# Aluminium Alloys

*Aluminium and Aluminium Alloys*

Commercially pure aluminium is a white lustrous metal which stands second in the scale of malleability, sixth in ductility, and ranks high in its resistance to corrosion. Aluminium combined with various percentages of other metals forms alloys which are used in aircraft construction.

Aluminium alloys in which the principal alloying ingredients are manganese, chromium, or magnesium and silicon show little attack in corrosive environments. Alloys in which substantial percentages of copper are used are more susceptible to corrosive action. The total percentage of alloying elements is seldom more than 6 or 7 percent in the wrought alloys.

Aluminium is one of the most widely used metals in modern aircraft construction. It is vital to the aviation industry because of its high strength to weight ratio and its comparative ease of fabrication. The outstanding characteristic of aluminium is its light weight. Aluminium melts at the comparatively low temperature of 670 °C. It is nonmagnetic and is an excellent conductor.

Commercially pure aluminium has a tensile strength of about 90 MPa, but its strength may be approximately doubled by rolling or other cold working processes. By alloying with other metals, or by using heat-treating processes, the tensile strength may be raised to as high as 460 MPa or to within the strength range of structural steel.

Aluminium alloys, although strong, are easily worked because they are malleable and ductile. They may be rolled into sheets as thin as 0.04 mm or drawn into wire 0.1 mm in diameter.

The various types of aluminium may be divided into two general classes: (1) casting alloys (those suitable for casting in sand, permanent mold, or die castings) and (2) wrought alloys (those which may be shaped by rolling, drawing, or forging). Of these two, the wrought alloys are the most widely used in aircraft construction, being used for stringers, bulkheads, skin, rivets, and extruded sections.

Aluminium casting alloys are divided into two basic groups. In one, the physical properties of the alloys are determined by the alloying elements and cannot be changed after the metal is cast. In the other, the alloying elements make it possible to heat treat the casting to produce the desired physical properties.

The casting alloys are identified by a letter preceding the alloy number. When a letter precedes a number, it indicates a slight variation in the composition of the original alloy. This variation in composition is simply to impart some desirable quality. In casting alloy 214, for example, the addition of zinc to improve its pouring qualities is indicated by the letter A in front of the number, thus creating the designation A214.

When castings have been heat treated, the heat treatment and the composition of the casting is indicated by the letter T, followed by an alloying number. An example of this is the sand casting alloy 355, which has several different compositions and tempers and is designated by 355-T6, 355-T51, or C355-T51.

Aluminium alloy castings are produced by one of three basic methods: (1) sand mold, (2) permanent mold, or (3) die cast. In casting aluminium, it must be remembered that in most cases different types of alloys must be used for different types of castings. Sand castings and die castings require different types of alloys than those used in permanent molds.

Sand and permanent mold castings are parts produced by pouring molten metal into a previously prepared mold, allowing the metal to solidify or freeze, and then removing the part. If the mold is made of sand, the part is a sand casting; if it is a metallic mold (usually cast iron) the part is a permanent mold casting. Sand and permanent castings are produced by pouring liquid metal into the mold, the metal flowing under the force of gravity alone.

The two principal types of sand casting alloys are 112 and 212. Little difference exists between the two metals from a mechanical properties standpoint, since both are adaptable to a wide range of products.

The permanent mold process is a later development of the sand casting process, the major difference being in the material from which the molds are made. The advantage of this process is that there are fewer openings (called porosity) than in sand castings. The sand and the binder, which is mixed with the sand to hold it together, give off a certain amount of gas which causes porosity in a sand casting.

Permanent mold castings are used to obtain higher mechanical properties, better surfaces, or more accurate dimensions. There are two specific types of permanent mold castings: (1) permanent metal mold with metal cores, and (2) semipermanent types containing sand cores. Because finer grain structure is produced in alloys subjected to the rapid cooling of metal molds, they are far superior to the sand type castings. Alloys 122, A132, and 142 are commonly used in permanent mold castings, the principal uses of which are in internal combustion engines.

Die castings used in aircraft are usually aluminium or magnesium alloy. If weight is of primary importance, magnesium alloy is used because it is lighter than aluminium alloy. However, aluminium alloy is frequently used because it is stronger than most magnesium alloys.

A die casting is produced by forcing molten metal under pressure into a metallic die and allowing it to solidify; then the die is opened and the part removed. The basic difference between permanent mold casting and die casting is that in the permanent mold process the metal flows into the die under gravity. In the die casting operation, the metal is forced under great pressure.

Die castings are used where relatively large production of a given part is involved. Remember, any shape which can be forged can be cast.

Wrought aluminium and wrought aluminium alloys are divided into two general classes: non-heat-treatable alloys and heat-treatable alloys.

Non-heat-treatable alloys are those in which the mechanical properties are determined by the amount of cold work introduced after the final annealing operation. The mechanical properties obtained by cold working are destroyed by any subsequent heating and cannot be restored except by additional cold working, which is not always possible. The “full hard” temper is produced by the maximum amount of cold work that is commercially practicable. Metal in the “as fabricated” condition is produced from the ingot without any subsequent controlled amount of cold working or
thermal treatment. There is, consequently, a variable amount of strain hardening, depending upon the thickness
of the section.

For heat-treatable aluminium alloys, the mechanical properties are obtained by heat treating to a suitable temperature, holding at that temperature long enough to allow the alloying constituent to enter into solid
solution, and then quenching to hold the constituent in solution. The metal is left in a supersaturated, unstable state and is then age hardened either by natural aging at room temperature or by artificial aging at some elevated temperature.

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**Nonferrous Aircraft Metals – Wrought Aluminium**

Wrought Aluminium and wrought aluminium alloys are designated by a four digit index system. The system is broken into three distinct groups: 1xxx group, 2xxx through 8xxx group, and 9xxx group (which is currently unused).

1xxx group are used to indicate the hundredths of 1 percent above the original 99 percent designated by the first digit. Thus, if the last two digits were 30, the alloy would contain 99 percent plus 0.30 percent of pure aluminium, or a total of 99.30 percent pure aluminium. Examples of alloys in this group are:

* 1100—99.00 percent pure aluminium with one control over individual impurities.
* 1130—99.30 percent pure aluminium with one control over individual impurities.
* 1275—99.75 percent pure aluminium with two controls over individual impurities.

In the 2xxx through 8xxx groups, the first digit indicates the major alloying element used in the formation of the alloy as follows:

* 2xxx—copper
* 3xxx—manganese
* 4xxx—silicon
* 5xxx—magnesium
* 6xxx—magnesium and silicon
* 7xxx—zinc
* 8xxx—other elements

In the 2xxx through 8xxx alloy groups, the second digit in the alloy designation indicates alloy modifications. If the second digit is zero, it indicates the original alloy, while digits 1 through 9 indicate alloy modifications.

The last two of the four digits in the designation identify the different alloys in the group. [Figure 5-4]

Figure 5-4. Nominal composition of wrought aluminium alloys.

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# Effect of Aluminium Alloying Element

1000 series. 99 percent aluminium or higher, excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties, excellent workability. Iron and silicon are major impurities.

2000 series. Copper is the principal alloying element. Solution heat treatment, optimum properties equal to mild steel, poor corrosion resistance unclad. It is usually clad with 6000 or high purity alloy. Its best known alloy is 2024.

3000 series. Manganese is the principal alloying element of this group which is generally non-heat treatable. The percentage of manganese which will be alloy effective is 1.5 percent. The most popular is 3003, which is of moderate strength and has good working characteristics.

4000 series. Silicon is the principal alloying element of this group, and lowers melting temperature. Its primary use is in welding and brazing. When used in welding heat-treatable alloys, this group will respond to a limited amount of heat treatment.

5000 series. Magnesium is the principal alloying element. It has good welding and corrosion resistant characteristics. High temperatures (over 150 °F) or excessive cold working will increase susceptibility to corrosion.

6000 series. Silicon and magnesium form magnesium silicide which makes alloys heat treatable. It is of medium strength, good forming qualities, and has corrosion resistant characteristics.

7000 series. Zinc is the principal alloying element. The most popular alloy of the series is 6061. When coupled with magnesium, it results in heat-treatable alloys of very high strength. It usually has copper and chromium added. The principal alloy of this group is 7075.

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**Magnesium and Magnesium Alloys**

Magnesium, the world’s lightest structural metal, is a silvery white material weighing only two-thirds as much as aluminium. Magnesium does not possess sufficient strength in its pure state for structural uses, but when alloyed with zinc, aluminium, and manganese it produces an alloy having the highest strength to weight ratio of any of the commonly used metals.

Magnesium is probably more widely distributed in nature than any other metal. It can be obtained from such ores as dolomite and magnesite, and from sea water, underground brines, and waste solutions of potash. With about 10 million pounds of magnesium in 1 cubic mile of sea water, there is no danger of a dwindling supply.

Some of today’s aircraft require in excess of one-half ton of this metal for use in hundreds of vital spots. Some wing panels are fabricated entirely from magnesium alloys, weigh 18 percent less than standard aluminium panels, and have flown hundreds of satisfactory hours. Among the aircraft parts that have been made from magnesium with a substantial savings in weight are nosewheel doors, flap cover skin, aileron cover skin, oil tanks, floorings, fuselage parts, wingtips, engine nacelles, instrument panels, radio masts, hydraulic fluid tanks, oxygen bottle cases, ducts, and seats.

Magnesium alloys possess good casting characteristics. Their properties compare favourably with those of cast aluminium. In forging, hydraulic presses are ordinarily used, although, under certain conditions, forging can
be accomplished in mechanical presses or with drop hammers.

Magnesium alloys are subject to such treatments as annealing, quenching, solution heat treatment, aging, and stabilizing. Sheet and plate magnesium are annealed at the rolling mill. The solution heat treatment is used to put as much of the alloying ingredients as possible into solid solution, which results in high tensile strength and maximum ductility. Aging is applied to castings following heat treatment where maximum hardness and yield strength are desired.

Magnesium embodies fire hazards of an unpredictable nature. When in large sections, its high thermal conductivity makes it difficult to ignite and prevents it from burning. It will not burn until the melting point of 650°C is reached. However, magnesium dust and fine chips are ignited easily.

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