Technology of Aluminium Alloy Castings : A Review

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Abstract
A voluminous literature is available on different aspects of aluminium casting. The paper presents certain aspects of Technology of Aluminium Alloy Castings in a nutshell. Effects of alloying elements, process selection, melting practices, heat-treatment etc have been described here.

Casting process is readily adaptable to aluminium, which can be poured in both expendable and permanent moulds. The use of aluminium cast components in automotive and aerospace applications has increased during last ten years because of high strength-to-weight ratio which leads to an overall reduced weight and, thus, to reduce energy consumption. In addition, aluminium alloys (as a group) have the following desirable properties¹, which make the alloys logical choice in a wide variety of castings:

- Good foundry characteristics
- Good mechanical properties
- Desirable physical properties
- Good machinability and workability
- Good corrosion resistance in most industrial and outdoor exposure conditions, with no staining as with rust.
- Good finishing characteristics. Can be buffed, anodized, electroplated, painted and given a wide variety of mechanical properties.

A large number of aluminium alloys have been developed for casting². They are grouped into:

- Aluminium-Copper alloys
- Aluminium-Copper-Silicon alloys
- Aluminium-Silicon alloys
- Aluminium-Magnesium alloys
- Aluminium-Zinc-Magnesium alloys
- Aluminium-Tin alloys

1. Effect of Alloying Elements³

1.1 Silicon

The outstanding effect of silicon in aluminium alloys is the improvement of casting characteristics. Addition of silicon to pure aluminium dramatically improves fluidity, hot tear resistance and feeding characteristics. The most prominently used compositions in all casting processes are those of aluminium-silicon family. Commercial alloys span from hypoeutectic to hypereutectic alloys containing about 25 % Si.

In general, an optimum range of silicon content can be assigned to casting processes. For slow cooling rate processes (such as plaster moulding, investment casting and sand casting), the range is 5 to 7 %, for permanent mould 7 to 9 %, and for die casting 8 to 12 %. The basis for these recommendations is the relationship between cooling rate and fluidity and the effect of percentage of eutectic on feeding. Silicon additions are also accompanied by reduction in specific gravity and coefficient of thermal expansion.

1.2 Magnesium

Magnesium is the basis for strength and hardness development in heat-treated Al-Si alloys and is commonly used in more complex Al-Si alloys containing copper, nickel and other elements for the same purpose. The hardening-phase Mg₂Si displays a useful solubility limit corresponding to approximately 0.7 % Mg, beyond which either no further strengthening occurs or matrix softening takes place. Common premium strength compositions in the Al-Si family employ magnesium in the range of 0.4 to 0.7 %.

Binary Al-Mg alloys are widely used in applications requiring a bright surface finish and corrosion resistance, as well as attractive combinations of strength and ductility. Common compositions range from 4 to 10 % Mg, and compositions containing more than 7 % Mg are heat treatable. Instability and room temperature aging characteristics at higher magnesium concentrations encourage heat treatment.

1.3 Titanium

Titanium is extensively used to refine the grain structure of aluminium casting alloys, often in combination with smaller amounts of boron. Titanium in excess of the stoichiometry of TiB₂ is necessary for effective grain refinement. Titanium is often employed at concentrations greater than those required for grain refinement to reduce cracking tendencies in hot short compositions.

The aluminium casting alloys used by aeronautical industry in India are Aluminium-Copper alloys, Aluminium-Silicon alloys, Aluminium-Magnesium alloys and Aluminium-
Copper-Nickel alloys. In recent years, several new high strength aluminium casting alloys have been developed.\textsuperscript{4,5} The most widely used alloy for aircraft structural applications is A 357, an Al-Si-Mg alloy.\textsuperscript{6} Its nominal composition is given below:

<table>
<thead>
<tr>
<th>Element</th>
<th>wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>6.5 - 7.5</td>
</tr>
<tr>
<td>Iron</td>
<td>0.2</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.4 - 0.7</td>
</tr>
<tr>
<td>Copper</td>
<td>0.2</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.1</td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.04 - 0.07</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.20</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Balance</td>
</tr>
</tbody>
</table>

The excellent castability of this alloy, as exemplified by resistance to hot cracking and good fluidity, is attributed to the presence of Si. Mg is added for strength; it allows the alloy to be solution heat treated and precipitation hardened. Titanium is added to refine the as-cast structure, which additionally reduces hot cracking susceptibility. The elements Fe, Cu and Mn are present as impurities. Be is added to reduce molten metal oxidation and to enhance elongation and strength. When the alloy is cast and heat-treated in the approved fashion, 280 MPa yield strength, 350 MPa tensile strength and 5% elongation are guaranteed.

2. Casting Processes\textsuperscript{7-11}

Aluminium alloy castings are produced in hundreds of compositions by all commercial casting processes, including sand casting, permanent mould casting, pressure die casting, plaster mould casting, composite mould casting, investment casting and centrifugal casting.

Factors to be considered in selecting a process are:
- initial cost of equipment and material,
- moulding cost,
- degree of precision required in the casting to be manufactured,
- cost of the casting if made by competitive process,
- cost of machining,
- type of heat treatment required,
- post mechanical treatment required (like straightening, peening etc),
- quantity and frequency of requirement of castings, and
- cleaning method to be used.

Selection of specific casting method for aluminium depends on the characteristics and capabilities of each process in relation to the design of the part. Often, combining two or more basic processes will produce parts of the desired metallurgical and engineering characteristics at the lowest cost.

\textbf{Sand casting} is the most versatile casting process, with few limitations with respect to the part shape and the core work for internal cavities. The process is employed for parts which are relatively large, and when the quantity requirement is small, or when the design dictates the use of a completely expendable mould material. There is virtually no maximum size or weight constraint for a sand casting. Major limitation of the method is higher cost per part, rough surface finish and wider dimensional variations than with the other processes.

\textbf{Permanent-Mould casting} employs metal moulds and cores, with gravity or low-pressure pouring of metal. A mould may be used for thousands of cycles. The permanent mould method provides economical long run production with one set of moulds. Metal cores are employed. Frequently expendable cores, which permit undercuts and back drafts in the casting, are used in the semi-permanent mould process. The permanent mould method provides smoother surfaces and superior soundness as compared with sand casting. Pressure tight castings are produced more readily by this method than by sand- or die-casting. Maximum size of casting is limited only by cost.

\textbf{Die-casting} provides foundryman with one of the fastest means of producing castings with a much higher degree of accuracy than that normally obtained by conventional sand casting process. In die-casting the molten metal is forced under pressure, at high velocities into the heat-treated steel die. Compared with the other methods, die-casting offers greater accuracy and more uniform piece-to-piece reproduction, with superior surface details and finish. Die-casting is most economical method for production runs of parts of suitable design.

\textbf{Plaster-Mould casting}, which has grown rapidly in importance, has achieved status as a separate technique. Using an expendable mould of material such as gypsum, it provides very close dimensional tolerances, sharp reproduction of details, and fine surface finish. By combining plaster moulds with an investment technique and method of pressure pouring, such as centrifugal casting, an intricacy of details greater than by any other method can be obtained. Although the plaster process normally is used to fabricate small, intricate parts, there is no inherent limit to the size of the casting. Very heavy sections may require a mould material having higher chilling capacity than plaster.

\textbf{Composite Mould casting} incorporating several moulding materials, such as plaster, iron or steel and sand sections, is used to obtain optimum solidification sequence and to provide maximum soundness, machined properties and dimensional control. Parts made in composite moulds are known by various names, viz. premium-quality, premium-engineered, premium-strength or precision castings. Optimum combinations of mould materials, aluminium casting alloy and design of the part permit production of castings with maximum mechanical properties, minimum dimensional tolerances and the highest degree of reliability. In many applications, such premium castings utilizing
composite moulds may replace forgings, weldments or malleable iron castings. Where extensive machining can be eliminated by their use, and when design criteria are favourable, these castings may prove to be more economical.

Investment casting involves use of special materials like wax for making patterns, which do not need conventional removal from mould. The mould is made around patterns by investing or applying coats of refractory slurry having silica or zircon powder and ethyl silicate binder. It is preheated to 60 °C to remove the wax pattern by melting out or dewaxing. The mould is cured at high temperature at around 350 °C. Being a ceramic, it develops high strength. It is ideal for very small size, highly intricate casting, avoiding costly machining operations, and this process can be used for producing large quantities of precision castings.

Centrifugal casting involves rotating i.e. revolving a mould about an axis, and pouring molten metal in it. The centrifugal pressure forces the metal against the interior mould wall where it solidifies. Cylindrical parts or circular plates are usually the most preferable shapes for centrifugal casting. Tubular aluminium castings produced in permanent moulds by true centrifugal casting have higher structural strength and more distinct cast impressions than castings produced by static permanent mould process. However, other types of castings made centrifugally do not always develop properties superior to good static castings. Specific castings not adaptable to the centrifugal process probably can be produced with better quality and economy by static casting.

3. Aluminium-Alloy Melting

The function of the melting department of an aluminium alloy foundry is to provide for the production of castings molten metal which is at proper temperature, of satisfactory quality, of correct chemical composition and at the lowest cost. Aluminium foundries differ widely in size, scope and complexity of operations and in quality requirements. Hence, a wide variety of furnaces and melting practices are employed. There is no single best method for melting aluminium alloys. Every furnace and procedure has its advantages and limitations. With regard to melt quality, probably the most important aspect is "how a particular equipment is used, rather than which one is used".

3.1 Furnaces

The types of melting furnaces employed in aluminium foundries include:

1. Crucible furnaces
2. Sklenar furnaces
3. Electric induction furnaces

3.1.1 Crucible Furnaces

Crucible melting is the oldest and simplest way of melting aluminium-alloys. The metal melts under the heat of flame from the burning of oil or coke. In certain installations gas is also used. Modern installations also use electrical resistance elements. In these furnaces the radiation heat of the heating elements is used for metal melting. In all these cases the heat reaches the metal by conduction through the crucible walls.

**Crucibles**: Three types of crucibles are in common use: clay-graphite crucibles, silicon-carbide crucibles or cast iron crucibles.

- **Clay-Graphite crucibles** are widely used. As they are fragile they should be handled with care.
- **Silicon-carbide crucibles** have higher thermal conductivity and also longer life. These crucibles may cause silicon pick-up, which is detrimental in aluminium-magnesium alloys. Hence for melting such alloys their use may be avoided.
- **Cast Iron crucibles** are used mainly for "holding" the molten metal—mainly in die-casting foundries. They have long life, are strong and have good thermal conductivity. Their use results in some iron pick-up in the molten alloy. Iron pick-up can be prevented or minimized by controlling the bath temperature to a low level and by frequently coating the crucible by a refractory wash. These crucibles are also rotated periodically to prevent building up of hot spot near the burner flame outlet.

**Crucible Furnaces**: These are of three types: Lift-Out, Tilting and Stationary.

In Lift-Out furnace, the crucible is lifted out by a tong after the molten metal is ready. After pouring, the hot, empty crucible is again centered in the furnace and fresh charge is added. Capacity of lift-out crucible is limited to 40-50 kg of metal. As the crucible is emptied after each melting, alloy can be varied. Degassing, modification and other treatments are done in the crucible itself. The set-up is simple and low in cost.

In Tilting Furnace large size crucible can be used, up to 500 kg or even more. The crucible is centrally positioned and fixed with cement mortar. The furnace is mounted on trunions. The metal is tapped out into pre-heated ladles for pouring. Tilting can be manual, by electric hoist or by hydraulic means. These crucibles are popular in medium to large size foundries producing sand castings.

**Stationary Crucible Furnaces** are mainly used in gravity die-casting and pressure die casting foundries. These are either melting crucible or holding crucible. Molten metal is taken out by dipping hand ladles.

3.1.2 Sklenar Furnaces

These furnaces were popular during sixties and seventies. These are similar to reverberatory type furnaces having shallow open bath. The metal is heated by flames passing over it. As the metal and flame come in direct contact the gas pick-up as well as metal losses are high in these furnaces. Some modifications of these furnaces use electrical resistance elements in the furnace roof, the radiation heat from which melts the metal. These furnaces are useful to melt large quantities of metal of uniform
composition, but are less flexible in making changes of alloys.

3.1.3 Electric Induction Furnaces

In electric induction furnaces, the metal acts as a secondary winding of a transformer in which heat is induced by eddy current flow within the metal under the influence of power flowing through the primary coil. The crucible is either an integral part of the furnace—produced by ramming and sitting refractory mass as is the practice in ferrous melting—or a separate crucible is centered inside the power coil. Channel induction furnaces are also used due to their superior efficiency; the flexibility is, however, limited.

4. Furnace Selection

Requirement of the foundry, local availability of fuel or power, most economical overall cost and possibility of capital investment are the basic considerations in furnace selection. Most important is the degree of flexibility needed by the foundry.

- A jobbing foundry which has to produce castings in several types of alloys needs wide flexibility. For such a foundry a lift-out crucible is, perhaps, the optimum choice.
- For a foundry producing large quantity of castings from a single alloy, a stationary crucible or electric induction furnace may be an optimum choice.
- Tilting furnace may provide a good compromise between alloy flexibility and production of large size castings.
- A gravity or pressure die-casting unit producing small size castings in a large number may find either a stationary holding furnace or a channel type induction furnace an useful set-up.

There are many leading induction furnace manufacturers in India. Hence the best equipment is available if needed. Induction or resistance furnaces give very clean metal, low in gases. The melting losses are also very low. Hence sizable saving can be possible in the metal cost.

5. Melt Treatment

In order to consistently produce high quality castings with little scrap, it is necessary to improve the metal quality prior to casting. The important metal melting processing steps include: melting, fluxing, degassing, grain refinement, and (in case of Al-Si alloys) modification of silicon eutectic.

5.1 Fluxing

Aluminium gets readily oxidized in air. The oxidized layer is strong and tenacious and covers the entire surface, thereby preventing further oxidation of the solid aluminium. Hence all solid aluminium or aluminium alloy castings or ingots are covered with a thin film of aluminium oxide. During melting, the metal comes in contact with oxygen of the air or hot gases of flame and forms a heavier film. If undisturbed, this film remains on the top surface of the melt and protects the melt against further oxidation. This film is called dross. If broken, the film is immediately healed by formation of new oxide.

Clean metal has little dross. But presence of foundry returns into the charge or presence of alloying elements like magnesium increases the dross. If heavy dross has been formed, it may also carry with it some aluminium. Hence to minimize aluminium loss, fluxes are added to separate the liquid aluminium from the dry dross. Such fluxes are called dross drying or skimming fluxes. These are sprinkled over the top of the melt and mildly stirred into the top layer of the melt. The flux mixes with the dross and reacts rapidly to cause localized exothermic reaction. This raises the temperature of the aluminium entrapped into the dross and lets it drain out. The left over dry dross can be easily skimmed off. Gaseous agents like Nitrogen, Chlorine or their mixture are sometimes bubbled through aluminium melts to remove inclusion. Chlorine is most effective in cleaning metals having higher percentage of magnesium.

5.2 Degassing

Aluminium absorbs large volume of hydrogen gas under molten condition. The solubility increases with temperature. The main source of hydrogen is the water vapour in the furnace flame. Melted aluminium reacts with water vapour and forms aluminium oxide (dross), releasing hydrogen of the water vapour, which is readily absorbed in the melt aluminium.

If this gas is not removed from the melt, on pouring into the mould the metal cools and starts solidifying. In solid-state aluminium has very little capacity to retain hydrogen in solid solution. Hence the gas gets separated from the solidifying metal and forms gas porosity in the casting. Hence it is very essential to either prevent the hydrogen pick-up by the melt, or to remove the picked-up hydrogen before metal is poured into the mould.

The mechanism of removing the gas is called degassing. Bubbling of dry nitrogen gas or chlorine gas or their mixture through the melt helps in removing hydrogen. Alternatively (and more conveniently) use of Hexachloroethane ($C_2Cl_6$) tablets in the melt also removes the gas. Hexachloroethane tablets are plunged into the bottom of the melt. It releases dry chlorine gas which degasses the melt.

Gas content is one of the most important factors in the quality of aluminium castings. For producing prime quality castings for critical applications, the gas content must be minimum. But in many castings, presence of some gas ensures elimination of shrinkage, and hence it is beneficial. Presence of large quantity of gas, however, causes pinhole porosity.

5.3 Grain Refinement

Grain refinement of aluminium and its alloys is a common industrial practice. For a number of reasons, it is desirable
that aluminium and its alloys are grain refined to produce fine, equiaxed grain structure, irrespective of whether these are cast either as ingots/slabs for further processing or in the form of shaped castings for direct applications. As-cast structure usually shows coarse columnar grains unless the melt is treated for grain refinement prior to casting. The deliberate suppression of columnar grain growth in Al alloy ingots and castings and the formation of an equiaxed solidification structure is termed as grain refinement. This leads to excellent mechanical properties. Fine grains also ensure high toughness, high yield strength, uniform distribution of second phase and microporosity on a fine scale, resulting in improved machinability, good surface finish and various other desirable properties. There are several types of grain refiners such as aluminium-titanium or aluminium-titanium-boron master alloys.

5.4 Modification

Aluminium-Silicon alloys containing 6 to 13% silicon need modification for improvement in their mechanical properties. Silicon is soluble in molten aluminium, but is non-soluble in solid aluminium. During solidification, silicon comes out as microscopic particles in the form of plates or needles. Under slow cooling condition, the silicon particles become coarse, and impair the tensile strength and elongation of the alloy.

If the melt is modified by introducing approximately 0.05% sodium, the silicon particles are modified to solidify as spheres or globules rather than plates or needles. This results in improved strength and ductility. The popular aluminium-silicon eutectic alloy containing 12% silicon can derive maximum benefit from modification treatment. This introduction of sodium is called modification. It can be added either in the form of pure sodium or as a mixture of sodium salts. For optimum results the sodium addition should be done just a few minutes before pouring the metal into the mould.

Hypereutectic Aluminium-Silicon alloys containing more than 15% silicon can be modified with the use of phosphorous. Phosphorous is added in the form of copper-phosphorous hardener. Addition of 0.01% to 0.05% phosphorous is sufficient. Once introduced, phosphorous remains in the melt, hence its effect remains the same even under prolonged holding of the melt or even from melt to melt.

Sodium and phosphorous are used for different group of alloys – sodium for the hypereutectic and eutectic alloys, and phosphorous for the hypereutectic alloys. Faster cooling rate also modifies the shape of silicon particles. For this reason permanent mould castings or die-castings do not need modification by use of sodium.

Strontium (Sr) is sometimes used as an alternative of Sodium (Na) as a modifier. One important feature of Sr is that it has low oxidation sensitivity and its use leads to the elimination of two major problems associated with sodium modification, viz. fume generation and control of the amount of addition. These have lead towards a growing importance of Sr as a strong modifier. However there are certain limitations of using this metal to affect modification, in that it must be added according to specific criteria to obtain satisfactory results.

6. Heat Treatment of Al-Alloy Castings

Heat treatment of many aluminium-alloys results in a significant change in their properties. The tensile properties, hardness, machinability, dimensional stability, corrosion resistance, electrical and thermal conductivity of aluminium alloys can be changed through thermal treatment. By far the most important change produced by thermal treatment is the improvement in mechanical properties. Some of the well known alloying elements and group of elements which impart this property to aluminium-alloys are:

- Copper (Cu),
- Magnesium (Mg),
- Copper plus Magnesium (Cu + Mg),
- Copper plus Magnesium plus Silicon (Cu + Mg + Si),
- Magnesium plus Silicon (Mg + Si), and
- Magnesium plus Zinc (Mg + Zn).

When alloys containing these combinations are cast and solidification takes place, the elements combine with aluminium or with each other / one another in certain proportions to form compounds. Solidification progresses so rapidly that the resulting casting is not uniform in composition. The microstructure reveals that these compounds are mainly distributed at the grain boundaries. Under equilibrium conditions, a larger proportion of these compounds is soluble in the solid aluminium matrix at a temperature just below the melting point than at room temperature. The quantities of these compounds present in the alloy, as well as the size and distribution of the compounds not in solid solution, account for the properties obtained. The size and distribution of the undissolved particles are controlled by heat treatment.

Alloys which contain only silicon or only a small percentage of magnesium as alloying element are not amenable to heat treatment. The various steps in heat treatment of aluminium alloys are known as solution heat treatment, quenching, aging or precipitation hardening, stress relieving and annealing.

6.1 Equipment

Furnaces which are best suited for solution heat treatment of aluminium alloys are of re-circulating air-chamber type. They may be heated by electrical resistance units, radiant tubes, oil or gas. Provisions should be made that no sulfur or moisture is present because it may cause blistering and oxidation at the high solution heat treating temperatures. The use of small quantities of a protective compound, such as sodium fluoro-borate, in the heat-treating furnace will inhibit blistering and oxidation of the metal surface. The air should be forced and recirculated rapidly in order to obtain a uniform and fast heating rate. Baffles should be used to
direct the air circulation and prevent localized hot spots in the furnace.

Racks and Fixtures are often used so that castings may be loaded properly to prevent any warpage during solution heat treatment. The temperature throughout the furnace should be controlled to a ± 3 °C range for best results. Proportional controlling by reducing the heat input as the desired temperature is approached is a good method of preventing over-shooting of temperature. Automatic shut-off controls are excellent safety measures for cases where other controls may not have functioned properly.

Quench tanks should be located as close as possible to the furnaces so that the least amount of time elapses in transferring the heated load. The longer the delay in quenching, the lower the mechanical properties will be.

Aging furnaces are not as critical regarding atmosphere as solution heat-treatment furnaces because the temperature involved is much lower. However, the temperature control and heat distribution must also be closely controlled because ageing is dependent on time and temperature.

6.2 Solution Heat Treatment (T4 Temper)

Solution heat treating temperatures are usually of the order of 480 °C - 540 °C. When the castings are heated to these temperatures, the inter-metallic compounds of the as-cast structures slowly dissolve and diffuse into the aluminum matrix. The highest possible temperature, which will not distort or burn the casting, is used because the rate of diffusion increases rapidly with increasing temperature. The maximum solution heat-treating temperature is limited by the eutectic melting temperature of the alloy. In some instances, it may also be governed by the strength of the alloy at that elevated temperature.

If appreciable eutectic melting or burning should occur, the mechanical properties will be lowered and the casting surface impaired. If, after sufficient time at a temperature to obtain solution of the compounds, the castings were permitted to cool slowly, the dissolved constituents would again precipitate (relatively in a coarser form) because of the reduced solubility at lower temperatures. The distribution of the precipitate would be more uniform than before, but the mechanical properties of the alloy would approach those obtained in an annealed temper. In order to retain the alloying elements in solution, the castings are quenched as rapidly as possible so that practically no precipitation may take place.

Delay in transferring the castings to the quenching tank will result in temperature losses and less solute will be retained in solution. Usually, hot water (at about 80-100 °C) is used in order to eliminate warpage or even quenching cracks. Air-cooling may be employed for castings of intricate shape, but the mechanical properties will be lower. In this quenched condition, many alloys are soft and unstable because the aluminum grains are super-saturated with the solute. There are few applications, which use castings in this as-quenched condition.

6.3 Ageing

Ageing or precipitation hardening is the process which involves the precipitation of the inter-metallic compounds from the super-saturated solid solution. Mechanical properties depend on the size of particles precipitated from solution, and the size is controlled by the time and temperature used. The precipitation can occur as natural ageing, or it is usually carried out at some temperature in the range of 95 - 260 °C and is known as artificial ageing. Usually, natural ageing requires a long time to reach the stable condition and therefore, in commercial practice, artificial ageing is used. The lower the ageing temperature, the longer the time necessary to obtain required mechanical properties.

Three principal types of commercial artificial ageing treatments are described below.

Artificial Ageing of As-Cast Casting (T5 Temper): This treatment consists of applying an artificial ageing treatment to the casting in the as-cast condition. The cooling rates of most castings are rapid enough to retain a degree of super-saturation of solid solution at room temperature. Low temperature ageing in the range of 150-260 °C, when applied to castings that have not received solution heat treatment, will result in a slight increase in tensile and yield strengths and hardness with some loss in ductility. Castings in the T5 temper provide improved dimensional stability and machinability when compared to as-cast parts. A substantial degree of stress relief is also accomplished with this thermal treatment.

Solution Heat Treated and Artificially Aged (T6 Temper): This type of ageing treatment, commercially the most important of the three basic types of heat treatment, consists of giving a low temperature ageing to castings which have been previously solution heat treated and quenched. The ageing time and temperature are usually selected to produce high strength and hardness with a corresponding reduction in elongation. Other ageing treatment can vary time and temperature to obtain different combinations of tensile properties.

Solution Heat Treated and Stabilized (T7 Temper): This type of ageing consists of an intermediate temperature treatment following a solution heat treatment. The higher ageing temperatures are used to produce an over-aged material. The over-ageing results in precipitation in excess of that which imparts maximum strength and hardness. The T7 type ageing produces substantial freedom from growth in castings that are subjected to elevated temperatures, and also results in substantial removal of internal quenching stresses.

6.4 Annealing and Stress Relief (T2 Temper)

Annealing consists of heating the casting in the as-cast condition to a temperature intermediate between the
solution and precipitation heat-treating temperatures, in the range of 315-345 °C, for a short period of time. Castings are annealed to relieve internal stresses that may exist in the as-cast condition. The mechanical properties produced by annealing are about the same for most alloys as those of as-cast material. This treatment has only limited commercial application.

7. References


PERLITE ORE
(Turkey)
Size : -8 +30

VERMACULITE
Expanded and Raw (Indian)
Size : -4 +8

ASBESTOS WASTE FIBRE

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