

## GENERAL CHARACTERISTICS OF ALUMINIUM AND ITS ALLOYS

A unique combination of properties puts aluminium and its alloys amongst our most versatile engineering and construction materials. All alloys are light in weight, yet some have strengths greater than that of structural steel. The majority of alloys are highly durable, and no coloured salts are formed to stain adjacent surfaces or discolour products with which they come in contact, as they have no toxic reaction. Aluminium and most of its alloys have good electrical and thermal conductivities and high reflectivity to both heat and light.

Aluminium and most of its alloys can easily be worked into any form and readily accept a wide variety of surface finishes.

Light weight is perhaps aluminium's best known characteristic having a density of approx.  $2.7 \times 10^3$  kilograms per cubic metre at 20°C as compared with  $7.9 \times 10^3$  for iron and  $8.9 \times 10^3$  for copper.

Commercially pure aluminium has a tensile strength of about 90 mega Pascals. Its usefulness as a structural material in this form is thus somewhat limited. However, by working the metal, as by cold rolling, its strength can be approximately doubled. Much larger increases in strength can be obtained by alloying aluminium with small percentages of one or more other metals such as manganese, silicon, copper, magnesium or zinc.

Aluminium has a high resistance to corrosion on surfaces exposed to the atmosphere. A thin transparent oxide skin forms immediately and protects the metal from further oxidation. Unless exposed to some substance or condition, which destroys this protective oxide coating, the metal remains protected against corrosion. Aluminium is highly resistant to weathering, even in industrial atmospheres that often corrode other metals. It is also corrosion-resistant to attack by many acids, but general direct contact with alkaline substances should be avoided as these attack the oxide skin and are therefore corrosive to aluminium.

Some alloys are less resistant to corrosion than others, particularly certain high-strength alloys.

In accordance with sound design principles, direct contact with certain other metals should be avoided in the presence of an electrolyte, as galvanic corrosion of the aluminium may take place in the vicinity of the contact area.

The fact that aluminium is non-toxic was discovered in the early days of the industry. It is this characteristic, which enables the metal to be used in cooking utensils without any harmful effect on the body and today a great deal of aluminium equipment is used by food processing industries. The same characteristic permits aluminium foil wrapping to be used safely in direct contact with food products.

Aluminium is one of the two common metals having electrical conductivity high enough for use as an electrical conductor. The conductivity of electrical-conductor grade (alloy 1350) is about 62% that of the International Annealed Copper Standard. Because aluminium has less than one-third the density of copper, an aluminium conductor of equivalent current carrying capacity is only half the mass of a copper conductor.

The high thermal conductivity of aluminium was noticed in the first large-scale commercial application of the metal - in cooking utensils. This characteristic is important in heat exchange applications where the transfer of thermal energy from one medium to another is involved, either heating or cooling.

Aluminium is also an excellent reflector of radiant energy through the entire range of wavelengths from ultra-violet through the visible spectrum to infra-red and heat waves, as well as electromagnetic waves of radio and radar.

Aluminium has a light reflectivity of over 80%, which has led to its wide use in lighting fixtures. These reflectivity characteristics lead to its use as an insulating material. For example, aluminium roofing

reflects a high percentage of the sun's heat so that buildings roofed with this material are cooler in summer and warmer in winter.

Not so well known as some of the other properties of aluminium are its non-sparking (against itself and other non-ferrous metals) and non-magnetic properties, which make the metal useful for electrical shielding purposes such as in bus bar housing or enclosures for other electrical or magnetic equipment.

Aluminium may be fabricated readily into any form. Often it can compete successfully with cheaper materials having a lower degree of workability. The metal can be cast; it can be rolled to any desired thickness down to foil thinner than paper; aluminium sheet can be stamped, drawn, spun or roll-formed. The metal also may be hammered or forged. Aluminium wire may be stranded into cable. There is almost no limit to the different shapes in which the metal may be extruded.

Most aluminium alloys may be machined speedily and easily, important factors contributing to the low cost of finished aluminium parts. The metal may be turned, milled, bored, or machined. Another advantage of their flexible machining characteristics is that aluminium alloy rod and bar, particularly the free machining alloys such as 2011 and 6262, may readily be employed in the high-speed manufacture of automatic screw-machine parts.

Almost any method of joining is applicable - riveting, welding, brazing, or soldering. A wide variety of mechanical aluminium fasteners simplify the assembly of many products. Adhesive bonding of aluminium parts has been successfully employed in many applications including aircraft components and some building applications.

For many applications Aluminium needs no protective or decorative coating; the surface supplied is entirely adequate without further finishing. Mechanical finishes such as polishing, embossing, sand blasting, or wire brushing meet a variety of needs. Where the plain aluminium surface does not suffice, any of a wide variety of surface finishes may be applied. Chemical, electrochemical, and paint finishes are all used.

These are the characteristics that give aluminium its extreme versatility. In the majority of applications, two or more of these characteristics come prominently in to play; for example, lightweight combined with strength in aircraft, railway rolling stock, trucks and other transportation equipment. High resistance to corrosion and high thermal conductivity are important in equipment for the chemical and petroleum industries: these properties combine with non-toxicity for food processing equipment. Attractive appearance together with high resistance to weathering and low maintenance requirements have led to extensive use in buildings of all types. High reflectivity, excellent weathering characteristics, and lightweight are all important in roofing materials. Lightweight contributes to low handling and shipping cost whatever the application.

Many applications require the extreme versatility which only aluminium has. Combination of properties is being put to work in new ways.

# METALLURGICAL ASPECTS OF ALUMINIUM

In high-purity form, aluminium is soft and ductile. Most commercial uses, however, require greater strength than pure aluminium affords. This is achieved in aluminium first by the addition of other elements to produce various alloys, which singly or in combination impart strength to the metal. Further strengthening is possible by means, which classify the alloys roughly, into two categories, non-heat treatable and heat-treatable.

## **Non- Heat Treatable Alloys**

The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat treatable alloys are usually designated, therefore in the 1000, 3000, 4000, or 5000 series. Since these alloys are work-hardenable, further strengthening is made possible by various degrees of cold working, denoted by the H series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated-temperature treatment called stabilising to ensure stability of properties.

## **Heat-Treatable Alloys**

The initial strength of alloys in this group is enhanced by the addition of alloying elements, which, either between themselves or in conjunction with aluminium, form compounds, which show increasing solid solubility in aluminium with increasing temperature. This phenomenon has enabled this group of alloys to be developed such that their strength may be improved by carefully controlled thermal treatment.

The first step, called heat treatment or solution heat treatment, is an elevated-temperature process designed to put the soluble element in solid solution. This is followed by rapid quenching, usually in water, which temporarily 'stabilises' the structure and for a short time renders the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at sub-zero temperatures until they are ready to form them. At room or elevated temperatures, the alloys are not stable after quenching, however, and precipitation of the constituents from the supersaturated solution begins. After a period of several days at room temperature, termed ageing or room-temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age-harden for longer period of time at room temperature.

By heating for a controlled time at slightly elevated temperature even further strengthening is possible and properties are stabilised. This process is called artificial ageing or precipitation hardening. By the proper combination of solution heat treatment, quenching, artificial ageing and cold working, the highest strengths are obtained.

## **Annealing Characteristics**

All wrought aluminium alloys can be supplied in annealed form. After additional working or between successive stages, such as in deep drawing, it may be desirable to anneal an alloy. Generally this poses no difficulty except that coarse-grained structure may occur as the result of annealing lightly-worked material such as metal in H 1 2 and H22 tempers.

## **EFFECT OF ALLOYING ELEMENTS**

**1000 Series:** Aluminium of 99% or higher purity has many applications, especially in the electrical and chemical fields. These alloys are characterised by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties, and excellent workability. Moderate increases in strength may be obtained by strain hardening. Iron and silicon are the major impurities.

**2000 Series:** Copper is the principal alloying element in this group. These alloys require solution heat-treatment to obtain optimum properties: in the heat-treated condition mechanical properties are similar to and sometimes exceed those of mild steel. In some instances artificial ageing is employed to

further increase the mechanical properties. This treatment materially increases yield strength, with attendant loss in elongation; its effect on ultimate tensile strength is not as great. The alloys in the 2000 Series do not have as good corrosion resistance as most other aluminium alloys and under certain conditions they may be subject to inter-granular corrosion.

**3000 Series:** Manganese is the major alloying element of alloys in this group, which are generally non-heat treatable. Because only a limited percentage of manganese, up to about 1.5%, can be effectively added to aluminium, it is used as a major element in only a few instances. These, however, are popular and are widely used as general-purpose alloys for moderate-strength applications requiring good workability.

**4000 Series:** The major alloying element of this group is Silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons aluminium-silicon alloys are used in welding wire and as brazing alloys where a lower melting point than that of the parent metal is required. Most alloys in this series are non-heat treatable, but when used in welding heat-treatable alloys they will pick up some of the alloying constituents of the latter and so respond to heat treatment to a limited extent. The alloys containing appreciable amount of silicon become dark grey when anodic oxide finishes are applied.

**5000 Series:** Magnesium is one of the most effective and widely used alloying elements for aluminium. When it is used as the major alloying element, or with manganese, the result is a moderate to high-strength non-heat treatable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8% magnesium being equal to 1.25% manganese, and it can be added in considerably higher quantities. Alloys in this series possess good welding characteristics and good resistance to corrosion in marine atmospheres. However, certain limitations should be placed on the amount of cold work and the safe operating temperatures permissible for the higher magnesium content alloys (5083, 5086) to avoid susceptibility to stress corrosion and exfoliation attack.

**6000 Series:** Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicide, thus making them capable of being heat-treated. Though less strong than most of the 2000 or 7000 alloys, the magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength. Alloys in the heat-treatable group may be formed in the T4 temper (solution heat-treated but not artificially aged) and then reach full T6 properties by artificial ageing.

**7000 Series:** Zinc is the major alloying element in this group, and when coupled with a smaller percentage of the magnesium results in heat-treatable alloys of very high strength. Usually other elements such as copper and chromium are also added in small quantities.

**8000 Series:** Used for alloys not covered by the above series.

## TEMPER DESIGNATION

The basic temper designations and sub-divisions are as follows:

**F: As fabricated** - Applies to products which acquire some temper from shaping processes not having special control over the amount of strain-hardening or thermal treatment. For wrought products, there are no mechanical property limits.

**O: Annealed, recrystallised** - Applies to the softest temper of wrought products.

**H: Strained-hardened** - Applies to products which have their strength increased by strain hardening with or without supplementary thermal treatments to produce partial softening. Two or more digits always follow the H.

**H1: Strained-hardened only** - Applies to products, which are strain-hardened to obtain the desired mechanical properties without supplementary thermal treatment. The number following this designation indicates the degree of strain hardening.

**H2: Strain-hardened and then partially annealed** - Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the H2 tempers have approximately the same ultimate strength as the corresponding H3 tempers. For other alloys, the H2 tempers have approximately the same ultimate strength as the corresponding H1 tempers and slightly higher elongations.

The number following this designation indicates the degree of strain-hardening remaining after the product has been partially annealed.

**H3: Strained-hardened and then stabilised** - Applies to products which are strain hardened and then stabilised by a low-temperature heating to slightly lower their strength and increase ductility. This designation applies only to the magnesium-containing alloys, which, unless stabilised, slightly age-soften at room temperature.

The number following this designation indicates the degree of strain hardening after the product has been strain-hardened a specific amount and then stabilised. The digit following the designation H1, H2 and H3 indicate the final degree of strain hardening. Numeral 8 has been assigned to indicate tempers having a final degree of strain hardening equivalent to that resulting from approximately 75% reduction of area. Tempers between 0 (annealed) and 8 (fully hard) are designated by numerals 1 through 7. Material having an ultimate strength about midway between that of the 0 temper and that of the 8 temper is designated by the number 4 (half-hard), between 0 and 4 by the numeral 2 (quarter-hard), between 4 and 8 by the numeral 6 (three-quarter hard) and so on for the numerals 1, 3, 5, and 7. Number 9 designates extra hard tempers.

The third digit, when used, indicates a variation of a two-digit H temper. It is used when the degree of control of temper or the mechanical properties are different from but close to those for the two-digit H temper designation to which it is added.

The following three-digit H temper designations have been assigned for wrought products in all alloys:

**H111:** Applies to products, which are strain hardened less than the amount required for a controlled H11 temper.

**H112:** Applies to products not having special control over the amount of stain hardening or thermal treatment but which acquire some temper incidental to the shaping processes and for which there are mechanical property limits or mechanical property testing is required.

**H311:** Applies to products, which are strain-hardened less than the amount required for controlled H31 temper.

**H321:** Applies to products, which are strain-hardened less than the amount required for a controlled H32 temper. It is specially fabricated to have acceptable resistance to stress-corrosion cracking and exfoliation attack.

**T:** Thermally treated to produce stable tempers other than F, O, or H. Applies to products, which are thermally treated, with or without supplementary strain hardening, to produce stable tempers. One or more digits always follow the T. Numbers 1 through 9 have been assigned to indicate specific sequences or basic treatments. A period of natural ageing at room temperature may occur between or after the operations listed for tempers T3 or T9. Control of this period is exercised when it is metallurgically important.

The significance of the digits following the T is as follows:

**T1:** Cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition. Applies to products for which the rate of cooling from an elevated temperature shaping process, such as extrusion, is such that their strength is increased by room temperature ageing.

**T3:** Solution heat-treated and then cold worked and naturally aged to a substantially stable condition. Applies to products, which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognised in applicable specifications.

**T4:** Solution heat-treated and naturally aged to a substantially stable condition. Applies to products which are not cold worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognised in applicable specifications.

**T5:** Cooled from an elevated temperature shaping process and then artificially aged. Applies to products, which are cooled from an elevated temperature shaping process, such as casting or extrusion, and then artificially aged to improve mechanical properties or dimensional stability or both.

**T6:** Solution heat-treated and then artificially aged. Applies to products, which are not cold worked after solution heat treatment or in which the effect of cold work in flattening or straightening may not be recognised in applicable specifications.

**T8:** Solution heat-treated, cold worked, and then artificially aged. Applies to products which are cold worked to improve strength, or in which the effect of cold work in flattening or straightening is recognised in applicable specifications.

**T9:** Solution heat-treated, artificially aged and then cold worked. Applies to products, which are cold worked to improve strength.

Additional digits may be added to designation T1 through T9 to indicate a variation in treatment, which significantly alters the characteristics of the product.

