Aluminium and its alloys can be subjected to a variety of thermal treatments including (1) heat treatment, which itself can be divided into solution treatment and either natural or artificial ageing (2) annealing and (3) stabilising.

Heat Treatment

Definition: An aluminium alloy is said to be in a heat-treated condition when it has been subjected to one or both of the following processes:

(a) Heating for a prescribed period at a prescribed temperature, then cooling rapidly from this temperature, usually by quenching (solution heat-treatment).

(b) Ageing, either spontaneously at ordinary temperatures (natural ageing) or by heating for a prescribed period at a prescribed low temperature (artificial ageing). The application of both solution heat-treatment and artificial ageing is often termed 'full heat treatment'.

Purpose: The purpose of heat treatment is to increase the strength and hardness of an alloy. Solution heat-treatment is an essential preliminary to artificial ageing, although an elevated temperature shaping process, such as casting or extrusion, can to some extent be used instead of normal solution treatment.

Solution heat-treatment on its own initially increases the ductility of alloys and enables a certain amount of cold work to be applied before natural ageing starts to harden the metal. In its own right it increases strength but not to the level achieved by subsequent artificial ageing.

General Principles: While a metallurgical evaluation of the structural changes that take place in aluminium alloys during heat-treatment is beyond the scope of these notes, a simplified explanation might be useful.

Effectively, heat-treatment is designed to alter the mode of occurrence of the soluble alloying elements, particularly copper, magnesium, silicon and zinc, which can combine with one and other to form intermetallic compounds. Solution heat-treatment takes these relatively hard constituents into solid solution, thereby softening the alloy: quenching retains the constituents in solid solution at room temperature, so that the alloy is still soft but unstable. The hard constituents gradually precipitate out in a more uniform pattern than they formed in the original un-heat-treated alloy, thereby improving the alloy's mechanical properties. Rates of precipitation vary from alloy to alloy so that the stable condition represented by complete precipitation may take anything from a few days to several years to achieve unless artificial ageing is used. Even with alloys which achieve relatively stable properties by natural ageing it is possible to obtain higher strengths by artificial ageing following solution treatment. In some alloys an additional increase in strength is possible by controlled cold-working of the alloy immediately after quenching from the solution heat-treatment temperature. Because of the complex interactions that take place during the processes of the heat-treatment, different alloys have different characteristics that require careful selection and control of the heating operations and specific combinations of temperature and time-at-temperature if the required properties are to be achieved in the heat-treated product. attained when the solution heat-treatment temperature is within the specified temperature range. If the temperature is too low, mechanical properties will be below requirements. If the temperature is too high there is a risk of cracking due to overheating. Heating periods cannot be given with the same accuracy as temperatures because of variations in the loading and spacing of the workload. The times should be determined by test and, when established, kept to. It is undesirable to solution heat-treat aluminium-clad alloy sheet for prolonged periods, or to re-solution treat clad material which has failed to achieve specification minimum requirements in terms of mechanical properties. This is because alloying constituents tend to diffuse from the core into the aluminium cladding, thereby reducing resistance to corrosion. In general, cast aluminium alloys need to be solution heat-treated for longer periods than wrought aluminium alloys.

Quenching Normally, wrought aluminium is quenched by plunging the hot metal into water, but often such rapid cooling may distort the metal and set up internal stresses. With sheet, distortion can be minimised by vertical immersion, and long sections or tubes should be quenched in the same way whenever possible. Distortion can also be reduced by decreasing the cooling rate, using hot water or oil as the quenching medium, and this is often helpful with castings and forgings.

Certain polymers in water can be used to control the rate of cooling. The solubility of these polymers is inversely proportional to temperature, and as the temperature of the water surrounding the metal rises they form a skin on the metal and produce a uniform temperature gradient. The percentage of polymer in the quench water controls the rate of heat extraction.

An important factor affecting the cooling rate is the time interval between removing the work from the furnace and immersing it in the quench tank. To ensure optimum mechanical properties and maximum resistance to intercrystalline corrosion, this time interval should generally not exceed 5 - 10 seconds.

Cold Working of Solution Heat-treated Alloys Heat-treatable alloys such as 2014 age naturally at room temperature. Working of these natural-ageing alloys must be completed within two hours of quenching, or, if severe forming is intended, within 30 minutes; that is, before age-hardening reaches significant proportions. If the scheduled amount of cold-working has not been completed in this time, the alloy can be re-solution heat-treated in order to complete the forming operation. However, solution treating too many times will reduce the value of mechanical properties that can be obtained by natural or artificial ageing.

Age-hardening may be delayed by storage of solution heat-treated material at low temperatures. Refrigerated storage, usually in the range -6° to -10°C is used for strip, sheet and rivets, and the work may be refrigerated for up to four days after solution heat-treatment to allow economical processing runs. If refrigerated storage is not used to prevent age-hardening it may be necessary to re-solution heat-treat before further working can be carried out.

very slowly at normal temperatures; hardening can, however, be accelerated by heating the solution heat-treated alloy in the range 100 - 200°C for a suitable period.

The length of time at the specified temperature, depending on the alloy, can be as short as two hours or as long as thirty hours. Maximum strength is generally achieved by prolonged ageing at low temperature rather than rapid ageing at high temperature.

Re-heat Treatment Alloys which have been incorrectly heat-treated, for example by solution treating at a lower temperature than that recommended or by precipitation at too high a temperature for too long a period of time, can be re-solution treated and then precipitation treated again to enable optimum properties to be achieved. If, however, solution-treatment has been carried out at too high a temperature, the condition cannot be remedied by re-heat treatment. Clad material should not be re-heat treated.

Annealing

Annealing is a thermal treatment for softening alloys that have been hardened by cold work or by heat-treatment. It is generally used to enable the metal to be cold worked. To avoid excess grain growth the metal should be heated to the annealing temperature as rapidly as possible, and held at temperature only as long as necessary. Excessive grain growth reduces the mechanical properties of the metal and may give a rough, 'orange peel' effect on the surface when the material is subsequently worked.

Temperatures and times for work hardening alloys are as follows:

Material	Temperature °C	Time at Temperature Minutes
1080A, 1050, 1200, 5251, 5154A, 5454, 5083	360 or over	20
3130, 3105	400-425	20

Heat-treatable alloys that have not been heat-treated can be annealed by heating at 360° ±10°C for one hour and cooling by air. Very slow cooling is not essential, although too rapid cooling could lead to some age hardening. In any case, severe forming should be completed within four or five days.

For many purposes this treatment is sufficient for alloys that have been heat-treated, but for complete annealing they should be heated at 400° - 425°C for one hour. In this case the rate of cooling should be about 15°C per hour down to 300°C; below this temperature cooling rate is not important.

The aluminium-zinc-magnesium alloys in the 7000 series are a special case as they are liable to age harden at room temperature after annealing at 420°C. It is necessary, after cooling in air, to reheat the material at 225°C for between two and four hours, when it becomes soft and stable. Alternatively, heating for two hours at 300°C may soften the material sufficiently for the work being done, and if this temperature is not exceeded the metal will remain fairly soft for a long time. Muffle, air-circulation and continuous furnaces are all used for annealing, and salt baths are also sometimes used.

In working metals it is sometimes helpful to anneal the material locally, and a blowpipe is often used. This practice is to be avoided with heat-treated aluminium alloys, since it impairs the properties obtained by the original heat-treatment. On work-hardened non-heat-treatable material, local heating may be applied provided the conditions are reasonably controlled. At the temperatures for annealing aluminium no visible change in appearance occurs, but there are two well-tried methods of determining when the metal has reached the annealing temperature. One is to coat the metal surface with a film of soap, which at annealing temperature turns black; the other is to heat until pine stick scraped along the surface leaves a brown char mark.

Stabilising

Stabilising is the relief of residual internal stresses by heating to a predetermined temperature, usually in the region of 250°C, then cooling slowly. The precise temperature depends on the history of the metal and its intended service use. The internal stresses may be set up during quenching from solution heat-treatment temperature or, in the case of castings, during solidification in the mould. In fact, stabilising is more widely applied to castings than wrought products as the stresses set up by different cooling rates, and consequently different shrinkage rates, are more significant in large castings and in castings with adjacent thick and thin sections. When the metal has solidified, these stresses are in a state of equilibrium, so that the dimensions of the casting will not alter under normal conditions. Machining or use at high temperature will disturb the equilibrium and the released stresses can cause distortion. This is particularly undesirable when close tolerance is required.