

## Heat Treating of Aluminum Castings

The heat treatment of cast aluminum alloys (Table 1) is carried out to increase their strength and hardness and to change their physical, mechanical and metallurgical properties. Let's learn more.

Different types of castings require different thermal treatments (Fig. 1). For example, improved mechanical and physical properties can be produced in sand and permanent-mold castings by heat treatment. By contrast, some alloys – such as 443.0 that contain little or no copper, zinc or magnesium – do not respond to heat treatment and do not exhibit improvements in mechanical properties. Others, such as die castings, can only be given a stress relief (and not solution heat treated) because of their porous internal structure due to fears of surface blistering and internal porosity. Each type of heat treatment is worth understanding in more detail.



### Heat Treatment

#### Solution Treatment – TB Condition (T4)

Castings are heated to a temperature just below the alloy melting point (dependent on chemical composition) and held at this temperature (dependent on alloy and cross-sectional thickness) a sufficient amount of time to allow the alloying elements to enter into solid solution. Upon quenching, these elements are in a supersaturated metastable state. Quench media include water, boiling water or polymer. Choice of the quenchant is often a balance between achieving mechanical properties and managing distortion while avoiding the buildup of internal stresses in the part. Although mechanical properties increase somewhat by natural aging, precipitation hardening (artificially aging) is typically employed to achieve maximum benefit to the mechanical properties.

**Table 1. Classification of thermal treatments of cast aluminum alloys**

Suffix Designation	Heat Treatment
M	None – As cast or as manufactured
TB (T4)	Solution treated and naturally aged
TE (T5)	Artificially aged
TB7	Solution treated and stabilized
TF (T6)	Solution heat treated and fully artificially aged
TF7	Solution treated and artificially aged and stabilized
TS	Stress relieved and annealed

#### Precipitation (Aging) – TE Condition (T5 or T51)

Artificial aging treatment is carried out at temperatures above ambient, typically in the range of 150-200°C (300-400°F). This type of heat treatment is done at these relatively low temperatures to eliminate growth. They are also used to stabilize the castings dimensionally (improving mechanical properties somewhat) and to improve machinability. Soak (hold) times can vary between two and 24 hours depending upon the alloy and the cross-sectional thickness of the part. Lower temperatures and longer times promote precipitation and often enhanced mechanical properties.

#### Solution Treated and Stabilized – TB7 Condition

After solution treatment, castings can be heated into the range of 200-250°C (400-480°F) for stabilization and homogenization of the alloying elements. Times and temperature vary with the type of alloy and mass of the component.

#### Solution Treatment and Precipitation Hardening – TF Condition (T6 or T61)

Solution treatment followed by precipitation (age) hardening produces the highest strength and mechanical properties (tensile and yield strength) while retaining ductility (elongation). Precipitation (age) hardening stabilizes the properties.

#### Solution Treated and Stabilized – TF7 Condition (T7 or T71)

Castings used for elevated-temperature service may benefit from a solution treatment and stabilization between 200-250°C (400-480°F) in order to stabilize mechanical properties when the component is exposed to temperatures close to or in this range. This heat treatment improves mechanical properties to a large degree, stabilizes the castings and usually results in a slightly lower tensile and yield strength but an increased elongation value compared to the T6 series of heat treatments.

#### Stress Relief and Annealing – TS Condition

Stress relief and annealing can be used to remove stresses in a casting or to soften the component for subsequent shaping or mechanical-working operations. Stress relief is typically performed between 200-250°C (400-480°F) while annealing is done around 300-400°C (575-750°F).



**Fig. 1. Cast aluminum engine block (Photograph Courtesy of Wisconsin Oven Corporation; East Troy, Wis.)**



## Alloy Selection

Aluminum casting alloys (Table 2) are numbered in accordance with a three-digit-plus-decimal designation in order to identify major alloying elements (and some alloy combinations).

The digit following the decimal in each alloy number indicates the form of product.

- “0” indicates the chemistry limits applied to an alloy casting.
- “1” indicates the chemistry limits for ingot used to make the alloy casting.
- “2” indicates the chemistry limits for ingot are different (typically tighter).

Generally, the XXX.1 designation indicates the ingot is supplied as a secondary product (e.g., remelted from scrap), whereas the XXX.2 designation suggests the ingot is produced from primary aluminum. Some alloy names are preceded by a letter so as to distinguish between alloys that differ only slightly in percentages of impurities or minor alloying elements (e.g., 356.0, A356.0, B356.0 or F356.0).

In order to choose the alloy, casting process and heat treatment, the engineer begins by understanding the service conditions under which the component part will operate. In order to achieve the desired strength, hardness, corrosion resistance, impact strength or machinability, designers have over 60 casting alloys in use today and up to five different heat treatments they can select (Table 3 – online).



**Fig. 2. Load of aluminum castings for heat treatment at a commercial shop (Photograph courtesy of Wisconsin Oven Corporation; East Troy, Wis.)**

Sometimes one mechanical property (e.g., yield strength) dictates alloy choice and/or casting method.

In most cases, aluminum castings are chosen as the most cost-effective solution based on raw material and production cost. However, knowledge of end-use service requirements and how to optimize design efficiency and/or lower production costs in manufacturing (e.g., reproducibility) may change the design. For instance, a casting with sound design may have a size or shape that will promote distortion in heat treating. A wide variety of applications (Table 4, Fig. 2) are possible.

Casting method is also an important consideration. For example, castings required in large quantities favor permanent molds, die casting or automated sand casting (provided the size and design features of the casting and available alloys are suitable). Sand casting often is used to produce parts with hollow cavities and a complex arrangement of

ribs or pockets and for parts unsuitable for casting in metal molds. Sand casting usually requires minimum tooling charge, but the unit price of the castings and the finished part can be high. Permanent mold casting requires a higher tooling charge, but the unit price is lower, particularly for longer runs. Die casting usually requires the highest tooling charge but also the lowest piece price on large quantities. **IH**



**Table 2. Cast aluminum alloy designations**

Series	Alloy Type
1XX.X	99.0% Al (minimum)
2XX.X	Al + Cu
3XX.X	Al + Si-Mg or Si-Cu or Si-Mg-Cu
4XX.X	Al + Si
5XX.X	Al + Mg
6XX.X	Reserved
7XX.X	Al + Zn
8XX.X	Al + Sn
9XX.X	Reserved

**Table 4. Typical applications**

Alloy	Typical Applications	Remarks
242.0 / A242.0	Cylinder heads, generator housings (aircraft), pistons (aircraft, diesel, motorcycle)	Applications where strength and hardness at high temperatures are desirable.
319.0 / A319.0 / B319.0 / 320	Sand castings: crankcases (internal combustion and diesel Engines), pans (oil), tanks (gasoline and oil) Permanent mold castings: engine components (various), heads (water-cooled cylinder), housings (rear axle)	Applications where moderate strength is required. Mechanical properties are not adversely affected by slight changes in impurity content.
356.0	Sand castings: brackets, blocks (water-cooled cylinder), cases (automotive transmission), fittings, housings (rear axle), pump bodies Permanent mold castings: bodies (valve), blocks (engine), brackets (springs), elbows (fuel tanks), fittings (fuselage, tank car), hardware (marine), machine tool parts, pump parts, rudder-control supports	Applications where excellent casting characteristics are required. In the -T6 condition for marine applications where pressure tightness and/or corrosion resistance are required.
A356.0	Airframes, chassis parts (trucks), machine parts, missile components, structural parts	Applications where higher strength and higher ductility (especially elongation) are desirable.
A380.0 / B380.0	Housings (lawn mowers), heads (air-cooled cylinders), gear cases, radio transmitters	Applications for general-purpose die castings with good mechanical properties.
A390.0 / B390.0	Blocks (internal-combustion engines), brakes, cylinder bodies (compressors), pistons (internal-combustion engines), pumps	Applications where high hardness, good wear resistance and low coefficient of thermal expansion are required.
535.0	Brackets, c-clamps, computing devices, instruments, machined parts	Applications requiring strength, shock resistance, ductility and dimensional stability.
712.0	Castings (marine), farm machinery, machine-tool parts	Applications requiring good strength, shock and corrosion resistance, machinability and dimensional stability.