

The Identification and Prevention of Defects on Anodized Aluminium Parts

Chiswick Park, London, extruded and anodised aluminium louvres.

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Summary

Chemical pre-treatment, anodizing and final sealing are the three main stages in what is known as "aluminium anodizing", a processes employed to form a protective anodic film on aluminium. Each of these processes may highlight some pre-existing surface or metallurgical condition of the aluminium alloy used. Such pre-existing flaws or inhomogeneities in the substrate alloy can result in a non-uniform appearance of the finished anodized surface. This, as well as pits or more obvious forms of surface damage can be classified as a defect.

Similarly, handling, storage and finishing practices before or after the anodizing stage, if not controlled in a prescribed manner, can result in an imperfect surface which is not only aesthetically unacceptable, but may also reduce the service life of the finished component.

Such imperfections may be visible before or after the sequence of finishing processes. Alternatively, they may not develop until the finished part has been in service for some time.

Presented here, is a strategy that may be used to identify the source of such defects. Techniques are also described to establish whether a particular process stage or the aluminium alloy itself is responsible for a variation in surface appearance.

Anodized finishes are specified in some cases for primarily decorative purposes, in other cases to meet functional requirements (wear or corrosion resistance). How to ensure that such requirements are met, and that the anodized finish has the required properties to ensure satisfactory in-service performance, is also addressed here.

Methods of testing to establish that the product meets the properties specified are also listed. Most of these have their basis in National or International Standards.

Where practical, methods of preventing some of the defects discussed are indicated. Mahnagement procedures, to minimise the potential cost penalties resulting from the unsatisfactory appearance of a finished product, are also considered.

Introduction

Aluminium as a material of construction continues to grow in importance. It may enter the production process as sheet or as an extruded profile. It may be even be a diecasting or forging. In almost every case, the aluminium alloy will be finished for a variety of reasons. These include a wish to enhance or maintain the original metallic appearance or even to modify it to make it indistinguishable from other metals, alloys or metallized plastics. In many cases, the applied finish may be used to enhance the properties of a product where, for example, high corrosion or wear resistance is a requirement. The major finishing techniques employed with aluminium are anodizing, painting or powder-coating and their associated pre-treatments.

Anodizing preserves the metallic appearance of the base metal and provides a porous coating into which organic or inorganic pigments can be deposited to colour the anodic film. Although it is not considered to be the best pretreatment for painting it does provide a better key than no pre-treatment at all. Other organic species such as solid lubricants are claimed to be co-deposited with the anodic film to improve the wear resistance or lubricity of the finish. However, no convincing documented evidence has been presented in the literature to support this claim that the solid lubricants are incorporated or deposited in the pores of the anodic film. As many of the solid lubricants have molecules larger than the diameter of the pores in the anodic film it is not that surprising that the evidence is not available.

Painting covers the aluminium with an opaque pigmented film and therefore obscures the metallic character of the substrate. In purely visual (though not tactile) terms, the substrate is then indistinguishable from wood or steel. Paint or powder coating provides a wider range of colours than colour-anodized aluminium. However organic coatings have adhesion, wear and scratch resistance inferior to anodized finishes.

An anodic film is produced by the electrochemical conversion of the surface of the aluminium to aluminium oxide. For every two microns of anodic (oxide) film produced one micron of the base metal is consumed in the reaction, and pro-rata. The anodic film is transparent and therefore the type of pre-treatment given to the aluminium can influence the appearance of the final product before anodizing. (Some anodizing processes give a milky finish). (See Section 6. "Chromic acid anodizing") In contrast to anodizing, where the metal itself is converted to form the outer coating, painting is applied over the metal (or oxide) and does not directly react with the substrate although a surface pre-treatment is required to remove the natural oxide film on the aluminium and enhance the adhesion and of the paint film and the corrosion protection it provides.

The nature of the pre-treatment used for anodic finishes and the fact that the aluminium substrate is involved in the formation of the anodic film implies that any variation in the metallurgical structure of the substrate may have an effect on the appearance of the overlying anodized finish. This is less likely with painted finishes although the paint film will not necessarily cover every blemish on an extruded or rolled product.

In general, anodized finishes are more likely to highlight metallurgical defects or inhomogeneities in the substrate than painted finishes, although the latter are by no means an infallible panacea for all surface imperfections.

The scope of this review is restricted to defects associated with anodic finishes.

Categorisation of Defects

Defects may be categorised either as specific types, usually in terms of their appearance, or in terms of the process(es) or at what stage they originate or manifest themselves.

The most common defects may be described as **pitting**, **streaking** or **general non-uniform appearance**. Some defects may originate in the substrate metal as a result of the thermo-mechanical fabrication process used to produce the sheet or extrusion or during handling and storage of the material before finishing.

Defects can also result from a lack of control, or contamination, of the solutions used in the various stages used to produce an anodized finish.

The aim of this guide is to bring together not only the more commonly reported defects previously mentioned in the literature, but also some less frequently encountered defects or problems based on the experience of the author. Methods that may be used to identify the origin of some of these defects or problems are suggested.

In cases where defects only become visible after the surface treatment operation, precautions to reduce the occurrence of these are discussed.

Defect recognition – General

A preliminary examination of a sample can provide a considerable amount of information concerning the origin of a defect. Important points to establish are:

- 1. How much of a particular batch or load of material is affected by the problem?
- 2. Is the defect on all surfaces of the sample or only selected surfaces?
- 3. If only on selected surfaces how do these relate to the manner in which the samples have been stored before or after the anodizing process or the position in which the parts were located on the rack for anodizing?
- 4. Does the defect, such as pitting or streaking, have any directionality and, if so, is it along the axis of extrusion or rolling or does it relate to the direction of gassing (upwards) in a process solution?
- 5. Does the defect have a particular circular or oval shape or even that of a finger print?
- 6. Has any chemical attack in the process solutions resulted in a non-uniform rate of metal removal from the surface of the part?
- 7. It is always very useful if the history of the fabrication and finishing process and, if appropriate, service conditions, of the defective sample are available.
- 8. Similarly, if the problem occurs during the finishing process, a sample of the suspect material in the 'as extruded', 'as rolled', or 'as cast' (i.e. 'mill finish') condition as well as a sample illustrating the defect, is most desirable.

Without such samples and information, the investigation into the cause of the problem is made more difficult.

There are several observations in combination with a few relatively simple tests that can be carried out to help identify the cause of various defects. These are discussed under the specific defect categories.

If a defect is first noticed when the component is on-site, this may require a site visit unless good quality photographs illustrating the problem are available. If such photographs are not available or do not enable a considered opinion to be made on the cause of the defect, then removal of a defective part or a section of a defective part from the site, may be the only method of establishing the cause of the defect.

Even in cases where the defective part is available for examination, the evidence regarding the cause of deterioration may have already been removed by other events such as cleaning or simply washing by rain.

Defects have been categorised into general sections, namely: -

- 1. Pitting
- 2. Streaking
- 3. Non uniformity of appearance

4. Deterioration of the appearance of a finish in the service environment

Each of the above groups are treated separately, while section 5 deals with a basic approach to defect recognition.

Part 1. Pitting Defects

Pitting can occur before, during or after the actual anodizing processes. Visual examination of the sample can help to provide some evidence as to the cause of the pitting and where it has occurred but usually a more detailed investigation is required.

1a. Atmospheric corrosion of mill finish sections

In an industrial environment and most certainly in a metal-working plant, the atmospheric environment can be consistently or sporadically, highly corrosive. Acid mist, gaseous oxides of sulphur or nitrogen can be formed from plating or etching operations, from pyrometallurgical processes or heat-treatments.

Where the pitting is found only on certain faces of the sample, perhaps just a single face, and a sharp demarcation exists between the pitted area and a satisfactory area, the problem is probably due to corrosive media attacking exposed faces of the sample. A sharp demarcation line between the defect area and a normal area suggests shielding of the affected part by other parts or perhaps one face having been protected by lying on a shelf in storage (face-up, face-down). Pits often tend to run along die lines on extrusions where any natural protective oxide film is at its weakest (Figure 1). This is commonly observed with atmospheric



Figure 1. Typical atmospheric corrosion revealed by etching and anodizing.

corrosion of mill finish extrusions, particularly air quenched 6063 type extrusions, where the presence of a mixed magnesium oxide - aluminium oxide film on the surface, facilitates and accelerates the corrosion process. This type

of corrosion is not readily visible on the mill finish sample, but is revealed by an etching pre-treatment, and can be seen immediately after the etching stage. It is often not detected until the final inspection of an anodized and sealed product. The pitting may only be on one or two faces of an extrusion depending upon its shape and how it has been stored.

Storage conditions for mill finish extrusions are very important. They should be kept in a dust free, warm, noncorrosive atmosphere under conditions that prevent any form of condensation occurring on the parts. It is wellknown that as the temperature falls below the so-called dew-point and an aqueous film is formed on a metal surface, the rate of corrosion will significantly accelerate.

This type of corrosion cannot be removed by reprocessing. The only remedial action is to strip off the anodic film and then mechanically linish the surface to remove the pits. This is practically impossible on complex shapes and it is often more economic to re-extruded the alloy and ensure that it is handled and stored correctly prior to etching and anodizing.

1b. Finger print corrosion of mill finish sections

A pitting pattern having a distinct finger print shape is characteristic of finger print corrosion (Figure 2). (also known as finger-marking). This occurs due to handling, mainly of 6000-series aluminium alloys, after extrusion and before anodizing, without using gloves. Perspiration is acidic and contains chloride ions and removes the magnesia film present on the 'as extruded' 6063 extrusions resulting in rapid localised corrosion of the aluminium substrate. Again, it is not normally visible at the mill finish stage but is enhanced by the etching and anodizing processes. It is always recommended that cotton gloves be worn when handling 'mill finish' aluminium. Similar pitting may occur on aluminiumcopper alloy extrusions sheet or plate due to the reactive nature of this alloy.

As with the previous problem, this type of corrosion cannot be removed by reprocessing. The only remedial action is to strip off the anodic film and then mechanically linish the surface to remove the pitting. This is practically impossible on complex shapes and it is often more economic to re-extruded the job and ensure that it is handled and stored correctly prior to etching and anodizing.



Figure 2. Finger print corrosion on 6063 extrusion revealed by etching and anodizing.

1c. Paper corrosion

This form of pitting can be caused by the contact of aluminium with paper or corrugated cardboard, used to interleave layers of extrusions or sheet, especially when a consignment becomes moist in transit or storage. In the case of corrugated cardboard the pitting has a distinctive regular pattern where the surface of the extrusion is in contact with the corrugations (Figure 3). Paper corrosion is generally more random as illustrated in Figure 4. The corrosion is normally not visible until after the samples have been etched and anodized. The corrosion is initiated by acid radicals, principally chloride or sulphate, present in the wrapping or spacing material. This type of corrosion normally only occurs on the surfaces of the aluminium that are in contact with the paper or cardboard.



Figure 3. Corrugated cardboard corrosion



Figure 4. Paper corrosion

Using wrapping paper or spacing material of a controlled composition and taking precautions to prevent the package becoming wet during storage or transit should inhibit this form of corrosion.

A typical specification for wrapping paper would be: -

Moisture content	6 to 7%
Chlorides as NaCl	0.003 to 0.025%
Sulphates	0.025% maximum
Acidity or Alkalinity	0.05% calculated as sulphuric acid or sodium hydroxide.

The paper should be completely free from any copper salts.

1d. Traffic marking or fretting corrosion

Fretting corrosion or 'traffic marking' as it is often called occurs when extruded sections or sheet rub together in transit due to poor packing or inadequate use of spacers between the sections or sheets. The affected areas are not necessarily directional but, in the case of extrusions often have an orientation that is roughly at 90° to the axis of extrusion and tend to have a characteristic black appearance (Figure 5). (the black colour is usually ascribed not to any chemical change but to light scattering from the very finelydivided material).

The rubbing or fretting action produces a fine aluminium dust that rapidly oxidises to form very hard alumina particles, which cause rapid and cumulative local abrasion. The defect is highlighted by etching but is usually visible on the mill finish surface. The pitting occurs where the abrasive action of the alumina removes the protective natural oxide coating on the aluminium surface at the location of the fretting action.

Better design of packing systems and adequate interleaving of the sections or sheet during handling in the plant or transit should prevent this problem.



Figure 5. Appearance of fretting corrosion after anodizing.

1e. Acid or alkali corrosion

Accidental splashing of aluminium parts with acids or alkalis, usually when stored in the anodizing plant can cause pitting before anodizing. Such pitting is usually very localised and the pits are deep. Acid pitting will produce intergranular attack (Figure 6) whereas alkali pitting produces a well-rounded smooth pit (Figure 7). The form of the attack is best determined by taking a micro cross-section of the pit and examining it under the optical microscope.





Figure 6. Intergranular attack typical of acid corrosion. x 200

Figure 7 Rounded pit typical of alkali corrosion. x 200

In many cases when the mill finish extrusion is pitted before finishing, the pits may be difficult to see unless there is some corrosion product on the surface. It is the pre-treatment process that subsequently opens up these pits

although they are usually not obvious until completion of the anodizing process. This implies an anodic film is usually present over the pitted surface, although this would not be visible to the naked eye. The most satisfactory method of establishing if there is an anodic film over the pit is to micro-section and examine the sample under an optical microscope as illustrated in Figures 6 and 7. Where such equipment is not available, immersing the pitted sample in a solution of 2% copper sulphate in deionised water for 10 minutes at room temperature may be an alternative approach. If an anodic film is not covering the pits, a deposit of copper should form around the pit sites. (metallic aluminium in contact with aqueous copper salts undergoes a so-called displacement reaction, where copper ions are reduced to the metallic state, with metallic aluminium being ionised and going into solution. The process is also known as cementation. An anodic film will protect the aluminium from such attack)

Chlorinated solvents are now much less widely used for degreasing. It is often forgotten that by hydrolysis, hydrochloric acid can form in such solvents. Droplets of trichlorethylene vapour condensate, because they contain HCl, have been known to cause acid pitting. Mortar or cement dust is another common cause of alkali pitting Paying attention to storage conditions, particularly of acids and alkalis at the anodizing plant, and general good housekeeping should eliminate these types of pitting defects.

1f. Rinse water corrosion

Pitting can occur in several of the process stages used to produce the anodized finish. One of the most common forms occurs in rinse water stages, particularly the rinse which follows acid desmutting. Rinse water corrosion is always very shallow and the pits usually look very white and are often star shaped (Figure 8). There are more rarely-encountered forms of rinse water corrosion where the pits are even shallower but have a floret or sometimes a filiform shape and can be dark grey or black in appearance (Figures 9 and 10). Rinse water corrosion always occurs before the anodizing stage and therefore will be covered by an anodic film.

Once it is established in which rinse tank it is occurring, rinse water corrosion can be usually prevented by the addition of a small amount (0.5%) of an oxidising acid, such as nitric acid, to the offending rinse tank.



Figure 8. Rinse water corrosion illustrating white star-shaped form.





Figure 9. Rinse water corrosion illustrating black floret-shaped pits.

Figure 10. Rinse water corrosion having very shallow filiform type structure.

1g. Pitting in brightening solutions

Where extrusions are chemically brightened to provide a highly reflective finish, control of the process to prevent possible occurrence of several types of pitting is important. Operating the brightening bath at too high a temperature, too low a nitric acid content or with too little agitation of the solution can all result in pitting. This type of pitting is usually on all surfaces of the part and is usually very fine. It may also be associated with a dulling of the surface, which is often an indication that the solution concentration, temperature or the brightening times have not been optimised. An example of the type of pitting due to an out-of-balance brightening solution is illustrated in Figure 11.

This type of pitting is can usually be eliminated by adjusting the brightening solution composition to within the recommended operating range. Nitric acid depletion is a common cause of solution imbalance although this can also result in a dulling of the finish due to transfer etching or staining (see Section 3s).

Incomplete removal of polishing compound or tenacious dust from a mechanically polished surface in the degreasing stage prior to chemical brightening



Figure 11. Very fine pitting typical of that due to an imbalance in a chemical brightening solution.

can produce a 'castle-and-moat' type pitting defect during brightening. As the name suggests, the pit is characterised by a central area that has not been attacked (the castle) surrounded by a preferentially attacked circle (the moat).

The geometry of the `castle and moat' defect is usually clearly visible under a microscope and a typical example is shown in Figure 12. Figure 13 illustrates the appearance of the same defect when viewed by the naked eye.



Figure 12. Pitting of the 'castle and moat' type. x 20



Figure 13. Example of 'castle and moat' pitting. x 1

This type of pitting usually occurs on certain faces of the polished part and can be often be prevented by improving the degreasing practice. If this does not solve the problem then attention should be given to improving the cleanliness and dust extraction in the mechanical polishing shop.

The longer the polishing compound or dust deposits have been on the surface before degreasing the more difficult they are to remove. It should not be forgotten that aluminium and its alloys are relatively soft metals, while abrasives are by their nature extremely hard. Even casual handling of work with residual abrasives particles on the surface, can result in these becoming embedded in the metal, in which condition they are difficult to remove, and leave a cavity behind.

Vapour degreasing was, and still is a very effective way of removing superficial deposits of abrasive powders but, due to the environmental constraints on using this technique, and the difficulty in placing such degreasing equipment in an automated or semi-automated line, the most popular degreasing method is a hot non-etching alkaline cleaner. This needs to be operated as hot as is practical (70° at least) and kept up to strength, and in good condition, if effective degreasing is to be consistently maintained.

1h. Pitting during anodizing

Pitting can occur in a sulphuric acid or oxalic acid anodizing electrolyte during the anodizing process. Contamination of the anodizing electrolyte with chloride ions is a common cause. The source of the chloride contamination is usually mains water used to make up the anodising electrolyte. Even if it is initially below the critical level it can become concentrated by cumulative evaporative losses from the electrolyte. Such pitting has a very distinctive form, an example of which is illustrated in Figure 14. The pits are star shaped and on all faces of the sample. They are relatively deep and, as such, are usually black in appearance (scattered light trapping) There is no anodic film over the pits. In sulphuric acid electrolytes the critical level of chloride is about 80ppm measured as the Cl⁻ ion. The sensitivity of oxalic acid electrolytes to chloride is much greater and severe pitting and even complete holes can form in the parts when the chloride level is 20ppm or higher in this electrolyte.



Figure 14. Pitting caused by chloride in a sulphuric acid anodizing electrolyte.

The use of deionised water for anodizing electrolyte make-up and top-up is the most satisfactory method of eliminating this problem.

NOTE: Any form of process solution pitting, such as rinse water corrosion, brightening solution pitting and chloride pitting in the anodizing electrolyte have the common characteristic of being present on all surfaces of the sample.

Other forms of pitting such as atmospheric, finger-print, acid or alkali splashing, the pitting in a brightening solution due to contamination with polishing compound (castle and moat), or paper corrosion tend to be more surface specific.

1i. Pitting due to galvanic effects

The overall anodizing process (incl. colouring where this is required) consists of a sequence of stages. Some of these – notably the actual anodizing itself – are carried out using an external current supply. However many others are so-called "currentless" processes, and these include dyeing, sealing and rinsing. When no external current is imposed, it becomes easier for a galvanic couple to be created, when two dissimilar metals are present in the same electrolyte. Thus a stainless steel tank, where used, can form a couple with aluminium. Lightly anodised aluminium behaves much as the bare metal itself. Such galvanic couples, which then lead to galvanic pitting can sometimes occur in dye solutions (when colouring anodized work) or even in the final sealing solution.



Figure 15. Pitting due to a galvanic cell occurring between the stainless steel tank and the anodized part.

Such pitting often has a white halo around the site of the pit, as illustrated in Figure 15, and sometimes gas 'comet tail' marks originating from the pit centre are also present. The pits tend to form at the weakest points in the anodic film, such as sharp corners or prominent die lines, at which locations the anodic film is very thin. Galvanic pitting can be associated with a stray electrical currents in the anodising plant or galvanic currents can be set up not only between a metal tank wall and the anodized part, but also, for example between a titanium jig and the anodized part. The so-called flight-bar which carries the work from one tank to the next, is electrically energized during the anodizing sequence but in currentless stages, its potential may float and thus enable galvanic couples to be set up. One means for eliminating this is to arrange for the flight-bar to be earthed when it is not energized. Galvanic pitting is not a common defect in architectural finishes but may be seen on bright

anodized or other forms of thinly anodized decorative work. Intermetallic inclusions such as TiB_2 or MgO/Al_2O_3 spinels in the aluminium alloy, if bridging the barrier layer of the anodic film, may act as sites for galvanic effects.

The problem can usually be overcome by insulating the work carrier bar or jig from the sides of the dye tank. Alternatively, connecting both the tank and the carrier bar and jig to an earthing point, so that they are then at zero potential, should resolve the problem. Either technique is often an effective solution to the problem but it should be remembered that such pitting can be an indication of the presence of relatively weak areas in the anodic coating and, perhaps, the application of a slightly thicker anodic film would be a better approach. However the latter option may be precluded where a highly reflective finish has been specified.

1j. Pitting of the anodic film in service





Figure 16. Examples of pitting of anodic films in service due to the film thickness being below specification.

Pitting can occur during the service life of the anodized part. The most common form of this pitting on architectural anodic finishes, is caused by acidic atmospheres containing SO_2 . It may take from 5 to 50 years for such pitting to occur, depending upon alloy of the substrate, the anodic film thickness on the part, the degree of pollution of the atmosphere and the frequency and quality of the cleaning maintenance given to the anodized components. It might be noted that there are numerous publications and Standard Specifications relating to the care and maintenance of anodized aluminum cladding. (consult the database at www.surfacequery.com).

Atmospheric corrosion of this type is generally on the exposed faces of the component, and is usually more severe on faces protected from natural washing by rain. Typical examples of the latter are curtain walling panels under window-sills or ceilings under external canopies.

Pitting in service will locally destroy the anodic film. There is usually an amount of corrosion product associated with the pits, and also a circular stain around individual pits as illustrated in Figure 16.



Figure 17. Cement staining on a natural anodized finish.

A rarer type of corrosion is that caused by contact with dissimilar metals particularly copper. Such contact can occur when dissimilar metals are used for bolts or rivets to join anodized components or from rain running off copper flashing or roofs clad with copper or another unsuitable metal. Galvanized mild steel, notably corrugated iron will cause zinc-ion contaminated rainwater run-off. The latter type of corrosion is very localised and the pitting is usually very severe, sometimes to the point of perforation of the component. One very obscure incidence of this type of pitting was observed where sparks from a trolley bus cable that ran near to some anodized aluminium curtain walling, resulted in fine copper deposits on the anodized surface. The net result was very localised penetrative pitting of the anodized curtain walling. As discussed above, the driving-force of this process will have been the copper/aluminium displacement reaction.

Examination of the corrosion product may produce some evidence as to the cause of the corrosion. This is most easily done using a SEM and EDAX analysis or ESCA but, if such techniques are not available, then qualitative chemical analysis might provide some evidence. (e.g use of spot-testing, see Bibliography)

Accidental contamination of an anodic film with wet mortar or cement can give rise to attack of the surface as illustrated in Figure 17. However, on most well-managed building projects, the anodized surfaces are protected with a strippable coating or masking tape to protect the film from this source of attack during the construction period.

Normally, the most common forms of pitting in service are unlikely to result in any structural deterioration of the part. This is because the corrosion product formed tends to fill up the pit and stifle the corrosion process. However, pitting does detract from the appearance of the finish.

Refurbishing pitted anodized finishes, whatever the cause is very difficult. Removal of the part and reprocessing is usually impossible and very expensive, even then this will enhance the pits and they will still be visible. One solution, if practical, is to strip the anodic film and linish the affected surfaces to remove the pitting and then reprocess. This does tend to change the appearance of the finish and the economics of doing this may be less attractive than replacing the affected material.

Specifying the correct alloy and anodic film thickness for the application in combination with regular and effective maintenance is the most satisfactory method of preventing pitting in service.

Summary of pitting defects

As indicated pitting can be associated with various forms of corrosion of the aluminium alloy that may occur before the finishing process or as a result of lack of control of the finishing process itself. Furthermore, pitting of anodic films in service can also occur if the necessary precautions are not taken. When examining a pitted component there are a number of observation or rules that should be applied or questions to be asked. These are: -

a) Are the pits on all faces of the component or only on selected surfaces?

When the pitting is on all surfaces the problem is usually associated with process solutions.

If pitting is seen only on one or two surfaces or there is a sharp demarcation between a pitted area and a nonpitted area the problem is usually associated with some form of atmospheric attack or spillage of aggressive chemicals onto the surface.

b) What shape and colour are the pits?

Star shaped pits, if black in appearance, usually indicate pitting due to chloride in the anodizing electrolyte; if white in appearance, rinse water corrosion should be suspected.

If the pits are in clusters and take the form of fingerprints then they are probably due to handling before finishing. When the pitting is fairly fine, on specific surfaces and tending to be aligned in the extrusion axis or on die lines on extrusions, the problem is often associated with atmospheric corrosion.

c) Is there any corrosion product in or near the pit?

If so, then it is likely that the defect is either inter-granular pitting that has trapped sulphuric acid electrolyte during the anodizing process or some galvanic pitting has taken place after anodizing during dyeing or sealing. In general, any pitting that has occurred before the anodizing process, is opened up by the etching or brightening pre-treatment stages and will then be covered by an anodic film. There is usually no corrosion product associated with this latter type of pitting.

d) Are the pits random or do they have a linear distribution?

If the pits have a linear distribution they may be associated with a metallurgical problem such stringers of coarse TiB_2 particles or Al_2O_3/MgO spinels. Another source of linear defects can result from some directional mechanical pre-treatments such as linishing or polishing embedding inclusions in the surface.

e) Some spotting on coloured parts that have all the appearance of pitting may be due to spalling of the anodic film that can be a function of the anodizing or colouring practices used. A similar defect may also be linked with the inter-metallic phases in the alloy affecting the integrity of the metal/oxide interface. This is strictly not pitting and is dealt with in the section on non-uniform appearance.

Part 2. Streaking Defects

Streaking is a major but not the only cause of non-uniformity on anodized surfaces. Streaking is usually related to a non-uniform metallurgical structure in the affected part, or physical damage to the aluminium surface, that results in a variation in the etching or anodizing response of the material. These effects are manifested as a difference in brightness or reflectivity over or along a component. The main types of streaking are:

2a. Segregational streaking

This is caused by a variation in the distribution and size of intermetallic constituents in the alloy. Segregation of primary intermetallics or constituents normally originates in the inverse segregation band or in the shell zone of the ingot. The inverse segregation layer is very thin and close to the outer surface of the ingot and as such, in the case of extrusions, is not normally extruded into the section unless the extrusion ingot discard is very thin. A similar defect can arise in the case of rolled sheet when the ingot is not scalped. The shell zone in an ingot can vary from a few mm below the ingot surface to 20mm or more and its width is very much a function of the casting technique. Depending upon the width of this shell zone, it may well flow into an extruded section and if this segregated layer is just sub-surface the process of etching and anodizing can highlight it. It may show up, particularly after polishing, etching and anodizing, as a 'wood grain' effect as illustrated in Figure 18.



Figure 18. 'Wood grain' effect of ingot segregation on polished and anodized extruded section that was heavily polish to remove a locally severe die line.

A more common form of shell zone streaking on extrusions, also revealed by etching and anodizing, is where the streaks tend to run in the extrusion direction but may vary somewhat in width along the extruded length. A similar effect can be attributed to structural or die design streaking the main difference being that the streaks due to the latter do not vary in width along the extruded length. If there is any doubt regarding the source of this type of streaking a simple test is to strip the anodic film from the sample and to taper polish it from one end such that more metal is removed towards the end of the extrusion being examined. (the taper would typically be less than 5µm along the length of a sample). The sample should then be re-etched and anodized. If the streaks on the surface vary in width or move to the left or the right, or even disappear in the heavily polished zones, the streaking is likely to be due to shell zone segregation. If the streaks do not vary in width or move to the left or right then it is likely to be due to die design streaking. The latter is discussed in 2b. Figure 19 illustrates the effect of taper polishing, re-etching and anodizing a sample 6063 extrusion exhibiting shell zone streaking.

In the case of anodizing quality sheet, the ingot used to produce this is normally scalped prior to hot rolling to remove the shell zone. If it is not, the inverse segregation layer, which is very near to the ingot surface, may be revealed by etching and anodizing. An example of a defect due to inverse segregation is illustrated in Figure 20.

Special casting technology is available to reduce the ingot shell zone to a minimum. In the case of extrusions, any die design features that can influence metal flow during the extrusion process may increase or decrease the chances of the segregated layer being at or just under the extruded surface.



Figure 19. Example of shell zone segregational streaking after stripping the original anodic film, taper polishing the affected surface and re-etching and anodizing.



Figure 20. Inverse segregation effect on etched and anodized rolled sheet produced from an ingot that had not been scalped or had insufficient metal removed by the scalping operation.

2b. Structural streaking/Die design streaking

More common on extruded products than sheet, structural streaking results from variations in grain size and orientation, as well as the precipitate microstructure in the final aluminium product. In the case of extrusions the effect of die design upon the grain size or metallurgical structure is often the cause such streaks.

Structural streaking is usually consistent along an extrusion length or along a sheet in the rolling direction.

The streaks are usually constant in width and their reflectivity or apparent brightness may vary with the angle of viewing. The streaks are often associated with a feature of the extruded section geometry.

This type of streaking is usually associated with a change in surface contour, grain structure and perhaps also texture in the region of a change in the extruded section thickness.

Attention to die design in terms of the blending of the bearings into each other and ensuring that the bearing edges are sharp and clean may help to reduce the problem. Similarly, changing the extrusion speed or temperature may reduce streaking originating from section thickness changes. Reduction of extrusion exit speed may well prove beneficial.



Figure 21. Structural or Die design streaking revealed by etching and anodizing a 6063 extruded section. (x $1\,$

2c. Die line effects

This is a physical line or band of lines in the extrusion direction. Although always present on aluminium extrusions, extreme examples are probably associated with the condition of the die-bearing surface. An apparent streaking may be associated with prominent die lines, particularly when a significant area of the surface is affected. It has been suggested that there may be some metallurgical structure variations associated with groups of die lines that generates streaks when the extrusion is anodized.



Figure 22 (above). Examples of severe die lines on 'as extruded' section.

Figure 23 (right). Severe die lines showing up as darker streaks after etching and anodizing.



Usually attention to die design is required to reduce die line intensity including the nitriding of the bearing surface. Should the defect be found to vary in intensity with extrusion speed the problem might be partly due to the metallurgy of the extrusion ingot. The quality of the ingot is usually assessed in terms of its microstructure and its degree of homogenisation.

2d. Longitudinal weld streaking

This defect may appear as a longitudinal streak or lines of intermittent spots or pits corresponding to the longitudinal welds in hollow sections produced from porthole-type dies. The defect is caused by a narrow fillet of metal of different metallurgical structure or chemical composition filling the weld area or sometimes the entrapment of excess lubricant applied to the front end of the extrusion ingot. The appearance of longitudinal welds may vary, but Figure 24 illustrates how the weld line may be visible on a cross section of the extrusion.



Figure 24. Example metal flow on a hollow extrusion having a small hollow portion at one end of a relatively large solid portion of metal. This may also be part transverse weld/back-end defect. (10 minutes etch in 100g/l NaOH at 60°C.)



Figure 25. The same sample shows the streaks resulting from the metal flow at the surface of extrusion.
Depending upon how the metal flows over bridges in the die chamber and where the disturbed metal flow breaks the surface of the extrusion, the resulting variation in metallurgical structure can be highlighted by etching or brightening and anodizing. Figure 25 illustrates the effect, of caustic etching, on the appearance of the extrusion where the metal flow intersects the surface.

Similarly, when the same extrusion is brightened and anodized, the surface finishing response is non-uniform as illustrated in Figure 26. This is due to the effect of the metal flow over the bridge in the die, and its welding together before exit from the die, has had on the metallurgy of the material. A poor quality longitudinal weld can cause problems when the part is anodized and dyed as illustrated in Figure 27.



Figure 26. Non-uniform appearance of 6063 extrusion bright-anodized and dyed corresponding to the position of the transition from a transverse weld into the longitudinal welds and the effect of removal of the surface layer by mechanical polishing.



Figure 27. Poor quality weld on extruded tube causing colouring defects when anodized and dyed

Wherever possible the welds on a hollow extrusion should be placed in a position that is not readily visible on the finished product. Expertise in die design in the location of weld areas and the bridges holding the mandrel are also an important factor in minimising the undesirable visual effect of longitudinal welds. The contribution made by transverse welds at the front end of a hollow extrusion, as well as the occurrence of back end defect due to too short an ingot discard, also has to be considered and appropriate action taken.

2e. Transverse weld streaking

Transverse weld streaking occurs mainly on hollow extrusions and manifests itself as a variation in the degree of mattness or perhaps depth of colour across one or more surfaces of the extrusion. This streaking is revealed by etching and anodizing and is associated with metallurgical or structural differences in the material. A characteristic of this type of streaking is that the width of the streak changes along the length of the extrusion and usually tapers to a 'V' shape towards the front end. Figure 28 illustrates the effect of a transverse weld a few metres from the front end of the extrusion. These streaks may disappear completely over the next few metres of extrusion. Figure 29 is a typical example of a transverse weld at the front end of the extrusion. Mixing of metal in hollow section dies or solid dies using a feeder plate or welding chamber is the usual cause of this type of streaking. Metal from the front end of the ingot being extruded is mixed with metal from the back end of the previous ingot.



Figure 28. Transverse weld effect on a hollow extrusion after etching and anodizing.



Figure 29. Example of a transverse weld defect at the front end of an extrusion after etching and anodizing.

This type of streaking can be further enhanced when the extrusion ingot alloys are accidentally mixed. An extreme example would be when a 3000 series ingot was accidentally mixed with a batch of 6063 alloy. However, a more normal situation would be where, say, a 6463 alloy ingot was accidentally mixed with a batch of 6063 ingots. The former being a bright anodizing quality alloy with a higher purity base would produce a much brighter etching and anodizing response than the latter. The net result would be an extrusion having bright and matt streaks when etched and anodized as illustrated in figure 30.



Figure 30. Streaking due to mixing of alloys on a hollow extrusion.

Obviously the mixed alloy problem is a question of good housekeeping. In the case of a normal transverse weld, scrapping a sufficient length of section at the front end should eliminate the problem. It is also important to avoid using ingots from different sources, or with different thermal treatment histories or casting structures for a specific project. Finally, modifying the die design to reduce the feeder size may help reduce the defect by allowing smaller discards at the cut to length stage.

2f. Flecking

Non uniform light and dark flecks or short streaks in the extrusion direction on some anodized and electrolytically coloured components are usually attributable to a non- uniform distribution of the iron-bearing phases in the material. Figure 31 shows a typical example of the defect and figure 32 shows a schematic illustration of the variation in iron phase distribution between a normal and a flecked sample.

This non-homogeneity originates from the extrusion ingot and is usually considered to be related to the efficiency of the grain refinement during the casting stage.



Figure 31. Flecking occurring during electro-colouring due to iron phase segregation.



Figure 32. Schematic of iron phase distribution in a non flecked and flecked area

2g. Clusters of intermetallic particles

Clusters of intermetallic particles such as TiB_2 or MgO/Al₂O₃ spinels can produce streak defects. The streak usually takes the form of a row of pits or protrusions on the surface. These usually remain uncoloured when the finish is dyed or electrolytically coloured. An example of the streaking caused by coarse titanium diboride particle clusters in an ingot used to extrude a section for an architectural application is shown in Figure 33.



Figure 33. Streaking due to ${\sf TiB}_2$ clusters and oxide inclusions in the extrusion ingot used to extrude a section as revealed by anodizing and electro-colouring of the section.

The presence of coarse intermetallic or clusters of TiB_2 grain refiner particles in an extrusion ingot is usually an indication of poor casting practice. This may be due to the quality of the grain refiner rod or, poor control of the feeding of the rod into the molten metal. Similarly, inadequate filtering of the molten metal can result in coarse particles of grain refiner or aluminium oxide/magnesium oxide spinels being present in the ingot.

2h. Carbon Marking

Longitudinal black marks in the extrusion direction are sometimes visible on one face of an extruded section. These are commonly called carbon marks and are usually due to the extruded section rubbing on the carbon blocks as it emerges onto the run-out table. An example of carbon marking on an 'as-extruded' section is shown in Figure 34. In the case of rubbing on the run-out table the localised thermo-mechanical can affect the size and distribution of the Mg_2Si precipitate in that area. The metal in this area reacts differently in etching and brightening solutions to produce a contrast and hence a streak. Figure 35 shows the same sample after etching for 10 minutes in 100g/l sodium hydroxide at 60°C.



Figure 34. Carbon streaks on an 'as extruded' section.



Figure 35. Carbon marks after etching for 10 minutes in 100g/l NaOH at 60°C.



Figure 36. Graphite inclusion due to excess lubricant at front end of ingot. x 20

The problem is usually overcome by attention to the condition of the material used on the run-out table or walking beam and, if carbon blocks or rollers are used, replacing them with a material of lower thermal conductivity, such as Kevlar or Railco (see 3g).

A similar but not identical effect may result from excessive usage of graphite lubricant on the front end of the extrusion ingot, an example of this is illustrated in Figure 36. Reducing the amount of lubricant applied should resolve the problem.

2i. Back end defect

Back end or extrusion defect streaks are caused by ingot skin or container skin being extruded on or near to the section surface. These defects differ from transverse welds in that they normally occur at the back end of an extruded length and are not confined to feeder plate or hollow extrusions. They should be eliminated by inspection at the sawing-to-length stage. Etching a cross section of the defect in 10% NaOH is a simple way of demonstrating the problem.



Figure 37. Etched cross sections of extrusions demonstrating back end defects and associated streaking.







Figure 38. Surface streaking or flecks due to back end defect or transverse weld on an anodized and electrolytically pigmented extrusion.

Figure 37. Etched cross sections of extrusions demonstrating back end defects and associated streaking.

Adjusting the length of the ingot discard to prevent inflow of discard metal into the die should eliminate the problem. Extrusion conditions such as high ingot temperatures and small temperature difference between the ingot and container are likely to make the problem worse.

General comments on identification of streak defects

- Determination of the cause of streaking involves a combination of basic tests combined with visual observations or more sophisticated metallurgical examinations.
- Visual examination of samples of streaking can be very informative.
- If the streak tapers in a longitudinal V shape, then the problem is usually of the transverse weld type.
- If the streaks run in thin straight lines along the full length of the hollow, they are most likely to be caused by a defective longitudinal welds or die lines. Etching a cross section of the hollow section in 10% NaOH at 60°C for 10 to 20 minutes will reveal the position of the welds in the section wall.
- Where the streaks do not run parallel along the extrusion length or vary in width, they are likely to be caused by segregation or structure effects.
- Where streaks are of a consistent width, and are not associated with welds in the case of hollows, they are likely to be related to die bearing design or die line problems.
- In case of doubt, a simple test is to strip the anodic film from a short length of the section. The stripped section is then mechanically taper polished in the extrusion direction and towards one end on the surface showing the defect. The sample should then be re-etched for 10 minutes in a 10% NaOH etch at 60°C and the position of the streak observed.
- If the streak is still the same width and runs parallel to the extrusion direction, it is usually associated with a die design or perhaps a structural effect.
- If the streak varies in width or disappears as in Figure 39 or moves to the left or right and varies in width as in Figure 40, it is most probably caused by segregational effects.
- If the streak stays the same width but disappears in a position where most metal has been removed by the taper polish; it is likely to be caused by die lines.



Figure 39 (above). Effect of relatively uniform and taper polishing on the bright band on a polished and anodized extrusion showing a dulling due to a thin segregate layer on the surface near the edges. The heavier the polish the wider is the area of the brighter subsurface material revealed.

Figure 40 (right). Effect of taper polishing and anodizing a section having segregational streaking or back end defect streaking, upon the position of the streak. The heaviest polishing has been applied towards the bottom of the samples in this picture.



Part 3. Non-uniformity of appearance

The most common defects under this heading are white etch bloom, inconsistent etch response, hot spots, gas trapping, colour differences and white dots on coloured work. Less commonly encountered defects associated with water staining, mechanical pre-treatments, degreasing, etching, anodizing, rinsing, colouring and sealing area also mentioned.

3a. Mechanical polishing burn

When too much pressure and/or insufficient polishing compound or liquid is applied to a polishing mop, localised overheating of the aluminium surface may take place. This can result in some modification of the precipitate structure near the surface of the aluminium alloy that will subsequently affect the etching and anodizing response of the alloy. The normal effect is to produce a non-uniform abrasion or bloom pattern on the surface that is not removed by the etching treatment before anodizing as illustrated in Figure 41.



Figure 41. Non-uniform appearance on an etched and anodized extrusion caused by poor mechanical polishing.

Once this overheating has changed the precipitate condition, it is difficult to rectify the problem. Attention to the polishing mop pressure and/or improving the application of polishing compound should prevent future recurrence of the problem.

3b. Water staining and/or poor degreasing

When aluminium is in contact with moisture from condensation or water entrapment a thickening of the natural oxide film occurs. This is commonly known as water staining and examples are shown in Figures 42 and 43.



Figure 42. Water staining on samples of machined tube in storage prior to etching and anodizing.

In some circumstances, for example, if the water contains aggressive ions, quite severe corrosion of the substrate can take place. It is not until the parts are pre-treated by etching or brightening and then anodized, that the pitting problem is evident. Figure 44 shows the effect of brightening, anodizing and dyeing the water stained samples illustrated in Figure 42.



Figure 43 (left). Water staining on aluminium 1050 alloy foil caused by the coiled alloy becoming wet in storage.

Figure 44 (below). Samples of water stained material from same batch as samples in Figure 29 after brightening anodizing and colouring showing that quite severe corrosion was associated with the water staining

Where a section has not been adequately degreased or cleaned to remove dried-on cutting oil or any other protective film such as adhesive tape or lanolised dewatering fluid, a similar non-uniform etching to that resulting from water staining may also occur. It is important, when such a protective is used, that the anodizer is informed so they can take the necessary steps to ensure it is all removed before the etch stage. Once preferential etching has occurred due to inhibition in contaminated areas by the oily deposit, nothing can be done to rectify the problem. Such defects look similar to the effects caused by water staining and Figure 45 is indicative of the type of preferential etch that can result from inadequate degreasing.





Figure 45. Effect of water staining or inadequate degreasing prior to etching.

Aluminium should be stored in a dry atmosphere and at a controlled temperature at which condensation cannot occur. If any form of protective oil or tape is applied to the aluminium details should be provided to the anodizer in order that they may adjust their degreasing practices accordingly.

3c. White etch bloom

White etch bloom is the description given to a common defect that normally occurs in the caustic etching stage of the pre-treatment process before anodizing. It appears as a patchy non-uniform white etch that may show fingerprint patterns which are more specular or silver in appearance. It is due to the incomplete removal, in the degreasing stage before etching, of the mixed magnesium oxide/aluminium oxide film present on air quenched 6063 extrusions. The magnesium oxide is insoluble in alkali etches resulting in a roughening of the section surface due to preferential attack. This manifests itself as a patchy white finish perhaps wrongly named 'white etch bloom'. Figure 46 shows an example of normal 'white etch bloom' and Figure 47 is typical of 'white etch bloom' where some of the magnesia on the mill finish surface has been removed by handling of the extrusion prior to degreasing.



Figure 46. Typical example of 'white etch bloom' on 6063 extrusion.



Figure 47. Sample of 'white etch bloom' on 6063 extrusion showing brighter, or darker, areas where fingerprints have removed the magnesia film before etching.

The problem can be avoided by using an inhibited, non-etching, alkali degrease or an acid degrease. Alternatively, dipping in an acid desmut solution before degreasing will remove the magnesia. The latter may not be desirable as, in time, it will contaminate the desmut solution. The fingerprints are visible due to acid in the sweat on fingers locally removing the magnesia in the mixed oxide film. Aluminium extrusions or sheet in the mill-finish conditions should always be handled by operators wearing clean cotton gloves.

3d. Etch staining

When a load of sections is withdrawn from an etching solution, depending upon the solution temperature and the ambient temperature, the transfer time to the post-etch rinse can be quite critical. If this is too long, then the etching solution may dry onto the surface before it can be rinsed off. A non-uniform film of aluminium hydroxide then forms on the surface that does not rinse off and is not easily removed in the subsequent desmut stage. A very severe example of etch staining is illustrated in Figure 48.



Figure 48. Example of severe transfer etch staining on 6063 alloy extrusion.

The defect is rare but where it is encountered the etch temperature and transfer times from the etching solution to the post etch rinse should be investigated.

3e. Spangle etch or galvanising

This defect has a characteristic galvanised appearance due to the very pronounced preferential attack of the grain structure in the caustic soda etching stage as seen in Figure 49. The problem is usually associated with the level of zinc in the etching solution or in the alloy. When the concentration of zinc in a 6063 alloy is greater than 0.03%, some simple caustic soda based etches will produce this spangle finish (see figure 50). Simple caustic soda based etches will also produce the spangle finish on any 6063 alloy, irrespective of its zinc content, when the level of zinc in the etch reaches about 50ppm.



Figure 49. SEM picture of the surface of a 6063 extrusion showing spangle etching and illustrating the 5μ m step between grains caused by the preferential attack. (x 2000)



The maximum Zn content for extrusions in 6063 alloy to be used for architectural anodizing should not exceed 0.03%. Modern etches contain additives formulated to complex the zinc and hence eliminate the problem regarding zinc contamination of the etching solution. The zinc is often precipitated as zinc sulphide using an additive based on sodium sulphide. This is the reason for many long-life etch systems turning very black during use.

Figure 50. 6063 extrusion containing 0.04% Zn showing a light spangle etch.

3f. Inconsistency or variation in etching response

When a batch of etched and anodized aluminium in the same allov exhibits a difference in degree of mattness it could be due to one of several causes. A typical example of the degree of variation that can occur is shown in Figure 51. Causes could be a variation in anodic film thickness from one part to another, variation in the etching conditions used in the pre-treatment or the anodizing conditions used from one load to another, or some metallurgical variation from one part to another. The anodic film thickness should be measured to establish that the cause is not due to large differences in film thickness. The anodic film should then be stripped from samples illustrating the variation, using the standard chromic acid phosphoric acid stripping solution and their appearance examined again. If the samples now appear the same, variations in anodizing conditions used, could be responsible or the samples may be of a different alloy or temper. Check the chemical composition and temper of the samples. If there are no significant differences, re-anodize the samples and, if they are now the same, the original anodizing conditions should be suspected. If the difference is still present, mechanically polish one face of each



Figure 51. Variable etching response of 6063 extruded sections as etched and anodized.

sample and then re-etch them in 10% NaOH at 60°C. If the polished and etched surfaces now all look alike, it suggests lack of control in the original etch process used by the anodizer. If they still show a difference in mattness then check the size and distribution of Mg₂Si precipitate in the samples. Metallurgical factors that may affect the etch response of 6063 extrusions are well documented in technical literature. In cases where the above tests have indicated that the problem is associated with the metallurgy of the aluminium there is nothing the anodizer can do to overcome this. In such cases the metal usually has to be replaced. Where reprocessing eliminates the difference, the anodizer needs to look closely at the etching and anodizing conditions being used.

3g. Hot spot (also called soft spot or black spot)

A hot spot is a discoloured area sometimes seen on 6000 series alloys and is usually black on clear anodized finishes, as shown in Figure 52, but it can be white or grey on clear and coloured finishes. The defective areas are only on one face of the section and are usually at regular intervals along its length. If the defective sample is etched in a 10% NaOH etching solution at 60°C a heavy black smut will be observed in the area of the hot spot. This is a metallurgical problem, not an anodizing fault. Hardness readings taken in these areas will usually produce significantly lower readings than in the normal areas on the section. The defect is caused by excessive Mg₂Si precipitation in these areas, due to differential cooling on the extrusion run-out table or walking beam.



Controlling the time the hot sections are allowed to stand on the run-out table or the walking beam slats, when the extrusion is at a temperature higher than 230°C, should help to eliminate the problem. Forced air-cooling and purpose-designed materials, such as Kevlar or Railco, formulated to reduce the rate of heat conductivity from the extrusion have practically eliminated this problem. A cooling rate on the extrusion run-out table of 1°C per second, down to 200°C, is considered to be typical for a good air quench on 6063 alloy extrusions. The hot spot type defect is generally most likely to occur on thick wall hollow extrusions.

Figure 52. Example of a hot spot on an etched and anodized 6063 extrusion.

3h. Weld stain

The affect of localised overheating of 6063 alloy during TIG or MIG welding of aluminium alloys can result in some modification to the precipitate metallurgy in the heat-affected zone. This may manifest itself as an area of different colour or degree of mattness when the welded part is etched and anodized, as illustrated by the examples in Figure 53 and 54. The defect is usually visible at the etching stage and will still be present after anodizing.



Figure 53. Staining on a 6063 alloy welded and linished mitred window frame joint after normal etching and anodizing. The dark nature of the weld suggests the filler rod used for welding contained a higher silicon content than that of the alloy. The heat-affected zone in the extrusion adjacent to the weld is just visible.



Figure 54. Heat-affected zone on a sample of thin gauge Al-Mg sheet when the part was welded on the back side only of the sheet.

There is no simple method of overcoming the problem of these heat-affected zones. The effects may be minimised by using weld filler rod of a chemical composition as near as is practical to the alloy being welded. In addition, the use of heat sinks on the back of the part being welded and, where practical, just welding the back of the component will reduce the problem. The welding technique known as flash butt-welding is the best method of reducing heat-affected zones in the weld area. This method of welding may not be practical on all components, depending upon their size and shape. The most popular method of eliminating this problem is by the use of mechanical joining techniques.

3i Container skin

Sometimes the skin on the container of the extrusion press can become extruded into the section surface or subsurface. When etched and anodized this will show as a different texture to the bulk of the material and may present as illustrated in Figure 55.



Figure 55. Effect of container skin contamination after etching and anodizing a 6063 alloy extrusion.

The cause of this type of problem is usually associated with some ovality of the container on the extrusion press. Ensuring the correct temperature differential between the container and the ingot may also help to reduce the problem. The container should always be at a lower temperature than the ingot.

3j Barnacling

The name, barnacling, has been given to a defect that can occur in chemical brightening solutions containing phosphoric acid. Multi-faceted crystals, about 25µm in height, form on the surface of the brightened part during the brightening process. Typical examples of these crystals are shown in Figure 56. They are in fact crystals of aluminium phosphate and only form when the water content of the brightening solution is too low.



Figure 56. Barnacling on a sample of chemically brightened 6463 alloy.

An addition of water to the brightening solution usually solves the problem.

3k Anodizing burn

When the anodizing current density on a component is above a certain critical level, the anodic film may rapidly dissolve. This is known as 'burning' and it usually takes place at a weak point in the anodic film, due perhaps to a heavy die line or scratch in the substrate surface, a drilled hole or sharp edge or even a large intermetallic constituent. The lower resistance of the barrier layer at the weak point results in a localised higher current density and hence an increase in the temperature at that point. The metal/oxide interface overheats as a result of the high current density and the anodizing process breaks down and becomes a form of electrolytic etching. The problem sometimes occurs at a poor electrical contact between the aluminium being anodized and the rack material. Alternatively, where the agitation of the anodizing electrolyte is poor or there is a weakness at the metal/oxide interface, the local current density will increase resulting in overheating at this point. Once these situations occur, the problem is self-perpetuating and the net result is a large white shiny area (see Figure 57) and, in extreme cases, complete dissolution of the substrate. The aluminium high-copper alloys are very prone to burning particularly during hard anodizing.

The solution to the problem is to improve electrolyte agitation over the part and not to use too high an anodizing current density. In the case of hard anodizing of aluminium-copper alloys, attention to the anodizing electrolyte composition is often necessary.



Figure 57 (right). An example of anodizing burn in sulphuric acid electrolyte.

31. Poor rinsing between anodizing and colouring

After anodizing it is important to remove substantially all the aluminium ions dissolved in the acid electrolyte trapped in the pores of the anodic oxide film on the surface. Rinsing the anodized parts in a very clean and pH-neutral rinse directly after anodizing, results in the precipitation of aluminium hydroxide in the pores. This gelatinous precipitate of aluminium hydroxide blocks the pore of the anodic film resulting in a non-uniform deposition of colouring species in any subsequent colouring process. An example of an anodized finish rinsed in a neutral rinse only, after anodizing and then coloured in a red dye solution is shown in Figure 58.



Figure 58. Patchy dyed finish due to poor rinsing of an anodic film before colouring.

The first rinse after anodizing should always be in an acidic solution, preferably pH 2 or less, to ensure that the aluminium ions are rinsed from the pores of the anodic film. The anodized parts should then be rinsed in a second, less-acid rinse before dyeing or electro-colouring. In an anodizing plant operating at normal production rates, the post anodizing rinse is normally acid due to drag-over of the anodizing electrolyte. It is when this rinse is emptied for whatever reason and renewed with clean water, that the problem is most likely to occur. Under such circumstances the addition of an amount of the anodizing electrolyte sufficient to adjust the pH of the rinse to 2.5 should prevent the problem.

3m. Gas trapping

The trapping of air from the air agitation system or gas evolved by electrochemical reactions in the anodizing or colouring process stages, can result in pockets of gas on the underside of sections. These gas pockets act as insulators or masking agents. Depending upon the process-stage where such gas trapping occurs, it may inhibit the actual anodizing process or a subsequent colouring stage. The defect appears as random spots or areas of different hue or colour, on one face of a section. Often the anodic film is thinner in these areas. With dyed or electro-coloured finishes the colour may be lighter or darker in these areas depending upon the method of colouring, as seen in Figure 59.



Jigging the sections in a manner such that gas cannot be trapped under a horizontal surface or that any gas trapping is on a non-significant surface should eliminate the defect. Samples showing the defect can be stripped and reprocessed. For some types of thin film finishes it may be desirable to replace the air agitation with some form of mechanical agitation or use an eductor, hence eliminating one source of the problem.

Figure 59 (left). Typical examples of non-coloured areas due to gas trapping

3n. Colour differences

Colour differences are visually detectable and may be due to poor control of the colouring process. However, they can also be caused by a variable etch response of the extrusions and should be examined using the techniques described for this problem. (See 3f) An example of the latter is where the alloy ageing process is varied such that the size and distribution of the Mg₂Si precipitate is significantly different. This condition is indicated by a variation in colour of the smut after caustic etching as seen in Figure 60 and sometimes in the anodic film after anodizing and colouring as is illustrated in Figure 61. This variation in ageing conditions is not always detectable by measuring the hardness of the alloy and metallurgical examination is required to identify the variation.



Figure 60. Variation of smut levels on two 6063 extrusions having different size Mg2Si precipitates due to under-ageing and over-ageing, after etching in 10% NaOH at 60°C for 10 minutes.



Figure 61. The same samples as in Figure 60 after anodizing and dyeing black.

Any prolonged immersion of the 'as-etched' material in an acid rinse prior to anodizing can enhance these effects and under optimum pre-treatment and anodizing conditions, it is often possible to process 6063 extrusions even with different precipitate conditions, to a satisfactory finish. However, this should not serve as an excuse for the aluminium extruder to tolerate such variations in their extrusions, and every attempt should be made to produce a consistent product in terms of Mg₂Si precipitation.



A similar colour variation due to differences in Mg₂Si precipitate size or distribution can occur during electrocolouring, particularly with the interference techniques used to produce grey colours. In this instance the effect is often just to change the tone of the grey colour from a neutral to a bluer overtone as illustrated in Figure 62.

Figure 62. Variation in colour within a single load of interferencecoloured grey finishes due to poor control of the ageing practice on the extrusions resulting in differences in Mg₂Si precipitate size. Colour match problems can arise from lack of control of the anodizing and colouring processes and every precaution should be taken to ensure consistency in these practices.

Poor colour match can result from poor film thickness control as well as lack of control of the dye bath in the case of dyed finishes. Electro-colouring is more complex and colour control is usually a function of the process as well as the voltage-time regimes used. Colour can also be very dependent upon etching, rinsing and racking geometry. Because of the variables in the substrate aluminium alloy, and the number of critical process parameters in producing coloured anodic finishes, it is never practical to obtain an exact match from one rack load to another or in some cases, there will be colour variations on the same rack. All colour-anodized projects should be carried out on the basis of upper and lower colour limits as agreed by all parties. A set of these samples are held by all interested parties and can then be used in cases of dispute over colour match. Although it is not possible to define, in absolute terms, what the allowable colour variation should be for colour anodized work, the samples in Figure 63 would not be considered to be untypical for dark and light colour limits on a medium bronze finish. Regrettably, and without assigning any blame, problems where the customer is unhappy because of colour mismatch, either within a single consignment or over successive consignments, are all too common.



Figure 63. Fairly typical dark and light limits for a medium bronze anodized finish.

The degree of colour variation illustrated in Figure 64 however, would be considered to be too wide in the eyes of most architects, although it is a very subjective assessment.



Figure 64. Poor colour match on an architectural bronze anodized finish.

In the event of a dispute over the consistency of the colour match on a particular project the agreed dark and light colour limits should be used in any arbitration. However, it should be noted that the angle of viewing, the design of the extrusions or panels and how adjacent flat panels are located, all have an effect on perceived colour. The architect of a well-designed building should have taken such potential problems into account at the design stage.

To minimise colour variation, the anodizer should ensure that the 6000 type alloy aluminium extrusions are produced from a single ingot source and are preferably produced from primary ingot rather than remelted or secondary ingots. Wherever possible the ingot should be from a single cast lot. These rules also apply to sheet ingot used to produce curtain walling panels. However this is easily taken care of by using an anodizing quality

sheet in 5005A alloy for this purpose and, as such, these precautions are embodied in the process for producing this alloy. The anodizer should make sure that all etching, anodizing and colouring solutions, and their operating conditions are kept under close control to ensure optimum colour uniformity. The science and technology of colour measurement are advancing quite rapidly, and costs of such instruments are falling, both for continuous on-line measurements and those made in the laboratory. Although it has long been asserted that the human eye is the most sensitive means of discriminating between colour shades, the latest instrumentation now challenges this situation.
3o. White spots on electro-coloured work

This defect can occur on electro-coloured finishes produced using nickel or cobalt based colouring electrolytes. The white dots are usually numerous and very fine as seen in Figure 65. They are generally on at least two of the section surfaces, the top surface and the surface, as racked on the jig, which faces towards the pre-treatment end of the anodizing line. The defect usually occurs when a fine caustic soda spray, from the etching process, settles on the anodized load as it is transferred from the anodizing stage to the colouring electrolyte and inhibits colouration in these areas. There is usually some fine spalling (see 3p) associated with the white spot. It is sometimes possible to detect sodium in the spalled area using X-ray analysis but in many cases, the sealing process has removed all such evidence. This defect should not be confused with the spalling, or anodic film detachment, that can occur on some anodized and dyed strong alloys (Al-Mg-Zn in particular) that is sometimes called blistering. This type of film detachment is usually associated with the intermetallic constituents in combination with the anodizing conditions, both of which can be very different depending upon the alloy being processed.

Reprocessing the samples should eliminate the defect providing steps are taken to extract the caustic mist. Alternatively, care should be taken to ensure a load is not removed from the etching solution while anodized work is in transfer to the colouring stage.

Figure 65. White spots due to NaOH spray settling on an anodized surface before electro-colouring.



3p. Spalling

Electrolytically coloured anodic films can be susceptible to spalling. This is a detachment of the anodic film that may occur in the colouring solution or the during the hydrothermal sealing process which follows. Examples of the problem have also been observed in service, although this is very rare and usually only associated with aluminium high-magnesium (2.5% or higher) alloys. The problem is relatively unusual and does not occur when the correct voltage-time programmes and rate of voltage-change, are adhered to. Colouring electrolytes based on nickel and cobalt salts are more prone to this defect than those based on tin salts. Contamination of nickel and cobalt colouring electrolytes with sodium ions can cause spalling as well as difficulty in obtaining dark bronze and black shades. Anything that results in excessive hydrogen evolution at the metal/oxide interface, such as too high a colouring voltage, high sodium content in the colouring electrolyte or high colouring electrolyte temperatures, can produce spalling. Sometimes inclusions in the base metal can cause spalling but they are usually more likely to result in the defects described in sections 2g and 2i. Spalling is quite variable in terms of the size of the areas of detachment as can be seen in Figure 66.



Figure 66. Various forms of spalling on a 6063 electrolytically coloured extrusion caused by colouring at too high a voltage.

To eliminate the problem, the voltage-colouring programs should be adjusted to lower the colouring current density and any sodium ions in the colouring electrolyte should be removed by a purpose-designed ion exchange system. The source of the sodium contamination should be identified and eliminated.

3q. Coarse grain

It is unusual to find a coarse grain structure in the normal architectural alloys used in anodizing. However, it is often necessary to use 6082 or 6351 alloys for applications where strength and machinability are required. These alloys, particularly in extruded bar form, can develop relatively coarse grains during the extrusion process. This coarse grain structure may not run along the complete bar and may be more severe towards the back end of the extrusion. It is often variable across the width of the extrusion but is sometimes confined to an area near to the surface when it is described as a coarse outer band effect. When etched and anodized these coarse grains affect the appearance of the product and are often reasons for rejection. Figure 67 shows the variation of this coarse grain effect on components machined from one end of an extruded bar to the other.



Figure 67. Variation in degree of coarse grain on components machined from the same bar stock. The sample on the left has coarse grain, that on the right, normal grain size.

The effect of an outer band of coarse grain on a sample of etched, anodized and black dyed extrusion is illustrated in Figure 68.

A similar problem can occur when attempts are made to anodize forged 6082 alloy an example of which is shown in Figure 69. Such components can exhibit very large grain size, depending upon the thermomechanical history.

There is no easy way of reducing this problem other than to use another alloy. Depending upon the application, alloys such as 6063 or, perhaps a free machining alloy such as 6062, 6061A or 2011, might provide a suitable alternative.



Figure 68. Coarse grain outer band effect causing an apparent difference in colour on an etched, anodized and dyed 6082 extruded bar.



Figure 69. Giant coarse recrystallised grains on a forged, etched and anodized anglers fishing reel.

3r. Crazing

Some anodic films, especially if they are quite hard, can show a tendency to crazing during the final hydrothermal sealing stage of anodizing. Crazing has the appearance of a network of fine lines in a cobweb like pattern across the surface of the anodic film. As well as this thermal crazing, it is possible to form crazing in an anodic film by mechanically bending an anodized component. The fine lines produced by mechanical crazing are very similar to those of thermal crazing but they do tend to run parallel to each rather than in the random fashion typical of thermal crazing examples of which are shown in Figures 70 and 71. The tendency to crazing increases as the hardness of the anodic film increases. Samples having a smooth polished substrate before anodizing are also more likely to craze.



Figure 70. Example of thermal crazing. \sim (x 250)



Figure 71. Example of thermal crazing showing crack in the anodic film. $\sim (x~500)$

Reducing the thermal shock of the sealing solution, by using a 70°C rinse pre-dip will help reduce crazing. Using a more matt finish and keeping the anodic film thickness and hardness as low as is technically acceptable will also help minimise the problem.

3s. Transfer staining

Aluminium that has been chemically brightened is usually given a warm water rinse after the brightening stage and prior to desmutting. Sometimes after the warm water rinsing stage, a tenacious smut remains on the surface that is not removed in the nitric acid desmut solution. This staining is often called transfer etch staining because if the part is anodized without removing the smut a white stain, as seen in Figure 72, results.



Figure 72. Transfer-etch stain on 6063 polished and bright anodized extrusion.

This problem is usually associated with too long a transfer time between the brightener and the warm water rinse. If it is not possible to reduce this transfer time, then increasing the nitric acid content of the brightener or increasing the amount of additive used to aid these longer transfer times on automatic lines may solve the problem. Figure 73 illustrates the effect that increasing the nitric acid content of the brightener from 4 to 5% had on this problem.



Figure 73. Sample on left of tape brightened in solution containing 5% HNO_3 and sample on right brightened under same conditions but with only 4% HNO_3 in the brightening solution.

Sometimes an overall dullness of a section may be indicative of a coarse Mg₂Si precipitate in the 6063 or 6463 alloy being brightened, or it may be due to a low nitric acid content in the brightener or even a thick anodized coating. The latter explanation can most easily be confirmed or eliminated by measuring the film thickness. Stripping the film and reprocessing under optimum conditions is one method of determining whether the problem is metallurgical or due to the brightening process. Such an example is illustrated in Figure 74 where the satisfactory result on reprocessing suggested that it was the brightening process that was at fault. In such cases it is usually the nitric acid content of the brightener that is low, although the temperature, if too low, may have a similar effect.



Figure 74. Example of bright trim section showing an overall dull finish before reprocessing (to right of tape) and a satisfactory finish after reprocessing (to the left of the tape).

The satisfactory bright finish produced by reprocessing suggests that the brightening solution used to treat the original sample was out of balance.

Where the brightness obtained is less than that normally expected, the inevitable question is whether the substrate metal or the anodizing is the cause ?. Two simple tests are first to check the anodic film thickness and if that is satisfactory, to measure the hardness of the metal. If the hardness is lower than expected for the alloy and temper specified, then it could be that the aluminium has been over-aged. Thicker anodic films produce duller finishes. The next step is to check the brightening solution composition and make sure the nitric acid content is not too low. Having done this, the alloy should be reprocessed. If the problem is reproduced, then the alloy is suspect. If, on the other hand, reprocessing produces a satisfactory finish, then the original brightening conditions were most probably defective.

Part 4. Deterioration of the finish in service

Anodic films not formed according to the relevant specifications, may show premature deterioration in service. In the 1960's some architectural finishes were being produced with anodic films of inadequate film thickness and in some cases, with very low hardness values. Although this problem was addressed and practices defined to eliminate it, there are still isolated cases of thin anodic films causing premature pitting and also of soft anodic films resulting in chalking or white bloom. These problems are usually specific to external architectural applications.

4a. Pitting



Pitting of finishes is usually associated with an inappropriate anodic film thickness being used for a particular application. Alternatively, lack of correct regular maintenance can be to blame. Typical examples are given in Figures 75 and 76.

Figure 75. Example of pitting on a bronze anodized architectural anodic finish in service due to inadequate anodic film thickness.



Figure 76. Pitting of an architectural finish in service due to lack of cleaning maintenance.

It is most important to ensure that the specification of an anodized finish for architectural applications is correctly defined. Normally the BS 3987 is used for this purpose in the UK, but there is often confusion when parts to be used on buildings in the UK are processed on the Continent, the Middle East or even North America. The local architectural specifications in these countries may not be as demanding as the British Specification, particularly regarding anodic film thickness requirements and the hardness or abrasion resistance of the anodized finish. It should be noted that BS specification 3987 was developed as a result of architectural anodized finishes displaying two main problems. These were isolated cases of premature pitting or very rapid formation of a white powdery bloom upon exposure to the elements. This specification calls for a minimum average anodized

film thickness of 25μ m with a minimum local film thickness of 20μ m. The other important elements of the specification are a minimum abrasion resistance and adequate sealing quality. It is the abrasion resistance that ensures good weathering characteristics in terms of preventing formation of the powdery bloom. The other important parameter in ensuring adequate performance is regular maintenance of the anodic finish. It makes very little sense to apply a relatively expensive coating to aluminium to enhance its corrosion properties and provide an attractive appearance if it then becomes coated with dust and general grime. Dust particles can become moistened by condensation and absorb SO₂ from the atmosphere. If not removed this acidic dust particle can result in chemical attack of the anodic film surface and in the long term pitting of the film. Regular washing of such finishes with water plus a suitable wetting agent will maintain the appearance of the finish and prevent such pitting. The frequency of the cleaning will very much depend upon the location of the components but usually varies from 6 monthly in aggressive atmospheres to annually in more rural atmospheres. The position of the finish on a building

can also have a significant effect on its performance. Any part that is protected by an overhang such as an entrance canopy or windowsill and is not washed by rain will tend to deteriorate faster than surfaces that are regularly washed by natural rainfall. In short, to form and maintain a good quality anodized finish for architectural applications, the two important criteria are use of a correct specification and regular maintenance. Anodizers usually link any guarantee of an architectural anodic finish with the stipulation that regular maintenance is carried out, and that adequate evidence of that maintenance is documented on a regular basis.

4b. Staining due to mortar or cement splashes

Staining can occur if an anodic film is in contact with wet mortar or cement. This is normally localised and should not happen if adequate precautions are taken during the construction or fitting stage. A typical example is shown in Figure 77. Once stained in this way, an anodic film cannot be refurbished.



It is normal practice to protect anodized coatings during fitting on site, with a suitable protective tape or strippable lacquer coating. This protective coating is allowed to remain in place until the construction work is complete. It is then normally removed and the finish cleaned with water containing about 1% of a suitable wetting agent, such as Teepol.



4c. Staining due to poor sealing

One form of staining is a weathering effect that occurs quite quickly (usually during the first 6 months) on anodized work that has been poorly sealed. As can be seen in Figure 78 it is a whitish bloom and may incorporate other stains where water has run down the surface in an exposed location. Similar forms of staining or bloom can occur on a good quality anodized finish, over a prolonged period of time (3 to 8 years) if the finish is not subjected to a regular cleaning or maintenance program, or where the anodic film was insufficiently hard. This is discussed under weathering bloom in section 4d and chalking in 4f respectively. Staining on a poorly sealed anodic film, whether it has a good abrasion resistance or not, is due to chemical attack and cannot be removed by abrasive cleaning treatments. It will only occur on component parts that were originally sealed with less than acceptable seal quality. The anodic film may have self-sealed in service, making it difficult to establish that the original cause of the problem was a poor sealing quality.



Because this type of weathering stain is due to chemical attack of the anodic film not just on the surface but also within the pores, it is difficult, if not impossible, to remove the staining by any cleaning process. In this, it differs from natural weathering bloom or chalking due to a soft anodic film.

Figure 78. Sample of staining on a poorly sealed anodic film exposed to the atmosphere for about 6 months.

4d. Natural weathering bloom

When a good quality anodic film is exposed to the atmosphere for, say 5 years or more, depending upon the degree of atmospheric pollution, without any regular maintenance, and particularly if it is not washed by rain, a surface bloom may form. This bloom is often referred to as 'weathering bloom' or 'white bloom' and slowly builds up on the surface of the anodic film over a prolonged time. The bloom is a relatively thin micro-rough layer of reaction product that can be removed by a vigorous cleaning treatment. A typical example is given in the right hand panel in Figure 79.



Figure 79. Curtain walling panels that had not been given regular cleaning maintenance showing on the right hand panel the white 'weathering bloom' before cleaning. The left hand panel is a similar panel after cleaning with a Scotchbrite pad and a solution of Teepol in water.

Pumice powder on a damp cloth or pad or a Scotchbrite' abrasive pad and water containing a detergent such as 'Teepol' are often used to remove this type of bloom. This removes the 'white bloom' and a satisfactory surface is restored as shown in Figure 79, which, if then regularly maintained, usually performs perfectly satisfactorily for many years. No significant film thickness loss should occur on a good quality anodic film during this cleaning process. This bloom should not be confused with the white staining due to poor sealing (4c) or chalking caused by a soft anodic film (4f).

4e. Iridescence

Iridescence is another form of staining caused by weathering or a further self-sealing of the film. It is usually most evident on electrolytically coloured finishes; in many cases occurring on finishes that have not been cleaned during the first 6 to 12 months of service. An example is shown in Figure 80. It can be removed by cleaning the anodized surface using a mild abrasive, such as pumice, on a damp cloth. No significant film thickness loss should result from the cleaning.



Figure 80. Iridescence formed during outdoor exposure on a sample of anodized and electrolytically coloured aluminium.

Once removed by the mild abrasive treatment the problem does not normally recur and in the case of finishes that have been regularly cleaned since installation it is unlikely to occur at all.

4f. Chalking or white bloom on soft anodic films

Chalking, or the formation of a heavy white deposit as illustrated in Figure 81, on an anodic film during the first year after installation on site, can be serious. It is usually associated with an anodic film of insufficient hardness, and the surface is often powdery (see Figure 82). The chalking can be removed by abrasive cleaning using a purpose designed anodized aluminium polish or pumice powder on a damp cloth. There is usually a significant (5 - 8µm) film thickness loss during such a cleaning treatment. An alternative cleaning media is Scotchbrite abrasive pads wetted with a solution of Teepol in water. Even after such cleaning treatments the bloom may return and a second cleaning will be required, removing even more anodic film, to eliminate the problem.



Figure 81. Chalking of an anodic finish in service due to a soft anodic film.



Figure 82. Detail of surface deposit on chalked anodic finish showing the powdery nature of the flaked surface.

Such chalking is indicative of a soft anodic film and there is little that can be done to rectify this problem, other than removing the soft outer layer and this is no guarantee that the problem will not return. Attention to the quality of the anodic film in terms of abrasion resistance will prevent such defects. In general, soft anodic films are produced when the anodizing temperature or electrolyte concentration is too high or the anodizing current density is too low. The problem is more common on the thicker films specified for architectural use.

Part 5. Basic approach to defect recognition

There are a number of simple but useful rules that can be followed when investigating the cause of defects.

- Obtain a sample exhibiting the problem and, if possible, a sample of the alloy before anodizing.
- Obtain as much information as is possible regarding the history of the part, in particular where it has been stored before or after finishing.
- If pitting is present, check where the pits are located, what shape and colour they are, whether there is an anodic film over the pits and is there any corrosion product to be seen, associated with the pits.
- If corrosion product is present, it should be analysed. This may indicate the source of the contamination responsible for the corrosion. Aluminium components corroded before anodizing usually have no corrosion product in the pits as the pre-treatment and anodizing processes have removed it.
- If streaking is seen, check whether the streaks are parallel to the extrusion direction and of constant width. Does the spacing between streaks change, or do they get wider or narrower along the extrusion length. Check whether the streaks are removed or change shape or direction, when subjected to a tapered mechanical polish, followed by etching.
- If the finish is of a non-uniform appearance, stained or showing white bloom, ascertain whether the defect is only on one face of the section. If the surface is stained, can the surface stain be removed by cleaning? Does cleaning of the surface remove any anodic film? (use a thickness tester for this)
- Obtain information about the process used to produce the finish and, if appropriate, details of the specification to which it was produced, its service history and any cleaning treatments that may have been used on the building or part.
- Check for any unusual environmental conditions in the area where the problem occurred.

These details or observations provide the investigator with basic information. A strategy for investigating the problem can then be established and the appropriate tests or examination carried out as described in this guide. Having established the cause, it may be possible to recommend methods of eliminating or reducing its recurrence.

Several authors have published attempts to classify defects based on where they originate. Typical groupings are: - ingot (extrusion or rolling), handling, storage, transport, mechanical pre-treatment, degreasing, etching, brightening, conversion coating, rinsing, anodizing, colouring, sealing and in-service. Some of these papers as well as useful books are listed in Appendix 3.

Prevention is better than cure

The cost and customer dissatisfaction associated with problems related to the surface finishing of aluminium must make it worthwhile to take every precaution, at the design and planning stages, to ensure that the most suitable alloy and anodizing process is specified for each project. In addition tests to ensure that the finish is as specified and will perform satisfactorily, are available and should be carried out to ensure compliance. Suitable specifications exist for anodizing and painting of aluminium. The most common anodizing specifications cover anodic film thickness, seal quality, resistance to wear, resistance to fading in UV light and colour match samples (the last two for coloured anodized alloy) In addition to National and International Standard Specifications, many companies such as building contractors, automotive and aerospace have their own product, process or finishing specifications that finishers may be requested to meet. Some of these are detailed in Appendix 1. Correct use of such specifications go a long way to ensuring that many of the defects describe here do not materialise. A specification alone is not enough and the customer should ensure that the relevant quality control tests required to ensure compliance with such a specification. The finisher should carry out such tests in-house but in cases where there is doubt, the use of independent inspectors may be desirable or alternatively the customer may wish to carry out their own in-house OC tests. Relatively simple test specifications are available to determine the important properties of an anodized finish and these are listed in Appendix 2. Anodizing guality alloys such as 6463 extrusion and 5457 and 5657 sheet are available for bright anodized trim applications. Several anodizing quality versions of 5005 sheet are available for architectural anodizing and, although 6063 extrusions are used extensively and in fact almost exclusively for architectural anodizing, there is no specific architectural version of this alloy. There are several versions of the 6000 series Al-Mq-Si alloys and it is important that any specification for material that has to be anodized, requires that the sections should be produced from the same version of the alloy and preferably the same ingot source. Use of more than one type of 6000 series alloy will result in significant differences in etch

response and, therefore, the final appearance of the finished product. Ingots with a minimal shell zone, or that have had the shell zone removed by scalping, are obviously preferred for architectural anodizing projects. Any aluminium that is known to be required for a finishing operation should have explicit packaging, transit and storage instructions associated with the order. Communication between supplier, fabricators, finishers and final user of the product is an essential from outset of any project. Correct design, use of the correct specifications, and ensuring that these are carried out by the finisher, followed by correct packaging, handling and transportation will go long way to having a satisfied customer.

Part 6. Chromic Acid Anodizing

6a General Comments

Chromic acid anodizing of aluminium has always been a rather specialised activity and is a finish offered by relatively few anodizers. In recent years, environmental legislation has borne down extremely hard on all surface treatment processes involving chromium, especially in its hexavalent state. Of course, there is a valid distinction between processes on the one hand, such as chromate conversion coating, which form a coating that includes hexavalent chromium, and those such as chromium plating or chromic acid anodizing, which although they use hexavalent chromium, do not produce coatings containing this species. Nevertheless, both hexavalent chromium plating are subject to increasingly onerous environmental legislation (e.g effluent and airborne emissions) and as such, a cloud hangs over both processes.

Both aesthetically and in functional terms, chromic acid anodized aluminium has much to offer. In terms of the former, its milky white finish could easily be mistaken for an enamelled coating. Aluminium knitting needles are often finished using this process. In functional terms, it offers an excellent basis for subsequent organic coatings and also affords one of the most corrosion-resistant of all anodized finishes. It is widely used as a protective coating on aluminium components in the aircraft industry. Chromic acid anodizing is often preferred in aircraft construction because, should anodizing acid be trapped between surfaces, as in a riveted component, where its complete removal by rinsing is almost impossible, the chromic acid is much less aggressive to the aluminium substrate than similarly trapped sulphuric acid, indeed with its oxidising action, it may in fact be protective. However chromic anodized coatings are softer than their sulphuric acid analogues and less wear-resistant. These advantages and drawbacks have therefore to be weighed one against the other.

An interesting, if very specialised use of the process is as a method for crack detection on aluminium castings or forgings. If there are any flaws or cracks in the casting or forging, the anodizing acid will penetrate these and become trapped in the flaw. Then when the part is removed from the anodizing electrolyte, the chromic acid seeps out of the flaw or crack and stains the area of anodic film adjacent to the defect, hence identifying its position.

6b. Defects in Chromic Acid Anodized Work

Although none of the examples of the defects in Parts 1 to 3 specifically mention a chromic acid anodized coating, this form of anodizing would also reveal many of the defects previously described.

All of the pitting defects (Part 1), perhaps with the exception of pitting during anodizing (1h), could equally be present after chromic acid anodizing (see figure 83).

Similarly, all of the streaking defects (Part 2) would be seen through an anodic film formed in chromic acid. The one exception would be flecking (2f), which is specific to electrocolouring for which the film produced in chromic acid anodizing is not suitable.

Of the defects listed in Part 3, most of these would show through a chromic acid anodized coating with the following exceptions: - anodizing burn (3k), white spots on electro-coloured work (3o), spalling (3p) and crazing (3r). The latter does not occur because the anodic film produced in chromic acid is relatively thin and much softer when compared with the film produce in sulphuric acid.

In Part 4 which deals with the deterioration of finishes in service, the comments in this section would apply to equally chromic acid anodized films with the exception of natural weathering bloom (4d), iridescence (4e) and chalking or white bloom (4f) on soft films.

Chromic acid anodized films may have better corrosion resistance than sulphuric acid anodized films of the same anodic film thickness. However, they are not used for architectural finishes because the maximum thickness obtainable on a chromic acid film is only about 8µm compared to 25 to 35µm for sulphuric acid anodized films. Also the abrasion or wear resistance of the chromic acid film is much lower.

As decorative finishes the main problems with chromic acid anodized films are the loss of the characteristic opaque appearance or an etching or roughening of its semi-gloss appearance.

Roughening or etching of the anodic film is usually associated with chloride contamination of the electrolyte and, as with the sulphuric acid electrolyte, the use of deionised water is recommended in areas where the chloride content of city water is high. Chloride levels in the chromic acid electrolyte should be maintained below 0.2g/l as NaCl.

The loss of opacity is usually caused by contamination of the chromic acid electrolyte with sulphate ions, although about 0.1g/l as SO_4^2 is desirable to obtain some opacity. The best opacity is obtained between 0.2 and 0.3g/l SO_4^2 . Above 0.3g/l SO_4^2 the film becomes transparent and loses its opacity.

The other possible cause of a non-transparent coating is a very thin anodic film, say less than 2μ m (a typical anodic film thickness for chromic acid anodizing would be 3 to 7μ m). Thin anodic films can occur on certain alloys particularly when they are mixed with other alloys on the same anodizing load. An example of this would be to anodize 5000, 6000 and 2000 series alloys on the same jig load using the normal Bengough Stuart chromic acid anodizing process. The resultant anodic film thicknesses would be as follows plus or minus about 1 micron.

Alloy	Anodic film thickness (µm)
AA5056	9
AA6063	5
AA2014	2

Similarly, care should be taken not to use 1000, 5000 or 6000 series alloy jigs to rack 2000 series alloys for anodizing as all of the current will go to the jig and very little to the component being anodized. It is best to use jigs of the same alloy as that being anodized or all jigs need to be made from a 2000 series alloy.

The alternative is to use plastic coated aluminium jigs where only the contact point is unprotected. The area of the contact is then so small that it does not have a significant effect on the components whatever alloy they might be.

The use of titanium jigs is normally not recommended for chromic acid anodizing, as there is a danger of the anodic film on the titanium breaking down at higher voltages. Again an alternative may be to use plastic coated titanium jigs with just the contact tips exposed but this does not always solve the problem.



Example of chromic acid anodized finish showing some pitting on mortar bomb fins probably due to corrosion of the component before anodizing.

Fig 83a (above) Fin showing dark stains

Fig 83b (top right) Fin as chromic acid anodised

Fig 83c (top left) Same fin after removal of anodic film by etching in 10% NaOH at 60°C for 2 to 3 minutes





Appendix 1. Some Specifications for Anodized Aluminium

European

BS EN 12373-1 (ISO 7599) Method for specifying anodic oxidation coatings on aluminium and its alloys.

UK

BS 3987 : 1991 (Amended June 2001) Anodic oxidation coatings on wrought aluminium for external architectural applications.
BS 5599 : 1993 Specification for Hard anodic coatings on aluminium for engineering purposes.
DEF STAN 03-25/1 Sulphuric acid anodizing of aluminium and aluminium alloys.

France

NF A 91-450 (1981) (AFNOR). Anodizing aluminium and its alloys – general specification for anodic coatings on aluminium.

Germany

DIN 17611 (1985). Aluminium and aluminium alloy anodized semi-fabricated products with coatings at least 10µ thick – technical delivery conditions.

Switzerland

SN 237250 (1984). Anodizing of aluminium and its alloys – general directions and technical specifications.

Japan

JIS H 8601 1992. Anodic oxidation coatings on aluminium and aluminium alloys.

Appendix 2. Test Method Specifications for Anodized Finishes

BS EN 12372-2 (ISO 2106) Determination of mass per unit area (surface density) of anodic oxidation coatings (gravimetric method).

BS EN 12373-3 (ISO 2128) Determination of thickness of anodic oxide coatings: non-destructive measurement by split-beam microscope.

BS EN 12373-4 (ISO 2143) Estimation of loss of absorptive power of sealed coatings: dye spot test with prior acid treatment.

BS EN 12373-5 (ISO 2931) Assessment of sealing quality by measurement of admittance.

BS EN 12373-7 (ISO 3210) Assessment of sealing quality by measurement of the loss of mass after immersion in phosphoric-chromic acid solution.

BS EN 12373-8 Determination of the fastness to ultraviolet light of coloured anodic oxide coatings.

BS EN 12373-9 (ISO 8251) Measurement of wear properties with an abrasive wheel wear teat apparatus.

BS EN 12373-10 (ISO 8252) Measurement of mean specific abrasion resistance with an abrasive jet test apparatus.

BS EN 12373-11(ISO 7668) Measurement of specular reflectance and specular gloss at angles of 20°, 45°, 60° and 85°.

BS EN ISO 1463 Measurement of local thickness of metal and oxide coatings by the microscopical examination of cross-sections.

BS EN ISO 2360 Eddy current method for measurement of coating thickness of non-conductive coatings on non-magnetic basis metals.

BS 6161: Part 11 (ISO 7669) Measurement of total reflectance using a photoelectric reflectometer. BS 6161 : Part 18 Determination of surface abrasion resistance.

Appendix 3. Relevant Publications and Books etc

Publications

E. P. Short, A. J. Bryant, "A review of some defects appearing on anodized aluminium." Trans. IMF, 1975, <u>53</u>, (4), 169-177.

R. Akeret, H. Bischel, E. Schwall, E. Simon, M. Textor, "The Influence of chemical composition and Fabrication Processes on the properties of Anodized Aluminium Surfaces." Trans. IMF, Feb 1990, <u>68</u>, (1), 20.

Don Johnson, "Highlights of the First Annual Anodizing Workshop." Light Metal Age, Oct 1992, 39-40.

E. P. Short, P. G. Sheasby "Finger print and general atmospheric corrosion." Trans. IMF, 1974, <u>52</u>, (1), 66-70.

D. J. Scott, E. W. Skerry, "Protection of Aluminium in Storage and in Transit." Br. Corr. J, Nov 1970, <u>5</u>, 239-246

D. J. Arrowsmith, A. W. Clifford, "The Incidence and Avoidance of Gassing Defects in Chemical and Electropolishing of Aluminium." Trans. IMF, 1978, 56, (1), 46-50.

P. G. Sheasby, "The properties of anodic oxidation coatings on aluminium." Aluminium Industry, Mar 1983. 2, (1).

B. R. Ellard, "Defect Analysis in Anodizing" Proceedings of the Fifth International Extrusion Technology Seminar – 2000 May 2000 Chicago

Books

"The Surface treatment and Finishing of Aluminium and its Alloys" Sixth Edition P.G. Sheasby and R. Pinner, Finishing Publications Ltd, Stevenage (www.finishingpublications.com)

"The Technology of Anodizing Aluminium" A. W. Brace. Interall.

"Anodizing and Colouring of Aluminium Alloys" By Satoshi Kawai Finishing Publications Ltd. (www.finishingpublications.com)

"Theories of Anodized Aluminium, 100 Q & A" T Sato and K Kaminaga Kallos Publishing Co Ltd.

CD-ROM & On-Line Database

Surface Finishing Abstracts

A fully searchable web-based database with up to 10,000 abstracts on all aspects of surface treatment of aluminium and over 80,000 abstracts covering the whole field of all aspects of surface finishing, effluent treatment, printed circuit boards etc. <u>www.surfacequery.com</u>

Appendix 4. A brief description of the defects covered and their causes.

Pitting defects – Designation Comments				
1a. Atmospheric corrosion	Characteristic random pitting that occurs in transit or storage prior to			
	finishing, often not visible until after etching. Pits usually only on certain			
	surfaces exposed to the atmosphere.			
1b. Finger print corrosion	Occurs due to handling of extrusions and is usually only visible after			
	etching. Pits have characteristic finger print shape.			
1c. Paper corrosion	Pitting of surface in contact with wrapping paper or cardboard, usually most			
	sever if paper becomes wet and is of the wrong chemical composition.			
1d. Traffic marking (fretting corrosion)	Due to rubbing of samples in transit due to bundles not being correctly			
	interleaved or too loosely packed. Usually visible in the mill finish condition			
	when unpacked.			
1e. Acid or alkali corrosion	Due to chemical splashes on mill finish samples. An amount of corrosion			
	product may be visible on the mill finish surface but pits usually			
	exaggerated by pre-treatment.			
1f. Rinse water corrosion	Occurs in rinse water after etching, brightening or desmutting. Usually due			
	to pH of rinse being too near to neutral and containing no oxidising			
	chemical.			
1g. Pitting in brightening solutions	If on all surfaces as brightened it is usually due to a brightening solution			
	imbalance or if only on certain surfaces it can be caused by dried on			
	polishing compound or atmospheric corrosion.			
1h. Pitting during anodizing	Usually due to chloride in the anodizing solution, characteristic black star			
	shaped pits visible after anodizing.			
1i. Pitting due to galvanic effects	White stains at the centre of which is a fine pit usually cause by galvanic			
	effects between titanium jigs or stainless steel tanks and the aluminium			
	during dyeing or sealing.			

1j. Pitting of anodic film in service	Pitting of certain exposed surfaces of the anodic film in service, the pitting may be due to the environmental conditions or a thin anodic film.
Streaking defects – designation	Comments
2a. Segregational streaking	This is a non-uniform distribution of intermetallic constituents in the original ingot.
2b. Structural/Die design streaking	Usually associated with die design and metal flow during the extrusion process.

2c. Die line streaking	This may be caused a poor die bearing surface but can also be associated
	with other extrusion parameters.
2d. Longitudinal weld streaking/defect	Due to local changes in metal flow into the weld junctions within the welding
	chamber producing structural or grain size variations or changes in
	precipitate size and distribution.
2e. Transverse weld streaking	Due to debris of oxide and other non-metallic inclusions trapped on the
	interface of the weld junction between successive ingots in a porthole
	spider of bridge die.
2f. Flecking	Generally considered to be due a non-uniform distribution of the iron
	bearing phases in the as cast ingot. May be associated with grain refining
	techniques.
2g. Clusters of intermetallic particles	Usually associated with the presence of cluster of oxide spinels or titanium
	diboride grain refiner particles in the original ingot
2h Carbon marking	Occurs when a bet extruction rules on the carbon blocks or rollors on the
	extrusion press run-out table.
2i. Back end defect	The presence of ingot skin in the back end of the extruded length caused by
	the insufficient discard being allowed on the billet during extrusion.
Non-uniform appearance - designation	Comments
3a. Mechanical polishing burn	This is due to a modification of the metallurgical structure of the alloy,
	usually due to overheating during mechanical polishing.
3b. Water staining and/or poor	Caused by the inability of the degreasing or cleaning solution to remove
degreasing	heavily oxidised areas on the mill finish material.
3c. White etch bloom	A non- uniform white etch pattern due to the inability of the degreasing
	practice to remove the magnesium oxide present on the surface of air
	guenched AL-Mg-Si alloys.

3d. Etch staining	Caused by drying on of the etching or brightening solution during transfer
	from the hot process solution to the post process rinsing stage.
3e. Spangle etch or galvanising	This may result from a high level of zinc in the etching solution or when the
	zinc content of
	Al-Si-Mg alloys is much above 0.03%.
3f. Inconsistent or variation in etching	Can be caused by lack of control of the etching process from load to load
response	but if occurring on the same load is more likely to be due to variation in the
	metallurgy of the alloy.
3g. Hot spot (also called soft spot or	Due to non-uniform cooling of AL-Mg-Si alloy extrusions on the extrusion
black spot)	run out table, usually occurs when section is in intermittent contact with
	carbon blocks or rollers.
3h. Weld stain	This is cause by a localised change in the metallurgical structure of an alloy
	due to the heat-affected zone in the weld area.
3i. Container skin	When the extrusion press container is not correctly cleaned or has some
	ovality, a build up of oxide may occur which when released will contaminate
	the extrusion surface.
3i, Barnacling	An aluminium phosphate deposit that forms on the surface of chemically
	brightened aluminium due to insufficient water in the brightening solution.
3k. Anodizing burn	A dark or light stain due to too high an anodizing current density resulting
	in localised burning of the anodic film
31 Poor rinsing between apodizing and	A non-uniform distribution of colour in an anodic film due to the rinsing
colouring	stage not removing soluble aluminium ions from the anodizing electrolyte
Colournig	contained in the nerves of the anedic film
2m. Cas transing	Areas of non-coloured anodic film resulting from gas being transport under a
	Areas of non-coloured anound mini resulting from gas being trapped under a
	Surface outing difficulting of colourning.
3n. Colour differences	Poor colour match due to lack of control in the colouring process or a
	variation in the etch response of the aluminium resulting in different levels
	of reflectivity and hence apparent colour.

30. White spots on electro-coloured	Usually due to sodium hydroxide spray settling on anodized work during
work	transfer between the anodizing and electro-colouring stages.
3p. Spalling	Detachment of the anodic film during electrocolouring due to contamination of the colouring electrolyte with sodium ions or incorrect colouring conditions.
3q. Coarse grain	A non-uniform appearance on anodized parts due to coarse grains in the alloy usually due to the thermo-mechanical history of the fabrication process. Some alloys are more prone than others.
3r. Crazing	This is a series of fine hairline like cracks in the surface of the anodic film caused by mechanical or thermal shock. Hard anodic films are more prone to this problem.
3s. Transfer staining	A non-uniform stain caused by drying on of smut like deposits from brightening solutions during transfer from the process solution to the post process rinse.
Deterioration of the finish in service	Comments
4a. Pitting	Pitting of anodic films in service due to aggressive environment or too thin an anodic film for the conditions to which it was exposed.
4b. Staining due to mortar or cement splashes	Wet mortar or cement will permanently damage and anodic film due to their alkalinity.
4c. Staining due to poor sealing	A white or non-uniform stain due to chemical attack on a poorly sealed anodic film.
4d. Natural weathering bloom	A slowly forming white bloom that occurs on good quality anodic films when they are exposed to the atmosphere without any regular cleaning maintenance.
4e. Iridescence	A form of weathering on good quality electro-coloured anodic films during the first year or two of exposure. It will not occur where regular washing maintenance of the finish is carried out.
4f. Chalking or white bloom on softy	A powdery film that forms on anodized aluminium where the anodic film is
--------------------------------------	---
anodic films	soft. It may be removed by cleaning but a significant loss in anodic film
	thickness will occur.

Defects - where they originate and at what stage in process they are usually visible

I = stage at which defect is initiated V = stage at which defect is usually first visible

Defect	Ingot	Extrusion	Rolling	Handling	Mill finish	Mechanical	Degreasing	Etching	Brightening	Rinsing	Anodizing	Colouring	Sealing	In service
	-			storage	condition	pre-		-		_	_	_	_	
				transport		treatment								
Pitting defects during handling and processin	g													
1a. Atmospheric corrosion				I										
1b. Finger print corrosion														
1c. Paper corrosion				I										
1d. Traffic marking (fretting corrosion)					V									
1e. Acid or alkali corrosion					V?									
1f. Rinse water corrosion										ΙV	I			
1g. Pitting in brightening solutions									IV		I			
1h. Pitting during anodizing											ΙV		V	
1i. Pitting due to galvanic effects													ΙV	
1j. Pitting of anodic film in service														IV
Streaking defects						·								
2a. Segregational streaking								V			V			
2b. Structural/Die design streaking								V			V			
2c. Die line streaking		ΙV			V			V			V			
2d. Longitudinal weld streaking/defect								٧?			V			
2e. Transverse weld streaking								٧?			V			
2f. Flecking												V		
2g. Clusters of intermetallic particles												V		
2h. Carbon marking		ΙV			V			V			V			
2i. Back end defect								V			V			
Non-uniform appearance defects											•			
3a. Mechanical polishing burn											V			
3b. Water staining and/or poor degreasing							V?	V						
3c. White etch bloom								V			V			
3d. Etch staining										V	V			
3e. Spangle etch or galvanising								V						
3f. Inconsistent or variation in etching response			1					V			V			
3g. Hot spot (also called soft spot or black spot)								V						
3h. Weld stain								V			V			
3i. Container skin								V			V			
3j. Barnacling									I V?	V	V			
3k. Anodizing burn											ΙV		V	
3I. Poor rinsing between anodizing and colouring										I		V	V	
3m. Gas trapping		1		1								ΙV	V	
3n. Colour differences			I	1								ΙV	V	
3o. White spots on electro-coloured work									1			V	V	
3p. Spalling		1		1								ΙV	V	
3q. Coarse grain								V						

3r. Crazing											I	V	
3s. Transfer staining									I	IV	V	V	
Deterioration of finish in service													
4a. Pitting													ΙV
4b. Staining due to mortar or cement splashes													ΙV
4c. Staining due to poor sealing												I	V
4d. Natural weathering bloom													ΙV
4e. Iridescence													IV
4f. Chalking or white bloom on soft anodic films											I		V

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Ted is a metallurgist by training with over 45 years experience in the aluminium industry. His career began in the Alcan Aluminium (then Northern Aluminium Ltd) production facility at Banbury, working with the extrusion, casting and rolling of aluminium alloys. This was followed by 31 years in the R & D laboratory of Alcan International Ltd, also at Banbury, where he

worked for 25 years on research and technical assistance in the field of surface finishing of aluminium and six years as head of the analytical services section.

Ted has been an author or co-author and presenter of many papers on the surface finishing of aluminium. He was awarded the Sam Wyman Award and the AESF Excellence in Presentation Award at the SUR/FIN' 87 AESF Conference in Chicago, and the Jim Kape award for the best paper on aluminium finishing at the IMF 1988 Annual Conference, for a presentation on cold sealing. Among his more recent publications are papers in the journal "Light Metal Age" as well as a chapter in the most recent (6th) Edition of "Surface Treatment and Finishing of Aluminium" edited by Sheasby and Pinner Ted has been practising as an independent consultant on aluminium finishing since May 1994.



Figure 1. Typical atmospheric corrosion revealed by etching and anodizing.



Figure 2. Finger print corrosion on 6063 extrusion revealed by etching and anodizing.



Figure 3. Corrugated cardboard corrosion



Figure 4. Paper corrosion



Figure 5. Appearance of fretting corrosion after anodizing.



Figure 6. Intergranular attack typical of acid corrosion. x 200



Figure 7. Rounded pit typical of alkali corrosion. x 200



Figure 8. Rinse water corrosion illustrating white star-shaped form.



Figure 9. Rinse water corrosion illustrating black floret-shaped pits.



Figure 10. Rinse water corrosion having very shallow filiform type structure.



Figure 11. Very fine pitting typical of that due to an imbalance in a chemical brightening solution.



Figure 12. Pitting of the 'castle and moat' type. x 20



Figure 13. Example of 'castle and moat' pitting. x 1



Figure 14. Pitting caused by chloride in a sulphuric acid anodizing electrolyte.



Figure 15. Pitting due to a galvanic cell occurring between the stainless steel tank and the anodized part.



Figure 16. Examples of pitting of anodic films in service due to the film thickness being below specification.



Figure 16. Examples of pitting of anodic films in service due to the film thickness being below specification.



Figure 17. Cement staining on a natural anodized finish.



Figure 18. 'Wood grain' effect of ingot segregation on polished and anodized extruded section that was heavily polish to remove a locally severe die line.



Figure 19. Example of shell zone segregational streaking after stripping the original anodic film, taper polishing the affected surface and re-etching and anodizing.



Figure 20. Inverse segregation effect on etched and anodized rolled sheet produced from an ingot that had not been scalped or had insufficient metal removed by the scalping operation.



Figure 21. Structural or Die design streaking revealed by etching and anodizing a 6063 extruded section. (x 1



Figure 22. Examples of severe die lines on 'as extruded' section.



Figure 23. Severe die lines showing up as darker streaks after etching and anodizing.



Figure 24. Example metal flow on a hollow extrusion having a small hollow portion at one end of a relatively large solid portion of metal. This may also be part transverse weld/back-end defect. (10 minutes etch in 100g/l NaOH at 60°C.)



Figure 25. The same sample shows the streaks resulting from the metal flow at the surface of extrusion.



Figure 26. Non-uniform appearance of 6063 extrusion bright-anodized and dyed corresponding to the position of the transition from a transverse weld into the longitudinal welds and the effect of removal of the surface layer by mechanical polishing.



Figure 27. Poor quality weld on extruded tube causing colouring defects when anodized and dyed



Figure 28. Transverse weld effect on a hollow extrusion after etching and anodizing.



Figure 29. Example of a transverse weld defect at the front end of an extrusion after etching and anodizing.



Figure 30. Streaking due to mixing of alloys on a hollow extrusion.



Figure 31. Flecking occuring during electro-colouring due to iron phase segregation


Figure 33. Streaking due to TiB₂ clusters and oxide inclusions in the extrusion ingot used to extrude a section as revealed by anodizing and electro-colouring of the section.



Figure 34. Carbon streaks on an 'as extruded' section.



Figure 35. Carbon marks after etching for 10 minutes in 100g/l NaOH at 60°C.



Figure 36. Graphite inclusion due to excess lubricant at front end of ingot. x 20



Figure 37. Etched cross sections of extrusions demonstrating back end defects and associated streaking.



Figure 37. Etched cross sections of extrusions demonstrating back end defects and associated streaking.



Figure 37. Etched cross sections of extrusions demonstrating back end defects and associated streaking.



Figure 38. Surface streaking or flecks due to back end defect or transverse weld on an anodized and electrolytically pigmented extrusion.

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Figure 39. Effect of relatively uniform and taper polishing on the bright band on a polished and anodized extrusion showing a dulling due to a thin segregate layer on the surface near the edges. The heavier the polish the wider is the area of the brighter subsurface material revealed.



Figure 40. Effect of taper polishing and anodizing a section having segregational streaking or back end defect streaking, upon the position of the streak. The heaviest polishing has been applied towards the bottom of the samples in this picture.



Figure 41. Non-uniform appearance on an etched and anodized extrusion caused by poor mechanical polishing.



Figure 42. Water staining on samples of machined tube in storage prior to etching and anodizing.



Figure 43. Water staining on aluminium 1050 alloy foil caused by the coiled alloy becoming wet in storage.



Figure 44. Samples of water stained material from same batch as samples in Figure 29 after brightening anodizing and colouring showing that quite severe corrosion was associated with the water staining



Figure 45. Effect of water staining or inadequate degreasing prior to etching.



Figure 46. Typical example of 'white etch bloom' on 6063 extrusion.



Figure 47. Sample of 'white etch bloom' on 6063 extrusion showing brighter, or darker, areas where fingerprints have removed the magnesia film before etching.



Figure 48. Example of severe transfer etch staining on 6063 alloy extrusion.



Figure 49. SEM picture of the surface of a 6063 extrusion showing spangle etching and illustrating the 5µm step between grains caused by the preferential attack. (x 2000)



Figure 50. 6063 extrusion containing 0.04% Zn showing a light spangle etch.



Figure 51. Variable etching response of 6063 extruded sections as etched and anodized.



Figure 52. Example of a hot spot on an etched and anodized 6063 extrusion.



Figure 53. Staining on a 6063 alloy welded and linished mitred window frame joint after normal etching and anodizing. The dark nature of the weld suggests the filler rod used for welding contained a higher silicon content than that of the alloy. The heat-affected zone in the extrusion adjacent to the weld is just visible.



Figure 54. Heat-affected zone on a sample of thin gauge Al-Mg sheet when the part was welded on the back side only of the sheet.



Figure 55. Effect of container skin contamination after etching and anodizing a 6063 alloy extrusion.



Figure 56. Barnacling on a sample of chemically brightened 6463 alloy.



Figure 57. An example of anodizing burn in sulphuric acid electrolyte.



Figure 58. Patchy dyed finish due to poor rinsing of an anodic film before colouring.



Figure 59 . Typical examples of non-coloured areas due to gas trapping



Figure 60. Variation of smut levels on two 6063 extrusions having different size Mg2Si precipitates due to under-ageing and over-ageing, after etching in 10% NaOH at 60°C for 10 minutes.



Figure 61. The same samples as in Figure 60 after anodizing and dyeing black.



Figure 62. Variation in colour within a single load of interference-coloured grey finishes due to poor control of the ageing practice on the extrusions resulting in differences in Mg₂Si precipitate size.



Figure 63. Fairly typical dark and light limits for a medium bronze anodized finish.



Figure 64. Poor colour match on an architectural bronze anodized finish.



Figure 65. White spots due to NaOH spray settling on an anodized surface before electro-colouring.



Figure 66. Various forms of spalling on a 6063 electrolytically coloured extrusion caused by colouring at too high a voltage.


Figure 66. Various forms of spalling on a 6063 electrolytically coloured extrusion caused by colouring at too high a voltage.



Figure 67. Variation in degree of coarse grain on components machined from the same bar stock. The sample on the left has coarse grain, that on the right, normal grain size.



Figure 68. Coarse grain outer band effect causing an apparent difference in colour on an etched, anodized and dyed 6082 extruded bar.



Figure 69. Giant coarse recrystallised grains on a forged, etched and anodized anglers fishing reel.



Figure 70. Example of thermal crazing. ~ (x 250)



Figure 71. Example of thermal crazing showing crack in the anodic film. \sim (x 500)



Figure 72. Transfer-etch stain on 6063 polished and bright anodized extrusion.



Figure 73. Sample on left of tape brightened in solution containing 5% HNO₃ and sample on right brightened under same conditions but with only 4% HNO₃ in the brightening solution.



Figure 74. Example of bright trim section showing an overall dull finish before reprocessing (to right of tape) and a satisfactory finish after reprocessing (to the left of the tape).



Figure 75. Example of pitting on a bronze anodized architectural anodic finish in service due to inadequate anodic film thickness.



Figure 76. Pitting of an architectural finish in service due to lack of cleaning maintenance.



Figure 77. Staining due to wet mortar or cement being splashed onto an anodic film.



Figure 78. Sample of staining on a poorly sealed anodic film exposed to the atmosphere for about 6 months.



Figure 79. Curtain walling panels that had not been given regular cleaning maintenance showing on the right hand panel the white 'weathering bloom' before cleaning. The left hand panel is a similar panel after cleaning with a Scotchbrite pad and a solution of Teepol in water.



Figure 80. Iridescence formed during outdoor exposure on a sample of anodized and electrolytically coloured aluminium.



Figure 81. Chalking of an anodic finish in service due to a soft anodic film.



Figure 82. Detail of surface deposit on chalked anodic finish showing the powdery nature of the flaked surface.



Example of chromic acid anodized finish showing some pitting on mortar bomb fins probably due to corrosion of the component before anodizing. Fig 83a. Fin showing dark stains



Example of chromic acid anodized finish showing some pitting on mortar bomb fins probably due to corrosion of the component before anodizing.

Fig 83b. Fin as chromic acid anodised



Example of chromic acid anodized finish showing some pitting on mortar bomb fins probably due to corrosion of the component before anodizing. Fig 83c. Same fin after removal of anodic film by etching in 10% NaOH at 60°C for 2 to 3 minutes

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