquire a mainframe was being prepared by the rolling principal scientist Ian Calderbank. In 1985, the VAX785 mainframe was commissioned and serious process modelling could start. Where the Alcan rolling model was an in-house development, it was decided that for solidification modelling we would use the available commercial software to enable us to concentrate on application of models rather than development of models. In order to understand the HMF process and to make it work, the process needed to be modelled. In 1984, the state of the art CFD package was PHOENICS. PHOENICS was developed at Imperial College under the leadership of Prof. Brian Spalding and commercialised through the CHAM software company, based in Wimbledon near London. Before we decided to license PHOENICS, we asked CHAM to run several HMF case studies, for which PHOENICS needed to be adapted. The HMF process pushed PHOENICS to its limits, because of the liquid-liquid interactions, the turbulence, and the break-up of the hot liquid jet. It took CHAM about 6 months to adapt PHOENICS to the HMF process, so it could be used in-house by Steve Rogers to support the design and engineering for the casting equipment.

I became HMF project leader in 1985 with Steve Rogers for modelling, Colin Jeffs, Andy Darby, Phil Enright and Ian Hughes for the physical model and casting experiments on the project team. We concluded that to make the HMF successful, it had to be incorporated in a rapid casting process, otherwise the intermetallics would coarsen too fast, or they would simply settle out and cluster. At Kingston RDC we had access to a twin roll caster and the PHOENICS model was used to design a nose tip in which the liquid jet was incorporated. The different design options were furthermore tested with a water model. During 1985, we had several casting campaigns in Kingston. Although the casting trials were reasonable successful, we never achieved a good homogeneous structure and therefore the improvement in mechanical properties was only marginal. The HMF project was killed in 1986; brilliant concept but too complicated to make it work at that time. Instead, the modelling emphasis was redirected towards the mainstream casting process: DC casting and later on to the Osprey process.

PSICASO

One of the major problems in DC casting at that time was cracking of hard alloys at Kitts Green Birmingham. Before we could tackle the problem, a DC casting model needed to be constructed. It was decided to make this a joint effort between Kingston and Banbury. The Kingston team did consist of Al Langille and Mark Read and concentrated largely on the thermo-mechanical aspects of DC casting for which the ANSYS programme looked very suitable. The Banbury team with Steve Rogers and the new Oxford DPhil Stephen Flood constructed the core CFD program with PHOENICS. I had the overall coordination. We decided that a successful modelling project needed an acronym and PSICASO[2] was born.

[2] PSICASO=**P**rocess **S**imulation In **CA**sting and **SO**lidification

The PSICASO project team in 1987. From left to right: Mark Read, Al Langille, LK, Steve Rogers and Steve Flood

As already indicated the first application was cracking of hard alloys at Kitts Green. This was a complicated problem because to avoid cracking of the sheet ingots, wipers were used to reduce cooling at the lower end of the ingot. However, the reduction of cooling resulted in severe porosity that could not be healed by hot rolling. The porosity would show up during ultrasonic inspection of the 6 mm thick sheet. Therefore, the challenge for the Banbury-Kingston project team was to come up with a casting practice with no cracks and no porosity. Phil Enright together with Ray Bignell and Ron Smith from Kitts Green carried out an experimental program to quantify cracking and porosity conditions that could be used to validate the PSICASO program. With the CFD part, we could predict porosity levels, based on the liquid sump depth and with the ANSYS module, we could calculate the stress levels for the different casting conditions. So in the end we could propose two casting conditions (casting speed and wipe position for a given sheet ingot size) to Kitts Green based on the PSICASO model. The success was almost immediate both casting practices produced crack-free and porosity free ingots suitable for aerospace plate. Modelling in combination with the casting experience of the team had demonstrated its valuable use. The success did spread quickly through the company and we did get several requests from e.g. Oswego, USA and Alunorf, Germany to help and advise them on a few casting problems. Unfortunately, the Kitts Green success could not be repeated in a similar way. With the model, we were able to help the plants to improve their understanding of the casting procedures; improvements were made preventing start-up and butt cracks. Nevertheless, never as straight forward as for the Kitts Green case. In the following years of the PSICASO project, we tried to transfer the model to the larger plants. With the assistance of the programme managers Roger Wilson and Rod Jones, workshops were organised in Banbury to train dedicated plant personnel.

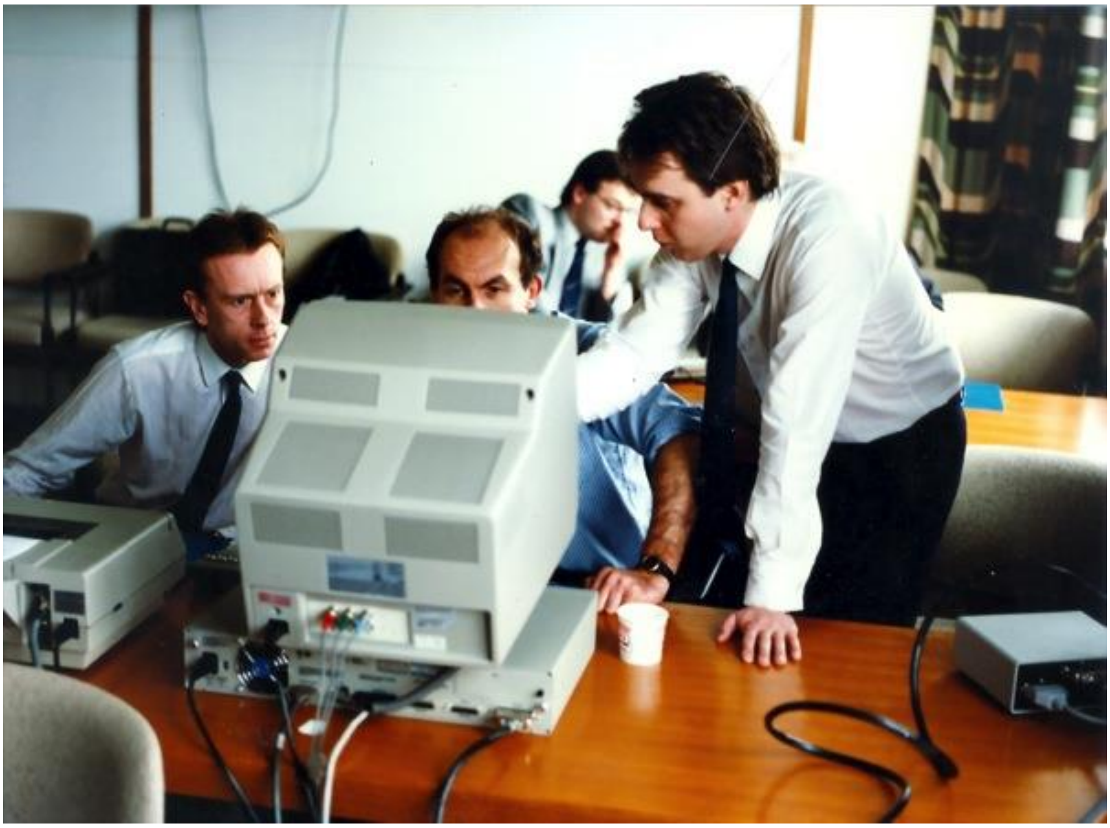
Other modelling activities included the Osprey process and the Alcan Cospray variant to produce metal-matrix composites. With the aid of a water model, we tried to improve our understanding of the complex process physics of this atomisation process. The Banbury project team, with Steve Rogers as chief modeller was extended with a large Oxford University team including Brian Cantor, Patrick Grant and other post-docs and PhD students. The total effort of the Cospray project with Dick Jordan as programme manager including the extended experimental program at the late eighties exceeded 20 lab years, but only became commercially successful after Alcan stopped the project and transferred the technology to a start-up company with Dick as managing director.

In the mid-eighties modelling had become a wide spread activity in all Alcan research labs: Banbury, Arvida and Kingston. In order to exchange experience in this field I organised the first interlaboratory modelling conference in Banbury in 1988, followed later on with similar events in Kingston and again Banbury.

1st Interlab Modelling Conference 1988; From left to right: Keith Waterson, John Clark, Cliff Fraser, David Double, Marc Dupuis, Jeanette Fine, Chris Davenport, Vinko Potocnik, Steve Timothy, Patrick Wai, LK, Graeme Marshall, Jim Gow, George Macey, Wael Montasser, Rod Jones, Steve Rogers, Jean-Paul Huni, Richard Boivin, Dubravko Nardini, Steve Flood

The VAX main frame, which had arrived in Banbury in 1985, had become too small and too slow within 3 years and needed to be replaced by a CONVEX mini super computer in 1989. To fulfil the large scale computing needs of the labs also collaborative programs with CRAY super computing centres were explored.

In 1988, Jeff Edington became director of KRDC and shortly after became President of Alcan International, John Hirschfield succeeded as lab director in Banbury. Wynn Edwards had left the company; David Culver retired as Alcan CEO and was succeeded by David Morton. With these changes, the largely exploratory Alcan International research program did swing back to core business: smelting, casting and rolling of can beverage sheet. The larger influence of the businesses in the research for ingot casting resulted in a Technology Improvement Group (TIG) for casting. The TIG was managed from Montreal and Arvida and the PSICASO project became part of their activities. Under the TIG responsibility, validation of PSICASO and transfer to the operating companies became the major task. After I left Alcan in 1992, all PSICASO activities were transferred to Arvida labs with limited support from Banbury by Stephen Flood.



PSICASO training course at Banbury Laboratories

6. ELECTRICAL DIVISION AT BANBURY LABS

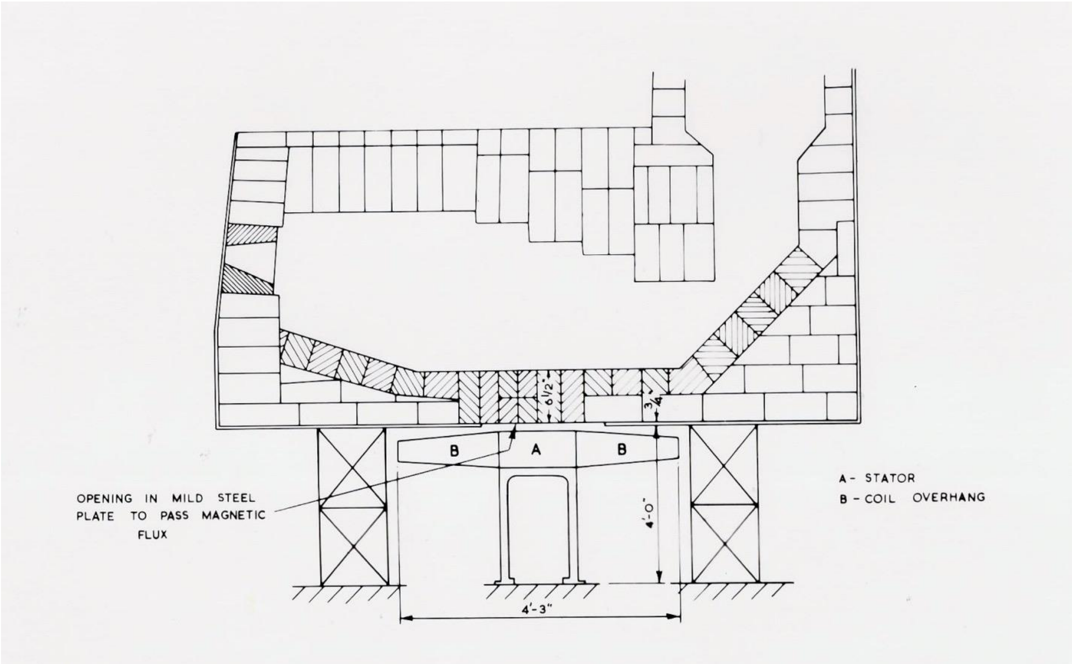
Reflections of Perry Bamji

The Prologue:

In April 1965 I was invited by Lee Roullier, Head of Electrical Division, to visit Aluminium Laboratories at Banbury. Lee was the Division Head at Banbury Labs and also a senior representative who sat as an "elder statesman" on the Graduate and Student committee of the Rugby area of the Institution of Electrical Engineers of which I was a student member. I was due to take my final B.Sc. (Eng) exams in Electrical Engineering in June 1965 and Lee casually asked me what were my plans once I graduated. I said I wished to take a break in India and then do my graduate training at either GEC at Birmingham or AEI in Rugby where I had done my vacation apprenticeships in previous summer vacations. He promptly said you should visit Alcan Labs in Banbury and see what we are doing in the Electrical Division, and I accepted. The day I visited Banbury Labs, Lee was in Canada so he had deputised Stanley Rundle to look after me. Stanley showed me round the laboratory and casually mentioned that he had made appointments for me to meet Dr R.T Parker the Laboratory Director and with Drs. George Stanford and George Forest who were Associate Directors. By the end of the afternoon I had also met Bob Bareham, Head of Physics, John Clare, Head of Castings and Alan Harding, Head of Physical Metallurgy. All this was very overwhelming as I had not expected to meet so many heads of departments, nor was I conscious that this was my "formal" interview! I went back to Rugby that evening to swat over my books for the upcoming finals. Two days later there was a letter from Dr. Parker stating that he was very pleased to offer me a position as an Investigator in the Electrical Division commencing July 1, 1965. To say I was shocked (and delighted) is an understatement as I had least expected to get employment even before graduating, when most of my classmates were not sure what was next in store for them!

My Role in the Electrical Division in the mid-1960s

In 1965 the Electrical Division was mainly involved in testing aluminium overhead conductors and associated ancillaries such as connectors and fittings for transmission lines The staff under Lee Roullier comprised Stanley Rundle (deputy), Hugh Halcro-Johnston, Ron Farley, Percy Bullock, John Morby, Bill Cooper, Ken Humphries, George Taylor and George Gibbard. Most of these persons, except Hugh Halcro-Johnson and George Taylor, were involved in technical service work on cables and overhead conductors for Alcan companies in UK. Lee wanted me to get into the "research stream" and work on applications of Electromagnetic Stirring of Molten Aluminium in his Division. The seeds of this technology were sown in an exploratory manner by an ex-employee Derek Jordan who had left labs before I joined. During the first few months of joining I was pouring over volumes of literature mainly from the steel industry in Sweden, the Ukraine and Russia where they were using Linear Induction Motors for stirring molten steel in large electric furnaces. I spent many hours sitting in the Lab's main translator, Harry Nowattney's smoke-filled office, while Harry gave me a brief synopsis of the Russian technical literature. He also fully translated some papers at my request. The Swedish EM stirrers manufactured by ASEA were frightfully expensive and no aluminium company at that time had ventured to purchase them. So Hugh Halcro-Johnston and I worked with AEI Rugby to design a linear motor for stirring molten aluminium. With great song and dance we demonstrated the feasibility of our first linear motor: 3 feet long x 2 feet wide which was placed under a specially- modified one-ton Sklenar Furnace in the Castings Laboratory. The linear motor did what it was intended to do: ie. it propelled molten aluminium around the furnace in a circular motion and thus mixed any alloying additions. Lee Roullier was ecstatic. He summoned Ken Bloor from the photographic section to take still and motion pictures of metal movement in the furnace. For the next six months Lee showed a short, but very convincing 8 mm, three-minute clip of film at several meetings in Banbury and Rogerstone works. These works had a need for a labour-saving method of stirring metal in large casting furnaces with a view to rapid mixing of alloys. The proof of concept was sound, however the technology was not proven on an industrial scale and Alcan plants in the UK were not prepared to conduct industrial-scale trials



A Linear Induction Motor placed under a melting furnace in the castings laboratory

Lee Roullier leaves Banbury Laboratory in 1966

In 1966 my mentor and my project champion, Lee Roullier, was transferred to Alcan Cable Corporation at Riverside in California and there was no senior person to champion this project forward. However, I was determined to see this work succeed, so between 1966 and 1970, I investigated several alternative electromagnetic methods of stirring and pumping molten metal. George Taylor and I first played with small scale models using Woods Metal (a low melting point (70 degrees Celsius) alloy of bismuth, lead, tin and cadmium) to replicate molten aluminium.

During my research I invented a method of propelling molten metal using the simple Jumping Ring principle that I saw being demonstrated by Professor Eric Laithwaite at an Institution of Electrical Engineers (IEE) meeting in Rugby. “Now just watch this ring” said Laithwaite, as he switched an alternating current to a coil of wire that was partially wrapped around a 24” long vertical ferromagnetic steel core. An aluminium ring approximately 4” in diameter and ½” thick that rested around the core adjacent to the coil went flying in the air some 20 feet from its original position. The principle of this demonstration is simple; the coil when energised with a single phase AC current induces an alternating current of reverse polarity on any metallic object (such as a ring /cylinder) that surrounds the steel core nearest to the coil. An Induced electric current flowing in the ring produces a repulsion force causing the ring to fly away from its original position and hence the name “Jumping Ring” (A name first coined by Eric Laithwaite).

Doc Parker’s casual visit to the Electrical Division

To apply the Jumping Ring principle to molten metal a suitably protected steel core was horizontally inserted into a small furnace (essentially a box constructed from Marinite) containing molten woods metal. The electric coil was located outside the furnace at the extremity of the steel core. When the coil was energized, induced currents surrounding the molten metal around the steel core (the ring of metal) produced a force and the Woods Metal whizzed around the furnace! Once, when George Taylor and I were conducting experiments, Dr. Parker casually walked in the electrical laboratory. (The Electrical Lab was somewhat isolated near the tennis courts in a building remote to the main laboratory building). Doc (as Dr. Parker was fondly known by all) was intrigued to see the metal whizzing round and round. He wanted to measure the speed of metal movement. He asked George to make an aluminium foil boat and we timed the movement of the boat at various power levels to the coil. A new champion was born and Doc gave us the green light to build a large prototype Circulator which could be tested in the castings laboratory. We recruited Gilbert Hill from the drawing office to design a half-ton capacity furnace that would accommodate a horizontally-placed, 36” long, 4’ x 4” square laminated steel core with ta 24” diameter electric coil located outside the furnace. The device worked beyond everyone’s expectations. Doc was pleased and so was the team! Alcan’s Jumping Ring Circulator (JRC) was born. However, the furnace was too small and half a ton of molten aluminium was not sufficient for the tremendous stirring force that this unit inherently had. We needed a full size production furnace to continue our research.

Electrical Division amalgamated with the Physics Division

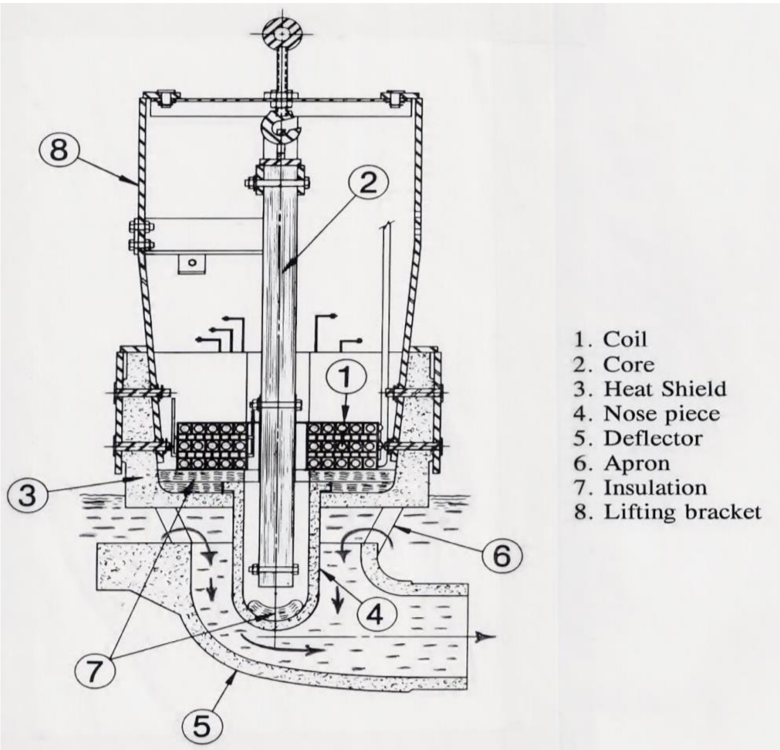
Between 1966 and 1969 two Division Heads Stanley Rundle and Hugh Halcro-Johnston, left Labs and the Electrical Division was amalgamated with the Physics Division under Bob Bareham. Bob was impressed by the JRC’s performance and at a technical meeting he was able to persuade Ross Crowford, Manager of Alcan Enfield Alloys Limited (Alenoy) at London Colney in Hertfordshire to come and see the labs JRC. Ross was impressed by the labs demonstration and gave us the green light to do full-scale trials using the JRC on one of their 23 tonne side-well type recycling furnaces at London Colney. A small team was formed with Gilbert Hill from labs drawing office, David Allen a metallurgist from London Colney and myself. Once again the initial trials were successful and the Jumping Ring Circulator circulated molten metal at an average rate of 4,500 kg per minute. Metallurgical tests using additives such as manganese, titanium diboride and zinc showed that the additives were fully stirred within 14 minutes (equivalent to two men manually stirring the furnace for the same time period). Both Ross Crowford and David Allen were suitably impressed to let us extend our trials.

Alex Olyarchuk of Alcan Aluminium Corporation shows interest in JRC

Our main concern was one of materials used in protecting JRC’s ferromagnetic steel core that was inserted into the molten metal. Several Labs reports on the London Colney trials were written and circulated to Alcan Group of Companies worldwide. Alex Olyarchuck of Alcan Aluminium Corporation in Oswego NY, USA who was following our reports was keen to install the technology at Oswego in one of their side-well recycling furnaces. He made a trip to London Colney to see the JRC in operation and see if he could help us with the materials problem. We wanted a ceramic material to protect the ferromagnetic steel core of the JRC. The material we needed had to be non-magnetic, non-wetting to molten metal and have a very low thermal coefficient of expansion to withstand thermal shocks. Alex introduced us to a ceramic component manufacture, M & T Manufacturing in Grand Rapids, Michigan, USA. M & T was a small family-run company who supplied fused silica troughs and casting pans to the aluminium industry including Oswego works.

A radically new JRC is born

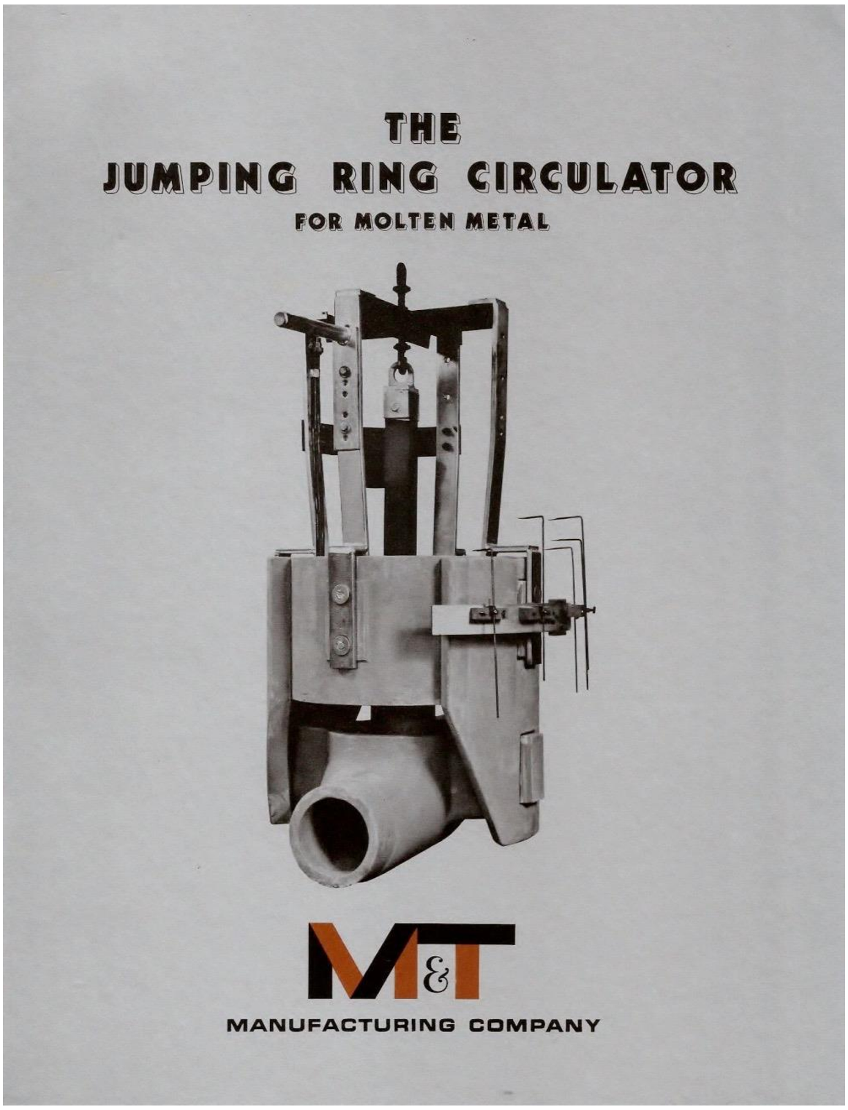
Once M&T were involved in supplying ceramic components for the JRC, Gilbert Hill and I worked on several designs incorporating the newly-introduced fused silica components that M&T specially manufactured for us. The revised design comprised a submersible type circulator that could be lowered into an open side-well type furnace. We commenced trials at London Colney to test the new design and the compatibility of the fused silica ceramic components. Gilbert Hill, David Allen, I and sometimes George Taylor once again spent several days at London Colney conducting more trials. After six months of successful testing the JRC was ready for any Alcan company wishing to improve the performance of their recycling furnaces but alas, there were no serious takers.



A Jumping Ring Circulator
(Height Top – Bottom ~ 4 Ft, Maximum Diameter ~2 Feet)

M & T Manufacturing Company shows interest in the JRC

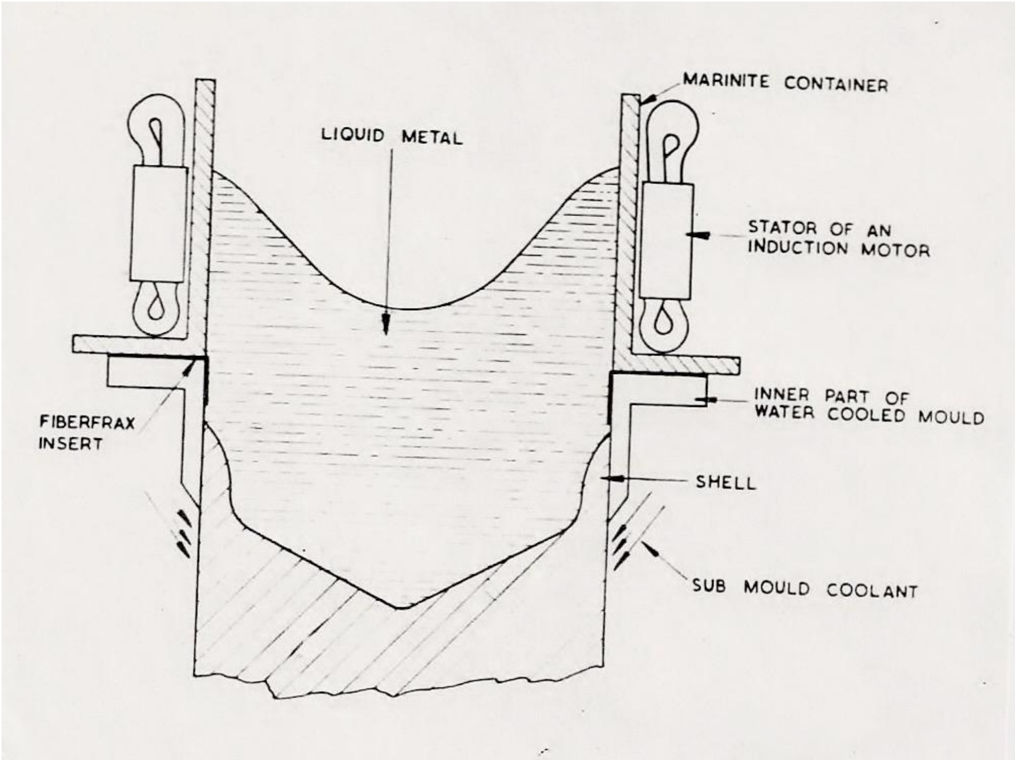
M & T Manufacturing Company's Vice President, Bill Perason Jr. who had made several trips to London Colney when we were testing the JRC with M &T's ceramic components was impressed with what he saw and got interested in licensing the technology to manufacture and sell the JRCs. Alcan had filed had several patents on the JRC and after due negotiations with the Technology Licensing Division in Montreal, Alcan offered M &T an exclusive license to manufacture and sell the units. M & T started selling the JRCs to aluminium foundries in and around the Chicago area. In the first three years of acquiring a licence, M &T sold over 25 units. Around that time period M &T's patriarch (Bills' father) had passed away, Bill Pearson Jr. himself suffered a stroke and the company gradually folded and with it, the JRC died a natural death!



Front cover of M & T's brochure advertising the Jumping Ring Circulator

My other pursuits at Banbury Labs

At Banbury Labs I was also involved in stirring a sump of molten metal in Direct Chill (DC) Casting. Gerry Lucas and I investigated this by mounting a stator of an ordinary induction motor outside the molten metal sump just ahead of the water-cooled mould. The object was to break up the dendrites just as the metal was solidifying and thereby achieve some form of structure refinement in the cast ingot. Initial trials were encouraging. Gerry was sufficiently encouraged and we had plans to improve the



Electromagnetic stirring a sump of molten metal prior to DC

technique by alternately reversing the direction of rotation and modulating the frequency of electrical power by lowering it in stages. Alcan did not pursue this further once Gerry Lucas was transferred to Arvida.

University of Bradford shows interest in my research activities

Whilst I was researching electromagnetic devices I had accumulated expertise on all kinds of Linear Motors and published papers in learned society journals. One such paper caught the eye of the head of Electrical Engineering Department at the University of Bradford. The department was working small-scale models of metal stirrers, when we in Alcan, had designed, built and successfully tested full-scale industrial devices. I was asked if I would extend my research extramurally at the University. This meant exchange of limited information that was in public domain. Dr. Parker gave me his blessing to collaborate with the university. It was a win-win situation as Alcan gained the theoretical expertise from the University and in turn the University gained practical knowledge to confirm theoretical predictions. On my part, I gained my Masters and PhD Degrees from the University for my research in" **Electromagnetic Devices for Handling Molten Aluminium"**. Between 1972 and 1976 it was tough going as I was poring over theoretical work in the evenings and at weekends, meeting my supervisor at the University at regular intervals, foregoing several domestic engagements and personal hobbies and at the same time, working full time at Alcan. However, in the later part of my career having a PhD under my belt helped me to open other doors in academia once I left Alcan.

My expertise in Linear Motors and Electric Furnaces

Electromagnetic stirring was not my only project. Amongst other molten metal handling and melting projects I was also involved in applying Linear Induction Motors and Electric Furnaces in various processes and developed sufficient expertise in these technologies. Wally Bennett of Alcan Fabricating Technology Division (who had an office at Banbury labs) got to know of my work on Linear Motors and asked if I could investigate why Linear Motors that were installed on extrusion pullers at AlcanItal's Ornago Works in Italy were malfunctioning and burning out. I went to Ornago and after a few trials managed to identify the problems and put the matter right with Lintrol at Loughborough, in UK, who had manufactured the motors specifically for the extrusion pullers. Lintrol subsequently sold several Linear Motor Pullers in the aluminium industry.

Around 1976 Roger Wilson and I were involved in investigating melting light aluminium scrap. Metal loss in recycling light scrap, such as swarf and machine turnings, in conventional side-well recycling furnaces was high because this type of light scrap floated on molten metal surface and oxidised if it was not immediately submerged. Coreless Electric Induction Furnaces with their inherent stirring were found to be suitable. We did not have such furnaces at Banbury Labs so we collaborated with my contacts at the Electricity Council Research Centre (ECRC) at Capenhurst, near Chester where they had various types of Electric Furnaces. I also interfaced with several electric furnace manufacturers. In particular I had an excellent working relationship with the chief engineer, Dick Sommer at Ajax Magnathermic in Warren, Ohio. Dick and his wife Linda still keep in touch every Christmas with my wife Annamaria and I. I had also established professional relationship with other electric furnace manufacturers like Brown Boveri in Switzerland, Demag in Germany and ASEA in Sweden and visited them when needed.

In the mid-1970s recycling of dross was given extra impetus. Rotating drum furnaces (also called Rotary Furnaces) used copious quantities of salt to extract metal that was entrapped in the dross. Dumping of spent salts was a perennial problem and we had pressure from environmentalists to cut down on the use of salts. I was asked to investigate if electric furnaces could help. So we used the coreless induction furnaces at ECRC to investigate the feasibility of melting of dross with a view to reduce or eliminate the use of salts. Although we succeeded in extracting metal with minimum metal loss, the stirring pattern in the furnace was such that the tenacious oxides were thrown towards the furnace wall where they adhered and very difficult to scrape off. This had a somewhat detrimental effect on the furnace refractory.

Alcan Ital, Borgofranco, Italy shows interest in Electric Melting of Dross

My reported work on electric melting of dross caught the eye of late Giorgio De La Pierre of Alcan Ital at Borgofranco, Italy. Alcan Ital owned three small electric power stations in the valley of Aosta at Dora, Hone and Moltato and these power stations invariably generated surplus electric energy. The Italian government had started putting punitive tariffs on organizations that were generating surplus energy. Georgio was therefore very interested in acquiring electric furnaces. I visited Alcan Ital, Borgofranco on several occasions and conducted comparative trials on melting dross in induction versus rotating drum furnaces. Through the years Georgio and his wife Helena, and my Italian wife Annamaria and I also developed personal friendships.

When Georgio came to England he invariably visited us in Banbury and we were entertained by the De La Pierres when we visited Italy.

Welding in Magnetic Fields

In late 1970s the welding division had identified a need to combat arc deflection due to the presence of magnetic fields of current-carrying bus bars in Aluminium smelters. Together with John Morby, I developed a welding torch which had an electric coil wrapped around its extremity. The coil generated its own magnetic field which interacted with the extraneous magnetic field and protected the arc from deflecting.

Fabrication Memorandum on Induction Furnaces for Melting and Holding of Aluminium

I was a member of Alcan International's task force in Montreal charged with a mandate to look at Electric Furnaces for melting and holding aluminium. In late 1980 I was asked by the Fabricating Technology Department of Alcan International, Montreal to write a Fabrication Memorandum on **Induction Furnaces for Melting and Holding of Aluminium.** This 40-page effort that took me well over three years on a part time basis to research and compile, gave details of all operational considerations including guidelines on purchasing such furnaces, choice of refractories, environmental considerations and also documented world-wide knowledge of all Alcan group of companies operating electric melting and holding furnaces.

My life after leaving Banbury Labs:

After sixteen years at Banbury Labs, in 1981 I was transferred to Kingston Laboratories to join the Hot Metal Division under John Hirschfield.

I served at Alcan a total of 28 very rewarding years: 16 in Banbury Labs, 6 in Kingston Labs, 2 years in Nippon Light Metals Laboratory at Kambara, Japan and finally 4 years in the Intellectual Property Department at Kingston.

When I left Alcan in 1993 and I was invited by Queen's University School of Business at Kingston, Ontario to take a position as an Associate Professor and Director of Small Business Consulting. Part of my work was to teach Project Management and Intellectual Property Management. I spent the next 11 years at Queen's University "Preaching what I Practiced" (mostly via case studies). The students just loved knowing about how projects in industry are conceived, executed and how they succeed or die!

A salute to my mentor Lee Roullier

My career at Alcan started with Lee Roullier casually inviting me to visit Alcan Labs. Least did he (nor did I) know at that time that I would spend the next 28 years with this company and have the opportunity to contribute to its technical advancement and to visit several countries. For this I am thankful to Lee and several others with whom I interfaced.

The photograph below (taken circa 1960) shows Lee Roullier standing on the extreme left. This photograph was recently sent to me by Lee's son Anthony Roullier.

Standing - Lee Roullier, George Forrest, ?, Bob Parker, George Gardam, Eric Thomas, Ken Maclean, Roman Guminski. Seated - George Stanford, Roy Hine, ?.

7. ROLLING AND STRIP PROCESS ENGINEERING

Ian Calderbank, Tom Farley, Dan Miller

The work carried out at the Banbury Laboratory on semi-fabrication processes, e.g., the rolling of aluminium ingot and billet to plate, sheet, strip, and foil over the years was driven by the continuing need to improve dimensional, metallurgical, and surface quality while permitting gains in productivity to enable the lowering of production cost and inventory. To deliver this, considerable efforts were made to understand the fundamentals of the forming processes and these efforts involved both empirical trial work and, increasingly as computing power increased, sophisticated mathematical and finite element modelling. As knowledge was gained and emphasis was placed on consistency of product quality together with higher operating speeds, the processes were progressively automated to lessen the variability arising from machine operator control. Successful automation itself then became dependent upon the integrity of the newly gained knowledge and our ability to generate the appropriate computer models and control algorithms.

The main emphasis during and in the immediate aftermath of World War II was to achieve constant thickness (gauge) along the length of plate and rolled coils of strip and foil. Early (1950's) mathematical models, relating change in the rolling mill deformation (housing stretch) to changes in rolling load (separating force) during changes in speed, e.g., during acceleration and deceleration at the beginning and end of rolling a coil, were created by John Alexander in conjunction with Professor Hugh Ford of Imperial College, London. At the same time, instrument manufacturers were developing better non-contact means of measuring the strip thickness at the mill during rolling. This led to Automatic Gauge Control (AGC) being employed to provide a feedback adjustment to roll gap settings (screw down or load) from the gauge measurement. For this, further mathematical modelling and empirical work for calibration was carried out in the Banbury Laboratory by John Alexander and later by John Willis and Derrick Murdie. Much of the driving force for this work came from the increasing demand for better gauge consistency to satisfy the development of the beverage canbody and easy-open end.

By the 1960's, the emphasis had moved from gauge control in hot and cold mills, which was then believed to be reasonably well understood, to strip flatness or shape control in cold rolling. This was being driven partially by the continual downgauging to thinner final products to save metal cost and partially by increasing quality requirements on products associated with printing, either direct images on to the strip or foil itself in packaging or in the publishing industry via the increasingly popular use of lithographic sheet in the new offset printing processes. Now, to understand the process, the mathematical model was required to look at not just how one place in the width of the strip varied along the length (as for gauge control studies) but how the gap between mill rolls changed across the width.

It therefore became essential to understand how roll bending, flattening, and thermal expansion changes the gap between the rolls across the width. The tolerance permissible on thickness across the strip width for flatness control was an order of magnitude smaller than that along the length for satisfactory gauge control. In fact the tolerance required of the roll was smaller than the accuracy with which the rolls could be ground. This meant that some "attenuation" of roll errors must take place during rolling, something which had previously not been appreciated or understood. Ian Calderbank and Gerry Tucker studied the phenomenon using mathematical modelling of the possible mechanisms involved, namely how the local flattening of the mill work rolls is influenced by residual stresses within the strip arising from any

Peter JS Brooks operating the laboratory rolling mill

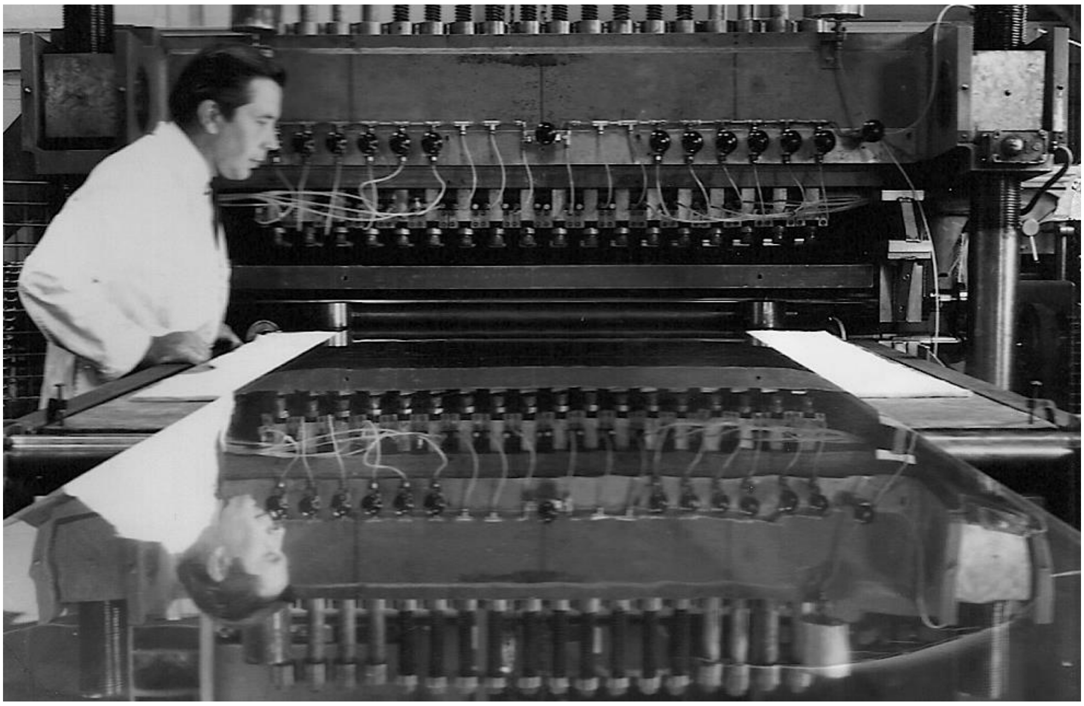
off flatness. They then calibrated the models by carrying out trials using rolls with deliberately induced minute but known dimensional errors. This led to algorithms being generated for an “Attenuation Coefficient” related to the various rolling parameters, such as the applied tensions which were found to be significant.

The off flatness in strip causes a variation in tensions across the width and, at the same time as the above work on roll attenuation was being carried out in Banbury,

Olivo Sivilotti from the Kingston Works was developing with ASEA a Swedish instrument maker a “Shapemeter” which exploited that fact using a series of internal load cells across the width of a deflector roll. Also, Maurice Tulett of the Kingston Laboratory was developing a sophisticated model (the Alcan Rolling Model) to describe in detail the metallurgical, thermal, mechanical, and hydrodynamic (lubrication) aspects of the rolling process and their influence on the final product mechanical and dimensional properties. The Banbury understanding and modelling of the attenuation described above provided a significant contribution to that model and the subsequent development of the process control algorithms required to enable Automatic Flatness Control (AFC).

At the same time as Alcan was developing the shapemeter in Canada, British Aluminium was developing at their Chalfont Park Laboratory a similar device (Vidimon Roll) but based on a deflector roll with a fixed arbour and rotating sleeve with an air gap between, the variation in air pressure across the roll being measured to assess the strip tension distribution across width and hence the off flatness. When Alcan and British Aluminium merged in 1982 the Banbury and Chalfont Park facilities were amalgamated and access was thereby obtained to the Vidimon and associated AFC system being developed by Ken Pearson, Mike Foster and Dan Miller.

In Banbury, the studies on strip flatness were following three lines of approach during that time. The one described above targeted improved flatness on existing rolling mills. However, the knowledge gained about roll attenuation was also being exploited in a second approach to develop a new mill concept – the Flexible Work Roll mill (FWR). This used small diameter rolls supported across the width by a series of hydraulic capsules (cushions) which permitted the rolls to deflect locally in response to the load variations caused by internal strip stresses more than would be the case with a conventional mill. These work rolls were also hollow further exploiting the attenuation effect. The development was driven by Bill Baker, Alcan's Chief Technical Officer in the UK at that time, and supported by Richard Hartree with Ian Calderbank and Bill Ferguson providing the theoretical and engineering design activities. After many trials on laboratory scale rigs, a prototype was built and used to demonstrate successfully the effectiveness of the concept. The photograph nearby shows this prototype being operated in the Laboratory by Syd King. Unfortunately, the engineering required to scale up to large volume production was considered complex and because considerable investment in both time and money was already being made in the development of AFC for the existing mills, the final outcome was a proven concept without a customer.



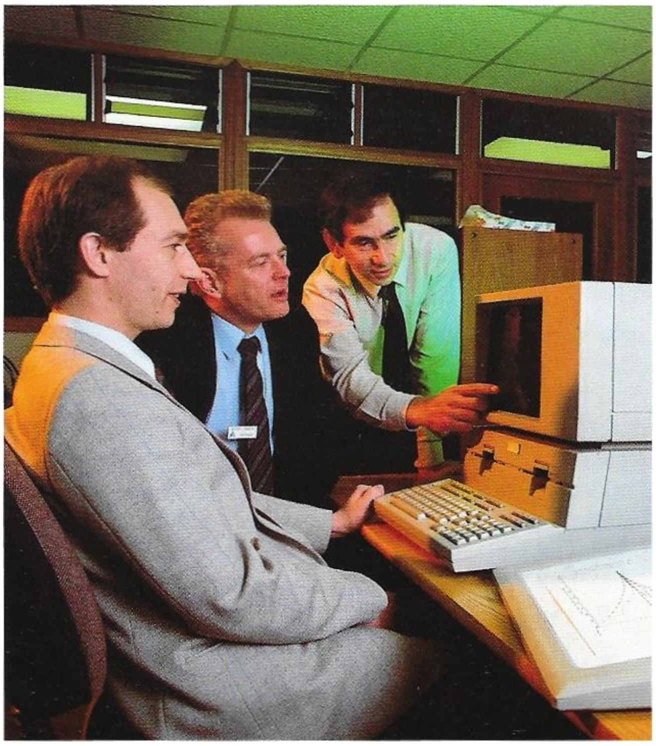
Syd King operating the FWR Mill

In later years under the direction of Randy Powers, who joined us from Alcan Rolled Products USA, AFC again received attention as the option of Alcan writing its own bespoke software was explored. Though novel algorithms were employed by Dan Miller to improve flatness control (for example in the Fairmont & Glasgow plants) it was decided that the development of commercial software was not a strength of the company, but the knowledge gained was used to modify many of the existing AFC systems in Alcan's cold mills and to achieve improvements both in quality and productivity.

The third line of approach to obtaining a flat strip product was to develop equipment to flatten the strip after rolling. There already existed various ways of doing this but with low productivity and reduced metal recovery. For example, plate and sheet stretchers processed individual pieces, roller levellers could remove coil set from strip in coil form, and more complex roller levellers could correct some off flatness but only slowly and with high operator skill requirement. Some equipment also existed which stretched strip continuously between driven large roll tension bridles. Various attempts had been made in the past to model the process of bending strip under tension, including work by John Alexander, Mike Sharp and Alan Beurrier in the 1950's but it had been difficult to validate the theories when multiple bends were considered.

So, in the mid 1960's, a programme of systematic trials were carried out on a specially designed medium scale test rig to generate empirical data and, from the information gathered by Frank Knight and Ian Calderbank, algorithms were developed from which to design the optimum configuration and specify power requirements for what became known as "simple tension levellers". The test rig itself was then used as a successful demonstrator and, following visits from members of most of Alcan's rolling operations, a large number of tension levelling lines were built to Banbury's specifications and supplied around the world including some to non-Alcan companies via third party technology sales to equipment suppliers. In later years an even better theoretical understanding of the recoiling and tension bridle behaviour was developed by Peter Alexander, Dan Miller, Dubravko Nardini and Andrew Hobbis with new algorithms being used to modify tension levelling equipment and recoiling strategies for improved performance. The development of models describing the coiling process and the changes in flatness that occur during the winding of coils and the cooling of coils is now part of the standard toolkit of all the major aluminium rolling companies. Throughout all this work much help and support was provided by Peter Limbach, David Wright and others at Göttingen.

Dan Miller discussing flatness with Peter Limbach and David Wright



The levelling of lithographic sheet is exceptionally demanding and the simpler tension levelling models were not sufficiently detailed to provide the insight needed for this critical product. With the support of the business unit at Göttingen, finite element models of the leveller were developed by Rade Ognjanovic focussing on the problems of multi-roll stretch levelling. The resulting suite of programmes also encompassed the analysis of the flatness measurement table, so that the predictions could be correctly compared against measured plant data.

By the 1970's the emphasis on downgauging products such as beverage cans was beginning to cause problems for gauge control. The tolerance being demanded to ensure satisfactory operation at the can makers was such that the variation in gauge across width (strip thickness profile) had become an issue. As flatness tolerances also tightened particularly for products such as lithographic sheet for critical printing processes it had become apparent that, even with the use of AFC during cold rolling and tension levelling afterwards, if the strip had a large enough thickness profile error, off flatness could occur within the final coil during final coiling (as mentioned above), storage, and transport to the customer. Theoretical studies were carried out and it became clear that the main causes of thickness profile error originated at the hot rolling mills. In previous years the main process developments at the hot mills had been concerned with surface quality and the need to control pick up of aluminium coating from the rolls on to the slab or strip by appropriate development of the emulsions (used for both roll cooling and lubrication and discussed elsewhere) and/or roll brushing techniques. Now, a new effort was made based on our earlier work with AFC but to develop algorithms for Automatic Profile Control (APC) at the hot breakdown and finishing tandem mills. More mathematical modelling was carried out at Banbury with Gerry Tucker, Stephen Rogers, George Macey, and Keith Waterson adapting parts of the Alcan Rolling Model and, in a large joint development project with Alunorf in Germany led by Peter J S Brooks and sponsored by Reinhold Wagner, much data logging was carried out on the hot line and control algorithms developed with Nick Martin creating the appropriate software packages. During this time, in anticipation of his pending retirement, Maurice Tulett was seconded from Kingston for a few years and Keith Waterson “cloned” to take future responsibility for the Alcan Rolling Model.

As part of the learning process for the above joint development a considerable effort was put into the understanding of the heat transfer processes influencing the roll thermal cambers and Chris Davenport carried out both detailed analyses and test rig data gathering culminating in another model which has since been used on many occasions to predict optimum roll cooling configurations for new or revamped hot and cold mills. Similar heat transfer modelling was also carried out to design interstand hot strip cooling (quenching) devices for multi-stand, or tandem mills, to enable higher speeds and influence downstream thickness profile.

There were many other people involved in the above profile control developments and the technology was transferred to both Oswego and Logan with Chris Davenport developing the appropriate algorithms supported by Nick Martin for the software packages. Much of the basic technology was also transferred to other Alcan plants with Kyle Smith heavily involved.

During the late 1990’s, under the direction of Paul Evans, a decision was made to create on-line versions of the Alcan Rolling Model allowing the knowledge embedded within this model to be applied to issues such as cold mill start-up and threading and also to hot mill profile control. In both examples the Alcan Rolling Model was run on-line, in parallel to the rolling operation and used to track the thermal state of the rolling mill rolls using continuous data updates from the mill. David Browne and Kyle Smith managed these projects, resulting in several implementations in Alcan plants.

As rolling speeds increased, another problem arose, namely mill vibrations and once again our modelling strengths and basic understanding came to the fore under the leadership of Tom Farley. During the early to mid 1990’s, several cold rolling mills were suffering from self-excited vibrations which would occur suddenly at high rolling speed producing very significant gauge variation, up to 40% in one case, at frequencies between 90 and 300Hz. Other higher frequency problems produced chatter marks on the backup rolls and sheet surface. A consequence was the involvement of key plants in a series of regular technical meetings. Tom reviewed existing internal and external industry knowledge of the problem and set about developing new understanding for Alcan. Computer simulations were created to predict and visualise the natural resonant modes of vibration of any mill, including torsional modes. A time simulation model was developed to show that the self-excited mill stand vibration resulted from a disturbance to the flow of aluminium through the roll bite, producing a simple mechanical feedback loop that becomes unstable at high rolling speeds (analogous to the famous Tacoma Narrows bridge becoming unstable and vibrating at high wind speeds). Experimental vibration work began on many mills, which when combined with results from the computer simulations, led to new ideas and patents for solving the different problems encountered. Solutions were developed involving hollow work rolls and tuned mass dampers, together with careful identification and removal of exciting vibrations. It was possible to completely solve some vibration problems and to reduce the amplitude of others to allow significant increases in mill rolling speed and productivity. The work was extended during the late 1990's to also include chatter of roll grinders and finishing lines, such as roller levellers. During the final years of Banbury Lab, the vibration work was highlighted as one of the examples of an R&D programme that had produced significantly more financial benefit to the company than it had cost.

As our knowledge grew and process models and algorithms for AGC, AFC, and APC were developed the "rolling team" became one of the strengths within the laboratory and its credibility with the plant operations' personnel led to increasing interactions through joint development projects (some major) and technical assistance on a more ad hoc basis. These interactions led to a gain in experience of the team so that strength built on strength. An Alcan Rolling Course had been started in 1984 and many of the team have contributed to this as faculty members with the Banbury Laboratory eventually becoming responsible for organising the courses over a number of years. Many of the team members are still actively working together internationally in the rolling field (and elsewhere) but now with Innoval Technology Limited, a company formed in 2003 following Alcan's closure of the Banbury Laboratory. In addition to helping "new" clients improve their processes they continued with the Alcan "teaching" tradition by providing on a regular basis an internationally recognised Aluminium Rolling Course and also took over responsibility for maintenance of the Alcan Rolling Model when Keith Waterson retired.

Most of the discussion above has been concerned with dimensional aspects of the production of plate, strip, sheet and foil. However, during the 1970's it became obvious that there was also a need to understand the mechanisms by which the surfaces are created during rolling in order to prevent defects occurring and thereby ensuring better and more consistent surface quality. Much time and effort had been expended in developing and optimising lubricants for hot, cold and foil rolling (as described elsewhere) but it had become clear that other rolling parameters were having on overriding effect on occasions. To do this, trials were carried out on both laboratory and plant mills, varying roll and other mill parameters such as speed and applied tensions in cold and foil rolling and, in the case of cold rolling, angulation of the entering strip away from the horizontal to brighten one side of the strip at the expense of the other. The work was carried out mainly by Peter J S Brooks with David Moore using the electron microscope to analyse the results. Probably the most significant result was a clear understanding of the causes behind loss of brightness (whiteness or lubricant entrapment pits) occurring as mill speed or lubricant viscosity increases. This led to important changes in processing for rolling lithographic sheet and foil, with new specifications for roll grind finishes and control of lubricant viscosity via temperature.

8. LUBRICATION

Mike Budd

Introduction

Lubrication is an essential component of all metal deformation processes. Its first role is to control friction to optimize the use of the applied load (energy) in bringing about the required dimensional change at the speed needed. Other simultaneous roles include to produce a surface quality as required for the intended use in terms of brightness and reflectivity and also in parallel, to avoid leaving objectionable, unsightly residues, including after any heat treatment used to produce the correct mechanical properties. Lubrication can be used for both hot and cold metal with different appropriate formulations used in each case. Lubricant costs are minimized by using recycling systems with continuous cleaning and regeneration. Other systems are used for environmental control and for the disposal of spent lubricants. Over the years all of these aspects became the target of R&D in Banbury. The objectives of the programme increased in complexity and multiplied with time as Alcan's rolling plants significantly increased in number, capability, equipment type and distribution across the worldwide market-place. In the larger market places: USA and Europe, (and latterly Brazil), a new generation of significantly more sophisticated equipment was used to meet wider and substantially more demanding product specifications and production rates. Among those requirements that had an increased impact on lubricants (quality, application, lifetime performance, cost, maintainability) were: significantly advanced control of the aluminium surface generation under more rigorous production conditions, including improving production speeds without prejudicing other quality requirements; in-plant maintenance procedures aimed at consistency of performance and maximum service life, which in turn is aided by monitoring methods including both analysis and specific property measurements usually using in-house, purpose-designed methods; developing special lubricants for processes other than rolling; environmental compliance (including the design and use of environmental control equipment) for on-line use; and ultimate disposal of lubricants and materials with which they had come into contact.

Much of the outcome of this work was disseminated to Alcan's worldwide rolling system by producing Fabrication Memoranda so that all Alcan plants could be made aware of the best available technology applicable to their operations and equipment and have a ready source of reference. This was accompanied by an ongoing and ever-growing support programme for the plants by means of visits and seminars, that in turn kept the laboratory up to date with their problems and led to joint projects in which we worked in the plants as well as in the laboratory. Our staff was also involved in audits of plants both abroad and in the UK covering their rolling practices and environmental control procedures. Little of this work was published in the public domain, since most of it was considered too valuable to allow both our competitors and the oil companies and specialist lubricant manufacturers to learn about it. The problem was both the relatively short working life of any patents obtained and the difficulty and cost of monitoring any breeches of them.

Lubrication first became a subject of research in Banbury commencing in the early 1950's, initially as a support activity to the Northern Aluminium Company plants in Banbury and Rogerstone, then gradually adding a research element in the second half of the decade and capitalizing on its outcomes. George Gardham first recognised the need for work on lubrication in the early 1950's and Roman Guminski was given the task of carrying out the first chemical work; he was joined by Gian Frontini in 1960, who took over when Roman replaced George Gardham on his promotion to Director of Research shortly afterwards; Mike Budd then managed the Section from 1963 to 1982, and Mark Foster from 1982 until the close-down of the Banbury Laboratory in 1994. It is noteworthy that there was no corresponding activity in Kingston Laboratories until the second half of the 1970s, so Banbury gradually adopted a global responsibility from 1960 onwards, that continued until the 1990s.The Lubrication Group rose in parallel to ten workers during the 1970's, before decreasing as the knowledge base matured.

The Beginning

Roman Guminski began working on lubricants at a time when most metal working lubricants were "made up" and supplied by either the oil companies (in the case of the UK: by BP, Shell, Gulf and Mobil, or by blending companies such as Edgar Vaughan, (Burmah and Castrol, as well as Shell and Mobil). The approach adopted towards aluminium was essentially empirical, often being no more than: "because we don't want to have to invest and do development work on aluminium lubricants, if it works for steel, even as a cutting/machining lubricant, we will propose its use for aluminium". This approach was used for both mineral oil and water-dispersible lubricants (needed in order to obtain a higher level of cooling), and was applied to hot, cold and foil rolling, tube and wire drawing, blanking, container drawing and later deep drawing and ironing. As a consequence, the aluminium industry in the UK found itself using lubricants based on light mineral oils containing natural fats derived from vegetable and mammal materials, and needing to do the R&D (that the lubricant suppliers might have been expected to have done). We and our industry did not know what the proprietary formulations contained, but of necessity were carrying a disproportionate amount of the development cost, including providing the pilot plant needed for evaluations. Also any successful products once in regular production, besides being sold by the oil companies and blenders as premium products, free from a significant R&D cost component, would soon be offered to competitors, now the suppliers knew that it worked.

All this might have been different if the analysis techniques now available for organic substances both singly and in mixtures had been on a par with those for inorganic substances. In fact they were between a hundred and two hundred years behind in commercial terms, although universities had developed techniques like chromatography for research purposes without really appreciating their commercial value in terms of capability and the potential income generation. The period from 1960 to 2000 was when it all happened as we shall see later.

<u>Empirical methods are all very well but we needed to use some science to understand the processes and hence plot the way forward. Cold rolling was the simplest starting point since the approach was essentially physical rather than chemical.</u>

The commercial attitude to lubricants and their formulation was only poorly understood at the time when Guminski started work in Labs. The opposite side of the coin, however, could be appreciated and addressed. So problems were identified for examination, including: what aspects of lubricant formulation are responsible for specific defects, principally brown stains, on finished cold-rolled products and what aspects restrict, for example, the maximisation and efficiency of reduction under applied rolling load. Here John Willis, an engineer in George Forrest's Engineering group played a significant role in designing the plane-strain compression test that helped to sort cold rolling lubricant additives in order of efficiency. Using it, he and

Guminski screened a number of different organic alcohol and acid lubricant additives, called load bearing additives, because they directly influence the properties mentioned above and prevent aluminium from sticking to the rolls while being rolled. He showed systematic trends occurred as a result of the carbon chain length.

Much later (1970's) other types of polar group (ester-COOR, amine-NH2, amide-CONH2, etc. were studied) By this time the Lubrication Section, now led by Mike Budd, had grown in both numbers and breadth of disciplines. In 1970 Roy Jones and Bob Pugh, and later Gordon Smith had reacted to the known restrictions of the old plane-strain compression test and had replaced it with a disc/ring compression test, that was then further modified so that it could also be used at controlled temperatures from room temperature up to 200deg.C. This was a major development for additive selection that confirmed the effect of carbon chain length and led to the recognition of the importance of chemical type, synergy when used in certain combinations, concentration, purity and working temperature range for a wide range of lubricant additives. It became the method of choice for all future load bearing capacity and coefficient of friction testing in the Laboratories.

Another aspect of cold rolling lubricants looked at by Guminski was their tendency to cause brown staining after annealing. Here again a sorting test was needed. David Hope, a young chemical engineer, developed an appropriate test based on heating a specific amount of lubricant to annealing temperature while contained in an aluminium can containing ventilation holes. This in turn was contained in a much larger aluminium box, to allow good temperature control. After the test the cans were opened and the stain on the lid visually compared with a set of standards. This test was first used to study the same range of substances that were used to develop the plain-strain test. Later the range was increased to include branched chains, chains containing double bonds and a range of commercial additives and base oils (the refined petroleum products in which the additives are dissolved to make lubricants). This resulted in the definition of the formulation needed to make a good cold rolling lubricant that could be blended in-plant using its individual components which were purchased separately. It also led to Labs' first lubricant patent that protected this formulation. The damaging effects of contamination of the rolling lubricant, usually from mill hydraulics and roll-neck bearing lubrication systems then became apparent. Laboratories' work was now focussed on developing alternative, non-staining replacement lubricants.

A rig that would simulate roll neck bearings operating dynamically and under a range of working loads was designed and built by John Grosse, a mechanical engineer in the Drawing Office. It was called the Foil Bearing Machine. A steel foil was looped around a babbit-coated steel shaft to which test lubricants could be applied while the speed of rotation was varied and the load applied to the foil could be independently varied as required. This provided the data to plot coefficient of friction against load and speed of rotation, and gave a direct comparison between different lubricants. He published this work in JIM (1963).

Gian Frontini (named George by George Gardham, and which he managed to correct only after his transfer to Kingston) used this machine to develop non-staining bearing lubricants formulations. Gian was a young newly qualified chemical engineer, whose father was the Works director of TLM, Milan, (at that time they were significant ingot customers of Alcan SA). He made no secret of the fact that he had come to Banbury to avoid National Service in Italy and would soon be transferring to North America. These non-staining lubricants contained a low-staining, synthetic, high viscosity component that could be adjusted to the required working viscosity by the addition of the base oil used for rolling, in order to replace the medium range viscosity mineral oil additives invariably present in commercial lubricants. The replacement component was a mixture of an organic polymer called poly-isobutylene and a viscosity stabiliser. This latter was propylene tetramer in the initial tests. When we came to file our second lubricant patent it was recognised by Mike that propylene tetramer was unlikely to be unique; he identified a significant range of organic substances with the viscosity-stabilising property, all characterised by containing an activated double bond. These were therefore included by him in the patent application; the patent, when issued, was never to our knowledge circumvented. The replacement lubricant was always referred to as a non-staining bearing lubricant; this was an overstatement, but it needed up to five times as much contamination with this material, than with a conventional proprietary product to give the same level of staining. At its maximum tolerable contamination level, the increased viscosity resulting from the high level of the non-staining additive would have a significant and undesirable dulling effect on the aluminium surface, a viscosity effect.

Poly-isobutylene is colourless but rather like treacle, however, it is much more viscous than treacle and much more sticky, and unlike treacle it cannot be washed off with water; adding water to it is about the worst thing that can be done and removing it with mineral solvent to 40-50deg.C is about the best.

While the alcohol patent was initially licensed to Shell-BP, both the alcohol and non-staining bearing lubricant patents were later licensed to Henkel International Gmbh., Dusseldorf by Eric Thomas, who was then our Patent Manager. Gian and Mike had by this time installed the latter on a number of Alcan mills, including ones in Kingston, Spain, Norway, Sweden, Denmark, South Africa and New Zealand. Consequently these lubricants already had a good track record. Nevertheless, to support Henkel's efforts, we carried out a fully instrumented evaluation in conjunction with Davy on a Loewy light gauge rolling mill in Rorschach fitted with Morgoil bearings which Davy instrumented for the test. These encompassed the worst cases of bearing abuse, including crash stops and rolling under maximum load/minimum speed conditions. Nothing untoward occurred and Loewy authorized the use of the lubricant without reservation.

By now we had established a good working relationship with Henkel, who had shown considerable drive in selling alcohol additives to the aluminium industry worldwide and providing us with significant revenue. They were now eager to widen their commercial effort by adding the non-staining bearing lubricant to the products they were offering. Eric supported this, but a significant piece of work was still needed to solve the problem of packaging the product in such a way that it could be easily marketed by Henkel and matched to the viscosity specifications and rolling lubricant type in use at their customer's plants. (In the case of the first Alcan mills converted by Gian and Mike, the non-staining lubricant was blended by them on-site by mixing its seven components in a piece of equipment designed by Gian; this comprised both heating and stirring so that the poly-isobutylene could be dispersed in the heated base oil before the other components were added). For Henkel, we developed two concentrates that could be used without the need for special blending facilities, using the same (cold rolling) base oil used in the mills where they were to be installed. The two concentrates were necessary to cover the range of base oils in use. We produced blending instructions and viscosity curves to assist Henkel in viscosity matching and then backed away. Henkel also sold the non-staining products as the basis for hydraulic fluids, thereby increasing their sales and our royalties.

The final chapter in this development was to investigate the possibility of making non-staining bearing lubricants for roller bearing systems lubricated with misted lubricant. After discussions with Norgren who manufacture such systems, we installed a lubricant misting system in the laboratory and quickly found that they tended to separate the high and low viscosity components of our non-staining formulations. We adapted by using mixtures of shorter chain poly-isobutylenes and the base oil to obtain the correct viscosity; these did not separate when the misting system was operated. (This invention was not patented, since we decided it was not sufficiently different from our existing patent).This work was the basis on which the roll neck bearings in the Sendzimir mill belonging to our Australian plant in Granville, NSW were converted to mist-applied, Banbury-designed, non-staining lubricants by John Grosse at the end of the 1960s. In layman's terms, a Sendzimir mill is a large heavy steel enclosure containing a cluster of self-supporting rolls with a conventional rolling lubricant system that also originally contained a special, but staining, additive for bearing lubrication. The Australian mill had 10 rolls at the top and 10 at the bottom, each roll having a roller bearing on each end, a total of 40 bearings. After developing the mill and lubricant modification strategy, a meeting was scheduled at Sendzimir's plant in Waterbury Conn., USA with Sendzimir (the inventor of the mill), with Peter Dodd Granville's Rolling Production Manager and Ken Gilbert their Work's Engineer attending, at which Mike gave a presentation on his proposals. Sendzimir agreed that the change would be appropriate. John Grosse, who had transferred to Alcan Australia worked with Ken Gilbert and his engineers to carry out a successful implementation.

Around this time Gian also put non- staining lubricants on all the foil mills in Kingston. By 1970 they were used worldwide on about twenty Alcan mills.

Before this work was carried out, inert atmosphere annealing furnaces were sometimes used as an expensive solution to preventing staining. They were originally justified because they allowed magnesium-containing alloys to be annealed at a sufficiently low temperature to minimize the formation of a surface film of spinel (magnesium-aluminium oxide), which causes rapid tool wear in subsequent operations such as drawing and ironing. However, since inert atmospheres are needed to prevent rolling lubricant residues causing staining during low temperature partial anneals, there was never a possibility that inert atmosphere furnaces could be replaced by using non-staining lubricants. Labs main contribution to this work was the elucidation and characterisation of the staining mechanism in terms of alloys, temperatures and annealing times. A potential problem with inert atmosphere furnaces is serious explosions if oxygen enters the hot inert atmosphere as a result of malfunction, eg. a cracked heating tube or poor door seal. We accordingly produced a Fabrication Memorandum on this type of furnace that covered design, use and maintenance and with special emphasis on safety features.

The value of contaminated cold rolling lubricants can be recaptured if the contamination can be removed by re-distilling them; otherwise they can only be burned to supply heat. Calculations showed that even in the 1950's, when oil prices were low, the pay-back from an in-house vacuum distillation unit would more than cover both depreciation and operating costs. Alcan's first installation was situated in Rogerstone, and used until the plant closed to recover contaminated lubricant on a regular basis. David Hope had worked on this concept in Banbury and then moved to Rogerstone where he helped with the installation and commissioning. He soon left afterwards, however, to join Shell-BP, where he remained a very useful contact for a number of years. Later, when oil prices rose from around £0.02/litre, (when the first still was installed in Rogerstone), other plants installed them including Fairmont, Oswego, Kingston and Norf.

Around 1970 Alcan installed two high-speed cold rolling mills in USA without knowing their precise implications for lubrication technology. Oswego showed that rolling at speeds up to nearly 8000ft/min was possible, but there were major engineering problems to be solved in containing the lubricant. Consequently the mill was never used at more than about 60% of its design speed. The other mill at Fairmont, West Virginia was used to roll light gauge products at speeds between 3000 and 4000ft/min. At this time Alcoa were in the lead on high-speed rolling having invested in a tandem mill, a water-based lubricant and a shielding system; they were believed to be able to reach speeds of around 5000ft/min when rolling can body stock.

Strong views existed within Alcan concerning the use of water-based cold rolling lubricants with the Europeans concerned about water staining and the North Americans inclined to follow Alcoa's approach. Sidal in Belgium working with Davy Engineering had installed a Davy-designed lubricant containment system on the exit-side of a cold mill in their Duffel plant. Olivo Sivilotti in Kingston Works had designed a similar box. We were faced with the question of what lubricant to use given that the engineers could design and satisfactorily maintain a containment box. The problems in controlling emulsions and bacteria (potentially difficult at the temperatures prevailing on a cold mill) led us to look at using single-phase (micro-emulsion) lubricants, that would be fully filterable and leave practically no organic residues on the strip. The chemical aspects of the lubricant development were the responsibility of Gordon Smith. He developed a candidate which we then tested on both a cold mill in Rogerstone and a foil mill in Rorschach, using the normal lubricant application system in each case. Both the rolling results and the annealing results were satisfactory. Consequently we decided to construct a containment box, using Olivo Sivilotti's design, that could be fitted on one of Endasa's foil mills in their Linares plant, where we could convert the mill to our candidate lubricant for two weeks at a time in order to carry out trials. We were able to roll down to 50microns (0.002inches), producing a foil that, after annealing, performed fully satisfactorily in the usual range of conversion tests applied for the acceptance of converter foil. However, because of both the low amount and low application pressure of the lubricant, there was a gradual build-up of detritus on the work-rolls which was slowly transferred to the back-up rolls. We had no means of removing this during rolling. Installing a rotating brush inside a containment box was complex and not attractive. We decided therefore, that there was no future in this approach for foil. Olivo, meanwhile was using conventional lubricant, applied as a mist, on the entry side of his mill and a dilute detergent emulsion in his containment box for cooling and shape control. While less elegant than our approach, it had the merit of working, and was subsequently successfully used on the next generation of cold tandem mills.

Tackling Hot Rolling lubrication.

Near the end of his period in Banbury, Gian Frontini turned his attention to hot rolling lubricants, an all together more formidable task than cold rolling lubricants. Later, after his transfer to Kingston, he and Guminski wrote a paper on the understanding developed when Gian was in Banbury and which he presented at the 1968 ASLE meeting in Cleveland. This describes metal and oxide transfer during hot rolling between slab and rolls, (with only the help of optical microscopy at that time to study what was happening), and the ad hoc tests that could be used to compare formulations and study how emulsions aged. This paper put the idea of using a passive mill for this purpose (see below) into the public domain. The major problems associated with both formulating and subsequently controlling hot rolling lubricants arise from the need to use hot rolling lubricants at temperatures well above both the flash point and fire point of their organic phases in order to obtain the required cooling properties (for both shape and surface control) require the use of water-containing formulations. Fundamental to Gian's analysis was the recognition that because a hot rolling lubricant is an emulsion of something quite like a cold rolling lubricant suspended in water, its performance is likely to be affected by: the stability of the emulsion, its ability to wet the roll surface and that it can separate the necessary amount of lubricant on a surface having a temperature in the region of 120deg.C, that is typical of a hot rolling mill operating under stable conditions (all three of these need to be maintained over an acceptable life). Finally, it is necessary to know how effective the lubricant is in consistently producing a high quality rolled surface.

The first step was to recognise that caustic-etched surfaces did not show defects so much as roughness; a better method was anodizing followed by optical examination and comparison with standards. This was to become the routine next-to-line method used in Alcan's major plants. Before he went to Kingston in 1973, David Moore was to make a major improvement by promoting scanning electron microscopy (SEM) for this examination. Gian and John Grosse designed and built a miniature rolling mill with 56mm long by 12.5mm diameter silver steel work rolls, the top one of which could be easily removed from the mill after rolling for examination, and which were supported at their ends by four freely rotating stub rolls narrow enough not to intrude on the area where the rolled strip deposited coating, and with a preset roll gap through which standard sized aluminium shot-blasted AA1200 strips, tailed at one end for threading through the mill could be pulled using a chain driven gripper.

A Norf Hot Mill
(Copyright Aluminium Norf GmbH)

Before rolling, the strips were heated to 500degC. The lubricant, supplied as a 4% emulsion in water was applied to the top roll via a spray nozzle. In this way rolling sets were carried out using four separate rolls to roll consecutively 1,3,5 and 7 strips. The aluminium coating transferred to the rolls was then chemically stripped and quantitatively analysed. The results when plotted showed at a glance the type of transfer that had occurred and the efficiency of the lubricant. A curve that continued rising indicated a poor and useless lubricant; one that rose, then fell before rising again indicated that the coating on the rolls was unstable and would have a tendency to become detached and rolled into the aluminium surface (also useless), while a curve that initially rose then flattened out at a low level indicated a product worth further examination. This work did not deliver anything like a comprehensive pass-fail test scheme, however, Gian, after his transfer to Kingston helped Konrad Wolf on work in conjunction with Stuart Oil Company to develop a formulation which he used to good effect on the Kingston hot mill and later on the first stand of the Saguenay hot coil line. Likewise in Banbury we helped Rogerstone by providing Mobil Research with the specification and drawings of our passive mill, so that they could use it to carry out release testing of product batches prior to shipment to Rogerstone; see later.

Characterisation of hot mill defects was a major subject of investigation when Mike took over from Gian. Mike had come from the Corrosion Section; he immediately became involved with Gian in the study of the effect of end marks on final product quality. End marks are the transfer replicas of the marks on the rolls that are formed by driving the front end of a slab into the mill or as the back end leaves the mill. Crudely, but effectively, cold chisels were used to mark each print on the slab edge after every transit of the mill, then after the slab had been rolled to final gauge, ready to be cut into circles for producing anodized coffee pots, the marked samples could be collected and anodized to see what effects the end marks from each pass had produced. Fortunately none were found to be serious enough to affect the final product.

One other quite different and lasting success of Gian, during his stay in Banbury was to marry a young English lady: Patricia who sadly had lost her father while he was serving in Italy during the 1939-45 war.

In 1964 Rogerstone experienced a number of major batch to batch variations in the performance and stability of the hot rolling lubricant: Prosol 44, used on their hot tandem mill. Mobil's Technical support staff worked with us to try to improve the situation. They had the formulation information and we had the testing methods and equipment.

Initially this led to a quick fix and our ongoing employment by Rogerstone to check pre-release samples of all blends that Mobil was going to ship to them. As confidence grew, we gained a very good perception of how Prosol 44 was formulated. This was to become of major importance when the Alunorf plant in Germany was commissioned in 1967. In 1966 Mike met the Oswego personnel who were to become the Alunorf hot-line commissioning team: Dick Dunsmore, Bob Flack, Barrie Cayless and Leroy Morgan, while visiting the Oswego plant. Their hot-line, dating from 1961 was a much smoother piece of equipment than Rogerstone's, that dated from the second world war. This encounter was to pay dividends at the end of the commissioning period when Mike was the first Labs person to visit Norf, at the invitation of Dr. Werner Gmoehling, Norf's Technical Manager. The Oswego group and Werner were well aware of the liaison we had with Mobil but did not know that we had discovered so much about Prosol 44 and moreover that its formulation is not the same in the three countries where we would now be using it, either in terms of individual components or their amounts. Nevertheless, an analysis of the results of the plant control tests indicated that their inability to speed up the mill to more than 60% of design speed was probably related to the load bearing package being used, in both composition and quantity. Mike was able to use the Henkel contact to obtain an immediate delivery of enough higher purity additive to make a test. Adding barrel quantities of immiscible organic liquids to 200,000litres of an aqueous emulsion to obtain an homogeneous whole was quite a gamble. Fortunately for all of us, one of the two operating people from Oswego suggested slowly adding it through the induction side of one of the recirculation pumps incorporated in the lubricant management system. This incidentally was their method for adding biocides. This appeared to work satisfactorily and allowed the mill speed to be increased by about 30% almost straight away and without adverse side effects especially on the quality of the re-roll product. Success was achieved in a morning. Norf were never to look back from this finding which was also immediately adopted by Oswego, who were soon hot-rolling some products at nearly 1000ft/min.

Werner and Mike then progressively applied the approach of analysis and replenishment to all nine components in the Norf lubricant. This brought further success that caused us to study the effect of changes in the levels of selected components and how we might control these to maximize consistency and performance. A consequence of this was that when Werner left Norf, Reinhold Wagner used to summon Mike to Norf to act as doctor, whenever there was a hiccup with his lubricant. One Christmas Dick Decker did the same, so Mike experienced his first real winter, but see later. Then Nippon Light metals adopted the technology for their Kambara Hot mill, helped by Masa Suzuki who had spent a year with us training in all aspects of our lubrication programme. Later Banbury trained the lubrication technologist selected by Moka for Kobe Steel's new hot line and Mike plus three operators from Oswego took part in the commissioning.

Tadieu Nardocci from Alcan Brasil also trained in Banbury before they commissioned their new hot-reversing mill at Pindamonhangaba. Likewise Deb Tapadar from Indal's Taloja plant, who was destined to run a small Lubrication R&D Centre covering Indal's national requirements. Richard Hartree played a major role in getting this agreed soon after he left Banbury and transferred to Montreal. The opening was marked by a visit to Taloja, where John Bates and Deb had been busy commissioning all the new, imported, equipment and putting right the "over enthusiastic" efforts of the Indian Customs inspectors which included cutting wires and trying to remove components. When he arrived in Bombay from Brasil, where he was now Alatina's Technical Officer, Richard was found to have been in a yellow fever area. Although he had a valid yellow fever inoculation certificate he was temporarily detained until Indal had been notified and "suitable arrangements" had been made to secure his release. He had arranged to hold an Alcan global lubrication Conference in New Delhi to mark the opening of the laboratory that included a reception to which dignitaries including the Indian Government Minister for Science, the Canadian High Commissioner, Directors of Indal and other dignitaries were invited and were present.

When Alcan gained control of the Logan, Ky., USA. plant in the early 1980's some Oswego staff were transferred permanently so that Alcan's technology could be transferred to their manufacturing centres, including their hot-rolling line. Dan Minwell, who had spent a lot of time working on both lubrication and hot rolling metallurgy and bright trim stock, Oswego's highest premium product at that time, and who had worked with Mike on the Oswego hot tandem mill emulsion with the objective of maximising both mill speed and product quality immediately following scheduled changes of their emulsion. Throughout the 1970s Mike was helping in the Oswego plant by spending around five weeks every year working on their hot mill lubricants. This usually followed Labour Day at the end of August, but one year also included all of January, the time when that area of New York State experiences sudden and, by our standards, huge snowfalls on the hot line lubricant. On that occasion Mike found himself on a delayed flight from London into New York on which he encountered Bill Baker who was transferring to Oswego to help their product and engineering teams. They eventually got to Syracuse Airport, having already phoned Barrie Cayless at Oswego to let him know their problem, to find a winter wonderland and a message from Barrie telling them they had rooms booked at the Airport Motel and would be collected at 9.00 am the following morning. Eventually, on the road leading down the river into Oswego Mike heard Bill mutter: “My God what have I done, Connie is going to kill me for this”. (She didn’t; when she arrived, the climate had relented and Bill had recovered from the initial shock).

Rogerstone had the first hot tandem mill in Alcan which outlived its obsolescence date by some years. Oswego was second, so many of the design deficiencies of Rogerstone had been addressed. Norf made a further huge leap forward in both lubrication system design and plant layout highlighting fundamental design limitations of the original design that were incompatible with the substantially stretched requirements 10-20 years later. Norf experience, not surprisingly, highlighted the individual deficiencies in the Oswego operation. Some we could ameliorate, but others such as the sizing of a lubrication system were dictated by cost.

We always recognised that we were not a lubricant blending company, so confined our efforts to maximizing the control of the lubricant components and controlling the quality of and quantity of the materials used. Reinhold Wagner (then production manager at Norf) valued the tandem emulsion in Norf’s first hot tandem mill so highly that he insisted that it was never changed, and it wasn’t. When Norf’s second hot line was commissioned in the late 1990s he decreed that a significant proportion of the lubricant from the Norf Number1 tandem mill should be transferred to the new Norf Number 2 tandem mill to assist its smooth commissioning. This, not surprisingly, was successful.

John Bates and Chris Pargeter worked valiantly to try to get some of the most appropriate new instrumental analytical techniques harnessed for the analysis of hot rolling lubricants. This was partially successful but by no means complete. The equipment was expensive, the procedures complex and time-consuming and needed the support of highly skilled and dedicated chemists. The methods were concluded to be unsuitable for even sophisticated plants like Norf and Oswego to use, but nevertheless supported laboratory work and trouble shooting.

Emulsions are like milk, which is a suspension of fat in water. They both can separate into aqueous and oil phases and are readily attacked and consequently changed by bacteria. Controlled stability is of major importance when using them. Mark Foster and before his arrival, Martin Smith, worked on this subject, paying attention to the effect of bacterial attack on emulsifiers and the selection and use of bactericides to control it. Mark also worked on emulsifiers and emulsifier balance in the different Prosol 44 blends. Bacteria multiply at colossal rates especially at temperatures around 40degC, where they double in quantity about every 20 minutes, so any analysis and evaluation of mill samples must be done immediately after sampling. However, bactericide use has been beset by tightening restrictions required by the environmental control agencies. This was morally correct, because some of the earlier used materials were highly toxic to humans. Methods for handling emulsions, including circulation, filtration and skimming were also studied and optimized. Disposal of used emulsions, (where the organic content is around 5% and the remainder is water with low dissolved solids) by an electrolytic method was investigated and found to offer an environmentally friendly route to their disposal.

By the end of the 1970s it was recognised that the passive mill had outlived its usefulness as a research tool. If we were going to study coating build-up and defects using a scanning electron microscope, we needed to provide the best possible samples. Mark organized the hot rolling studies using a 5in. wide mill with driven rolls and equipped with 1in. thick roll inserts which were ground in situ in the roll. The reduction taken and strip length were chosen so that no end-marks appeared on the insert. The insert was of such a size that after removal from the mill and cleaning, it could be placed on the sample stage of the SEM. Using this method Mark repeated some of Gian's early work, coupled it with David's early SEM work and then extended it to study how different lubricant components affected roll-coating formation and stability. Unfortunately this work was not published, but should have been; it was an elegant approach.

A major conclusion from his work was that oleic acid, a liquid at room temperature and with a carbon chain length of 18 atoms is clearly the best load bearing additive for hot rolling aluminium. It was this material that, originally used empirically, had allowed the Norf and Oswego hot tandem mills to be dramatically speeded up. It had also been shown by us to speed up the Kingston Polysol 6 lubricant in a test in Oswego when this lubricant was being considered for the Saguenay tandem and, later still, we used it at Rogerstone to demonstrate that both speed and surface quality deficiencies when attempting to roll lithographic sheet with the Kingston Labs. (experimental synthetic additive) hot tandem mill lubricant: HRF2, could be eliminated by incorporating oleic acid. Subsequently Kingston included this additive in their formulation, which is now used in Oswego.

The success of this work led Mark to look at measuring thermal separation in a much more meaningful way than by Gian's hot foil method, which was far too operator dependent. He organized the design and build of a swinging arm apparatus in which a removable-heatable steel sample simulating the roll surface in shape, topography and temperature (all of which could be varied) was sprayed in a predetermined way with the hot rolling lubricant under test (its temperature, composition, concentration, etc. were also optional variables). The speed at which the spray nozzle passed the steel sample equated to the rolling speed and was consequently also adjustable. At the end of each experiment the amount of lubricant on the steel sample could be determined by standard analytical methods. All the above equipment was contained in a steel box. Using it Mark gained a wealth of information on the interdependence of many relevant variables. Principal among these were roll roughness and temperature, lubricant concentration and temperature and rolling speed. Plotting the results provided curves that demonstrated clear trends that were extremely valuable. Mark loaned the rig to both Norf and Rogerstone; after using it, both asked us to order duplicates for their in-plant use. The work was the subject of a paper presented to STLE. None of the plant-related hot rolling lubrication work was either published or patented because Alcan recognised its extremely high value to both our own industry competitors and to the oil companies. Most remained a closely guarded secret.

A discussion that we should have had with Reinhold Wagner, but never got round to was on how to evaluate the financial benefit to Norf of the work we did there. The lubricant had already remained unchanged for 30 years when Banbury Labs closed; there is no reason to believe that it might not survive for the life of Norf's equipment. The savings can certainly be counted in millions of Pounds Sterling. By comparison, during the same period Oswego were forced to change their lubricant every three months and then accept a period of reduced productivity while the new batch was run in because they did not have a large enough system with appropriate tank configuration and ancillary equipment. At Norf, increasing production rates by up to 70%, and doing this consistently coupled with a much better level, control and consistency of surface quality were certainly of greater value than the lubricant cost savings. For example they underpinned the production of a significant volume of electro-graining quality lithographic sheet stock. The production cost of can stock manufactured in Norf, Oswego Logan, Pinda (Brazil) and Nagoya was also a significant beneficiary.

With the high level of control now achievable, hot rolling lubrication was agreed to be mature and development was scaled back to a technical assistance level in 1990, by when each of the major hot-rolling plants employed their own team of graduate lubrication chemists.

Foil rolling lubrication revisited

When Gian transferred to Kingston Works in 1963, one of his first jobs was to convert their foil-rolling mills to use a lubricant that Alcan Engineering Services personnel had discovered being used advantageously by other North American competitors. This comprised butyl stearate and lauric acid dissolved in a light kerosene. Its major advantages were better control and increase of rolling speed, coupled with a cleaner foil surface after annealing, which in turn led to fewer breaks on unwinding during conversion.

The same lubricant components were used on each mill, but the additive levels were tailored to the thickness of the foil being rolled, gradually reducing the additive levels to increase friction with decreasing entry thickness to maximize rolling speed. This technology was adopted by all Alcan’s foil rollers.

During the 1970s our friends in Alicante alerted us to a new source of cold rolling base oil in Spain that they had put on their cold mill. It comprised predominantly straight chain saturated paraffins and had a remarkably narrow boiling range and consequently a low loss rate through evaporation during use. We discovered that it was a by-product from the feed used for the alkylation of benzene, to produce intermediates used in

A modern Danieli Foil Mill

making synthetic detergents. The by-products could be separated by fractionation into a range of narrow boiling point products, one of which could be used as a foil rolling base oil. It was clearly the best available anywhere and its discovery led us to identify similar products worldwide.

At more or less the same time, we recognized that we had two testing methods available in Laboratories that could be potentially valuable tools with which to make significant improvements to the foil-rolling additive package. These were our temperature-controlled disc-compression rig and a new generation of gas-chromatography columns. A literature search had revealed that butyl stearate does not evaporate when heated to foil-annealing temperatures, rather it decomposes and so leaves undesirable residues on the foil surface. However, among esters with low boiling points and that did not decompose we identified methyl laurate as apparently the most interesting. This ester and other candidates as well as butyl stearate, for comparison, were tested in the compression tester over the range 20-150degC. Again methyl laurate was superior to butyl stearate. Having, filed a patent application, we contacted Henkel to provide a range of commercial samples, going up to 90%-plus purity. We found that the highest purity was the best and the additional cost was easily able to be offset by the advantages. In parallel we had made a selection from the range of lauric acid grades available. Dr. Winfried Sturm, the then Technical Director of the Rorschach foil plant had been made aware of and supported our development and carried out the plant evaluation. This was entirely successful, yielding the expected improvements, including a significant reduction in annealing time and costs. Subsequently, there was a rapid conversion to the new lubricant by Alcan’s foil rollers on a global scale. The patent, in Mike’s and Mark’s names was granted in 1984.

If you want to control lubricants during use, you must be able to analyze them

Up until the early 1960s, all laboratory analytical tests for lubricants were by classical wet methods. These in turn were hampered because in the interests of minimising costs, lubricants were blended using natural products. A simple cold rolling lubricant nominally containing say, 5% lauryl alcohol (C12. H 25.OH), dissolved in a light kerosene base oil, would comprise an additive made up of 50-60% C12 alcohol, around 30% C14 alcohol, perhaps 2-5% C16 alcohol as well as 5% of C8, C10 and C18 alcohols and a base oil comprising a mixture of saturated and unsaturated hydrocarbons some with straight and branched chains and some containing carbon rings with and without saturated bonds. Clearly their analysis was complex and not economically viable. The door was partly opened in the second half of the 1960s when gas chromatography began to be used after being packaged by instrument manufacturers such as Pye, Perkin Elmer and others. We purchased a Perkin Elmer unit and used it successfully to analyse alcohol contents of rolling lubricants and to determine the purity and often reasons for impurity of additives such as lauryl alcohol, lauric acid and butyl stearate. So, we could now help our fabricating companies with their choice of additives, based on expected performance rather than lowest cost. Infrared spectro-photometers were also being packaged by the same group of manufacturers. They can save time because a smear can be used, followed by a scan to provide immediate information about the chemical groups present in the sample. This in turn gives ideas on the optimum methods for further analysis.

This was an important time in lubrication technology when production, technical and purchasing departments came together to operate as a team. We subsequently purchased a Pye instrument because it was more research-compatible and allowed us to make our own columns (the part of the instrument where different components of mixtures are separated from each other and can be identified and quantified). Using this knowledge, John Bates produced columns with which we could analyse organic acid mixtures, organic ester mixtures and ultimately both acids and esters quantitatively in the presence of each other.

When we had developed these methods, Roman who was Division Head of Chemistry at the time was to cause us a lot of unnecessary work. On his biennial visit to Arvida accompanied by Evan Jack, so that goose and duck shooting could be placed on the agenda, he was persuaded by their analysts that they should expand their reference analysis scheme, hitherto confined to pitch samples insofar as organic components were concerned, to lubricant analysis methods. The first candidate was John Bates' method for the simultaneous analysis of lauric acid and butyl palmitate/stearate in foil rolling lubricants. Their results showed that there was instability of the results obtained when the same sample was tested over a period. After swapping additive samples with them and still obtaining the same difference in performance, there was only one variable left: the base oil. Instead of obtaining this from Kingston, they had gone to the Hudson Bay Co. and bought kerosene which would normally have been for lamps and cooking, etc. We called it the "Eskimo cooking oil problem", implying no fault to the Eskimos but certainly to the other two parties involved. That was fortunately the end of the reference analysis idea. We still are unable to equate the cost of our man-hours to the value of the ducks and geese; this is left to the reader's imagination. Instrumental analysis methods now became more freely available. We also obtained a gel-permeation chromatograph with which to try to analyse the aqueous-emulsion hot-rolling lubricants used by our plants, but this was not successful despite the best efforts of John and Chris. Our aspirations were in advance of the equipment's capabilities. A Coulter counter, used in hospitals for blood corpuscle sizing measurements enabled us to study the size-range of oil droplets in hot rolling lubricant emulsions and how they are influenced by natural ageing during use by bacterial contamination and by deliberate additions aimed at reducing the breaking in time of new emulsions, or on the other hand, increasing stability should this become necessary.

But there were publications

Much of the technology relating to lubricants was written up in the form of Fabrication memoranda. These specifically excluded formulations and individual plant control procedures, in the interests of guarding this type of information and not assembling too broad a range of technology in one place. Rather we worked on the basis of providing documented information as relevant to the recipient. The exceptions to this rule included memoranda on filtration systems for hot and cold rolling lubricants; recovery by vacuum distillation; the Norf fume exhaust and lubricant recovery system; cold rolling lubrication with mineral oil lubricants; testing methods for the selection of cold rolling mineral oil lubricants; the use of inert atmosphere annealing furnaces; etc, most of which were written by Mike (in his spare time). Mike also wrote a manual on Cold Rolling Lubrication as part of the technology package sale organized by Reinhold Wagner in support of the Kubychev, Russia cold mill. In the 1970's. Mike helped Indian Aluminium Company to incorporate a lubrication R&D facility in their Taloja plant. As already mentioned, this involved specification of equipment, training of personnel in Banbury and commissioning on site, assisted by John Bates. Presentations were made by Mike to all local plants that could use the facilities. Also a review was written by Mike for and published by Indian Institute of metals on the current status of Aluminium Lubrication Technology at the request of Indal's MD: David Corbett-Thompson.

Where have all the flowers gone?

By the end of the 1980's Alcan decided that there was no further need for lubrication R&D because know-how was mature and adequate, so the work in Banbury (and Kingston) was run down and quickly ceased.

George Gardam, Roman Guminski, John Willis, John Bates and John Grosse are sadly no longer with us. Mark Foster and Chris Pargeter currently work for Innoval Technology, while Gian Frontini, Mike Budd, and David Moore have retired. The remainder left Alcan for pastures new.

Gian became Director of Alcan Engineering Services in Montreal and then Technical Director of Alcan Rolled Products Ltd; Mike became a Programme manager in Banbury in 1980 and transferred to Kingston in the same role for a 2-year spell in 1985 before a final spell back in Banbury as Operations Director. Mark's interest's broadened into foil conversion and thence into the forming lubricants used for the adhesively bonded components employed in aluminium vehicles.

All I can say in conclusion is: It was fun, or I wouldn't have done it; the Alcan family has been the source of much friendship and enjoyment and I loved working in both Banbury and Kingston. My wife did a brilliant job of bringing up our two sons, while teaching Biology to university entrance level while I was away helping Alcan plants, often for up to a quarter of each year.

9. EXTRUSION

Ian Calderbank, Bill Bryant, Roy Woodward & Steve Court

Although the hot extrusion of aluminium had been well established when Labs reopened after WW2 in 1946 and much work done to establish those engineering and metallurgical practices that had to be employed to ensure sound, economical material to be produced, it was recognised that more needed to be done. Work by George Forrest, Ken Gunn, John Alexander and Lionel Butler in the 50's went a long way to understanding metal flow in the press container and the die, by using billets which had been split and a grid marked on the inner surfaces, flow at several stages could be observed and measured. Also the way in which residual stresses in extruded sections were created and the means of avoiding them were studied and proved invaluable to users, particularly in the context of strong 2XXX and 7XXX series alloys required for aircraft production. In addition to those named above, Ray Durham played an important role. Some limited work was also done to look at the effect of conditioning the billet, including coating with glass but this proved to be of little use because of the poor surfaces on the extruded product.

After the merger of Alcan's strong alloy interests with those of James Booth Aluminium and later with the British Aluminium Company, Bill Bryant became almost entirely occupied with work on medium-strength extruded products, particularly 6000 series alloys. In this he linked with Ken MacLean's Fabrication Technique Division, with Len Howells, an experienced extrusion press shop engineer, and Les Steele, a Rogerstone D.C. casting metallurgist who had moved over to Alcan U.K, a London-based technical sales company. Alcan U.K. was one of a number of subsidiaries set up by Alcan to sell extrusion ingot and billet produced at the company smelters. As a legacy of WW2, the market for extrusion ingot was wide open because of the extreme housing shortage, so Alcan were assured of a ready demand for their "50S HO" extrusion billet, sold from all Alcan smelters in the as-homogenised condition from its inception in the mid-1950s until at least the mid-1970s. However, there were many different outlooks on the market according to the locality, including national, social and political history, geography and economics considerations. Labs involvement in this business was to be the scientific/technical view divorced from nationalistic or political. To hammer this home, it was decided that the best way was to present the technical facts as a metallurgical symposium. This was implemented under the general supervision of W. Gordon Barry, an Alcan: Kingston metallurgist, who had developed the concept of a starting billet of constant composition, structure and cleanness which could be relied on to produce the same result from one day to the next. This result was achieved successfully, proving the concept. Banbury Labs continued to work with Gordon, Carl Lynch of Alcan: Kingston and Les Steele of Alcan U.K. to carry out trials to demonstrate the quality and consistency of performance of "Alcan 50SHO" in Alcan owned extrusion plants and third party customers. Following the successful introduction of Alcan 50SHO the Labs metallurgists collaborated with the market teams and ingot manufacturers to grow Alcan's share of this lucrative market. Personnel from Research Engineering Division (Roy Woodward, Bill Bryant, Maurice Reynolds, John Willis, Nick Parson, Chris Jowett, Jeff Hankin), Surface Finishing Division (Ted Short, Peter Sheasby, Barry Ellard) and Physical Metallurgy Division (Tony Thomas, Sandy Davidson, David Evans, Brian Evans, Ron Elkington) became involved because Alcan wished to widen the scope of the Barry concept to medium-strength alloys of both Al-Mg-Si (6000 series) and Al-Zn-Mg (7000 series) alloys. The reason for Alcan's interest in 7000 series alloys was partly because the alloys are air-quenchable at the press (thereby reducing heat treatment costs), and also for their resistance to general corrosion, medium strength levels and good toughness – an ideal combination of properties for structural materials. However, at a European industry technical meeting, Bill Bryant heard woeful reports of stress-corrosion failures in Zurich tramcar couplings and other stressed engineering components in service in the U.K. Following this, development work was stopped and the approach was switched from Al-Zn-Mg to Al-Mg-Si alloys (6005 and 6005A), which could be regarded as a dilute 6082 alloy, with better extrudability and less susceptibility to peripheral coarse grain. This had to be evaluated against AA6261 alloy (Alcan D65S) which has a copper addition, not popular among European 6000 series alloy extruders because of scrap contamination. Later, in the 1980's and 90's Steve Court, Nick Parson, Hang Yiu and Jeff Hankin continued further medium/high strength alloy developments and demonstrated the usefulness of 6005A for high productivity with good strength and toughness.

At the same time, a significant amount of work was also carried out on developing high speed AA6060-based alloys for architectural applications, working closely with colleagues in NLM and in Alcan Brasil. In addition, specific effort was focused on understanding the effects of alloy composition and heat treatment on the performance of Al-Mg-Si alloys in automotive structural applications (eg, longitudinal crash members, side intrusion beams, etc.).

On the process side, much of the engineering development work for extrusion was aimed at improving productivity by increasing speed without sacrificing surface quality caused by localised melting at the die/aluminium interface. Because of the often complex extrusion section, die design itself had been much of a "black art" for many years and the die manufacture a highly skilled operation, usually subcontracted out to specialist manufacturers. In the early days of the laboratory, studies were essentially empirical concerned mainly with analysis of data from plant trials. People involved were John Willis and Alan Beurrier in the 1950's and 60's with David Jones joining from Alcan's Sales Development team in the mid 1960's, this time in support of Wally Bennett who had the responsibility for improving performance of Alcan's extrusion businesses worldwide. Much effort was made in working along with the manufacturers of die making machines and the die designers themselves. Chris Jowett also made a significant contribution to the understanding of the extrusion process before transferring to Kingston.

By the mid 60's, it was decided that, in order to study these and many other issues more fully, an experimental extrusion press would be needed and a decision taken to set aside a 1500 tonne press at Alcan Rogerstone which would be given first priority to research activities using sufficient loads to ensure steady state conditions. Sadly a variety of events including increased commercial needs for the presses, cost of such full scale work and not a little clash of beliefs between Laboratories and Works personnel involved, caused the concept to be abandoned after only a few trials.

David Jones and Mike Budd meanwhile were also involved together with universities and National Standard Co, with experimental use of the hydrostatic extrusion press owned by National Standard. In particular the possibility of producing aluminium wire clad with copper for electrical use was studied and, for a time, Alcan had used the press to produce aluminium sections for other end use. The very high production speeds and uniform structure, which resulted from a fully lubricated billet extrusion, seemed to offer advantages, but the project died by the early 70's.

Later in the 1980's, with the arrival of finite element and finite difference modelling and following initial work carried out in Kingston by Nouri Levy and Chris Jowett, attempts were made by George Macey and Jim Gow to understand better the metal flow through the chamber and die. The modelling was complex, attempting to predict temperature changes at the surfaces for different die design features associated with the basic components of extrusion sections. Model calibration was difficult because the thermal and flow effects being modelled were local in nature whereas instrumentation on the extrusion presses was only general. Attempts were made to obtain local measurement of temperature and eventually some success achieved. This led to further work on various techniques for cooling of the dies as a means to increase speed and productivity. George was also involved in transferring to the extrusion process knowledge gained from earlier modelling studies for hot rolling products, hot slab and strip cooling. Clearly the potentially more complex cross section of extrusions made for some difficult analysis but the modelling carried out in conjunction with the manufacturing company Bertin in France led to prototype quench units being developed.

In 1986 when Roger Fielding took over from Wally Bennett as Manager of Extrusion Technology for Alcanint, the models had been developed sufficiently to be used in a predictive mode and Modelling Memoranda were produced showing how dies could be modified to improve performance. The Fabrication Memoranda were also updated and made more relevant with Eric Wootton pulling together the various contributions from around the Group. During this time, Mike Johannes was seconded from Kingston to Banbury for a few years to build up the "extrusion team" and Richard Dickson transferred from his Mechanical Testing responsibility to help Mike in the now large scale activities taking place around the Alcan Group extrusion operations. A new extrusion press was also acquired for the laboratory to facilitate many studies including of course significant metallurgical developments. The Banbury process team was also part of an ongoing international effort to improve quality and productivity worldwide. A number took part in various plant technical audits and workshops, e.g., George Macey at the Hulett Die Shops and Steve Court to Aratu and Niigata in 1991. Although anodising is discussed elsewhere, it was an important downstream operation for the extruders and Ted Short and Robin Furneaux attended the NLM Finishing Review in 1992.

When Alcan sold most of its European extrusion operations to Hydro in 1986, the Banbury Labs effort was focussed on Japan, some of which involved Richard Dickson being located there for some months. Support of the Banbury works continued until 1996, when Alcan sold all of its U.K. extrusion, plate and speciality businesses to a management buy out team under the title of Luxfer Group. In due course, Banbury Works was re-sold to Alcoa, later in partnership with SAPA, but was closed down in 2007.

1972 Roy Woodward, in his role of Lead Division Head - a system being tried then to bring together the efforts of Banbury, Kingston and Arvida Labs – had drawn up the following Table of problems needing to be addressed at that time for consideration by Montreal.

Improve the casting speed of DC extrusion ingot. It is believed that at least 50% increase can be achieved.

Improve the quality of DC extrusion ingot to meet production and market demands (this involves development of filtering and degassing systems).

Identify factors in the ingot and the die which control extrudability of 6063 and other alloys, so that the maximum speed through the die can be achieved and still maintain the required surface finish.

Modify casting processes and/or alloy composition to enable homogenization to be carried out with optimum efficiency.

Find out how to avoid or reduce die corrections. Improve die design methods to give best shape/surface and finish/speed combinations.

Develop a modified medium strength alloy composition/quench system which will allow extrusion at high speed with adequate surface finish.

Develop further and apply the necessary instrumentation to ensure that the extrusion process proceeds with maximum efficiency.

Find out how to extrude thinner and wider sections than can be produced at present, in order to maintain or increase market penetration.

Over the next two decades, the people mentioned above, working in co-operation with their colleagues at the Kingston and Arvida Labs and the technical personnel of the main extrusion plants, achieved considerable success in improving the performance of the extrusion business but all or at least most of the items identified then as needing effort were still being studied when Labs finally closed (Emeritus January 2004 article).

10. THE ELECTRON OPTICS STORY

Mike Wheeler, David Moore and Mel Ball

"*A picture is worth a thousand words.*"
Napoleon Bonaparte

Introduction

By the 1950's, the limitations of conventional optical metallography in determining the microstructure of metals, particularly aluminium alloys, had become abundantly clear. However, it was known that the subtleties of microstructure, most significant to mechanical properties, are extremely fine and well beyond the resolution of the optical microscope. Coarse impurity particles (iron and silicon-rich) could be seen as could the grain size but not the dislocations and fine precipitates that are now known to be critical in controlling strength and deformation behaviour. At that time around 10% of our available time in Labs. was being spent on sample preparation, mounting, polishing and, if necessary, etching them, then examining them on a microscope before selecting appropriate areas that were then photographed onto glass plates as negatives. The last step was the development, enlargement and printing of the photographs. This photographic stage alone required two full-time staff who were permanently engaged to do this job. Therefore, we required not only much more powerful tools for studying metallography and to identify the chemical nature of different regions, including inter-metallics and inclusions, but a procedure that would be much less time consuming. The development of the electron microscope appeared to offer us an opportunity to achieve this.

During the next thirty years both our research and development and technical support programmes were to cause a major increase in the range of electron-optical techniques available in the Banbury and Kingston laboratories. As they became available on the market, so we identified how they could be applied to drive our work forward and when we could justify their purchase, we acquired them. Applications of these instruments was not confined to metals as mentioned above, but included non-metals, surface behaviour and coatings which in turn led to the development of new products and technologies. The more significant of these are described in the next chapter. All together this work spanned fifty years.

Here we propose to describe our work chronologically, because both it and its application were closely associated with technological progress made in the second half of the 20th century. The present chapter will therefore describe the range and applicability of the techniques adopted by us, while the following one will describe how we used them in Banbury to further our understanding of new technologies as well as established ones. Now we will return to our starting point::- the examination of aluminium and alloy samples

The management of Aluminium Laboratories during the 1950s supported, and indeed encouraged, what was essentially basic research in aluminium behaviour - and the advanced techniques that were necessary to break new ground in support of that research. Banbury was as capable as any university department in the physical metallurgy arena and close collaboration was maintained with the universities and technique developers. Probably the greatest support and pressure for progress came from the defence industry, particularly the Ministry of Aviation (M of A) and that part of Alcan servicing it. Britain still had a large defence industry and aerospace/defence was still big business for Alcan, in the UK at least. The M of A was most interested in getting ever higher strengths from heat-treatable alloys, such as Al-Zn-Mg, but also in overcoming the serious problems of stress-corrosion cracking and fatigue to which the high strength alloys were susceptible. Aluminium armour plate was becoming big business with the new AFVRE vehicles (Scorpion, Fox, Stalwart etc.) and other military hardware such as forgings for torpedoes. A more detailed understanding of the microstructure was critical to further progress. As well as this research-orientated activity, there was a great need to be able to "see" and analyze the small features of the general purpose alloys produced by Alcan Industries and the products of its customers.

The First Instruments; Installation and Initial Applications

The first electron optical instrument that was obtained by Banbury Labs was to satisfy this broader need and was an immediate success. It was not an electron microscope, but an electron probe microanalyser. The "probe" came from Cambridge Instruments Ltd. and was delivered in 1962.

Henry Lamb operating the early Electron Probe Microanalyser

X-ray microanalysis is based on the fact that when a high energy beam of electrons hits a surface, atoms will be ionised and X-rays will be generated, some of which have wavelengths (and therefore energies) which are characteristic of the elements present. Using crystal spectrometers, the specific wavelengths for elements of interest can be selected and the X-ray pulses can be counted. The "probe" incorporates several high precision crystal spectrometers, which can be individually "tuned" to select different X-ray wavelengths, so that the concentrations of each element of interest can be determined.

Its first and always operator was Henry Lamb, while Mike Wheeler was in charge of the so-called X-ray section in which it was located. Now, it was possible to "see" the microstructure in an eerie greenish light on the phosphor screen and "scan" for any element "heavier" than sodium in the periodic table and take a polaroid picture of the elemental distribution. Inclusions could be identified – titanium di-boride streaks in Hoover washing machine and spin-dryer lids and Joseph's bright anodized coffee pots; and oxide films or bits of furnace lining in other products. Les Steele, Herbert Chadwick and Harry Taylor in the UK were regular and impatient customers. There were also requests for work, sometimes very urgent from colleagues in Kingston and Arvida laboratories and the Alcan General Metallurgical Department (GMD) in Montreal. So began the library of defects that became a Fabrication Memorandum. (Fabrication Memoranda were written for the benefit of the technical staff in Alcan's fabricating plants around the world. Their authors were acknowledged experts in the subjects covered, many of them resident in the Laboratories in Banbury and Kingston. The memoranda were treated as highly confidential documents.) More detailed work showed the different types of AlFeSi intermetallics that caused the "fir tree" effect in anodized sheet; composition gradients in ingots, showing the efficacy of homogenization or the effects of heat treatment in sheet. The probe became a general workhorse, used full time until it was given to the University of Aston in the mid 1970s. A new probe was bought at that time and continued in service until it was eventually replaced in the 1980s by a more modern instrument with much improved imaging capabilities.

The first transmission electron microscope (TEM) at Banbury arrived later in 1962. It was a Siemens Elmiskop 1A, operating at 80kV, a wonderful instrument. Mike Wheeler with John Clare had wisely selected this instrument over the competing Dutch Philips and British AEI models. Alcan was one of only three industrial companies in Britain to operate electron optical equipment at that time – British Steel in Rotherham and Tube Investments (inc. British Aluminium) in Hinxton Hall being the others. The resolution of the optical microscope is limited by the wavelength of the natural light by which the sample is viewed. A beam of electrons however, generated by a tungsten filament energized to a high voltage, say 80,000 volts (80kV), has a wavelength many times smaller. Provided that the electron beam can be controlled, focussed and observed we now had a means for observing far smaller features. Magnifications of 20,000 times and more now become possible compared with, say, 500 times for a good optical microscope.

The Siemens Elmiskop operated by Gunnars Blankenburgs

The transmission electron microscope opened up a "new world" of microstructure. Dislocations, sub-grain boundaries, fine incoherent and coherent precipitate particles could all be observed and investigated. This, sometimes strange and exotic world, was both interesting and fascinating and keen microscopists would often spend many hours searching and exploring to understand the changes which occurred in different alloy systems during metal fabrication. One of the challenges in all microstructural studies is that observations are restricted to very small specimens. A typical modern day ingot or coil in a rolling mill could weigh in excess of 20,000 kg., whereas the typical region observed in a TEM is generally only a few milligrams. With this in mind, it is always important to select and prepare samples very carefully and also to make efforts to ensure that recorded observations are as representative as possible. Generally this means examining many samples and building up experience of what would constitute a "typical" region of the material and what might be an isolated feature.

Although hard temper, cold worked materials have such a high dislocation density that the images resemble confusing black tangles, samples which are partially or fully annealed, or only lightly cold worked can be usefully studied. Fortuitously, the heat-treated alloys in the W or T6 condition are essentially re-crystallised and make for perfect viewing. Given the aforementioned interest from the aerospace people, the Al-Zn-Mg alloys were first on the list to be studied. Peter Thackerey and Harold Holl, led by Tony Thomas made immediate progress in seeing the tiny precipitate particles of MgZn2, only a few nano-meters across that give the age-hardening strength to these alloys. The effect of grain boundaries, impurity particles and dislocations on the age- hardening process was ground-breaking work. Whereas the universities, such as Cambridge, were studying super-purity versions of these alloys, the iron and silicon impurities and the "real" deformation and heat treatment conditions that we were familiar with were found to be very significant in understanding alloy behaviour. One special attribute of the Siemens instrument was that a small aperture could be used to select an area of interest or an individual particle and a diffraction spot pattern obtained. From this the crystal structure of the particle could be determined and the particle identified (David Munson).

All of this work, in parallel with the efforts of Maurice Reynolds, led to the development, with the plants – by now including Kitts Green with Peter Band - of much improved plate alloys such as 7010.

Preparing specimens for the TEM was a difficult and tedious affair – samples had to be thinned down, without any deformation, to about 5 nanometers in thickness in order that the electron beam could pass through to the viewing phosphor screen. Gunnars Blankenburgs set up the initial jet electropolishing method but George Tatam became the virtuoso specimen maker using this technique. George also worked like a beaver developing all of the glass photo plates that were produced, logging them, marking them with indelible ink and filing them. There were thousands of them within a few years – when they were archived or destroyed, as appropriate.

Because high voltages generate X-rays, all of us using these instruments had to go to Banbury's Horton General Hospital every quarter for blood tests to see that our blood count was not affected by any stray irradiation. The Horton used to delight in giving this job to the newest nurse". This is the first time I've done this" was so often heard! As a further precaution, X-ray sensitive film badges were also provided to staff working in the electron optics and X-ray labs. Fortunately, the results of all these tests were negative.

The Expansion of Applications

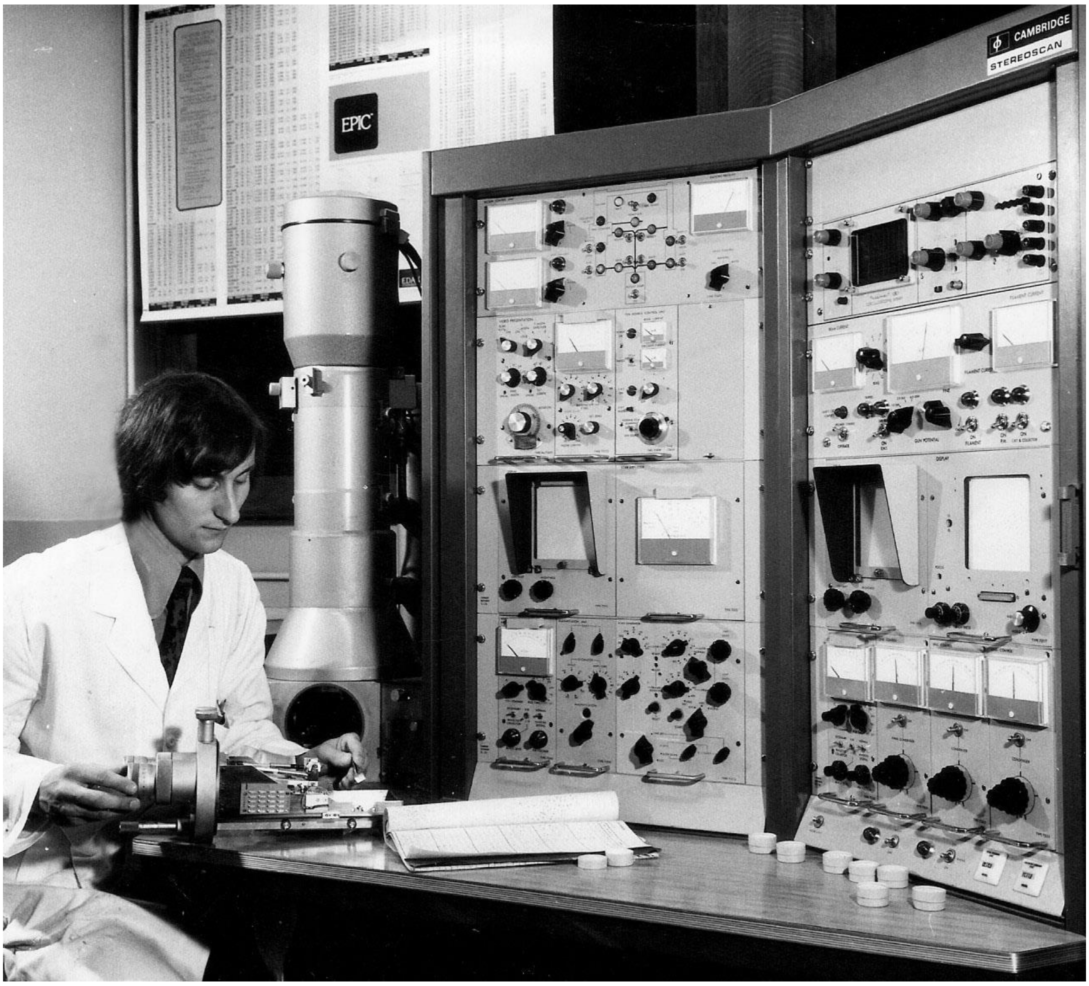
The TEM story continued with David Moore being given the task of studying the Al-Mg-Si alloys – led by Tony Thomas again and with strong linkage to the work of Paul Fortin in Kingston. The interest in the 6000 series – or 50S, 51S and B51S as we called them, still using the Alcoa codes from Alcan's erstwhile parent, came from the extrusion side of the business. Brittleness of 51S (ladder and scaffolding failures!) versus the quench sensitivity of B51S was Bill Bryant's concern; the TEM revealed the roleplayed by small manganese particles in causing quench sensitivity but also their ability to "stop" and diffuse deformation bands in getting to the grain boundaries. The better solution would have been to use the North American-favoured alloy 65S – but this contained a whiff of copper – anathema to Europeans, especially Germans, possibly because of the disastrous use of remelted scrap aircraft Al-Cu-Mg alloys right after the war for school roof trusses, which promptly corroded and failed.

David continued TEM work on these Al-Cu-Mg aircraft alloys when it was announced in 1968 that there would be a Super-Concorde needing even higher temperature resistance skin and structure than the RR58 alloy (Rolls Royce code this time – from the first world war!) used in the "conventional" Concorde – yes, it was that long ago, 1962, that Concorde was designed. The more advanced aircraft was soon dropped as had been the TSR2 and the supersonic Harrier – and so went much of the aircraft industry courtesy of Mr. Harold Wilson. The legacy of the TSR2 is the fields of yellow rape crops disfiguring our landscape each spring, another story, another of Wilson's decisions, but not relevant to this history.

Although in many cases, the interpretation of image features such as inclusion particles and grain boundaries is reasonably intuitive and similar to optical microscope images, in other cases, the peculiarities of electron diffraction and scattering produces unusual contrast effects. For example, the dislocations, which play a major role in material deformation, are visible in the electron microscope because of the local distortion of the crystal lattice and the resulting change in diffraction which occurs. There was one memorable occasion when Phil Morris was outlining some of the work he had been doing to characterise the changes which occur during cold rolling. His study showed that during the early stages in lightly deformed metal, a relatively low density of dislocations is generated. In samples with a higher cold reduction, the dislocations begin to interact, tangle and develop into a cellular network. George Stanford, the deputy lab director at the time, had been listening with mild interest to Phil's presentation but at one point he suddenly leaned over the desk to carefully examine a particular image. "That looks like an upside-down monkey!" he exclaimed, to the great amusement of the others present. There then followed a heated, in-depth discussion of the different features in the "monkey" image where the tangled dislocation networks clearly did resemble the head, arms and legs of a very hairy primate. Needless to say, the conversation eventually reverted to the business of the day and the development of dislocation substructure during fabrication.

The next, and very important, step in the electron optics saga was the arrival in the laboratory of the Scanning Electron Microscope (SEM). The Cambridge Instruments Stereoscan 2A had been selected by Mike Wheeler before he left for Kingston but it was not installed until just after he left in 1971. In the SEM, electromagnetic coils scan a focused, high energy beam of electrons over the surface of a sample causing ionisation and the emission of secondary electrons. A special detector collects these electrons and feeds the resulting signal information to the display monitor where a magnified image of the surface appears.

The SEM was an instant hit – not only for showing the mandatory fly's head at 1000x magnification – all visitors wanted to see that – but also for being able to look at almost any object at great magnification and depth of focus. The sample chamber could accommodate relatively large samples, and in most cases very little specimen preparation was required.



Martin Amor operating the Cambridge Instruments Stereoscan 2A Scanning Electron Microscope

In due course, SEM users became very familiar with the differences between ductile, brittle and fatigue fracture surfaces and the characteristics of different types of corrosion. However, the first task was requested by Eric Wootton and was to look at the pick up in the can making D&I process simulator (see Alec Lovell et al's chapter). We were only able to tell him that it was aluminium and aluminium oxide which wasn't much help! The D&I story eventually moved to Alcan Aluminumcorp and Kingston whence the mechanism of this form of pick-up was resolved, as many millions of tons of 3004 can testify. The next customer was George Runnels – from the front GMD office. George specialised in foil manufacturing in Ken Maclean's Fabrication Technique Division. At that time we had eight foil-rolling plants in our area of responsibility, with several more in prospect. So George wanted to understand how rolled surfaces developed, particularly on foil, and how they might be made more uniform and defect-free. This led to major advances in understanding hot mill pick up and the mechanisms of lubricant/surface interactions in hot and cold rolling.

Another somewhat unexpected customer came from across the water; Arvida Labs wanted to know more about the mechanisms of alumina precipitation. With them we were able to show how the tri-hydrate crystal form changed with operating conditions and thereby improve the productivity of the alumina plants in Canada and Jamaica. The SEM also proved to be very versatile in looking at pre-treatment and paint layers. We looked with some dismay at the first laminated plastic toothpaste tube in the early 1970s – with about eleven layers of various plastics and one tiny, ultra-thin layer of aluminium compared with the good old impact extruded solid aluminium tube!

New Staff and Second Generation Equipment

In the early 70's, significant changes were occurring throughout Alcan and these had implications for the R&D system. There was a belief at the time, that new products and processes would be essential for the future success of the company and that the mandate of the laboratories should reflect this. It was a time of substantial change in Banbury. A number of new researchers was recruited, and new equipment was also being considered. Over the years, the Banbury Research Centre, had established strong links with key university departments, and this proved to be valuable in attracting and retaining some talented scientists. By this time, electron microscopy had become a key research tool for most University materials science departments, and many of the new recruits were experienced users of these instruments. This was also a time when rapid advances in microscope performance were taking place.

By the end of 1974, the decision to replace the ageing Elmiskop 1A had been made, and Phil Morris, Mel Ball and others were evaluating the latest generation of instruments. Although Siemens were still in the business, both Philips and JEOL had become well established, with some excellent new instruments. These microscopes incorporated a much more versatile lens system, and the mechanical alignment and pole-piece changes required in the Elmiskop 1A had been largely superseded by the use of microprocessor- controlled lenses and electromagnetic alignment coils. Instead of reaching up to tweak mechanical lens alignment controls to guide the electron beam, the operator was now able to adjust deflector coil currents very precisely and easily using control knobs. Other major improvements included the incorporation of additional lenses to extend the range of magnification from less than 100x at the lower end to over 100,000x in the high resolution mode. With different lens settings, the electron diffraction capabilities were also extended to allow a wide range of effective “camera lengths” (different magnifications of the diffraction patterns). Special double-tilt specimen holders allowed for a much greater range of tilt about the two principal axes, and this could be important for studies of, for example, the crystallographic orientation of grains or sub-grains.

A very important new development during the early 1970s was the incorporation of X-ray microanalysis into the TEM. In the late 1960s, liquid nitrogen cooled “energy dispersive” X-ray detectors were developed and introduced. In this case, X-rays arriving at a very small solid state detector cause ionisation, which can be captured as an electrical pulse. Different X-ray wavelengths have different energies and cause different amounts of ionisation. Each energy will give rise to a characteristic pulse, corresponding to the characteristic energy of the ionised element. With these detectors, most of the X-ray lines could be collected simultaneously, and displayed to give a rapid visual indication of the main elements present. Quantifying the data was a much more difficult exercise. Low energy X-rays from the lightest elements below Na in the periodic table could not be detected at all since they were absorbed by a thin beryllium window over the detector. Peak intensities were also affected by various absorption and fluorescence effects, and overlapping peaks in the collected spectra also complicated quantification. Nevertheless, the ability to detect key elements from submicron regions and get an estimate of concentration was a major step forward. The first use of this type of detector system in the lab was for the SEM and it quickly proved itself invaluable, in large part due to the efforts of Sandy Davidson.

With all these new developments, the selection of a new transmission electron microscope was not a trivial exercise. Over a period of several months during 1975 there were numerous meetings, often in cigarette-smoke filled rooms, to discuss instrument specification details. As the evaluation progressed, there were also visits to demonstration centres to evaluate the leading contenders. Several competing X-ray microanalysis systems had also to be evaluated.

Towards the end of this exercise, JEOL announced the introduction of a significantly improved "scanning" unit, which provided some additional capabilities. This tipped the balance in favour of the JEOL, JEM 120C microscope and the decision was finally made. Based on experience with the X-ray microanalysis system on the SEM, Link Systems, based in High Wycombe, was selected as the supplier for a system for the new TEM.

In the months that followed, there was frenzied activity in the lab to prepare and test a room for the new microscope. It was early in 1976 when the new microscope finally arrived and very quickly became a key part of many research project activities. The new microscope room was comparatively spacious and soon became a frequent stopping point for visiting customers or colleagues. This was especially true in the hot and humid days of summer when the air conditioning units made it one of the more comfortable locations in the lab.

In 1980, a similar exercise was carried out to replace the original Cambridge Instruments SEM. This time the chosen instrument was a newly developed ISI DS130 SEM. This microscope had two specimen chambers: an upper chamber which could only take small samples but had very high resolution capability, and a large lower chamber for bulkier samples. By this time, Martin Amor had become the principal SEM operator and was routinely able to get outstanding images.

As with all new instruments, there were new techniques to learn and develop and calibration experiments to perform. This was well appreciated by the management of the time, and although ongoing business support work was always the main priority, the development of new skills and techniques was also well supported. While the basic operation of the new TEM was, in many ways, easier than with the Elmiskop 1A, the increased versatility and new capabilities required some additional training and practice. The demand for time on the new microscope was such that a booking system had to be rigorously implemented and coordinated with the specimen preparation requirements. Typically, users were limited to two half-day sessions per week, although some "horse trading" was always possible. There was also a significant amount of use after hours when the need arose.

The Implementation of the New Instruments

- Casting and Solidification

Armed with a “state of the art” analytical TEM, a microprobe analyser and the SEM, the Physical Metallurgy group under the guidance of Alan Harding, Tony Thomas and Dick Jordan, was now well positioned to support most of the ongoing projects and new initiatives. One area of activity which benefited from these new capabilities was casting and solidification. Studies of the distribution of alloying elements during solidification, and the changes which occurred during subsequent homogenisation heat treatments could now be explored. Phil Enright and Ian Hughes devoted some considerable effort to developing an understanding of the mechanisms of grain refining and the role of titanium di-boride additions. Although the chance of actually finding the nucleation site of a new grain is very remote - “the needle in the haystack problem”, by studying the grain refiner hardener additive, some clues about the mechanism could be extracted. Of particular interest here was the close relationship between the crystal spacings on specific facets of the TiB2 crystals and the aluminium lattice spacings. It is this lattice matching which facilitates the nucleation of a new aluminium grain during the solidification process.

Another significant area of work in the solidification group was the development of the continuous belt caster. By casting thin continuous strip, ingot scalping, homogenisation heat treatment and a major part of the hot rolling process associated with conventional fabrication are eliminated. All these factors affect the surface and the internal microstructure and performance of the resulting product. An objective of the project was to try to adjust alloy compositions and processing conditions so as to match as closely as possible, the properties and performance of the conventionally cast products. However it was also recognised that there might be opportunities to exploit the process differences for new products. In all these activities, the new electron optics capabilities, along with the more traditional optical metallography, provided key supporting data.

- Fabrication

As noted earlier, electron microscopy was already contributing to the understanding of the various fabrication practices. For key alloy systems, the homogenisation heat treatments, hot rolling, cold rolling and annealing processes were all being explored. In the late 1970s the annealing practices and the factors controlling re-crystallisation and grain size, were subjected to detailed investigation. Elements such as manganese, chromium and zirconium were known to be useful in achieving a desirable fine grain size, and the ability to study the precipitation and substructure of alloys containing these elements resulted in a much improved understanding of the important roles they played. In the 3xxx series manganese-containing alloys, the coarse AlFeMnSi particles which form during the casting process are much harder than the aluminium matrix, and during rolling, higher local deformation around the particles is induced. These sites, with the higher stored energy, then act as potent sites for new grain nucleation during annealing heat treatments. As the heat treatment progresses, the cellular dislocation structure produced during the cold rolling, develops into a fine sub-grain structure which is pinned by a dispersion of fine sub-micron manganese containing precipitates. These particles act as obstacles to slow down the movement of boundaries by a process known as Zener drag. This allows time for more new grains to nucleate and the result is a finer grain size. It should be noted that during the course of this work there was close collaboration with Kingston Research Centre and with University contacts. David Moore, who had by this time transferred to Kingston, was working with Larry Morris and Harry Sang at Kingston Research Centre and they developed a new class of particle stabilised ultra-fine grain sized alloys, referred to at the time as "255 alloys". These alloys had an interesting and useful combination of formability and strength. There was also close interaction with the NKK laboratory in Kambara, Japan, and in 1978, Phil Morris started a two year secondment to expand this collaboration. During his stay, an inter-laboratory meeting on "Re-crystallisation" was organised with attendees from Kingston, Banbury and Kambara.

A high profile project at Banbury at that time was the rapid, continuous annealing of rolled sheet by a process known as "Transverse Flux Induction Heating". This was a system developed in collaboration with the Electricity Research Council laboratories in Capenhurst, Cheshire. Achieving uniform heating across the width of the strip was a major engineering challenge, with the strip edges being of particular concern. Metallography and electron optics techniques provided an essential support function for this work. As a result of the much faster heating rate and shorter annealing time, the microstructure of the annealed sheet differed significantly from the conventional, coil annealed product. Typically, there was less time available for precipitation of alloying elements, and a much higher rate of grain nucleation, leading to a finer grain sized material. While this provided opportunities to produce sheet with different combinations of formability and strength, most of the development effort at the time was devoted to finding ways to adjust the alloy compositions to try to match established product specifications. A "Transverse Flux Induction Heating System" was eventually installed and successfully operated in Japan at the Nagoya plant of NKK.

High strength Materials

Our work on Al-Zn-Mg alloys and Al-Li- Cu alloys is adequately covered in the relevant chapters of this document. The recently acquired TEM was the principal technique used to study potential failure mechanisms.

- New Challenges and New Techniques

There were many projects where the establishment of a suitable sample preparation methodology was a necessary part of the investigation. The standard jet electro-polishing method could produce good quality specimens from most metal samples quickly and efficiently using a 3mm diameter disc as the starting point. However, there was often a need to examine the microstructure of thin sheet or foil in cross section, and this was much more tedious and challenging. There was also a growing interest in studies of the near surface and surface regions of materials and a particular interest in surface treatments such as anodising and pre-treatments for painted sheet.

Ion-beam thinning or milling, uses an energetic beam of argon ions to erode the surface of a material and gradually thin it to a point were it can be studied by transmission electron microscopy. At the initiative of Sandy Davidson, Banbury laboratory acquired an ion mill manufactured by Ion Tech Ltd of Teddington. It incorporated two focussed ion guns so that both sides of a thin disc sample could be eroded simultaneously. While this machine opened up some new areas of study, it was a very slow and tedious process and a typical specimen could take many hours to prepare, with no guarantee of success. One of the first successful applications of ion milling was for studies of anodic film structures, where the nano-scale porous oxide and barrier layer details could be examined and characterised in both planar section and in cross section.

The Surface Technology Chapter's section on Anodising describes studies made of both anodic film structure and colouring using metallic pigments. The TEM was the technique of choice and specimen preparation was a critical step. However, with the electro-polishing methods, the ion beam thinning equipment and the ultra-microtome, almost any sample of interest could be prepared for transmission electron microscopy. However each method had advantages and limitations and a key part of any investigation was the careful selection of the appropriate method.

Quantitative Methods and Microstructure Modeling

The new TEM, combined excellent electron diffraction capabilities and X-ray microanalysis with outstanding imaging performance, and this provided opportunities to explore aluminium alloy microstructure in much more detail than before. However, many of the techniques were still in the development stage and the team at Banbury played a significant role in their improvement. The need for more quantitative compositional data from sub-micron features was a particular area of interest. The microprobe had demonstrated the value of quantitative analysis in a wide range of applications but was always limited to features or regions of a few microns in diameter. This was due to the fact that when the focussed electron beam hits a typical sample, it penetrates a few microns into the surface but is scattered to generate X-rays from a "pear shaped" volume several microns across and the measured composition is the average over this volume.

In the case of a very thin TEM sample, and a higher energy electron beam, the electrons pass through the specimen with very little scattering, so that the analysed volume is only slightly larger than the electron beam spot diameter. The typical spot size for microanalysis in the TEM can be less than 0.1 microns, so features such as sub-micron precipitate particles can easily be analysed with very little contribution from the surrounding material. Phil Morris and Mel Ball, in collaboration with the Link Systems group and some university contacts, were able to establish procedures and standards for calibration of the detector system and for processing the raw data to extract useful compositional data.

The study of the "earing" of rolled aluminium sheet was an example where the micro-diffraction capabilities of the new TEM were made full use of. Earing is the tendency of rolled sheet to deform in a non-uniform way so that during the deep drawing of a cup, or the drawing and ironing process used in can making, ripples or "ears" form around the top edge of the cup and have to be trimmed off and scrapped. Some time earlier Gerry Tucker had carried out a series of experiments using carefully produced single crystal sheet samples and showed that the earing behaviour was due to the sheet stretching more easily in some crystallographic directions than in others. The normal rolling process is anisotropic, with a significant elongation along the rolling direction and a concomitant reduction in thickness, but with the sheet width remaining virtually the same. With these differences, it is not too surprising that some directionality develops in the mechanical properties and the subsequent forming behaviour. X-ray diffraction studies showed that rolling and annealing processes both affect the crystallographic orientation distribution within the sheet, so that certain crystal orientations are preferred. The ability of the new TEM to examine the sub-grain microstructure and to obtain diffraction patterns from regions of only a few nanometres in diameter, provided an opportunity to study the individual sub-grain orientations, and the mis-orientations at the boundaries, in much more detail than before, in the hope that this would lead to a better understanding of the factors which control the development of certain preferred orientations and suggest strategies to minimise the resulting earing behaviour.

As it turned out, collecting the diffraction patterns in the TEM was the easy part of the problem. The analysis of the diffraction patterns to extract good, unambiguous orientation information was much more challenging. At the time, Gerry Tucker headed the "Mathematics" group at the lab and was responsible for the main frame computer. With his crystallography background and in collaboration with Phil Morris, a program was developed to determine crystallographic orientations from TEM diffraction data. However, for each diffraction pattern, careful measurements of the spacings and orientations of diffraction features were required, and this was very time consuming. Typically, 25 or 30 diffraction patterns could take several hours to measure, and so, although the technique was successfully demonstrated, it could only be considered for very limited applications.

This is an early example of the use of computers in microscopy. X-ray microanalysis was another area where computers were an essential part of the operation, both in the collection and processing of the data. In the early 1980s, an image analysis computer system was acquired. This machine was designed to acquire and digitise images, and then process the resulting data to extract and quantify, for example, particle volume fractions, numbers, sizes and size distributions. Initially, the Image Analyser was primarily used with an optical microscope, but other image data could also be digitised and quantified as necessary. In the years which followed, the rapid advances in computer speed and capabilities, and a continued refinement of the instruments have led to widespread use of these techniques.

Professional Association and Inter-Laboratory Involvements

The importance of electron microscopy and related techniques has been well recognised within the scientific community, and professional bodies in the UK, such as The Institute of Physics, The Royal Microscopical Society and The Metals Society were very active, organising meetings and conferences on a regular basis. Banbury Research Centre was well represented at these meetings, with many papers being contributed on a variety of topics covering both the technique development work and the applications of electron microscopy in the aluminium industry. The monthly meetings of the local branch of the Metals Society were generally held in Oxford, and a group of people from the lab would set out after work in a couple of cars to attend them. The "Modern Metallography" conferences were full day meetings held annually at different Universities. This was a very popular series of meetings and encouraged the early reporting of work in an informal setting. The Institute of Physics had established an Electron Microscopy and Analysis Group (EMAG) and organised a series of one day meetings on specialised topics. They also organised an annual three day conference with published proceedings which attracted several hundred attendees. These meetings also included an exhibition area, where the scientific equipment manufacturers could display and demonstrate their latest developments. In addition to the formal sessions, these meetings provided valuable opportunities for informal discussions with other scientists working in similar fields. Many useful contacts were established and maintained in this way.

In the spring of 1979, a two day inter-laboratory meeting on "Electron Microscopy" was held in Kenilworth, not far from Banbury. About fifteen people attended altogether including David Lloyd who was working in Banbury on a two year secondment from Kingston. Tom Malis and Helene Lagace also attended from Kingston. Interestingly, an invited speaker at this meeting was Paul Butler, who was at Imperial College at the time, and who would later join Banbury laboratories, eventually to become director at Kingston Research and Development Centre. A similar inter-laboratory meeting was held the following year at Chaffeys Locks near Kingston on the topic of “Surfaces and Surface Characterisation”. These meetings helped to build and maintain good working relationships between research workers at the two laboratories, and facilitated the exchange of ideas on methods and techniques as well as supporting some collaborative project activities.

Involvement in a New Generation of Alloys: Alcan’s Automotive Programme

AA5182, an aluminium magnesium alloy, was quickly identified as the leading candidate for structural bodywork, but because of the surface roughening which occurs when this alloy is formed, it was not suitable for outer panel components. For these applications, alloys of the AA6xxx series were favoured. These alloys rely on age hardening to achieve the desired mechanical strength, and optimising the alloy composition and heat treatment processing required a significant research effort. Electron microscopy was one of the key techniques used to support this development work.

Another of the many hurdles to be overcome when using aluminium alloys for car body manufacture was the joining. Although welding of aluminium, by the MIG or TIG methods, was well established, it was more demanding than the industry standard methods of steel welding. Banbury pioneered the use of structural adhesive bonding for the car body application and eventually, a process combining spot welding with structural adhesive bonding was adopted for a new generation of high performance Jaguar cars. The detailed surface preparation, pretreatments, spot welding and painting processes were primarily established with the support of surface analytical techniques such as ESCA (Electron Spectroscopy for Chemical Analysis) – now more commonly known as XPS (X-ray Photo-electron Spectroscopy), along with SEM and microprobe analysis. The automotive work is dealt with in detail in the relevant chapter.

The End Game and Postscript

Throughout the1980s and 1990s, electron optics continued to play a major role in Banbury. During this period, Andries Bosland was coordinating the activities and making sure that equipment was maintained and replaced when necessary. One of the most significant new instruments which arrived at this time was the Field Emission Gun SEM (FEG – SEM). Conventional SEM’s use a heated tungsten filament to provide the source of electrons but in the FEG-SEM, a specially sharpened tungsten tip is subjected to a very high electric field, which causes an intense beam of electrons to be emitted. The high intensity of electrons from a very small point source results in almost all aspects of SEM performance being enhanced. In the FEG-SEM, very high resolution imaging is combined with much faster X-ray microanalysis. Crystallographic orientation measurement and mapping is also speeded up considerably. This improved performance and speed both increased productivity and enabled more systematic and statistically significant measurements to be made. Thanks to the efforts of the Banbury team, suitable operating practices for many of these techniques were established and this experience proved to be of great value when the FEG-SEM was eventually moved to Kingston after the Banbury laboratory closed.

Over the years, dramatic improvements in computers had also increased the capabilities of all the electron optical instruments, and the often ”hand-waving” interpretation of images was being superseded by quantitative image analysis, more precise compositional information, high quality crystallographic data and orientation maps. The growth in the automotive sheet business continued to be a major activity, but significant efforts were also devoted to some developing technologies such as spray casting and super-plastic alloys.

When Banbury Labs was closed, besides the equipment transferred to Kingston, some was also transferred to Neuhausen; this is now a Novelis story. However, electron optics within Rio Tinto Alcan is still alive and well…..in Voreppe! Roy Woodward once said that Alcan Labs “boxed above its weight”. We certainly did in electron optics and alloy development.

One final curiosity – there must be something about X-rays and electron microscopes that drives people westward. Kingston is now the home to Mike Wheeler, David Moore, Mel Ball, Phil Morris and David Lloyd!

Footnotes

1. In 1986, Ernst Ruska was awarded the Nobel prize for Physics for his pioneering work on the development of the electron microscope. Most of this work was started in the 1930s with his development of magnetic lenses for focusing beams of electrons. This eventually led to the construction of the first prototype microscope. Working with Siemens, he played a major role in the development of the Elmiskop 1, the first commercial transmission electron microscope. Launched in 1954, this was an immediate success and opened up whole new fields of study, initially in the life sciences and medicine, but materials science applications soon followed.

These first microscopes incorporated an electron gun to generate a beam of electrons, which was then accelerated and directed down though a system of apertures and electromagnetic lenses. As the beam of electrons passes through the thin specimen, it is scattered or absorbed by the sample material and the resulting beam is then magnified, focussed and projected onto a fluorescent screen to reveal an image of the internal structure of the sample area

2. Richard Hartree was director of Banbury Research Centre from about 1972 until 1979 It is interesting to note that his father, working in the Cavendish laboratory at Cambridge University had made an important contribution to the understanding of atomic structure. The Neil's Bohr model had successfully explained the energy levels of the simplest atom, hydrogen. Hartree and co-workers were able to extend that model to take account of the interactions between electrons in other atoms and to calculate the expected energy levels. It is the transitions between these energy levels which give rise to the X-ray signals used for microanalysis.

3. Before his appointment as Laboratory Director of the Banbury Research Centre, Jeff Edington, had been a highly accomplished electron microscopist, with extensive publications including at least one series of text books on the subject. Other senior managers who were also appointed after distinguished contributions to electron microscopy include Paul Butler and Ricky Ricks.

David Moore, Phil Morris, Mike Wheeler, Mel Ball, Dave Lloyd in Kingston.

11. SURFACE TECHNOLOGY

Introduction

Understanding Surfaces involves a number of inter-related and quite major studies including topology, chemical composition of both the surface and any sub-surface likely to become exposed or subject to reaction during its use, and the applicability and use of state of the art electron optical and computer-controlled physical techniques that allow quantification of surface attributes to be made. These had been developed by the universities for their research needs and sometimes for NASA. Such studies became a significant part of our work from 1970 onwards and our use of them together with the staff involved played a major part in establishing the scientific reputation of our Laboratory.

This needs to be put in an historic perspective in order to appreciate the progress made during the period from the late 1940's until the shut down. Before the1970's work on surfaces was split into anodizing, corrosion and oils and lacquers (which included lubrication) and there were three Sections in the Chemistry Division carrying out the associated work. An Analytical Chemistry Section provided a support role to the site as a whole, for example for casting work carried out by our Foundry Section.

From the late 1950's onwards, Laboratories management recognised the need to employ new graduates with university research experience; this had a major impact on the Laboratory and helped to replace the old section-structure with a science-driven project/customer one. This was a major step that paved the way for the work done in the final 40-50 years of the Laboratory, both on fabricating processes and finished products. Some of this is described below and the Lubrication work under Rolling.

11a. SURFACE ANALYSIS & PRETREATMENT

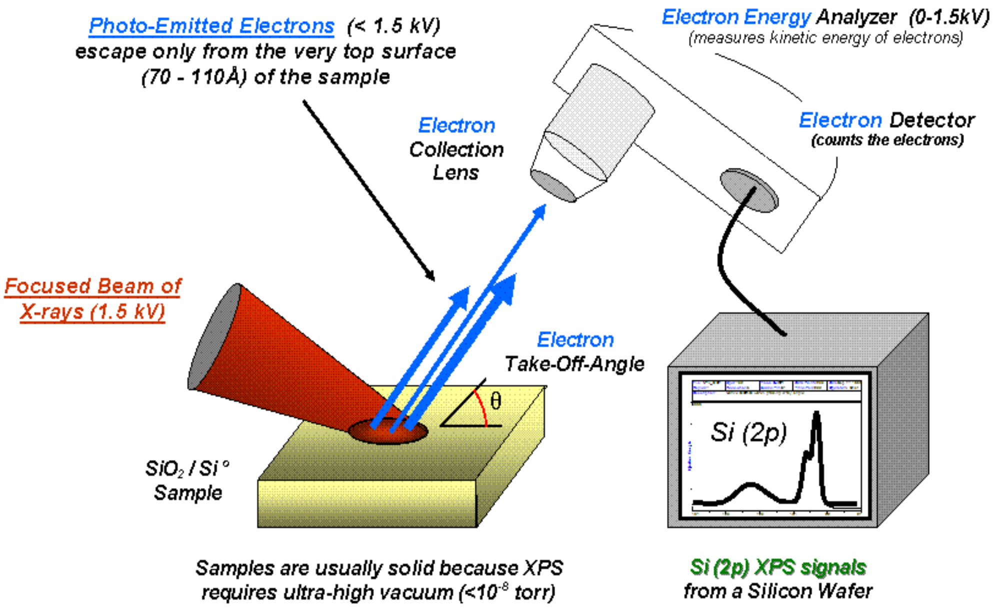
Nigel Davies

In 1972, before he transferred to Kingston, David Moore teamed up with Maurice Lunn to justify the purchase of the first ESCA (Electron Spectroscopy for Chemical Analysis) instrument in Alcan. Whereas the electron optical techniques previously discussed provide high spatial resolution to a depth of microns, ESCA will analyse a beam diameter of 50mm but to a depth of only a few atom layers.

Hence ESCA or XPS (X-ray photoelectron Spectroscopy) is a surface chemical analysis technique that can be used to analyse the surface chemistry of a material in its "as received" state, or after some treatment, for example, ion beam etching and conversion coating.

It is a semi-quantitative spectroscopic technique that measures the elemental composition, empirical formula, chemical state and electronic state of the elements that exist within a material. XPS spectra are obtained by irradiating a material with a beam of X-rays while simultaneously measuring the kinetic energy and number of electrons that escape from the top 1 to 10 nm of the material being analysed. ESCA requires ultra-high vacuum (UHV) conditions.

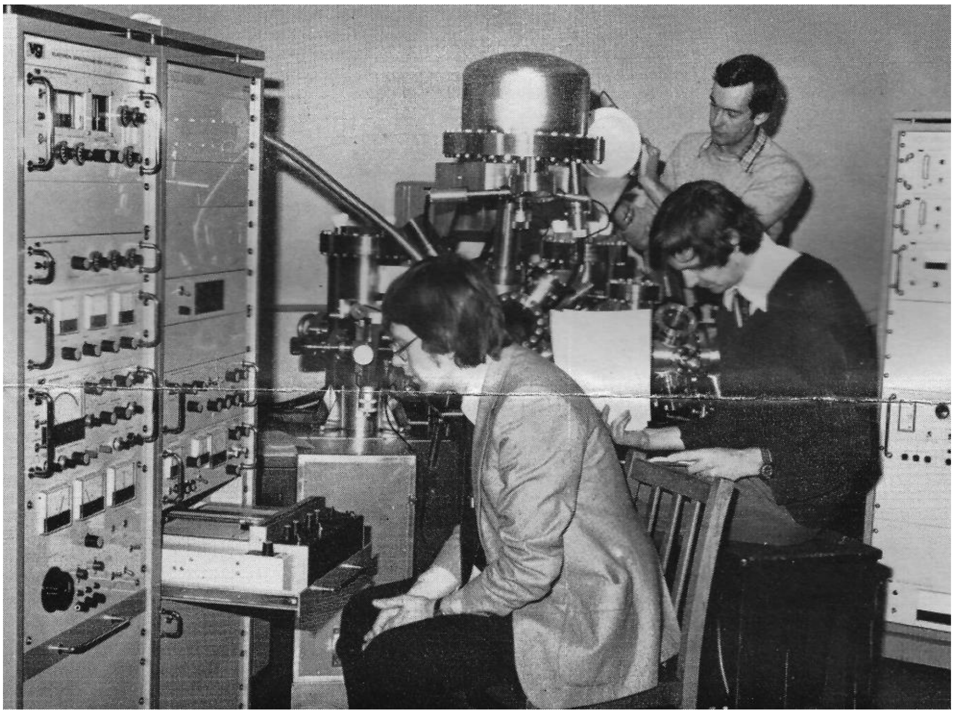
The original justification for the instrument was for research-based projects on aluminium oxidation and adhesion. John Treverton joined Maurice Lunn as the main operators and Nigel Davies, who had previous experience of the technique, joined them in 1974. Maurice departed for Bradford University in 1975 to study for a PhD and then moved to the USA.



Although the original justification for the equipment was followed, it became evident that the arrival of the technique was an opportunity to study directly the various surface layers on aluminium products. Such surface sensitive analyses had not been possible before. The approach was to analyse the top surface and then ion etch stepwise through the surface layer. At each step, the newly exposed surface was analysed in detail and a 'depth profile' of how elements and their chemistry were distributed through the surface layer, was generated. Knowing etch rates, average film thicknesses can be measured. In parallel with these studies it was necessary to develop methodologies to improve the quantification of the technique. This was carried out in-house and with UK user groups.

Hence there followed a period when surface related problems were studied on all aspects of the industry from alumina through to consumer complaints of stained turkey foil. For someone new to the industry this was an excellent opportunity to gain a broad knowledge of processes and products. The downside to these studies was the time taken for analysis. Even with thin films of known chemistry, a full analysis took a minimum of one day.

Peter Andrews joined John and Nigel in 1978 and 5 years later a second instrument was purchased. The biggest change here was that instead of handling data manually, there was data collection and automated measurement. With 2 instruments running and mainly carrying out our own maintenance, there was a further opportunity to develop life skills in plumbing, electronics, the Telegraph crossword and vacuum engineering.



Nigel Davies, John Treverton and Pete Andrews posing with the 2nd instrument

The technique was widely used over a 20year period, in that time; new technique development aided by increased computing power meant that faster, complimentary surface analytical techniques and equipment became available. With the basic surface knowledge and database of 'ideal surfaces' already developed, these other techniques were used to rapidly assess surfaces for both research and plant needs. These techniques include FTIR (Fourier Transfer Infra Red) Microscopy and GDOES (Glow Discharge Optical Emission Spectroscopy). ESCA still had its place for the new or more complex problems and also for monitoring brazing sheet surfaces for very thin oxide film measurement. It was also used to study and measure copper diffusion into and through super purity aluminium cladding on 2000 series strong alloys after artificial ageing.

Below are some major examples of where ESCA was applied: -

1. **Mg levels in Annealed Foil**
2. **AC Sulphuric Acid Pretreatment**
3. **Chromium based Pretreatments**

Magnesium levels in Annealed Foil

The study of lacquer adhesion problems on the surface of annealed aluminium foil was first highlighted when severe de-lamination was encountered on yoghurt lidding stock produced by Alcan Foils Wembley; this problem did not manifest itself until the product was in its final packaged form, and caused expensive rejections. It soon became evident that other foil producers, who were carrying out long batch annealing cycles at ~400^{0}C were encountering similar problems.

ESCA, in conjunction with depth profiling, was able to evaluate the distribution of elements within the oxide films. It was shown that If the foil alloy had a bulk level of >40ppm Mg, then during oxidation the Mg diffused to the outer surface of the oxide film and concentrated there at levels of say up to 3%. If such a lacquered surface was subjected to a moist environment, then de-lamination occurred due the reaction of water with the excessive levels of magnesium oxide. If the bulk magnesium levels were <40ppm then the oxidized magnesium did not concentrate at the outer surface but as a layer within the oxide film and no subsequent de-lamination occurred. As a result of this work Alcan placed a global maximum of 40ppm of magnesium for their foil alloys.

This work next extended to lithium contamination within foil alloys. A phenomenon known as 'blue film corrosion' occurs when very low bulk levels (<10ppm) of lithium are present in aluminium foil alloys. Corrosion can occur within a coil of annealed foil which causes inter-lap sticking of foil surfaces, which take on a pale blue appearance. This is caused by lithium diffusion during lower temperature annealing, than with the magnesium effect, subsequent reaction between lithium oxide and atmospheric water vapour gives rise to the effect.

This proved much harder to study with the analysis proving to be beyond the sensitivity of ESCA. The approach taken was via an even more surface sensitive technique called SIMS (Secondary Ion Mass Spectroscopy) in conjunction with electron microscopy. As a result of the joint work of the Banbury group with John McCubbin and Dave Creber in Kingston, bulk lithium levels for foil alloy specifications were set at <0.8ppm. This impacted up-stream to the extent of defining which bauxite sources could be used by the smelters for the aluminium production.

2 AC Sulphuric Acid Pretreatment

In the 1970s continuous anodising based on sulphuric acid was being used as a packaging pre-treatment in Goettingen, Rogerstone, Huletts: Pietermaritzburg and Endasa: Alicante. Other than lacquer adhesion testing the only quality control tool was based on a 'weigh-strip-weigh' technique of dissolving away the oxide film and estimating the average oxide film thickness over the two sides of the test sample.

At various times all foil-finishing lines were experiencing lacquer adhesion problems coil to coil, within a coil and across the width of the strip. After substantial ESCA analyses of material it became evident that there was a critical level of carbon contamination, critical levels of sulphate ions within the anodic films and a thickness range that gave optimum performance. However in almost all cases, it was shown that if the oxide film thickness was correct, at 40nm to 80nm, then the chemistry was correct.

For a while ESCA became the quality control tool for all 4 lines. With analysis taking on average 1 day for $1cm^2$ of sample, this became untenable both from response time and cost. Using the basic knowledge that film thickness was critical, an ellipso-metric technique was developed that produced close-to-line, across width oxide film thickness measurements on both sides of the strip. This was then used for optimization of the process and as a product release test over the next decade (Section x.4)

3 Cleaning and Pre-treatment

Coil coating of aluminium is used as a high-speed process to clean, pretreat and lacquer/paint a surface for value-added applications in packaging, building products, automotive etc. For these products the aluminium substrate gives the mechanical and physical properties to the manufactured item and the organic coating adds value by improving corrosion and chemical resistance and by giving decorative and various other properties that may be required. The effective cleaning and pre-treatment of the substrate has the vital role of providing compatibility between the substrate and the applied organic coating to ensure the optimum adhesion and corrosion resistance characteristics of that coating are obtained.

Almost all of the early pre-treatments were based on chromium compounds and had been developed by chemists on a trial and error basis to create a brew of chemicals that met specifications. In the mid-70s some Alcan coil coating operations were experiencing adhesion problems and the ESCA technique was used for the first time on these surfaces, prior to painting.

Two basic types of chromium pre-treatment were being used: those based on hexavalent chromium for building products and others based on trivalent chromium for packaging. After examining many samples and identifying and measuring the distribution of elements through the pretreatment layer, John Treverton and Nigel Davies were able to propose ideal structures and mechanisms of formation of these films. This work was published and was probably the first scientific study of the ‘black art ‘ of pre-treatment.

There followed further work on the range of spray, roll-coat-able, chromium, non-chromium pre-treatments that were brought to market by the chemical suppliers. Additionally this work provided a basis for in-house developments of packaging and automotive pre-treatments. John Treverton continued to study these systems both from a chemical and morphological perspective and, with others, produced a body of work on aluminium pre-treatments that is still referred to today.

As pre-treatment technology has moved away from chromium because of environmental concerns, new chemically benign pre-treatments have put a greater emphasis on cleaning technology. As such the knowledge developed in these studies on alkali, acid and electrolytic cleaning gave Alcan an advantage in coil coating and lithographic sheet processing.

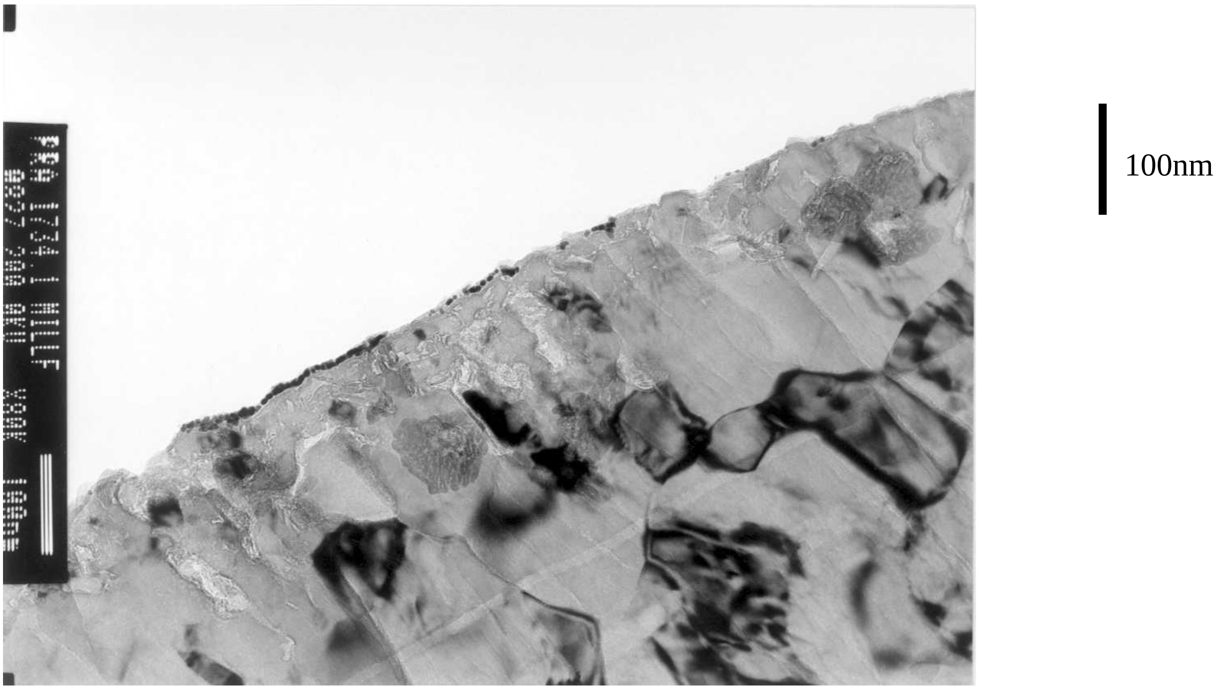
11b. NEAR SURFACE ACTIVE REGIONS

The bare aluminium strip surface presented to the first process step of the cleaning process has residual rolling oil from the cold rolling process, oxide films generated during the high temperature rolling passes (most evident on magnesium-containing alloys where magnesium oxide segregates at the surface) and deformed or surface active layers.

Up until the mid 1990s, the accepted understanding was that cleaning was required only to remove residual carbon and the oxide film. However European funded work led and championed by Geoff Scamans proved that, on certain alloy groups this was insufficient and that there existed a surface microstructure that also needed to be removed for optimum product performance i.e., the near-surface active region.

He and Andreas Afseth demonstrated that these surface-active layers, in most instances, controlled corrosion susceptibility of painted products. The focus of this work was an industry-wide Brite-Euram programme on filiform corrosion. At that time there had been a number of failures of painted aluminium on prestige buildings, such that aluminium's market share was under threat within Europe. In reality these suppliers had not cleaned the aluminium sufficiently.

These surface-active layers arise from the high level of surface shear induced during rolling that transforms the near-surface microstructure.



A 100 nm surface-active layer on AA3105 cold rolled sheet.

Deformed surfaces are characterised by an ultra-fine grain size that can be stabilised by magnesium oxide pinning in magnesium-containing alloys However, it is not the fine grain size that is responsible for the enhanced corrosion susceptibility of the surface layer, but the preferential precipitation of manganese-rich dispersoids during annealing treatments, which is related to the manganese-solid-solution level and the temperature and time of annealing.

These deformed surface layers on aluminium alloys are produced most readily by hot rolling and, generally, the layer thickness on sheet and plate after hot rolling is of the order of a micron. The deformed-layer thickness is progressively reduced by cold rolling so alloys that have been extensively cold rolled have thinner deformed layers that can more readily be removed by conventional etch-cleaning operations. Therefore, resistance to corrosion can be improved by increasing the transfer gauge thickness so that after cold rolling the amount of surface to be removed at final gauge is 0.2µm or less. Most working processes like grinding, machining and shearing aluminium also produce deformed surface layers that can be responsible for corrosion or surface appearance problems. However, all issues relating to deformed surface layers can be removed by effective surface cleaning to remove the layers.

11c. CONVENTIONAL ANODISING

Ted Short

Aluminium Laboratories was recognised world wide for its contributions in the field of anodizing. In the early 1950's anodizing was already quite a mature technology very much based on experience and sensible, although sometimes unproven technology, rather than scientific facts. Much of the development up to the 1950's was carried out by operating companies such as Acorn Anodising in Bletchley; Aluminite & Alzac in London; Coloral and Anotints in Birmingham and perhaps Roundhay Metal Finishing in Leeds. The contributions of Vernon Henley, Jim Kape and Frank Spicer in the UK spring to mind.

In the 1950's Alcoa Laboratories was carrying out research on various processes particularly integral colour anodizing (Duranodic). Alcan Laboratories in Kingston, led by Roy Spooner who was ably assisted by Ernie Cooke and Ernie Howlett was also investigating the effect of the parameters used for sulphuric acid anodizing upon the properties of the film produced, both for architectural finishes and decorative anodizing.

Aluminium Laboratories, Banbury under the guidance of George Gardam also built up a team including: Arthur Brace, Ron Peek, Bob Polfreman, John Gross and Ken Pocock, who worked on projects associated with chromic and sulphuric acid anodizing. A modest amount of work was also done on vitreous enamelling and lacquering aluminium for outdoor applications; this was the responsibility of the Oils and Lacquers Section under Roman Guminski. Les Lister and Frank Meredith were much involved with the latter in the early days.

Considerable work was carried out to obtain a better understanding of the mechanism of electrolytic and chemical brightening as pre-treatments prior to anodizing and papers were published by Arthur Brace, Ron Peek and Ken Pocock.

At the beginning of the 1960's Gardam, Brace, Peek, Pocock and Polfreman moved on to other fields either within the laboratory or outside and Jim Kape and Peter Sheasby took over the running of the anodizing department with Ted Baldwin as steward, Jim Kape moved into the chemical supply house industry after about two years and Peter Sheasby was joined by Terry Castle, Brita Wilson, Ted Short and Mike Swindell. Over the next 10 years they were ably assisted by a series of newly hired staff, including Martin Smith, Simon Barrett, Graham Cheetham and Geraldine Bancroft. They were involved in a very active period when work was carried out, with the aid of Henry Lamb and later Martin Amor of the electron optics laboratory, to obtain a better understanding of the mechanism of the etching, brightening and anodizing response of aluminium alloys and the role that their metallurgy, in the form of inter-metallic constituents or precipitates in the various alloys, had on these processes.

At the same time considerable work was carried out to prepare samples of anodized finishes of various film thicknesses, on a range of alloys, to be exposed to various atmospheric conditions at sites across the UK., including industrial, heavy industrial, marine, industrial marine and rural. The samples were monitored at regular intervals for degradation and any signs of corrosion. The results of this exposure programme have been reported in a number of papers and valuable information on the performance of natural anodized anodic coatings in the above environmental situations for periods in excess of 25 years were of significant value when persuading architects of the merits of anodized aluminium for prestige building projects.

Peter Sheasby worked on an etching solution that would produce a more matt and uniform finish on extruded sections used in the architectural window frame market, the resultant etch was marketed by The Walterisation Company as Noralbryte.

Ted Short operating the anodising pilot line

The anodizing business was a rapidly growing worldwide and there was considerable financial support from the Alcan Plants for this work, as many of them had decided to build their own anodizing plants to service this growing market. Plans were soon in place to modify the plant in Pinon, and to build plants in Raeren, Uphusen, Copenhagen, Ornago, Banbury, Bangkok, Jakarta and Kuala Lumpur.

In the prestige-architectural-building market there was also a demand for finishes with a better light fastness than the established coloured finishes produced by pigmenting with organic dyes.

Alcoa and Kaiser had addressed this to some extent by introducing integral colour or one step colour anodizing processes (Duranodic and Kalcolor) where the colour was formed in a special anodizing electrolyte based on sulphosalicylic acid. These were high voltage processes compared with the conventional sulphuric acid process and not easy to control chemically. The colours produced were mainly a range of bronzes and were very sensitive to slight variations in the metallurgy of the alloy as well as the anodizing conditions.

Numerous buildings including the P & O building in London and the Heathrow-Terminal-1-building were clad with aluminium using this type of process.

Alcan Laboratories also developed a process based on a saturated oxalic acid electrolyte in an attempt to compete with Kalcolor and Duranodic. It was marketed as Alcanodox and produced a gold colour on 6063 and light bronze on 6082 or 3003 alloys.

Installed commercially by Acorn Anodizing at Bletchley, it was used to produce the cladding on the Aluminium Federation Building in Birmingham and the facia on the roof of the Brighton Pavilion but did not otherwise enjoy great popularity. A further attempt to increase the range and depth of colours in this electrolyte was made using pulsed-current-dc-anodizing. At a current peak to mean ratio of 6:1 and a pulse frequency of 10 Hz every light bulb in the laboratory pulsed when the process was running. It was calculated that for a full sized plant a transformer capable of handling 33KV would be necessary and the process, which Roman Guminski once described as one of our successful failures, never got off the ground.

At about this time, Asada in Japan had published work describing a process he had been working on for pigmenting anodic films by electrolytic deposition from a metal salt solution. Alcan Laboratories, Kingston negotiated an agreement with Asada to have the sole rights to this process and commenced work on it to bring it to a stage that was considered to be commercially operable. They took out patents for the process and decided to market it under the trade name of ANOLOK. Deposition from electrolytes containing metals such as Nickel, Cobalt, Copper, Antimony, Silver, Manganese and Iron were covered by the patent but, for reasons known only to Kingston, tin was omitted. This was to be seen as a serious and expensive omission in years to come.

Alcan Laboratories, Banbury built and operated a line with 2 metre long tanks to help scale up the process before our personnel were involved in commissioning facilities all over Europe, the Middle East and S.E Asia at both Alcan-owned plants and third party anodizers. The original advice had been to use a nickel electrolyte but after trials in the laboratory and a full size anodizing line trial at Acorn Anodizing, Bletchley, the limitations of the process soon became apparent. Further work at Banbury entailing some modification to the colouring electrolyte chemical composition, and substituting the nickel sulphate with cobalt sulphate, resulted in a much more commercially viable process.

Alcan Laboratories Banbury personnel were involved in the commissioning of new anodizing plant and the electrolytic colouring process all over Europe, the Middle East and South East Asia, at both Alcan owned plants and third party anodizers who had signed up as ANOLOK licensees. At one stage Alcan had some 50 licensees world wide all of which had paid for the trade mark agreement and know how. This agreement stipulated that they had to use Alcan metal if they wished to call the finish produced ANOLOK. Furthermore, for an initial period they were asked to pay a royalty on every kilogram of aluminium treated through the colouring process.

This extra work load resulted in further additions to the anodizing laboratory staff, including: Bryan Carter, Peter Maunder, Barry Ellard, Chris Gilkes and Fred Durrants. The hands-on experience in the Alcan plants, and those of licensees, served as a very useful learning experience of what was not always appreciated in the laboratory environment.

An example was how rapidly the pH would change in the boiling water seal solution when a load was placed in the seal solution. Not only was it necessary to make an addition of ammonia after each load to restore the pH but it was also necessary to stir the tank that contained boiling water, to produce a uniform pH. This can prove to be rather debilitating in a climate such as that in Bangkok and it soon became clear that we needed to devise a method of stabilising the pH. Hence today, following a discussion with Roy Hine on the subject of chemical buffering solutions, all seal additives contain ammonium acetate which conveniently buffers the pH at around 6.0.

The other effect of good quality sealing is to produce heavy powder or smut on the surface of the anodic film. To remove this smut manually is labour intensive and monotonous and additives were developed by chemical supply houses to prevent this smut formation. This was fine until an attempt was made to speed up sealing by adding amines to the seal solution. The net result was the amine boehmite accelerator was overriding the boehmite inhibitor in the anti-smut additive thus negating its effectiveness. A simple but successful way of overcoming this was devised in our Laboratory where the pores were filled with the amines in a static cold rinse prior to sealing and then the anti-smut additive in the subsequent sealing solution worked satisfactorily, Although small process modifications, they all added up to considerable cost savings in labour and energy in the plants.

The finishing group was also very active in helping plants to design their anodizing facilities and later, in the design and commissioning of effluent treatment systems to treat the rinse waters before they could be discharged to local water courses. A particularly stringent situation was in Alcan Raeren, Belgium where the treated rinse water had to be discharged to a stream that contained trout and was regularly fished by the local anglers. Trout are very sensitive to aluminium and the discharge limit was set at 5mg/l in order not to kill the fish. This was achieved by careful pH control of the discharge effluent aided by precipitation, coagulation, settling and consolidation by filtration of the precipitated aluminium hydroxide.

The electro-colouring process slowly replaced integral colour anodizing but was not without its problems, in particular the sensitivity of the electrolyte to sodium and the effect this had on colour uniformity and a tendency to spall the anodic film. The colour uniformity within a load and from load to load was improved significantly by using a power supply developed by NLM in Japan. The periodic reversed square wave generator (UNICOL) used to do this was designed by Fuji Electric who licensed the unit world wide. It transformed colour control and colour uniformity and was commissioned on a commercial scale at Alcan New Zealand in 1983. Ted Short and Teruo Miyashita commissioned the unit at the Wiri plant ably assisted by Alan Wilson, Martin Haszard and their staff, however, although it gave a significant breakthrough in colour anodizing, its high capital cost (about 10 times the cost of a normal ac supply), restricted its use to only one plant in the UK (LHT) and in Alcan Malaysia outside of New Zealand and Japan. Part of this disappointing uptake was due to the development of an alternative electro-colouring process by Chemical Supply Houses who circumvented Alcan's patents by using a Tin electrolyte (see above), which had superior throwing power to the Co electrolyte patented by Alcan and these companies further improved their processes by using a combination of dc and ac to carry out the electrolytic deposition.

By the early 1990's Tin-based dc/ac processes were the predominant colouring process in the architectural anodizing business, although LHT still have a leading position in the architectural anodizing business in the UK, part of which can be attributed to the quality of the finish they produce using the UNICOL power supply. This power supply also plays an important role in the production of blue-gray finishes using a process also developed to a commercial scale in the UK by us.

This process, often described as the first generation interference colour process, originated in Japan but again was developed to a commercially viable process at our Laboratory in the early 1980's. Graham Cheetham assisted by Peter Sheasby and Ted Short commissioned a full size production line for using this process in the Alcan Aluminium Ltd. plant in Banbury. Once it was up and running, Alcan Aluminium Ltd decided they did not wish to be in this market and the plant was moved to LHT Uxbridge along with Graham Cheetham as the technical expert. To this day it is still operating successfully and is LHT's main profit generator. As there is no competition from alternative processes they can command a very attractive price for the product. The blue-grey finish is also a very a popular colour with architects. Since transferring from Banbury, Graham has also used his experience to modify the process so that they can now produce three shades of blue-grey.

Another innovation in the 1980's was cold impregnation of anodic films with nickel salts as an alternative to hydrothermal sealing. Akira Morita and Ted Short assisted by John Treverton studied this process in some detail and their published results are still often referred to in current papers on the subject.

Robin Furneaux, Rob Gardener, Roy Rigby and others were involved in the use of stripped anodic films as a filter membrane for various analytical chemical and industrial uses. The process for making these involves anodizing super pure aluminium in phosphoric acid and then electro-chemically separating the film from the substrate to form a membrane which, when supported in a suitable holder, could be used in filtration applications. A process step involved using a dissolution step to control the pore size, so that a size selective filter could be produced. We developed the concept from the prototype stage to a full production process under the name of ANOTEC, before it was sold to Whatman, the filtration specialists, who are still operating profitably in Banbury today.

In addition to production-orientated projects the Anodizing section also carried out considerable work on testing and evaluating new products entering the market. Their corrosion protection and the light fastness of their colour were the main aspects evaluated. Numerous papers were published on these subjects and Peter Sheasby played a major role in getting many of these tests along with the information they provided into British Standards and European Norm Specifications.

11d. CONTINUOUS ANODISING

Eric Wootton & Jon Ball

Some of the earliest successes of food packed in metal containers are of sardines packed in Norway Spain and Portugal and herrings packed in North Germany. Such packaging expanded after the Second World War, but still using cans almost exclusively drawn from tin plate. However, soon the scarcity and high price of tin led to the search for alternative materials and opened the way for A/S Nordisk Aluminiumindustrie to exploit the aluminium versions of fish cans.

The surface of rolled aluminium strip usually carries residual rolling lubricant, varying amounts of oxide, and general rolling detritus. This surface must be thoroughly cleaned, and possibly modified, to provide sufficiently good adhesion for a wide range of lacquers, which may have to withstand quite severe drawing operations for some packaging applications.

Relatively shallow containers for such products as face creams etc. that generally are not aggressive to aluminium, do not call for a high degree of lacquer adhesion. Furthermore, the material used for such containers is usually of commercial purity or an Aluminium-Manganese alloy and adequate lacquer adhesion can be achieved by a simple degreasing process. However, drawn containers such as fish cans, and the much deeper double-drawn cans, are made from stronger alloys, particularly those containing magnesium, and may have to contain relatively aggressive products. Consequently, those are the containers, which pose the main problems in lacquer adhesion. When alloys containing magnesium are heated, e.g. in annealing processes, the magnesium migrates towards the surface where its oxidation produces a magnesium-oxide-enriched layer. When exposed to moisture, this oxide is converted to magnesium hydroxide, which can attack the metal underneath a lacquer coating, resulting in loss of adhesion. Moisture migrating through the lacquer film can produce the necessary hydration with consequent under-film creep and loss of adhesion. It is therefore necessary to modify this magnesium rich oxide film, or to remove it and replace it with a stable film before cans are formed.

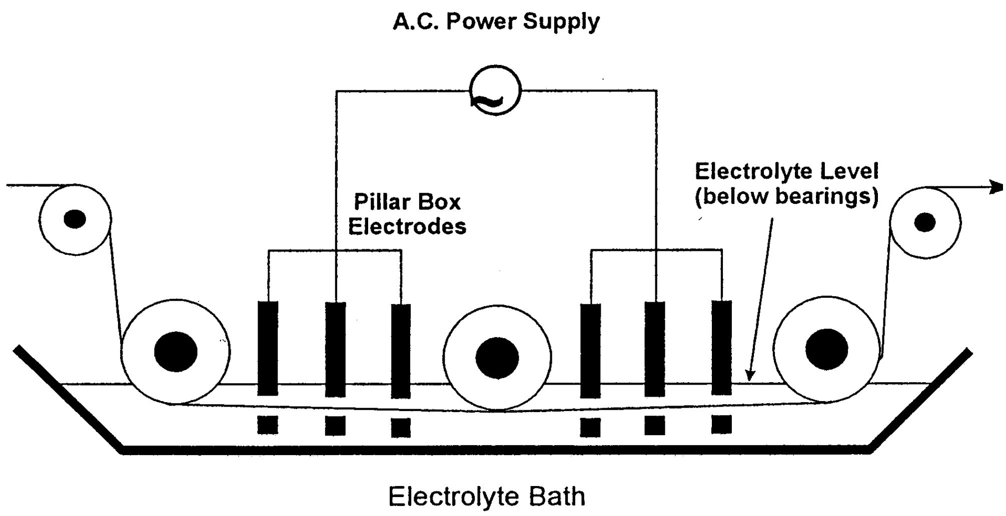
The two major commercial processes historically used for aluminium can stock were chemical conversion and electrolytic processes. The chemical conversion process involves degreasing plus the application of a chromate-phosphate solution using a roller coater, and allowing a certain reaction time (around 10 sec) before rinsing off excess chemicals, and creating contaminated rinse water for disposal. Only non- toxic trivalent chromates can be used for material destined for food products; hexavalent, dichromates are toxic and must be avoided. Conversion coatings were favoured in North America. Europe, on the other hand, favoured using an electrolytic (anodising) process for food can material, eliminating any possibility of chromate-contamination and disposal of contaminated rinse water.

Nordisk had anodised coiled strip since 1936 on a continuous line, incorporating degreasing and anodising, using a contact roll to feed DC current into the strip as it passed into a bath containing the electrolyte and counter electrodes in the electrolyte which was 15% sulphuric acid. They produced a conventional D.C. anodic film 0.3µm thick with 30 sec process time. The strip was then cut into sheets for subsequent lacquering and if necessary printing. At this time the lacquer coatings required 10 to 20 minutes to cure, until new lacquers such as organosols and epoxy phenolics became available with curing times as low as 20 sec. prompting Nordisk to build a line incorporating degreasing, anodising, lacquer roller coating and stoving, running at speeds up to 100 fpm. They designated this product as Con-ano-lac.

This material was excellent for fish in the relatively shallow ¼ “dingley” cans but borderline with aggressive sauces in the deeper ¼ club cans (albeit considerably better than tinplate cans). Our Sheet and Strip Division collaborated with Nordisk in optimising the specification for the cans, including selection of alloys, gauge reduction (down from 0.35mm in the original cans to 0.20mm), pre-treatment, lacquer and shelf life.

While studying how the anodising conditions might be modified to speed up both production rate and quality we found that using an alternating (AC) voltage and an electrolyte temperature of 80°C gave both an enhanced lacquer adhesion and a processing- time reduction from 30 to 2-3 seconds. These important findings were based on experiments carried out by Les Lister (anodising) and Jack Mantle (lacquering and product evaluation). To verify these findings, under the guidance of Eric Wootton, Laboratories designed and built a continuous pre-treatment line for 8-inch wide strip to run at various speeds ranging from 48 to 180 fpm, equivalent to anodising times of 7 to 2 seconds in a special 2-compartment anodising cell. The cell dispensed with the Nordisk contact roll by having electrodes in each compartment i.e. liquid contact. The electrolyte was 15% sulphuric acid heated to 80°C. Sample strip was lacquered, drawn into cans and tested, confirming results superior to the conventional DC film and even better than the best conversion coatings, giving excellent results with fish in aggressive sauces e.g. tomato, even in the deeper ¼ club can. Another advantage was that by using AC, the cathodic part of the cycle together with the hot acid gave a very good degreasing of the strip, dispensing with the necessity for a separate degreasing section.

A production version of the cell was then designed and built by our Sheet and Strip and General Engineering Divisions and fitted into the current Nordisk Con-ano-lac line. With excellent collaboration from the Norwegians Knut Nilsen (Engineering) and Anton Kragness (Line Manager) this cell ran in continuous production for several weeks before being serviced to replace some heating elements incorporated in the cell. Subsequently the electrolyte was re-circulated through an external heating tank, which also assisted in the separation of the degreasing contaminants. The performance of this hot electrolytic pre-treatment fulfilled all expectations. Subsequently, Nordisk built other Con-ano-lac lines including two lines for the USSR. Pre-treatment-only lines featuring the electrolytic cell, with tension levelling and sheet cut-to-length facilities were built for Rogerstone, Goettingen, Alicante and Pietermaritzburg. These lines could run at a maximum speed of 300 m/min operating from coil-to-coil, and lower speeds when cut-to-length was required.



The original cell design with ‘post-box electrodes.

The hot electrolytic pre-treatment process produces an anodic film of 0.05 µm thick. The rate of dissolution in the hot acid and the rate of producing the film in the anodic half of the AC cycle are approximately in equilibrium with equally good results obtained over a wide range of times. Thin anodic films and similar surface topographies produced under other conditions do not give as good lacquer adhesion results - the important factors are the conditions under which the pre-treatment is carried out

Subsequently it was ascertained that this pre-treatment gave the ideal substrate for subsequent electro-graining and anodising of lithographic sheet.

At the same time as these hot electrolytic pre-treatment lines were being developed, so-called 'paint lines' were also being built to provide material, primarily for the building market. These lines used the chemical conversion type of pre-treatment (hexavalent dichromate) applied by roller coating and with paint-coating systems capable of applying a 2-coat system on the critical topside and a single coat on the reverse. Also more recently no-rinse conversion pre-treatments have been developed which avoid the problems of disposal of contaminated rinse water. Goettingen invested in such a line and Laboratories (Ray Young) assisted with the product development and evaluation, and in collaboration with Goettingen developed a system for measuring paint film thickness and feeding data to a computer controlled coating machine developed by Bob Innes at Kingston Laboratories.

The continuous anodising lines based on sulphuric acid continued to be run in Goettingen for packaging applications and strip cleaning. However during the 1970s and using ESCA, John Treverton and Nigel Davies had shown that the critical parameter of sulphuric acid films for adhesion to lacquers was film thickness. With each measurements using ESCA taking at least 1 day, this technique could be used forensically but not for quality control. (Section X.1)
Hence a joint project was undertaken to develop a close-to-line quality control technique for across strip oxide film thickness measurements using ellipsometry. This project involved a number of memorable Banbury to Goettingen road journeys including border crossings with equipment and computers (which we were not trying to smuggle into East Germany!). The project team in Banbury included Nigel Davies, Peter Andrews, Martin Amor, John Ward and Jon Ball (on his arrival from British Aluminium, Chalfont Park) whilst in Goettingen it included Peter Limbach, Amin Kumpart and David Wright. This became a close working relationship that continued for the next 20 years with a range of successful surface finishing projects completed.

Even with the improved quality-control method, it became apparent that better adhesion was needed for some packaging applications than was achievable by sulphuric acid anodizing. The requirement appeared to be to use the more porous film produced when using phosphoric rather than sulphuric acid. However, phosphoric acid made the process more difficult to control in that it is more chemically aggressive; hence operating windows needed to be established where film growth dominated film dissolution. Once these windows were established (N.B. typically 3secs process time), Eric Barlow was able to show that this was a far superior pre-treatment to other options available at the time for lacquered food cans. Nigel Davies and Peter Sheasby applied for a patent for a range of products that included automotive and packaging. Later the application was successfully defended in court by a team led by David Goodchild. Our opponents then were AluSuisse and later the gentlemen appearing for them became members of Alcan when we merged, much to their embarrassment.

In the mid 1980s the Goettingen lines were changed to phosphoric acid. The first was changed over at 5 o'clock in the morning and much to the operators' consternation was unexpectedly attended by Reinhold Wagner, Head of Alcan Deutschland and an Alcan Board member, indicating the importance attached to this upgrade.

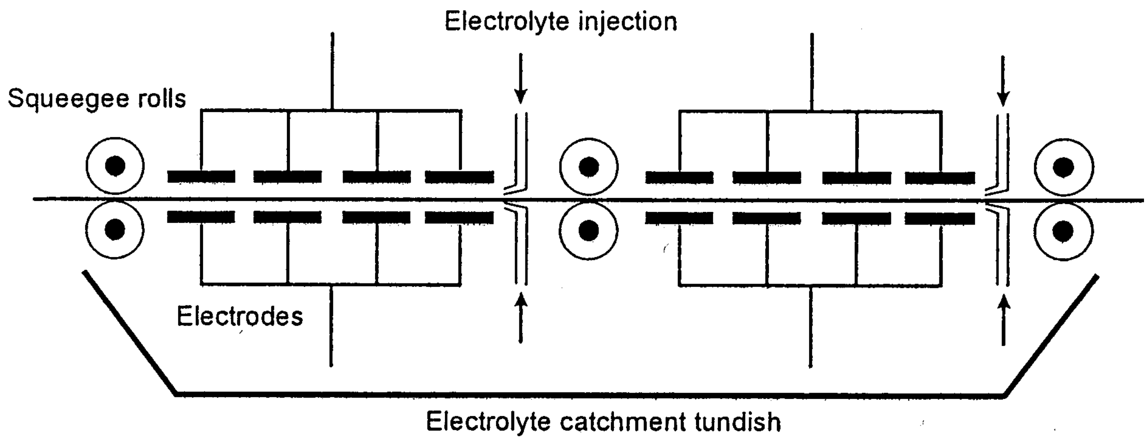
Significant effort was expended on the lines in Goettingen, pilot line trials in Depiereux GmbH and in the labs to adapt the lines to phosphoric acid. Despite best efforts it became apparent that the cells were not suited to this more resistive process. So while the lines were run for about 2 years in this mode eventually a new dedicated lacquer line was built with using roll coat conversion pre-treatment.

However, in a fortuitous twist the electrolytic lines were converted to cleaning lithographic sheet. Essentially this is done by anodizing at a temperature high enough to dissolve the film as fast as it can grow. Peter Andrews showed that the surface produced was the cleanest industrial finish known and had only a thin (2 nm) and uniform film left on the surface. Furthermore the small amount of phosphate contained in the film helped prevent corrosion during transportation thus allow minimal packaging for dispatch. This and other metallurgical developments in litho allowed Alcan Deutschland to grow the market consistently for the next 2 decades and become top quality suppliers to the industry.

Before leaving litho it's interesting to note that during the mid eighties Nigel Davies' pre-treatment team had had the opportunity to characterize the parameters affecting phosphoric acid anodizing. So when most of this team were later working on characterizing nitric acid electro-graining as part of the litho quality improvement drive, it was noted that many of the characteristics of the graining process were similar to anodizing unlike the then better understood hydrochloric acid system (having been the focus of Peter Sheasby's and the British Aluminium teams a decade earlier). When Jon Ball and Martin Amor were looking at electrical characteristics of the process, Ted Short commented it looked a bit like burning in anodizing. Subsequently it was shown that the pitting process proceeds by an anodizing followed by dissolution similar to the cleaning process mentioned above, the overlying surface was passified by anodizing but also slowly eaten into by the dissolution process so revealing new sites for pitting, re-passivation of pits was also by anodizing and even the inter-metallics in the surface were removed by dissolution after being preferentially anodized in a current surge at the onset of graining. John Ward elicited the influence of the various elemental components on the graining response and Graeme Marshall which metallurgical sites were responsible for where pits formed.

By the start of the nineties work had been in progress with a number of car companies for about a decade on the aluminium car. As well as conventional chromate pre-treatments anodizing was also kept in mind as a possible option. In addition electrolytic cleaning was also considered as a useful high-speed system that would avoid the use of hydrofluoric acid. The cleaning of automotive materials was also characterized and in 1992 Martin Thornton showed the manner in which this process removed the mixed magnesium and aluminium oxides and metal detritus from the surface (which were later to be termed as near surface active regions). A cleaning patent was applied for successfully that was to be of considerable value in the future. Other patents in this area followed later using adhesion promoters with anodic films and barrier layer films to promote improved graining response for lithographic sheet.

In 1991 it was decided to build an automotive line for the foreseen volume car market. As the various car manufacturers had not settled on any single pre-treatment/coating options it was decided that the first line would have to be able to apply all the existing contenders. However, because of its speed, cleanliness and safety electrolytic cleaning was to be the only cleaning option installed. The line was originally intended for Goettingen but with the reunification of Germany was switched to the newly acquired plant in former East Germany in Nachterstedt. Known as the GLA (for Glueh- und Lackier-Anlage; prosaically Heating and Coating Line) it could optionally anneal or solution heat treat, clean, anodize pre-treat, coat and lubricate all in one line. (Surprisingly having all this in one line made sense as the majority of the mechanical costs lay in the coil handling parts.) For a finishing line it is enormous being on two levels and as long as the Queen Mary. It could handle material up to 3mm thick, 2.3 m wide and could have as many as four coils in the line at any one time. Most of the technology was 'conventional' except the 6 new electrolytic cells, though Labs also contributed in modelling the water quench in the cooler and of course the formulation and characterization of various coatings such as the new PT2 roll-coat pre-treatment.



The new electrolytic cell concept used at Nachterstedt

The characterization of the phosphoric anodizing process in the eighties allowed a new cell concept to be developed to minimize the voltage needed to obtain suitable films in a commercial timescale. Peter Limbach (Goettingen) and Jon Ball adapted D.C. galvanizing cell from Krupp to the a.c.-phosphoric-acid process. Inductance losses were minimised and centre tapping of the transformers allowed the use of safe working voltages. Technology developed for offshore oil rigs was employed in the form of a high power semiconductor which controlled the anodizing waveform (so called pulse-pause) and allowed the same anodic film structure to be grown on the surface independent of line speed.

In 1994 commissioning began and lasted effectively for one and a half years. Eric Barlow was seconded to Nachterstedt. At this time the "East was as if the war just ended" said a Wessie (West German). The roads were so broken down that they were dangerous at night or in rain because of the depth of the potholes. The nearest large town was Quedlinberg. It looks like a classic medieval city with castle/cathedral rising over a walled town with narrow cobbled streets and 1,700 half-timbered houses. On closer inspection at night the roofs and walls of many houses had enormous gaps and that winter temperatures never rose above freezing for four months.

There were numerous incidents but two in particular stand out. While testing the transformer controls it was decided to try an extreme case of pulse-pause control with one pulse on followed by one off. The 6 massive transformers each rated at 0.5 Mw were mounted on another deck above the cells and over the service side of the line. So directly underneath them when the test was initiated were Eric Barlow, Jonathan Sharman and Jon Ball. Unfortunately the test pattern was effectively 25 Hz and hit a resonance in the structure. The effects on the personnel of six enormous transformers bouncing up and down over their heads to a deafeningly deep single note can only be guessed at!

Once the line was close to running effectively the pressure was on to produce some test coils for customer evaluation. Reinhold Wagner, now close to retirement and treating the plant as his train set and the GLA in particular was very hands on at this point. On one occasion a large trial was underway with many engineers from Sundwig and ABB overseeing the performance of the line when a loud bang signified the coil had broken in the 90 m oven. At 500C this meant work was over as it would take a day to cool before rethreading and so all 50 personnel started walking. Reinhold came up to Eric and said, “I dashed into the switch room and asked (shouted) ‘Who did that?’ and do you know, no one owned up” And then he laughed!

On a similar occasion we had started early and been waiting around all day to test the cells but were constantly told it would be another half hour before the line could run. Finally at 3 o’clock we were told it would be two more hours so we shot off to a nearby Kebab House for lunch as the canteen was shut (later permanently on H&S grounds!). On arriving back in good time in transpired that the line had been ready for ages and Reinhold was running around ranting “Wo sind die Englandern!” Guaranteed to ruin a chap’s digestion!

In the end the cells performed exactly as predicted and have been a success. However, during construction they were over-engineered due to a series of logical steps that has no place here and the original simple and cheap cell concept was lost. In fact each one has about 400 parts and it’s a telling tribute to the maintenance crew at Nachterstedt that they keep them running for as long as they do.

In 1999 at what turned out to be the last Technology Advisory Group Meeting for Surfaces, Peter Limbach asked the question “How far can this technology go?” This led to a project to explore just this called High Speed Surface Treatment. The ultimate desire would be to be able to finish materials as fast as we can roll them but this was deemed too big a step in one go so a pilot line was constructed with a maximum speed of 600 m/min. (The Goettingen lines ran at about 200 m/min max then but later achieved close to 300m/min). At the same time it was realized that the rate of cleaning or film growth could also be improved upon and so a large transformer was employed. Because of the wish to also be able to electro-grain continuously a novel gearbox was designed that also allowed the line to run at only 0.1 m/min giving an extraordinary speed range. Dubbed the CTC line (for Coil to Coil line – where do they get these names from?) it started running in 2002. During commissioning the cell was seen to perform well at full speed with 25,000 A/m2 applied, and was even videoed by Martin Amor, starring John Ward and Barry Ellard, so that it could be shown to a wider audience than those visiting Banbury.

With these sorts of currents it was demonstrated that anodic film growth could be as fast as a staggering 1 micron per second. In addition after some modifications the simple cell concept was proven. Thanks to Peter Band the line was allowed to be run by Barry Ellard and David Newton right up to the last minute of the labs closure deadline being disassembled and dispatched to Neuhausen. David literally switched it off and went to catch his flight to Switzerland. He went on to get a PhD in this subject. The line is now in Goettingen under the tender care of David Wright and run by Ged Flynn. Eric continues to make strides in packaging material using this facility.

Many of the people who helped develop this technology have already been mentioned but many more also contributed particularly to the engineering and running of the commercial lines. Several others in the Labs made contributions to the analysis of the surfaces produced, such as Chris Pargeter using LECO and FTIR, who together with Peter Andrews and John Ward comprised the Lab based team backing up the commissioning group in Nachterstedt.

What of the future of the technology? Well it is clearly with us still for some time and with the patents soon expiring, several other firms are taking an interest in using it. So Eric Wootton's legacy, which has already run for 4 decades, looks to be healthily continuing for some time yet.

11e. CORROSION STUDIES

Mike Budd, Geoff Scamans

Work on corrosion was driven by two requirements when Labs' began activities after the 1939-45 war. One was the development of improved alloys for aircraft, armour and ship-building and the other the utilisation of the vast collection of scrap fabricated metal that the M.O.D. etc had accumulated during the war, but retained because aluminium was classified as a strategic material. Among this scrap were all the domestic items, such as saucepans, that Viscount Lindeman, who was later to become Lord Cherwell, had persuaded housewives to donate for the manufacture of aircraft (sic) in the early stages of the war. Northern Aluminium's Sales Development group identified many of the "across the board" opportunities open to us and sponsored much of our programme on metallurgical, mechanical properties, structural, electrical, packaging and welding development work, anodizing and corrosion.

By the early 1950's there was a team working on corrosion in Nevill Turner's fiefdom. For some obscure reason this did not then include galvanic corrosion and the development of cathodic protection alloys, which were Roy Hine's responsibility in the Analytical Chemistry Section, nor aluminium-magnesium alloys that were Kingston's responsibility. The new Corrosion Section comprised Fred Booth, who had a background in welding, Ron Elkington, returned from the army (a quiet ex-Major) who specialized in stress corrosion of both aluminium-copper-magnesium and aluminium-zinc-magnesium high strength alloys. Keith Latimer who dealt with atmospheric and marine exposure resistance came slightly later. He had responsibility for the aluminium raft, moored in Brixham-Harbour, which was used to study full immersion and intermittent (tidal) immersion effects. Many people in the Laboratory thought this to be a real doddle, however, it was more than offset by the corresponding heavy industrial atmospheric exposure site situated in the tunnel used by each of the many trains using St Pancras and King's Cross Stations in London. Up to the 1960's all trains using the stations were pulled by coal-burning engines that belched smoke and sulphur dioxide into a room in the tunnel roof, above the tracks, where the specimens were exposed.

A later addition to the Section was Laurie Gilbert, who worked in conjunction with the Alloy Development Division. He didn't stay all that long and was replaced by Mike Budd, who worked on electrochemistry, galvanic, inter-crystalline and layer corrosion. He identified one of the dual causes of the Hoover lid anodizing defect. At that time, these lids were used for state of the art twin-tub washing machines and stand-alone spin-dryers. They were the premium product of the Banbury Works. They were made from a high purity aluminium-magnesium alloy that combined formability and strength with excellent brightening and anodising response. Their manufacture was extremely labour-intensive and hence it was expensive to replace rejections. However, Hoover were returning them by the hundred because of linear defects that made them unfit for purpose by marring the appearance of their electric blue surfaces. Sandy Ross-Macdonald (a metallurgist), used chemical extraction followed by compacting to separate fine particles (which he observed were present at the sites of the defects) and then compacted these into pill-size samples. They could then be examined first by conventional chemical analysis (and later using our new electron-probe-micro-analyser) which proved that the defects were centred on titanium di-boride clusters strung out in the rolling direction. Mike Budd was called in by George Gardham to investigate the electrochemistry of the extracted material in the context of the anodising process and defect formation. He showed that the di-borides only caused the defect when the blue dye/sealing solution used after anodizing was contaminated by chloride as a result of the process used to manufacture the dye (it was an azo-dye salted out of solution as the last step in its manufacture). Corrosion was further enhanced if stray currents (quite commonly present in commercial anodising lines at that time) were present. He was then able to provide an immediate solution to the problem by identifying dye materials that had sufficiently low chloride content to reduce the conductivity of the dye solution (i.e. increase its electrical resistance) to a level where the local corrosion would not be a problem.

Salt Spray testing in the 1950s

Ken Johnson, later to be joined by Gordon Murray, worked on the pitting corrosion of aluminium containers and re-circulatory systems in water and tap-water environments. A significant effort was supporting the use of clad aluminium tubes in the heat exchangers of the Mol atomic energy plant then being built in Belgium.

Corrosion problems with commercial-grade-aluminium (CGA} scrap were many initially, but decreased both because of its growing poor reputation and exhaustion of the stockpile. This was accumulated in the early part of the war following an appeal made by Viscount Lindeman (later Lord Cherwell) on behalf of the government for housewives to hand in their aluminium saucepans and other aluminium articles for the war effort. The expectation was that the resulting pool of aluminium could be used for aircraft production. However, this was pie in the sky turned to rubbish on the ground, because the metal was heavily contaminated by oxide and other refractory materials, it contained all sorts of other elements, including copper, magnesium, silicon, zinc, iron, phosphorous, etc, making it totally unsuitable for aircraft and many other envisaged structural applications. Consequently, it was collected together as scrap aluminium and cast into CGA ingots for appropriate uses. Its poor corrosion resistance had by this time begun to be recognised, so these could not have been many; however, it was thought to be suitable for use in large utility buildings, such as aircraft hangers and farm buildings, where the effects of corrosion were less noticeable than on smaller buildings, and the rotted appearance caused by its inbuilt electrochemistry was more obvious. Thereafter its use rapidly declined to zero.

Our programme was expanded at this time to include examining the corrosion behaviour of aluminium-magnesium-silicon alloys, including a new variant containing manganese, to improve its impact resistance. Intended uses included rail transportation and passenger facilities at railway stations, including platform awnings, passenger bridges, etc. This was at the time when several aluminium industry bodies were established because the potential markets and associated service problems were of significance for all the UK manufacturers. When appropriate, jointly funded and executed projects were entered into, although sometimes with some reticence and suspicion. Laboratories who were one step removed from Alcan's manufacturing and marketing operations, were often chosen to represent Northern's interests. The Aluminium Federation's precursor, The Aluminium Development Association (ADA) had offices in London and generally provided meeting facilities and a Chairman for each meeting. Independent research bodies such as British Non-Ferrous Metals Research Association, and Fulmer Research Institute, who were funded by the private companies like Alcan and British Aluminium, also participated, and when necessary could be called on for an independent opinion. Meetings usually lasted until 12-12.30 pm and were followed by a good lunch in a restaurant close to the site of the new Cross-Rail station at the junction of Bond and Oxford Streets. The Committee always seemed to swell by at least 50% for lunch as various back-woodsmen in ADA found excuses to join in. Many of these appeared to be ex-servicemen.

After lunch, following one meeting Mike and Rex Banks (a structural engineer, working at Laboratories) went to London Bridge, sub-urban Station to inspect the station-roof structural members. This station was another one principally served by coal-burning steam trains, and we were looking for signs of poor performance.

The inspection involved climbing a ladder to enter the spaces around the roof supports and proceeding through them and above and across the train tracks, while, hopefully avoiding (but not always) the smoke and steam issuing from the trains passing beneath. Today, the Factory Inspectorate would have had a field day. However, no injuries were ever sustained. Rex also played another role in the Laboratory; he was one of a triumvirate who met with the writers of all Laboratory Research Reports to ensure they were fit for purpose. He was joined in this activity by Jolly-Jack Fearon and George Stanford. They met with the author at 9.30am each day and continued for at least an hour every day until the report was acceptable to all; there was a little arm twisting on occasion.

Before Mike transferred to the Oils and Lacquers Section to take over from Gian Frontini, who was soon to be transferred to Kingston Works, he investigated the use of the electronic potentiostat in both stress and layer corrosion. This instrument's electronics allows the natural electrode potential of a sample undergoing corrosion to be controlled to and maintained at a selected value, while the corrosion current is simultaneously measured. Earlier so-called impressed current tests were like using a sledge hammer to crack a nut. Inter-crystalline corrosion, layer corrosion and stress corrosion are all potential-difference (voltage) driven processes, wherein the corrosion current is the consequence of the difference between the natural, resting potential, of the inter-metallics and alloying-element-denuded zones along the grain boundaries and the applied testing potential. This and not the resultant current is what should be controlled in any accelerated test. Similarly, all impressed current tests were carried out in a chloride-containing solution, even for aircraft alloys and at a time when not many sea-planes were being manufactured. Mike showed that the combined use of the potentiostat to accelerate corrosion and an electrolyte relevant to the chemical nature of the intended service exposure gave a statistically significant correlation between accelerated stress-corrosion test failures and performance in the intended service environment. This test was shown to be superior to the results from parallel impressed current testing, where a much poorer correlation existed. Using the same approach, Mike also developed an accelerated test that would indicate the degree of susceptibility of an alloy to exfoliation or layer corrosion, (like that occurring on CGA).

Soon after Mike's transfer to Lubrication, Fred transferred to Montreal, Ken and Keith left the Lab. and Gordon Murray, after an elegant piece of work that culminated in the design of an artificial corrosion pit that allowed him to measure pitting rates in different liquids using a zero-resistance ammeter that he had inherited from Mike, left both the Lab' and Alcan. None of them were replaced, so when Ron Elkington, the last member standing, also retired, the Section as it had been was deemed to have served its purpose and all traditional work was discontinued.

From this time onwards a much more scientific approach was taken to a highly selective programme co-ordinated by Geoff Scamans initially to support the use of weldable aluminium-zinc-magnesium alloys in armoured fighting vehicles and later, the development of aluminium-lithium alloys that were designated for use on the European-fighter aircraft. The stress corrosion study was based on work done at Imperial College, London that showed a critical role for hydrogen embitterment in the cracking process. High resolution microscopy using the newly installed Temscan- electron-microscope in Laboratories was able to provide the critical evidence that confirmed the role of hydrogen in promoting stress corrosion failure, although this did not solve the problem. The 1970s was a period of extensive university interaction with the Banbury Corrosion group, which had led to the employment of Geoff, who was soon followed by Clive Tuck and Henry Holroyd, to work on stress corrosion cracking and Mel Ball, Robin Furneaux and Sandy Davidson to work on the basics of anodizing. By early in the1980s this group had changed the concept of corrosion as a rather negative process to become a more positive and science-based study. The surface engineering of filter media, as described above, was one outcome, durable adhesive bonds for automotive structures was another and anodes for batteries was a third. The lasting legacy of the bond-durability work is the use of aluminium in automotive structures by Jaguar Land Rover in their XJ and XK models and beyond into the next generation of Land Rovers. Fortunately, we are still waiting for our first bond failure.

The main development in corrosion studies in the1990s was the understanding of the nature of the rolled surface on aluminium sheet that is produced by the high level of shear experienced during rolling. This produces an extremely thin corrosion -susceptible surface layer on aluminium sheet that is responsible for the filiform corrosion of architectural products. This problem is simply solved by cleaning to remove the layer. The same problem has also been seen on aluminium car-body panels, although in this case it was caused by the rectification process that involved grinding of the sheet surface before painting. This problem was easily resolved by eliminating the surface-grinding step, particularly where the paint finish could be damaged by the impact of road debris, such as stones, during driving.

This was the last major research activity in corrosion at Laboratories before the 2003 closure.

12. STRONG ALLOYS OVERVIEW

Maurice Reynolds

12a. Aerospace Applications

2000 series

Very little genuine alloy development work was carried out on the established medium strength (2014) or damage tolerant (2024) alloy series. However considerable process development work was undertaken to improve material quality and productivity. Don Collins and others developed casting practices involving degassing and improved structural control, and work to improve extrusion productivity was successfully carried out by Bill Bryant and David Jones, notably to reduce speed cracking during extrusion and thus increase extrusion speed. This work involved nitrogen die cooling and die lubrication. Bill Bryant and others worked successfully to improve the mechanical properties of 2014 alloy, in particular low short transverse ductility and poor stress corrosion resistance. As described elsewhere by Roy Woodward, following the failures of the de Havilland Comet fuselage, Bob McLester and Ray Durham undertook a major programme of fatigue testing.

With the prospect of supersonic airliners, Bill Bryant and Roy Andrews carried out development of elevated temperature alloys and, during the design stage for the use of these materials in Concorde, Ray Durham and others completed an extensive programme of creep testing. In response to poor toughness characteristics in the developed alloy (2618), a development programme was carried out by Tony Thomas and Maurice Reynolds, which looked into the effect of germanium additions on elevated temperature properties. This did not lead to a commercial solution but, subsequently, an EEC funded project (Brite Euram) participated in by Maurice Reynolds led to the development of a new improved alloy for future supersonic commercial airliners. The patented alloy is designated 2650.

7000 series

Development of an alloy combining higher strength than 7075 with improved stress corrosion resistance and better fracture toughness was the aim of work started in the 1960's. This work, with Ministry of Technology support, commenced with research into the effect of a silver addition on stress corrosion performance. The work by Ron Elkington and Maurice Reynolds was patented but there was no commercial exploitation. Continuing work on compositional changes and heat treatment practices led to the development of a new alloy designated 7010. This alloy has been used commercially in a variety of tempers since the early 1980's. At the same time, fundamental research aimed at understanding the stress corrosion characteristics of this family of alloys was carried out by Geoff Scamans and Henry Holroyd, the latter undertaking important work in the development of testing techniques. Phil Enright and John Worth addressed issues involving the castability of very high copper containing alloys and grain refinement practices. The work by Phil Enright led eventually to the Cospray development.

8000 series; Aluminium Lithium Alloys

Work on these alloys began in Banbury in the early 1980's and was led by Dick Jordan. However, in 1982, Alcan purchased British Aluminium and merged the newly acquired Chalfont Park R&D Centre with the Banbury resources. Roger Grimes led the merged research programme and Alcan benefited from the previous work carried out with Government funding which led essentially to the AlLiMgCu alloy designated 8090.The research programme to develop a lightweight aluminium alloy for aerospace applications was one of the largest projects undertaken by the Banbury Laboratory and is described later in more detail by Roger Grimes. The scale of the development involved issues ranging from casting problems through to alloy development and mechanical property assessment. On the casting side Dick Jordan, Roger Wilson and Brian Gillett developed practices that led to a dry pit casting technique which overcame the explosion risks during casting. The extensive metallurgy programme at Banbury was led at various times by Bill Miller, Jeff Crompton, Ian Palmer and Maurice Reynolds. This work concentrated on compositional and heat treatment practices to produce a range of tempers and to mitigate against the inherent brittleness problems. Limited commercial use has been made of these alloys mainly due to the high cost of the lithium addition. Lockheed used thick plate and heavy gauge forging in a space application and sheet and forgings are used on the Merlin helicopter. A considerable number of patents were applied for in the course of the development programme.

7000 Series Alloys for non Aerospace applications

Earlier evaluation of the age hardening characteristics of weldable AlZnMg alloys led to their introduction into commercial applications in the 1960's. However, because of their poor stress corrosion resistance and a number of high profile service failures they were quickly withdrawn. This prompted considerable work in the Banbury Laboratory aimed at understanding and improving the stress corrosion resistance. Ron Elkington, Gunnars Blankenburg, Tony Thomas and Maurice Reynolds carried out the work but no commercial solution was achieved. However in the military field the alloys were successfully used in both bridging and armour applications. The Banbury Laboratory was involved in developing welding techniques but the bridging development was mainly an MOD programme. The successful use of the AlMgZn alloys in military bridging was achieved by the use of protective metal spraying after welding. The use of aluminium for armour, though, was very much a Banbury development. The initial work was carried out by John Willis and continued by John A. Wheatley and Maurice Reynolds. The work led to the development of 7017 armour alloy that was used extensively as rolled plate for military vehicle programmes such as the Scorpion light tank and its derivatives, and also for the Warrior battlefield personnel carrier.

12b.The Aluminium Lithium Development

Roger Grimes

Although aluminium-lithium based alloys have a history going back to the 1920's interest in what became known as second generation aluminium-lithium only began in the West as a consequence of Soviet developments. In 1975 the Russians filed patent applications in the West for a low density, stiff, fatigue resistant Al-Mg-Li based alloy that appeared to be superior to any aluminium alloy available to the western military. This led to major development programmes, initially sponsored and funded by the MoD in the UK and the DoD in the USA although as time went on large civil programmes were also initiated and virtually every western airframe constructor of any significance ran programmes, frequently in conjunction with other national aerospace laboratories and universities. In the UK the initial work on the new alloys was sponsored by the Procurement Executive of MoD with work divided between their own establishment (the, then, Royal Aerospace Establishment, Farnborough), and the University of Nottingham with industrially orientated aspects covered by High Duty Alloys Research Department at Slough. The HDA work concentrated on developing casting practices for extrusion billet, the intended goal being production of extrusions at their Distington extrusion plant. However, MoD was anxious that UK capability should be developed in all the semi-fabricated product forms and so a small contract to develop sheet was given to British Aluminium to process cast metal, provided by HDA, into sheet. This early work was virtually all based on the Russian Al-Mg-Li-Zr alloy (Russian designation 01420) and variants around it. Conventional DC casting was employed in which the success rate was remarkably low and the quality, generally, indifferent.

The early DoD funded work in the United States was directed towards the needs of the USAF and seemed to be leading to the conclusion that because of problems in controlling gas content it would be necessary to resort to powder metallurgical routes to manufacture the new alloys. Thus, by the late 1970's, Alcoa had terminated work on the ingot metallurgy route to Al-Li based alloys. In 1978 British Aluminium Research Division, driven by the increasing reluctance of their operating companies to fund them, had taken a stand at a small exhibition in Los Angeles and set up their stall offering to make special aluminium alloys to order. There was great interest in the offer and the Boeing Commercial Airplane Company subsequently ordered small quantities of sheet in several Al-Li based experimental alloys of their design. Boeing were also working closely with Martin Marietta's Los Angeles facility and let it be known that they were in serious discussions with Martin to jointly fund an Al-Li melting and casting facility. Clearly there was no serious likelihood of British Aluminium or Martin Marietta being major suppliers for a new Boeing airliner and at least one major purpose of these activities was to act as a goad to Alcoa. However, there was a major furore after Boeing announced, at the 1983 Paris Air Show, that their next aircraft would be constructed from Al-Li based alloys. This writer was summoned to a USAF sponsored meeting in Dayton at which the DoD sought explanations, from the American organisations to whom they had contracted their developments, as to how it could be that a civil airframe constructor could, apparently, be able to consider building with ingot metallurgy materials when the DoD had been led to believe that that the USAF would have to await development of alloys made via a powder metallurgy route. (By this date Alcoa was, once more, running a serious ingot metallurgy programme).

However, the British Aluminium contract had only just commenced when High Duty Alloys decided to close their Research Department. In consequence, MoD transferred all of the work that had been contracted to HDA to British Aluminium. Initial work at Chalfont Park continued to attempt to develop satisfactory casting practices for the Russian alloy, but with little more success than that achieved at HDA. Numerous run-outs were experienced with no dramatic accompanying activity. Thus there was some scepticism when Alcoa announced, based on work done by Long in 1957, that the danger of violent molten metal/water explosions might be far higher with Al-Li based alloys than with conventional aluminium alloys. A few months later Alcoa made rounds of the organisations believed to be involved in casting Al-Li based alloys to play a film showing recent experiments at their explosion facility and demonstrating very violent, spontaneous explosions, as molten Al-Li was poured into water. This was sufficiently sobering to convince us of the need to commission a limited number of explosion tests and Professor Mike Page of Aston University was contracted to conduct a programme of four tests at an explosion facility in the Wyre Forest. The fourth test resulted in an explosion of such violence that the concrete blocks that made up the protective blast walls were moved outwards to such an extent that the walls had to be re-built. Almost immediately after this the merger between British Aluminium and Alcan Aluminium UK was announced and work on the explosion issue continued through the Banbury Laboratory with Professor Page as Consultant and funding from RAE.

In the meantime RAE had made and tested a wide range of alloys and identified an Al-Li-Mg-Cu-Zr alloy (initially designated F92 but to become 8090 in due course) that appeared to have very considerable promise. Although a little more dense than 01420 (2.54g cm^3 v 2.51g cm3), the new alloy appeared to be capable of a much improved balance of strength and toughness while achieving a 10% density reduction and a 13% increase in stiffness. The RAE philosophy which then evolved, and which dictated the UK's subsequent development of Al-Li based alloys, was to produce material that could be directly substituted into existing aircraft designs and thereby achieve an immediate 10% mass saving together with a stiffness improvement of, at least, 10%. It was envisaged that there would be a medium strength material capable of substituting for AA2014T6, a damage tolerant material to substitute for AA2024T3 and a high strength variant to substitute for AA7475T761. Initially, it appeared that all three materials could be achieved from the new composition, simply by varying the production conditions, but experience showed that the full spectrum of properties that would be required in the high strength material could not be consistently achieved within the 8090 composition.

The more detailed investigation of the explosion hazard in casting confirmed the Alcoa view that any explosion with an Al-Li based alloy could be substantially more violent than explosions involving comparable quantities of conventional alloys and water. The energy released increased exponentially with lithium content. However, the Alcan experiments did not replicate Alcoa's spontaneous explosions and eventually concluded that, while the possible energy release if an explosion did occur made use of conventional DC casting with a water filled pit completely unacceptable, the actual probability of an explosion was no greater than that with a non lithium containing alloy. This work led to the concept that DC casting could be safely conducted if the pit was so designed that cooling water was continuously pumped from the pit bottom. Full scale experiments to test this concept were performed in the derelict, former British Aluminium, Rheola factory in South Wales. A dummy casting pit was set up in one of the old soaking pits so that should an explosion occur no serious damage should result. Tests were then conducted, employing all of Professor Page's ingenuity, deliberately to try and create an explosion, but none resulted.

The knowledge gained from these experiments was then applied to convert the largest Chalfont Park casting pit to the scavenged mode of casting and allow casting development to continue safely. Fortuitously, it fairly quickly transpired that 8090 was considerably easier to cast than the Russian alloy and ingot size and quality increased reasonably rapidly to the point that factory processing to produce sheet (Falkirk and Dolgarrog) and plate (Kitts Green) was possible. Alan Titchener, Renee Wilkins and Derek Martin continued to work on improvements in liquid metal treatment and casting procedures for rolling ingot while factory development of heat treatment and rolling practices involved numerous individuals, but notably, Maurice Reynolds and Alex Morris.

Major programmes to develop properties were undertaken at RAE and Banbury and as the airframe constructors recognised how attractive these properties were we were faced with large demands for factory processed (laboratory cast) material so that the potential users could conduct their own test programmes. British Aerospace (BAe) (both military and civil) were closely associated with the programme from the outset, conducting both property determinations and trial manufacture of sub assemblies in order to confirm that their established procedures would be applicable to the new alloy without significant modification. As enthusiasm for the new alloy grew six collaborative programmes were undertaken under the auspices of the EU's BRITE/EURAM framework and a GARTEUR collaborative programme was also agreed. These programmes involved virtually every airframe builder in Western Europe as well as several national aerospace laboratories and several universities. All required Alcan to provide, at least, some of their test materials.

As more knowledge of the 8090 alloy in its various forms and tempers was gained, Saab Scania (sheet and extrusions), Deutsche Airbus (sheet) and Westland Helicopters (forgings, extrusions and sheet) joined BAe as European organisations envisaging early use of the material, while in the United States Lockheed Missiles and Space (forgings, plate and extrusions) and the military arm of McDonnell Douglas (plate) had plans for early use. Demand for the material was such that it seemed easy to make a case for early requirements for substantial tonnages and a proposal was made to DTI to provide a £3 million grant for the construction of a melting and casting facility on the British Alcan Plate site at Kitts Green. This comprised a scavenged casting pit, based upon that tested at Chalfont Park, together with a high frequency melting furnace and a holding furnace in which the lithium additions were made while the atmosphere was controlled with argon. The development was completed in early 1985 and allowed the Alcan ingot size to be increased to 3000kg from the 1000kg maximum with Chalfont Park cast ingots. Randy Hilditch of Kitts Green supervised the project.

Plate development included determining the optimum combination of stretching and heat treatment temperature in order to achieve the best strength/toughness balance within acceptably short ageing times. After the Chalfont Park foundry closed there was a regrettable hiatus before the Banbury casting pit was converted to scavenged operation, but development of extrusion billet casting practices then followed (Roger Wilson, John Worth and Brian Gillett).

The first use of 8090 in a structural flying situation was provided by the USAF/NASA demonstrator programme to investigate the use of vectored thrust to create STOL capability and employed a McDonnell Douglas F15B as the test vehicle. The first part of the programme consisted of substituting 8090 plate for 2014T8 as the aft upper wing skin. The modification resulted in a mass saving of X kg together with improving the aircraft's performance from ±6g to ±9g. There were plans to use a single, larger 8090 plate to replace two of the original 2014 plates but, sadly, Kitts Green failed to deliver the necessary material. The BAe EAP (Experimental Aircraft Programme, in effect a Typhoon prototype) had been constructed with thick 8090 sheet belly skins and thin 8090 plate for the flaperon skins and this aircraft, too, made its maiden flight at about the same time.

McDonnell Douglas F15 short take-off and landing demonstrator in flight. Gold coloured A.A.8090 plate in upper wingskins.

From a relatively early stage considerable enthusiasm for the alloy was demonstrated by the Lockheed Missiles and Space Company (LMSC). This was during President Reagan's "Star Wars" period so that there was ample funding in the US for relevant programmes. Initially our material went into the manufacture of hardware referred to by Lockheed as the "Gorilla Cage" and, presumably, a military satellite. This was a complex cuboidal structure of roughly 3 metre side where the corners were machined from triaxially forged, cold compressed 8090 (by High Duty Alloys Forgings, Redditch) welded to 8090 extrusions for the edges. Large associated development programmes were conducted by LMSC, HDAF and Banbury and one of the "break throughs" in the welding programme was the suggestion, by Maurice Reynolds, of the use of a high zirconium Mg-Zr alloy as filler. Later LMSC programmes included the payload adaptor for the Titan IV rocket, largely constructed from 8090 plate.

While interest was strong in all the product forms, it became clear that the earliest significant commercial applications were likely to be with sheet. The designs of the new Airbus A330 and A340 aircraft were at an advanced stage and Deutsche Airbus, as the Airbus Industrie partner responsible for fuselage design and manufacture, were very advanced in their investigations into the use of Al-Li based alloys as a substitute for 2024T3 in the pressure cabin. Their investigations included assessment of Pechiney's 2091 and Alcoa's 2090 as well as our 8090. However, for a while, it appeared that 2091 would be the alloy of choice for damage tolerant applications and we actually went to a meeting in Bremen to concede defeat. To our great surprise, at the meeting Deutsche Airbus announced that they had found unacceptable thermal instability in 2091 and that, therefore, 8090 had become their preferred alloy. They also made clear that they wanted Alcoa as a supplier of 8090. In consequence, Alcoa took a licence from Alcan that would allow them to manufacture 8090 sheet and thereafter Alcan and Alcoa supposedly collaborated in the further development. Nevertheless, Alcoa's participation was always half hearted and it was quite clear that, at least, the people responsible for Alcoa's technical development did not want the alloy to be a success. For our part, Deutsche Airbus range of requirements included wide, long, relatively thick sheets that were beyond our Falkirk factory's size capability and we had extremely good collaboration with Hoogovens Aluminium Koblenz in rolling and heat treating ingot supplied from Kitts Green.

While these activities were going on with the potential users, Banbury development was endeavouring to establish the optimum sheet structures for medium strength and damage tolerant applications. Eventually, it was concluded that two variants were required, one with a low zirconium addition (0.05%) to allow recrystallisation to a fine grain size for damage tolerant material and one with a higher zirconium addition (0.15%) for medium strength and superplastic applications (Bill Miller, Ian Palmer).

As the Deutsche Airbus internal testing programme developed, concern was expressed at the tendency, with some batches, for fatigue crack deviation during fracture toughness testing. It was feared that if such deviation occurred in a real fuselage the crack might evade the crack stoppers that are built into the structure. Excellent work was done on the problem by Kevin Gatenby and it became clear that the phenomenon was related to crystallographic preferred orientation, albeit it was not fully explained before the development ended. While Deutsche Airbus was never fully committed to build the pressure cabins of their new vehicles from 8090, they included significant quantities of the alloy in their full scale barrel test for the A330/340. Their philosophy in doing this was to qualify new materials, such as 8090 and GLARE, at the same time as more traditional alloys and thus leave their freedom of materials selection open.

Very large sums had been spent with this application in mind. Quite apart from the huge expense to Deutsche Airbus of their internal programmes, RAE had, specifically for the Airbus fuselage application, developed their testing facilities to enable measurement of fracture toughness with 2 metre wide panels while our own internal programme had absorbed much manpower. While problems with damage tolerant 8090 sheet certainly still remained, there was no reason to suppose that they were insoluble when British Alcan delivered a fatal blow to the Deutsche Airbus project, and a major blow to the whole Al-Li programme, in announcing their intention to cease manufacture of all aircraft sheet at Falkirk. No prior warning was given and British Alcan's top management did not see fit to discuss, or even explain, their decision with their equivalent management level in Airbus Industrie and it was left to the writer to inform Deutsche Airbus that they had, in effect, been wasting their development efforts for the last several years.

In terms of Alcan's potential Al-Li products, this immediately eliminated virtually any possibility of significant sheet applications in civil aircraft, simply leaving the limited size, medium strength/superplastic sheet variants made on the Dolgarrog mill. BAe remained reasonably committed to 8090 and each of the fourteen Eurofighter (now Typhoon) prototypes contained over 2,000 parts in the alloy including three large superplastically formed components. However, these were all in the front fuselage (for which BAe had responsibility) and the overall design left the aircraft's centre of gravity too far back, so that there was no benefit from reducing the weight of the front end of the aircraft. While MBB, who had responsibility for the rear fuselage, were favourably disposed to employing an Al-Li based (plate) alloy, they did not regard 8090 as being sufficiently strong. While our 8091 plate (Bill Miller) did, on occasion, achieve the required combination of strength, toughness and short transverse ductility, it did not do so consistently and casting problems were never fully resolved.

Undoubtedly the most successful aircraft project in the entire Al-Li programme was the Westland/Agusta EH101 helicopter. This is a large, three engined machine intended to be suitable for air/sea rescue and anti submarine warfare but also with civil variants. The main lift frame is manufactured from cold compressed, large, 8090 die forgings (a major innovation) and there is also extensive use of 8090 extrusions and sheet. Over 90% of the aluminium alloys in the helicopter are Al-Li based. While, traditionally, the lift frame would have been constructed from 7010 plate resulting in an extremely low fly/buy ratio (<10%), the die forgings developed in conjunction with Otto Fuchs of Meinerzhagen resulted in greatly more efficient use of the 8090. The helicopter, now known as Merlin, has had a distinguished service life, users including the Royal Navy, the Royal Air Force, the Italian Navy and the Danish Air Force.

The collapse of the Soviet Union between 1989 and 1991 was the eventual death knell for the aluminium lithium programme. With the end of the cold war the western military rapidly became more concerned with cost of acquisition rather than the ultimate in performance so that the newly developed alloys were perceived as too expensive when related to the performance benefits that they brought. As far as the civil builders were concerned, the dramatic increase in the price of jet kerosene that Boeing had forecast in 1982 did not take place. In 1983 the prevailing price was about US$1 per gallon and they forecast an increase to more than US$2 per gallon by 1990. Thus the cost of operating a fleet of large passenger jets seemed likely dramatically to increase and it would be worth paying significantly higher material costs in order to reduce aircraft mass. In reality, the price actually fell to about US$0.80 over that period and the amount that the civil builders were prepared to pay to save mass fell to a level that, given the price of lithium, could probably not have been achieved.

Had the aluminium industry, at the outset, taken a broader view to the new development, it is quite possible that the end result would have been very different. The opening plenary address at the Fourth International Aluminium Lithium Conference in 1987 was given by J P Roeder, Technical Director of Airbus Industrie. While expressing enthusiasm for the development of Al-Li based alloys he begged the (aluminium) industry to follow the lead of the aircraft industry and “very seriously consider the merits of cooperation”. We dismally failed to do so, and only when it was already too late did we embark upon half hearted collaborations with Alcoa and Pechiney (and we rejected an approach from the Japanese Alithium consortium because, in the view of Alcan management, they had entered the game too late). Had the huge sums of money that were spent by Alcan, Alcoa and Pechiney been spent on a coherent Aluminium Industry Aluminium Lithium Programme, with an agreed target of three alloys, it seems reasonable to assume that appropriate alloys could have resulted far more quickly, larger scale use might then have been achieved and realistic knowledge of the cost of the alloys when in quantity production could have been obtained. Instead of which we have the Boeing 787 made from carbon fibre composites and titanium.

As a postscript it is, perhaps, worth pointing out that although overall the programme had, at the outset, strong central support from David Culver and Hugh Wynne Edwards and some strong local support (notably Derek Sharrock at Kitts Green), it is difficult to escape the conclusion that, despite its size, Alcan had neither the equipment nor the mind set to play in the aerospace big league. Although it can be argued that in this development, Alcan (plus RAE) technically led the world for a considerable time, commercial failure was probably inevitable with the retirements of the above individuals.

12c. Aluminium Lithium Development Postscript

The aluminium lithium story did not end with the demise of the Banbury research programme, the sale of Alcan’s aerospace operations and the switch to carbon fibre composites by Boieing and Airbus for their largest aeroplanes (A350 and Boeing 787). Alloy development continued both within Alcoa (for Boeing) and Pechiney (for Airbus) and a third generation of aluminium copper lithium alloys was developed. This development concentrated on strength and fatigue crack growth improvement using a reduced lithium content compared to the earlier alloys and optimization of thermomechanical processing.

The potential size of the opportunity for Alcoa and Constellium (from the Pechiney developments) for the manufacture and sale of aluminium lithium alloy plate and sheet is enormous as the demand for new aircraft for both military and commercial use is growing strongly. Over the next 30 years, both Boeing and Airbus project demand for approximately 19,000-23,000 single-aisle aircraft like the 737 and the A320 where aluminium is preferred over composites. The latest aluminium lithium alloys enable improvements in structural performance while utilizing the current manufacturing supply chain, thereby reducing manufacturing risk, and with investment can support the required manufacturing rate. Overall, between 28,200 to 34,000 new aircraft are expected to be delivered to meet growth and replacement needs over the next 20 years.

Constellium opened a new aluminium lithium foundry in Issoire in March 2013 to produce their third generation alloys now called Airware. The new casthouse has the capacity to produce 14 ktonnes of aluminium-lithium per year. Airware's first two customers, Airbus and Bombardier, use the alloy for the A350 XWB long-haul twinjet and the 100- to 160-seat C Series, respectively. The capacity of the Issoire plant is projected to double by 2016 and by then will produce enough aluminium lithium alloys for 140 A350s per year at 75 to 80 tonnes per A350. As the buy-to-fly ratio is close to 20%, machining processes produce more than 60 tons of turnings that are all recycled back into new alloys. In 2012, Constellium's aerospace revenues were $845 million.

Alcoa is projected that its revenue from aluminium lithium alloy sales will quadruple by 2019 to nearly $200 million. They have completed their expansion of aluminium lithium capacity at the former Alcan Kitts Green plant to serve the growing demand for the third generation aluminium lithium alloys. The completion of the Kitts Green expansion was announced at the Paris Air Show in 2013. Alcoa are also expanding in the US with a new $90 million facility to be completed by the end of 2014 in Lafayette, Indiana, that will provide an additional 20 ktonnes of aluminium lithium alloys in sizes compatible with the largest aluminium aerospace components in service today.

The latest third generation aluminium lithium alloys provide the best strength-to-weight performance combined with better stiffness, damage tolerance, and corrosion resistance. The alloys are used in extrusions, forgings, sheet and plate applications across aircraft structures, including wings and fuselage components. The use of these alloys has the potential to increase fuel efficiency, reduce inspection intervals and improve passenger comfort whilst lowering capital costs for aerospace manufacturers. The aerospace business worldwide spearheaded by the third generation of aluminium lithium alloys is worth multi-billions of dollars in terms of value- added revenue to the aluminium industry.

13. DEVELOPMENTOF CONTAINERS FOR THE PACKAGING MARKET AT ALUMINIUM LABORATORIES

An Essay by Alec Lovell of Aluminium Laboratories Limited 1949-1960

Introduction

In the years immediately following the end of World War II Alcan or Aluminium Limited as it was than styled, was in great need of expanding the worldwide market for ingot produced mainly in Canada. It was evident the way to achieve this end was through the development of new end products for certain potential major defined markets. To accomplish this aim the establishment of a combination of research and development activities concentrated in a restricted number of locations throughout North America and Europe was foreseen.

The main markets considered were building products, transportation, electrical and packaging. The centres chosen for activity were Kingston, Ontario: Banbury, UK; and Geneva, Switzerland. Banbury was selected to be the laboratory where development work was carried out in the field of applications of aluminium in the packaging industry.

In order to start work without delay the policy decision was made, where appropriate, to recruit experienced and qualified individuals from the specific market areas concerned.

In the case of the packaging market it was decided to concentrate on the development of the use of aluminium in the packaging industry with particular emphasis on the aluminium can.

In each of the respective markets it was decided to hire a suitably experienced individual to direct the development programme.

The leading can maker in the UK immediately after the War in 1949 was The Metal Box Company Limited (MBC), which possessed a Research Department employing more than 100 staff, and with close connections to Continental Can Company in the USA and the Food and Quick Freezing Research Association in Chipping Campden. The main laboratory was at West Acton in a suburb of London. Other centres were at Neath in South Wales and Perrywood in Worcestershire.

The person hired for the job was Alec V Lovell, a graduate in Chemistry with wartime experience in a Royal Ordnance Factory in the production of cartridge brass shell cases made by the cupping, drawing and ironing process. This latter experience was to prove a strong influence on the direction of development on the aluminium cans ten years later.

The range of experience gained during four years spent in the can making materials section of the Metal Box Research Laboratory was extensive. It included the effects of can design on the integrity of side and end seams and their effect on the performance of built-up (three piece) cans. Work also embraced that of cans made by the blanking and cupping process from pre-lacquered sheet.

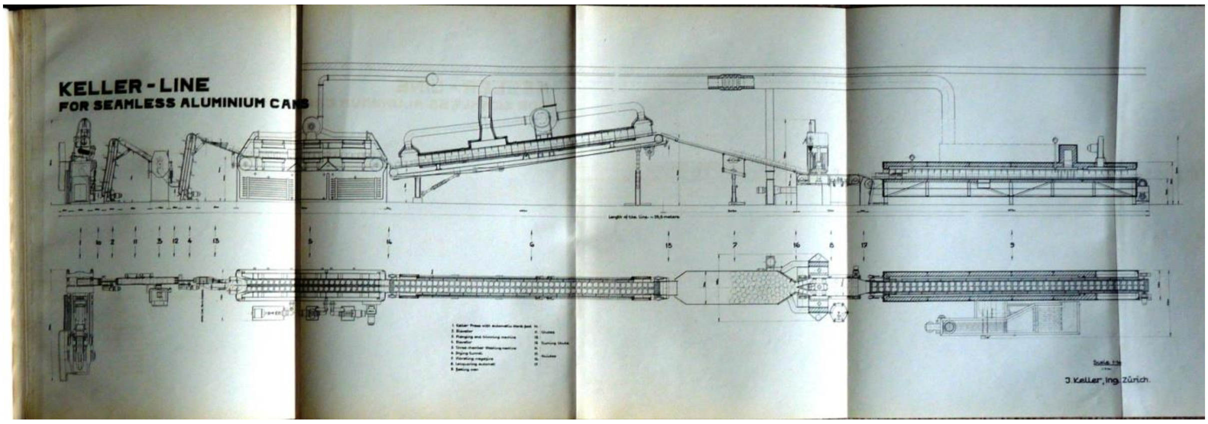
The four years spent in the Research Department of The Metal Box Company provided an excellent perspective of the non-food ‘general line’ metal container and the processed food industries from basic material to finished and product-packed can, thus providing an excellent foundation on which to base the future development of the aluminium can. The time spent also provided experience in the techniques for carrying out bio tests on containers for processed foods.

Can development at Aluminium Laboratories Limited (Alulabs)

Preliminary visits

Alec Lovell joined Alulabs in April, 1949, reporting to D W Taylor and to F R C. Smith, the then, Director of Development activities. At this stage there existed no facilities, neither buildings nor equipment for experimental and practical work to be carried out. The immediate plan was to make organized trips to the two countries where aluminium had been used under war-time conditions for can-making and to study what had been achieved. These were Switzerland, where drawn and ironed (Keller) cans had been used for the packing of milk products, and Norway, where shallow drawn cans for packing sardines had been produced from continuously anodized strip and from continuously anodized and lacquered coiled sheet.

The visit to Switzerland took place in May 1949 and the party consisted of Dr. E. G. Stanford (Physics), Mr. Patrick Murphy(Chemistry) and Alec Lovell(Development). Visits were made to condensed and powdered milk packing plants, to the offices of Engineering Consultants Keller A.G. and to CIBA, producer of the recently developed and patented class of epoxy-vinyl resins used in the manufacture of high speed, high temperature baking coatings.The visit to Keller was to prove hugely significant because of the close relationship that developed between Keller and Alulabs.



The Keller line as conceived by Laboratories and engineered by Keller A.G.

The visit to Norway was in mid June 1949. The party included Dr. R. T. Parker, H. (Bert) Glendenning (Northern Aluminium Company), Pat Murphy and Alec Lovell. Time was spent at the Holmestrand Works of Nordisk Aluminium Industri where the two products - continuously anodized and sealed coiled sheet, and anodized and lacquered coiled sheet, were produced.

The second part of the trip was to Bergen on the west coast of Norway to see fish cans being packed and processed. Of particular interest was the use of over-pressure autoclaves to prevent distortion of the weaker (compared to tinplate) cans during the autoclaving process. This method of processing was the basis of the processing method used universally for the sterilization of the weaker aluminium fish can in the future.

During the visit, samples of sheet, for examination at Alulabs, and a range of cans for hot-room and ambient storage tests were obtained.

In December Alec Lovell returned to Nordisk Aluminium Industri to collaborate with Knut Nilsen, the engineer responsible for Nordisk's anodizing and coating lines, in the writing of a technical report describing in English their design and operation.

The start of the development programme

As part of Aluminium Limited's residential building development programme, a Canadian-designed aluminium-framed Kingstrand house had been erected at the rear of Laboratories in Banbury. Since the structure was of suitable size it was decided to fit it out as a small can development laboratory. Mr. J H Mantle (Jack) was hired from the Research Department of Metal Box Company to take charge of day-to-day-work in the canning laboratory. Jack had valuable experience in the evaluation and testing procedures of food containers and also had valuable experience in bacteriology.

The first step was to assemble a range of equipment for producing and testing cans made by the cupping and drawing process together with an associated can end. A second-hand 40 ton mechanical press was purchased for this purpose and the press tools were designed and made in the machine shop. These were mounted in die sets so that the tools could be changed quickly and easily. Can bodies require to be flanged to accept a double seamed can end. To do this easily a simple hand-operated die-flanger was purchased from Metal Box Company together with a basic standard MB 1A hand-fed double seaming machine. The can ends when placed on the can could be double seamed so replicating the action of the commercial process.
For the testing of lacquered sheet more equipment was needed. In the can-making industry lacquers are applied by the roller coating process which requires quite complex equipment. For our purposes roller coating was too cumbersome a method. We elected for the system of applying liquid lacquer to a spinning sample sheet clamped in a horizontal position on a horizontal disc and rotated at a modest speed. A small amount of lacquer was poured on to the spinning specimen and by experience a judgment of the required time of application was made. Stoving or baking of the specimen was then carried out in an electrically heated laboratory oven with air circulation. This method replicated the conditions of the commercial process and was ideally suitable for our future work. Furnished with this equipment we were then fully equipped to carry out the entire range of testing work on pre-treated and lacquered specimens.

Anodizing versus chemical methods for pretreatments

In development work, having a little luck is always invaluable! And we were most fortunate!

In a then-current trade magazine there was an article that caught our eye. This originated from the Paints Division of ICI. It was primarily aimed at the pretreatment of aluminium sheet for architectural applications where there was little actual distortion of the surface of this product due to subsequent forming operations. The question was – Would the application of ALOCROM or ALODYNE films be effective as a pretreatment in very light form on relatively thin aluminium where there is substantial disturbance of the surface in subsequent forming operations? Accordingly a visit was arranged to ICI's Slough plant and our interest discussed. Our proposals were accepted enthusiastically by ICI and plans were developed for a collaborative experimental programme.

Preparation of samples for evaluation

Sheets of 3S ½ H material, about 6 square feet in area were cleaned using an aqueous commercial cleaner and dried. These were transported to Slough where the chemical pretreatment was applied. After cutting up into a suitable size these were ready for lacquering and forming in the cupping operation. As a control on the tests a similar set of specimens was produced using anodized films as a pretreatment in a range of thicknesses.

Results of the tests

On carrying out the test procedure the results were dramatic:-

Whilst the use of even light anodized films as a pretreatment resulted in break-up of the lacquer coating on forming the can, pre-treatment using light chemical films yielded outstanding performance and integrity of the lacquer film. This progress offered the strong possibility of developing much-improved drawn cans and ones with significantly wider potential commercial applications.

Development of cans produced by the cupping, redrawing and flange trimming process

The potential advantage of a relatively deep aluminium can over a three-piece built-up, side-seamed-soldered tinplate can is enormous. The deep aluminium container can be produced in a few simple pressing operations compared to the complexity of the three-piece can-making process. Moreover, the potentially hazardous use of tin-lead solder for joining the side seam was eliminated.

Experimental tools were made in the machine shop to produce a cup of suitable size, a redraw die to form the deeper cup and a trimming die to complete the flange of the can. Sample cans were made in the laboratory from a range of pretreated sheet samples and these converted into experimental cans. The results of the evaluation tests were highly encouraging and a meeting took place with members of Metal Box Company. Their view was that, although the test results were undoubtedly encouraging, the cans were so relatively light they would be difficult to handle under commercial manufacturing conditions. To answer this criticism a series of commercial can-handling conveyors typically used by can packers was purchased (from Metal Box Company) and a demonstration test rig was set up in the laboratory.

As a result of the can handling investigation it was unequivocally demonstrated that light aluminium cans could be successfully conveyed and handled using commercially available conveyor systems.

Commercial application of the cupping redrawing and flange–trimming process using chemically pre-treated and lacquered sheet

The underlying aim of the work on aluminium container development was to encourage can makers to use the technology and buy the treated aluminium sheet from the aluminium industry. To ensure that the work was in the public domain and to protect it, it was decided to publish an account of our work in a prominent engineering journal. This, together with widespread reporting throughout the Alcan

Group, resulted in the interest being expressed by Central States Can Company of Massillon: Ohio through Alsales in New York. The outcome was a visit by Jim McClusky, President of Central States to Banbury to discuss our work and to explore the possibility of developing the process to the commercial stage.

The Central States company was enthusiastic about the process and collaborated with Kraft Foods in the USA in the development of the double drawn can for a new range of milk-based products using coated coil lacquered material made by Kaiser. The business grew tremendously and Central States expanded to be a major producer of double drawn aluminium cans.

Introduction of drawn and ironed cans into the experimental programme

The work with the Keller Press had demonstrated the value of the process for the production of aluminium cans whose height was greater than the diameter. A Keller press was actually purchased by Metal Box Company but the company had discontinued development work on drawn and ironed cans because of uneconomic cost forecasts. We, being less discouraged, suggested to Metal Box that we arrange for the indefinite loan of the press for our development programme. This they were generous enough to agree to do. The eventual results of our work would be freely available to can makers who would have the opportunity of following progress. The transfer of the press to Banbury was arranged and it was located in the new canning laboratory.

The feedstock for a Keller press is a fully annealed disc of commercially pure aluminium. In a single stroke of the press the disk is formed into a cup and then, in a long stroke, the walls are reduced in thickness by passing through a series of ironing rings. The resulting shell is then trimmed and flanged in separate operations.
At this stage in our work it had become apparent that the future of the aluminium can was in two forms:-
cans drawn in one stroke and cans drawn in two or more strokes, both types being made from continuously chemically pretreated sheet which, in a subsequent continuing operation, was lacquered on both surfaces and then baked.
Cupped redrawn and ironed cans made from stronger alloys, washed, chemically pretreated, spray coated with lacquer and baked in a continuous oven.

These are the two basic can-making methods in use today (2010) for many types of steel cans as well as aluminium containers.

Development of process for continuous cleaning of D&I cans

The basic process of cleaning a light, hollow shell is to first wash the can in an alkaline cleaner such as is used in bottle washing operations, rinse with clean water and dry using hot air. To enable the process to be continuous a pilot plant was designed consisting of a horizontal open wire-mesh conveyor on which the cans were placed, mouth down. There were three sections in the washer - hot wash with detergent, hot water rinse and drying. The cleaning and rinsing sections were each served with two sets of pumps providing pressure supplies of cleaner and water to stray jets located above and below the mesh conveyor belt. By adjusting the force of the sprays so that the downward acting force exceeded the force on the cans from the lower sprays, it was possible to keep the cans on the belt during the cleaning process.

The experimental programme provided the data on the practical range of the variables of temperature, concentration of cleaner, and time required to clean the cans for the design of a production machine. The chemical pre-treatment of cleaned cans was carried out by hand dipping, washing and drying.

Can-packing and testing at the Fruit and Vegetable Research Association at Chipping Campden

The laboratories of the Campden Research station were fully equipped for the filling and processing of acid (fruit) and non-acid (vegetable) products. The canning programme on the deep drawn and ironed chemically pretreated and spray lacquered cans comprised room temperature and elevated temperature storage tests. Typically, all metal cans containing acid foodstuffs fail by corrosion which results in the evolution of hydrogen gas and the can becomes distorted (known as a hydrogen swell). Organoleptic (taste) tests were made and yielded promising results.

General results of the work

The results of the tests on the canning of vegetable products (neutral in acidity) were encouraging. There was no taint from the lacquered can. The indications of the tests were that, technically, vegetable packing in aluminium cans would be feasible and failure by corrosion would not be a problem.

The results of the test on acid fruits were less successful and the conclusion was reached that commercial packing of acid foodstuffs, even in chemically pretreated and spry lacquered cans, was unlikely be commercially feasible.

Work involved in other packing tests using aluminium Keller-type drawn cans.

Encouraged by commercial results obtained in Switzerland with sweetened, condensed milk and with evaporated milk packed in cans protected from corrosion by batch anodizing and water sealing, we embarked on a test packing programme in Sweden. The company collaborating was the Harlosa Mjilk Industri, a dairy co-operative in Sweden. The quality of evaporated milk is very sensitive to processing conditions. Over-processing or lack of agitation in the sterilizing process results in yellowing of the product. At Harlosa a specialized type of autoclave was employed. Even though it was essentially a batch process by applying a rocking motion to the baskets containing the cans, it was possible to produce a product of superior quality.
The work on aluminium can development was widely reported throughout the Alcan group of companies, and through Alsales in New York it came to the notice of George Malby of the Chicago Alsales Office. George contacted the American Dairy Association in Chicago, who in turn, requested sample cans that were sent for examination. The quality of the contents was found to be unusually high compared to tinplate-equivalent cans – so much so that a Laboratories' representative was invited to visit the offices of the Dairy Association in Chicago. Alec Lovell went to the USA and gave a presentation to members.

The results were accepted as being interesting but there was no follow-up. There was, however, a consequence of the highest significance.

Commencement on the work on the 12oz aluminium beer can

An American business man, Lou Bronstein, who had made his fortune during the Second World War acquiring depressed dairy companies in the USA, was actively interested in the use of aluminium cans for the packing of processed and also non-processed milk products. Through the agency of the Montreal Head Office, Lou was introduced to Mr. R. D. Hamer, Vice President of Aluminium Laboratories: Banbury. As a direct result of this introduction, Messrs. A V Lovell and E G Maeder accompanied Mr. Bronstein on a series of visits to milk packing cooperatives in North Germany. Once more there was no commercial outcome. However, during the trip to Germany, through Aluminium Werke Goettingen a visit was made to the Henninger Brewery in Frankfurt which was engaged in the filling of black-plate side-seam welded three-piece cans for the US forces in Germany. The quality of the canned beer was far from satisfactory and we considered that it would be possible to produce a can from aluminium by impact extrusion, Goettingen already having a great deal of practical experience with the impact extrusion process.

An agreement was made between Goettingen and Laboratories to design an automatic production line based on a single P8 Herlan impact extrusion press to form and clean and decorate 60 cans per minute. The mechanical elements of the line and the can cleaning equipment were sourced in Germany while the printing and decorating equipment were purchased from Winkler Fallert in Switzerland. Mr. E. G. Maeder and later Mr E. A. Wooton played important parts in the commissioning and operation of the Goettingen Line.

The effect of publicity of the Laboratories/Goettingen can line on aluminium can development

An article on the aluminium beer can line in Goettingen was published in a UK packaging trade journal and aroused much interest since copies of the article were circulated widely among Alcan companies both In the UK and overseas. This stimulated visits to Goettingen and to Banbury by members of the international can-making fraternity.

Programme of work on beer cans.

At this stage there were two main streams to the work being carried out on the beer can:-

The production of sample fully decorated impact extruded cans for packing tests in Germany, Holland and Denmark.

Investigations into impact extrusion as a commercial means for producing can bodies.

In this latter connection a P8 Herlan Press was sent on loan to Banbury. The press was fitted with load and displacement gauges so that the loads generated during production could be analysed. The results of this work demonstrated that the impact extrusion process is fundamentally susceptible to causing wide variation in the dimensions of the finished can. The reasons for this were not fully understood. It was, therefore, decided to borrow a Herlan P8 press from Goettingen and to install it in the Banbury laboratory. Once there it was equipped with strain and punch-displacement gauges so that the image of the operating conditions of load and displacement of the punch could be displayed and photographed on the screen of an oscilloscope. The results cast doubt on the viability of impact extrusion as a commercial process for precision can making.

The underlying reason was:-

The thickness of the base of the can was highly sensitive to the operating conditions involving the amount and quality of lubricant, the temperature of the system and, in spite of being relatively short and stubby, the punch proved to be quite compressible. Added to this factor the frame of the press itself was quite elastic and stretched with the load. The result of these limitations was that it was not possible to control accurately the dimensions of the finished can.

This conclusion prompted a fundamental shift in our plan for beer can development.

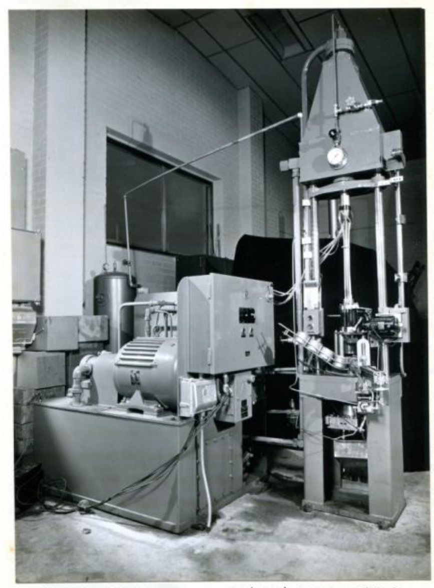


Figure 5. Hydraulic press, showing (right) the press and tools and (left) the power unit and oil storage tank.

The new approach was to blank and form a cup, then in a second operation, redrawing it into a deeper and smaller diameter cup. Then, in a third continuing operation, to pass the redrawn component through a series of ironing rings so that the wall of the component was reduced in thickness.. In this way, rather than using fully annealed blanks as in the original Keller process, it was possible to use work-hardened sheet as the starter stock. This method had two major advantages:-

It became possible use of work-hardened can body stock rather than using annealed discs.

The can body and the base itself was stronger and the latter could be given a strengthening dome-shape contributing to its resistance to internal pressure.

Work at Laboratories on cupped, redrawn and ironed cans

Following the recognition that the future of beverage can making lay in the direction of multiple cupping, redrawing and ironing, the decision was made to purchase a hydraulic press so that the loads and forces involved in the various operations could be measured. The availability of the press enabled us to develop the design of the press tools and to produce sample cans for experimental work.

Commercialization in the USA of the cup, redraw and ironing Process

The work being carried out at Laboratories and in Goettingen was well publicized and visits to the UK and Germany were frequent. Edward G Maeder, at the time, already involved with the can line in Germany, was recruited by Charles G Kinghorn of Kaiser Aluminum's development department to go to Chicago to join Kaiser. In association with Kraft Foods, Kaiser planned to install on automatic can line to produce a deep two piece drawn can. This end was achieved successfully and production commenced. Existing business was taken from American Can who then raised the question of conflict of interests - “Was Kaiser in the aluminum industry or was it a can maker?” The outcome was that Kaiser closed down the Chicago line!

E. G Maeder, who was left jobless, took the initiative and approached Reynolds Metals Company, through Vice president W. Reynolds, head of developments, with a presentation for a D&I can line for aluminium beer cans. The proposal was accepted enthusiastically and the association developed into a close one which resulted in Reynolds becoming a significant force in the production of aluminium beverage cans. Reynolds were responsible for the development of the attached-d tab easy opening end, the use of which displaced the earlier ring-pull easy opening ends This latter end was the direct result of extensive work carried out by Alcoa but later abandoned because the discarded tab caused so much environmental damage to bird life.

Continuing work on shallow drawn fish cans

Dating from the start of can development at Banbury the market for the aluminium fish can had always been an attractive one. In the early days trials were made with Nordisk anodized and lacquered material in Morocco and in Portugal, the emphasis being on the packaging of sardines in oil. There was considerable interest in Portugal and it was decided to establish, in partnership with a Portuguese fish canner, a small can making operation styled Fabeal to produce aluminium ¼ Dingley cans and ends. Mr J J E Holden (John) of Alulabs was transferred to Lisbon to supervise the production of the cans. The plant itself was managed by Mr D C G Lees (Douglas) who was transferred from Aluminium Union London. Mr F G Knight (Frank) of Alulabs provided valuable back-up support to the team. His experience at Fabeal was to prove invaluable for work later in Germany with the development of the aluminium Hansa Can for the packing of herring.

Initially, in Portugal, all went well and then it was observed that, immediately after opening a can there was a noticeable and distasteful sulphurous/ammoniacal smell. This dispersed within a few seconds of opening the can but was nevertheless considered to be a real disadvantage.

The problem was eventually overcome largely because of the skill of Mr J H Mantle earlier employed at Alulabs and it was his work with the Portuguese Food Ministry eventually identified the problem which was caused by the reaction of the constituents of the lacquer and the fish product.

Frank Knight’s contribution in Germany was focused on the design of the press tools. Usually the use of tools designed specifically for tinplate can bodies for working with aluminium, is completely unsatisfactory. The different moduli of elasticity of the two metals results in increased “spring-back” when aluminium is employed. This difference has to be compensated for by substantial changes in the design of the press tools and Frank found a way to accomplish this.

Retrospect and reflections

As this is written in the year 2010 the market for high quality, mill-finish, coiled sheet and pretreated sheet has become probably <u>the</u> most important for aluminium. This market extends to all the major countries and recycling of used cans and process scrap has proved to be a powerful economic advantage.

At the outset of our work at Laboratories some severe limits to the future market seemed inevitable. However, as work progressed and with the, then, current development of the beverage market our horizons widened as did the scope of our efforts.

The efforts of that small team in Banbury, supported by vigorous investment in development work, principally in the USA, ultimately yielded a return beyond their wildest dreams.

There is a Chinese proverb which says:-
"The longest journey starts with the smallest step."

So it was with Canning Team Laboratories.

14. STRUCTURAL INTEGRITY OF ALUMINIUM AND ITS ALLOYS

Roy Woodward

Introduction

From its early beginnings in the fourth decade of the 20th century, Alcan's laboratory in Banbury set out to equip itself with machines and people capable of measuring those properties of the materials, developed and produced by the company, that needed to be known for their satisfactory use in existing and possible future applications. Also it recognized the need to be able to monitor the performance of products marketed by the company as well as to be able to compare them with a wide range of competitor materials.

Most of the early work involved a study of properties determined from tensile tests i.e. tensile strength, proof stress, ductility and elastic modulus. Also it was able to measure impact strength, fatigue performance, using simple tests on small carefully prepared specimens, and elevated temperature creep strength. Data from these tests were needed to ensure that Alcan's materials met the demands of specifications set by British Standards and similar bodies in Europe. Indeed much of the data was used in the preparation of adjusted or new standards, and laboratory personnel were much involved in these efforts. In this broad context staff produced, in addition to numerous internal reports, technical papers for publication in the journals of professional institutions and learned societies.

In all of these activities the people involved worked closely with other groups within Labs; working in the development of new alloys, surface studies and the evaluation of chemical and electrical performance, since most, if not all, of these interact with mechanical performance, often in very complex ways.

While the work was mainly concerned with what Alcan produced it was obvious at an early stage that many of the people involved needed to be concerned with 'where, why and how' the materials and their properties were to be utilised by existing and potential customers and to be able to examine, study and analyse any service failures should they occur. In consequence, close contact with company personnel who were engaged in developing new markets for aluminium was seen to be essential as well as the ability to deal directly with end users, when the need arose. Since few applications of aluminium involve the product supplied in the form of sheet, plate, extrusions, wire, forgings or castings without some additional processing by the user, such as machining, forming, or joining, a knowledge of how these factors influence final performance was seen as essential.

In the light of these developing needs Labs soon equipped itself to be able to test components and structures in form and size as near as possible to the actual end-use products and in those cases where that was not possible, to seek to employ facilities in other R&D establishments such as National Physics Laboratory, National Engineering Laboratory, The Welding Institute and also in customer plants, particularly when use in aircraft was involved. In many of these activities contact with the Kingston Laboratories was essential as was involvement with the design office in Geneva.

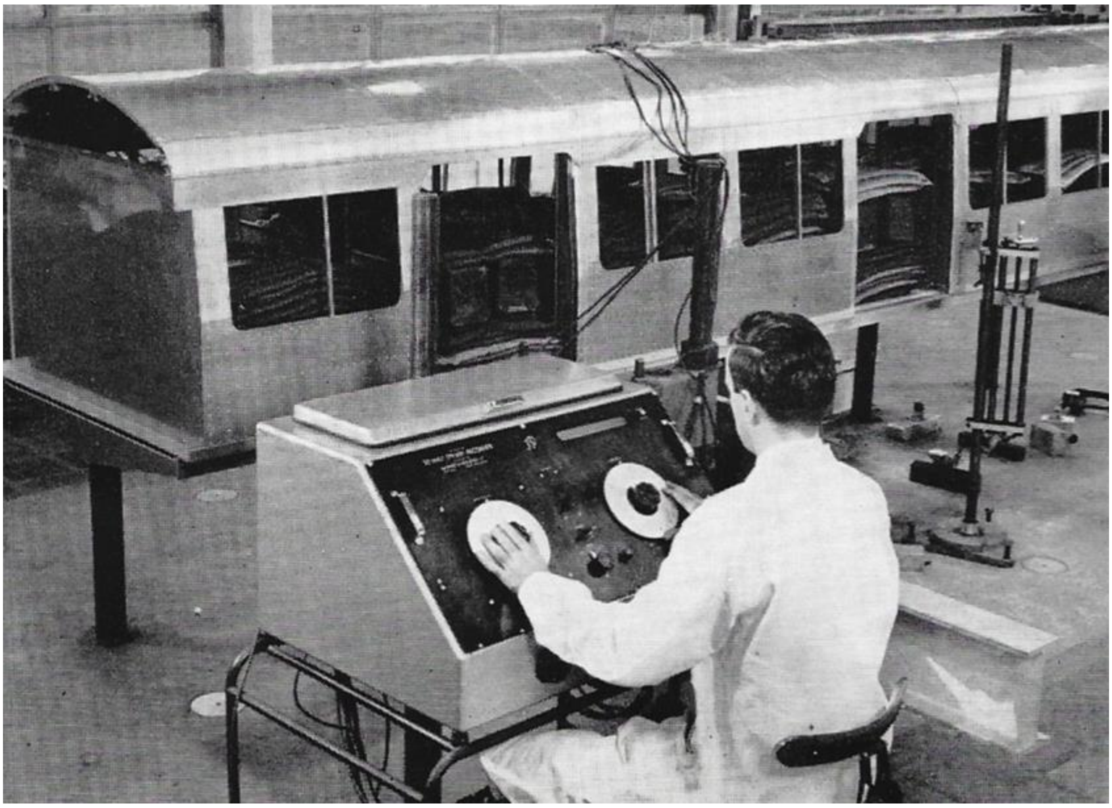
An effort has been made to illustrate some of the issues outlined above by use of specific examples. Some of the observations might seem to be obvious in the climate of 2013 and it should be remembered that many of examples chosen were happening 60 years ago without the benefit of equipment and instruments now available; it is however just possible that some lessons could still be learned from them! Examples are listed in something approaching chronological order but in some cases the practice has been adjusted in order to best illustrate as many of the quite complex factors involved in examples which occurred over a period of years in varying forms. Note that the work to establish the mechanical performance of materials at room and elevated temperature was needed also in the establishment of data for modelling of rolling and extrusion processes and is described elsewhere.

Use In Structures Subjected To Static Loads

The ease with which aluminium alloys can be extruded to almost any cross section shape, coupled with their low density and good corrosion performance led to consideration of their use in many structural applications which had previously been made in steel sections, which were restricted to a few simple profiles, and needed to be protected from the environment to avoid rusting. The calculation of the structural constants for each complex profile had to be made, a process which was be more taxing than that needed for steel in the days before computers, and Labs engineers provided the data needed to allow users to take full advantage of the sections. Such data, together with other issues relating to design, were used in the production of data sheets and structural handbooks produced by Alcan for customer use. Also, while the performance of the sections under bending, torsion and compressive loading, and combinations of them, was capable of calculation, it was necessary to test the validity of these by testing representative structures. To this end a Structures Testing Laboratory was built which had a reinforced concrete floor on which a variety of testing rigs could be arranged to accommodate a range of assemblies. Also included was a tensile/compression/bending machine with 100 tonne load capacity. The facility was also used for testing of sheet roofing profiles, which were being developed to replace galvanised steel.

Strain tests on a petrol tanker

A good specific example of the work undertaken is provided by the testing of a 1/3 scale model of a proposed London underground coach designed with the help of Alcan and Labs. The tests included the use of 100 electrical resistance strain gauges located at critical points. Proof of the value of this work can be seen today in the use of aluminium for all London underground stock!



Reg Smith testing the London Underground coach prototype

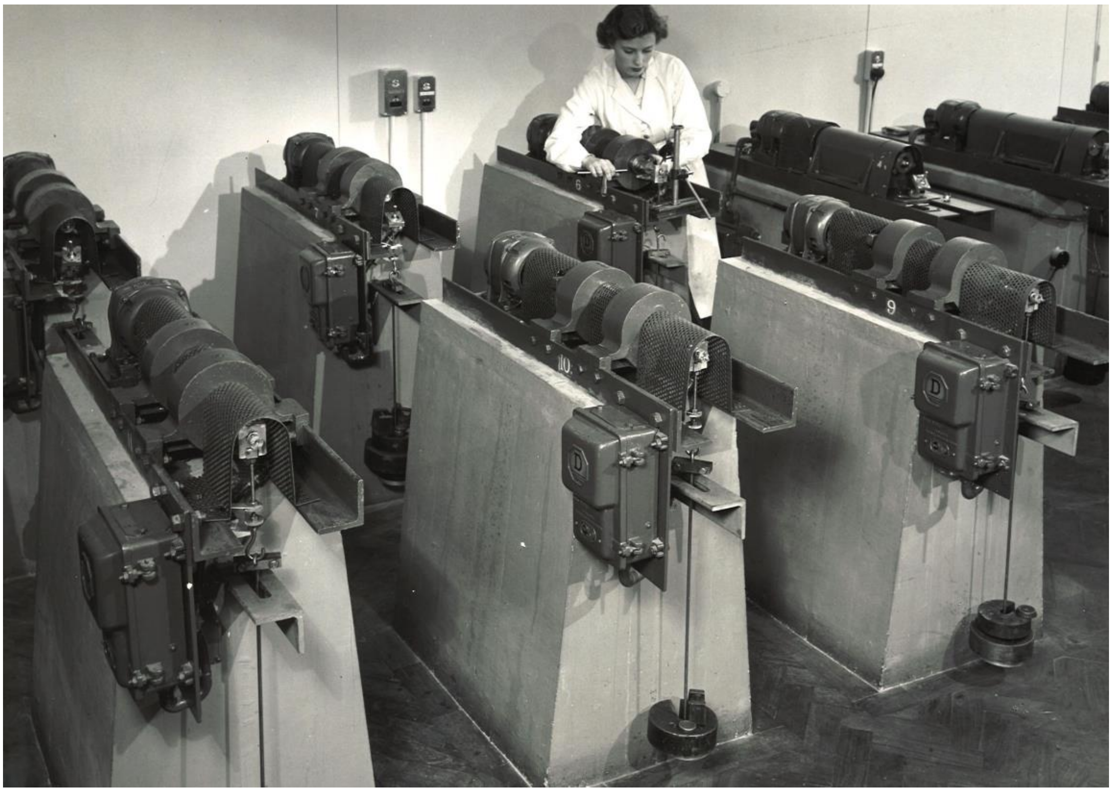
While this example was typical of many which proved a design, a study of a service failure involved considerably more expensive work which resulted in a very significant change of an ‘established’ alloy and the recognition that more control was needed in the extrusion process. An aluminium roof covering an open warehouse in a marine location collapsed. Extruded angle sections in an alloy produced to British Standards were found to have fractured at bolted joints. Although it was found that some of the bolts called for in the design had not been installed, and this certainly contributed to the failure, a full study of the mechanical properties of the sections was made together with a comprehensive metallurgical examination and an examination to establish if any corrosion had occurred. The alloy was in the 6000 series with a composition designed to combine relatively high mechanical properties with ease of extrusion at high speed to enable complex sections to be produced as economically as possible. Also it was possible to air quench the sections as they emerged from the extrusion die, thus providing the required solution heat treatment conditions, followed by stretching and artificial ageing. It was found that while the tensile and proof stress of the sections met the specification (and note here in those far off days all material was checked by the supplier in the context of mechanical properties) the elongation of the sections which failed was well below the specified level. But not all of the sections examined had the low ductility. Tests in Labs showed that when sections were loaded in the manner used in the roof, the stress at the bolted joint was much higher in the low ductility metal. The loading was transmitted through one leg of the angle and the uneven load distribution in the section with low ductility was causing premature failure to occur. The omission of some of the bolts, previously mentioned, did not help!

An investigation of the reasons for the low elongation in some sections showed that for the Al-Mg-Si alloy in question extrusion at high speed followed by air quench could result in low elongation if exit temperature was high enough and that even the careful check tests on the material could miss this deficiency. The composition of the alloy was adjusted and the speed control improved. This observed interaction between production parameters, inspection and properties is a feature of other examples, and resulted in much work on the control of the extrusion process. Some subsequent failures occurred in other applications in service but no material had to be withdrawn.

Structures Subjected to Dynamic Loading

While most of the work described above involves structures which were subjected to static loading, many others also required attention to the response to dynamic i.e. fluctuating loading, which if not taken into account could result in fatigue failure - a mechanism which causes fracture at much lower stresses than those which are produced by static loading. These issues were of particular importance in aircraft.

Strong aluminium alloys in the 2000 series (Al-Cu-Si-Mg) had been widely used for the manufacture of military aircraft in WW2. Fatigue failures in such aircraft did occur but was much less likely to result in loss when compared with that arising from enemy action! Also in the late 1940s, although fatigue had been recognised and investigated for many years, the methods for its study, its exact causes, means of prevention and detection were in their infancy. When military uses declined and civil air transport began to demand aluminium, fatigue failures became more evident all too frequently, when problems ranging from the need to replace cracked components to catastrophic failure, resulting in loss of life, occurred. Laboratories was well equipped to carry out fatigue tests on small carefully prepared specimens cut from plate, extrusions etc. but quickly realized that equipment for testing large, more representative ones, was needed. To remedy this 2 Amsler high frequency Vibrophores were purchased from Switzerland - they were the first to be used in the UK- and we developed equipment in-house to test complete sections. This awareness was soon shown to be wise when aircraft companies, NPL and others in the USA and Sweden began to be publish work which showed that tests on complete structures or components were yielding much lower fatigue strengths than those predicted from the formal small specimen tests. Indeed in many such studies it appeared that the actual strength was as low as 20 per cent of that previously predicted by formal tests. If such data was accurate it would have a serious effect on the reliability of aluminium. It would need to be taken into account in design, with aluminium becoming less effective as a weight saving measure, since design stress would need to be reduced.



Fatigue Testing Lab

Work over a five year period at Labs, as well as a massive effort by aircraft companies, while showing that some of the earlier reports were indeed very pessimistic, emphasised the need to test real ‘specimens’ and that the formal tests often reported in Data and Design sheets were indeed misleading. Labs findings are outlined below with note taken of work by others

Effect of Equipment used in test, specimen size and nature of applied stress

The Amsler Vibrophore had been designed to apply very accurate axial load in tension and compression to test a range of specimens and forms under fluctuating loads superimposed, when needed, on static ones thus matching to some extent the loading likely to occur in service. We were able to prove that much of the information published by those who were using less accurate test machines, many of which were in service, was faulty for the simple reason that the stresses calculated as causing specimens to fail were in fact much higher, because in addition to applying an axial load, additional bending stress also existed. Also these machines had been used to ‘show’ that large specimens gave lower results than small ones tested on other machines and while the Vibrophores allowed us to counter the full extent of this claim they were also able to show real reasons why big specimens could have lower strengths. In addition the effect of tensile and compressive stresses superimposed on the fluctuating stress was studied for a range of alloys and some modifications made in the previously existing theory to calculate them. Work using the Amslers showed that some alloys did have lower fatigue strengths when under axial load compared with bending test results on specimens of the same size and this was shown to arise from the fact that methods of fabrication in those alloys could result in microstructural differences which produced, in effect, a real size effect since the axial test exposed the whole specimen to maximum load whereas the bending test only involved a much smaller volume. Extension of this work to 7000 series alloys shows that if specimens made from large cross section extrusions were compared with same size specimens taken from small cross section extrusions the fatigue was very much lower. The big sections were extruded from large diameter DC cast stock, the smaller ones from small DC billet. Hence the casting conditions reflected into the microstructure of specimens being tested. Remember this was over 50 years ago and that such a difference in the metallurgical structure would not now occur because of adjustment to casting conditions. But read on. Because sections used for aircraft required, in most cases, some form of mechanical joints, tests were made on specimens with both the high and low fatigue strength, in which stress raisers of machined notches were made. The fatigue strength was the same for both! Extension of the work to bolted joints brought to light a further effect, only at the time just being noted by other researchers, namely a phenomenon known as fretting corrosion which occurs when two surfaces in contact under pressure, where micro movement can occur, in fact weld locally. The welds break and the effect is to produce a stress raiser greater than that arising from the bolted joint and again the fatigue strength is not affected by the microstructure.

While this work was in progress (and note that fatigue tests require observing effects for up to 10^8 cycles of stress, which take some 10 weeks per specimen) work at Banbury, RAE and Fulmer Research was aimed at finding ways of improving basic fatigue strength of aircraft alloys, of which there were even then a large selection, and measuring the effects by the use of the specimens referred to above. While much of that work involved adjustment of composition and microstructure, including the effect of other fabrication variables proved invaluable in that overall performance, the recognition that joint design, location and other factors that do not involve the influence of microstructure e.g. residual stress, have an overriding effect on fatigue cracking. Note here that at that time the study of fracture toughness had hardly begun as was the case with crack propagation. Other writers deal with later studies covering the development of aircraft alloys in which the full portfolio of properties were taken fully into account. A significant event in that context was the catastrophic loss of two Comet jet airliners in 1953. Twenty-twenty hindsight is a great advantage and is easy to quote, but it is worth noting that at the time of the loss of these aircraft, shown by intensive study at RAE to be caused by a fatigue crack at a cut out in the fuselage which propagated rapidly to final failure, we in the Labs were testing small specimens of the alloy used, a clad sheet version of a 2XXX series alloy. The RAE work showed that while a full scale fatigue test on the fuselage cabin had been made in the design stage, it had been made on the cabin which had been proof tested to 1.5 times the normal working pressure prior to the test. This procedure caused a high tensile stress to occur at the cut out on application of the load, which was high enough to cause sufficient plastic deformation to result in a compressive stress remaining on reduction of the pressure. Hence when the fatigue test was made the material where the crack occurred in practice was under compression and hence did not fail until after the pressure reversals representing landing and takeoff, in excess of service expectation, had been sustained.

When all of this evidence was available, and comparing it with our tests, it showed that failure could have been predicted at about the 3000 pressurising cycles to which the cabins which failed had been subjected. Reader please note that fatigue performance is subject to a great deal of scatter in results with perhaps a 50:1 factor in life at a given stress applied in some cases but that the scatter in results at the high stress involved at the Comet cut-outs is far less. Also no reason for a study of all of the data that was available in various establishments existed when the Comet was designed and tested, and in any case there was no Internet! But the lessons learnt made fatigue failure an even greater issue than hitherto and the fact that residual stress can have a very considerable effect prompted much work at Labs in future years.

Much of the early use of aluminium in airframes involved relatively thin extruded sections and sheet but as airplanes became larger thick extrusions and plate were needed. The 2XXX and 7XXX series alloys can develop a coarse outer band of crystals during extrusion and subsequent heat treatment and doubt was expressed by users as to the effect this could have on fatigue strength. In fact many users designed sections so that the outer band could be machined away thus adding to cost. A study of the effect could not be made using machined specimens in the available tests machines and in consequence a method of testing complete sections was developed. Work at TWI had shown that vibrating long steel sections at their natural frequency as 'free-free' beams allowed low cost equipment to be employed; this mode of vibration transmits only very low loads to the supports reducing the need for heavy bearings. Vibration had been induced by using out of balance rotating weights but the location of the attachment of these were likely to interfere with the surface of the extrusions that we wished to test. Meanwhile at NPL a device known as a 'slipping – clutch' had been shown to allow transmission of load to a vibrating system in a more convenient, cheaper mode than that used by TWI. We combined the two concepts whereby we were able to fit a light clutch in a way that avoided affecting the surface of the extrusion. The means of delivering a load consisted of a piston driven by an electric motor which slipped in the clutch until the speed matched the natural frequency of the vibrating section, at which time vibration at an amplitude that could be adjusted by the eccentricity of the piston occurred. Three machines were built using simple steel angles and channels to form a frame with motors of 1/2 HP capable of vibrating beams up to 15 feet in length at up to 3000 vibrations per minute. When a fatigue crack occurred, the natural frequency of the section under test changed and vibrations ceased. The equipment was used over a period of 10 years, a summary of the results of the work on strong aircraft alloys being listed below.

Using 1 inch diameter extruded round bar in a 2000 series alloy it was shown that extrusions supplied 'as produced', i.e. as a customer would receive them, had a fatigue strength at 10^6 cycles up to only 50 per cent of the then quoted fatigue strength obtained from simple polished specimens cut from the bars.

Bars polished to remove around 0.005 inches from the surface to match the finish on the formal specimens gave results only slightly lower than the formal tests, the difference being due to the fact that the vibrating beam test exposed far more surface than the small formal tests piece i.e. a small 'size' effect existed.

The removal of the thin surface layer did not remove the coarse outer band demonstrating that the outer band had little or no affect on fatigue strength

There was a very considerable scatter of results for a range of as extruded bars produced at different times

Much of the scatter, which was far greater than that expected for the alloy, when tested as formal specimens, was shown to be related to the degree of rectification, i.e. stretching, which had occurred in production, but the top of the scatter band was still below the strength of a polished bar.

The difference was believed to be the result of the different degrees of residual stress arising from the stretching operation; bars with no stretching had a surface residual compression stress which masked some of the surface effects.

[Note that at the time the exact reason for the surface itself causing a reduced fatigue strength was not identified and it could be that this stretching in some way adversely affected the surface in addition to changing the residual stress pattern; no electron microscopes were available at this time!]

When a hole was drilled at the point of maximum stress in the bar all bars, irrespective of the fatigue strength of bars without a hole, failed at the same stress.

A limited number of tests carried out on Z sections approximately 0.25 inches thick x 2 inches x3 inches showed similar results to the 1 inch bar

Sections of a similar shape in a magnesium based alloy showed that the fatigue strength was lower than that of the 2000 series and a number of samples suffered fatigue failures away from the area of maximum stress at very low endurance. It was assumed, although not proven, that the alloy suffered from a notch sensitivity combined with low fatigue strength in a transverse direction.

The work on (8) and (9) was funded by MOD.

[The use of magnesium based extrusions in critically stressed applications is almost zero after 50 years!!]

Some 5000 and 6000 series alloys were tested in the form of 1" diameter bar and showed that the extruded surface affected fatigue strength but with a smaller reduction than that obtained for the 2000 type. However far fewer samples were tested and the scatter band of results was tighter.

It was shown that the introduction of surface compressive residual stresses by shot peening, surface rolling or plastic bending could bring the fatigue strength of as produced extrusions up to that of polished bar.

The work described, showed that surface condition, stress concentrations produced by holes, joints and fretting corrosion, residual stresses and some real size affects as distinct from test machine influences, played a far greater role than the fatigue strength as obtained from small polished specimens and regarded by many as a fundamental characteristic of an alloy. As a result of this, and of course in-house work by aircraft companies and efforts by other authorities, it was obvious that data for design in aircraft components had to be obtained by testing of such under manufacturing and expected service conditions, a situation which we could not provide to a significant extent in Laboratories. As a consequence of this much of the fatigue work by Labs was switched to the study of welded joints in 5000 and 6000 alloys used, or being proposed for use in road, rail and marine applications, a market which was fast growing. The needs of these industries were such that Labs experience in both the welding process and the performance of the welds was to prove valuable. Also the work of aircraft alloys and the Comet failure had shown the importance of not only the start of fatigue cracking but also with the way in which a crack propagated and its effect on final failure. This work is described elsewhere

'If You Can't Join Don't Join'

The welding of some aluminium alloys using oxy-acetylene gas or stick electrodes required the use of fluxes to protect the weld area from oxidation. The fluxes used were corrosive and had to be removed before the component can be exposed to the atmosphere. The processes had been in use for many years and were not highly regarded for structural use. However in 1944 the TIG process (Tungsten Inert Gas) was introduced which used tungsten as an electrode to produce the necessary heat and an argon shroud to prevent oxidation of the weld area and avoid the need for any flux. Ten years later the MIG process (Metal Inert Gas) became available with a continuously fed aluminium wire acting as the electrode. By the mid 1950s Labs was equipped with both processes for use in R&D projects and in the training of potential users who were customers of Alcan companies. The earlier available processes could still be considered for some applications but wherever possible TIG and MIG were promoted.

Other joining techniques were not neglected with soldering, brazing and adhesive bonding in the portfolio. Seen to be of great importance was the need to have people who were skilled in the use of various equipments and Labs had a group of ‘welders’ or ‘joiners’ second to none. The Kingston Laboratories was likewise equipped and had an equally strong welding group with which Banbury had close contact. It is certain that the early work of Labs was instrumental in the introduction of welded aluminium to many end use industries.

Albert Holmes welding beer barrels

Close contact with welding equipment manufacturers was essential and it was common practice for these companies to install equipment at Labs for both experimental and development work and for the training of customer’s personnel. Data on the performance of welded aluminium did not abound and had to be obtained to enable designers to predict performance, ensure safety and be as economical as possible. Alloy choice, selection of best filler wire, joint design, environmental performance, repair, inspection and structural integrity had to be established. In the context of this later issue, two examples are chosen which also include some cover of the others.

Fatigue Performance of Welded Joints

The Amsler Vibrospheres and slipping clutch equipment described elsewhere were used to carry out fatigue tests on a variety of joints in the 5000 and 6000 series alloys. Comparison with the performance of bolted and riveted joints was made since welding had to be considered as an alternative.

The majority of the work was done by carrying out axial load tests on the Vibrophores using specimens 4"wide x ¼" thick in various joint forms with a range of alternating stresses superimposed on static stresses. As indicated elsewhere, while the two Vibrophores applied around 10,000 stress cycles per minute, endurances up to 10^7 cycles or above had to be covered, hence the tests described below were quite time consuming.

It was shown that for welded joints in a wide variety of configurations (e.g. butt joints with weld beads attached, the same joint with weld bead removed, transverse and longitudinal filler welds with weld plate on either one or both faces etc.) that while the static strength of all could be the same the fatigue strengths were in all cases lower than that of unwelded plate and that some of the joints had very low fatigue strength. Such joints might have an attraction because of their location in the structure which made access easy and or more economic but would have the potential for failure. Well made butt joints had about the same fatigue performance as riveted or bolted joints but it was shown that some weld defects which might be acceptable in a component or structure designed only against static load could have an adverse effect on fatigue. These defects included actual weld shape, porosity and stop and start weld craters.

The data from these tests was used initially in helping designers with Alcan metal in specific uses in road, rail and marine transport and building applications. It was used as the main input to British Standard (CP118), which years later became BS 8118 and eventually EuroCode 9. The work was also reported in a number of papers to institutions etc. Lab's staff responsible for the work were closely involved with the drafting of these specifications.

The slipping clutch equipment was used for testing larger structures represented by box beams, some 15 feet in length, with four longitudinal seam welds which emphasised the fact that weld defects could have some failures occurring well away from points of maximum stress. Also because some shape rectification was needed as a result of distortions caused by extensive welding, considerable residual stresses could be present. It was not possible to measure their exact magnitude – nor indeed would it have been economic to have suggested that such be done in actual structural applications. As a result of this the specifications that now exist make the assumption that some tensile stress will be present in any welded structure and the design stress permitted takes this into account, the data relating to the effect of mean static stress obtained from the Vibrophores tests described above being invaluable.

All of the tests showed, that as far as fatigue evaluation was concerned there was no difference in the performance of the 5000 and 6000 series alloys. Furthermore when in the 1970s the weldable 7000 series alloys were introduced, their fatigue performance was no higher than that of alloys with lower tensile strength and in specifications and codes of practice all of these structural alloys are grouped together in fatigue performance. This observation was to take on important considerations when fatigue might occur because any advantage to be gained by the higher static strength of the 7000 series joints was not only cancelled but could be dangerous if such designs erroneously assumed that only static stress need to be considered.

This issue is shown to be important in descriptions of some specific applications.

Note however that choice of alloys can be influenced by issues in addition to fatigue e.g. form in which the alloy is available, economic, environmental performance, toughness, response to finishing. Also it is important to recognise that by careful design welded joints can often be located away from points of maximum stress.

While the effect of a high residual tensile stress is taken into account in specifications, we had shown that high compressive stress induced by plastic forming, peening of surface or the sequence in which welding was carried out would have a favourable effect. However to have taken account of this to allow more economic or weight saving fabrication it would be necessary to be able to confirm that these compressive stresses had indeed been present. Such determination using NDT methods would not be possible in large structures, but now some 40 years after our work was finished efforts still are made to remedy this!

While the above work was of general value across a wide range of applications, and indeed remains so via the specifications mentioned, a specific example from the early 1960s illustrates other issues in an application involving welding and the establishment of the integrity of an important application. At that time it was evident that the extensive availability of natural gas would involve its transport from where it was to where it was needed either by pipeline or in large vessels. Aluminium alloys were known to have good mechanical properties at low temperatures in that not only their tensile properties increased but, more important, they suffered no dramatic drop in ductility, as was the case with most of the steels then available. This property made them attractive for the projected transport of liquefied natural gas, with only a fraction of the volume of the product at room temperature. The low weight possible with aluminium was also an advantage. However large containers to be carried by ship needed aluminium plates up to 6 inches in thickness and even the largest in the area had to be welded; proof is required that the welds would not crack or rupture completely. Fatigue was not a problem.

Ray Durham undertaking a low temperature tensile test

Although the low temperature performance of aluminium was well documented, tensile tests were made on plates of the 5000 series alloy in the form of welded butt joints with the maximum dimensions capable of being broken in the 100 tonne machine available at Labs. A ‘shroud’ fitted around specimens, which were 4’’ x ¼’’, allowed them to be subjected to liquid nitrogen temperatures and it was shown that the plate and the filler wire used for welding confirmed the integrity expected at the low temperature. Proof was also provided that plate up to 6 inches thick could be joined by the then available MIG process, the plate edges requiring to be bevelled using TIG cutting equipment to produce a shape which had to be filled by some 40 weld passes. No equipment existed that was available to test such a welded joint to destruction but since much of the envisaged fabrication would be in 2 inches thick plate it was accepted that the satisfactory test could be made on 2’’ thick welded specimens again requiring a similar edge preparation. Because even that plate required several weld passes, it was thought necessary to satisfy the relevant authorities that should a weld defect occur – note that the tanks proposed would require many feet of welding – no catastrophic fracture would occur. The eventual specimen agreed was 24 inches wide at the test length and 48 inches at the ends to be gripped for testing. A 'defect' to simulate a possible severe weld defect consisted of a slot machined in each of the butting plates at the locations of the weld seam that the welding would not completely fill the slot thus leaving a sharp crack. The load required to break such a specimen would be around 1000 tons, the exact figure depending on the actual effect of the defect. One of Alcan's plants had produced the plates and they had a stretcher used to rectify such material with a capacity capable of applying such a load. It was not possible to make the test at low temperature; surrounding the large specimen with a shroud to hold liquid nitrogen might have been possible but however unlikely it was that a leak could occur, the effect on a steel unit, essential for the production of large volumes of plant production, was too great even to debate! Fortunately the Labs tests were seen as adequate to confirm the low temperature effects. It was, however, required to examine the propagation of the defect under load and how could that be achieved? So confident were we that the toughness of the 5000 series alloy would be such that the crack growth would be slow, an engineer with a ruler stood on the specimen as the load was applied and measured the crack growth. Today's health and safety rules would not have allowed such bravery!!

The outcome of this work was the use of aluminium in the fabrication of large welded LNG tanks for transport by several ships. The subsequent introduction of 9% Ni steels which, like aluminium have good low temperature properties but with a much higher strength, made it an obvious competitor for the future growth of the market. Because thinner plate was needed in steel, the welding required was less and overall costs favoured it. The current demand for energy saving and the belief that some fuel sources will be scarce could increase the demand for LNG. Techniques for welding thick aluminium have improved since the 1960s; could aluminium become a competitor again?

Military uses of aluminium

By the early 1960s military engineers were considering the use of aluminium for air portable military bridges which could be assembled easily by a few soldiers; hence lowest possible weight was demanded. Their initial assessment ruled out the 5000 and 6000 series alloys because they were inferior to maraging steels from the weight saving point of view. [Initially they were dubious about welding of the modules, until we were able to demonstrate the use of TIG and MIG processes.] However, the weldable 7000 series alloys offered an advantage over the steels. These alloys are quench insensitive and naturally age over a short period of around 30 days so that their welded properties reach almost that of parent plate in that time. They were being used in Sweden and were selected for the first UK bridges, the Medium Girder Bridge (MGB). Use was also being made of them in Germany, Canada and Switzerland for some road and rail transport applications. There was however debate as to the best composition with respect to Zn/Mg ratio and minor element content, with the best balance between ease of production, weldability and strength. There were in consequence a number of combinations either already in use or proposed. In order to be weldable none of the versions contained copper, unlike the 2000 series aircraft alloys, and they were not believed to be susceptible to stress corrosion as a result of tests made using the then available equipment.

This debate was reflected in the choice of the extruded sections, each module being made up of many shapes, to be used in the prototype MGBs. The material supplied by Alcan was selected with ease of extrusion to complex shapes as the main issue and they had a Zn/Mg ratio of 5:1, while those supplied by a competitor had a composition based on welding tests made at TWI which indicated an advantage of a 4:2 ratio. Both versions were required to meet the mechanical properties and in consequence design stresses were the same. Initial agreement was reached that the sections would be water quenched as they emerge from the press but when the MOD designers witnessed extrusion of the Alcan material, an extrusion was delayed in entry to the quench tank and, as a result, a formal solution heat treatment in a furnace was demanded. All sections were artificially aged, thus ensuring that the material supplied for welding had a close control over properties.

Between the time of the delivery of the material and approved testing of the bridges - a period of several months - events in Canada involving Alcan material became alarming! A composition similar to that used by the competitor for the MGBs had been used for the manufacture of heavy duty off highway dump trucks. The fabrication procedures were however different in that the sections were air quenched at the press and artificially aged but the mechanical properties of material was not very different from that of the formal thermal treatment bridge material.

One truck which had been in service for a few months was struck a heavy blow by a loading shovel and suffered severe cracking; indeed the failure was described as shattering, good choice of word! The fracture surface indicated a very low impact value and subsequent testing showed that some of the sections in use did indeed have very low ductility; others however were as tough as had been shown in tests done at the time of manufacture.

Both the Banbury Labs and those in Kingston were at the time engaged in extensive work to rationalise the wider range of 6000 series extrusion alloys then in use and were very well aware of the failures in such an alloy reported herein! In consequence of that earlier work, attention was naturally being given to the effect that air quenching of the sections could have and it was seen as a likely cause of dump truck failure. Some previous experimental work had shown that an addition of Mn to 7000 series alloys improved toughness and an alloy with this modified composition which was water quenched was shown to be free from a possible toughness drop. This would seem to have solved the problem apart, of course, from the fact that the formal heat treatment would make the material less attractive from an economic viewpoint. Until, that is, in the summer of 1965 when MOD called us to see an MGB made from Alcan material which was under test. At a load well below the maximum design requirement cracking had occurred. Not one crack, but many at about 2 inch intervals and some in members which had only low stresses created by loading. If anything the cracks were remote from the many welds. No cracks had occurred in the competitor material. A possible initial explanation was that the cracks had occurred because the extrusion was made under conditions which produced hot short cracking at the die but inspection at the plant would have rejected such material. Detailed examination of the cracks, which it can be imagined was done urgently, showed the failures to be intergranular and having all the features associated with stress corrosion. No evidence of low ductility was seen and the bridges had not been subjected to any impact loading. Because no cracking had occurred with the competitor material and, bearing in mind that fabrication and welding had been controlled, the only key appeared to be the different chemical composition. Further examination however showed that when the Alcan sections were cut for examination, very severe distortion occurred which indicated high residual stresses were present. In what was almost a dramatic detective story we found that when the sections had been heat treated and aged i.e. when the material was at its maximum strength, the sections were found to be not quite the shape specified and that some final rectification had been made, involving sufficient plastic deformation to leave the high residual stress. Thus every section so treated was its own little testing machine! Soon however it was shown that the belief that 7000 series weldable alloys were free from stress corrosion was a fallacy and that water quenching was perhaps the biggest factor in its presence. Indeed by the end of the year the competitor material in the MGB had cracked and inspection of a number of other UK uses had suffered failures. These included lamp posts, a footbridge and painters cradles in use on a bridge over the Thames. While composition variations as well as the use of air quenching rather than fast cooling water quenching, and attention to the avoidance of residual stress, seemed to avoid the stress corrosion sensitivity, the potential for extensive use of the 7000 series was never realized. Indeed failures occurred in rail transport applications in Germany and Switzerland in versions which had previously been believed free from the problem. Stress corrosion, like fatigue, involves testing which has to be accelerated and in consequence can be invalid. At about this time it was evident that more accurate tests must be developed. This issue is covered in a later section.

One end use, however, did continue to be rigorously pursued - namely aluminium armour plate. Use had been made in the USA of 5000 series alloys but UK military engineers had seen the value of the stronger 7000 alloys. In fact they ask for higher strengths than those employed in the MGB in their quest for even more weight saving for air portable vehicles. Extensive ballistic tests showed that adjusted compositions allowed a small but significant weight saving compared with the then available steel armour and because the aluminium plate had to be almost three times as thick as steel the resulting structure was stiff enough to reduce the need for a support structure thus keeping cost to a minimum. The alloy chosen had to have a balance between resistance to penetration by projectiles, avoidance of spalling from the back face, optimum weldability and, as time went by, maximum possible resistance to stress corrosion. As shown above, this latter requirement was a movable feast and a range of vehicles which were made and entered into service as a result of the complex set of tests were seen eventually to require a protective coating in the vicinity of welds to avoid cracking.

The various examples relating to the suitability of a range of alloys for applications in which cracking might occur had resulted in a detailed study of not only initiation of a crack but also the way in which such cracks can propagate and, of course, means of avoiding them. This issue was of particular importance for the 2000 and 7000 series alloys used in airplanes.

The evaluation of tests being developed by other authorities and modification of these by Labs resulted in our ability to make significant advances in the measurement and means of improving fracture toughness.

Also the need to be able to detect and monitor cracks in all structural alloys led to the development of tests, some of which were already available, for the detection of defects in products produced by Alcan e.g. ingot for extrusions and rolling. The expertise was invaluable in the examination of actual structures and equipment.

The effect of low temperatures on the performance of aluminium has been covered, but what of the earlier reference to Labs ability to study creep at elevated temperatures? Labs ability in this respect became of great importance when the first and, as it turned out, only commercial supersonic airliner Concorde was conceived. Because skin temperature in such aircraft at twice the speed of sound would be of the order of 130° C, Alcan had to be able to produce sheet capable of achieving the necessary creep resistance and Labs equipment and expertise in its use were invaluable.

Technical assistance on behalf of Alcan companies

Lab staff engaged in research and in the development work in connection with the specific end-use applications described were able to help in the solution of many problems presented by Alcan companies and their customers in the UK and in Europe. Some examples are listed below and serve to illustrate their versatility.

1958 A complete collapse of a large crane which was made from 6000 series alloy of unknown origin was shown to be the result of a design which failed to take account of the effect of bolted joints on fatigue performance. The working stresses had been calculated using fatigue data obtained from tests on polished specimens listed in information then available on the alloy. Fracture had occurred after only a few months in service. Our data showed that not only should the design stresses have been much lower but that we could have predicted the early failure! Also, while the material was believed to be a 6000 series alloy of the type recommended by the then available British Standard, it was in fact one used in the USA, although for both alloys there was the same need to note the effect of the bolted joint. Our ability to offer design experience and to be able to identify an alloy from the nature of fracture led to the demand by the chief designer of the company that made the crane, that in future any use by them of aluminium must involve Alcan!

Note: This example occurred before the publication of BS CP118, which contained our data on fatigue.

1956 Four large welded lighting towers in a railway marshalling yard in Switzerland suffered cracking at many of the welds. The weld designs were not ones which would be expected to have poor fatigue strength and they contained no obvious weld defects. However, the design stresses had been calculated on the assumption that the deflection of the towers be limited to a degree which was less than that observed. In fact the towers were often subjected to a steady wind flow velocity which, together with their geometry, resulted in a vibration mode which was subject to 'negative damping' and which would continue to increase. We were asked if the towers would fall down and had no option but to say 'yes' unless they were redesigned to take them out of the vibration mode. These modifications were made.

Note: This work was done in conjunction with Labs Geneva Office, one of whose engineers was later involved in the production of an Alcan 'Design of Structures' manual. Labs Banbury experience in the use of equipment which involved knowledge of vibration modes had proved useful.

1966 An aluminium jetty carrying lighting for an airport runway began to vibrate and in consequence had to be taken out of service. The problem occurred as a result of the phenomenon described in (2?) but the design had been made with knowledge of the vibration possibility. However, examination showed that the extruded angles used in the construction had been assembled the wrong way round! A simple adjustment, which fortunately employed bolted rather than welded joints, solved the problem.

Note: However good the communication in design data and its employment, the final fabricator must get it right!

1967 Aircraft propeller blades machined from forgings supplied by Alcan were vibrating in service. The blade manufacturer claimed that some variation must have occurred in the previously successful forgings. We were able to argue that the natural frequency of the blade was controlled by three factors, the blade dimensions, the elastic modulus of the blade material and its density, a fact obviously known to the fabricator. The latter knew blade shape had not been changed, we knew that modulus and density could not have changed. We said that in our belief the engine frequency must have changed thus bringing it near to the propellers natural frequency. It had!!

Note: Never lose sight of the fact that what one is told might not be true.

1959 When two large cruise lines, the Oriana and the Canberra, were built the superstructures of both each contained over 1000 tons of welded 5000 series extruded sections and plate. Alcan supplied to the Oriana, a competitor to the Canberra. Initially, welding service was given by Alcan and the competitor. However problems occurred with the welding of the Canberra and the expertise of one of labs MIG welding staff was sufficiently recognised to result in a call for his help, a situation which was acceptable in the knowledge that the continuing failure to complete the ship reflected not only on the competitor but on the use of aluminium in general. Reports that weld cracking had occurred when welded plates were vibrating during assembly had to be investigated. A detailed “hands and knees” examination of hundreds of feet of welded plate, that had not been moved after welding, detected cracks! Not a scientific response but a successful one! We, of course, were able to show how the cracking could be cured by adjustment of the welding practice.

1970 When the liner Queen Elizabeth was built its superstructure had 1400 tons of aluminium extrusions and plate. Guess who provided both the metal and the welding expertise?!

1985 Welded doors on a high speed train were found to be suffering from fatigue failure. The alloy and design data were blamed, the former supplied by Alcan and the latter by CP118. Examination showed that the actual quality of the welds as distinct from their design shape was very poor. The alloy, of course, was as specified.

Note: Again an issue mentioned under (3?) but because it occurred 20 years later it shows that lessons are not always learned!

1966 - 1982 An early specification relating to building materials stated that aluminium sheet should not be employed in some applications because ‘it could contribute to the spread of fire’. Labs designed and supervised a test in conjunction with the Aluminium Federation which provided data sufficient to have this restriction removed. Two one storey buildings, one with a steel roof and one with aluminium, were erected side by side in a large aircraft hangar, the climate of which could be governed. Identical fires were lighted in both and the results filmed. We, of course, knew what would happen. The aluminium roof melted and allowed the fire to escape thus resulting in minimum damage to the rest of the structures; the steel roof took longer to melt and much more damage occurred. Aluminium was allowed for future building use.

By 1982, as indicated in other examples, aluminium was widely used in the superstructure of ocean going vessels, the weight advantages resulting in more stable and better load carrying platforms. However, in the Falklands war it was reported that several ships had been lost as a result of fires which caused the superstructures to burn. While we were able to counter this erroneous statement with evidence that aluminium in the form of plate, sheet and extrusions did not burn it took some time to convince potential users of the fact. Also another issue arose from the losses in the Falklands which again illustrated the fact that however much design data exists, it is only of real use if it is properly employed by both designers and fabricators. The MOD investigation accepted the innocence of aluminium with respect to fire but told the aluminium industry that many of the warships superstructures were exhibiting fatigue failures, accelerated by exposure to heavy South Atlantic seas and possibly corrosion. We learned that, in fact, the designers of the ships knew of CP 118 (and the then replacement BS 8118) but had decided that the stress levels allowed by the code low enough to mean that weight savings expected from the use of aluminium could not be realized!

It is speculation, built perhaps on expectation and probably some desire to preach, but it is a good opportunity to close on these thoughts now that Labs and its expertise is all but gone.

What if the background available as a result of all of the work done in Banbury on fatigue, welding, residual stress and corrosion, had been made available for the use by the ship designers – and applied?

If the weld designs were such that the low stresses called for made for a heavier than expected structure, could they not have been be relocated to less stressed regions?

Were the actual welds well made or did they suffer from defects of the type known to reduce the fatigue strength and which should have been avoided?

If some 'bad' design welds had to be made in critical areas, could regular inspection have located cracks which might have occurred, and repairs made.

If corrosion was believed to be a contributory factor could not, say, some of the experience in protecting other structures e.g. fighting vehicles, have been employed.

If fatigue combined with corrosion i.e. corrosion fatigue, had indeed been evident, would this have prompted some more basic work on its mechanism and ways of taking It into account? With advantage to future users

These questions, dear reader, together perhaps with a few others raised in other chapters, will sadly never be answered.

1975 Two extrusion presses operating in Alcan plants, one in the UK and the other in Belgium, made by the same manufacturer each suffered catastrophic fracture in one of the three 15 inch diameter tie bars. The retaining nut on one, weighing some1/5 tonne flew some 30 feet through the air, the other fell to the floor. Fortunately no one was injured but the presses were out of action for some time before replacements could be obtained. Examination of the rods by Labs showed that the failures were caused by a fatigue cracks which had propagated for more than half of the diameter prior to fracture. As a result all tie rods in presses operated by Alcan were examined by Labs NDT experts and many were found to have cracks of various lengths. Some time later another UK press suffered a crack in the steel main cylinder. Again fatigue was identified and the repair system set up; the failure was caused by the welding of a bracket to the cylinder to allow it to be handled in construction, followed by removal of the bracket not the weld affected region which presented a serious stress concentration.

Some dozen press manufacturers in UK, Europe and North America were contacted and a description of the failures supplied, with a request for their views on the failures and on their design methods. Only four answered (!) But it was concluded that the tie rod design was based on the need to pre-tension them so that fluctuating load during the extrusion process was kept to a minimum, thus avoiding fatigue. Regular maintenance should ensure that this precaution is taken but it was evident that such practices, while being well documented, were time consuming and not always observed. A major German press maker said that they were aware that some, or even all, of their competitors cut costs, both in design and fabricating and that they were not surprised that failures had occurred, adding that, of course, when the demand for extrusions was high, presses when needed to meet increased production hence a greater number of stress reversals occurred in a shorter time. These observations were noted by the Labs engineer, who some two years later was asked to comment, in the presence of one of the German engineers on a fatigue failure of one of their presses!! 'Ask not for whom the bell tolls'. The Labs NDT expert was kept busy for some 10 years, including time after he retired from Labs acting on behalf of non Alcan companies. He died in 2008; if press operators should be reading this, remember to duck!!

1973 Some 10 years after the slipping clutch machines described earlier had been dismantled the results obtained on them were called into play. As noted we had shown that when stress concentrations, such as the bolts, rivets, machined holes and notches exist, fatigue strength is much lower than that obtained with the plain material without the stress concentrations; but that un-machined extrusions without obvious notches had a strength below polished bar, the exact extent of the reduction being, at least in part, affected by residual stresses arising from either manufacturing process or applied loads or combinations thereof. At the time of the Vietnam war, U.S. were experiencing so many helicopter losses as a result of enemy action, that extruders in USA could not keep up with the need to supply sections for helicopter blades and a UK supplier, Alcan, was asked to help. The outside surface of the hollow blade section was machined but the internal as- extruded surface remained. The U.S. blades had been tested and passed for the possibility of fatigue failure but it had been shown that when the tests were extended to allow fracture to occur it originated at the inside surface away from the bolted joint with the rotor, the vibration mode being such that the maximum stress in the blade occurred away from the joint. Alcan blades, when subjected to similar fatigue tests, experience failures in the same location but at significantly lower endurance cycles. All of our data relating to the effect of the stretch applied to the blade extrusions, effect of applied residual stress by peening and our views on the effect of, or lack of, effect on fatigue of various surface imperfections, was made available. One further observation seeming to prove useful. If we compared all of our data on unmachined extrusions and with that on the U.S. blades, the stress at a particular endurance for UK blades was exactly half that for U.S. blades. We asked if the equipment used to test U.S. blades could be wrong by a factor of 2:1. We were never told but UK blades, with their internal surface subjected to shot peening, were supplied.

Note: the helicopter blades are now made from carbon fibre.

The 10 examples listed show how expertise and data from R&D helped in technical assistance; a final observation shows how a reversal of this order prove to be very important.

From 1965 Alcan had supplied material to a company which had begun to make high pressure gas cylinders. Cylindrical ingots in a range of diameters in 6000 series alloy were cold extruded to form shells which were headed and machined to receive a brass valve following a double heat treatment, and are now used for CO_2, oxygen, air and specific medical gases. In order to provide proof that such cylinders would be safe and to assist in the provision of standards for their production and use, Labs supplied both design experience and testing facilities.

By 1969 specifications had been introduced and the cylinders were in wide use for CO_2 in the U.K. while the U.S. branch of the company was also making cylinders for scuba diving and oxygen in addition to CO_2. A few UK cylinders were found to have surface cracks in the neck which held the brass valve. The cylinder alloy was in wide use in U.K. as hot extrusions in road and rail transport and building. It was known to have good pitting corrosion resistance and no stress corrosion failures had ever been reported. Initial examination by cracks showed them to be intergranular and the structure of the neck to be a very coarse grain, a feature also to be found in the outer band of hot extrusions. It was suggested that this structure, when subjected to the stress created by the insertion of the taper valve, had developed the cracks when the mismatch between the tapers on the valve and neck was great but within specification.

It was, however, impossible to reproduce the cracking when inserting the valve, whatever the mismatch. We knew that the cold forming operation to form the shell was such that the top of it had received little cold work and suggested that one inch should be removed before necking. This practice was introduced and the cracking problem seemed to have been solved. We had not been able to reproduce the cracking by subjecting specimens from the neck region to very high stresses but had to accept that the failures had been time dependent and that in consequence perhaps the tests would not have long enough to produce cracks. However very few cracks had occurred and any leakage of gas was slow. Burst tests on cracked cylinders showed that failure originated in the barrel of the cylinder as was the case with sound ones.

Then in 1976 inspection of cylinders which had been cropped were now showing some cracking at the five year inspection period and it was realized that while removal of the relatively unworked rim of the shell might have reduced cracking propensity it had not eliminated it. Extensive testing by the production company, which had by now been merged with Alcan, and by a university, showed the very wide range of stresses which could occur in cylinder necks; a ‘good’ match between valve and neck producing very low stresses, a ‘bad’ one giving stresses up to the yield strength of the alloy! No means existed of estimating the distribution of the mismatch nor did it seem practical to measure every valve and cylinder neck but it was recommended that as low a torque as possible should be applied when fitting the valve. No cracking had occurred with U.S. made cylinders and this was seen as a clear indication of the ‘taper thread syndrome’ since all but a few such cylinders had parallel threads sealed with an ‘O’ ring which caused no neck stress. It was obvious that every effort should be made to replace taper threads with parallel ones in UK, but this would be time consuming, expensive and require agreement by customers who saw the taper valve as a better way of sealing against leakage – assuming of course that no cracks occurred! Eventually change was achieved but it was also seen as necessary to learn how and why the 6000 series alloy suffered this form of fracture.

The first essential was a short term test which could reproduce the long-term failures and one was fortunately becoming available. It has been pointed out earlier in this chapter that the study of stress corrosion, itself a time dependent phenomenon, needed a more accurate test and one was being used in the development work on higher strength aircraft alloys. This test involved slowly subjecting a specimen to an increasing load to fracture, the timescale being a few days. The test called ‘slow strain rate’ showed that the 6000 series cylinder alloy in the neck could be made to fail in any intergranular fashion and that, as we believed, it was not dependent on the environment in that it could be achieved in a vacuum. We gave it a name new to aluminium, or as far as we know to any other material, named ‘Room Temperature Intergranular Creep Rupture’ (RTICR). While some improvement could be made in the performance of the neck structure it was considered necessary to find a replacement alloy, the obvious choice for a first evaluation being a similar strength 6000 version, already in the U.S. cylinder specification and one used in the UK for many structural applications. This alloy was shown to be free from RTICR and, bearing in mind the debate which had been needed in the formulated change from taper to parallel threads, the change was eventually made. Most cylinders were made in this alloy until a further Labs development allowed a stronger 7000 series alloy arising from the aircraft and military studies to be used. Obviously this changeover also took time in that proof of stress corrosion resistance, freedom from RTICR, adequate fatigue resistance and fracture toughness was needed.

Lest anyone ask why RTICR has not been seen in the suspect 6000 series alloy widely used in other applications, note that it requires a sustained high stress for long periods, a situation that only occasionally occurs in normal design. A side effect of all of this work showed some previously unobserved effects of minor elements on fracture and the need to adjust the techniques for measuring their actual concentration. Was it not noted that integrity is a wide open subject?

CAST

Mechanical Testing

Ken Gunn, Ray Durham, Dulcie Keeling, Leslie Osborne, Arthur Mold, Doreen Hankin

Fatigue Testing

Ken Gunn, Bob McLester, Lionel Butler, Janet Tickle, John Bliss, Roy Woodward

Structural Testing

Alistair Mackie, Reg Smith, Mike Lancaster, Arthur Mold

Joining

Derek Claydon, Bill Gardner, Dick Blewett, Albert Holmes, Hector Constantine, Bob Turnbull, Eric Wilson, Percy Barrett, Jack Grant, Roy Woodward

Cryogenics

Ray Durham, Bill Ferguson

Military Uses

John Willis, Maurice Reynolds, Bill Bryant

Technical Assistance

Roy Woodward, (2) Roy Woodward, Cedric Marsh(Geneva), (3) Bob McLester,

Roy Woodward, Bob McLester, (5) Hector Constantine, Roy Woodward,

(6) Derek Claydon, Hector Constantine, (7) Dick Blewett, (8) Ray Durham, Fred Dickinson, Roy Woodward, (9) Fred Dickinson, Tom Garrett, Roy Woodward, (10) Roy Woodward

Gas Cylinders

Henry Holroyd, Bill Bryant, Ray Durham, Warren Hepples, Roy WoodwarD

15. THE AUTOMOTIVE PROGRAMME IN BANBURY LABORATORIES & ITS PART IN THE WORLDWIDE ALCAN AUTOMOTIVE PROGRAMME

Mike Wheeler

The Alcan Automotive Program to develop a new market in the automotive field for aluminium essentially began in 1983 when the company became aware of an experimental aluminium bodied energy conservation vehicle (ECV3) that was being developed by British Leyland Technology (BLT) in its Gaydon Research Centre in Warwickshire. This came to the attention of Dr John A. Wheatley who was in the Sales Development Department of Alcan Industries in the UK and who had been approached by BLT about the availability and supply of aluminium materials. This might have been treated as a routine request for materials but John realized the significance of the request and the potential opportunity it represented for Alcan. There was also a recognition in the company for the need to develop new markets and hence for a much more significant response to BLT.

The situation in Alcan at this time was made for a strong and significant response to British Leyland Technology. Dr Hugh Wynne-Edwards was then the Vice President Technology for Alcan International with responsibility for the Alcanint Research Laboratories and was mandated to search out and develop new market opportunities. Also, the Gaydon Research Laboratory of BLT was conveniently just a few miles from the Banbury Laboratory. The ECV3 project was being led by Mr. Spencer (Spen) King who was a renowned vehicle designer with notable vehicle designs to his credit such as the Rover P3 and the Range Rover, a SUV type vehicle which, in its latest form, is still a market leader. A key concept in the assembly of the aluminium body structure of the ECV3 was the use of adhesive bonding and clearly this was an area of technology where the Banbury laboratory could bring its knowledge and expertise in surface treatments and the adhesion of coatings. Alcan through Alcan Rolled Products, its North American sheet supply company, had already recognized the emerging opportunity for aluminium in the North American Auto Industry and had established an automotive office in Detroit in 1979 with technical, market development and sales activities. Dr. Mike Wheeler, formerly from the Banbury Lab and then located in the Kingston Research Lab of Alcanint, transferred to the Detroit office in early 1980 to head up the automotive product development activities from there. By 1983, the office was already involved with the Kingston Lab in the development of a new automotive skin sheet alloy AA6111 and this was to become a key material for Alcan and the Auto Industry.

At the time the programme started, almost all volume manufactured passenger cars had the main body structure, the body-in-white, made from stamped steel sheet material, joined together by spot welding. This is still mostly so today. The body-in-white is the main structural element in such vehicles and is the single heaviest component of these vehicles. This mode of construction is frequently known as unibody construction. The ECV3 vehicle demonstrated that the required strength and structural stiffness required for vehicle body structures could be achieved in sheet aluminium with adhesive bonding combined with spot-welding, giving significant weight reduction and the added benefit of much improved noise, vibration and harshness (NVH) characteristics. In this respect, the vehicle, although small, had NVH characteristics much more like larger, high end vehicles. Hugh Wynne-Edwards recognized that the concept that BL Technology had devise of combining formed aluminium sheet with adhesive bonding to provide structural stiffness and durability

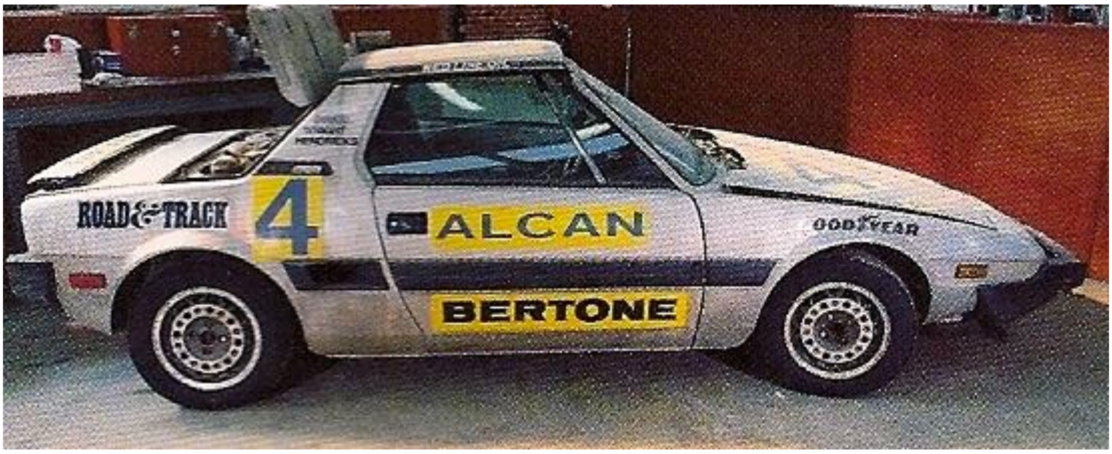
The ECV3, based on the Austin Metro

represented an enormous opportunity for aluminium. It could replace steel in the body-in-white structures of volume production vehicles to give very significant weight and hence fuel savings. He quickly established contact with Spen King and initiated a technical exchange between the Banbury Lab and BL Technology. In due course this led to the development of a technical development and a licensing agreement with BL Technology, with the Banbury Lab to lead the development of appropriate sheet alloys, a durable adhesive bonding system suitable for volume manufacturing and related enabling technologies such as an adhesive compatible forming lubricant, spot welding and finishing operations. This in turn required the redirection of a number of researchers in the Banbury lab to lead these activities and the recruitment of new staff to complete the range of technical capabilities needed to pursue such a significant challenge.

A key investigator and local program leader on whom a large part of the ensuing Banbury program would be developed was Peter Sheasby. He already had an international reputation as surface finishing expert for aluminium and backing up Peter was Bill Marwick who came to the lab with significant knowledge of adhesives. However, it was recognized that an appropriate program manager was needed to coordinate the work and to lead the evolving contacts with the BL Gaydon Lab. The key part of this was a proposal to form a joint Alcanint/BLT team to build and then evaluate a small fleet of adhesively bonded aluminium-bodied Austin Rover Metro vehicles for the assessment of structural performance, durability and crash worthiness. Mike Wheeler, with his knowledge of both the Banbury and Kingston labs and his growing experience in the automotive industry, was asked to take on this role in addition to his Detroit activities and he remained active in the technical management and promotion of the technology over the next 15 years from Detroit, then Cleveland and eventually Kingston. The lead staff for the aluminium Metro build at BLT was Fred Law as project manager together with Pat Selwood and David Kewley, Kewley having worked closely with Spen King in developing the ECV3. At this point, the concept of an aluminium stamped sheet and adhesively bonded/spot welded vehicle body-in-white structure was identified in Alcan as the Alcan Aluminium Sheet Vehicle Technology or ASVT.

In brief, the ASVT concept was to produce a structural aluminium sheet product coated with a pretreatment to provide a durable bonding interface for the adhesive, an adhesive compatible press-forming lubricant that would not compromise the long term adhesive bond-strength durability and a heat-curing adhesive that yet would still allow spot welding (or more accurately weld-bonding) to be carried out through the adhesive along the joining flanges. This led to the development of cooperative programs with Ciba-Geigy to develop a heat-curing epoxy adhesive (XD 4600) and with Leek Chemicals to develop a supply route for a lecithin-based, adhesive-compatible lubricant code named AL070. The leadership for these activities came from the Banbury staff with appropriate involvement of the patents/intellectual property staff (Roy Hines and David Goodchild) and the whole activity necessitated the establishment in the Banbury Lab of appropriate test specimen designs and equipment for assessing the stress-humidity durability and impact-peel resistance of bonded joints. This included setting up a number of test cabinets for accelerated environmental exposure for the evaluating a very large number of test specimens.

As the program developed and expanded, more staff were assigned and added to the Banbury team and John Wheatley himself became directly involved when he transferred to the Banbury lab to manage the second vehicle build and assessment project, the building of 5 aluminium structured Bertone (Fiat) X1/9 sports cars. Other researchers who were to play significant roles in the development of the technology were Ian Wilson, Nick Hartman (Stress-humidity and impact peel resistance), Alan Seeds, Yi Gao, Dubravko Nardini, Iain McGregor, David Meadows, (structural design and crash worthiness) Henry Holroyd, Chris Newton, Doug Boomer (spot welding and weld bonding) and Alan Carr (sheet forming and formability).



The Bertone X19

Promotion of the Technology

In parallel with the development of the technology, there was a concerted effort to publish information about it in order bring the attention of the auto industry to the technology and make public the data on which the claims for the technology were based. In addition, more promotional-type material and articles were generated as significant developments were achieved such as an article about the aluminium structured X1/9 vehicles in AutoCar and Motor magazine. This activity involved the Banbury staff but was led by the Jimmy and Bruce McWilliams, automotive consultants working for Hugh Wynn Edwards. Compass, the Alcan company magazine also had several articles on the program through the period when the program was active.

The first significant technical publication was in fact an SAE paper on the BLT ECV3 Technology by David Kewley. This was presented at the SAE's International Congress in Detroit in early 1985. This was followed by a group of four papers at the SAE International Congress in 1987 covering various aspects of the technology, two of which were jointly authored by Alcanint and BLT and one of these reported on the evaluation of the aluminium structured Austin-Metro vehicles. A significant publishing activity continued with SAE papers in 1989 and 1996 and papers in IBEC (International Body Engineering Conference) in 1994 and 1995. Many other papers and presentations were given during this period, one of which caught the attention of the group that had been retained by GM to design the body structure for GM's EV1 and this resulted in the Alcan Technology being adopted for this vehicle. Almost all of the Alcan staff involved in the program was part of the technical publication activity.

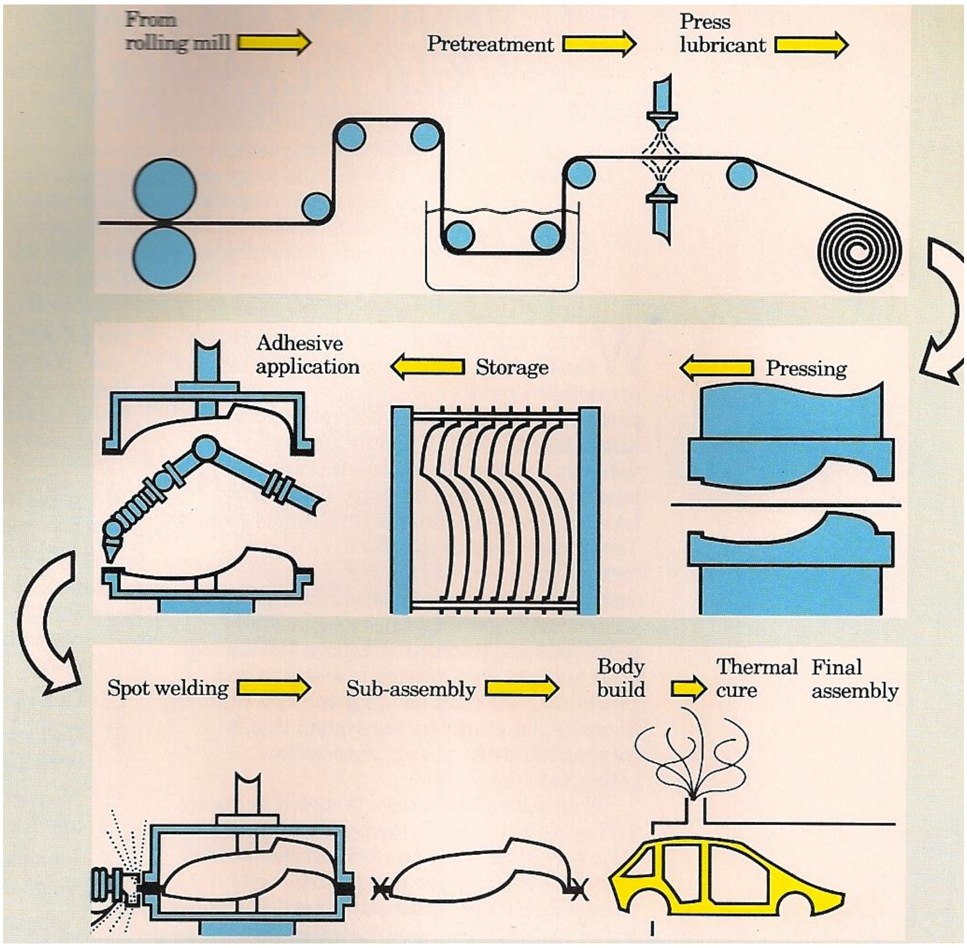
The General Motors EV1

The Evolution of the Program

It was recognized early on that the scope of the industry contacts for ASVT needed to be expanded beyond the Austin Rover Group and a promotion activity was started to bring it to the attention of various European and North American auto companies. This included Ford and General Motors in the US and especially the Pontiac Division of GM through the Alcan Rolled Products Detroit office, BMW, Daimler Benz, Jaguar, Ferrari and Bertone in Europe. This last company specialized in building limited runs of vehicles for other major car companies including the X1/9 open sports car for Fiat and two door sports version of the Volvo 960 model. Both these vehicles were to play an important part in the development of ASVT.

As these activity continued to develop and expand, it became clear that a dedicated full time leader was needed and Ms Germaine Gibara in the Alcan Montreal office was appointed to this role, reporting to Hugh Wynne Edwards (Sept 1987) In turn this led to the establishment of Alcan Automotive Structures (AAS). This was headed by Ms Gibara, with Mike Wheeler as the Technical Director and Tony Warren and Mike Kelly, two recent recruits from BL Technology as the respective leaders of vehicle-structure engineering and vehicle manufacturing and assembly. Warren and Kelly were based in Banbury in AAS, which had its own building on the Banbury site, and among other things this facility had demonstration and development equipment for spot welding/weld bonding and robots for automated adhesive application.

Contacts were also established in Japan with Nissan, Toyota and more significantly with Honda which had produced its aluminium intensive NSX sports car with a stamped, spot-welded body structure. As part of this staff, from AAS, Banbury and Kingston was involved in a major technical presentation to Honda R&D in Tochigi. (In the latter stages of the program, the name was shortened to the Alcan Aluminium Vehicle Technology (AVT) to reflect a wider application of Alcan automotive technology.)



The AVT Process Route

Promotion of the technology to the auto industry and the development of the body-in-white assembly method continued through the joint participation of the Banbury lab and the AAS group. Two of the aluminum structured X1/9 vehicles were kept at Banbury and were used for drive demonstrations at a local disused airfield to auto companies interested in AVT; one such demonstration being set up for Nissan. Another significant activity at this time was to develop and then to demonstrate the robotic application of the adhesive in a vehicle build. This was accomplished in the Bertone plant in Italy where the assembly in aluminium (in place of steel) of the front end sheet structure of the Volvo 960 model mentioned above was demonstrated. A commercially available robot and dispensing system was used to apply the XD 4600 adhesive to the joining flanges of the panels followed by spot welding. This was an activity led by Mike Kelly. (Interestingly, the use of structural adhesives to provide enhanced structural stiffness and to improve NVH characteristics and fatigue resistance has become commonplace in vehicle assembly and in part stems from the demonstration of the benefits in the ECV3 vehicle and then the promotion of the AVT technology)

Material Supply

Material for building demonstration components and full vehicle structures became a major issue as the program developed since this required the supply of pretreated and prelubricated structural sheet and was well beyond the capabilities of the Banbury laboratory to supply. The choice of medium strength Al-Mg alloy AA5754 was made very early on in the program due to its formability and excellent resistance to corrosion and especially to stress corrosion and the fact that modulus rather than yield strength would generally determine the material thicknesses required. The AA5754 sheet for the first vehicle builds, the Austin Rover Metros, was supplied by Alcan Industries C/O John Wheatley with the pretreatment and pre-lubrication being applied in local jobbing shops. Next an attempt was made to set up a facility in the Falkirk plant of Alcan Industries (a former British Aluminium plant) where spray application was adopted. This equipment was devised by David Bray, a consultant working through the Banbury ASVT team. However, it proved difficult to obtain uniform coating and to handle the coated material. Clearly an effective prototype line was needed for supplying the sheet and this was set up in the Bresso plant near Milan of Alcan Italy, with the base sheet being sourced from Alcan Deutschland. Ian Campbell who had worked for BL Technology with David Kewley had joined Alcan Goettigen from BLT and was the principal contact for the material supply. The design of this finishing line was conceived by the Banbury lab and was run on behalf of the program by the Bresso plant with guidance from Sheasby, Wheeler and others. However, even this was a short term solution and was really only suitable for supplying material for prototype builds. Finally this line was superseded by a dedicated production facility for producing the pretreated and pre-lubricated sheet which was set up in the Warren Ohio plant of Alcan Rolled Products under the leadership of Bruce Robson. This line was also used for finishing AA6111 automotive skin sheet, this material having become the preferred product in the automotive market.

Another aspect to the material supply was to obtain the US EPA approval for the AL070 lubricant. This product was approved for use in Europe but not in the United States. This necessitated obtaining survival data for fish and other aquatic species in water dosed with measured amounts of lecithin. The data from this then had to be related to the likely volume of water used in a typical automotive finishing line to show whether the water effluent would cause any toxic concerns. This exposure work was carried out by an independent laboratory in Missouri and the data was then used by Mike Wheeler and Jean Sang of the Kingston lab to show that the likely amounts present in effluents would not be toxic to marine life. Overall, this topic was managed by Gerry Lucas, Mike Wheeler and Bruce Robson and it was Bruce who worked with the EPA to secure approval for the use of the lubricant in automotive manufacturing.

Another later stage activity was the development of a chromium-free pretreatment. The original pretreatment contained chromate ions although not in the active chrome-six form. Nevertheless it was deemed important to move to a chrome-free pretreatment to avoid any concerns about the toxicity of the pretreatment. The Banbury lab under the leadership of Peter Sheasby was successful in this and again a rigorous series of stress-humidity durability and impact-peel testing of bonded joints and weld-bonding trials were required to validate the suitability and service performance of the new pretreatment.

Other Vehicle Builds

Other build and technology assessment activities during this time were the build of two aluminium structured Pontiac Fieros with the Alcan technology for durability assessment. The lead person here was Bill Swenson, a recent recruit to the Alcan Detroit office from the Chrysler Corporation. Another was the building of a folded sheet body structure for the Ferrari 408 experimental vehicle and this was featured in the Alcan exhibit at the SAE International Exposition and Congress in 1988. While the Fieros did not result in a production build, the excellent results from the assessment of these vehicles and especially their structural and environmental durability played an important role some 6 years later in convincing the GM Management to adopt the Alcan Technology for the body structure for its EV1 all electric vehicle. More than 50 of these vehicles were built. Inexplicitly, GM cancelled the program despite very favourable reports from users and all the vehicles were recalled and scrapped. The activities with BMW eventually led to the building by them of four 3-Series aluminum structured test vehicles, demonstrating significant weight reduction and a 50% increase in stiffness.

The BMW Body in White

This work by BMW was triggered in part by the excellent work of Alan Seeds, Yi Gao, Dubravko Nardini and Iain McGregor in demonstrating the stiffness and energy absorption efficiency of weld-bonded aluminium box beam structures. Again, the cooperation with BMW did not result in the adoption of the Alcan technology but it did convince them of the effectiveness of aluminium for structural applications, including crash energy absorption and subsequent production models of their 5-Series model were built with a front-end sheet-based aluminium structure, fulfilling both the structural and energy absorption requirements.

There was also some involvement with the Jaguar Car Company where its specialty group based near Banbury was developing the XJ220, an aluminium structured super sports car. The main structure of this vehicle was based on aluminium honey-comb sandwich panels but the front-end supporting and energy-absorption structure was folded-sheet based with a significant amount of adhesive bonding. The structural adhesive that was being developed for ASVT was made available to Jaguar and in fact Alcan provided a large oven for curing the adhesive.

North American Developments

Interest in ASVT was also developing in Ford in the US and following a major presentation by the Banbury-based AVT team in 1990/91 to a Ford group that was exploring technologies for building reduced weight vehicles, the technology (now renamed AVT) was adopted for an aluminium intensive vehicle called the Synthesis 2010. This was based on the body structure of the then current Ford Taurus but also had aluminium closure panels in the Alcan AA6111 sheet as this product had by then become the preferred automotive closure sheet material in N. America. At about this time, there was a major move by Alcan Rolled Products to expand the Detroit office under the leadership of Dr. Don MacMillan to form Alcan Global Automotive Products to focus on promoting AVT and the AA6111 closure sheet and to develop long term metal supply contracts, concentrating especially on Ford and General Motors. The office moved to Farmington Hills and the staff expanded to include engineering design, forming simulation, marketing and manufacturing (Gerry Lucas, David Charles, Walt Pivinski, David Rinehart and Bruce Robson) and a significant technical and design staff including both Tony Warren and Mike Kelly who transferred from the AAS operation in Banbury. Others who joined the office were David Moore, Doug Boomer and Mike Bull. It was at this time that the production facilities for the pretreated and prelubricated sheet were set up under the leadership of Bruce Robson in the Warren Plant of Alcan Rolled Products. The production facilities for the AA6111 closure sheet at Kingston Works had also been progressively upgraded and improved under the guidance of Bruce Robson and AA6111 had become a well established product. In fact, it was licensed to Alcoa and became a significant revenue generator for Alcan.

The Impact of the US Government's PNGV Program

In 1993 the US Government's program for a Partnership for a New Generation of Vehicles (PNGV) was announced. This was a partnership between the government and the three major US car companies where one major goal was to develop technologies for mid-sized vehicles with three time the fuel efficiency of then current vehicles without compromising size, safety and performance. The expectation was to have demonstration vehicles by 2000 and production ready vehicles by 2004. Aluminium was seen as a material for enabling the auto companies to achieve these goals and in no small way this was as a result from the development of Alcan's AVT.

In a program to confirm the viability and durability of aluminium and particularly the Alcan AVT system, Ford embarked in 1992/3 on a program to build and then assess a fleet of aluminium intensive vehicles based on the then current Taurus design using the AVT for the body structure and AA6111 closure panels. These vehicles, which were known as Ford AIVs, were some 400 lb (180 kg) lighter than the production vehicle, had improved acceleration and braking performance compared with the production car and also identical performance to the production car in the US Government's frontal crash impact test. They also demonstrated excellent structural durability throughout the several years that they were in regular road service. Alcan operated two of these vehicles for several years.

Based on its success with the AIVs, Ford next adopted AVT for a stretched version of the Ford Mondeo/Contour, a slightly smaller vehicle than the Taurus and achieved a weight of just 2000 lbs, a weight saving of some 40% compared with the production Taurus. This vehicle was identified as the Ford P2000 and in a cosmetically modified shape became the Name?, Ford's demonstration vehicle in 2000 for the PNGV program. The Detroit office was also involved with General Motors in their evaluation of aluminium and the AVT technology for light weighting vehicles and an aluminium intensive version of the then current Oldsmobile Aurora was built. The Detroit office was also involved with GM in the development of its PNGV demonstration vehicle the Precept.

The Ford 2000

Vehicle Developments in the UK

Mention has already been made to the aluminium intensive Jaguar XJ 220 super car and the use of the use of the XD 4600 in its assembly and contacts continued with both Jaguar and Land Rover in the UK as both companies were seen as the most likely to use aluminium in vehicle construction. In fact, aluminium was already used extensively for the base Land Rover’s body panels and also for the Discovery model. However, Jaguar, facing competition from Mercedes, BMW and especially Audi which had introduced the Audi A8 with an aluminium space-frame structure based on technology from Alcoa, decided to adopt the AVT technology for their all new top-of-the-line XJ sedan. As per the AVT technology, the materials were to be essentially AA5754 structural sheet for the body-in-white and AA6111 skin sheet. However, Jaguar opted to use self-piercing steel rivets rather than spot welding to obtain a riv-bonded structure. (Riv-bonding was always a viable alternative to weld-bonding but would reduce the weight saving slightly and could compromise eventual recycling due to iron contamination from the rivets.)

The Jaguar XJ220

Overall management project for the technical input to Jaguar and the material supply came from the Alcan Global Automotive Products office in Detroit through David Charles while the Banbury lab through Peter Sheasby, Alan Carr and others provided local technical support and know-how. This included working with Jaguar in the building of 20 of the then current S-Type production vehicles using the Alcan technology to provide a learning experience for Jaguar and to confirm the soundness and reliability of the technology.

Prior to the advent of this project, Alcan through the Alcan Deutschland had been building and commissioning a new large combined continuous heat treatment and coating line in the Nachterstedt plant in the former East Germany. One major purpose for line was to provide a European production facility for heat treated autobody sheet such as AA6111 but it also had the potential to produce the pretreated and pre-lubricated AA5754 structural sheet. However, considerable development work was required to develop the required product properties and quality and again both the Detroit office and the Banbury lab staff were involved in this together with the staff from the Alcan Deutschland technical staff from Goettingen and Nachterstedt.

Since the XJ Jaguar was not expected to be produced in high volumes, the cost of producing blanking dies for the body and panel stampings could not be justified but the automated production of blanks by laser cutting was seen as the way around this difficulty. This was technology that had been emerging in the auto industry (along with laser seam-welding) but it was new to Alcan and Alcan had little first-hand experience in the production of blanks. David Charles led this activity and it was a key enabling step for producing the aluminium intensive XJ Jaguar and for the first production application of the Alcan AVT Technology. The body-in-white was first shown to the public in the Aluminium Association’s Automotive Seminar in the Detroit area in the spring of 2000 and the production vehicle was exhibited at the Frankfurt Auto Show in 2002 The vehicle has now been superseded by a second generation model but is continuing the use of the same Alcan sheet-based adhesive bonding technology.

Throughout the prototype builds and the initial production of the vehicle, Alan Carr and colleagues from the Banbury lab provided technical support and they continued to do this as a small self-contained Alcan support group following the closing of the Banbury lab.

The End of the Road

While Alcan's promotion of aluminium in automotive applications continued in N. America and Europe and the market for the AA611 closure sheet and its later derivatives continued to develop, there was a shift in the emphasis in Alcan's market strategy and the adoption of AVT for the Jaguar XJ sedan essentially marked the end of the serious promotion of the Technology. By this time, several of the key staff had left the company, retired or had moved onto other activities within Alcan. In concluding it is worthwhile noting how many of the staff of the Banbury lab played a very important part in developing and promoting AVT and other related aluminium material for the auto industry including some who had moved from the Banbury lab but who became involved in the program through their new positions and or locations within Alcan.

15.a CANS TO CARS POSTSCRIPT

Geoff Scamans

This was by no means the end of Alcan's AIV technology story and its impact on worldwide automotive production in general and the revival of manufacturing in the UK in particular. Following on from the successful build of the second generation Jaguar XJ saloon, the major aluminium technology champion within Jaguar, Mark White, became their Chief Technical Specialist with responsibility for BIW development both within Jaguar and within their sister company Land Rover and within the parent company Ford. Following the sale of Jaguar and Land Rover by Ford to Tata in 2008 for £1.8 billion there were initial fears of plant closures for the new Jaguar Land Rover Company (JLR). However Tata soon realised the value of the AIV technology and Mark White was able to introduce five new aluminium intensive vehicles in quick succession starting with the all-aluminium Range Rover (2012), then the Range Rover Sport (2013), the F-type sports car (2013) and most recently the iQ[Al] that will be the replacement for the X-type, with a 100kg lighter body, and will start production in 2015. JLR have plans to take the AIV technology to vehicle production rates in the UK of 850k vehicles/year with plans already in place for vehicle production lines in India, China and Saudi Arabia and possibilities already under discussion for lines in Brazil and North America. The Chinese venture alone represents an investment of £1 billion for JLR. Today, JLR, Britains's largest exporter of manufactured goods with revenues of £11 billion/year, are leading the world in lightweight vehicle technology that is still based on Alcan's AIV technology for mass vehicle manufacture. This is driving a major investment programme within the aluminium industry that involves both new hot and cold rolling mills and numerous heat treatment and finishing lines. The vision from the 1980's is now being realised. Within a few short years it is quite probable that automotive sheet tonnages will exceed a million tonnes in the EU, North American and Asian markets and automotive sheet is poised to take over from can sheet as the major product that the industry produces.

The AIV technology was ready and waiting for this surge in demand but it required legislation to force the change. The main factors driving the change were the cost penalty that vehicle manufacturer's would have to pay for exceeding fuel consumption targets that get progressively stricter each year and requirements to recycle up to 95% of all the materials from end of life vehicles. The AIV technology and the recycling advantage of aluminium compared to steel provided JLR with just what was required to both satisfy the legal requirements and to mass build world leading vehicles. JLR have become the leaders in automotive sheet recycling and derive a major financial benefit by segregating and recycling all their aluminium manufacturing scrap. The AIV technology is spreading from premium vehicle into the more affordable market segments.

North America is now following the UK and Ford have announced plans to build their F150 truck, the largest selling vehicle in the US, using the AIV technology. This will be a body-on-frame-vehicle with an aluminium body on a steel frame. The automotive sheet requirements alone for AA5754 and AA6111 have required the building of four new heat treatments lines by Novelis and Alcoa. The large potential market has re-awakened Alcoa's interest in the automotive sheet market and they are expecting revenues of $500 million from automotive sheet sales to Ford in 2015. This is just the beginning for the AIV technology in mass vehicle manufacturing in North America and further major vehicle builds are expected to be announced shortly. Ford are taking the AIV technology to the highest level of mass vehicle production yet.

The development of the AIV technology continues to be directly supported by many of Alcan's AVT team through their work for Innoval Technology and Novelis in association with the vehicle manufacturers. The technology will repay the development cost many times over for the aluminium industry around the world.

16. NEW OPPORTUNITIES

Nigel Davies & Geoff Scamans

The early 80's saw a major restructuring of Alcan International with fewer but larger, focussed projects. On the one hand core business programmes became more driven by process improvement, best practice (globally), quality and, on the other hand, a portfolio of projects known as 'New Opportunities' was created.

Ihor Suchoversky was Alcan's VP of Research and Operations plus the head of Alcan Int, and his team focused on business activities and the integration of technology worldwide. Hugh Wynne-Edwards had been brought in as Alcan's Chief Scientific Officer whilst reporting to Suchoversky as VP Research and Development within Alcan Int.

Wynne-Edwards was empowered to deliver a technology portfolio in support of the Company's new long-range strategy of diversification and greater market penetration, new products, new applications, and probably for the first time, the investigation of new business opportunities. This in turn led to statements by the year 2000, X % of Alcan's business were to be in non-core markets. Looking back, who was to say that there was not some truth in this, as aluminium has become a low margin commodity? In general the early focus was on energy, transportation, IT and new materials. Part of the challenge was choosing what product lines to follow in order to create new markets and then potentially to be able to launch new businesses with the results.

The programme in Banbury was driven by Jeff Edington initially encompassing fibre reinforced metals and composites, aluminium lithium alloys for aerospace and transport, engineered materials such as for automotive and the exploitation of anodic structures. Some of these topics have been covered elsewhere in this document e.g. Automotive by Mike Wheeler and aluminium lithium alloys by Roger Grimes and others. This summary will focus on the exploitation of anodic technology to develop the ANOPORE membrane and the company ANOTEC, the aluminium-air battery, Cospray and sol gel technology. The latter was a technology that was added to the Banbury portfolio in the mid 80s by recruitment of key individuals from Harwell.

As background to both the aluminium air battery and the anodic membrane development, Jeff Edington set the scientists, led by Geoff Scamans, the challenge of rather than treating corrosion and oxidation of aluminium as a problem, think of it as an opportunity to harness these properties that they understood, to create new, differentiated products.

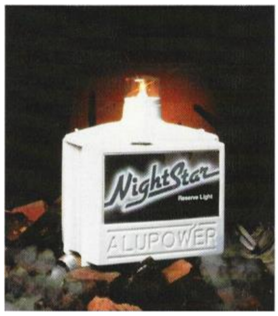
16.a The Aluminium/Air Battery and Alupower (GMS)

Work on the aluminium/air battery system started in response to a report from the Lawrence Livermore Laboratory in California that suggested that primary aluminium could be used as the fuel in a battery or partial fuel cell system that could provide an alternative propulsion system for road vehicles essential using aluminium as a fuel. As this would consume large tonnages of metal it was considered as an appropriate research topic for Alcan Int and projects were started in both Banbury and Kingston Laboratories under the direction of Nigel Fitzpatrick. The Banbury team lead by Geoff

Scamans, supported by Clive Tuck and John Hunter, set up a number of university interactions and set out to understand the fundamentals of aluminium as a potential fuel in an electrochemical system. The Kingston team took a more pragmatic approach and set up the production and testing of a large array of trial anode compositions. John Hunter set up the first microcell system that allowed an anode to be activated in a battery cell and then to be examined at high resolution in a scanning electron microscope. This relatively quickly showed that the only activators of aluminium were low melting point metals that had a lower melting point than aluminium (mercury, gallium, indium, tin, lead, bismuth, cadmium and thallium) and that only one activator was required due to the activator dominance effect. The Banbury team were able to show convincingly that the best aluminium battery fuel was an aluminium tin alloy with a low level of magnesium to control the high level of corrosion on initial activation. The initial aluminium/air battery microcell concept was developed into a microcell by Jon Ball for the study of the electrograining of lithographic sheet. This enabled Alcan Goettingen to develop a leading position in lithographic sheet technology and a leadership in the market that was maintained for many years until lithographic research was discontinued within Novelis and the mantle was passed to Hydro Aluminium.

Alupower Inc and Alupower Canada

Bob Hamlen was head-hunted by Alcan to set up the commercial development of aluminium/air batteries and he set up Alupower close to his home in Bernardsville in New Jersey. He realised that the aluminium/air battery for vehicle propulsion was a long term development and that a range of more near term products was required to develop a revenue stream. These took the form of science kits, emergency lights and small portable generators. However none of these products found a sustainable market niche and it was clear that the main opportunities were in reserve power for communications systems and for military applications mainly associated with underwater surveillance during the cold war. Alupower Canada was set up by John Stannard to develop engineered battery systems and to pursue leveraged funding opportunities.



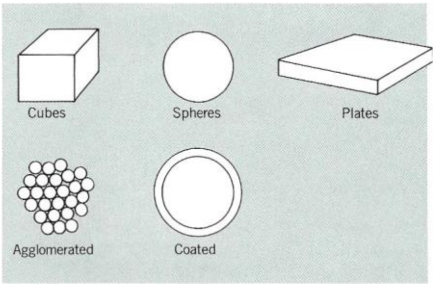
Once it was realised that the aluminium/air battery for vehicles was an impossible dream and not a potential alternative to petrol for vehicle propulsion and that the other potential markets were not of sufficient size to interest Alcan the battery programme was stopped and the companies were either sold (Alupower Inc) or metamorphosed into a fuel cell company (Alupower Canada).

Filiform Corrosion and the Beilby Layer

The experience gained during the battery project was put to good use in the understanding and control of corrosion of aluminium rolled products particularly for architectural sheet and automotive sheet. The critical observation was that all aluminium rolled surfaces have a deformed layer on them that controls corrosion and appearance properties a layer that had originally been discovered by Sir George Thomas Beilby in 1921 who suggested that an amorphous surface layer was generated by mechanical polishing of a metallic surface. Understanding of the properties of this layer and how it is developed at all stages of rolling from the initial passes in the break-down mill to the final finishing passes in the cold mill have solved an number of difficult technological problems for the aluminium industry. These include the control of filiform corrosion of automotive sheet and building sheet, the control of surface appearance of can sheet and the control of smut generation in rigid containers. The legacy of the battery project was not in new business development but in solving and controlling intractable problems in more conventional rolled sheet businesses. The microcell techniques first explored in the battery project were developed for the study of corrosion and were combined with high resolution transmission electron microscopy of microtomed surface layers mainly with Manchester University. Banbury through Martin Amor and Andreas Afseth were the first to combine ionic plasma etching with high resolution scanning electron microscopy. In this way surfaces could be progressively etched away and evaluated for corrosion performance after each etching step and this performance could be directly related to microstructure. This was the forerunner to the development of the 3D microscope at Manchester that combines both surface sectioning and high resolution examination in a single instrument. The Banbury laboratory was at the forefront of this important development at the time of its closure.

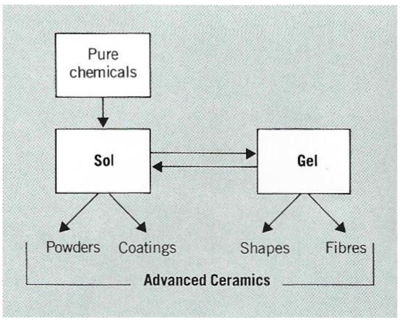
16.b Sol-Gel Technology (NCD)

In the mid 80's Alcan Int chose to add to its materials expertise by employing a team from UKAEA Harwell, led by Jim Woodhead, that specialised in sol-gel technology.



Sol-gel technology processing is a way of making superfine, high purity advanced ceramic materials of controlled particle size and shape. It is a generic technology capable of producing wide range of oxides and non-oxides in a number of product forms having specific tailored properties.

The chemical synthesis of ceramic powders by sol-gel processing involves wet chemical reactions at low temperatures. This processing generates materials with controlled particle size, shape and homogeneity including powders, coatings, shapes and fibres. The key step in the process is control of the sol to gel transition, which can determine the product form.



Conventional ceramic powders are processed traditionally by crushing, milling and grinding followed by high temperature calcination resulting in them being agglomerated and with some impurity. Thus product advantages via sol-gel processing include finer grain sizes, more tightly controlled composition, higher strength and purity thus leading to improved reliability. Such advanced ceramics have good mechanical properties, possess unique electrical and optical properties, have good dimensional stability with resistance to high temperatures.

The approach taken by the group was 'broad-brushed' in pursuing opportunities for structural ceramics this included coatings, coatings in metal working and machining, heat engine and wear components. Electronic ceramic opportunities included thermistors, dielectrics optical sensors/ transducers such as piezoelectric materials.

Linking with the Anotec/Alcan Separations development Ultra Filtration (UF) membranes were taken through to prototyping. These were produced by sol-gel coating the anodic membrane with a thin, controlled porosity layer. These produced membranes typically below 0.1microns. Also the Ceramesh membrane was developed in partnership.

Another development that was piloted was thermal barrier coatings for jet engine components. Such coatings significantly improved the thermal and oxidation resistance of components in hostile environments thus improving engine efficiency. Such coatings were applied by plasma spraying, where free flowing ceramic powders were required with carefully cotrolled size ranges and a deposited composition/ microstructure that met the needs for low thermal conductivity and a long coating life.

A pilot plant, capable of producing a wide range of ceramic powders, was built in collaboration with Magnesium Elektron Ltd. (then part of the Alcan Group). Zr-based materials were used as the starting material. Thermal barrier coating powders were made that met the specifications of the major aero-engine companies and were trialled within Europe and the USA. After initial success, the technology was transferred to MEL.

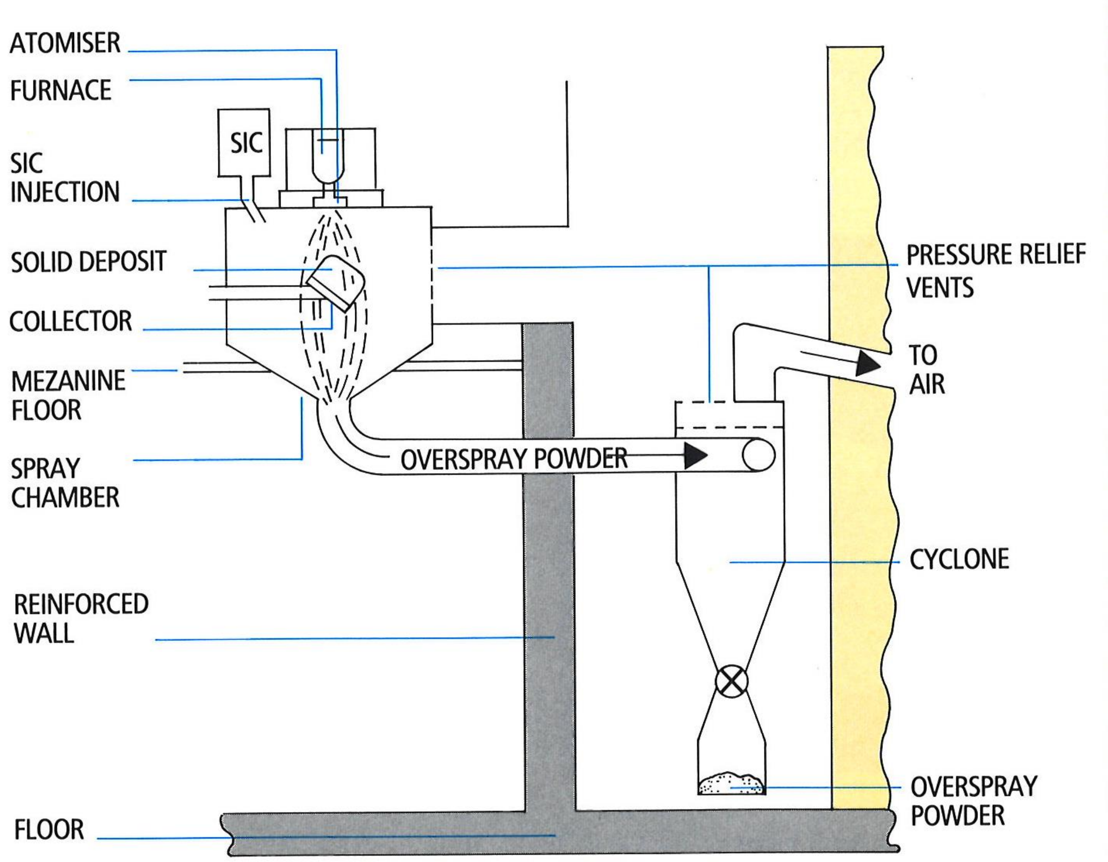
When Alcan decided to return to it's core business, these activities ceased. Some individuals left the company but others were successfully integrated into core business programmes and remain active in the aluminium technology to this day. To my mind this wide ranging activity was one of technology push rather than market pull. However sol-gel technology was and is an important enabling technology. One example was in non-Chrome pretreatments were Zirconia - Polyacrylic acid pretreatments were developed way before the major pretreatment suppliers.

16.c COSPRAY – Al / Metal Matrix Composites

The potential advantages of Aluminium / Metal Matrix Composites (MMCs) providing improved specific strength and stiffness were identified as a potential opportunity for applications in the aerospace, automotive and defence markets. This area also built on Labs molten metal and materials expertise.

At this time MMCs had high production costs often arising from the incorporation of expensive starting materials, such as fibres or whiskers, within the aluminium alloy matrix. These types of material also led to anisotropy within the final product. However particulate Silicon Carbide (SiC) offered a lower cost solution with potential isotropic properties that could mean that affordable materials could be provided for automotive applications.

Labs identified the 'Osprey' process as a potential lower cost production route. This technology was licensed from Osprey Metals of Neath, South Wales and then further developed within Banbury. Silicon Carbide particulate materials were sprayed by gas atomization together with a matrix Al alloy, and the SiC and Al droplets were collected on a substrate to produce a dense composite ingot for further processing.



Schematic of the Cospray process

The business side of the development was led by Peter J S Brooks with Dick Jordan providing the technical expertise. In 1986 a medium-scale laboratory unit was built, this was capable of producing 10Kg ingots. The planning of a larger "Design and Demonstration' unit was initiated in 1987 and commissioned mid 1988. The D & D unit was capable of producing a 100KG extrusion ingot in 9 minutes with a high process recovery.

Typical evaluation materials produced were AA2014 +10% SiC and AA 6061 + 13% SiC for the extrusion market, plus varying Al –Li (AA8090) / SiC compositions for aerospace. Material was produced for in-house testing and for processing through British Alcan plants. The material produced had increased elastic modulus (over the base alloy) but with reduced elongation. For the aerospace market, the materials produced had a property balance that resulted in a significant increase in stiffness to weight ratios.

The Cospray process did not provide the low cost route to aluminium based metal matrix composites and the search continues today for such a process route to exploit this unique class of materials.

16.d The Anopore Membrane, Anotec and Alcan Separations (NCD)

Sandy Davidson, Robin Furneaux, Mel Ball and Roy Rigby were ‘locked away’ for six months and challenged the exploiting Banbury’s knowledge of anodic films in markets other and building products. There was a range of opportunities identified, which could exploit the unique, ordered, porous structure of the anodised aluminium. These included electronic based applications in field emission, digital scan TV, thin circuitry, solar cells, photochromics, glow discharge devices, memory devices etc. plus concepts for catalysis and membranes.

However a decision was made to focus on a novel process developed by the team that detached the anodic film from the aluminium strip substrate creating a freestanding porous membrane. It is worth noting that many of the electronic ideas for anodic films listed above are being rediscovered and are under investigation by researchers globally.

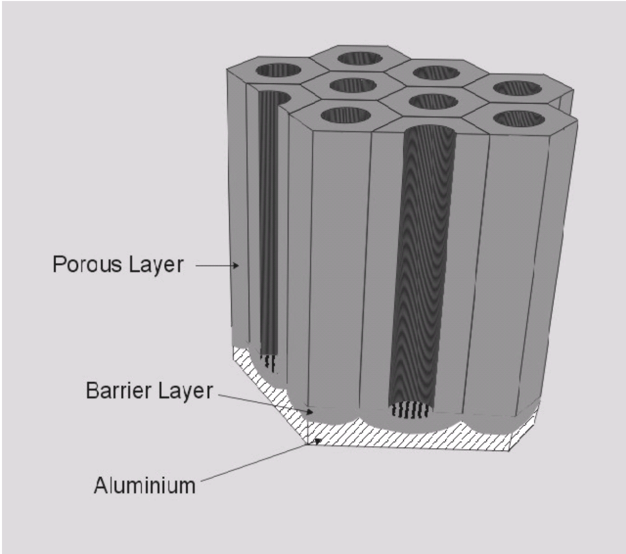
The anodic oxidation of aluminium, which has been used for many years for both decorative and protective architectural applications, can produce porous films on aluminium with well-defined pore structures and high porosity. In theory, this structure fulfilled many of the requirements for a filtration device; however the major problem of using this approach to produce membranes was that the film is attached to the aluminium by a non-porous layer of alumina known as the barrier layer. The basic Anopore development and subsequent patent resulted in an electrolytic process, which both separated this film from the aluminium and converted the non-porous layer to a porous one, thus producing a membrane.

The basic technology: - When aluminium is anodised in certain acid electrolytes a porous oxide film is produced which exhibits a uniform array of hexagonally close packed cells, each containing a cylindrical pore (Figure 1). Following initial growth of the barrier layer its depth remains constant for constant applied voltage because of an equilibrium between the oxidation of the aluminium at the metal/oxide interface and enhanced chemical dissolution at the base of the pores caused by the electric field. The barrier layer thickness, the cell and pore size are all controlled by the voltage. The thickness of the porous anodic film is controlled by the current density and anodising time, with the following basic relationships

Cell diameter ∞ Applied Voltage (1V ≈ 1nm)

Barrier Film Thickness ∞ Applied Voltage

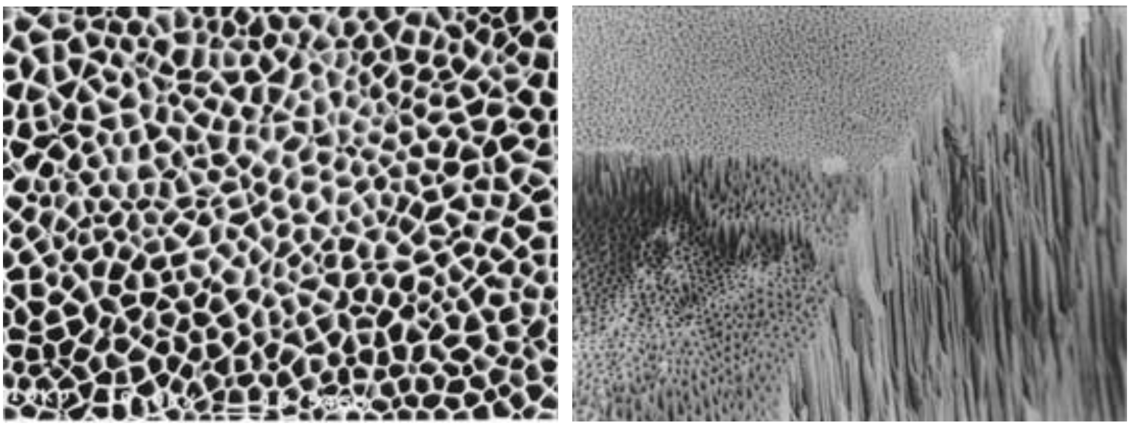
Film Thickness ∞ Time



Aluminium Anodic Film Structure

By selection of the appropriate electrolyte and voltage/current parameters, pore diameters between 10-250nm; pore densities between 10^{12} and 10^{15} per m^2 and film thickness up to 100μm can be achieved. This ability to design porous films of a pre-determined morphology makes them potentially well suited for use as porous membranes.

In order to produce a freestanding filtration membrane, it is necessary to detach the film from the aluminium and remove the barrier layer. This can be achieved by computer controlled lowering of the anodising voltage after completion of the film growth, which results in thinning of the barrier layer with smaller pores being formed. The size of the voltage reduction is critical and effective separation of the film can be achieved if the voltage is decreased in small steps. This then results in a uniform pore nucleation within the barrier layer. By progressively lowering the voltage, pore nucleation continues until the barrier layer is so thin it is dissolved by the anodising electrolyte. This voltage reduction process was the key element of the basic patent.



Scanning Electron Microscopy images of the Anopore membrane

Production and sales focused on commodity laboratory filtration products with the pore size range between 0.02 and 0.2μm with phosphoric acid as the electrolyte providing a robust manufacturing route. A top surface structure and cross section of a membrane are shown above.

On completion of the procedure the membrane remains attached by an extremely thin barrier layer to the aluminium. Separation is brought about by immersion in a higher concentration of the anodising electrolyte. This dissolves the remaining barrier layer and produces hydrogen, which lifts the film from the substrate. After rinsing and drying the membrane is removed from the panel and the metal is reused.

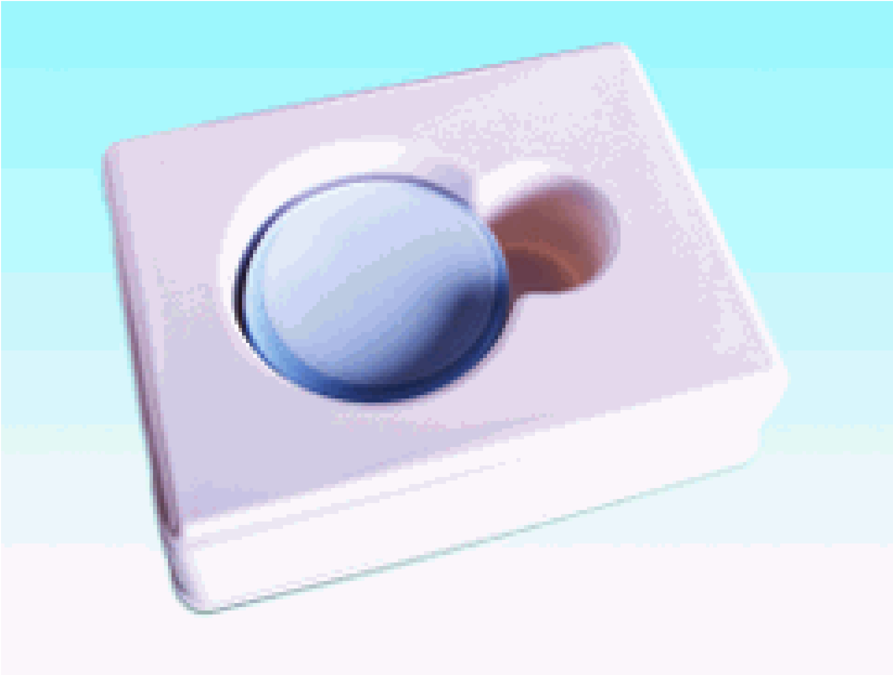
The process used very little aluminium with panels being reused often up to 20 times. The substrate was >99.9% purity and usually diamond polished: this approach was to minimise any structural defects within the anodic film (e.g. from intermetallics) or surface structure (e.g. roll lines).

Scale Up and Commercialization: - With the decision made to spin out this opportunity as a stand alone business, there was a recruitment drive to acquire the necessary business and technical skills needed by the newly named company, Anotec. There was also recruitment into the labs of skills in support of the new, non-core aluminium, markets that were being targeted e.g. biotechnology.

The first full-scale production unit was built within Labs but the first commercial offices and product development labs were in nearby Beaumont Close. Some long-standing Labs employees were transferred into the new entity, including Roy Rigby, Robin Furneaux, Beth Andrews and Steve Murray. Steve was responsible for manufacturing and, more than anyone, stayed with this product as it changed ownership and introduced manufacturing facilities at Wildmere Road and Beaumont Road, within Banbury.

The production process typically involved anodising 16 Aluminium panels each a cm x b cm and then detaching the 32 anodic films. Laser cutting was used to size the membrane for different devices. As one can imagine, these anodic films were relatively fragile and the key manufacturing skills developed were less in anodising but mainly in the encapsulation of ‘difficult’ materials into devices. Two such devices for the laboratory filtration market are shown on the next page.

25mm ANOTOP syringe filter for chemical filtration



0.47mm ANODISC (membrane with thermally bonded PP edge ring)

In these lab filtration applications, the precise pore structure and narrow pore size distribution of the membrane ensured a high level of particle removal efficiency. Microorganisms and particulates were captured on the surface of the membrane for subsequent analysis by light or electron microscopy. When wet, the membrane was virtually transparent, which meant that retained particles did not need to be transferred to another surface before microscopic examination.

With a route to market established, further technical challenges identified and new product managers employed by Anotec, there were new challenges for Alcan Int. This resulted in a portfolio of projects in support of this new direction and the need for new skills. One such group was the biochemists led by Liz Scamans and Andrew Walker, bringing knowledge of areas such as cell culture and diagnostics. This group worked closely with the material scientists to identify, develop and improve products for Anotec's markets. Also at that time a new group was recruited and established to pursue sol-gel technology (see later), their skills were also brought to bear on these challenges.

From a business perspective, Anotec 'grew' into Alcan Separations with some investments in external businesses and the creation of Ceramesh. This was based on another Alcan Int materials / sol gel development, which was developed by Sandy Davidson and Mike Thomas. It was a large, inorganic industrial filter with a range of potential pore sizes. The filter was formed by coating a fine woven mesh of Inconel 600 chrome-nickel alloy of a 100micron mesh size with a porous zirconia coating. Typically, the zirconia was 200 micron thick and had a pore size of 0.1 micron. Mac Tracy led Alcan Separations initially from Banbury but then from Boston, from where the overall New Opportunities initiative was managed by Tim Tuff. Nigel Davies operated out of Alcan Separations/Anotec managing the materials and product development both within the Separations group and Alcan Int.

Further Technical Developments: - There was a range of developments in support of Anotec and more widely with the Separation's business. Below is a list of some of those activities

1. Improved pH resistance through calcination of Anopore

2. A stronger, supported Anopore by selectively anodising thin aluminium foil. Photolithography was used to protect an integral Al grid, which would not be anodised. The remaining areas of the grid were anodised until the Al was consumed. Other activities in Anotec were engineering solutions to supporting larger area Anopore

3. Functionalizing the membrane so that it could be used in diagnostics (pregnancy testing!) and chemical monitoring devices.

4. Anopore is naturally hydrophilic further hydrophilic /hydrophobic functionality was undertaken by PVD techniques

5. The use of the membrane in flow through catalysis by depositing metal catalysts in the pores, (NB this is still the subject of EU funded research in 2012)

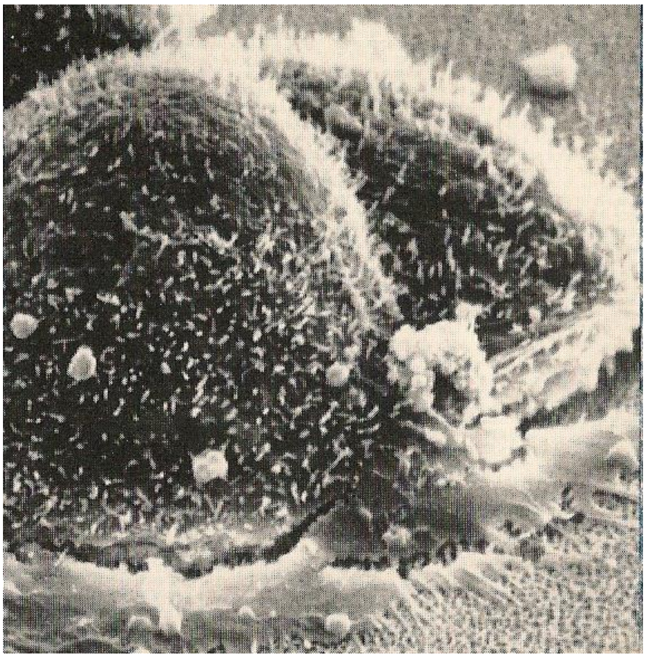
6. The development of controlled size inorganic particles for packing in chromatography columns

Some specific products were:

UF Membranes. These ultrafiltration membranes were controlled porosity zirconia layers deposited and fired on the Anopore membrane. This produced membrane with pore sizes below those of Anopore (<0.02μm}.

Anocell was a product produced for the tissue culture market. Laboratory studies of animal cell growth were traditionally carried out on plates, by replacing the plates by a controlled porous structure such as the Anopore membrane the cell structure could be supplied by diffusion of nutrients from both above and below. This is a big advantage for some cell systems e.g. epithelia (found in skin and walls of internal organs) and is closer to real life. Other advantages of the Anopore membrane was that it is transparent when wet enabling easy microscopic evaluation of cell growth plus it was ideal for staining of cells for monitoring.

Removal of the Anopore membrane from the Anocell device



Cell growth on the Anopore membrane

Ceramesh. One solution to the mechanical weakness of the Anopore membrane was the development of Ceramesh. The ingenious solution was to mount a porous zirconia coating on an Inconel wire mesh. The manufacturing process resulted in the mesh acting like a reinforcing rod in concrete. As a result a ceramic membrane was made which had sufficient tensile strength and flexibility that it could be wound into a spiral. The pore sizes made were generally larger than Anopore addressing the industrial filtration market. Ceramesh was set up as a stand-alone business fronted by Paul Gallagher and was bought by North West Water in 1992.

All of this work was subject to an aggressive Intellectual Property strategy. The approach was to develop satellite patents around the core patent for the Anopore membrane patent, thus deterring market entry from other companies. As one can imagine the mention of 'diagnostic kits' and 'cell growth products' was way beyond the comfort zone of those running a traditional aluminium business.

16.e The End-Game & Hindsight (NCD)

To this day, the topic of New Opportunities can still stimulate discussion and argument as to its merit. One thing that was certain in the early 80s, the Laboratory had to change to survive. The approach of New Opportunities alongside larger focused business projects enabled Jeff Edington to make that change. During this period Alcan Int developed a reputation as probably the leading materials laboratory in the UK and, as such, was able to attract high calibre professionals to Banbury. Individuals recruited to both approaches have remained active in the core aluminium industry to today.

Within the New Opportunities portfolio, one can argue that the more conventional topics of automotive and Aluminium - Lithium alloys would have been developed anyway, but being part of this portfolio allowed these subjects to be addressed more widely than if they had been part of a more incremental, business improvement approach. Their advantage was that they were closely related to Alcan's existing businesses and hence had existing routes to market. Therein lay the fundamental issue evident in other products, e.g. Anopore and the Aluminum – Air battery, in that these developments were technology push rather than market driven activities. This is always a high risk and often flawed strategy.

For instance, as Anotec was formed and started trading, routes to market were established mainly at arms length via distributors, although unique and of high performance, the membrane was addressing only a niche sector of the laboratory filtration market. Further developments broadened this offering but throughout, we were up against larger established suppliers.

If Alcan had been serious about its diversification strategy and this was a chosen market, then the only potential path for success would have been the acquisition of an established filtration company to provide the route to market and market intelligence for the materials development. Another approach would have been to develop the technology to a granted patent with pre-production capability and then sell the technology, however secrecy abounded.

In 1991 Alcan decided that it would withdraw from a diversification strategy and revert to a core business of primary aluminium plus rolled products. A number of businesses and technologies had evolved from Banbury, Kingston and Manlabs (Boston); this portfolio was transferred to Ampersand Inc., a Boston private equity company, for divestment.

Anotec was sold to Whatman who in turn were taken over by GE Healthcare. GE continued to produce Anopore membrane in Banbury up to 2010. Ceramesh was sold to North West Water in the UK.

Personally, Anotec and Alcan Separations was a 4year period in the middle of a 30-year Alcan career in rolled products. Although initially a sceptic, it was the most challenging and enjoyable period of that career, allowing greater business exposure than was possible in a traditional technology role.

17. Alcan Primary Raw Materials R&D Programme:

Banbury Laboratories 1989-2002

Chris Newton

The link to the Recollections web page was a pleasant surprise in my Email invitation to an Alcan 30 Year Club lunch meeting. I was grateful to take up the offer from Peter Band to re-open the web pages and add my description of the Alcan Primary Raw Materials R&D Programme in Banbury Laboratories. For me this chapter was more than a different technical facet of the Banbury Laboratory activities because it characterised the values of many who worked for Alcan International. In my opinion it demonstrated how the flexibility and abilities of many talented professional people combined to achieve more than working alone. Individuals with different disciplines and diverse cultures regularly solved a wide range of problems in production plants on five continents. The benefits of remote collaboration to work together in dispersed groups with a common interest, these skills networks became a way that many solved problems and individuals became life-long friends.

In preparing this essay I realised that its origins stem from 1988 when John Hunter, Henry Holroyd and Geoff Scamans succeeded with their second attempt to recruit me from UKAEA to the Banbury Laboratories' Corrosion team. Thereafter I had over 18 years with Alcan International in various roles during which it was a privilege to be presented with a diverse range of technical and personal opportunities. In retrospect I realise I enjoyed this most because it helped fulfil my ambitions to work with great materials engineering professionals and to see the world. Alcan trained me and many others to lead successful technical teams including both small and large R&D teams in both its Fabrication and Primary business streams. These included leading project work in New Opportunities R&D where I helped contribute to the technology of high volume structural joining of aluminium sheet by weld-bonding and the development of advanced lightweight aerospace alloy production including Al-Li Cospray MMC's. These topics are described in other sections of Recollections and overlap some of the parallel time lines on the various subjects summarised below. Significantly for me this multi-business stream arrangement regularly bewildered Alcan's Directors of Technology who usually thought I worked for each of them exclusively. Occasionally I was asked by a colleague working in the Fabrication business stream why it was necessary to do any Primary R&D work at all in Alcan. My reply would usually be based around my understanding that the majority of the aluminium ever made is still in use and that the successful efforts to replace heavier and less recyclable materials in transport and other initiatives generates an on-going demand for primary aluminium. Rightly, aluminium parades its green environmental credentials, but this ubiquitous material comes at a price and leaves a footprint on the earth. To successfully extract aluminium in a modern, energy-efficient, pot-line smelter demands strong, low-dusting, low-sodium alumina feedstock. For around a century Karl-Joseph Bayer's Process has been used to extract the majority of the world's alumina hydrate which, when it is calcined efficiently, usually meets the specification. Research on the chemistry and chemical engineering of the Bayer Process has proved an essential element of the energy efficient manufacture of aluminium. This is because the dispersed geology and extraction chemistry required for different bauxite reserves is diverse and there is a need to minimise the environmental impact of these multi-million tonne production plants given most of the caustic bauxite residue from aluminium production is still deposited where it was processed.

Another section of Recollections mentions that novel electron microscopes in Banbury Laboratories were occasionally employed to examine hydrate. However, the traditional home of Alcan's R&D work on Raw Materials was the Arvida Research and Development Centre in the Saguenay in Jonquiere, Quebec, interchangeably referred to as "CRDA" or "ARDC" depending on your preferred language. It was well recognised in Alcan Primary that there was an on-going need for highly-trained technical skills in geology and chemical engineering to work with process and materials specialists to optimise Alcan's global bauxite reserves. For some years Alcan International also maintained a world-class capability on Bauxite Digestion and Speciality chemicals in Kingston Research and Development Centre (KRDC) that complemented Arvida's work with world-class ground-breaking technological contributions on the chemistry and engineering of bauxite digestion led by Steve Ostap and George Fulford and their teams. Both helped familiarise personnel from Banbury Laboratories with the many challenges of handling Bayer Liquor.

In 1989, Ian Porteous, Alcan Primary's Raw Materials Director of Technology, visited Banbury Laboratories. As explained in other articles in Recollections, around that time Alcan wanted to reduce the New Opportunities R&D initiatives and refocus its efforts toward its core businesses. Coincidentally the relatively new joint Alcan / Billiton venture (1.1Mtpa design capacity) Bayer process plant, at Aughinish Alumina Ltd (AAL) in Ireland was seeking to expand to 1.5Mtpa at minimum cost by breaking the so-called free-caustic barrier. Some bauxites require higher digestion temperatures and this barrier was a common challenge in AAL and its sister high-temperature digestion Bayer Process plants in San Ciprian, (Alumina Española, known as Inespal) and Gladstone (Queensland Alumina Ltd known as QAL). At that time it was accepted that an increase in the caustic concentration of the recirculated Bayer Liquor could result in unacceptable risk to process plant equipment and compromise safety and economics. Each time the free-caustic concentration was allowed to increase subsequent process plant equipment failures and shut-downs were routinely attributed to this barrier. To safely exceed this unproven barrier with confidence more technical evidence was needed. AAL had tried to gain help from the whole Raw Materials programme and requested physically closer technical support than seemed practical from Canada. Consequently, after the intervention of Ian Porteous, the AAL technical leadership, including John Hillary and Damien Clancy visited Banbury and asked the Laboratory Director, Mike Sporton, where Banbury Laboratories could offer to help. Many areas were discussed. Initially top of the list from the Banbury service-offer was the alternative use of Red Mud (a caustic waste from the Bayer process often stored in large stacks and lakes). Research by Jim Woodhead, Les Howarth, Dave Double and Nigel Steward (later a VP of Rio-Tinto Alcan) looked at a variety of technology options and diverse ideas including the use of rheology and membranes etc. That research was not allowed enough programme time to prove fruitful and R&D was stopped when the majority of the New-Opportunities programmes were terminated.

The search continued to find durable materials for process plant to survive the perceived free-caustic limit in the complex caustic chemistry of the re-circulating liquors used in the digestion circuit of the Bayer process. Materials of construction were exposed to a range of chemistries, acids, alkalis, organics and afflicted by a variety of process scale accumulations. George Fulford and John Hillary (later to succeed Ian Porteous as Director of Technology) quickly recognised this challenge was a question where materials expertise and more specifically corrosion engineering skills from Banbury Laboratories could make a difference. The aim being to provide evidence that the life of process plant construction materials could be maintained or improved while the free caustic limit could be exceeded without compromise to safe plant operation. This opportunity generated a sense of expectation and ambition that generated momentum for change and therefore all the plants supported this work.

While increasing the caustic concentration allows more alumina to be dissolved it also affects precipitation including retarding its kinetics. Also as more bauxite was processed more process scales formed to block heaters, pipes and tanks limiting process efficiency forcing expensive cleaning and choking the benefit of higher caustic. In the late 1990's there were many Bayer process scale related issues. For example in AAL high temperature digestor descaling was a manual process and generated cramped and dangerous physical conditions for three people working inside large vertical pressure vessels for six weeks, 24 hours per day. With two or three descaled digestors out of service annually to remove 300t of tenacious process scale the plant was constrained. Across all the Bayer plants hundreds of large welded carbon steel precipitator tanks were systematically cleaned to recover capacity lost to alumina hydrate scale accumulation. Without stress relief tanks the tanks were prone to leaking welds affected by caustic embrittlement. Also across all the plants inappropriate heater tube metallurgy and poor acid-cleaning practices for process heaters had led to premature failure of the heater tubes eventually crippling their thermal efficiency and safety. Having spent 37 hours getting to Alumar in Brazil (a 5% Alcan majority owned Alcoa Billiton plant) John Haines and I found their Bayer Liquor shell-tube heat exchanger efficiency figures were to be admired as the best in industry but after a few simple questions it was revealed there was a complete lack of use of any corrosion inhibitor during sulphuric acid cleaning / descaling. This had generated extensive acid thinning of the tubes, tube-sheets and the liquor heater heads such that they were in danger of loss of integrity given they were close to operating with no corrosion allowance whatsoever and not being able to safely retain the process fluids or regenerative steam.

Given the background, three areas formed the basis of Banbury laboratories research themes (a) materials degradation, (b) alleviation of process scale and (c) product precipitation. Each area grew rapidly from small technical assistance activities into a multiple lab-year programme. Initially the programme of work in Banbury Laboratories supported the reduction of Bayer plant corrosion and process scaling and was later joined by precipitation and heat transfer modelling. Over 12 years between 1990 and 2002 in total it amounted to close to 100 lab-years of investment in R&D work in Banbury Laboratories with major contributions from the highly skilled and diverse talents of the flexible staff available in Banbury. Most of those who worked on the Raw Materials R&D Programme in Banbury were from the existing Fabrication and New Opportunities R&D programmes, working first with Roger Wilson as Programme Manager and then me and included Doug Boomer, Andrew Howells, Andy Darby, Jonathan Sharman, Chris Wiseman, John Haines and Ged Flynn. The group was recognised internationally as supporting the global Alumina business via by the Alcan Alumina Technology Club (ATC) holding one of its annual meetings in Banbury 1999, coincidentally the year Ian Porteous and Bryan Hiscox decided to leave Alcan to form AluminPro.

Significantly the Banbury Laboratory Raw Materials R&D programme attracted secondees and collaborative support from Alcan's sister laboratories in Kingston and Arvida. This included Dennis Audet and Hélène Boily who both transferred from Arvida to Banbury between 1998 and 2001 to develop industry leading advanced hydrate precipitation models. The research completed in Banbury improved the hydrate quality in enhancing its strength (reducing attrition and dust formation) while maintaining sodium content control. Following the integration with Alusuisse in

2001/2, Dennis Audet moved this research again, this time to work at the specialist laboratory that was established in Brisbane to provide technical support both Nabalco and QAL (later Rio Tinto Alcan).

Thanks to Alcan International's support from Bryan Hiscox in Montreal, Banbury Laboratories Raw Materials R&D became directly involved in the operation of two significant pilot plants with Inespal located at San Ciprian, North West Spain. The first was on dedicated digestor liquor heaters carefully running at barrier breaking high caustic concentrations. A few tubes had thinned and collapsed but the use of advanced electrochemical corrosion sensors (including a novel reference electrode) showed that tube life could be extended by a controlled flow of warm Bayer liquor into heater exchangers when brought back into operation after heater acid-cleaning. It was attributed to promoting the carbon steel to passivate in the Bayer Liquor reducing the subsequent rates of erosion corrosion after each restart.

The other San Ciprian pilot plant was a collaboration involving co-operation between a Danish firm and Alcan using novel Solid Liquid Calcination technology for liquor oxalate removal. Hélène Boily then worked with Andy Caruthers from Montreal's Engineering team on the Bayer Liquor organics removal process piloted on an industrial scale operating at 120t/year. Organics, like oxalate, suppress alumina precipitation and accumulate on each recycle of the process liquor. This process to remove the oxalate was revolutionary. Banbury's contribution included the 1998 secondment work by Hélène Boily. Her co-authorship of a paper describing this work in Light Metals 2000 was later selected in 2013 by The Mineral Society (TMS) to be republished in a book as part of the definitive collection of papers describing the Bayer Process.

At its peak the activities of the Banbury Raw Materials R&D programme supported twelve Bayer process plants around the world and included a number of third-party producers who paid for access to Alcan's research via a research levy of around US$1 per tonne of calcined alumina produced. Given these plants annual production was in millions of tonnes the sum was significant. The specialist proprietary high-temperature corrosion probes were used for in-plant condition monitoring projects within Alcan were invented and assembled in Banbury and then used in Inespal, Aughinish, Queensland Alumina Ltd and Alumar. Banbury Laboratory's consultancy in Alumar and Alunorte in Brazil, Shimizu in Japan and Belgaum in India made the opportunities to generate a surplus income for Alcan International. It is noteworthy that, around that time, the third-party technology sales of Alcan's Raw Materials technology and intellectual property was managed by Jean Doucet in Montreal. Income was of sufficient magnitude to fund all Alcan's Raw Materials R&D in Banbury, Kingston and Arvida, meaning Alcan plants occasionally paid no annual levy for the approximately 50 lab.-year programme of R&D support from Alcan International in some years during the 1990's.

An important and remarkable element of Banbury's contribution was Banbury Laboratories Raw Materials R&D group members forming and in the case of Andy Darby, Dennis Audet and me, leading, three separate groups of engineers each with common interests and need to share skills. These remote teams were known as skills networks. Across Alcan Primary Raw Materials there were a number of these, each comprised multi-discipline multilingual international teams of Alcan and third party plant experts coordinated by Jean Pierre Riffaud. Technical questions would be asked and problems solved between network members including some that were difficult because they might have revealed a lack of understanding to their local colleagues. As part of this networking and knowledge sharing Banbury Laboratory

Raw Materials team hosted and ran several international workshops that promoted best practice and the use of Banbury's R&D expertise. This included workshops on Corrosion in Banbury in 1995, a workshop on Corrosion and Scaling in Jamaica in 2000 and Heat Transfer and numerical Process Simulation in Banbury also in 2000. These international teams worked together in a cooperative way to solve common problems. All involved in those sessions from the Alcan International Raw Materials teams and its many third party clients were particularly sociable. This led to many memorable international cultural moments like the wooden skittles evening at the "The Horse and Jockey" held at a skills network leaders meeting in Banbury and, my personal favourite, Ged Flynn and Jim Dundon leading folk signing in Mandeville Jamaica in 2000. Over the years these skills group meetings ensured that safer practices were embedded in Bayer process plants in particular on precipitation tank and heater cleaning after a number of dramatic erosion-corrosion and insidious stress corrosion failures had led to avoidable downtime in Alcan and sadly fatalities in non-Alcan plants. Most significantly this method of sharing best practice facilitated the networks that safely embedded the associated production cost improvements by supporting increasing Bayer process caustic concentrations in a number of high temperature process plants leading to a multi-million tonne production improvement per year. The work attracted multiple third party technical support contracts from non-Alcan plants. A number of legacy technical activities led to functions and capabilities that continued to run in Canada, Australia and Ireland.

Running parallel to the Raw Materials team in Banbury Laboratories was the specialist chemicals applications team under Ken Evans who transferred from Chalfont Park into the purpose built two story building built at Banbury following the 1997 quadrangle fire. The Burntisland Bayer Process plant of British Aluminium in Scotland paid for this work. Established under permission of Karl Bayer in 1917 to produce smelter grade alumina, from 1972 it produced special chemical grade alumina becoming Alcan in 1982 and closing in 2002 when Alcan withdrew from the European speciality chemicals market, after selling the equipment to Boxitogorsk in Russia. Consequently Alcan Chemicals R&D team was disbanded shortly after their arrival in Banbury Laboratories. So, in 2000, some Chemicals technical staff transferred across to work on the Banbury Laboratories Raw Materials R&D projects. There were notable successes including work with Rothamstead Soil research on the use of Burntisland Red Mud to rehabilitate heavy-metal contaminated soil in India and around zinc smelters near Bristol.

In 2001 when Raw Materials R&D left Banbury laboratories to move to its new home in Brisbane, Australia to support the Nabalco (Alusuisse Plant at Gove and QAL) I chose not to leave Banbury Laboratories. I remained working for Alcan Primary based in Banbury. In 2002 I remained part of Alcan International Ltd and I joined the Alcan Primary Alternate Smelter Technology Programme working with Nigel Steward (Montreal), Ghislain Dube (Arvida) and Dave Creber (KRDC). The work revisited development of alternative environmentally-friendly Smelter Technology as part of the ARDC R&D programme because Alcoa and other Primary producers were seen as a threat. Interestingly this included the discovery of secret work of Vitorio DeNora (then 90 years old) on coated metallic non-consumable anodes (he was someone I had previously worked with indirectly in the early 1990's with Steve Court and Mike Stowell as part of the Moltech project). Remarkably he had nearly achieved success but the purity of the metal he manufactured from his rented Alusuisse electrolysis cell was not quite good enough (and never would be) even after spending US$50M of his own money. The arrival of Pechiney into the Alcan family stopped all alternative smelter technology R&D and returned the focus back to the conventional.

My Alcan Primary work continued between 2003 and 2007 on a number of topics. This included the successful introduction of the chemical pilot-plant making the environmental treatment process for handling fluorides in spent pot lining “SPL” for North American smelters. The process plant co-invented by Frank Kimmerlee is based in Jonquiere in the Saguenay and is called Low Caustic Lime and Leach Technology. My support activity in Banbury for the demonstration plant continued from 2003 to 2007 under the name Alcan International: Banbury from the Colin Sanders Innovation Centre. However, I reluctantly chose to leave Alcan in 2007 which was just before the sale of Alcan to Rio Tinto because I was unable to accept an offer of relocation to the former Pechiney Grenoble R&D facility for personal reasons.

This is my opportunity to say thank you to all who knew me in Alcan because it was my privilege to be part of the many Alcan international teams I worked in. Those still in the industry today tell me that the Banbury Laboratory Raw Materials R&D team made a significant difference in helping facilitate confidence in multiple lower capital cost alumina plant expansions and in particular contributing to safe de-scaling. It was a sad day for me to leave Alcan International but I know the teams I was privileged to collaborate with made a difference. And, to this day, I miss working with all my friends and colleagues from Alcan. I hope you have enjoyed reading and looking at a few of the images and photographs below.

Corrosion in Alumina Plants Workshop: Banbury Laboratories 6-8 JUNE 1995

List of Attendees:

Alcan International Ltd: Banbury
Tony Blake, Doug Boomer, Jason Fisher, John Haines, Andrews Howells Chris Newton, Jonathan Sharman, Graeme Wilson, Roger Wilson

Alcan International Ltd: Arvida
Luc Parent

Alcan Jamaica Co Ltd: Kirkvine
Steve Gooden

Alcan Smelters & Chemicals: Jonquiere
Pierre Rodrigue, Francois Fortier, Pierre Tremblay

Alumina Española: San Ciprian
Pilar Eiroa-Leon, Ricardo Lopez-Mora, Julian Barrera-Fernandez

Aughinish Alumina Ltd: Askeaton
Jim Dundon,Katie Sheehan

Queensland Alumina Ltd: Gladstone
Daniel Thomas, Rex Tomlins

Alcan Chemicals Europe: Chalfont Park
Tom Dingwall

UMIST: Manchester
Lionel Fournier, Stewart James, Roger Newman (not on photograph), Margaret Stack

Indian Aluminium Co Ltd: Calcutta
C C Pal

Alcan Aluminio do Brasil SA: Brazil
Paulo Rossi

Nippon Light Metal Co Ltd: Shimizu
Tsuyoshi Kawarasaki

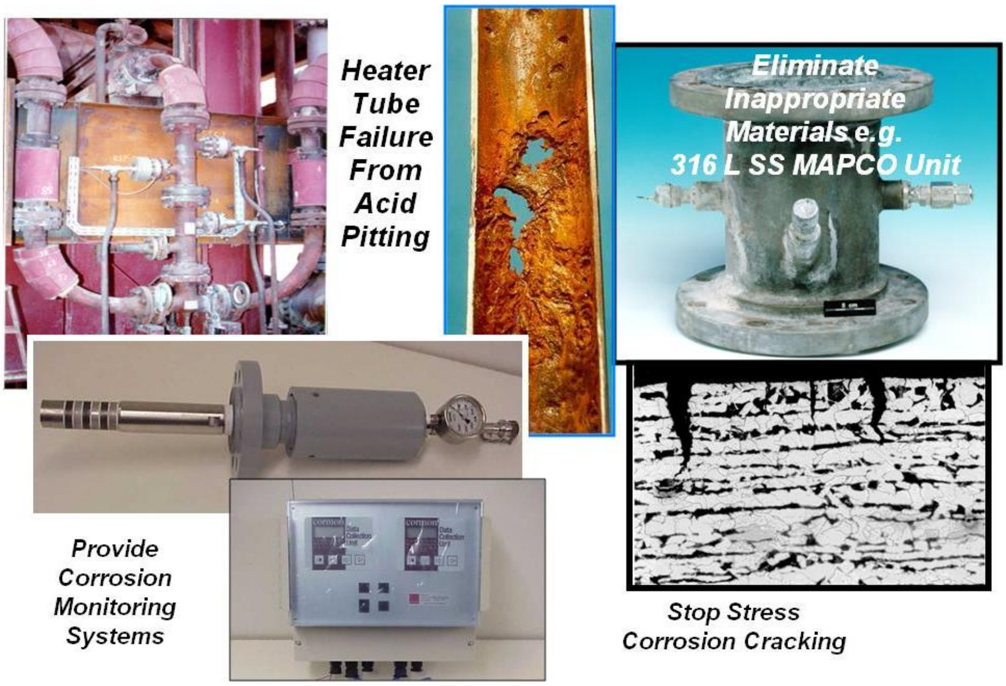
Alcan International Ltd: Montreal
Bryan Hiscox

Alcan Chemicals Europe: Burntisland
Tom Irvine

Mike McCatty's Aljam team hosts of the March 2000 Scale and Corrosion Workshop in Mandeville.

The meeting formed a large multidiscipline group from AAL, Vaudreuil, QAL with some of the same attendees from Corrosion Workshop in 1995. Apologies for not remembering all the people on this picture but the eagle eyed will spot John Haines, me, John Hillary, Chris Wiseman, Andy Darby, Raymond Breault (Arvida).

On the front row Ged Flynn (who led a few sessions of folk singing in the bar) with Jim Dundon from AAL

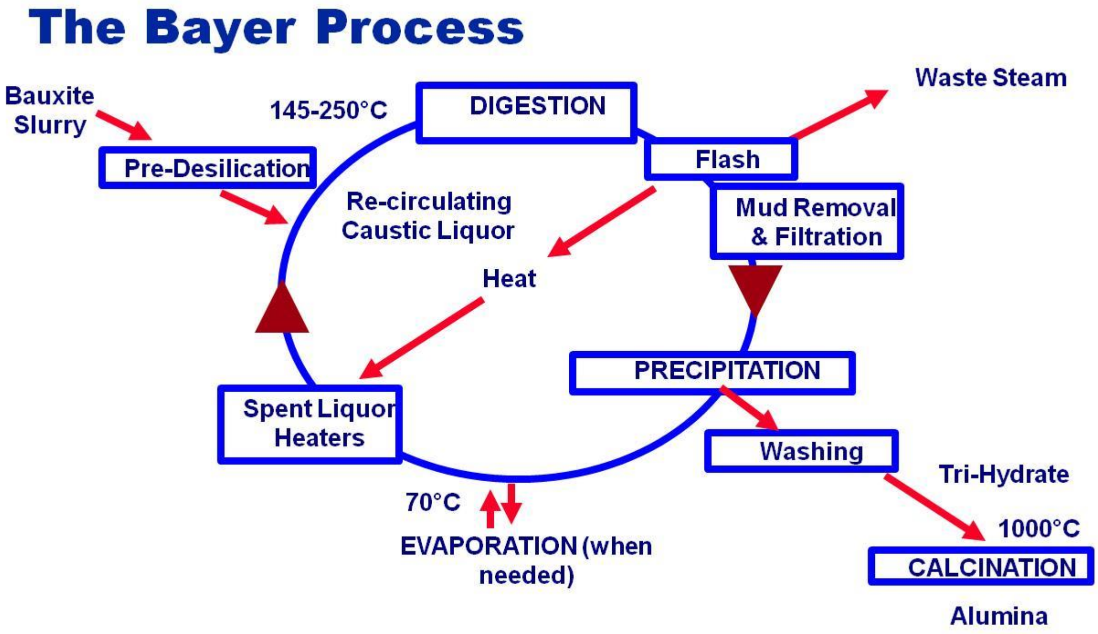


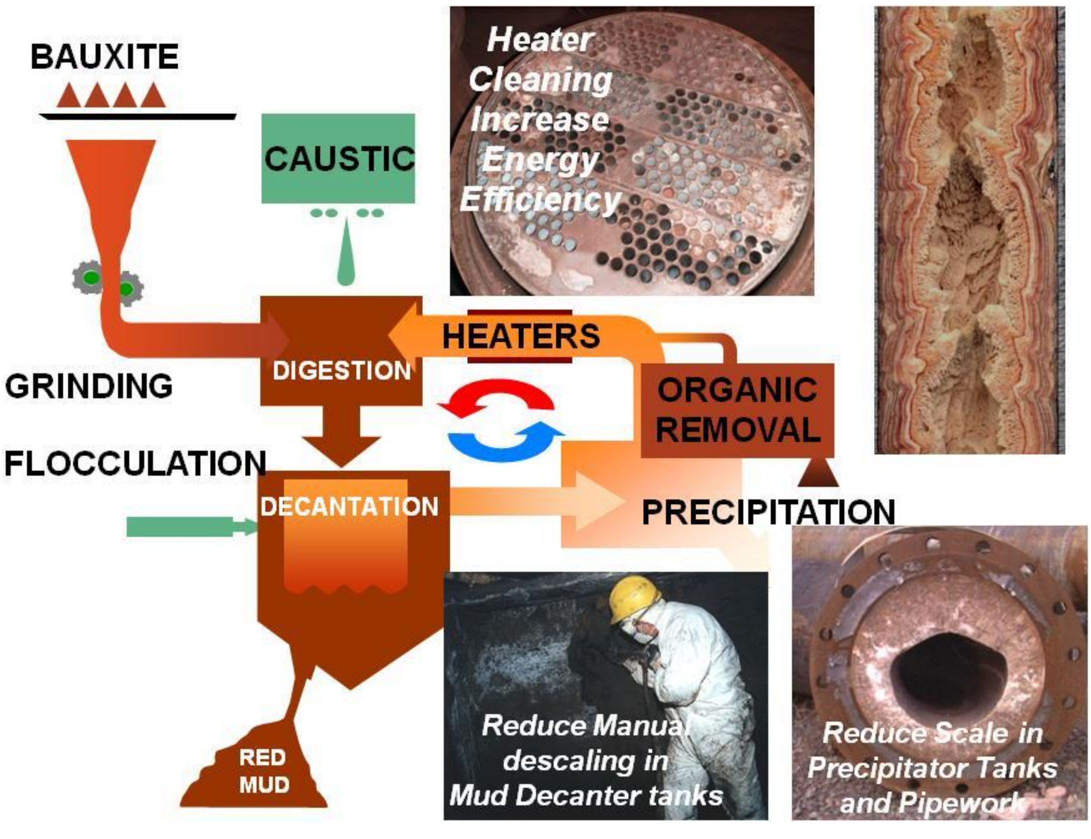
Electrochemical Corrosion Monitoring 1990 to 2002

This required development of novel materials suitable for safe operation in the Bayer process (240°C approximately 15M NaOH caustic liquors + inhibited sulphuric acid cleaning).

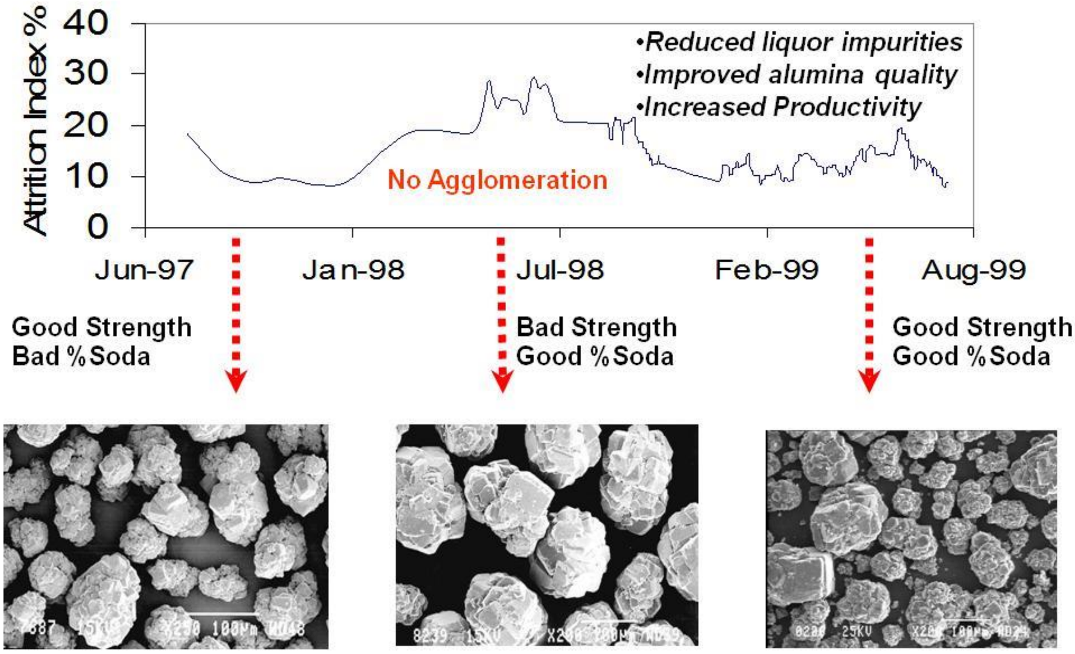
Use of impedance and a proprietary reference electrode led to optimised heater and precipitator cleaning practices to stop tube leaks and elimination of caustic embrittlement in carbon steel welds

QAL Bayer Process plant £3.9M t/a in 1992 at Gladstone Queensland Australia
a Joint Venture owned by Alcan, Comalco, Billiton and Kaiser
(Parsons Point Smelter in background)





Scale Reduction to increase productivity and eliminate multi-million dollar process costs in low and high temperature Bayer Process plants



Improvements in Alumina Tri-hydrate Precipitation from R&D at Banbury Laboratories

18. AT THE CLOSE OF THE DAY

Peter Band

In June 2002 my boss, Harold Jenny, called me to a stop-over meeting at Birmingham Airport. The subject was not mentioned but I expected an opportunity to discuss with him two current projects - proposals to seek external R&D contracts that would add to our revenues and, hopefully, reduce the charge rate on our businesses and, secondly, to explain a portfolio of technology platforms we believed could be exploited by Alcan's operating companies. In the event, the purpose of the stop-over was for me to be told that the Banbury Lab was to be closed.

Seen in hindsight against the background of other corporate activity, the decision to close Banbury should not have come as a total surprise. Indeed, it had been a background worry for the Banbury management since Alcan had retreated from its technology-driven 'new opportunities' mode, had divested itself of its UK-based aerospace and speciality businesses and had sought to evolve into a super-sized commodity producer through the acquisition of its rivals, Alusuisse and Pechiney. In this new environment Alcan did not have the need for its considerable R&D fire power. Costs could be reduced.

The Banbury Laboratory was no longer in the right place! The immediate market for its services - the U.K. manufacturing plants - was generally under-invested, was losing competitiveness and, step by step, was being sold or closed. Within its wider market of Europe, Alcan had a newly acquired R&D facility at Alusuisse, Neuhausen, and, perhaps with patience, Pechiney and its R&D Centre at Grenoble would also become part of the Group. Only one of these research laboratories would surely be necessary to support the future of Alcan's European operations. But there was a problem with this argument. Banbury had some good people - some of whom provided unique services not only to Alcan's European plants and customers but also to the North American and wider global operations. So the closure plan had to be based on disposing of the physical assets of Banbury whilst retaining the services of those people who were deemed to be most valuable to Alcan.

The idea was to transfer the most needed personnel to either Neuhausen in Switzerland or to Kingston in Ontario. In the event of a less than enthusiastic sign-up for transfer to these locations, the fall back position would be the establishment of a new locally based technology group, outside the company, to provide services to Alcan as well as to certain third parties. Using a piece of employment legislation, known as Transfer of Undertakings (TUPE transfer for short), it would be possible to transfer staff to the new organisation without offering terms of redundancy. Salary levels would be maintained but pension contributions terminated. In addition, a small group of staff would be retained within the company to help service the Jaguar automotive business. In total, nearly half of the Banbury team were to be offered re-locations. For the remainder it was a matter of redundancy and support to find new jobs.

The design of the potential new technology company became a matter of fierce argument. The original proposal had been put to Alcan by Jeff Edington - formerly V.P. Technology for Alcan and now in consultancy. The new business would be led by Jeff and owned jointly by him, by venture capital interests and by the staff.

Once the emotions of the closure announcement were put behind us, groups got together to debate the options. In the course of time only 3 people chose to transfer to Kingston and a further 10 to Neuhausen. A group of 30 scientists and engineers elected to create the new technology company but, for several reasons, rejected the scheme proposed by Jeff Edington. With the assistance of John Castle - formerly of British Alcan - and, with Alcan's financial assistance, a new business, Innoval Technology, was established with ownership entirely in the hands of the employees on an egalitarian basis. The first Managing Director was Paul Evans. Innoval's agreements with Alcan included a service contract that utilised most of Innoval's capacity in year 1 but declined to zero after 5 years. The intention was to provide Innoval with an initial cushion of work and income, whilst a portfolio of external business was being developed. The ramp down arrangement also gave Alcan time to hire replacement skills. From its third party income Innoval was to re-pay Alcan its set-up loan. The quid pro quo was that Innoval was prevented from providing services to those companies that Alcan chose to see as competitors or listed as key Alcan customers. These restrictions became issues of intense negotiation and debate between Innoval and Alcan personnel over the life of the agreement. Nonetheless, Innoval Technology has operated successfully for over 8 years, is now totally independent of Alcan support and has grown a business that provides technical expertise not only to the aluminium industry but to its equipment and materials suppliers and its customers. In the course of time, Paul Evans was succeeded as M.D. by Nigel Davies, and more recently by Tom Farley.

The new Automotive Support Group was set up in Banbury away from the Lab with 6 ex-Lab staff under the direction of Alan Carr. This group went on to provide assistance to the Jaguar aluminium structure vehicles at the Castle Bromwich site.

Everyone else was made redundant by Alcan. For some of the team this created difficulties - for others opportunities. Fortunately, the closure happened during a period of economic growth and most of the Lab staff were able to find new jobs in a short period of time, ranging from Food Processing Research to Formula One engineering. In the process of disposing of the physical resources of the Laboratory, we were able to come to a deal with the Pennsylvanian company, Westmoreland Mechanical Testing and Research, who were looking for an opportunity to establish a European satellite. Westmoreland bought a large part of the Banbury state-of-the-art mechanical testing equipment but, more importantly, they took on a full half dozen team of Alcan technologists, including Neil Poyner who continued for some years as M.D. of the Westmoreland U.K. facility.

Little now remained but to close down the site. Equipment wanted by Alcan for other research locations was shipped out, equipment not required was donated to universities in exchange for access deals for Innoval and, finally, the remainder was sold or scrapped. The records of research and intellectual property were transferred to Kingston for retention or disposal, at Alcan's discretion, and the administrative records were put into archive by British Alcan. After making the site safe for hand-over to a subsequent buyer, a small decommissioning team closed the Laboratory on 30th September 2003.

The legacy of six decades of aluminium research and development in Banbury is to be found in many of the products and industrial practices employed today, not only by Alcan but across the industry. However, it could be argued that of equal importance was the supply from Banbury of well trained scientists and engineers into both technical and managerial positions throughout the global family of Alcan companies.

After the Labs people were cast off in their various life boats, Alcan's fortunes experienced some turbulence. An immediate success for the company in 2003 was the long desired acquisition of Pechiney. However, in 2005 Alcan's entire Rolled

Products Division - previously the Banbury Laboratory's principle customer and sponsor - was spun off as a new company, to be named Novelis. The Kingston Lab was part of the deal. In 2007, Novelis was purchased by Hindalco, a division of the Indian Aditya Birla Group. In the same year, Alcan was taken over by the Anglo-Australian mining giant Rio Tinto, whose main interest in Alcan was its upstream operations from mining through smelting. Over the next two or three years, Rio disposed of Alcan downstream packaging and engineering divisions, closing its Neuhausen Lab. In 2011, the Novelis Kingston Lab was broken up with some resources being moved to Atlanta, Georgia and a few kept in Kingston pro tem. What remained of Alcan - now Rio Tinto Alcan - was a major mining and mineral processing company with a research centre continuing to thrive in Arvida, Quebec. The company had returned to its 1927 origins and strengths. The cycle was complete

19. APPENDIX

EMERITUS PUBLICATIONS

Emeritus is a half yearly Montreal publication for Alcan retirees that invites contributions from across the world. Alcan International Banbury retirees are regular contributors. Below are some of their publications.

Farewell To Banbury Labs

I joined the Laboratory (then known as Aluminium Laboratories Limited) on January 1st, 1953 from Northern Aluminium Rogerstone where I had been employed in the Technical Department since my arrival straight from Bristol University in October 1951 with an Honours degree in Physics. I remained in Banbury until I retired in 1992 after nearly 40 years. The Banbury Laboratory was a very special place and I count myself very lucky to have spent the bulk of my working life in such a pleasant and stimulation place. I served under seven directors and one acting director beginning with R. D. Hamer and finally with Dr. M. Sporton. I can divide my time into two significant phases.

As a researcher in the field of physical metallurgy especially in the study of the microstructure of alloy systems and relating these to their mechanical properties working under the leadership of Alan Harding. This approach got a huge impetus with the arrival of a 100 MEV transmission electron microscope. We gradually acquired a splendid team of specialists in particular, Gunnars Blankenbergs, who pioneered techniques for thin foil preparation, Peter Thackeray, Harold Holl, David Moore, Mike Wheeler, Phil Morris and many others. There is no doubt that during this period we were in the forefront of research in this field. We also became aware of the equivalent work by the competition (at Texas Instruments, British Aluminium etc.), many of whose researchers were ultimately to become our future colleagues as a result of various mergers. This was a most exciting time.

Much later, as a result of management restructuring, I found myself one of three programme managers responsible for the initiation, funding and implementation of a range of short and long-term research and development programmes. During this time I travelled quite extensively and established many contacts and friendships with the worldwide Alcan community. At this time, with colleagues Mike Budd and Roger Wilson, I worked with Jeff Edington, John Hirschfield and later Rod Jones. I also enjoyed close links with colleagues in the Kingston Research Centre, especially with David Lloyd, Mark Gallerneault and Geoff Torrible and renewed old relationships with Mike Wheeler, Phil Morris, Mel Ball, Gerry Lucas and David Moore. This too was a very exciting and enjoyable time.

Since my retirement, I was much comforted by the thought that just down the Southam Road in Banbury, there were people still working fruitfully with our friends in Kingston and co-operating with Alcan operating companies here and overseas. I cannot do this anymore. The Laboratory building is still there but now closed and silent; all the amazing facilities have been dispersed and disposed of. It seems such a pity.

Finally, I must mention the Banbury Labs cricket team. This runs like a golden thread through my years at the Laboratory. I am sure it helped to create a friendly and cooperative feeling about the place. It was an activity shared by all parts of the work force from management to office staff. It all helped to make Banbury Laboratories such a great place to work. I am very sad it is now all over.

A.T. (Tony) Thomas

Chacombe, Banbury, UK

Ah Wilderness

Eugene O'Neill is said to have written his only comedy in just five weeks; various government bodies and industries have taken 50 years to create the technology wilderness that now exists in the United Kingdom.

There are readers whose whole working life with Alcan revolved around the subject of technology. Many will recall the times when we sought to push back the frontiers and extol the advantages of using aluminum.

While U.K., readers will probably be aware of the situation it is possible that older alumni in other countries might be interested in the sad state of affairs and possibly comment on their own experiences. I for one would be surprised if say, John Millson, Jim Sutherland, Bill Gardner, Hugh Goddard, Newton Braidato, Lee Roullier, Mike Wheeler and Maurice Tulett do not have memories of valuable content with at least one of the names in the following 'obituaries'.

The *Institute of Metals*, until around 1970, devoted its activity to non-ferrous issues while the *Iron and Steel Institute* covered ferrous metals. Both were learned societies embracing all relevant parties while the *Institute of Metallurgists* acted as a focus for 'professionals', be they ferrous or non-ferrous. Over the years, these three organizations merged to become the *Metals Society*, with only a hint of what was to come some decade later when the 'metals' became 'materials' by adding plastics, ceramics and rubber to the swelling portfolio. Now, as the 21st Century marches on a further rationalization has resulted in the formation of the 'IOM^{3}'– the *Institute of Materials, Minerals and Mining.* So much dilution has now occurred that one can read the Institute's journal *Materials World* and often not find metals even mentioned. Past presidents of the old *Institute of Metals* included Bob Hamer and Stan Clotworthy of Alcan and others from British Alcan, Alcoa and Birmetals. In those days the National Physical Laboratory (NPL) and the National Engineering Laboratory (NEL) had perhaps 2,000 scientists and engineers working on problems associated with metals. Now the numbers are down to perhaps 300 or less, with issues such as bioengineering, nanotechnology and sustainable development foremost in their programs. Ernie Dewing spent his early time with Alcan at Fulmer before transferring to Arvida in an effort to develop the monochloride process as an alternative to Hall-Heroult. He and others will be interested to learn that the most recent *Aluminum Association* road map issued in March 2003 calls for renewed effort to do what Alcan tried to achieve all those years ago.

Alcan once had 300 people in Banbury, British Aluminium had its laboratory in Chalfont Park and High Duty Alloys had research and development in Redditch. Now it is all gone apart from the few who were once Alcan and are now Alcoa in Kitts Green and Banbury. Twenty-eight of the survivors at Alcan International in Banbury have been set up as *Innoval* just 200 yards down the Southam Road, so all is not lost. And lest anyone should feel that I have placed undue accent on aluminum, note that British Steel had a huge research and development activity in Sheffield. Its research director, George Wistreich filled the same role in Banbury for a time. British Steel became *Corus* and moved its activity to Swinden. Then it reduced the activity further and set up, with some U.K., government support, a group of some 30 scientists under the name *Namtec*. Hopefully, they and *Innoval* will provide platforms from which great things will spring.

While metals are not at the end of the line, there is not one university in Britain that has a Metallurgy Department and even in the Materials Science and Materials Engineering Departments there is concern over the lack of students choosing these courses. Some statistics show that by 2006 there will be none. The university professors provide a last bastion for technology albeit on occasion, without the ability or desire to see the real needs of industry. That is in part the fault of industry that no longer has the time, money or people to give proper attention to the necessary interface between the two.

These sad events relate specifically to the U.K., but similar stories are told elsewhere in Europe. What can be done to halt the slide? Your correspondent along with others in a far better position to judge fears that it is too late to remedy the situation and that the decline of U.K., manufacturing is certain to continue. Before it reaches its final conclusion there are those in government and indeed in industry who will seek to halt the decline, fail to do so and look for someone to blame. Five will get you ten the finger will point to those who warned of the problem – the technologists.

Roy Woodward

Nottingham, UK

Northern Lights

In the ‘good old days’ before the aluminum extrusion and re-melt plant on Southam Road, a couple of miles outside Banbury was Alcoa Extrusions or even British Alcan Extrusions, but just good old Northern Aluminium, the photograph shown here was taken. There is no date on it but I reckon it was taken after 1954 – so let’s say 1955. It was probably a Saturday or Sunday afternoon and by the look of those featured not too warm a day! Indeed cricket, for that is the event pictured, is usually played in damp, cool weather with gusty wind and hovering cloud. UK readers will confirm that, but there are Canadians, and even those from United States who have actually played the game on visits to our shores. Bob Hamer certainly did and I once loaned my sweater to a shivering soul who never played again.

No key to those in the photograph is available but a number of the players and some of the wives are recognized by me, as you will now find; perhaps others will be identified by readers who will write and tell us who was present, and relate even what has happened to them in the past half century. One sobering thought is that even the tiny baby, with proud mother, fifth from the right is now around 56!

The event was a domestic one, Sales Development vs Treasury, a challenge no doubt thrown down by one of the keen cricketers such as Colin Scarrett, extreme left with wicket keeping gloves and pads; (the 'left' definition is of course for identification in the photograph and has nothing to do with his political views!) Colin recently celebrated his 80th birthday and I was pleased to be invited to the dinner, together with Tony Thomas, another Labs cricketer. Fourth from the left is Arthur Cooper, then just beginning what was to be a long and distinguished career in handling company money. In the centre, under the tree to the right of the telegraph pole, arms akimbo is Dave Mitchell, then responsible for aerospace development but soon to depart for Hong Kong and then Tokyo, only to return for a short while to Banbury before leaving Alcan. He died a few years ago having been a good friend and golf partner for some ten years. Next to him with only his ever-smiling face visible, is Dick Nuttall, then Deputy Head of Sales development under Martin Bridgwater. Dick's wife Veryl is seated second from the right. She worked for Northern Aluminium and if my memory serves me well, also for some time at Aluminium Laboratories. Further along in the back row, with patent-leather black hair and then still fashionable centre parting is John Coles; having served Treasury for many years he transferred to Labs and also became active in local government. Last time I saw him, which was about five years ago, he hadn't changed in appearance from the image now before you. Finally in the back row, stand three who stamped their characteristics on my memory in quite different ways. Wearing spectacles – the only man to do so – is Doug Able who convinced the manufacturers of ladders to use aluminium and eventually went to work for one of them. Doug will always be associated with good stories of his contacts with potential customers, some of which might just have been adjusted a little to add interest! At the very end of the row is Tom Griffiths, the railway man; whenever one rides on an underground train – or indeed a surface one – in the U.K., remember that Tom was a, if not the, driving force in convincing builders of trains as to the benefits of aluminium. To the best of my knowledge Tom is still around, living in Devon at the ripe of old age of 92. He had worked in the rail industry before joining Northern Aluminium after WWII; we were together in 'digs' in Banbury for a time. He told how, when he visited one manufacturer and showed a drawing he had made of a proposed aluminum coach, one elderly gentleman sucked on his teeth and said, “Oh, I. K. wouldn’t have liked that.” By I.K. he meant Isambard Kingdom Brunel!

And now to my dating of the picture; next to Doug Able is Hector Constantine, the one player not working for Northern. Hector came to work at Aluminium Laboratories in 1954, hence the ‘not before’ syndrome. He was beyond any question the best M.I.G. welder ever to switch on a torch. His proximity to Doug and Tom perhaps reflects the help he gave to them in their promotions, and I presume they asked him to guest for them. He was a very good cricketer, having played in the Lancashire League. Few men can, without fear of contradiction, be classed as true gentlemen but Hector was one in every sense of the word. He died at the age of 90 a few years ago; I regret that I lost contact with him when I left Banbury in 1982.

So many memories revived by one photograph.

Roy Woodward

Banbury - Yes It Is An Exceptional One Horse Town

This is the story of a small apartment in the centre of Banbury, overlooking Banbury Cross, and some of the young Alcan men who made it their home in the late 1940s and early 1950s. All of them were graduates in engineering or science. For many of them, it was their first job, either working at The Northern Aluminium Company or Aluminium Laboratories. I was one of them and we all thought of it as temporary accommodation.

Our address was One, The Horse Fair, Banbury. The apartment was in a much-altered Georgian building and was on the first and second floors immediately over a ladies lingerie shop run by the Misses Carpenter. This involved one of us visiting the shop to pay our monthly rent. We got along well with them and, in fact, on the wall in my study is the aneroid barometer wedding present they gave to Jean and me when I finally left the flat in 1952.

To the left of our entrance was a greengrocer run by a Mrs. Woodall who was a widow and was often to be seen outside the shop arranging the display of vegetables. She was referred to, somewhat disrespectfully, by the ‘boys’ as ‘Dirty Mary’. We were customers of Mrs. Woodall for fresh produce, all supplies then being bought from locally owned shops. The era of the supermarket was years away in the future! Widow Woodall owned property in many parts of the town and had a ‘daughter fair’ who one of our members, who shall be nameless, dated and took to the local dance hall, *Wincotts*, to enjoy the music of Ken Prewer and his Band.

What had One, The Horse Fair to offer? Accommodation provided for four men and a cooked lunch prepared by our daily lady and cleaner – Mrs. (Ma) Needham. New residents had to be prepared to take turns cooking the breakfast – bacon, eggs, the lot – for healthy, hungry men. Ma Needham did, however, wash the dishes! Everyone had an obligation to participate in making the evening meal. Curries were especially popular and we had a good system for preparing rice. Risottos were often on the menu. Martin Bridgewater, an early resident, was particularly fond of jugged hare. After slaughter, the carcass was hung by the hind legs and the blood allowed to drip from its nose to be incorporated later in the final dish.

As an aside it may come as a surprise to our readers that food rationing in the U.K., continued for eight years after the end of the war, as did petrol rationing which was at the rate of 5 gallons per month. There was, however, a black market where petrol coupons could be acquired.

My recollection is that I was invited to join the establishment some time in 1950. A member had left to get married and four residents were needed “to spread the overheads”! The names of Alcan people who populated the flat included David Humphreys, Roy Ansell, Maurice Tulett and Martin Bridgewater.

Martin, who was a structural engineer, was an early member of Northern’s Sales Development Department under the leadership of J (Jackie) H Mayes and left to join another company. My recollection is that Martin was at the CEI in the same year as S. (Sandy) M. Treat, my former colleague at Alcan Corporation, Cleveland.

David Humphreys, a Royal School of Mines graduate, was a member of Northern’s Technical Department and was one of the first members of the company I met. We both shared a passion for hill walking and enjoyed many mountain walks in Snowdonia and in the Highlands of Scotland.

David spent a year at the CEI and this experience continued to be of great value to him as a volunteer worker at the local branch of the Royal National Institute for the Blind in Norwich, not far from the village to which he and Jean retired. After his year in Geneva, David was transferred to Rogerstone Works where he was a member of the Technical Department.

Maurice Tulett was a physicist by profession and was a member of Dr. E George Stanford’s team at Labs: Banbury. Maurice was transferred to Labs: Kingston where he played a major part in the development of the rolling mill process model which enabled rolling to be transformed from an art form into a quantifiable and predictable scientific process.

Roy Ansell was another Horse Fair resident who eventually served the company in North America, spending the remainder of his career, I believe, at the Riverside: California works.

Now just a word of explanation regarding the title of this contribution! When a friend living in Montreal received a letter from me bearing the Banbury address he could not resist commenting: “I always knew that Banbury was a one-horse town but I never figured that you would have a one horse address.”

Maybe this comment is a little unkind but, fifty years ago, each Thursday morning I remember that cattle were still being driven to Banbury market along the roads and in the process awoke us with the sounds and smells of the country. The Bicester Hunt, huntsmen, hounds and riders, met for the stirrup cup each Boxing Day outside the Whately Hall Hotel before moving out into the country.

This story concludes with rather an ironic and amusing twist! For, indeed, it really has become a One Horse Town, of sufficient potential note to attract the Princess Royal last April to unveil a one and a half times size bronze sculpture of the ‘Fine Lady upon a White Horse’ made famous by the Ride-a-Cock-Horse nursery rhyme. The work has proved enormously popular with visitors and townspeople alike.

Number One, The Horse Fair was one of a number of places in the town where young employees stayed when they first came to work for Alcan. It is my hope that my recollections of half a century ago will prompt others to recall Banbury and Alcan at that time.

Alec Lovell

Banbury, Oxon, UK

Photo: LovellFineLady.jpg

Photo: (print)
Left to right: Rex Banks, George Stanford, Rowland Parker, Colin Buchanan-Dunlop, Robert (Doc) Parker, Bob Hamer, George Forrest, Bill Howell, Jack Fearon, George Gardam, Nevill Turner and Jim Durrance.

TOLD LIKE IT WAS - OR SO IT SEEMED TO ME

The photograph shows a meeting of the managing group of Aluminium Research and Development Laboratories taken around 1954. When Bob Hamer saw it he said that he knew that the photographer worked for him but that it could have been Leonardo da Vinci had there been 13 at the table instead of 12!

Bob was director of the laboratory with Robert (Doc) Parker, director of Research, as his right hand while Rowland Parker headed Development. George Forrest ran research engineering, George Stanford was responsible for physics and George Gardam headed chemistry. These three Georges reported to Doc, as did Nevill Turner whose remit was Metallurgy. All had PhDs. There was a fourth George, one George Ball, not in the photograph, who was the laboratory's electrician. This surfeit of Georges allowed anyone guilty of failing to communicate the escape route of claiming "Well, I told George" without identifying which one. George Gardam was a relative newcomer having arrived in late 1952. He had previously worked for one of the London Guilds and as a result had been awarded "Freedom of the City" which allowed him to drive sheep through the streets. To my knowledge he never took advantage of this honour.

Rex Banks was a civil engineer who had spent many years in Canada, although not with Alcan. His role at the time was to oversee all technical activities not covered by those above, including drawing and design office, machine shop and maintenance. He was a master of the English language and was fond of using clever one-liners. In one debate about the necessary dimensions of aluminium roofing sheet he coined the classic "0.2 thick is 'oh-too' thin." (For young Canadian and UK readers and any other Europeans, the 0.2 refers to inches. US-Americans, of course, still use these real units!).

A few years after the time of the photograph Rex and George Stanford each headed panels made up of both technical and administrative staff whose job it was to review all reports and check them for clarity, layout, spelling and grammar. When I took over the packaging division for Alec Lovell, who had moved to Montreal in 1960, the panels had become infamous and a massive report on the drawing and ironing of aluminium beer cans was being processed. It garnered 160 changes from one panel. I made the changes and passed the report to the other which proceeded to suggest about the same number of changes to other aspects. The panels did not long survive.

Rowland Parker's role as development director was still evolving but he already had a group of section leaders covering the aforementioned packaging lead by Alec, electrical applications, headed by Lee Roullier and joining under the wing of Bill Gardner, all names and activities oft mentioned in these pages. Rowland had service in the army during the war and had been engaged after it in a survey of German technology. He later moved to Zurich and was replaced by George Stanford. Rowland spoke and ate faster than anyone I have ever known!

The four in the photograph not yet identified held posts, two of which survived for many years, while the others were short-lived when Bob Hamer left for Zurich and Doc Parker became laboratory director. I merely note the timing with no comment on the coincidence. Jim Durance looked after finances of Labs – UK politicians could well have done with his services in the recent context of members of parliament expenses.

Bill Howell dealt with the many patent applications being made by Labs people. He had recently moved from Alcan's Rogerstone Works with a legal qualification replacing his metallurgical one. When he moved to Montreal in 1959 he was succeeded by Eric Thomas, previously a physicist working under George Stanford. Eric in turn was followed by Roy Hine, a chemist by training while, when Roy retired, he saw David Goodchild, another metallurgist fill the important role; clear evidence of the flexibility of them all. On reflection I cannot recall anyone with a legal background becoming a technologist; could remuneration have anything to do with that?

Colin Buchanan-Dunlop had joined Labs in 1949 and was responsible for the administration of a raft of non-technical groups including the increasingly important public relations. He had been awarded a Military Cross for bravery in the war, when as an army major he invited a party of the enemy to share a box of hand grenades. His experience then and during his spell at Labs stood him in good stead when he left Labs around 1955 to head on of Northern Aluminium's sales offices. My last sight of him, long after he retired, was in a television programme 'The Antiques Roadshow' when he talked about an ornate chandelier with the authority and style he displayed during his days with Alcan.

Jack Fearon was another newcomer. He had a previous background as a pressman and was now head of library and publications, the latter involving both internal reports and papers for the technical press. Later he moved to work with Lee Roullier in the electrical development department.

All, except 'young' Nevill Turner, now a youthful 88, have departed this earth. I remember them as if it were yesterday in their sober dark suits, ties, polished black shoes and smart haircuts, not posed for the camera but everyday drill. I played cricket for many years with Bill, Jim and Nevill, a regular golf far-ball with Doc and Jack, proposed a toast at the wedding of George Gardam's daughter and worked under George Forrest, George Stanford, Rowland and, of course, indirectly, under Doc. I acted as a baby-sitter for both of George Stanford's daughters and Nevill Turner's three sons – all five of them now grandparents! Bob Hamer twice told me that I was on a short list for the CEI school in Geneva; it was always short.

Looking closely at the photograph I see that all eyes are on George Stanford who seems to be holding forth. From some of the expressions and body language we can assume that not all agree with him, not an unusual situation. Jim Horwood once said that George and I were the easiest guys he knew to argue with. I told this to George and we argued about what he meant.

Fifty-five years on I doubt if many *Emeritus* readers will have known of this gathering. Should those who do have their own memories, I hope they will write about them to *Emeritus*, or to me. I have neither e-mail nor fax, but a stamp and envelope still operate in this neck of the woods.

Roy Woodward
Nottingham, UK

Some Long Trails Only Cross Once

I realized the other day that while my ramblings in *Emeritus* had mentioned many UK members of Alcan, I had failed to include more than a few from beyond these shores. True I had, in the context of a now faded photograph of those attending a canning meeting held in Banbury in September 1963, recalled with pleasure such names as Gord Black, Charlie Nash, Marcel Richiger, Axel Taranger, Derek Barnett and Jörgen Zigler thus embracing in a couple of paragraphs Canada, United States, Switzerland, Norway, Australia and Germany. In one whole contribution I had reminded readers of Mo O'Leary, but what of the host of others whose paths crossed mine, albeit in some cases, briefly? I have picked a few, most now sadly departed but remembered with pleasure, respect and even awe!

Who could forget Dr. Karl Sutter head of the small but vibrant structural engineering group of Aluminium Laboratories in Geneva? I met him first in his office, the phone rang and he arranged to collect the caller from the rail station; they had never met so Karl said, “look for someone who looks like a Mexican bandit.” It was an accurate description. Before I joined Labs he had visited Banbury at a time when food rationing was still enforced and hotel meals could not exceed 5 shillings. He looked at the menu presented at dinner at the White Lion Hotel and said “bring the lot.” As I recall he would not fly so I wonder if he ever visited North America. His expertise in structural engineering certainly involved contact with his opposite numbers in Canada and I have no doubt that Jim Sutherland and others can tell stories of some slight differences of opinion in that respect! Around 1970 Alcanwerke in Frankfurt hired a youngish salesman whose previous employment had been in the cosmetic industry. His name was Hubert Olias du Basque, but he preferred to be called Bert Olias. To say that Bert was an extrovert doesn’t tell the whole story He loved golf. I collected him one Sunday morning at Heathrow and drove to Banbury in pouring rain. We had lunch at home and played 18 holes, still in pouring rain. I casually asked why he had come to in the U.K., and while his explanation involved a vague reference to a meeting that held some relevance to his job, I was not fully convinced. He drove a car like he drove himself and once invited Eric Wooton and me to go with him to dinner in a village ‘near’ Göttengen where huge steaks could be had at low prices. It took a good two hours to find the place and at one time we were in a ploughed field in pitch darkness. Later Eric was instructed to get out to view what looked like a signpost. He got back in and reported, as casually as only Eric could, “Actung Minen”. Göttingen is quite close to what was then the East German border.

One lovely summer’s day in the 1970s, Newton Braidato came to my office and said, “They told me that the weather in England would depress me, but it’s beautiful!” Newton was on a short stay in Banbury prior to taking up a longer appointment the following year. I told him that there could be times in the winter when he might not see the sun for six weeks. A year or so later when he was becoming a ‘Banburian’ he opened my door and said, “You were right.” He always reminded me of Clark Gable, without the big ears. He is the only Brazilian I have ever met so I can’t say that his humour was typical of that country but he certainly had a nice touch. I took him to the canteen at Northern Aluminium one lunchtime and asked what he thought of our coffee. “It’s not a bad drink, but why call it coffee?” was his evaluation.

Gerry Ardill and Larry Smith provided comments that have remained in my memory as little classics of astute observations; one that all modest men or women might use to advantage and the other that the many who knew those mentioned might confirm. I asked Gerry on one of the few times we met if he could use his influence to engineer a change of policy in the attitude to the job in which we were engaged. “Roy,” he said, “with my influence and 10 cents you can ride a streetcar”

Larry’s response to an observation by Axel Taranger that I related to him was terse and will no doubt cheer the hearts of all North Americans not yet converted to so-called healthy diets. Axel had said that three things remained fast while all others might change. “George Stanford always orders soup; Roy Woodward only drinks gin and tonic; Larry Smith only eats steak. What else is there?” settled the debate. On the subject of debate, Larry once said of a mutual contact, not of course in Alcan, that when one told something to that person you had to decide whether it went in one ear and out the other or stayed in and got lost.

Finally with my title in mind, I ask readers if they remember and indeed know what ever happened to Jean-Paul Ouellette or perhaps just JP. He was part Native

American Indian descent, one-eighth Huron, born in Arvida and not able to speak English until he was 15. These were his descriptions. I first met JP when he was in the Brussels office of the then Aluminium Union and I was in the Welding Division of Aluminium Laboratories; it was1959. We visited several companies in Belgium and Holland that were using or about to use aluminum, including the atomic energy establishment at MOL. JP drove a big car with Canadian plates and when stopped for speeding or other infringements, not an infrequent event, he pretended he could speak no French. I suppose it could be argued that his French was just a little different from that spoken in Belgium! At one stage he wanted to hold welding courses at the plant of a potential customer in Holland. The plant manager was not too keen on the idea but his sales director wanted to proceed. In order to be ready to act at short notice JP arranged for 50 copies of the excellent Alcan Welding Manual to be shipped to the Canadian Embassy in The Hague; they could still be there. JP had been a student at CEI in Geneva and I am sure that many graduates of that school will have either witnessed or heard of his real or mythical exploits. He left Alcan around 1968 and I last saw him in Montreal a year or so later when he was selling Russian dolls and other toys made in that country.

I had thought to head this piece "My most Unforgettable Character(s)" with acknowledgement to *Readers Digest*, but settled on the one used. However, if I had to pick another it would have to be "JP".

Should anyone from Quebec or Montreal know what happened to JP or his family, I would to be pleased to hear from him or her.

Roy Woodward

Nottingham, UK

Alcan Advanced Rolling Technology Meeting held in Rio, Brasil in 1989.

Front row, left to right: Richard Hartree, Sergio Castellaros, Wilke Parra, Mike Budd, ?, ?, Newton Braidato. Back row, left to right: Valdir Cortezi, Ian Calderbank, Derek Churchill, ?, ?, ?