THE DEVELOPMENT OF AN EXPERT SYSTEM FOR THE IDENTIFICATION ANODIC COATING PROCESS DEFECTS AS A CONTRIBUTION TO THE DISSEMINATION OF ANODIZING TECHNOLOGY

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Doctor of Philosophy

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SUMMARY

Initially this thesis examines the various mechanisms by which technology is acquired within anodizing plants. In so doing the history of the evolution of anodizing technology is recorded, with particular reference to the growth of major markets and to the contribution of the marketing efforts of the aluminium industry. The business economics of various types of anodizing plants are analyzed, Consideration is also given to the impact of developments in anodizing technology on production economics and market growth. The economic costs associated with work rejected for process defects are considered.

Recent changes in the industry have created conditions whereby information technology has a potentially important role to play in retaining existing knowledge. One such contribution is exemplified by the expert system which has been developed for the identification of anodizing process defects. *Instead* of using a "rule-based" expert system, a commercial neural networks program has been adapted for the task. The advantages of neural networks over 'rule-based' systems is that they are better suited to production problems, since the actual conditions prevailing when the defect was produced are often not known with certainty.

In using the expert system, the user first identifies the process stage at which the defect probably occurred and is then directed to a file enabling the actual defects to be identified. After making this identification, the user can consult a database which gives a more detailed description of the defect, advises on remedial action and provides a bibliography of papers relating to the defect. The database uses a proprietary hypertext program, which also provides rapid cross-referencing to similar types of defect. Additionally, a graphics file can be accessed which (where appropriate) will display a graphic of the defect on screen.

A total of 117 defects are included, together with 221 literature references, supplemented by 48 cross-reference hyperlinks. The main text of the thesis contains 179 literature references.

Key words: Anodizing Business economics Defects Hypertext Information technology Marketing Neural networks

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Further, I would like to acknowledge the help of Mr P G Sheasby, also of Alcan International's Banbury Laboratories, for correcting some factual errors, and particularly for providing information on the development of electrolytic colouring, of which he has a unique knowledge.

Some of the knowledge of defects comes from industrial sources as a result of my consultancy activities. I trust that those concerned will accept this collective acknowledgement of their contribution. However, a word of thanks is particularly due to Mr Stephen Parkes of L B Parkes & Co. Limited, Walsall, who provided several examples of defects which had not previously come to my attention.

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Chapter 1: The Development of Anodizing and Allied Processes

Anodizing is the most recently developed of the commonly used metal finishing processes. It shares with electroplating the feature of being a "wet" process, i.e. one carried out in an aqueous solution. Its distinguishing feature is that, whereas in electroplating the work is connected to the negative terminal (i.e. cathode) of an electrolytic cell, in anodizing the work is connected to the positive terminal, i.e. the anode, from which the name "anodizing" is derived.

There are a number of metals, such as tantalum, niobium and zinc, on which an anodically formed oxide film can be produced. However, by far the most widely used anodizing process is that which produces an anodic film on aluminium, so that the term anodizing is usually associated with the process of forming an anodic coating on aluminium.

1.1 Development of anodizing processes

The use of thin "barrier" layer oxide films on aluminium anodised in boric or phosphoric acids as elements in a rectifier circuit was the subject of a patent granted to Pollak[1] as early as 1896. Further details were given in a subsequent paper[2]. Later, the process was utilised commercially for the production of electrolytic condensers. Subsequent investigation of the anodic behaviour of aluminium in other common acids would seem to have been a logical step, but there appears to be no such published work in the years immediately following Pollak's paper.

(a) The Basic Processes

The first commercial anodizing process was that of *chromic acid anodizing,* discovered by G D Bengough and J M Stuart[3] working at the Royal School of Mines, London. There is a certain folk-lore attached to this discovery. One story is that Bengough was investigating the chromium plating of aluminium and his assistant Stuart inadvertently connected up the experimental cell in the reverse manner to normal. Bengough is claimed to have recognised the potential importance of the film produced and to have investigated it further. It is doubtful whether this tale is true, since the chromium plating electrolyte that had just been developed used 250 g/1 chromic acid, plus 2.5 g/1 sulphate [4].

The subsequent discovery of the ability of the chromic acid film to absorb dye[5] has been stated by Henley[6] to be accidental. He claimed that the laboratory cat knocked over a bottle of red ink on to some chromic acid anodized panels and Bengough found that the colouration remained after the surplus ink had been rinsed off. This ability to absorb colour in the film is a feature unique to the anodizing process.

In 1927, the process of *sulphuric acid anodizing* was patented by Gower and Stafford O'Brien and Partners[7]. There is little recorded of the circumstances which led to the filing of this patent. Sutton had been engaged on further research on anodizing electrolytes and a D.S.I.R. report[8] prepared in 1926 records experiments made using sulphuric acid solutions as electrolytes. However, Sutton had confined his experiments to low voltages which only gave anodizing current densities of 0.3 - 0.5 A/dm^2 (3-5 A/ft^2), whereas the above patent refers to current densities of 0.7 - 1.3 A/dm^2 (8-15 A/ft^2), now used industrially.

In 1927, Kujirai and Ueki in Japan patented the use of *oxalic acid electrolytes* for anodizing[9]. These could produce films of 15 micrometres thickness, or greater, but required the use of high voltages. In chromic acid anodizing the films only reach 3-5 micrometres thickness with a 50V potential applied. The oxalic acid process was used commercially in Japan, as well as in Germany and other European countries, where it was employed, *inter alia*, for anodizing shop fronts and building facades.

The first use of the chromic acid anodizing process was in the aircraft industry, which has remained firmly wedded to the chromic acid process for many of its components. This is mainly because it serves as a flaw detection method, as well as a protective process, being primarily used as a basis for painting. However, over the years, sulphuric acid anodizing has been increasingly used on components in aircraft control systems where they could not be painted, as well as for components where a coloured finish, such as black dyed propellor blades, was needed.

Apart from the aircraft industry, plants progressively preferred the sulphuric acid process, mainly because of the lower voltages, and therefore lower power costs, than the chromic or oxalic acid anodizing processes. The chemical costs are also lower and it is an easier process to operate.

After the patenting of these basic processes, there was a flurry of activity over the next ten years which was devoted to devising other electrolytes, or hoped-for improvements on the basic processes, mainly by using additions to the basic electrolyte. This was mainly an attempt to circumvent the existing patents or to develop a coating with specific properties for a given end use, e.g. for electrical insulation etc.

(b) Hard anodizing

Towards the end of the 1939-45 War, the first tentative attempts were made to exploit the results of laboratory tests which showed that wear resistance and hardness increased as the electrolyte temperature was lowered below ambient and the current density increased. Components processed under such conditions were referred to as "hard anodized". The process utilised a sulphuric acid electrolyte cooled to around 0°C (32°F) and operated initially at a current density of 1.7 A/dm^2 (15 A/ft^2), later increased to 2.7 - 4.0 A/dm^2, to produce films of 25-50 micrometres.

Work continued after the war and, in Scotland, Campbell [10,11] developed a process which utilised A.C. superimposed on D.C., and a high rate of electrolyte flow, operated at a temperature around 0°C. This process can be used at very high current densities (25-35 A/dm^2) and produces films of up to 100 micrometres thickness. Some years later Sandford Process Corp. patented a process[12] which restricted the superimposed A.C. voltage to that of the D.C. voltage, which is claimed to produce "hard" anodic coatings at 10°-15°C., using current densities of 2.7 - 4.0 A/dm^2.

In the U.S.A. the M.H.C. (Martin Hard Coat) process[13] was patented in 1953, having as its main feature electrolyte agitation using carbon dioxide. The patent was later acquired by Alcoa, who promoted the process in the U.S.A. Much of the subsequent activity in the United States was directed towards studying the effect of additives, such as oxalic acid and other carboxylic acids. One of the additives patented was hexacarboxylic acid[15], the basis of the Sandford process which has a number of licensees in the U.S.A. and other countries. Other electrolytes for hard anodizing have been reviewed in ref.[14].

In recent years pulsed current has been used for hard anodizing[16], especially of high-copper alloys, which are difficult to hard anodize.

Industrial users have found that avoidance (or at least a minimization) of "burning" is its main advantage, although the ability to anodize most other alloys at higher current densities is an additional attraction.

Because of their unique properties hard anodic coatings produced have been progressively adopted for specialised applications in the aerospace, automation, automotive, electronics and other industries. These properties are further enhanced by application of solid film lubricants.

(c) Integral colour anodizing

The first significant post-war new anodizing process was that of Kalcolor™, developed by researchers of Kaiser Aluminum and Chemical Corporation [17], which employed an organic acid electrolyte - sulphosalicylic acid - with a small addition (5 g/l.) of sulphuric acid. This process produces bronze to grey shades depending upon the anodizing conditions and alloy employed. It has been highly popular for external use on buildings i.e. facades, curtain walling, windows, doors etc. The commercial success of the process also stimulated the development of a number of alternative processes.

Some of these, such as the Duranodic™ [18] and Eurocolour™ [19] processes, involve the use of one or more organic sulphonated carboxylic acids, instead of sulphosalicylic acid. Others, such as Permalux™ [20], and Veroxal™ [21], are based on carboxylic acids, with a small addition (1-10 g/l.) of sulphuric acid. Alcan used a slightly different approach in their Alcanodox™ process, employing pulsed current to increase the depth of colour from oxalic acid electrolytes[61]. These processes are referred to generically as "self-colour" anodizing processes.

These self-colour processes require close control and the final colour is also affected by the composition and fabricating treatment used for the aluminium alloy being treated. In addition, they require voltages which may reach over 60 volts on some alloys, thus requiring higher power consumption and refrigeration than is associated with conventional architectural anodizing using sulphuric acid. A further problem is that the aluminium salts formed in the electrolyte from the anodic reactions have a low solubility. Kaiser patented[22] the use of a cation exchange column as a means of overcoming this difficulty.

However, the energy crisis in the 1970's resulted in a return to sulphuric acid anodizing followed by electrolytic colouring (see p. 14), which requires only a modest additional consumption of current.

1.2 Development of electrolytic and chemical polishing

(a) Electrolytic polishing:

When aluminium is anodized after mechanical polishing there is some dulling of the coating. This is mainly due to inter-metallic phases in the aluminium becoming entrapped in the anodic coating during anodizing. Bad polishing can also produce a patchy dull appearance after anodizing.

New markets for anodized aluminium were opened up by the almost simultaneous discovery in 1934 of the "Brytal" and "Alzak" processes of electrobrightening in Great Britain[23] and in the U.S.A.[24] respectively. In these processes the work is treated anodically for 10-20 mins in a hot alkaline solution (Brytal) or a slightly warm fluoboric acid solution (Alzak). This results in a significant improvement in reflectivity, much or all of which is retained after anodizing, depending upon the purity of the aluminium used.

These electrobrightening processes opened up a new range of applications for anodised aluminium. One of the most important was reflectors for anti-aircraft searchlights, but this also led to other uses such as reflectors in surveying equipment and optical instruments, street lighting reflectors, infra-red reflectors, floodlights etc. However, both of these processes suffered from the drawback that they demanded a high standard of polishing before electrobrightening and the use of 99.8% or 99.99% purity aluminium sheet. During World War II electropolishing processes were developed, such as those described in patents[25,26] which overcame the need for a high standard of polishing.

The process described in ref. [25] employed a phosphoric acid - glycerol electrolyte, whilst that detailed in ref.[26] used a phosphoric acid-sulphuric acid electrolyte to which inhibitors such as methyl cellosolve were added. Between 1943 and 1946, investigators at the Battelle Memorial Institute in the U.S.A. developed a phosphoric-sulphuric-chromic acid electrolyte[27,28], which could process most types of aluminium alloys, whereas the earlier processes were primarily suitable for high purity aluminium. Even so, these processes were not suited to mass production industries because electro-brightening and electropolishing processes involve skill in jigging and a 10-20 minute treatment at relatively high current densities (2.5 - 10 A/dm^2).

(b) Chemical polishing

In the late 1940's chemical brightening was developed[29]. According to Henley[6], an operator put work in a phosphoric-sulphuric electropolishing electrolyte without the current on and went off for his tea break. On returning, he found that the work had a bright etched finish, and drew it to the attention of the works chemist. Further work established that a mixture of 75% (vol.) phosphoric acid and 25% (vol.) sulphuric acid at 90 - 100°C produced an attractive bright etched finish and gave good surface levelling.

Subsequently, Vernet in Switzerland found that the addition of up to 10% nitric acid to phosphoric-sulphuric mixtures produced a highly specular brightness combined with levelling[30]. The process was originally sold in Europe as Alupol IV and in the United Kingdom as Phosbrite 159. Other chemical polishing patents followed such as the R5 process of Alcoa, which is a phosphoric-acetic-nitric acid mixture[31] and the Monsanto Chemical Corp. phosphoric-nitric acid process[32,33].

These processes do not require electric current, nor do they call for special jigging techniques or dedicated equipment other than a stainless steel tank, fume extraction and scrubbing equipment. The process time is usually in the range of 1 - 5 minutes. The availability of chemical brightening opened up the possibility of mass producing bright aluminium trim for the automobile and consumer durable industries. The first applications in these fields came in the mid 1950's and subsequently bright anodized aluminium made steady inroads into the markets formerly dominated by nickel-chromium plating on steel or brass components.

The Erftwerk™ process was developed in Germany [34,35] for the 99.99% purity aluminium-magnesium trim alloys, originally used for Volkswagon trim (see p. 34). This employed a mixture of 16% (wt.) of ammonium bifluoride and 13% (wt.) of nitric acid, plus approx. 25 g/l of dextrin or and levelling on aluminium of 99.85% purity or higher, but used on lower purities it is inferior to phosphoric acid based solutions. Kaiser Aluminum and Chemical Corp. developed a similar but more dilute solution [36], containing nominally (by wt.) 2.5% nitric acid, 0.6% ammonium bifluoride, 0.6% chromic acid, 0.6% glycerol and 0.05% copper nitrate. This process has had limited industrial use.

1.3 Dyeing and Colouring:

(a) Adsorption dyeing

In the 1930's the dyeing of anodized aluminium was a rule-of-thumb process. On a trial and error basis various textile dyestuffs, particularly acid wool dyes, were tested for their ability to dye anodized aluminium. The Bengough-Stuart patent [5] mentions the use of an anthraquinone acid dye and an anthraquinone mordant dye. Some dyes would not react with the anodic coating, others had very poor light fastness, but gradually a range of colours was established which were commercially usable. In this area of technology, Sandoz A G, Switzerland, has reached the position of supplying most of the market, combining vigorous marketing with an on-going research programme.

An important associated technique, which was developed in this period, was that of stopping-off areas of the surface so that they remained undyed [37,38]. Another variant [39] was to protect, say, a black dyed pattern or lettering and the surrounding dyed area was bleached out; the stop-off was then removed to leave the black design on an aluminium background. This enabled anodized aluminium nameplates, instrument dials and scales, and many other products to become available which had previously been produced by laborious etching of brass. In the 1960's printing inks containing solvent soluble dyes became available which would colour the anodised aluminium by direct printing [40].

Another technique for reproducing fine detail and designs, developed in the 1930's, was a photographic technique, based on impregnating the anodic film with light sensitive silver salts [41,42].

(b) Inorganic colouring

In the 1930's a process was developed and used commercially which involved colouring the anodic coating by dipping alternately in two different inorganic solutions which precipitated an insoluble coloured pigment in the pores of the anodic coating [43]. Most commonly, the anodized component was dipped in a solution of cobalt acetate and then into a potassium permanganate solution to give light-fast bronze tones. This development, along with a patent [44] by Budiloff in 1936 for producing fade resistant gold shades from a single immersion in a solution of ferric salts, stimulated interest in colour anodized aluminium for architectural and decorative applications. This double dip bronze process was in industrial use in the 1960's, but was then supplanted by the newly developed electrolytic colouring processes.

(c) Electrolytic colouring

The "Asada" or "Analok"™ process was developed by Asada in Japan in the 1960's. In the original process, very light-fast shades of bronze or black were obtained from an electrolyte containing nickel salts, by the electrodeposition of fine nickel particles in the pores of a conventionally produced sulphuric acid anodized coating using A.C. [45]. After Alcan acquired the patents, the problems they experienced with the nickel salts electrolyte resulted in the development of an alternative process using cobalt salts and other additives. A number of alternative competing processes appeared on the market about 10 years after the introduction of the "Analok" process. These were mainly based on electrolytes containing tin sulphate and sulphuric acid and are currently the most widely used processes. A review of these and other electrolytic colouring processes can be found in ref. [46].

1.4 Sealing of anodic coatings:

(a) Hydrothermal sealing

The ability of anodic coatings to absorb dyestuffs opened up new decorative possibilities but it also gave rise to problems. An undyed anodised coating could suffer staining from accidental contact with other substances, such as grease, ink, or perspiration on fingers. Many of the early anodized articles were given a final hot water rinse to dry them quickly. Further tests established that for the anodic coating to become non-staining a final boiling water treatment [47,48] was essential and became standard industrial practice.

This boiling water treatment became known as "sealing" because it was considered to "seal" the pores of the anodic coating. In the 1950's the increased external use of anodized aluminium, particularly on buildings, revealed that inadequately sealed anodizing developed white stains and bloom on exposure, which were very unsightly. Research showed that the temperature and pH of water and the level of certain impurities, particularly silica, were critical. This led to the industry progressively changing to using deionized water for sealing architectural anodizing.

Sealing in steam had been patented [49] and operated in a number of plants in Germany. Practical experience showed that the design of the equipment used for steam sealing was also critical. The sealing vessel was constructed to maintain the steam under a slight pressure (approx. 5 lbs/in^2). Although the process was used commercially in Germany, it has been little used in Great Britain because of its cumbersome nature.

Around the same time that steam sealing was patented, it was found that the addition of a small amount of cobalt or nickel acetate to water prevented the "bleeding-out" of the textile dyestuffs in sealing [50], which occurred with a number of the dyes then in current use [51]. It also led to the use of cobalt and nickel acetate solutions for sealing undyed work.

The use of potassium dichromate solution for sealing anodic coatings was patented [52,53] in 1931. It produces a distinctive yellow colour to the film. This sealing treatment gives a high degree of protection against corrosion and is normally specified [54,55] for the sealing of anodic coatings used for aerospace and defence.

When mains water was used for sealing, a "chalky" deposit was usually present in hard water areas. This necessitated a cleaning rub with a damp cloth to remove it, which also helped to remove a very thin hydrated layer known as "sealing bloom". In some anodizing shops a slightly acid pH, e.g. (4.5 - 5.0) was found to minimize sealing bloom.

With improved sealing quality, as a result of better technology and the use of more stringent tests for sealing, this technique proved unsatisfactory because it resulted in rejection of work. Hand wiping became increasing unwelcome as the volume of output increased and labour costs rose. Various chemical process suppliers offered additives to alleviate this. Probably the most active in this field initially were a German chemical company (Henkel) who developed a "sealing bloom preventer", which was the forerunner of a number of other proprietary compositions, mainly based on various organic acids or salts. These have been extensively reviewed in ref. [56].

(b) Impregnation sealing

The 1980's saw the introduction of so-called "cold sealing" in which the essential ingredient is nickel fluoride [57]. Currently, based on investigations of the sealing mechanism, the term "impregnation sealing" is preferred. The process results in a network of aluminium oxy-fluoride being formed which fills the pores in the anodic coating and results in a stable "sealed" coating. Some formulations now contain cobalt fluoride to avoid the development a green colour which can develop in sealing if the process is not closely controlled.

Sealing in fatty acids and/or waxes has been used with infra-red reflectors whilst many other organic sealants have been mentioned in the literature [58]. More recently lacquer sealing of aluminium sections for architectural applications has been practised in Japan [59,60].

1.5 Improvements in plant and equipment

To a large extent, improvements in electroplating plants have been adapted to the requirements of anodizing plants. Initially, rubber and welded PVC linings replaced lead linings for anodizing and rinse tanks. Subsequently polythene and polypropylene linings have also been used. Corrosion resistant weldable stainless steels have been vital for processes such as chemical brightening, dyeing and sealing.

Improvements in temperature control equipment used in electroplating have been directly usable in anodizing plants. New types of rectifiers, particularly the silicon rectifier, have been important in anodizing, where the higher operating voltages are obtainable more efficiently than from older types. Improvements in voltage control or devices for current regulation have largely derived from electroplating requirements.

The various straight-through and return types of automatic plant used in electroplating have been adapted to anodizing processes, mainly for the production of anodized parts for large volume consumer durables However, the need to process long aluminium extrusions has presented a handling problem. This was initially solved by using manually operated hoists, and later automated. The subsequent development of programmed hoists enabled significant labour savings to be made in small and medium sized plants, thereby reducing costs and giving better utilisation of the available floor space.

Parts to be anodized are held on jigs and racks which were initially made of aluminium. Where heavy etching is involved, as in architectural anodizing, or chemical brightening (used for automobile trim), jig life is relatively short. The introduction in the 1960's of long life titanium jigs was an important development which produced significant cost savings. The introduction of plastic clamps for jigging architectural sections gave significant cost savings, mainly in labour time.

1.6 Improvements in materials

Although all metal finishing processes have to take into account the nature of the metal surface being processed, anodizing has certain unique features in this respect. The anodizing process converts the surface of the aluminium into a transparent film of aluminium oxide, and in so doing slightly reduces the thickness of the aluminium and reveals metal below the initial surface. To avoid an uneven, streaky appearance, uniformity of metallurgical structure must be of a high order and it must be free from non-metallic inclusions.

Another problem is that small amounts of metallic impurities such as iron and silicon, normally present in commercial metal, form inter-metallic compounds with aluminium. These particles are not converted to oxide in anodizing but become included in the anodic coating, dulling the appearance of the work after anodizing. This is particularly noticeable on work which has been electrolytically or chemically brightened prior to anodizing, the effect increasing with thickness and with current density.

The aluminium companies have devoted considerable efforts to producing materials with a satisfactory response to anodizing. In the 1930's the primary aluminium available was normally only guaranteed to be of 99.0% purity. To improve on the quality of finish after anodizing the industry offered anodizing quality materials, which were initially of 99.5% purity, and later 99.8% purity grade, at a price premium. Subsequently, very high purity (99.99%) aluminium, obtained by subjecting the lower purity metal to an electrolytic refining process, was also introduced. However, this very high ("super") purity aluminium sold at approximately twice the price of the commercial purity metal.

In Germany in the early 1950's, Volkswagon pioneered the introduction of bright anodized aluminium trim using 99.99% purity aluminium-magnesium alloys, which was later replaced by 99.9% purity when new smelters were built. Metal of this purity was obtained by selection, with a consequent lower price than prevailed with 99,99% purity. Some of the early applications of bright anodized aluminium in the British automobile industry also used 99.99% purity aluminium alloys with approximately 0.5 or 1.2% magnesium. However, the higher price of this material made it uncompetetive for many applications.

In Germany, where it was possible to obtain 99.9% purity by selection of primary metal, this grade initially replaced 99.99% purity metal for bright trim. In most countries improvements in smelter technology resulted in metal of at least 99.3% purity becoming readily available, with 99.5 - 99.8% being obtainable by selection from suitable casts of metal. The foundation was laid for the production of large tonnages of anodizing quality material, particularly for bright anodizing. Most of the bright trim (mainly non-automotive) now used in the United Kingdom is based on aluminium-magnesium alloys of 99.7% (min.) purity. In extrusion, the aluminium-magnesium-silicon alloys dominate. For architectural anodizing a uniform fine grained structure free from extrusion defects is essential, but normal commercial purity aluminium is adequate as the basis material. Where such extrusions are required for bright trim a 99.7% (min.) purity base alloy containing small additions of magnesium and silicon is used.

Although a base metal purity of less than 99.7% is acceptable for extrusions and sheet for windows, mullions and panels used on tall, multi-storey buildings, uniformity of appearance is essential. This calls for close control in casting and rolling to ensure a uniform metallurgical structure, as well as freedom from hot-mill pick-up, a surface defect found when the sheet welds in small local spots to the rolls of the hot mill. For this purpose aluminium-magnesium alloys, such as 5052 (Al-2%Mg), have been widely used in the United Kingdom and the U.S.A., but some European plants also offer Al-1%Mg and Al-3%Mg alloys

An aluminium alloy containing 3 - 5% silicon, which anodizes to give a slate grey colour, was developed in the 1950's for use in architectural applications and was manufactured as both sheet and extrusions. However, difficulties experienced by both extruders and rolling mills in securing a product which anodized to a consistent colour, has resulted in this material being no longer used. Other attempts to produce a 'self colour' by alloying, such as aluminium-chromium, aluminium-chromium -manganese and aluminium-nickel alloys, have also given rise to difficulties in maintaining consistency in their metallurgical structure in large scale production.

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2. The Commercial Exploitation of the Anodizing Process

2.1: Early licencees of the chromic acid process

The chromic acid patent became the property of the Department of Scientific and Industrial Research, which held the main licence and granted sub-licences. From the beginning the main users were the aircraft industry - Fairey Aviation, Hawker Aircraft Co., de Havilland Aircraft and Vickers were early sub-licencees. In the 1930's the Bristol Aeroplane Co and Blackburn Aircraft also took out licences. The basis of licensing the process was payment of a royalty per square foot of treated surface [1].

The first trade plater to use the process was Technical Platings Ltd., Teddington, who took out a licence in 1930. Although part of their work was for aircraft sub-contractors, initially they also produced chromic acid anodized holloware. Around the same time, Kings Cross Plating Co. Ltd. also became licensees and used the process mainly for commercial work, such as ash trays, cigarette lighters and similar fancy goods. In the late 1930's chromic acid anodizing began to be used in armament applications, such as fuse bodies. In addition, Gibbons Bros Ltd, Wolverhampton, who were architectural metal workers, took out a licence for chromic acid anodizing. One of the documented applications was its use for the doors and windows of the Cambridge University Library [2].

2.2: The commercial development of the sulphuric acid process

(a) Early developments

The sulphuric acid anodizing patent of Gower and O'Brien was sold to Aluminum Colors Inc., of Milwaulkee, U.S.A., who were subsequently acquired by the Aluminum Company of America. A group of three British businessmen decided that there were interesting possibilities for the process and sent one of their number - E Windsor-Bowen - to negotiate a licence agreement on their behalf. He secured a licence covering the United Kingdom and the rest of Europe, plus the British Empire - but only his name appeared on the license. The consequences of this are considered later.

Windsor-Bowen was primarily interested in obtaining licence income, but he found it essential to start up a plant to demonstrate the practicability of the process. Accordingly, Alumilite (Great Britain) Ltd was registered and operated a plant in Hammersmith. The first sub-licensee was Alarco Ltd, Slough, who subsequently moved to Alperton. They were licensed only to anodize cinema facades and decorative trim for large ocean-going liners. They supplied decorative metalwork for the "Queen Mary". However, after a few years of operation they became insolvent. In the meantime, a sub-licence had been granted to a firm in Bristol - Hills Engineering - to produce anodized ash trays and also to Joseph & Williams Ltd for "ironmongery" and metal boxes.

A significant source of licence income developed from an agreement by which P Vernet of Geneva, Switzerland became a principal sub-licensee. Vernet set up a company Vernal S.A. to operate the process, but also granted licences to several important German companies, including Siemens and Halske A.G., Schering A.G., and Langbein-Pfanhauser Werke GmbH. The terms of the licence provided for pooling of any patents taken out by the licensees. This subsequently gave Alumilite (Great Britain) Ltd access to important developments, such as the use of silk screen applied stop-offs in the production of multi-coloured designs and a process for photo-sensitising anodic coatings developed by Siemens & Halske A.G.

At this point a firm of metal spinners and pressworkers - Acorn Products Ltd of Hendon - became interested in anodizing and set up a small plant at Clapham, but it was too small to be viable and soon ran into financial difficulties and was closed down.

In the meantime, the former associates of Windsor-Bowen set up the Aluminium Protection Co. with the express intention of circumventing the Alumilite patents and Acorn Products Ltd also invested capital. A research company - Electro-Metallurgical Research Co. - was set up and later a plant was established at Willesden, which traded as the Aluminium Protection Co., to exploit the patents which were subsequently granted.

By this time the original sulphuric anodizing patent had been acquired by the Aluminum Company of America and was marketed as the "Alumilite"™ process. They backed Alumilite (Great Britain) Ltd in opposing the patents operated by Aluminium Protection Co. However, the action in the High Court was unsuccessful and the monopoly of Alumilite was broken. Meanwhile, S R Sheppard had also taken out a patent [3] which covered operating conditions outside of the Alumilite and Aluminium Protection Co patents, and a company - British Anodising Ltd - was registered and established with works at Merton Abbey, London S.W.19.

In the late 1930's, one of the Aluminium Protection Co employees left the company and set up Anotints Ltd in Birmingham, in conjunction with the Adie brothers. An ex-Alumilite employee was also involved in setting up Advance Anodising Ltd, who specialised in silk screen printed anodised nameplates. Another new enterprise came into existence in the north of England at Radcliffe, Lancs., under the name of Anodisings and Platings Ltd., using the Sheppard patent. This company was set up on the initiative of Craig of Technical Platings Ltd, who was friendly with Sheppard, and was licensed to use his patents.

Finding a market for anodized aluminium in the early days called for an approach still in its infancy in the 1930's, i.e. an overall marketing strategy. It was not simply a question of finding customers who wanted aluminium anodized, but of persuading companies to manufacture articles in aluminium which also involved anodized finishes. In addition, most companies preferred to send their work to be electroplated, or finished in any way, to the same sub-contractor. Consequently, the early anodizing companies had to install electroplating plants, since many potential customers would only grant them anodizing business if they would also take their electroplating business. Consequently, both Aluminium Protection Co and Alumilite (Great Britain) Ltd, operated sizeable electroplating plants.

(b) Rearmament and the war period

When the Aluminium Protection Co was set up, the first board of directors included one J G Workman. In 1937 a decision was taken to remove Workman and another director from the Board. The former then linked up with J V Rushton, a former employee of Gibbon Bros, and set up a plant in Wolverhampton. With the onset of the war, Rushton - who proved to have considerable entrepreneurial abilities - set up a factory in Leeds and two in London. At the end of the war he sold out to

Midland Holdings Ltd for £120,000. The latter company embarked on a public placing which was a disastrous failure and shortly afterwards it went into liquidation.

In the late 1930's Windsor-Bowen had increased the number of licensees as a result of the rearmament programme. The first two licensees were Sperry Gyroscope Co. Ltd., Stonehouse, Glos., and Rotol Ltd., Gloucester. The latter used sulphuric acid anodizing to produce airscrews with a matt black finish, followed shortly by De Havilland Aircraft Co. Ltd. The basis of the royalty was the installed amperage from which an annual number of ampere-hours of operating was computed, so that the royalty was charged per ampere-hour.

This is of some interest, in that at the end of the war a claim was made by United Anodising Ltd. on the Defence Ministries for royalties which would have been received for the use of patents during the war period had these been licensed commercially. The sum claimed was based on the estimated total number of ampere hours of operation of such plants. The total claim submitted amounted to nearly £1,000,000, but was finally settled at £169,000.

In the early years of the war ownership of Alumilite (Great Britain) Ltd changed hands. During 1940 Alumilite (Great Britain) Ltd ran out of money, which is believed to be due to weaknesses in its commercial management. Windsor-Bowen sold out his controlling interest and his patent rights to Aluminium Protection Ltd for a sum believed to be slightly in excess of £50,000. The other major London anodizer - British Anodizing Ltd - also ran into trouble. Its operations had apparently showed no profit. Under the war-time Excess Profits Tax legislation all its profits were forfeit, so the Company was taken over by Aluminium Protection Co Ltd., who formed United Anodizing Ltd as a holding company for these subsidiaries. These plants subsequently traded as Alumilite and Alzak Ltd., and a further plant was established at Worcester. Their main competitors were the Rushton companies.

(c) Post-war changes

Despite the pre-eminence of Alumilite and Alzak Ltd. in anodizing, a decision was taken at the end of the war to shut down all its factories except the one at Merton Abbey. This seems incomprehensible in the light of the rapid growth of other new anodizing companies and the subsequent disappearance of the Rushton companies. This decision led to the slow but inexorable decline of Alumilite and Alzak Ltd., who went into voluntary liquidation in 1968. There seems to be little evidence that any significant part of the £169,000 award from the Government [4] was ever reinvested in the sole remaining plant at Merton Abbey.

One of the directors of Alumilite and Alzak Ltd during the war was Musgrave, who also owned Acorn Products Ltd. He persuaded two former Alumilite and Alzak Ltd employees - Smith and Shaw - to join him in setting up Acorn Anodising Co Ltd. This company grew to become the largest single trade anodizing company. In the 1960's they were acquired by Pillar Holdings Ltd, an engineering holding company also having aluminium fabricating interests, which included Independent Aluminium Extrusions Ltd. and Pressweld Ltd.

The main growth in the number of "trade" anodizing businesses in the post war years has been by employees leaving an anodizing firm and setting up on their own, although usually having only a minority capital interest. Initially, former employees of Alumilite and Alzak Ltd, or the Rushton organisation, were the main source of managers or entrepreneurs setting up new plants, but subsequently the sources became wider.

(d) Plants installed by window manufacturers

The late 1950's saw the installation of a "captive" anodizing plant at William and Williams Ltd., Chester, which was followed by plants at Heywood-Helliwell Ltd., Huddersfield, Henry Hope Ltd., Smethwick and Crittall Windows Ltd., Braintree. These plants were specially designed for anodizing aluminium windows and represented a landmark in the evolution of anodizing, in that it established anodizing as the finish normally applied to architectural aluminium. Initially, anodizing was carried out on complete window frames, which were usually flash butt welded, which presented handling problems in the anodizing plant. However, in the U.S.A., a new assembly technique was being developed using mechanical joints on window frames. In turn, this made possible the anodizing of lengths of extruded sections instead of frames. The gains in cost reduction and in performance were significant.

2.3: The Involvement of the Aluminium Industry in Anodizing

(a) The entry of the aluminium extruders

In the United States in the 1950's there was a rapid growth of independent (non-integrated) extruders. They soon realised that they could add value (and profit) by undertaking simple cutting, drilling and forming operations on extrusions, to which anodizing was soon added. The change-over in window manufacturing to mechanical joints instead of welding, produced a rapid growth in the output of cut-to-length anodized extrusions. The independents soon realised the market potential of this development and installed suitable plants.

In 1961 Independent Extrusions Ltd was set up in Cheltenham by Fredjohn, who had been associated with an independent extruder in Canada. At the same time BKL Alloys Ltd, a producer of secondary aluminium, established an independent extrusion company - Midland Extrusions Ltd. - in Birmingham. Both companies subsequently set up anodizing plants, although in the case of Midland Extrusions Ltd, it was operated as a separate company - Reliable Anodizing Ltd. Both of these companies were very successful in the early years and have subsequently further expanded their business.

Other non-integrated extrusion and anodizing operations included Frontier Aluminium and Engineering at Bridgend, set up by a former Alcan employee, and Century Aluminium Ltd., Sanquahar, later acquired by Norsk Hydro and CEGO Engineering Ltd., Silver End.

(b) The Entry of the integrated aluminium companies

The integrated aluminium companies, (i.e. those producing products from ore to semi-fabricated product) viewed with concern the loss of extrusion business to the independents having anodizing facilities. In the late 1960's RTZ set up an extrusion and anodizing plant at Widnes, as did Amax Inc., U.S.A., via their architectural aluminium subsidiary - Kawneer Inc. - who set up a plant at Runcorn. Other extrusion and anodizing operations followed in the 1970's and early 1980's. The list of such plants is given overleaf:

Alcan Aluminium Ltd (Canadian)	Banbury
Aluminium Precision Extrusions (Swiss)	Newport
British Aluminium Co Ltd (British)	Warrington
Kaye Pechiney (French)	Doncaster
R.T.Z. Extrusions Ltd. (British)	Widnes
The Kawneer Co. Ltd., (U.S.A)	Runcorn
S.A.P.A. (Swedish)	Chesterfield,

The trade anodizers viewed these developments initially with alarm, expecting a significant loss of business. However, far from this being the case, the entry of these companies with their marketing skills stimulated a rapid growth of the market, particularly for architectural uses. Later, the larger trade anodizers, who had installed suitable plants, found that the aluminium semi-fabricators actually became significant customers, since they used the jobbers to help cope with sudden peak demands.

(c) The contribution of the integrated aluminium companies to anodizing process development

The integrated aluminium companies had traditionally played a role in anodizing. The acquisition of Aluminum Colors Inc. by the Aluminum Company of America (Alcoa) in the 1930's and the R & D effort subsequently devoted to anodizing by Alcoa, reflected the importance then attached to the development of new applications for aluminium. In the United Kingdom the British Aluminium Co Ltd, who had been represented on the Board of Aluminium Protection Co, were also responsible for the development of the first electro-brightening process. In the 1940's they developed a process for the continuous anodizing of aluminium wire [5], which was operated commercially by an associate company, Aluminium Wire and Cable Co. Ltd.

In the post war years Alcan Aluminium Ltd, Canada, through their British subsidiaries, aggressively challenged British Aluminium Co Ltd's close association with anodizing and were initially successful in developing the bright trim market, especially for motor cars. Subsequently, Alcan were particularly active in anodizing research and development in the architectural market. Alcan made freely available its know-how [6] on colour anodizing for architectural applications to all member companies of the Aluminium Development Association. This was done on the basis that it was growth in consumption of primary aluminium that determined Alcan's profitability. Further, only British Aluminium had primary production facilities in the United Kingdom, and these were inadequate to meet its needs. Alcan was the major supplier of aluminium billet and rolling slabs to the United Kingdom market.

Around the same time, Kaiser Aluminium Corp. (U.S.A.) developed the Kalcolor TM process, which produced bronze or grey shades by anodizing in a sulphosalicylic acid electrolyte [7]. Kaiser had a financial holding in James Booth Aluminium Ltd, Birmingham, who were one of the smaller British semi-fabricators. The fact that the process was more difficult to operate than conventional sulphuric acid anodizing, and the small share of the aluminium market held by Booth, resulted in only a few plants operating the Kalcolor process in the U.K. However, this development stimulated the market internationally for colour anodized aluminium on buildings and established anodized aluminium as a dependable product.

In the United States, Alcoa developed its Duranodic process [8] as an alternative to Kalcolor, but the latter remained synonymous with "integral" colour anodizing, although Alcoa's market pre-eminence ensured that the "Duranodic" finish became an accepted alternative to Kalcolor. Other integrated aluminium companies, such as Reynolds Metals and Olin Mathieson, also devoted effort to developing anodizing processes, but had a smaller impact on the market. Integral colouring processes were also developed in Europe, e.g. AlcanadoxTM in the England, EurocolourTM in France, PermaluxTM in Switzerland and VeroxalTM in Germany, .

At this time all of the integrated aluminium companies had a similar strategy in marketing the process. The term "Kalcolor" or "Duranodic" could only be used when the process was used on metal supplied by Kaiser or Alcoa respectively, and a substantial license fee was involved. In return, the aluminium companies undertook a marketing campaign to promote the finish.

During the 1960's there had been a series of moves by all the major aluminium companies to expand the proportion of the sales of primary metal going to their own subsidiaries by acquisition of hitherto independent semi-fabricators, plus a number of ventures into the production of finished fabricated products. In 1966, Alcan acquired the rights of the electrolytic colouring process developed in Japan by Asada [9], and marketed it under the trade name of "Analok". Alcan's marketing strategy, as far as "Analok" has been concerned, appears to have been governed by two primary objectives:

(1) to strengthen their market position as far as the architectural market was concerned.
(2) to ensure that, in addition to their directly owned subsidiaries, licences were only granted to users who appeared to have an adequate level of technical competence to operate the process.

When Alcan acquired the Asada patents they had already been filed internationally but there was one important omission from the elements listed in these patents - which was tin. As far as is known, this omission was entirely accidental. Initially, the process was based on the use of an electrolyte containing nickel. When operated on the scale needed in large architectural plants the process was found not to be easy to operate, there were problems of pH stability and it did not give a black, which was a market requirement. By the early 1970's, Alcan had established a workable process using cobalt salts, which also gave a good deep black even on 15 micrometrescoatings.

Having established a viable process, Alcan required licensees to use the trade name "Analok" on Alcan metal anodized and coloured using this process. They charged a substantial fee, publicised the finish, whilst providing detailed operating instructions, technical support and promotion of the finish. By the mid 1970's the process was firmly established and around 50 plants world-wide were licensed to operate the process. However, by the mid-1980's technical support became minimal.

In Germany, following Alcan's acquisition of the Asada patents, there was much activity by Josef Gartner (the largest German architectural fabricator who had been refused an Analok license), also by Vereinigte Aluminium Werke A G (the major German owned aluminium company) and later, by Henkel KG (a supplier of chemical cleaners, etchants and adhesives). This resulted in the development in the late 1970's and early 1980's of V.A.W.'s "Metoxal" and Henkel's "Almecolor" processes, followed by a number of others. These companies believed that they had no fear of being involved in an action for patent infringement because (i) tin had been omitted from the original Alcan patent, (ii) there were patents granted in the 1930's to Caboni [10] and to Langbein Pfanhauser Werke [11] for electrolytic colouring. However, although Alcan did not challenge the use of tin-based electrolytes, it obtained an out-of-court settlement for infringement and an injunction preventing Alusuisse from operating cobalt or nickel electrolytes.

For chemical supply companies, tin-based electrolytes offered a new market and one in which the knowledge gained from electroplating of tin could be applied. Tin sulphate is not stable, changing from the soluble stannous salt to the insoluble stannic form. To operate the process, a stabilizer had to be added. Further, the throwing power could be improved by the use of organic additives. These additives were virtually essential to the process and provided the profit. However, it also gave rise to intense competition between different suppliers. The writer has had verbal reports of companies offering a free initial supply of the chemicals required to operate the process.

Whilst a rapid growth of the market resulted in Europe, quality of the product often left much to be desired. An Alcan researcher subsequently published a paper [12] showing that poor operating practices and control could have a deleterious effect on outdoor corrosion resistance. However, according to Brace [13], based on an inspection of buildings in Germany, corrosion problems do not appear to have occurred on electrolytically coloured anodic coatings produced under proper conditions by competent companies using "Almecolour" and "Metoxal" tin-based electrolytes. Surprisingly, companies in the U.S.A. were slow to adopt the process and only began to do so after loss of market share to powder coaters.

The attraction of electrolytic colouring is that it is carried out after producing an anodic coating by conventional sulphuric acid anodizing. Since the former process has become available, the proportion of coloured anodized work used in architecture has risen steadily and it has replaced the integral colour processes. The absence of patent restrictions and absence of a license fee, combined with the competition for business from chemical supply companies offering tin sulphate-based processes, has resulted in them becoming by far the most widely used processes.

2.4 Locational aspects

The early anodizing plants were located with regard to their potential customers. The original Hammersmith plant of Alumilite (Great Britain) Ltd was chosen with a view to access to West London engineering firms. The breakaway Aluminium Protection Co set up in Willesden, so as to be well placed to serve the Park Royal/North Acton engineering firms and with good access to other engineering centres. The subsequent entry of British Anodizing Ltd, who were based at Merton Abbey, resulted in a "gentlemen's agreement" whereby Aluminium Protection Co primarily sought business north of the Thames and British Anodizing Ltd south of it. Both regarded Alumilite as their main competitor. It is also interesting to note that the next entrant to the anodizing business in the London area - Advance Anodising and Plating Ltd - set up in the Camden Town area, the home of traditional small engineering industries.

Outside of London, the establishment of the anodizing businesses of Anotints Ltd. in Birmingham, Rushton's in Wolverhampton and Anodisings and Platings in Radcliffe were responses to the prospect of business in these regional markets, once anodizing had established itself in the London area. At this time proximity to customers was considered to be essential, especially since a 24-hour delivery service was expected.

It has been noted previously that in the early years Alumilite and Alzak Ltd, found it necessary to undertake electroplating as a means of securing anodizing business. In the early years licensees fell into two main categories - trade finishers and companies using the process for their own products. Since the early 1950's, apart from companies installing plants to process their own products, growth has occurred mainly from:

(i) the growth of companies who followed Alumilite and Alzak Ltd's policy of concentrating only on anodizing.
(ii) growth from entry of the aluminium extruders.
(iii) growth in the number of trade electroplaters who have installed anodizing facilities.

It is difficult to obtain any accurate estimate of the number of electroplaters who also have an anodizing facility. Essentially, Greater

London was the main centre with 14 plants operating in 1960 and 15 in 1970. The main concentration is in the newer engineering centres of West and North-West London, but plants exist in the other centres in the North, East, South-East, South-West of Greater London.

The West Midlands is the second largest centre of specialist jobbing anodizers. In the Jewellery Quarter of Birmingham their numbers increased over the 1960 - 1970 period from 2 to 5, but in the rest of Birmingham the numbers increased from 6 to 7. The higher numbers are located outside the Jewellery Quarter, which is the reverse of the pattern for electroplaters. In the rest of the West Midlands the number of anodizers increased from 2 to 3, with a plant closing in Old Hill, and new ones being established in Lye and Walsall. A small number of specialist trade anodizers are also located in each of the main engineering centres, i.e. the North West, Yorkshire, East Midlands and the South Coast.

The spread of the use of anodizing is reflected in the changes in the locational thinking of Acorn Anodising Ltd, the largest company post-war. The first works to be established was at Hendon, then a few years later a works was set up at Hanwell, followed by a further plant at Boreham Wood. With this spread of locations the company felt it was strategically well placed to serve the main London markets. Later the company acquired a plant at Old Hill, West Midlands for access to that market.

Changes in the company's locational thinking occurred with the initiation of the motorway programme. At this time the architectural anodizing market was growing rapidly, but instead of setting up plants in the main regional markets, the company decided to set up one large central plant at Bletchley. This site was chosen because of its accessibility to the main markets of London and the West Midlands, being roughly equi-distant from each. With extensions to the motorway network the company found that it could serve adequately customers as distant as South Wales and Scotland.

During the 1970's the company became an RTZ subsidiary, and revised its general anodizing operations. From this a significant change emerged in locational policy. At the end of the 1960's the Hendon plant, which was rather small, was closed down. In the 1970's the company set up a new plant at Hayes, Middlesex and closed down not only its Hanwell and

Boreham Wood plants, but also the Old Hill plant. It found it quite practicable to serve Midlands customers from Hayes. It also set up a plant for hard anodizing at Kirby-in-Ashfield, Notts., partly because of market potential in the area and also because of certain cash incentives to set up in a "grey" area. In the late 1980's the company closed its Bletchley plant, due to decline of the architectural market, and has now concentrated all its anodizing activities at Kirkby-in-Ashfield, also adding electroplating facilities.

2.5: Growth and decline in markets for anodizing

(a) The trim market

The 1950's opened with the Korean War, which also coincided with rapid growth in the automobile industry in the U.S.A. and Europe. Germany was struggling to reconstruct its economy and was permitted by the Occupying Powers to re-open the Volkswagon plant at Wolfsburg. The Korean War resulted in a severe shortage of nickel, which had unforeseen consequences for motor car manufacturers. With a shortage of nickel the service life of nickel-chromium plated trim was drastically reduced due to thin nickel undercoatings to the chromium, with the consequence that rust spots would appear in electroplated trim before the vehicle was out of the guarantee period. In the mind of consumers, bright chromium plated trim had become synomynous with early rusting in service. It took the motor car industry more than 10 years to re-establish public confidence in chromium plated trim.

The commencement of production of the Volkswagon car brought an unexpected bonus to the aluminium industry. Faced with a world-wide shortage of nickel, the Volkswagon engineers studied alternative bright trim materials and came up with aluminium. In this they were influenced by the availability in Germany of a plant with a capacity for the production of about 1000 tons per annum of 99.99% aluminium, obtained by refining commercial purity aluminium. With the co-operation of the state-owned Vereinigte Aluminium Werke (VAW), the production of sheet, strip and extrusions in 99.99%Al-Mg alloys was commenced.

At that time the Alupol IV™ (equivalent to Phosbrite 159) phosphoric acid-based chemical polishing process was in use in Germany. However, V.A.W. developed a nitric-hydrofluoric acid chemical polishing solution which was cheaper to operate and highly effective on the trim materials used by Volkswagon. This finish was protected with a nominal 7µm anodic coating thickness. The original Volkswagon became a legend for reliability, not the least of which was the durability of its aluminium bright trim. On some of the early models the condition of the nickel-chromium plated bumpers contrasted unfavourably with the aluminium trim. It was not many years before it was adopted by Mercedes and B.M.W., with Opel and Ford following later.

In Great Britain, both Alcan Aluminium Ltd and the British Aluminium Co. Ltd. began to offer similar materials. Alcan devoted a significant effort to demonstrating how bright anodized trim might be produced, with pilot scale facilities at Banbury to process samples for potential customers. British Aluminium Co. followed a similar path a little later. The trim initially installed on Ford models was based on 99.99% based material. However, the competitive economics of the motor industry came to the fore on grilles of two models of Ford cars. Brass was used on these models, since less nickel was needed. The brass suppliers responded by offering a higher price for the brass scrap produced in blanking out these grilles, which left 99.99% aluminium uncompetitive. Attention then turned to the use of high purity (99.7% min.) aluminium-magnesium alloys which were cheaper and thereby established themselves firmly for trim.

In the meantime, the industry in the U.S.A. was equally aware of these developments and proceeded along its own path of development. Initially, they utilised material of a 99.5% (min.) purity and employed very thin coatings, e.g. 2µm for interior trim and 5µm for exterior trim. However, these thin coatings did not give adequate service life, and in due course the American producers also employed 99.7% (min.) purity alloys. Although the above alloy compositions were applicable to sheet and strip, the better extrudability of high purity Al-Mg-Si alloys led to the development of a high purity alloy specifically for bright anodizing.

The use of bright trim in the automobile industry reached its Nader with the attack launched by this gentleman on the safety of U.S. automobiles, which included a claim that reflections from bright trim constituted a safety hazard. Since then the amount of bright trim used on automobiles has remained minimal, with a consequent decline in output.

However, these developments formed a basis for the wider use of bright trim in applications such as refrigerators, kitchen appliances, office furniture and equipment and bathroom shower cabinets. The more recent development of electrolytic colouring, with the ability to produce colours to close limits by the use of computer control, has opened up expanded markets for some companies who have had the foresight to see how a process originally introduced for architectural anodizing could enlarge their business.

(b) The architectural market

Throughout the 1960's and early 1970's anodizing was firmly established as the finish for architectural aluminium, especially for monumental buildings. There was quite widespread use of roller coated painted strip for building cladding. In the latter part of the decade, white electropainting for the replacement window market grew rapidly. Two factors contributed to the decline of anodizing in the architectural market in the 1980's - (1) competition from UPVC windows, particularly for the domestic and factory window market, and (2) the development of powder coating with its wide colour range.

An estimate made by Ablewhite [14], compiled from industry sources, shows the following as the market breakdown between anodizing and painting for finished aluminium extrusions in the architectural market between 1970 and 1978 for the United Kingdom and other European Countries:

Table 1: Estimates of the market share of anodized and painted painted aluminium in architectural applications

Country	Consumption (tons)		% Anodized		% Painted	
	1970	1987	1970	1987	1970	1987
United Kingdom	16,000	69,000	100	40	0	60
Italy	75,000	170,000	99	75	1	25
France	22,000	66,000	100	87	0	13
Germany	39,000	80,000	98	75	2	25
Belgium	29,000	65,000	79	55	21	45

The decline in anodizing was greater in the U.K. in this period than in other European countries, but in all countries some further loss of market share by anodizing has occurred since 1987. There is no generally available information on the reason for these changes, except that the appeal of colour has been a strong factor, plus the fact that colour was obtainable at a lower cost by powder coating than with anodized finishes. At the beginning of this period the aluminium industry, in conjunction with the anodizers, informed the architects which colour anodized finishes were technically sound. By the end of this period architects were able to say what colours and textures they required, which were often not anodized finishes but organic finishes.

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1. I am grateful to Mr V F Henley, formerly Technical Director of Acorn Anodizing Co Ltd. for much of the information on the early history of anodizing. In addition, I would also acknowledge the contributions made Mr P Smith, formerly Managing Director of Acorn Anodising Co Ltd., London; Mr J D Craig, formerly Managing Director of Technical Platings Ltd., Teddington, and Mr Frank Spicer, Managing Director of Roundhay Metal Finishers (Anodisers) Ltd., Batley, W Yorks.
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3. The Economics of Anodizing Businesses

3.1 Types of anodizing plants

There are many ways in which such plants can be classified, but from the standpoint of business economics the following is suggested as the most relevant classification of businesses undertaking anodizing:

(1) Specialist "captive" plants producing work solely for the enterprise in which they are situated.
(2) Plants which are part of an extrusion operation and whose function is decided by the company's marketing strategy.
(3) Specialist 'trade' anodizing plants which process anodizing work solely as sub-contractors.
(4) Anodizing plants which are part of a trade electroplating business.

Each of these types of plants operates under specific production and market conditions. This results in certain distinctive economic characteristics applying to each of these separate groups of enterprises.

(a) Specialist "captive" plants:

Where specialist 'captive' plants exist, their characteristics are determined by the nature of the enterprise and the final product or products produced. Thus, a plant producing bright anodized trim for domestic appliances operates in a totally different business environment from that applicable to the aerospace industry or to architectural products. These differences are reflected in the administration, the production methods and anodizing technologies applied to the enterprise.

Such plants have the advantage that they can be designed to optimize the available technology to obtain the lowest unit production cost. However, for such plants there is a minimum economic level of output. Below this it is cheaper to utilize the services of a trade anodizer.

Further, there are significant economies of scale possible in anodizing, particularly in large architectural plants. A second, or even a third anodizing tank may be added without adding further cleaning, etching and rinsing tanks. This reduces the marginal capital cost required for the marginal increment in capacity. Further, due to the variety of size, shape and quantities required of particular components, trade anodizing plants are frequently operated at only 50 - 75% of their nominal capacity. On the other hand, captive plants have been known to operate at 80 - 95% of their nominal capacity.

However, there is a corresponding limitation to the advantages of these specialist plants. They represent a large "lump" of investment, so that once capacity has been fully taken up, a significant capital expenditure is needed to further increase the output of anodized components. However, if it is a matter of coping with occasional "peak" output demands, such plants can secure lowest average costs by off-loading this peak demand on to trade anodizers. Since the market for aluminium has grown by 8-10% per annum for most of the period 1950 - 1980, such plants have normally been operating under conditions of a steady fall, in real terms, in the unit costs of producing anodic coatings.

(b) Plants 'tied' to an extrusion operation:

One of the most interesting phenomena since the 1950's has been the growth of the independent extruders in the U.S.A., who have taken the major share of the market. Of course, over a period not all of these businesses have remained independent. Many have failed, some have become part of an industrial conglomerate or have sold out to one of the integrated producers. The innovative approach of the independents in the domestic American environment has been based on attempting to maximise the value added to the billet they extrude. This is achieved by selling lengths of anodized extrusions wherever possible, or by co-operating with customers in developing designs in which components could be made from extrusions by simple cutting, drilling or forming operations, followed by finishing. Other finishing operations such as stove enamelling, electropainting or powder coating may also be undertaken. In more recent years the integrated producers have offered lengths of finished aluminium extrusions.

Anodizing plants operated in conjunction with extrusion plants have their own special characteristics. They are usually "in-line" plants i.e. a series of tanks of about 8m. in length, placed close to each other in line, with a product range which depends on market requirements and the type of business the company is seeking. There are many variations of coating thickness, surface texture and colour that can be demanded of such a plant. Some degree of rationalization of the range is usually necessary. Such plants are of large overall size and necessitate the use of manually operated or semi-automatically controlled hoists to move the work through the process sequence. Where the establishment produces small components cut from extrusions a different plant is required.

In many respects the characteristics of architectural anodizing plants and those offering lengths of anodized extrusions are similar as far as their economies of scale and production costs are concerned. Many of the plants in the U.S.A. have installed either return-type automatics or programmed hoist plants for handling large numbers of components made by cutting, drilling and blanking out from lengths of extrusions and anodizing them. Such plants offer a cost saving over what would be possible from a manual plant operated by a trade anodizer.

As with specialist captive plants, the rapid expansion of the market for architectural aluminium has also meant that these plants have been operating under conditions of falling unit costs in real terms.

(c) Anodizing plants operated by "trade" anodizers:

These plants operate under very different business conditions from those of the specialist 'captive' or 'tied' extrusion plants. Essentially, such enterprises regard themselves as being a 'service' industry, in that they undertake sub-contract anodizing solely on customer's products, In this respect they provide a service (similar to that provided by transport) which enables such customers to complete on time the sequence of production operations required for the manufacture of the particular product without investing in anodizing plant. The contribution of trade anodizers is to provide the inputs of the factors of production needed to produce the outputs of components requiring anodized finishes at a cost lower than would apply if the customer installed a "captive" plant.

There are distinct economic characteristics of such plants, which are similar to those of trade electroplaters. Such enterprises mainly represent the response of the small entrepreneur to economic opportunity, e.g. that of a former plant manager setting up his own business.

3.2 Economic factors affecting the businesses of 'trade' anodizers

(a) Barriers to entry:

Bain [1] states that the basic economics of the firm are influenced by the "barriers to entry" to the industry which, he concludes from his studies, are the following:

1. The economies of scale inherent in the industry.
2. The absolute cost advantage of existing firms.
3. The degree of product differentiation in the industry.
4. The level of capital required to enter the industry.

Taking these criteria in turn, there are no major economies of scale inherent in the industry, as is the case in the oil or iron and steel industries. In anodizing there are only moderate economies of scale. Finished anodized components differ in specification, size and quantity required, thereby limiting the economies of scale.

It is also evident from the rapid increase in the number of firms undertaking anodizing, that there is no significant cost advantage enjoyed by existing firms. The level of specialist "know-how" required is, at best, a low-to-moderate barrier to entry.

Product differentiation in terms of anodized products is low-to-moderate, since most products are produced to well established finishing specifications. Certain firms attain a degree of product differentiation by acquiring a reputation for producing certain types of finish, such as colour anodizing or hard anodizing, where there is a moderate degree of skill and experience needed.

The level of capital needed to enter the industry is relatively low by general industry standards. A factor promoting a rapid increase in the number of trade metal finishers in the early post-war years was the availability of low cost used equipment left over from war-time plants. On the other hand, the cost of installing large plants to anodize extrusions, has limited the number of trade anodizers in this field in the United Kingdom, but there are more in Germany and the United States.

Overall, in general industrial terms, trade metal finishers are characterized by a relative small unit size, low barriers to entry and the lack of a final marketable product.

These features create the characteristic conditions of uncertainty, i.e. firms have little certainty of the amount or type of work that may be required beyond the next week or two. Also, they have limited knowledge of the degree of competition prevailing in their main markets and future trends. Further, they may face irrational price competition in that, from time to time, prices will be quoted by a competitor which are lower than average production costs or even the marginal cost. These characteristics are not confined to metal finishing, but are found in many other industries.

(b) The consequences of "uncertainty":

The existence of "uncertainty" and its economic implications were first referred to by Robinson [2]. There have been studies of other industries by economists, e.g. that carried out on 64 industries by Schwartzmann, who concluded that in these conditions "industry grows largely through increases in the number of firms rather than in average size" [3]. The conclusion seems valid for both trade anodizers and electroplaters.

Apart from competition arising from the existence of numerous competitors, there is also the possibility of loss of business from one or more major customers who may install their own captive plant; also in certain markets customers may switch to buying pre-anodized extrusions. In addition, competition is also experienced from trade electroplaters who install anodizing facilities so as to retain business from customers who are substituting anodized finishes for electroplated ones.

A consequence of uncertainty is that the trade anodizer normally opts for a plant layout and technology which will give maximum flexibility, so as to accommodate the variety of types of work (shape, size, finish etc.) which is likely to be demanded. This may not represent the one which gives the lowest average unit cost, or even the one which offers an optimum technology. Even so, most firms have certain types of work and anodized finishes in which they tend to have particular skill or experience. Reliability of quality and delivery, and an ability to meet special requirements of a customer, are forms of non-price competition which prevails in certain markets, especially where there is a 'going' or 'normal' price prevailing. The consequence of such specialist ability is that often competition may be restricted to only a few firms.

The view has been expressed privately [4] by a former leading figure in the industry, that one of the problems limiting the size of the establishment is the ability of management to communicate to the shop floor the variety of customer requirements and to ensure quality, once the number employed exceeds more than 40-50.

(c) Anodizing by "trade" electroplaters:

Initially, the production of anodized finishes by trade electroplaters was primarily a defensive reaction to the trend in some products to substitute anodized finishes for nickel-chromium plating. In introducing anodizing into the establishment the electroplater has to undergo a significant 'learning' process. In electroplating the coating is deposited at the cathode and is conductive. In anodizing the coating is produced at the anode and is non-conductive. The anodic coating grows by conversion of the surface of the aluminium to oxide and is not a deposited coating, as with electroplated coatings. These differences in the fundamental technology also result in significant differences in the production technology and techniques, as well as in the economics of the two processes. Generally speaking, most trade electroplaters do not produce high quality anodizing.

There is another problem faced by the jobbing electroplater in pricing anodizing. For example, it is not too difficult to price the direct labour, power and chemicals involved, but overhead costs, including effluent treatment, are more difficult to assign when a variety of processes are involved. With higher treatment costs being inherent in the treatment of electroplating effluent, if averaged, they may represent a higher cost than that faced by a specialist trade anodizer.

3.3 The Economic Effects of Changes in Anodizing Technology

In common with most other industrial processes, there have been significant changes in the technology employed over the past 40 years.

They include the following major changes:

1. The widespread use of chemical polishing for decorative finishes.
2. The development of specialized cleaning and etching formulations.
3. The introduction and decline of integral colour processes.
4. The development of hard anodizing processes.
5. The introduction of electrolytic colouring processes.
6. The introduction of sealing smut removers.
7. The development of "cold" (impregnation) sealing.
8. The use of superimposed A.C. and pulsed D.C. in hard anodizing.
9. The use of mechanised hoists and automation of equipment.
10. The development of computerised control of power supplies.

(a) Economic theory relating to technical change

Much of the thrust of economic theory has been directed to developing models which will indicate the possible macro-economic impact of technological change, as expressed through inventions and innovations [5], especially in terms of assessing its impact on the production function [6,7]. This has lead to consideration of technical innovation in terms of its effect on the productivity of capital and labour. However, this ignores the fact that innovation also results in the development of new products and markets. This consideration has led to the modification of models of induced innovation, such as those of Kennedy [8] and Wiezsacker [9]. The model of economic growth developed by McCain [10] considered particularly the effect of product innovation.

The introduction of new processes should be distinguished from that of new products. New processes may reduce costs by improving labour productivity, thus lowering labour costs, or by reducing the cost of capital. In turn, this may facilitate the introduction of a new product by reducing the price at which it can be produced. In addition, process innovation may change the technical quality of the product, which may again increase its value in the market. The following is an assessment of the impact of innovations in anodizing on these factors.

(b) The economic impact of anodizing innovations

The table below assesses the impact of the process innovations listed above in terms of their effect on capital and labour costs, plus their effect on market demand. It can be seen from the table how complex can be the impact of process innovations. In the first place, it is necessary to consider how developments in the industry have affected capital costs. There have been divergent factors operating. A paper published in 1967 by Ashby [11] showed that the capital cost of power rectifiers for electroplating had fallen significantly in the post-war years. There is no reason to doubt that this applies to rectifiers for anodizing. Comparative costs of plant are not easily obtained, but a personal impression is that it is also accepted in the industry that the cost of process tanks has fallen in real terms. More intense utilization of plants and economies of scale have also tended to lower capital costs per unit of output. On the other hand, factors such as rising labour costs in real terms, and the increased level of mechanisation, have significantly raised capital costs, in terms of fixed working and fixed capital.

Table 1: Effect of Innovations on Costs and Markets

	Innovation Description	Effect on Capital Cost	Effect on Production Cost	Effect on Market Demand
1.	Chemical polishing	Increase	n.a.	Increase
2.	Special etchants	Negligible	Reduction	None
3.	Integral colouring	Increase	Increase	Increase
4.	Hard anodizing	Increase	Increase	Increase
5.	Electrolytic colouring	Decrease	Decrease	Increase
6.	Sealing smut removers	Negligible	Decrease	Negligible
7.	Cold sealing	Slight increase	Decrease	Negligible
8.	Solid film lubricants	None	Negligible	Sl. increase
9.	Handling & automation	Increase	Reduction	Negligible
10.	Computerization	Increase	Uncertain	Negligible

Note: The decrease in capital and production costs from the introduction of electrolytic colouring relates to the savings over the costs of producing similar finishes using the integral colour process.

A further factor raising the capital cost has been the pressure for higher quality standards for anodized products, which have necessitated more costly controls, testing and inspection. Non-destructive thickness testing had only begun to be used in the 1960's. The level of testing was frequently confined to a few readings per load, with statistical sampling being unheard of. The only tests for sealing quality in use were the Anthraquinone Violet dye stain test and the fingerprint test. Neither of these subsequently proved to be adequate as acceptance tests for architectural anodizing or bright trim. With the introduction of the British Standard for Architectural Anodizing (BS 3987), came the need to install deionized water for sealing to pass the sealing test - another increase in the capital investment required.

On the other hand, the introduction of etchants which could be delivered by bulk tanker and their ability to last for extended periods without scale forming on the tank walls, constituted an innovation that reduced process costs. The introduction of sealing smut removers was another cost saving process innovation, since prior to their introduction, it was common practice to rub or wipe down all work before delivery to the customer, to remove the sealing "bloom" which was usually present.

The introduction of chemical polishing opened up new markets for aluminium for trim used in consumer durables and automobile applications, despite the investment needed in fume extraction and scrubbing equipment. The development of integral colouring (later replaced by electrolytic colouring) had a significant impact on the architectural market. Demand for coloured work produced an overall large growth in the market, and with it radically changed the product mix demanded. Prior to integral colouring, it was unusual in most anodizing plants for the output of coloured finishes to exceed 10% of total output (with only gold and black available). The introduction of the various bronze shades (from integral colouring) probably increased the demand for colour to over 50% in the "monumental" market (i.e. prestige office buildings etc.). These are personal estimates, as industry figures are unavailable.

Hard anodizing is an interesting example of how the technical qualities of the product have been almost entirely responsible for the growth of the market. The original stimulus was derived from aerospace and defence, where weight saving is a paramount requirement. However, the "know-how" built up initially in these areas also stimulated interest in the finish in other markets, such as automation, general engineering, automotive engineering, control gear and even for use in the joints of artificial limbs.

Over the past five years the use of the coating as a base for solid film lubricants, such as polytetrafluoroethylene (PTFE) or molybdenum disulphide, has grown rapidly in the U.S.A. and is now beginning to be utilized in Europe. This attractive combination of a hard film with a low coefficient of friction has opened up further markets.

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4. The Dissemination of Anodizing Technology

The term "dissemination of technology" is used in preference to the term "transfer of technology", which is currently associated with the transfer of technology from an advanced economy to a developing economy, often with a different culture. A study of the dissemination of anodizing technology since its invention is instructive, in terms illustrating the mechanism of the diffusion of technology in an industrial sector made up mainly of small and medium sized businesses.

4.1 Technology dissemination from the licensing of patents

(a) Chromic acid anodizing:

It has already been pointed out that the chromic acid anodizing process was licensed to firms by the D.S.I.R. Initially, this was done through staff employed at the National Physical Laboratory, Teddington, where Bengough had originally worked. Later, this function passed to the Royal Aircraft Establishment, Farnborough, where Dr H Sutton (a former collaborator of Bengough) was then employed.

Since the primary use of chromic acid anodizing was for protecting aircraft components, quality assurance was the responsibility of the Aeronautical Inspection Directorate, Accordingly, it was necessary to formulate a process specification (DTD 910) that their inspectors could use to ensure that it was operated correctly.

(b) Sulphuric acid anodizing:

It has been mentioned previously (p. 15) that the first patent for sulphuric acid anodizing was ultimately acquired by the Aluminum Company of America (Alcoa), who licensed the process. Their means of dissemination of techology was based on the following elements:

1. Provision to licencees of a process instruction manual.
2. Technical support in licensees plants by qualified personnel.
3. Providing demonstration capability by establishing a processing facility to process components to solve licensees problems.
4. Direct production experience by its acquisition of a holloware

company in New Kensington which had an anodizing plant.

5. A significant research and development effort devoted to understanding the process at the metal/oxide interface.

A manual "Instructions for Applying Alumilite Finishes" was supplied to licensees, and set out recommended processes and operating conditions. So successful was this that, even today, the "Alumilite" process is almost universally used in the U.S.A. for decorative and protective anodic coatings. This can be contrasted with the United Kingdom where, even now, variations in the anodizing electrolyte concentration from 90 - 450 g/l of sulphuric acid are permitted in the current British Defence Specification [1]. This is a reflection of the variety of conditions used in the early years because of the confused patent and licensing situation.

The licence granted to Alumilite in Great Britain led to the creation of a patent pool and sharing of information with companies in Switzerland, Germany, Belgium and Sweden. This proved particularly valuable in making available the silk screen printing technology that Siemens and Halske developed in Germany. World War II broke off the contact with European licensees, but there was a continuing interchange of information between Alcoa and Alumilite (U.K.), especially in the field of the electropolishing of aluminium.

Although the basic patents for anodizing and sealing expired in the late 1940's (their period of protection having been extended because of World War II), many companies continued to pay an annual fee to Alcoa for use of the "Alumilite" trade name and a modest level of technical support. Elsewhere, the expiry of these patents encouraged further new entrants into anodizing.

4.2 The dissemination of chemical polishing technology

The patents of Alumilite and Alzak Ltd. relating to chemical polishing of aluminium were acquired in the 1950's by Albright and Wilson Ltd., a specialist chemical manufacturer who was the sole U.K. source of phosphoric acid of S.G. 1.75. Other manufacturers of this acid did not supply this grade, but offered acid of S.G. 1.70. The difference in S.G. is accounted for by water, which affects the brightness obtained.

Albright and Wilson were in the position of having a virtual monopoly of the supply of the acid, and even with the expiry of the original patents they have continued to be the major supplier in the U.K. Competitors believe that they are at a price disadvantage in trying to compete with a monopoly supplier. The main response by competitors has been to modify the process chemistry so that S.G. 1.70 acid can be used.

Albright & Wilson Ltd promoted this product, along with other products for metal finishing that the company subsequently developed, by setting up a metal finishing division, which subsequently became a separate operating company. The acquisition of the chemical polishing patents was effectively a recognition that the process was a practical, commercial process. Albright and Wilson Ltd. then recruited appropriate staff to form a sales organisation with technical support staff. The use of the process grew rapidly as interest in bright trim increased in the various user industries.

Initially, a problem was experienced with a phenomenon referred to as "transfer etch". It was found that in the course of the time required to transfer the work from the chemical polishing bath to the first rinse, etching of the surface could occur. The company sponsored research at Aston University to understand the nature of the problem. It was found to be related to the ratio of phosphoric acid to sulphuric acid in the solution. As a consequence Albright were able to modify the bath and patent an additive which inhibited etching. Other research at Aston included the role of nitric acid and of copper. This work also provided a better understanding of the mechanism of the process and the role of the individual constituents [2-6].

Albright's technical efforts were initially confined to the chemistry of the process. When bright anodized trim became accepted by the motor car industry, they supplied automatic plants for anodizing, but later withdrew from this activity.

Alcan had initially persued a different path, having initially introduced 99.99% aluminium for bright trim and installed in its Banbury Laboratories a pilot facility for chemical polishing using the German "Erftwerk" process. However, only one plant was subsequently installed this process for production of bright trim in the United Kingdom. With the shift to

99.7% purity based alloys which cannot be polished by the "Erftwerk" process, interest shifted to Albright's proprietary "Phosbrite" processes.

Facilities for bright anodizing prototype components using this process were installed later in the laboratories of both Alcan and British Aluminium. Part of the initial investigations at Alcan were simply devoted to building up an understanding of how to operate the process. For example, Brace and Kape published a paper [8] showing the effect of metal purity and nitric acid content of the "Phosbrite" chemical polishing bath on the specular reflectivity obtained from 99.7% and 99.99% aluminium-magnesium alloys.

In the course of supplying customers with material for bright anodizing, it was found that not only did the grain size and the size and distribution of the inter-metallics have to be controlled carefully, but the anodizing conditions also affected results. Scott [9], and later Jackson and Thomas [10] in British Aluminium's laboratories at Chalfont Park published the results of research showing how anodizing variables, such as concentration, temperature and current density, affected the properties of the anodic coatings produced. A more limited investigation of these factors was also carried out at Alcoa's Research Laboratories in the U.S.A. [11]. An important contribution was made by Cooke [12] at Alcan's Kingston Laboratories (Canada), who studied the inter-relation between the nature and distribution of inter-metallic particles and their effect on the loss of brightness on anodizing. This was particularly valuable in explaining the loss of specular reflectivity on anodizing. Unpublished work at Alcan, Banbury, also showed how the presence of impurities (such as iron) in the electrolyte, could reduce brightness when anodized.

As can be concluded from the above, the publication of research results in journals of the technical institutes, such as the Institute of Metal Finishing, was an important means of disseminating knowledge of these new processes. Both Alcan and British Aluminium had staff who gave technical support to customers and communicated information on a one-to-one basis with the relevant staff of major customers.

Although small bright anodizing facilities had been installed at the Radiators Branch of Morris Motors and at the Morris Singer Co, Exeter, the first large plant for producing bright trim was that of the London

Aluminium Co Ltd., Birmingham, an aluminium pressing and holloware company, who installed an automatic plant specifically intended to produce bright trim for the motor car industry. They were joined by a new company - Pressweld Ltd., Gloucester, a company set up by Pillar Holdings Ltd., with integrated pressing and automated bright anodizing facilities, thus providing two major production facilities. This resulted in two of the traditional suppliers of electroplated trim - Pianoforte Supplies Ltd. and Coventry Radiator Ltd. - also installing an automatic plant. However, other major trim suppliers - such as Wilmot Breeden Ltd. - were reluctant to commit themselves.

4.3 The role of Alcan in developing architectural anodizing

Reference has already been made to Alcan Aluminium Limited being particularly active in supporting work on architectural anodizing. The figures previously reported in Chapter 3, show that at its peak a large tonnage of anodized aluminium was used architecturally, but initially this was "natural" (uncoloured) anodizing. Considerable effort was needed to provide the window industry with an understanding of anodizing technology and to widen the appeal of anodizing by promoting suitable light-fast colours.

Spooner [13] at Alcan's Kingston Laboratories had published the results of outdoor exposure and accelerated fading tests on a large number of anodized and dyed panels. This was taken as a starting point for the assessment of possible colours for architectural use. It was suspected by Alcan (and subsequently confirmed) that an even wider range of dyed panels had been subjected to long term testing by Alcoa, who made available to its customers and "Alumilite" licensees a range of colours recommended for architectural anodizing in the late 1950's.

(a) Marketing theory:

As an international supplier of primary aluminium, in the early 1950's Alcan had identified building and architectural as a major potential market. Alcan's marketing approach was undoubtedly influenced by marketing strategies then in current use in the United States. Corey, of the Harvard Business School [14], published a series of marketing studies, one of which refers to the efforts of Alcoa in the 1930's and in the post-war period to introduce aluminium windows. Since the extent of demand for aluminium windows was unknown, window manufacturers had little incentive to introduce them. Alcoa directed their attention initially to architects and property companies.

Alcan in the United Kingdom followed a similar strategy. Although steel window manufacturers did eventually produce aluminium windows, it was the pioneering work of a few companies who began producing aluminium windows without prior involvement in the industry (e.g. Alumin Ltd., Weston-super-Mare) that resulted in a response to the competitive challenge from the established manufacturers.

In the initial period, the aluminium industry in the United Kingdom had no agreed view on whether a finish should be applied. A typical statement in aluminium industry publications was that aluminium is a corrosion resistant metal that "weathers to a pleasing grey patina" [15]. Certainly, a number of building owners in industrial cities did not share that view. The erection of the Alcoa Building clad in anodized aluminium as Alcoa's new head office building in Pittsburgh, set the seal on approval of architectural anodizing by the market leaders in the U.S.A. This later assured its adoption in the United Kingdom.

Architectural anodizing was not a novelty to this country. Several examples of its use were published in 1938 in one of the early issues of "Light Metals" [16,17]. However, to secure acceptance of anodized aluminium windows the following conditions needed to be fulfilled:

- There had to be a demand for the product.
- The aluminium windows must be functionally as good, and preferably better than their steel counterparts.
- There had to be confidence in the durability of the finish.
- There had to be plants capable of producing the work.

Corey's studies [14] of the marketing of new products included several aluminium applications. He arrived at the following general conclusions:

"To develop the markets for materials, the material producer has found it necessary to undertake marketing programs of great breadth and complexity at two market levels. He has had to work extensively with his immediate customers, the end-product fabricators, to build an industry which will make and supply the new product to end users. In addition, he has had to undertake long-range promotional programs in the end-product market to create demand for the product among consumers and industrial purchasers."

An important phase in changing from one material to another, is the ease and speed with which it can be introduced. The S-shaped learning curve has been invoked as a model [18] to explain the nature of technical innovation. Once a product innovation has been made, the speed of its introduction to the market is affected by a number of factors. The rate at which production staff are able to learn how to produce the new product will affect the initial rate of growth of its production, and hence the cost of the "learning process". This factor is referred to by Peck [19] as the "demonstration effect".

Schumpeter's view [20] of the innovation process is that it is divided between a primary wave of leaders and a secondary wave of followers. The proposition in the demonstration effect is that the adoption process depends critically upon the actual observation and imitation of the success of the leaders with the new innovation. Corey [21] refers specifically to the introduction of aluminium windows. He points out that a steel window company, in attempting to make a decision to manufacture aluminium windows, can only estimate transfer cost and cost savings within a fairly wide range. Corey also reported that two companies he interviewed found it incompatible to manufacture steel and aluminium windows on the same line. This made the introduction of aluminium windows dependent on a company being willing to invest in new manufacturing equipment and techniques, thereby hoping to save costs or increase its market share.

Peck [22] considers that "competition furnishes additional force to the demonstration effect, for it punishes a failure to follow a successful innovator. In addition, cost savings are available to the followers, for a new application of aluminium involves a cost for experimentation in the development of products and processes". The marketing effort of the aluminium industry was directed at supporting the demonstration effect, thereby reducing the period required for the initial learning process. Steel windows have mainly been protected by hot dip galvanizing which is also used as a basis for painting, although some windows produced were painted without galvanizing. The introduction of anodizing therefore involved learning new process technology, as well as additional capital investment. Some producers held back from selling anodized windows as a standard product, using trade anodizers to produce this finish if demanded by customers. Not all window manufacturers were successful in making the transition. One of the largest steel window companies - Williams and Williams Ltd. - was the first to install an in-house anodizing plant for windows, but it ran into financial problems and was effectively bankrupt in the 1960's. Later, Heywood-Helliwell Ltd., a smaller but successful aluminium window manufacturer, acquired the company.

(b) Alcan's marketing strategy:

In the United Kingdom, Alcan was involved in marketing on two levels. As the major supplier of primary aluminium products to semi-fabricators during the 1950's and 1960's, they were concerned with developing the architectural market as part of their overall international market development strategy. At that time, Alcan's international sales organisation was Aluminium Union Ltd., who maintained a London Office and sales staff. At another level, development of sales of semi-fabricated products was also a major target for the sales development staff of Alcan's semi-fabricating subsidiary Northern Aluminium Co Limited, whose name was later changed to bring it under the Alcan umbrella.

By the mid-1950's Alcan had decided to promote anodized finishes for use in architectural applications. Part of the market development strategy was to support anodizing research and development. This strategy (Diagram 1 - p. 56) was based on the theory that the demonstration effect shortened the learning period and reduced the cost of introducing a new product, as well as providing a technical basis for the acceptance of the finish by architects and window manufacturers.

To develop the architectural market involved a complex marketing activity at various levels. As a primary aluminium supplier, growth of demand in the architectural market was seen as a potential major growth factor, so that there had to be a strategy that took into account the role of Alcan of an international supplier, but it also had to be integrated with the

Marketing Target	Marketing Programme
Architectural Products Manufacturers	- Assist with Design - Assist with Prototypes - Manufacturing Advice
Architects and Property Companies	Promote Aluminium by - preparing brochures - publicity in trade press - visits to leading figures
Anodizing and Anodizers	Process Development - Anodizing Techniques - Test and Select Colours - Develop Colouring Techniques - Develop Quality Tests - Disclose to Users
Aluminium Development Association	- Disclose Recommendations to the Finishes Committee - Secure Industry support for process recommendations - Jointly seek support from the Trade Anodizers for above - Publicise these recommendations - Set out Quality Requirements as basis for future British Standard

Diagram 1: The Marketing Strategy for Architectural Aluminium developed by Alcan Aluminium Limited.

marketing activities of its semi-fabricating subsidiary companies. The United Kingdom market was judged by Alcan's management in Montreal to be likely to be the largest available to it outside of the United States.

Within the United Kingdom, its subsidiary Northern Aluminium Co Ltd. (later renamed Alcan Industries Ltd.) evolved a marketing strategy of great depth and of broad coverage. This strategy involved the elements shown in Diagram 1 on the previous page.

4.4 Establishing the anodizing technology:

Alcan's success in expanding the architectural market was linked with its ability to provide significant help and advice on design and manufacturing techniques, as well as on anodizing. Regarding the latter, they were fortunate in that Gardam joined Alcan's Banbury Laboratories in 1953 as Head of Chemistry Division. He had a high reputation in electroplating from his association with the Royal Armament Research and Development Dept., Woolwich. In 1955 he recruited Brace to head metal finishing R & D, who later added both Kape and Sheasby to the team. Each of these subsequently established a reputation which resulted in Banbury becoming recognized internationally as a centre of anodizing expertise.

The primary objectives of the work carried out in the period 1955-1960 by this team were :

1. To understand anodizing and the processes associated with it, especially in terms of the factors which could cause problems in large scale production.
2. To recommend processing conditions for the production of anodized finishes for products required by Alcan customers.
3. To appraise and recommend a range of colours for architectural use.
4. To develop test methods which would ensure that quality standards could be drawn up for anodizing to ensure its acceptance in the main markets.
5. To provide assistance to Alcan companies in assessing the response of materials manufactured by them for use in anodizing.

The diffusion of the anodizing technology built up by the Alcan R & D team utilized the following means:

1. Written research reports distributed initially to Alcan companies.
2. Papers based on this research were presented to the Annual Conferences and branch meetings of the Institute of Metal Finishing and other technical institutes. Contributions were also made to trade journals, such as "Light Metals" and the main finishing journals.
3. A Symposium held in Banbury to summarize R & D findings for the benefit of personnel in Alcan companies with an interest in finishing and finished products to summarize experience.
4. A handbook "Recommended Practice for Architectural Colour Anodizing" was prepared, printed and widely distributed to Alcan companies and customers.

In the U.S.A., Alcoa had a background of outdoor exposure testing of the performance of anodized aluminium, which extended back to the late 1930's. Alcan's Kingston Laboratories had a more limited experience, since outdoor testing had only been initiated in the late 1940's and there were fewer specimens involved. Alcoa were recommending a minimum film thickness of 20 micrometres for industrial conditions and 12 micrometres (minimum) for less severe environments. Alcan's Banbury Laboratories had data on bare metal corrosion rates which were 2 - 5 times higher in N.W. Europe than in the U.S.A. Inspection of anodized installations in the United Kingdom and in a limited number of European sites were also made to assess the outdoor performance of anodized aluminium.

Also of concern, was the question of ensuring that the colours used were lightfast. Although there were a number of dyestuffs in use, these were of textile origin and were of only moderate light fastness. It was essential to restrict the colours used to the few that were lightfast, since a dramatic failure by fading would be a severe setback to the acceptance of colour anodized aluminium. Based on Alcan's testing, gold, black, two shades of blue, a yellow and a red were recommended, plus bronze shades produced by double dipping in cobalt acetate and then potassium permanganate solutions. Only the gold and black were widely used, but a large window company used this bronze process until the "Analok" process became available.

It should be appreciated that Alcan Aluminium Ltd (Canada) had a corporate marketing strategy at two levels: (1) the development of architectural sales internationally to stimulate the demand for primary aluminium and (2) support for the sales development activities directed at the architectural market by its international subsidiaries.

When the work on architectural colour anodizing had reached an advanced stage, Alcan disclosed this information to a primary customer – High Duty Alloys Ltd., who themselves had carried out work on inorganic colouring techniques. Alcan's management at its headquarters in Montreal later decided to make this information available to the aluminium industry in the United Kingdom through the Aluminium Development Association, which was co-ordinating the industry's promotional efforts.

4.5 The Role of the Industry Association

The aluminium industry had set up the Aluminium Development Association at the end of World War II to promote aluminium and co-ordinate industry development activities. The detailed work was carried out through a series of ad-hoc committees, one of which was the Finishes Committee. The aim of the Alcan strategy was to secure industry acceptance of its recommendations on architectural anodizing and to prepare the way for drawing up an industry quality standard. By this means its was hoped that there would be increased demand from its primary aluminium customers, and an enhanced sales position for Alcan Industries Ltd., a producer of semi-fabricated products.

(a) Liaison with trade anodizers:

The aluminium industry, through the Aluminium Development Association, accepted the Alcan recommendations which had been approved by the Finishes Committee and subsequently published them, with minor modifications, as industry recommendations (see p. 37, ref. [6]). An essential element at this point was to secure the support and co-operation of trade anodizers, since it was evident that some window companies were initially not going to install captive anodizing plants, so capacity in the trade would be essential to market development.

The Finishes Committee had previously met twice with an ad-hoc group of leading anodizers to exchange views and information, particularly in relation to quality testing of bright trim. With architectural anodizing there were a number of issues for which the co-operation of the trade anodizers was essential. All of these were related to quality.

(b) Establishing quality standards:

The high bare metal corrosion rates measure at sites in the United Kingdom and other European locations, combined with examples of pitting of anodic coatings of 15 micrometres thickness within 5 years of outdoor exposure led to much discussion on the minimum thickness to be recommended. Work on accelerated corrosion testing using acidified salt spray published by Brace and Pocock [23], showed that there was a very significant increase in the time before pitting occurred as the thickness was increased beyond 15 micrometres. Taking these factors into account, the Industry Finishes Committee proposed a 25 micrometresminimum film thickness. At that time several plants were producing shop front sections to a 15 micrometresthickness, so there was some reluctance to adopt a 25 micrometrescoating universally. Initially there was a provision for a 15 micrometrescoating for less severe environments.

Another question that occupied the attention of both researchers and practical anodizers of subsequent years was the question of an acceptance test for sealing. At that point the Anthraquinone Violet Dye Stain Test was almost universally used as an acceptance test, but investigations at Banbury had shown that work could pass this test yet still develop an unsightly white bloom on exposure. The work of Brace and Pocock [23] had shown that a SO_2-humidity test produced white bloom on inadequately sealed work. A later modification of the test by Edwards provided an improved design of cabinet with accurate control of the SO_2 concentration [24]. This resulted in this becoming an accepted test method (BS 1615;1972, Appendix H). The fact that it was a subjective test ("had it bloomed ?") resulted in other quantitative tests being developed by Kape [25] and by Alcoa investigators [26] which have subsequently been refined and accepted as I.S.O. Test Methods.

In due course. the main Alcan recommendations became accepted and formed the basis of most British architectural anodizing practice. The Standard for Anodizing (BS 1615) was amended to take in to account the requirements of architectural anodizing. Later, a separate standard BS 3987 "Anodic Coating on Aluminium for Architectural Applications" - was drawn up specifically for architectural anodizing.

In the years following the setting up of the Aluminium Federation, which replaced the previous Aluminium Development Association, there was a change in emphasis, with market development being left primarily to the member companies. With individual members of the Federation installing captive anodizing plants to anodize mainly lengths of extrusions, plus a concern to ensure the maintenance of quality standards in the architectural market, the British Anodizing Association was formed. Although nominally open to all anodizers, in practice its membership was drawn mainly from those of its extruder members who had installed anodizing plants. plus the larger trade anodizers whose main business was architectural anodizing,

Later, the European Anodizing Association was formed, which provided a centre for co-ordination of information on technical and commercial matters of concern to the industry. In addition to undertaking a program of outdoor testing of the performance of anodized finishes, it developed "Qualanod", a quality standards organisation which awarded the "Qualanod" label to those plants who met its standard when independently inspected. This scheme was quite well supported in some European countries, but its support in the U.K. was lukewarm.

(c) Support for research

The Aluminium Development Association was the vehicle for providing financial support for University research on topics which the industry considered to be of particular interest. It provided finance for a research student (now Prof. G C Wood. U.M.I.S.T.) to undertake research into the sealing process. The technique used was based on making measurements of the changes in the A.C. resistance and capacitance of the anodic film during sealing of a testpiece in a specially constructed test cell. After publication of the research [27], investigators in Germany modified the method by developing an instrument with a circuit that measured A.C. admittance values directly on the surface of an anodic coating [28]. This instrument, with minor refinements, was subsequently sold by Fischer Instruments (Germany) under the trade name "Anotest".

Later the Association also provided a degree of financial support for work carried out at Battersea Polytechnic on chemical brightening [29], and at Glasgow by Giles and his co-workers [30] on the mechanism of dyeing anodic coatings.

4.6 Change and decline in architectural anodizing

The 1960's saw a significant growth in architectural anodizing. Whilst the traditional gold and black continued to be used, the Kalcolor process was installed in several large plants in the United Kingdom on account of both the colour range available from a single anodizing stage and the intrinsic quality of the film produced. During this period Alcan developed the "Alcanodox" process which used a modified oxalic acid process, but it only achieved limited use. However, for some time the demand for colour rarely exceeded 10-15 % of architectural output.

With the acquisition by Alcan of the Asada patents for electrolytic colouring using alternating current [31], there was an intense R & D effort in the 1970's directed at establishing the process industrially.

By the end of the 1960's there had been large changes internationally in the structure of the aluminium industry. Traditionally, the international market had been dominated by three major primary aluminium producers in the U.S.A. - Alcoa, Kaiser and Reynolds - plus Alcan. By now there had been new entrants into primary aluminium production, such as Amax (a major non-ferrous metals company), Anaconda (a copper producer) and Olin Mathieson (a chemical company). There had also been the entry of Pechiney (France) and Swiss Aluminium Ltd. into the international market, particularly by establishing overseas subsidiaries in the U.S.A. and elsewhere. In addition, the four major companies acquired or secured shareholdings in a number of previously independent semi-fabricators. The main objective of these companies appeared to be to protect their market share in terms of primary consumption.

This determined Alcan's marketing policy in this period, particularly in relation to its licensing of "Analok". Further, there was a desire to ensure that amongst Alcan's customers and trade anodizers the process was only licensed to companies that were technically competent. Within the limitations of this strategy, Alcan achieved quite significant success, in that a number of large plants in many countries were licensed and operated the process. One of these was a large window manufacturer in the United Kingdom - Heywood Williams Ltd - who found the market responsive to the colours available from the process, resulting in demand for colour accounting for more than 50% of its output in the 1970's. Alcan expanded their laboratory anodizing facilities at Banbury with improved, larger pilot line facilities and increased staff. They also supported University research, e.g. that carried out at U.M.I.S.T.[32,33].

However, Alcan's role was that which it had previously fulfilled - the innovation leader. As the merits of the process became obvious, other companies in Europe sought to find an equivalent process. The largest German architectural aluminium company (Gartner) in conjunction with Henkel (a chemical company) developed an electrolytic colouring process, as did the German aluminium producer - Vereinigte Aluminium Werke A G. The processes developed by these companies were based on utilising tin salts, whereas the Analok process utilised nickel salts (and later cobalt). Other companies followed this path, although some used mixed electrolytes containing both tin and nickel salts.

This development took place despite the Alcan patents, because tin salts had been omitted from the claims in the original Asada patents. Although there are operational factors associated with the "Analok" process that avoid or minimize problems associated with tin-based electrolytes, to exploit the process internationally would have constituted a major marketing problem for Alcan, since it would require entry into the process chemicals supply market, of which it had no prior experience as far as metal finishing was concerned. Understandably, Alcan decide to use the process to promote Alcan products.

From this point onwards electrolytic colouring based on the use of tin salts accounted for most of the market, with it being sold via the process chemical supply houses. However, for some years Alcan derived useful income from their process licensees which numbered some 40 to 50.

By the 1980's paint and powder coating finishes began to take an increasing share of the market, so that by the end of the 1980's Alcan ceased further research on electrolytic colouring and associated anodizing processes. Similar decisions were taken during this period by Reynolds and Kaiser. Other companies, such as Alcoa, also cut back their effort to one of a modest level of support for specific developments by customers involving anodized finishes. and investigating complaints of metal quality.

4.7 The contribution of process and plant suppliers

(a) The domestic suppliers

In the 1950's anodizing business in the United Kingdom was small compared with that of electroplating. The supply of process chemicals and plant was dominated in the U.K. by two companies - W Canning & Co Ltd and Efco-Udilyte Ltd., a subsidiary of Oxy Petroleum, U.S.A., who also owned the Udylite Corporation, a major electroplating plant and process supplier in the U.S.A. The former company employed V F Henley, formerly technical director of Alumilite & Alzak Ltd., for a few years, to deal with anodizing plant enquiries. During that period they were responsible for the installation of the first anodizing plant installed by a window company (Williams & Williams Ltd., Chester). Efco-Udylite secured the order for the first automatic anodizing plant which was installed at Hoover (Washing Machines) Ltd, Methyr Tydvil.

W Canning and Co Ltd viewed with alarm the introduction of bright trim, in view of the potential loss of electroplating business in the motor car industry. Added to which was the fact that the bright trim plant installed at London Aluminium Co Ltd. was supplied by Albright and Wilson Ltd., who had entered the plant business to support its sales of chemical brighteners, although they subsequently withdrew. One of the defensive steps taken by the company was to commence research on developing a process for producing a sound zincate coating on aluminium and its alloys prior to electroplating. On the other hand, Efco-Udylite made no effort to develop processes intended specifically for aluminium but, as with W Canning & Co., they secured anodizing plant orders.

Neither company made significant in-roads into the architectural market, despite the fact that Canning's also obtained orders from Heywood Helliwell Ltd, and H Hope & Sons Ltd., when these companies installed their architectural anodizing plants. When the large plants were installed by the trade anodizers and aluminium extruders, other suppliers were used. The reasons for this related to three factors.

1. Many of the early anodizing plants installed by trade anodizers were not supplied as a complete package from a plant supplier, but the components forming the installation were ordered from selected manufacturers of tanks, rectifiers, handling equipment etc. and installed by the anodizers. This was largely due to these companies believing that they had "know-how" which they did not wish others to acquire.

2. The main expertize of the traditional metal finishing plant suppliers, apart from specialized plant supplied to the aircraft industry, lay in the design of electroplating plants. They did not appreciate there were factors in anodizing which called for differences in plant design from that practised for electroplating.

3. In the early years the main consumables were caustic soda, alkaline cleaners and sulphuric acid. All of these are of low cost and low profit margin, so there was considered to be little incentive to invest in the R & D effort into products for anodizing, particularly at a time when demand for electroplating plants for the motor car industry was growing very rapidly. Anodizing was regarded as a marginal activity.

This proved to be a shortsighted view, when compared with the situation in Germany. Even in the later 1950's two of the leading suppliers - Riedel & Co and Langbein Pfanhauser Werke - had special products for anodizers., as did Henkel & Co, a privately owned company, based initially on selling industrial and domestic cleaners. They developed a range of cleaners, etchants and desmut solutions, followed by sealing bloom removers and electrolytic colouring processes.

In a characteristic manner, this was backed up by a significant R & D effort and much published work. In the late 1980's, Henkel subsequently acquired both Amchem and Parker in the U.S.A., major suppliers of cleaners, etchants and pretreatment processes for painting on aluminium and steel, becoming internationally the largest suppliers of such processes by the end of the 1980's.

The contribution of Albright and Wilson Ltd. to the development of bright anodizing has already been mentioned. In the early years they supplied the plant and chemicals, although they withdrew from supplying plant later. In addition to the "Phosbrite" chemical brightening process, they also offered cleaners, etchants and desmut solutions. They established overseas sales offices, and following their acquisition by Tenneco Inc., U.S.A., an effective operation was built up in the U.S.A. This has led to their entry into supplying chemicals for the newer processes, such as electrolytic colouring, sealing bloom removers and cold seals.

Another major company supplying metal finishing chemicals was the Pyrene Co Ltd., who were firmly established as suppliers of phosphating processes for steel, having a major share of the U.K. market and close links with the Parker Corporation in the U.S.A. Through this connection they introduced the Bonderite processes for producing conversion coatings on aluminium prior to painting. In the 1970's they became part of Brent Chemicals Ltd., a company whose main business was then industrial cleaners. This company did not become a major supplier to anodizers, i.e. the captive anodizing plants operated by extruders and large window manufacturers. When the coil coating lines began to be built, and when electrophoretic painting was introduced into the window market, the company attained the status of a major supplier to this market. Its main competitor was the Paints Division of I.C.I. Ltd., who sold the "Alocrom" processes developed by Amchem in the U.S.A.

(b) The role of foreign suppliers

In the electroplating field competition to domestic chemical process suppliers came from many sources. Companies such as Harshaw Chemicals, U.S.A., Schering A.G. in Germany and Silvercrown (Sweden) set up operations in the U.K. The high cost of R & D makes entry into a foreign market attractive, in terms of payback on R & D costs.

These foreign suppliers had strong domestic markets, whereas the United Kingdom based companies had weak domestic markets which constituted a competitive disadvantage. The lack of innovation by traditional plating suppliers in the anodizing field has already been mentioned. The weakness of U.K. suppliers has led to two foreign companies - Henkel and Novomax Technologies - becoming major suppliers to the domestic market.

However, it is appropriate to contrast the macro-economic background of metal finishing in the two countries. The success of the German economy needs no elaboration here. In terms of metal finishing the success of the

German automobile industry provided a growing market for the process chemical companies and a strong stimulus to invest in R & D. In addition, the German aluminium industry benefited from sustained economic growth, and in the 1980's achieved a per capita consumption level near to that of the United States. The lack of a strong domestic market reflected itself in a much reduced level of growth in the United Kingdom, to the extent that the gross consumption of aluminium actually fell in the 1980's. At the end of that decade also, imports of semi-fabricated aluminium exceeded exports. Part of these imports were of anodized extrusions - a new development adverse to U.K. anodizers.

The first foreign supplier of chemicals for anodizing in the late 1950's was Novomax Technologies, then operating as the Diversey Corporation. The parent company is the Molson Brewery Company, a large Canadian brewery group who had seen earlier an opportunity for diversification by supplying cleaners for bottles, casks and plant used in brewing, with a subsequent expansion into dairying (having fairly similar needs). It was only at the end of the 1950's that Diversey began selling their products (cleaners and an etchant) to British anodizers. Their success in the 1960's was largely attributable to the fact that they had acquired rights to a patent [36] covering the addition of sodium gluconate or sodium heptonate to the caustic soda solutions then widely used for etching aluminium. The choice of either gluconate or heptonate is largely dependent upon the price at which these compounds is available.

When aluminium is etched in a caustic soda solution it dissolves to form sodium aluminate and hydrogen is evolved. After about 25 g/l of aluminium has been dissolved in this way, an irreversible reaction occurs in which aluminium hydroxide is precipitated and usually rapidly forms a hard scale on the sides of the etch tank which reduces heat transfer and is almost impossible to remove. The addition of gluconate sequesters the aluminium and prevents this reaction taking place until a much higher figure - around 50 g/l aluminium. This proved to be a significant advantage to anodizers involved in heavy etching - the standard treatment prior to anodizing for most architectural aluminium.

Diversey's success in this area was further strengthened by additions to their product range of other cleaners, conversion coating processes, desmuts and sealing bloom preventers, followed by electrolytic colouring and cold sealing processes. Diversey had built up significant sales of their products in the U.S.A., as well as establishing sales organisations in the major world market centres. In the later 1980's they acquired Specialty Chemicals Inc, Atlanta, Ga, USA, who had been very successful in building up sales to anodizers. With the subsequent acquisition of Reef Chemicals in South Africa and Australia, accompanied by a change of name to Novomax Technologies, the company is believed to now have attained the position internationally of being the second largest supplier of process chemicals used by aluminium finishers.

Mention must also be made of one other specialist supplier. In the 1950's dyes for colouring anodic coatings were sold by four companies - CIBA Ltd, Durand & Hugenin (via their agents Bard and Wishart), Geigy Ltd. and I.C.I. Dyestuffs Division. By the early 1960's all of these companies, had withdrawn from supplying dyestuffs specifically tailored to anodizing requirements, except for Durand & Hugenin. This company was later acquired by Sandoz A.G. (Switzerland) and became virtually the sole supplier to anodizers internationally. In 1960's and 1970's they carried out a number of investigations, supplemented by exposure testing, of their range of "Aluminium" dyestuffs to ascertain the factors affecting their outdoor exposure, which resulted in the "Sanodal" range of dyestuffs being marketed.

With the rapid acceptance of electrolytic colouring, and the development of electrolytes which would give a good black, sales of dyestuffs (especially black) fell dramatically in the 1980's. In response to this Sandoz acquired "know-how" from Havilland Products Ltd (a small specialist company in the U.S.A.), which included an electrolytic colouring process and a cold seal formulation. Sandoz have made continued efforts to widen their market share of processing chemicals in the U.S.A., in addition to dyestuffs. They have made limited impact in the U.K., although they have had modest success in other European countries.

See next page for references

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5. The Diffusion of Technology within an Establishment

5.1 The acquisition of knowledge within an establishment

The foregoing text has been primarily concerned with an examination of the process of the diffusion of anodizing technology across the whole industry. In the early stages anodizing was a "youthful" technology with a high rate of innovation and rapid growth. Now it is a "mature" technology with well established practices and a lower level of innovation. In the "youthful" stage there were large differences over the range of anodizing plants in the level of "know-how" and competence in producing the finish to current quality standards. With the attainment of "maturity" these differences have been narrowed but not eliminated. It would appear instructive to examine the process of diffusion of technology within the individual establishment to account for these differences.

Table 1: Intrinsic and Extrinsic Sources of Anodizing "Know-How"

Intrinsic Sources	Extrinsic Sources
Written process specifications "Know-how" of staff specialists, e.g. process engineers, technical managers, chemists, metallurgists.	Advice from technical staff of chemical process suppliers Customers' Process Specifications
Records maintained for Process Control and Inspection.	Published technical literature (books, the trade press, papers published by technical institutes)
Experience of Line Personnel	Trade Associations Advice from Consultants

At any given point in time, an establishment carrying out anodizing will have a certain level of expertise - a "knowledge base" - that represents its own "state of the art". It is important to recognise that the "knowledge base" is not static but is subject to change, which is a reflection of both the knowledge intrinsic to the establishment and that which is extrinsic to it. The main sources of the "know-how" are shown in Table 1 on the previous page.

(a) Sources of knowledge intrinsic to the establishment

Within the establishment there are sources of process "know-how" which are embedded in the formal organisational structure and operating practices. Equally important, but often neglected, are the informal lines of communication and process knowledge, whose existence is often not recognised. In manufacturing establishments with "in-house" facilities the "knowledge-base" is considered to reside in those staff specialists, such as process engineers, chemists and metallurgists, whose function is to provide line personnel with the information needed to produce the required finish. The function of line management is to ensure that production schedules are met and costs controlled. Process control and inspection records also represent a source of knowledge of the operating characteristics of the plant.

The variety of sizes, materials and specifications required often lead to a situation where line personnel acquire a range of knowledge related to handling, jigging, plant operation etc., which is crucial to successful production, but not necessarily covered by the instructions in the process specifications. On problem jobs, investigation will often reveal that there is an unrecorded variation in the process being operated.

This needs to be examined carefully, since the assumption is that it is these variations that are a source of problems or rejects. Usually, they reflect the fact that line personnel have had problems when operating the standard process. The variation represents an attempt to solve the problems without resort to the formality of seeking an amendment to the process specification, which often acts as a barrier to introducing new technology. Any organisation tends to resist change, partly on grounds of cost, and partly because of uncertainty - the fear that change may cure one problem but lead to another.

(b) Sources of knowledge extrinsic to the establishment

The previous chapters have illustrated the crucial role that extrinsic sources of knowledge have played in the diffusion of anodizing technology. In recent years the aluminium industry has concentrated solely on material and product development. Now it is the suppliers of process chemicals (and to a limited degree plant suppliers) that are the main source of innovation or process improvement. A recession situation tends to further strengthen the position of the industry leaders, since in recession the level of technical support tends to be reduced by the smaller companies. Trade anodizers are mainly of small size by general standards, which means that most of them have no R & D, but follow the innovation leaders. Also, under recession conditions, irrational price competition prevails in an attempt to retain business. Similar factors operate amongst the smaller process chemical suppliers.

However, there are areas in which the process supplier's activities may not meet the needs of the industry. One such area is in quality testing and assurance, which is often dependent upon work carried out within the industry or by research institutes or universities. Publication of papers by technical institutes, such as the Institute of Metal Finishing, are an important source for the diffusion of new technology. In terms of awareness of new products, the technical press plays a key role in making anodizing plant management aware of new developments, especially in plant and equipment. Publication of data does not ensure that potential customers read the information, but it creates an awareness that new knowledge is emerging.

The success of many of the specialist Symposia organised within the Institute of Metal Finishing is probably mainly due to the following:

1. The presentation of review type papers allows attendees to make a rapid appreciation of developments.
2. The opportunity they present for personal contact with others, leading to a collective appraisal of the new development.

Most anodizing establishments buy technical books, mainly as a source of information not incorporated into the formal "knowledge-base" of the establishment. They have the advantage of preserving knowledge that might otherwise be forgotten. Their limitation is that they are never up to date, since they may have been written 2 to 15 years previously.

Another source of information which has become more important in recent years, is that from Trade Associations. With the increasing amount of Government legislation affecting the industry, especially in areas of effluent discharge, atmospheric pollution etc., its application involves the interpretation of highly technical provisions, which may require legal and technical expertise not possessed by individual members. They have become an important contributor to the diffusion of such knowledge. Consultants also play a role in the diffusion of knowledge in various fields, but their contribution is usually specific to a particular client and not of a general nature.

Customers can also have a role in the diffusion of new knowledge. This can arise simply because to achieve a specified level of performance, the finish may have to be specially developed for this purpose. The customer may not wish to install production facilities for this specialized finishing, but will sub-contract production to a component manufacturer or a trade anodizer. In this way new technology may be introduced to the industry.

It is evident from the foregoing that this diffusion of new anodizing technology is a complex process. Within an establishment there is a dynamic tension between the forces making for innovation and those which resist change, because of the uncertainties that it introduces, both in terms of cost and the possible impact technical change may bring to a manager in terms of personal uncertainty as to his future role or competence.

The main source of innovation in anodizing comes from outside the establishment. In the earlier years it was often from aluminium companies, but increasingly in recent years it is from process suppliers. Even here its impact is uneven, with a few suppliers leading the introduction of a new type of process, followed by a larger second wave of imitators, and with more following later.

Companies vary in the speed of their response to innovation and in the commercial success that they achieve. Technical personnel tend to assume that commercial success is related to technical expertise. The post-war history of anodizing provides examples of companies who have not been successful despite a high degree of technical competence. Commercial success depends upon many factors, e.g. managerial and entrepreneurial skills, adequate capital, and good timing of major investment decisions.

Given these skills, in a mature industry the leading companies may lose their leadership from: 1) complacency - "We're the best !", 2) failure to keep up with new developments and maintain technical leadership, as well as 3) loss of expertise resulting from staff turnover and a reduction in the numbers and resources available to maintain and develop expertise.

5.2 The impact of the recession on the acquisition of new knowledge

The past decade has seen an overall contraction of the United Kingdom manufacturing base, which has affected the demand for aluminium and anodized products, particularly architectural anodizing. In addition, there has been a prolonged economic recession affecting the whole of industry. This has given rise to two main responses:

1. Wherever possible the numbers employed have been reduced.
2. These reductions have been especially severe where indirect labour is concerned, affecting the number of staff employed, increasing the intensity of utilisation of those remaining.

In turn, this has also resulted in a reduction in the level of expenditure on technical information as evidenced by the reduction in the number of individual and sustaining members of the Institute of Metal Finishing.

In addition to these developments, a new factor has emerged, which is the actual loss of expertise within the establishment. As far a trade anodizing establishments have been concerned, much of the expansion in the 1950's and 1960's resulted from personnel in existing anodizing establishments either setting up their own enterprises or being recruited by new enterprises, many of which were setting up new in-house anodizing facilities. Such people often combined good production management ability with a fairly high level of technical expertise. During the past decade this appears to have changed significantly, but it should be noted that this is a subjective personal judgement, rather than one based on quantitative data.

In recent years there seems to be an increasing number of anodizing plant managers who are essentially line managers with limited technical expertise. This has been accompanied by a reduction in the number of technical support staff employed as part of the general drive to reduce overheads. In addition to this there has been a continuing loss of experienced plant or technical managers as a result of retirement and redundancy. The net effect has probably been loss of expertise intrinsic to the establishment.

Chapter 6: Process Defects and the Potential Application of Information Technology to their Identification and Avoidance

The previous chapters have been devoted to a description of the development and diffusion of anodizing technology. It is considered that anodizing is now a mature technology in which the fundamentals are firmly established. Much of the activity in the post-war years has been concerned with the introduction of new process developments. The question that needs to be posed now is what are the main requirements in the near future.

6.1 The role of anodizing technology

In terms of existing plants, the main requirement is to be able to make a profit on anodizing operations. This is partly dependent upon the macro-economic environment, which is a matter beyond the scope of this work. However, this also requires a continuing, and preferably an expanding, demand for articles for which an anodized finish is specified. In the past the creation of the demand has been affected significantly by the marketing efforts of the aluminium industry and their R & D work on anodizing. The aluminium companies have virtually ceased anodizing research, so that for the future innovation is likely to be dependant on the efforts of the companies supplying process chemicals. With an established mature market they have an incentive to pursue this path.

Over the period 1950 - 1980 internationally there were significant resources devoted by the aluminium companies to improving anodizing technology, which benefited all anodizers. As the average plant size is relatively small by general industrial standards, the R & D expenditure is small or absent, which is reflected by the small number of patents taken out by anodizing companies.

There is no cohesion in the industry, in terms of a central organisation representing a majority of the main companies. For the same reason, efforts to promote the use of anodizing have been mainly confined to the small number of companies regarded as the industry leaders. It seems appropriate to enquire what is the role of technology in anodizing plants.

The following appears to be its main roles:

(i) The primary role of technology is as an insurance. Some part of the organisation has to ensure that the processes are properly controlled and operated correctly.

(ii) A secondary role of technology is to ensure that the technology is optimised in terms of its cost effectiveness.

(iii). A further contribution of technologists is to advise management on developments that may affect the business, such as new processes, equipment and quality standards, the technical implications of environmental legislation and similar matters that will affect costs and the company's position vis-a-vis its competitors and the community.

(iv) Technology should be cost effective in terms of processing costs, but the technology used should be such that shop floor personnel can operate it consistently and with a minimum of rejects.

6.2 The literature on defects

In relation to para. iv above, it seems appropriate to consider the published literature on the origins and causes of process defects in anodizing and to examine their importance. Until the publication of "Anodic Coating Defects" [1] there had been no comprehensive attempt to classify defects. The literature seen falls into the following groups:

(a) Ad-hoc descriptions of defects and their avoidance.

(b) Investigations of particular process defects.

(c) Reports of investigations of defects arising from the material or in component manufacture.

(d) Papers using a "trouble-shooting" approach to defects.

(a) Ad-hoc descriptions of defects

The earlier literature on anodizing was mainly concerned with providing existing and potential processors with a better understanding of the process, with any reference to defects being almost an aside comment. One of the early contributions by Henley [2] provided a useful survey of the current state of the art in 1938. In this he gave some useful advice on avoiding defects caused by bad jigging, obtaining colour uniformity and the causes of defects in black dyeing. A subsequent publication by Hill[3] related to dyeing anodic coatings using I.C.I. dyestuffs, in which he briefly reviewed the origins of patchiness due to the presence of grease, and the cause of "specky" colouring. A later paper by Henley [4] added some recommendations on overcoming the problem of "spotting-out" from porous castings, and reviving anodic coatings which have been dried and printed with a silk screen ink resist prior to dyeing.

(b) The investigation of specific process defects

1. Bright Anodizing: With the rapid growth of bright anodizing in the 1950's, problems were encountered in producing uniformly bright films. A number of German plants used the Erftwerk™ brightening process. Possible defects which could be encountered using this process were discussed in various papers, such as those by Lattey and Ginsberg[5], and Lattey and Neunzig [6].

However, a number of plants in Germany and elsewhere in Europe used either Alupol II (R5) or Alupol IV (Phosbrite 159). Spahn [7] published a paper which briefly reviewed the phosphoric acid brightening baths and drew attention to the role of water in the formulation and provided a method for estimating its content accurately. Fischer and Koch [8] analysed the composition of the gases evolved from Alupol IV baths and showed the importance of the nitric acid content in producing optimum brightness. Ledford and Jumer [9] reported on the adverse effects of polishing compound contamination of these baths.

The use in automatic plants of Phosbrite 159 and its later derivatives, led to the need for further investigation of the process to overcome the defects encountered. Arrowsmith and his co-workers reported on the effect of copper [10] and subsequently on the avoidance of gassing defects [11], the control of transfer etch [12], and the causes of icing defects [13] on brightened surfaces.

The loss of brightness with increase in film thickness had already been established in the 1930's, but this failed to explain differences in brightness obtained by plants using the same material and brightening conditions. Unpublished work in the late 1950's, later summarized in Brace and Sheasby's book [14], showed contamination of the sulphuric acid electrolytes with iron above 25 p.p.m. caused a loss of brightness during anodizing. Further investigations on the effects of contaminating ions are reported in refs. [15,16].

Alcoa investigators [17] showed that the loss of brightness in anodizing was diminished by the use of higher electrolyte temperature or higher electrolyte concentrations. Scott [18] at British Aluminium Co's Research Laboratories established the improvement in brightness obtained by using two weak electrolytes operated at higher temperatures than normal.

Cooke [19] subsequently investigated further the loss of brightness on anodizing bright trim materials and suggested that this loss was due to "cone" formation on the metal-oxide interface beneath inter-metallic particles trapped in the anodic coating.

2. Architectural anodizing: By the early 1960's the basis of sound anodizing technology had been established, although it was to be further refined in the coming years. Much of the subsequent work reported was directed towards investigating specific defects or problems. For example, Polfreman and Budd [20] investigated the origins of galvanic pitting in dyeing. Gardam [21] reported on colour measurements on architectural anodizing and showed how colour shift can occur in the absence of instrumental measurements of colour. Brace and Alsop [22] reported on the effects of contamination by ferric ammonium oxalate on the behaviour of Aluminium Deep Black MLW. They also showed that the colour variation observed when dyeing work in an Alizarin Red dyestuff originated from calcium salts in the main's water used in dyebath make-up.

The main problem with integral colour processes in the 1970's was that of maintaining uniformity of shade. Kaiser Aluminium established that the rate of voltage rise affected the colour obtained [23] and developed devices [24,25] with a controlled rate of rise of voltage up to the required operating current density, followed by constant current density anodizing for the rest of the process time. They also found that to maintain the conductivity of the electrolyte, removal of the aluminium built-up in the electrolyte by use of a cation exchange column was essential if uniformity was to be maintained [26].

3. Defective quality: From the 1960's, and into the 1970's, attention was devoted to the development of equipment and methods for the testing of anodic coatings [27,28,29], but particularly to ascertaining the causes of defective sealing [30-34]. The removal or avoidance of sealing smut was the subject of several later investigations [35,36].

Some of these investigations were concerned with tests such as abrasion testing, reflectivity and corrosion resistance, but were mainly devoted to establishing test methods, rather than with the causes of rejection in these tests. However, Jackson and Thomas [37] investigated failures of bright trim materials to produce consistent brightness, with particular reference to the effect of current density and the variations in thickness produced when components made from two different trim alloys were anodized in the same anodizing tank.

4. Defects arising in the material or during omponent manufacture: In the 1950's anodizers were particularly concerned to make their customers aware of the problems that could arise from the material or in the process of manufacturing. An early contribution by Smith and Shaw discussed the effect of metal purity on brightness after anodizing [38], the need for anodizing quality material where appearance was critical. The authors also discussed the difficulties in producing a satisfactory finish on castings, the avoidance of corrosion from lubricant residues, problems with riveted and welded joints, and retaining dimensional tolerances. These topics were treated further in the Aluminium Development Association's Symposium on Anodizing [39,40].

The growth of the use of anodizing, especially in architecture, led to the aluminium semi-fabricators receiving complaints from anodizers of problems considered to be of material origin. Problems of non-uniformity of appearance have always been associated with anodizing and the aluminium industry has made great efforts to ensure that its products will respond satisfactorily to anodizing. During the 1970's, many aluminium semi-fabricators instituted investigations into the origins of defects which anodizers had complained were of material origin.

This led to work on the causes of fingerprint and general atmospheric corrosion, as well as patchiness produced on alloys containing magnesium as a result of mixed magnesium-aluminium oxide films being present [41]. There were also a number of investigations of the metallurgical factors affecting the appearance after anodizing, many of which were published. Until the publication of the "Anodic Coating Defects" book by Brace [1] in 1992, the paper by Short and Bryant [42] published in 1974, constituted the most comprehensive summary of information on anodic coating defects.

(c) The "trouble-shooting" approach to defect indentification

Defects tend to be regarded as an unavoidable part of production, but they are usually approached on a "look-and-see" basis. If the plant personnel see the defect and recognize it, the work is reprocessed in a manner which it is hoped will see removal of the defect. Intrinsic in this is the hope that it is a known defect, or that an intuitive guess will solve the problem. A little consideration of this situation will show that it is not always quite that simple. There are many stages in the production of an anodized finish, so this requires that the person responsible for making decisions must make a decision as to what stage of the process gave rise to the defect.

An example of this approach is the paper by Mahn [43], which identified sources of problems under the headings - metal, handling, cleaning and pretreatment, anodizing, and sealing. He concludes with observations on the importance of objective identification of the problem and the need to identify its source. This is discussed with particular reference to determining the origin of pitting when it occurs, illustrated by an example of its occurrence. More recently, a paper written by a member of the staff of a process chemical supplier, gives a more detailed breakdown of types of defects which can be found at the various stages of the anodizing process [44].

The trouble-shooting approach has its obvious limitations. It assumes that the person responsible has sufficient experience to identify the problem. If this proves to be inadequate, the trouble-shooting approach is of little help to someone limited in their knowledge of the possible origins of defects.

6.3 The economic significance of rejections due to defects

Personal experience appears to indicate that reliable data on rejections is lacking in most plants. Rejects can occur at the following stages:

i Inspection of incoming work for damage or corrosion.
ii. Inspection by the operator or foreman during processing.
iii. Removal of work from the jigs or workbars after processing.
iv. On inspection by Quality Assurance personnel.
v. After receipt of the work by the customer.

Generally speaking, there is no record kept of rejects at stages 2 and 3, mainly because personnel recognize that if work has been reported as rejected and management inspects such records, they may conclude that a particular operator or foreman is at fault. In these circumstances, unwillingness to be identified is understandable, but regrettably, it often leads to failure to identify the origin of a problem which will therefore reoccur later.

Instances could be quoted from personal experiences of plants where process specifications have been properly observed but, nevertheless, rejects have occurred. Because such defects are unrecorded, the answer to the problem remains with line personnel and is lost by management.

With the increased used of formal quality systems, such as BS 5750, there is a tendency for Q. A. personnel to feel that they have to show that they are alert, so that some rejects are ones that might otherwise have not been made. In the sense that this improves quality and provides records of actual causes of rejects it is to be welcomed.

Rejects by customers are always a cause for concern by an anodizing plant because they cause friction between the parties concerned. In a number of cases the cause may be attributed by the anodizer to the material, or as having arisen in manufacture. Even if the anodizer believes this to be the case he has to convince either the customer or plant management that it is a material or manufacturing defect. Both parties may lack the expertise to draw the correct conclusions.

However, both parties sustain a loss in terms of the costs of such rejects. These costs are not simply the reprocessing costs, but include the following:

i. The cost of stripping the anodic coating and possibly the cost of repolishing or other preparatory operation.
ii. The profit lost on work that could have been processed during the period the reject work is being reprocessed.
iii. The time costs of management and staff involved in investigating the causes of defective work.
iv. The cost of delays to the customer's production line due to hold-up due to inability to complete operations on the whole of the batch.

It is therefore considered that rejections due to process defects represent a major area where costs are incurred that could be avoided, so that there is a need to deal with these. It could be argued that with a vast amount of published literature available on anodizing and much production experience, there should be no problem. However, this does not appear to be so, as far as personal experience in investigating defects is concerned.

6.4 The information gap

There is an information gap, which has always been present, that appears to have increased over the past decade. In the first place it arises simply from the increase of available knowledge of the process, as well as from the wider range of products and processes being operated. More importantly, the existence of published information does not ensure its diffusion amongst those who are concerned with the actual production of anodized finishes. The previous chapters have demonstrated the multiplicity of sources and mechanisms by which the diffusion of knowledge concerning the production of anodic finishes has taken place. Pressures on the production manager and technologists are such that they have little time for reading technical literature. Verbal communication of new developments seems to be the main source of current awareness.

Most trade anodizing plants operate on the basis of knowledge acquired by key personnel, often the owners and/or managers of the plant. This knowledge is rarely committed to paper, primarily due to the pressures of meeting the needs of production, and to a degree because of a fear that such knowledge might reach competitors if recorded in an accessible form. Within larger companies, moves of personnel to other duties, retirement of experienced personnel and redundancy, often lead to a loss of information.

The information lost tends to divide into two categories:

i. Knowledge of the handling, jigging and pretreatment of work to meet specialized needs within the plant or required by customers.
ii. Loss of experience of the causes of defective work leading to its rejection.

Loss of knowledge specific to the plant and particular jobs can be avoided if plant management realises it and considers that this is important. It is not difficult to photograph specific jigs or to record specific processing details. On the other hand, loss of knowledge of the causes of defects is a more complex subject, because such knowledge is not static but changing, and involves knowledge that may not be intrinsic to plant operation. To a greater degree than with other processes, the final finish depends upon material quality as well as correct processing. Some of the expertize lost relates to the ability to distinguish between process and material defects, plus much accumulated experience in identifying defects and in implementing corrective measures.

The main conclusion from this analysis is that the informal knowledge which exists in an establishment is always in danger of being lost by movement and changes of personnel, unless incorporated into a formal database. This has important implications for the retention of existing and future expertize. It is appropriate to consider now the contribution that developments in computer-based information technology has to offer.

6.5 The potential contribution of computer-based information technology

Central to the problem is the fact that, in many plants, information on process defects is not kept with any formal system but resides in informal and often unconnected sources. This information gap is accentuated in metal finishing generally, by the increased number and sophistication of processes being operated. It should be evident that computers can provide a means of storing and readily accessing information, including the process expertise residing in any given plant or establishment. There is a psychological barrier to the use of information technology in a number of plants because production managers are not at ease with computers. This is reflected, judged by personal experience, by the limited use of computer databases and information retrieval in such plants. Computers are used primarily for the financial transactions of the company.

The following are examples of the types of computer software which are relevant to the technical activities of an anodizing plant.

(a) Spreadsheets:

One of the major advantages of computers is their ability to store large amounts of information in a form which can be retrieved rapidly and readily. One type of program applicable to data from anodizing plants is the spreadsheet. Spreadsheets are a means of entering large amounts of numerical data and carrying out the basic arithmetical operations of addition, subtraction, multiplication, division, as well as statistical calculations. In this way data such as chemical analysis results, thickness and sealing test values, can be recorded, trends observed, and the results plotted as graphs, bar charts etc. Using this data and applying statistical techniques, trend lines can be plotted and statistical control limits established.

(b) Databases:

Databases can be of various types and their usefulness depends on the structure of the database, so they need choosing with care. They depend mainly upon organizing information into a series of fields, the data contained therein being retrievable by suitable search commands contained in the software. Mathematical operations can also be carried out on data contained in these fields. Some of the commonly used databases, such as Lotus 123™ and Reflex™, are structured such that they do not appear to be user friendly for someone with limited computer literacy. Many databases provide facilities for importing data from spreadsheets for further treatment.

A bibliographic database may offer greater simplicity and flexibility for storage and retrieval of technical information, since it can contain more text and information can be retrieved by the use of single or multiple key words or a set of letters and numbers (an alphanumeric character string), which is very useful for storing abstracts of technical papers, internal process sheets, customers process specifications etc.

With a graphics database, text may be combined with graphics. This is particularly useful when storing information displaying photographic images such as defects. Text describing these can be displayed along with other relevant information. They can also record special jigging and racking, etc. that may need to be illustrated.

(c) Expert Systems:

Essentially, expert systems represent an attempt, using the advantages of a computer, to provide the user with expertise in the particular topic which is the subject of the expert system. In its simplest terms, an expert systems "shell" (an outline program) enables the expert to embody his expertise within a set of "rules". When completed the expert system interrogates the user and, from the replies given, arrives at a conclusion as to the problem on which it is consulted. However, this may be inadequate as far as the user is concerned. For example, an expert system may conclude that a defect is pitting due to dyebath contamination, but it will not necessarily advise the user on how to eliminate pitting in the dyebath, unless designed to do so.

An expert system usually consists of an expert system "shell" which interrogates the users as described above and an information database that provides the user with all the expertize currently available on the various topics covered by the expert system. This information base (often referred to as a "knowledge-base" in the U.S.A.) should contain a high level of information and expertize on the subject area in question, preferably with bibliographic references and, where appropriate, supplemented by a graphic, displaying a diagram or picture etc.

If the level of computer literacy of the potential user of an expert system has not extended beyond simple word processing programs, this can limit the value of an expert system, unless the technologist is prepared to acquire a degree of computer literacy, or his company invest in training to this end.

A second limitation is that basic computer law "garbage in - garbage out" applies, so that any expert system must be based on real expertise. This is not to deny the value of a program which guides a user through a diagnostic process. This is usually implicit in the commencement of any expert system consultation. If the expert system depends upon a significant input from the user, it needs to be constructed so that this information is cross-checked during the consultation procedure.

A further limitation to expert systems is that the writer of an expert system cannot know the plant, equipment and operating conditions of every plant in which the system is used. He can only guide the user in the direction of probable solutions. In fault finding or defect analysis, the expert may arrive at a partly intuitive, partly deductive conclusion, which is referred to as "fuzzy logic". Therefore, the criterion for the compiler of an expert system is "Will the expert system lead to a correct diagnosis of the problem ?" An expert system should be potentially capable of identifying specific defects and summarizing existing knowledge of process and material defects in a readily accessible form. If properly constructed, further data can be added by any user as new knowledge becomes available.

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Chapter 7: The Development of an Expert System for Process Defects

Based on a number of years experience of investigating anodizing defects, there seemed to be merit in trying to develop a methodology, by means of which it would be possible to arrive at a correct identification of a defect. The following text describes the steps in the evolution of an expert system which has been developed to this end.

7.1 An algorithm for defect identification

When this work was started most of the expert systems shells available for use on a micro-computer were relatively expensive (£500-2000), to which would have to be added (in some instances) the cost of a reference base program. A price of over £500 would probably be a deterrent to the use of an expert system in the average anodizing plant. However, it was assumed that software costs should fall in succeeding years, which could increase the likelihood of expert systems being of interest, at least to the larger plants. Disregarding any commercial potential or limitation, there remained an attractive intellectual challenge to develop such a system.

Against these considerations, it seemed essential to first make a logical analysis of the problem of how to identify defects. The result of this initial study [1] was an algorithm (see Appendix A) which was not computer based, but provided the reader with a step-by-step approach to identify the defect. The rational approach seemed to be that of helping the user to identify at what process stage the defect occurred, as well as taking into account defects originating in the material.

The basic structure of the approach used was to first guide the user through an analysis of the possible origins of the defect, as follows:

The user is asked first to state if the defect is:

i. Beneath the anodic coating, *or*
ii. Within the anodic coating, *or*
iii. In sealing or on the surface.

From the answers to these questions defects can be classified as follows:

(a) Defects beneath the anodic coating

Defects beneath the anodic coating arise either from the material or from processes carried out prior to anodizing, and can be further categorized as follows:

Defects associated with Material Origin:	*Defects associated with Processing Origin:*
Casting	Mechanical pretreatment
Corrosion	Chemical polishing
Extrusion	Cleaning
Fabrication	Etching
Sheet	

(b) Defects within the anodic coating

Defects in the anodic coating arise from the following:

i. Defects arising in anodizing.

ii. Defects arising in dyeing and colouring.

(c). Other process defects:

These are defects classified as:

i. Defects arising in sealing.

ii. Defects found on the surface.

After completing this algorithm it became evident that even if it provided a correct analysis of the nature of the defect, other information was needed for the non-expert, particularly advice on how to overcome the problem. Such information could be provided as a "library", such as some form of database.

7.2 Development of a modified bibliographic database on defects

Following publication of the paper describing the algorithm [1], it was decided to complement the algorithm with the compilation of a database which would contain a series of index cards describing individual defects and offering advice on a remedy. In compiling the database, use was made of a commercial program [2] "Squarenote"™, which is a modified bibliographic database program which allows for an extended abstract to be added to the usual bibliographic reference retrieval facilities. This had been used to compile previously a summary of all the papers relating to aluminium finishing, published in the Transactions of the Institute of Metal Finishing (1960–1985) [3].

```
"DEFECTS" has 86 notes. 10 selected. UNS      ^U begins underline       Fast

   Defects\Anodic coating\Electrolytes\Film thickness wrong\Sulphuric acid\
   ------------------------------------------------------------------------
   Category: Anodic coating defects
   Classification: Incorrect film thickness
   Alternative classification: Too thin/too thick coating
   -'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'--'-

   As is evident from the classification, this relates to films which cause
   the work to be rejected for incorrect film thickness.

   The causes of thin films are:
   1. Poor jig/rack contacts from lack of springiness in contacts.
   2. Failure to strip jigs/racks after each anodizing cycle, particularly
   after hard anodizing.
   3. Work removed before the specified process time.
   4. Inadequate current density during anodizing. If the area of the work
   is not known with reasonable accuracy, this may be due to a low voltage
   producing a low current density for the alloy being anodized.
                                                 ==Use PGDN to see more==
Edit note
Press <F1> key to view HELP screen

                                                       <Esc> to end edit
```

Fig. 1: Typical screen display of "Squarenote" database

This program displays the title of the paper, the authors, the journal reference and keywords, at the top of the screen in a card index format (Fig. 1). This is separated from the main body of the text by a line of dashes (a "perf"). All information above the "perf" can be retrieved without a search through the main text, thus providing quite rapid access. It is also possible to search the main text for a string of up to 20 characters in length. In addition, it is possible to retrieve multiple keywords using "and/or" combinations .

As can be seen in Fig. 1, the index cards covering defects were constructed so that two alternative descriptions of the defect were entered above the "perf", plus keywords relating to the features of the defect, the material and processes with which it was associated, so that these could be retrieved rapidly. The text below the perf contains a description of the defect, and a section headed "Remedy" suggests measures needed to correct the defect. For convenience of access, the cards were grouped into the various categories listed above. The database, containing over 60 defects, was demonstrated to the 1991 Conference of the Institute of Metal Finishing [4] (see Appendix B).

Subsequently, the text prepared using "Squarenote"™ was converted to ASCII format and transferred to a word processor. This was then expanded to describe over 100 defects which, with photographs (where available), was later published [5] as a book. This book is intended to be a useful reference source to someone familiar with anodizing. Although it attempts to help the inexperienced to identify defects systematically, it contains only outline guidance on defect identification. Accordingly, it seemed desirable to develop a comprehensive expert system.

7.3 Criteria governing the choice of an expert system

(a) An initial evaluation of expert system "shells"

In compiling this algorithm and the bibliographic database, the intention was to use it as the foundation for a computer based expert system. Initially some work was carried out in trying to write a program in Basic, but it soon became evident that this would be very time consuming. After consulting computer journals and obtaining literature on programs available, several low cost "Shareware" expert system "shells" were obtained and examined [6,7,8]. These were written in various languages (Basic, Pascal, Turbo Prolog) with the following underlying structure:

Question to user
Answer - Yes/No
If "Yes" ... then:
If "No" ... then:

Based on these answers the user formulates "rules" which allow conclusions to be made on the premise that:

"If .... and .... and ..., then ...."

However, some so-called expert system "shell" programs available are little more than a program that interrogates the user and diagnoses simple faults. It is important that expert system shells should be able to analyse multi-factorial interactions. They should also take into account that there may be an element of uncertainty in the answers given by the user during a consultation.

This had been recognised in two of the programs examined, where users have the ability to apply a probability weight to their answer, ranging from 0.90 for a high degree of certainty, down to 0.50 for a uncertain answer, with values diminishing down to 0.10 where the answer is one that it is almost certainly incorrect.

Even so, this brings a further problem, in that it requires a subjective judgement on the part of the user, effectively making him part of the expertize. A further difficulty is that in areas such as metal finishing processes, the processing may have destroyed or changed the defect, thereby being likely to give rise to erroneous answers.

(b) Objectives in the selection of the expert system shell

In the work subsequently carried out, the following were the objectives that it was hoped could be met in the construction of an expert system for the identification of anodic coating process defects:

i. The cost of software should preferably not exceed £500.
ii. The final system should not require more than a limited degree of computer literacy.
iii. The information base should be capable of a graphics display.
iv. It should be as comprehensive as possible.

The following remarks only concern considerations of the design of an expert system for the identification of anodic coating process defects and related material defects. They may be relevant to other problems, but each situation has to be analysed before assessing which type of expert system may be required. The fundamental factor was considered to be the uncertainty which prevails about the actual conditions in a plant when defective work is produced.

(c) The basics of an expert system for anodic coating process defects

Consideration of past experience in identifying anodic coating defects suggested the following as a basis of the expert system.

PROBLEM ANALYSIS	- Identify the process stage at which defect occurs - Define features of the defect - Identify defect
ELABORATE IDENTIFICATION	- Provide a detailed description - Provide a graphics display of the defect where possible
PROVIDE EXPERTIZE	*Compile Information Base containing* - Advice on corrective measures or future avoidance - Bibliography relating to defect

Outline of an Expert System for the Identification of Anodic Coating Defects

(d) Limitations to rule-based systems

Much thought was given to the problem of selecting an expert system shell. Several of the low cost programs designated as "expert system shells" were considered to be essentially diagnostic aids rather than being designed to meets the needs of a high level of expertize, which might also involve an intuitive approach. If the objective of low cost was ignored, there remained a fundamental problem of assessing whether any of these programs would be suitable for the task.

It was thought that when using a rule-based expert system shell the obvious steps are to construct the analysis so that the user is asked to verify the process conditions employed and to answer individual questions on the features of the defect[9]. This approach has been used in developing an expert system for analysing problems in the electro-plating of nickel[10]. Such a procedure might prove to be self-defeating, since the user will tend to confirm that conditions were correct unless there is positive evidence to the contrary. The fact that a defect has occurred shows that the process itself, or its execution, is deficient.

Further, the person investigating the problem is usually uncertain as to what happened, since those directly concerned with production at the time may not have made any observations. Additionally, there is the human tendency to withhold information, or to give the "right" answers, when there is a problem being investigated by management. A further problem with the anodizing process is that the surface of the material is being subject to a continuing change of environment at each process stage. These changes may destroy features that would be most helpful in identifying the defect. Another factor that cannot be ignored is the possibility of more than one type of defect being present on a component.

(e) The potential advantages of neural networks

Over recent years much attention has been given to the development of artificial intelligence. It is appreciated that human intelligence is a highly complex phenomenon which cannot readily be represented in terms of a computer model. However, computers do have a capacity for storing and quickly retrieving stored information, as well as identifying patterns. Neural networks represent an attempt to use the computer as a means of recognizing associations of digital or analog data stored in memory and comparing them with new data supplied by the user of a neural network program. The process of storing this data in a form where its various associations can be recognised and compared with new data fed in, is known as creating a neural network.

Such neural network programs are claimed to imitate the learning process and associations formed by the network of cells forming the brain. At best, neural networks are only an early step in developing artificial intelligence. However, neural networks are capable of handling problems involving "fuzzy logic" and recognizing patterns of association.

After a preliminary evaluation of several expert system shells, a review was seen in each of two computer journals, of a recently developed neural networks program [11] ("NeuroShell"™). This program was obtained and evaluated. It provides for the input of data either in binary or in analogue format. The latter is appropriate for the input of numeric data displayed in graphical format and for pattern recognition.

In binary mode, information relating to a particular problem, i.e. the identifying characteristics of a defect, or a group of defects, are entered and displayed in the upper half of the screen. Each line should only contain one identifying characteristic. Having entered one or more such identifying characteristics, the classifying characteristic is then entered and displayed in the lower half of the screen (below the dotted line appearing on the screen) and must not exceed one line.

7.4 Development of an expert system based on neural networks

After some preliminary trials with the sample files provided, it was considered that the program appeared to be a promising approach to defect identification. However, this called for consideration of how the relevant information should be organised. The handbook supplied recommended the use of small files for speed of use. Since the display is confined to a 24-line display this factor reinforced the need for small files, since if more than 20 defect characteristics are entered they fill the screen, even before the classifications are entered.

(a) Preliminary work classifying mechanical pretreatment defects

It seemed advisable initially to confine attention to a relatively simple group of defects, i.e. those relating to defects arising in mechanical pretreatment applied to components prior to anodizing. Accordingly, a file MECHDFTS was started using the following procedure:

When the program was loaded the message appears "State Name of Problem". The file name "MECHDFTS" was entered. The Main Menu Options then appear on the screen and the option "Define the Characteristics" is selected by placing the cursor on that line and pressing return. This presents a blank screen except for a line of dashes one line below the cursor. Facilities to "Insert" or delete a line on the screen are provided by the program, along with a very limited line editor.

The following defining characteristics were entered:

```
The parts have been abrasive blasted before anodizing
Work has a patchy uneven appearance beneath the anodic coating
--------------------------------------------------------------
```

The following classifying characteristic was then entered below the broken line:

```
-----------------------------------
These are "abrasive blasting marks"
```

This routine was continued for the 8 defects which have been allocated to this file. These characteristics are saved when the "Esc" is pressed and the main menu appears on the screen. However, it is important to maintain a record of the defining and classifying characteristics of each defect, since these have to be then entered as separate cases before they can be "learnt" by the program. There is provision for the user to check that there are no duplicate cases entered before "learning" commences, which is invoked from the Main Menu. The final result was that shown below:

```
==================== Define Characteristics ====================

The parts have been abrasive blasted before anodizing
The components have been barrel polished
The work has been linished before either polishing or processing
The work has been mechanically polished
Some surfaces have been wire brushed
Work has a patchy, uneven appearance when the anodic coating is removed
There is a fine, speckled, slightly duller background
Dark uni-directional lines are revealed after processing
There are grooves in the surface having a "comet's tails" appearance
The surface has a "wavy" appearance often with retained polishing compound
The surface has duller white patches after cleaning and anodizing
There are tear lines in the brushing direction terminating in craters
After processing the surface shows heavy local pitting
--------------------------------------------------------------
These are "abrasive blasting marks" - see Card M1 -
These background marks are "barrel polishing defects" - see Card M2 -
These are "linishing marks" or lines - see Card M3 -
These are "polishing drag marks" - see Card M4 -
These patches are "polishing mop burns" - see Card M5 -
This is due to "polishing mop chatter" - see Card M6 -
These are "wire brush drag marks" - see Card M7 -
This is due to "wire brush pick-up" of a foriegn metal - see Card M8 -

-scroll   Enter-edit   Ins-insert before   Del-delete   F1-show Fx
```

When this was complete, checks were carried out on the file by entering cases other that the test cases entered to verify the correctness of the defect identification. Examples of such test cases have been retained on the disc files accompanying this thesis.

Having established that the "NeuroShell"™ program appeared to be potentially capable of adaptation to the problem of identifying process defects in anodizing, it seemed necessary to consider how best to organize the files required.

b) The organization of the files identifying the defects

In a previous approach to the problem [1], the author used the following approach to the problem of the primary classification of process defects:

Does the defect appear to be:

(i) Beneath the anodic coating ?
(ii) Within the anodic coating ?
(iii) Associated with sealing or surface deposits ?
(iv) Associated with the material ?

This basis for the identification of defects has been retained when using the "NeuroShell"™ program. The user is first advised to consult the file IDENTDFT which is intended to identify the process stage at which the defect has originated. In compiling the IDENTDFT file a total of 57 cases were entered. These utilised combinations of 17 identifying characteristics and 12 classifying characteristics (corresponding to the 12 files listed in the next paragraph). This file was the last to be completed in developing this expert system.

The IDENTDFT file refers to the file which should enable the user to identify the defect by further consulting one of the following files:

Beneath the anodic coating	*Within the anodic coating*	*Sealing or surface*	*Material related*
MECHDFTS	ANODFTS	SEALDFTS	CASTDFTS
BRITEDFT	COLORDFT		CORRDFTS
CLEANDFT			EXTRDFTS
ETCHDFTS			FABRDFTS
			SHEETDFT

The nature of the type of defects classified in each file is such that it is intended to be recognisable to the user from the filename.

As supplied the "NeuroShell" program does not enable preliminary information to be displayed, the user is advised to first load the hypertext database (see p. 105) and open the file "AN-INTRO". This informs the user that they may commence either by loading the "NeuroShell" program which relates to the process stage at which the defect is believed to have occurred, or to make this decision using the IDENTDFT file. In this way the needs of both experienced and novice users can be satisfied. The "run-time" version of the program enables preliminary information to be displayed.

(c) Examples of the primary classifications of defects

To classify the main type of defect, using the IDENTDFT file, the user places the cursor on the line of the screen that gives a description relevant to the defect and presses "Return". This highlights the lines selected. An example of a two line entry made to identify a defect is now shown:

The defect is within the anodic coating
The appearance of the work after anodizing is unsatisfactory

When this step is completed and the user presses the F3 function key, a line in the display giving the defect classification is highlighted, together with a number less than 1.0, and will normally lie between 0.1 and 0.9. If the value displayed is greater than 0.5, this indicates that the expert system assesses this as the probability of the defect being displayed is correct. However, if the value is less than 0.50, this indicates that the data entered is not sufficient for the user to correctly identify the defect in question.

In the case of the example above, pressing the F3 key produces the following line highlighted in the lower half of the screen:

This is an anodic coating defect - see the ANODFTS file 0.91.

It will be seen that the program attaches a value of 0.91 to the probability of the answer being correct.

The file is also capable of making a correct identification if there is more than one type of defect present. The user may examine a defective component and highlight the following defining characteristics:

```
The defect is within the anodic coating
Chemically polished work has an unsatisfactory appearance
The appearance of the work after anodizing is unsatisfactory
------------------------------------------------------------
```

On pressing the classify key the following highlighted display appears:

```
------------------------------------------------------------
This is an anodic coating defect - see the ANODFTS file  0.80
This is a chemical polishing defect - see BRITEDFT file  0.91
```

In this way the program advises the user of the file or files relevant to the stage or processing at which the defect probably occurred.

(d) Examples of anodic process defect classified by the ANODFTS file.

Having been advised that there is probably an anodic coating defect, the unsatisfactory appearance may be, for example, dulling of the appearance of the anodic coating on anodizing. This can be due to different causes:

1. Dulling of the coating from use of a high current density.
2. Metallurgical factors such as precipitation of inter-metallics.
3. Contamination of the electrolyte with heavy metals.

We can now examine how the program handles such defects. If the user highlights the following identifying characteristics the program classifies the defect as follows:

```
The work has been sulphuric acid anodized
The coating becomes duller than normal after anodizing
The dulling increases with thickness and current density
--------------------------------------------------------
This is classified as "Dull appearance"  0.90.
```

Alternatively, if the user enters the following identifying characteristics, the classification will be as shown:

```
The work has been sulphuric acid anodized
The coating becomes duller than normal after anodizing
The electrolyte contains more than 50 p.p.m. heavy metals
---------------------------------------------------------
This is classified as "Dulling - contamination"  0.90.
```

One of the advantages of the neural network is that it will provide an assessment of a problem even if incomplete data is entered. If too little data, or partially incorrect data is entered by the user, the probability factor indicated for the correctness of the answer will diminish, at worst to below the 0.50 significance level. This can be illustrated by the following example where incomplete defining characteristics have been entered:

```
The work has been sulphuric acid anodized
The coating becomes duller than normal after anodizing
------------------------------------------------------
This is classified as "Dull appearance"  0.51
```

In other words, the program recognizes the defect but with incomplete information it only gives an 0.51 probability of the defect being "dull appearance". However, the following line is also displayed:

```
------------------------------------------------------
This is classified as "Dulling - contamination"  0.33
```

All the other classifications show probabilities around 0.10. This shows that whilst it is likely that the defect is "dull appearance" there is a also some probability that it could also be due to contamination.

The file also provide classifications if two defects are present. Suppose the user enters the following identifying characteristics:

```
The work has been sulphuric acid anodized
When viewed at a glancing angle to light, fine cracks appear
The electrolyte contains more than 50 p.p.m. of heavy metals
------------------------------------------------------------
This is classified as a "Crazed/cracked anodic coating" 0.91
This is classified as "Dulling - contamination"  0.57
```

The above probabilities show that, based on the cases entered, the probable defects have been correctly identified.

It will be noted that on the expert system disc submitted, there is additional information following the probability value, which takes the form (for example) "See Card A9". This refers to the card in the hypertext database which is displayed on p. 106. This provides the user with a more detailed description of the defect, advice under a heading "Remedy", as well as a hyperlink to any literature references relating to the defect. Within the description hyperlinks are provided to enable rapid cross-referencing to other defects having similar characteristics. For example, pitting defects can occur at most process stages, and Card A8 cross refers to other instances of the occurrence of pitting.

(e) Details of the defect files compiled using neural networks

When a primary identification is made using the IDENTDFT file the files listed below are those to which the user is directed.

File Name	No. of Defining Characteristics	No. of Defects Classified	No. of Cases Entered
ANODFTS	22	15	33
BRITEDFT	15	7	9
CASTDFTS	14	8	10
CLEANDFT	16	9	9
COLORDFT	13	9	10
CORRDFTS	11	10	10
ETCHDFTS	17	10	10
EXTRDFTS	22	16	32
FABRDFTS	12	8	10
MECHDFTS	13	8	11
SEALDFTS	14	10	14
SHEETDFT	10	7	9
Total	179	117	166

7.5 Developing the Information Database

With the probability that the "NeuroShell" program has identified the defect correctly, the information database has to fulfil a vital role in several respects:

1. It should contain more detailed information on the defect, so that the conclusion arrived at from the "NeuroShell program can be confirmed.

2. It should give advice on how to correct the defect and/or avoid its recurrence in the future.

3. Also, it should preferably provide literature references to the defect.

4. Where possible a graphic illustrating the defect should be available.

(a) Comparison of the retrieval capabilities of the "SquareNote" and "Information Please" programs

Reference has been made on p. 91 to the early work carried out using the "SquareNote"™ bibliographic database program [2]. The format of "Squarenote" is such that, instead of the lines above the "perf" being author and literature references, these lines could provide a primary and secondary description of a defect. The use of key words in searching for information was considered to be a further advantage. The text below the "perf" can be used to describe the defect. A limitation to its use as part of an expert system is that the program does not provide for importation of graphics which could be added to illustrate the defect where appropriate.

However, subsequently a program ("Information Please"™) was located with a similar format, except that it does not have the "perf" feature, but it will also display graphics stored in .PCX files [12]. However, it should be noted that the graphic does not appear alongside the relevant text, but requires a function key to be pressed for it to appear on the screen. The format of "Information Please". The following is a brief comparison of the two programs:

Feature	*SquareNote*	*Information Please*
Searches for single keyword	Yes	Yes
Keyword list	Yes	Yes
Multiple AND .... AND search	Up to 9 words	Up to 10 words
Multiple OR ...... OR search	Up to 9 words	Up to 10 words
In-text search	Up to 20 characters	Up to 10 words
Search and replace	Yes	Yes
No. of records displayed	5	1
Select multiple records	Yes	No
Graphics display	No	Yes

It can be seen that "Information Please" can provide similar search and retrieval facilities to "SquareNote" plus the ability to display graphics, although the text display format of the latter is preferred.

Another problem in compiling the information database is that certain characteristics, such as patchiness or pitting can be produced in various processes. For example, pitting can occur in anodizing, cleaning, etching, rinsing, dyeing and sealing. It was felt important to provide a cross-referencing facility. In the case of "Information Please" this could be achieved by retrieving all the cards relating to "pitting", but it has the disadvantage that all the cards must be contained in one file. Retrieval of a group of cards relating to defects at the various process stages would only be possible by use of a keyword, such as "etching" etc. The program had a simple hypertext facility.

(b) Consideration of the possible advantages of "hypertext" for information databases

Hypertext programs enable information to be stored in a form in which it can be rapidly retrieved and linked to other parts of an information database by means of specially designated symbols, known as hypertext links. It is thus possible to describe a process defect using text, provide a bibliographic database relating to the defect, then add to it a graphic showing the defect. This additional information could be readily accessed by the hypertext links. These can also provide rapid links to other related information within the same file or in a separate file. In principle, all the data comprising the information base could be stored in a single file, but this tends to slow up speed of retrieval when using the hyperlink on 286 or 386 computers. Usually, the information base is split into a series of smaller files for speed of access.

Such programs are often either card based or text based. The best known example of the card based system is the Hypercard™ program [13], developed for use with the Macintosh computer. Using this program, the information appears on the screen in a card index form, requiring a separate card for each topic. Other hypertext programs are text based, allowing large amounts of text to be incorporated within a file.

Hypertext links can be constructed within the file and across files. By this means rapid cross-referencing can be made between topics, thus avoiding the necessity of exiting to other programs or having to consult reference books to obtain additional information,

Several possible programs were assessed [14,15,16] in Shareware™ or Demo format, from which it was concluded that "Black Magic"[16] was the program best suited to constructing the hypertext data base because:

1. It has the option of a card-based or text-based format.
2. It provides "windows" in which bibliographic information or graphics can be displayed.
3. The cost of the program was only U.S. $99.00.

(c) The structure of the hypertext information database

For ease of retrieval the files in the hypertext database have the same filenames as those used in the neural networks program. One additional file has been provided - AN-INTRO - to provide on-line information on the structure and use of the Black Magic hypertext database and the NeuroShell neural networks program. The run-time version of the latter program provides space for introductory notes.

As an example of a hypercard database file, on loading the ANODFTS hypercard file the following display is seen on the screen:

ANODIZING DEFECTS - LIST OF CARDS

Card no.	Description	Card no.	Description
A1	Blistering		
A2	"Burning"	A9	Galvanic pitting
A3	Chloride pitting	A10	Inter-metallic dissolution
A4	Clear chromic film	A11	Irridescence
A5	Crazed anodic film	A12	Patchiness - poor rinsing
A6	Dull appearance	A13	Powdery anodic coating
A7	Dulling - contamination	A14	Soft anodic coating
A8	Excess aluminium content	A15	Wrong film thickness

Files for Other Main Classes of Defect

Arising in Processing	Arising from the Material
Mechanical pretreatment defects	Casting defects
Brightening defects	Corrosion defects
Cleaning defects	Extrusion defects
Dyeing and colouring defects	Fabrication defects
Etching defects	Sheet defects
Sealing & Surface defects	

Screen display on opening ANODFTS hypercard file

The card numbers cross refer to the numbers given in the "Neuroshell" files. The word (or words) giving the description provide a hyperlink to the relevant card, and are the only way that they can be accessed. The lower part of the display lists the other files that are in the database, apart from the AN-INTRO file, which is introductory and explains the nature the hypercard files. Although these have hypertext links, they will usually be accessed by normal file loading procedures. The links have been provided primarily so that the user can see what cards are included in any file of interest.

7.5 Organisation and layout of database hypertext reference cards

Having loaded the ANODFTS file the user will wish to consult one of the cards, for example Card A9. If the mouse arrow is placed within the brackets surrounding the words <Galvanic pitting> the display shown below is seen on the screen,

---

GALVANIC PITTING (AFTER ANODIZING)

Alternative description: Pitted coating

For a variety of reasons, work may be held in a rinse tank after anodizing and before dyeing and sealing. If the tank is made of mild steel there is a potential difference between the mild steel and the aluminium. The dilute sulphuric acid present in the rinse water after anodizing is a good conductor of current. If the workbar carrying the anodized work is in direct contact with the wet rim of the rinse tank, pitting of the anodic coating can occur. This defect may prove difficult to identify as to origin, since it resembles rinse water corrosion after etching, especially since the pits penetrate through to the metal. It is necessary to check whether it is present after rinsing prior to anodizing Card E7, rinsing after anodizing, or rinsing after dyeing Card C3 or after sealing Card S5.

Remedy:

The essential remedy is to make sure that the workbars and jigs are electrically insulated from the tank. This is normally achieved by putting insulating plastic strips on the top or the rinse tanks in the area where the work bars would otherwise rest on the tank rim.

A8   Next card   Previous card   File list   Bibliography

Screen display of Card A9 "Galvanic Pitting (after anodizing)"

It will be noted that there are green hyperlink brackets providing cross-references to Cards E7, C3 and S5. If the link to Card E7 is activated, the following display immediately appears on the screen:

RINSE WATER CORROSION

Alternative description: Pitting

When work is left in the rinse tank after etching or desmutting, a pitting type of corrosion can occur (View Graphic). It usually occurs in heavily contaminated rinses, especially if the flow rate of rinse water is low. Its occurence is also often promoted by a galvanic current which can be produced when the work rail is in direct contact with the rim of the rinse tank, since there is a potential difference between the tank and the aluminium. It may also occur if there are stray currents in the plant. Rinse water corrosion can also occur after anodizing Card A7.

Remedy:

Workbars should always be insulated from the rinse tanks to avoid galvanic effects. It is good practice to earth all process tanks in the anodizing line. The presence of at least 0.1% nitric acid in the post desmut rinse will overcome the problem, which mainly occurs with high sulphate/sulphuric desmuts.

E7 Next card Previous card File list Bibliography

Screen display for Card E7 when hyperlink activated.

If the mouse arrow is placed over the word "Bibliography" and is pressed, the following display appears as a "window":

Rinse water corrosion

This defect has been described by E P Short and A J Bryant (Trans Inst Met Finishing 1975,53,169-77) and in Brace "Defects" (p. 53), who states that, according to E J Short (letter), the presence of 0.1% (vol.) HNO3 in the post desmut rinse will prevent this defect, which is not normally present when HNO3 is used as a desmut. The increasing use of proprietary acid sulphate desmut solutions makes this defect more likely to be encountered. Brace also notes that it can also occur after alkaline etching if galvanic currents occur between the work and the steel tank, e.g. by direct contact between workbar and the tank.

It will be seen that there are hypertext links such that the user can make a hyperlink jump to the next card or to the previous cards, as well as to the file index card.

If there is a need to return from the database to the neural networks program, this can be done by using the "Exit" command or pressing the <ALT> and <F10> keys. Since "Neuroshell" is memory resident, the screen display then becomes the Advanced Options Menu of that program which was displayed before the "Black Magic" program was loaded. If the <Esc> key is pressed twice, the Main Menu Options screen replaces the Advanced Options Menu.

7.6 Summary of the hypercard database

The following summarizes the information contained within the hypercard database:

File Name	*No. of Cards*	*No. of Refs.*	*No. of cross-ref. links*
ANODFTS	15	37	11
BRITEDFT	7	13	5
CASTDFTS	8	17	0
CLEANDFT	9	17	4
COLORDFT	9	20	8
CORRDFTS	10	14	5
ETCHDFTS	10	15	1
EXTRDFTS	16	40	2
FABRDFTS	8	10	2
MECHDFTS	8	9	2
SEALDFTS	10	20	5
SHEETDFT	7	9	3
Totals	117	221	48

7.7 Graphics Display

It was considered desirable for the user of the expert system to be able to view a graphic display of the defect when such a display would assist in a positive identification. To do this, after making the identification from the appropriate "NeuroShell" file the user would press "Esc" to return to the initial screen display, and then transfer to the Advanced Options Menu and load the "Black Magic" database program if a further description or details were required.

When this database was being compiled it was thought that the screen image grab facility would enable a hyperlink to be made which, when activated, would display the appropriate graphic image. However, it was found that the size of image which could be displayed was limited and the hyperlink facility could not display text with the graphic.

Accordingly, this approach was discarded in favour of finding a program which would allow the user to display a graphic to confirm the identify of the defect. Some difficulty was experienced in finding a graphics display program that was well suited to this approach. Most recent programs of this kind are Windows™ based, and not compatible with the other DOS-based programs used for this expert system. Trials were made using the Information Please™ [12] and the Image Access™ [17] programs. However, both of these first display text information, such as a description of the defect, and on pressing a function key the display is removed and replaced by a graphic. This did not seem to be the most attractive way of displaying the graphic, since a display of text with the graphic was desirable.

After further investigation, a shareware program Vpic™ [19] was acquired which displays text and graphics simultaneously (and costs only $25). Using the computer disk supplied with this thesis, the program is loaded from DOS using the VPIC file command, which then displays on the screen the names of the graphics card files available. The cursor is placed over the name of the graphic required, "Return" is pressed, and the graphic is displayed. The graphic can be displayed on EGA, VGA and SVGA monitors.

VPIC has the ability to recognise many of the graphic chips used on high resolution monitors. Where it has not been recognised, pressing the F4 function key changes the resolution. The scanned images are primarily designed for a 640 x 480 display. The file names displayed on the screen after loading the program correspond to the cards numbers used in the "NeuroShell" and "Black Magic" programs. By selecting the correct card the relevant graphic can be displayed. The program occupies 182K, although this includes facilities for a slide show display. To use the VPIC facility for displaying the graphic it is essential for the user to exit to Dos from either the "NeuroShell" or "Black Magic" programs.

If the program does not recognise the graphic chip used, the monitor defaults to a 320 x 200 and is oversize. Pressing the F4 function key enables the display to be changed to the 640 x 480 mode used.

The graphic files are identified by a card reference which is the same as that given to the database card describing the defect, i.e. entering VPIC CARD-A1 displays the graphic referred to in the ANODFTS files as CARD A1 in both the "NeuroShell" identification program and the "Black Magic" database.

The computer disc accompanying the thesis contains the VPIC program plus the following graphics cards:

- CARD-A1 - Blistering in a hard anodized component
- CARD-A2 - Examples of "burning" in anodizing.
- CARD-A3 - Pitting due to chloride in the electrolyte
- CARD-A5 - Crazing and cracking of an anodic coating
- CARD-A6 - Factors affecting the brightness after anodizing
- CARD-A8 - Staining due to excessive aluminium content
- CARD-A9 - Galvanic pitting during rinsing
- CARD-A10 - Cavity in a hard anodic coating due to inter-metallic dissolution in a 2024 alloy
- CARD-A12 - Patchiness due to inadequate rinsing

It has to be borne in mind that such graphic displays require much memory. A full screen display of 860 x 640 pixels requires 590 K of memory. However, since only one graphic is displayed at a time and each only occupies around 150K of memory (plus 182K for the program), there in no memory problem.

The basic features of this expert system have been described in a recently published paper [19] (See Appendix C), which includes a basic description of the principles of the back propagation neural network containing a layer of hidden nodes used for the "NeuroShell"™ program employed in the "ANOXPERT" system developed in this thesis.

Detailed instructions of the installation and use of the "ANOXPERT" expert system which is contained on the enclosed computer discs are given in Appendix D.

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8.0 Possible Further Development of the System

The work carried out provides an expert system for the identification of defects found on anodized components. It has also met the objective of keeping cost of the software below £500. Part of the original concept was that the program should be flexible and capable of becoming an expert system which could be used industrially. This should be possible in several ways, such as the following:

1. Proviision of a "run-time module" for users not wishing to add to the data contained in the expert system. This is available at a modest cost from the company selling "NeuroShell". The "MAGREAD" program used for the hypercard database is in the public domain and can be freely used. The addition of further graphics to include all the cards in the hypercard database would be needed to complete the expert system.

2. A further possibility is to upgrade the present program by converting it to Hyperwriter™ [1] developed by the same company as developed Black Magic™. This has much improved facilities for the incorporation of graphics and provides hypertext links with the graphics, enabling text and graphics to be displayed simlutaneously on the screen. Alternatively, the more recently developed "Orpheus"™ [2] hypertext database program might be used. Some work will be needed to evaluate the relative advantages and limitations of these two programs.

3. It should be possible later to exploit the pattern recognition abilities of "NeuroShell™ by scanning photographs of material defects, such as extrusion defects, so that an extrusion plant could use the expert system to identify appearance defects originating in the material.

4.. Provision could be also made for users to log data recording the incidence of defects identified by the expert system, the date they occurred and the corrective measures implemented. In this was the expert system could form a "Library" which could be accessed from a computer controlled system which automatically advises steps needed to maintain correct process conditions.

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APPENDICES

APPENDIX A: "An Algorithm for the Identification of Defects in Anodic Coatings" Proceedings of A.E.S.F.S. Annual Technical Conference - Sur-Fin '90, pp. 307-322.

APPENDIX B: "A Computer Database for the Identification of Defects in Anodic Coatings" - Proceedings of The Institute of Metal Finishing Annual Technical Conference 1991, pp. 177-190.

APPENDIX C: "The Development of an Expert System using Neural Networks for the Identification of Process Defects in Anodizing" - Technical Proceedings A.E.S.F.S. Annual Conference - Sur-Fin '94, pp. 381-198.

APPENDIX D: "Instructions for Using 'ANOXPERT' - an Expert System for the Identification of Anodic Coating Process Defects"

Appendix A

American Electroplaters and Surface Finishers Society, Inc.
77th Annual Technical Conference - Boston
Light Metals Finishing II
Session E

AN ALGORITHM FOR THE IDENTIFICATION OF DEFECTS IN ANODIC COATINGS

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THE INSTITUTE OF METAL FINISHING

Paper to be presented at the Annual Technical Conference

at Torquay 24 - 26 April 1991

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Appendix B

A Computer Database for the Identification of Defects in Anodic Coatings

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SUR/FIN® '94—Indianapolis Technical Proceedings

Appendix C

Session H
Light Metals II

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The Development of an Expert System using Neural Networks for the Identification of Process Defects in Anodizing

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