**HISTORY, PROPERTIES AND ALLOYS**

The history of the light metal industry, as that of many other industries in this century, is one of notable and ever accelerating expansion and development. There are few people today who are not familiar with at least some modern application of aluminium and its alloys. The part it plays in our everyday life is such that it is difficult to realise that a century ago the metal was still a comparative rarity.

The excellent corrosion resistance of pure aluminium is largely due to its affinity for oxygen; this results in the production of a very thin but tenacious oxide film which covers the surface as soon as a freshly-cut piece of the metal is exposed to the atmosphere. This oxide coating is of great significance in the production of practically every type of surface finish for the metal. It is, of course, the basis of what is probably the most corrosion-resistant finish of all, namely, that group of finishes which involves the technique of anodic oxidation in its varied forms. Here, the natural film is, in effect, greatly thickened and strengthened by electrochemical means.

On the other hand, the tenacity of the natural oxide film is a serious adverse factor in the production of other finishes, such as those based on electrode position, and also, but to a lesser extent, the organic finishes, as it must be removed or transformed before the alternative coating can be successfully applied. Special techniques have had to be evolved to effect this.

**History of aluminium**

Aluminium is a strongly electro-negative metal and possesses a strong affinity for oxygen; this is apparent from the high heat of formation of its oxide. For this reason, although it is among the six most widely distributed metals on the surface of the earth, it was not isolated until well into the nineteenth century. Alumina (A~0 ) was known, however, in the eighteenth century, and the first unsuccessful attempts to isolate the metal were made by Sir Humphry Davy in 1807, when the isolation of the alkali metals had made a powerful reducing agent available. It was not, however, until 1825 that the Danish Worker, H.C. Oersted, succeeded in preparing aluminium powder by the reduction of anhydrous aluminium chloride with sodium amalgam; two years later, F. Wohler replaced the amalgam by potassium, and between 1827 and 1847 discovered and listed many of the chemical and physical properties. However, many years passed before the metal could be produced commercially.

The father of the light metal industry was probably the French scientist, Henri Sainte-Claire Deville, who in 1850 improved Wohler's method of preparation by replacing potassium by sodium, and by using the double chloride of sodium and aluminium as his source of the metal, thus making the production of aluminium a commercial proposition; the price of the metal, however, was still comparable with that of gold.

The production of aluminium received a further impetus when Robert Bunsen and, following him, Deville, showed how the metal could be produced electrolytically from its ores.

In 1885, the brothers Cowie produced the first aluminium alloys containing iron and copper, soon after which the invention of the dynamo made a cheaper supply of electricity available and resulted, in 1886, in Herault's and Hall's independent French and American patents for the electrolytic production of aluminium from alumina and molten cryolite (AIF3NaF). Thencefmth, the production of aluminium in Europe centered round the first factory in Neuhausen, while Hall's process was applied in the U.S.A. in Pittsburgh. Modem production of aluminium begins from the mineral bauxite, which contains approximately 25% of aluminium. This is converted to alumina by digestion with a solution of sodium hydroxide under pressure (the Bayer process), and the purified alumina produced is added to a molten mixture of cryolite and fluorspar. This mixture is electrolyzed in a cell with carbon anodes and the molten mixture is tapped from the bottom of the cell.

**Properties of aluminium**

The three main properties on which the application of aluminium is based are its low density of approximately 2.7, the high mechanical strength achieved by suitable alloying and heat treatments, and the relatively high corrosion resistance of the pure metal. Other valuable properties include its high thermal and electrical conductance, its reflectivity, its high ductility and resultant low working cost, its magnetic neutrality, high scrap-value, and the non-poisonous and colourless nature of its corrosion products which facilitates its use in the chemical and food-processing industries. Still further valuable features are obtained by various treatments of the metal; these will be considered when the applications of aluminium and its finishes are considered.

In its pure state, aluminium is, however, a relatively soft metal with a yield strength of only 34.5 N/rrnn2 (5,000 lb/in2) and a tensile strength of 90 N/mm2(13,000 lb/in2). Through the development of a wide range of alloys, however, very varied strengths and ductility can be achieved, and this has led to the many applications of today. For example these range from the use of very thin foil material in the packaging industry, ductile materials for drink containers, and highly conductive alloys for electrical purposes, to relatively low-strength alloys for the building industry and high strength materials for aircraft and armoured vehicles.

The metal in its pure state has a relatively high corrosion resistance and needs less protection than most metals. On the other hand, the commercial metal and its alloys, though resistant, are distinctly more sensitive to corrosion, and the development of high strength light alloys, containing quantities of heavy metals such as copper, zinc or nickel, has heightened the need for protective surface treatments. The nature of the heavy metal additions appreciably influences the alloy's susceptibility to corrosion, and high mechanical strength and corrosion resistance have so far proved largely incompatible. The development of satisfactory protective finishes for these metals has been, therefore, of very great importance. Brief consideration is now given to the properties of the various aluminium alloys which are available in relation both to their corrosion resistance and applications.

**Development of aluminium alloys**

The chief alloying constituents added to aluminium are copper, magnesium, silicon, manganese, nickel and zinc. All of these are used to increase the strength of pure aluminium. Two classes of alloys may be considered. The first are the 'cast alloys' which are cast directly into their desired forms by one of three methods (i.e., sand-casting, gravity die casting or pressure die casting), while the second class, the 'wrought alloys', are cast in ingots or billets and hot and cold worked mechanically into extrusions, forgings, sheet, foil, tube and wire. The main classes of alloys are the 2000 series (Al-Cu alloys), which are high-strength materials used mainly in the aircraft industry, the 3000 series (Al-Mn alloys) used mainly in the canning industry, the 5000 series (Al-Mg alloys) which are used unprotected for structural and architectural applications, the 6000 series (Al-Mg-Si alloys) which are the most common extrusion alloys and are used particularly in the building industry, and the 7000 series (Al-Zn-Mg alloys) which are again high strength alloys for aircraft and military vehicle applications.

The alloy used in any particular application will depend on factors such as the mechanical and physical properties required, the material cost and the service environment involved. Ifa finishing treatment is to be applied, then the suitability of the alloy for producing the particular finish desired will be an additional factor to be taken into account. The great benefit of aluminium is that such a wide variety of alloys with differing mechanical and protection properties is available, and these, together with the exceptional range of finishes which can be used, make aluminium a very versatile material.

**CORROSION OF ALUMINIUM**

Whilst aluminium and its alloys generally have good corrosion resistance, localized forms of corrosion can occur, and it is important to understand the factors contributing to these forms of corrosion.

Corrosion may be defined as the reaction between a metal and its immediate environment, which can be natural or chemical in origin. The most recognizable form of corrosion is, perhaps, the rusting of iron. All metals react with natural environments but the extent to which this happens can vary; for noble metals like gold the amount is insignificant whereas for iron it is considerable. Aluminium is no exception but, fortunately, it has the propensity of self passivation and for many applications corrosion is not a problem.

**Factors contributing to corrosion**

There are two main factors which influence the general corrosion behavior of aluminium; one is the type and aggressiveness of the environment and the second is that of its chemical and metallurgical structure. Environments can vary from outdoor atmospheres to media such as soils, waters, building materials, food and chemicals etc. Outdoor atmospheres are usually classified as either rural, industrial or marine depending on their location. In rural atmospheres the degree of natural pollution is usually low, but industrial and marine environments are more aggressive, usually due to the presence of sulphates and chlorides respectively. Soils, waters and building materials vary in aggressiveness depending on such properties as composition, chemical activity, degree of aeration and electrical conductivity. Chemical environments usually have unique compositions and their corrosive effects can be fairly accurately determined.

Pure aluminium displays the highest corrosion resistance, but as purity decreases and alloying elements are added this resistance decreases. 10 Copper lowers resistance more than other elements, whilst magnesium has the least effect.

The metallurgical state of an aluminium alloy for a given composition is determined by its fabrication history. In the wrought form it will be made either by the procedure of work-hardening or by that of solution heat-treatment. Aluminium alloys are also available in the cast form. Briefly, work-hardening involves deformation at room or slightly elevated temperatures, and for semi-fabricated products the process used is that of rolling. The main features resulting from rolling are dislocations, in arrays varying from sub grains with ragged boundaries, to high density configurations of 'forests' and slip bands; illustrates some of these. Cold worked structures also arise from processes such as shearing, stamping and forming. The two main work-hardening alloy groups are those based on Al-Mn (3000 series) and on Al-Mg (5000 series). In general terms solution heat-treatment consists of two basic stages. The first involves soaking at temperatures between 450°C and 550°C for predetermined periods depending on the particular alloy composition, followed by quenching either into water or into air, again depending on the alloy. The second stage is that of ageing, which is carried out at temperatures between 20°C and about 175°C. During the first stage most of the alloying elements are taken into solid solution and then partly released from this state during ageing. Except at grain boundaries and other energetically favorable regions, material released from solid solution remains coherent with the matrix and by so doing increases strength. If the ageing period is prolonged or the temperature raised, coherency tends to break down and strength decreases. At the grain boundaries the ageing process is usually more advanced than that elsewhere and incoherent particles are precipitated. The principal heat-treatable alloys are those based on Al-Cu (2000 series), Al-Mg-Si (6000 series), Al-Zn-Mg and Al-Zn-Mg-Cu (7000 series).

Although a fairly large number of casting alloys exist, most of them derive their properties from the addition of magnesium, silicon and copper either singly or in combination. The amount of magnesium can range from about 3 to 11%, that of silicon from 3 to 13% and that of copper from about 1 to 5%. They are produced in a range of tempers from 'as cast' to 'solution heat-treated' depending on alloy composition. Their basic structure is mainly that of dendritic cells in a matrix of aluminium. Some changes to the basic structure result from heat treatment.