CHAPTER-1

1.0 INTRODUCTION

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1.0 INTRODUCTION

Aluminium alloys have been in use since 1940. The development of lightweight Al-Si alloys led to its usage in wear resistant components. The property of lightweight and good thermal conductivity of hypoeutectic, hypereutectic alloys such as A357 and A380 enabled automobile industries to manufacture Al-Si cylinder blocks by the method of die-casting. The cast A357 alloys with improved mechanical properties, low porosity levels, good dimensional accuracy, dimensional stability and good surface finish can be ranked as number one with respect to dimensional stability, fluidity, pressure tightness and weldability.

Classification, designation, properties, composition, modification, heat treatment, wear characteristics and corrosion behavior of Al-Si-Mg alloy have been considered for the study in this chapter.

1.1. Aluminium and its alloys

Aluminum is a soft, durable, lightweight, malleable, silverish white metal [1]. Aluminium base alloys find extensive application in automobile industry, air craft industry and other general engineering industries due to their good corrosive resistivity and good strength to weight ratio. Aluminium alloys are known for easy machinability and very good casting characteristics. They also have good electrical and thermal conductivities and highly reflective to heat and light [2, 3].

1.2. Classification of aluminum alloys

Based on their method of fabrication, aluminum alloys are classified [4] as wrought alloys and cast alloys. Wrought alloys formed by plastic deformation, show different properties such as microstructure and strength when compared to cast alloys.
Each major group can be divided into two subgroups i.e., heat treatable and non-heat treatable. Heat treatable alloys are age hardened whereas non-heat treatable alloys are, strain hardened or dispersion strengthened.

1.3. Designation of aluminium alloys:

Different systems of identifications [5] are there for wrought and cast aluminium alloys. The wrought alloys have a four digit system and cast alloys have three-digit and one decimal place system.

1.3.1. Designation of wrought Alloys:

Wrought alloys are specified based on composition as four digit number (Table1). The first digit specifies the major alloying element(s), the second digit indicates modification of the alloy or impurity limits. The last two digits identify aluminum alloy or indicate the alloy purity.

1.3.2. Designation of cast aluminum alloys:

Each cast alloy is designated by a four digit number (Table2) with a decimal point separating the third and the forth digits. The first digit indicates the major alloying element and the second and third digits indicate the alloy purity with alloying element. The last digit indicates whether it is cast or ingot.

1.4. Temper designation of basic aluminum alloys:

The aluminum association casting temper designation system uses letters and numbers to indicate the major type thermal treatments applicable to engineered castings.
1.4.1. **T-Temper codes:** Temper codes from $T_1$ to $T_{10}$ indicate the heat treatment conditions.

1.4.2. **H-Temper strain hardening codes:**

H1, H2, H3 are the commonly used H-temper codes.

1.5. **Alloying elements:**

Alloys employed in premium-engineered casting are characterized by optimal concentrations of hardening elements and restrictively controlled impurities. Specifications for aluminum alloy chemistries include the effect of major, minor and impurity elements [6, 7].

1.5.1. **Effect of some important alloying elements on aluminium alloy.**

The casting characteristics like fluidity, feeding characteristics and hot tear-resistance are improved by silicon. Silicon combines with magnesium to form $\text{Mg}_2\text{Si}$ in heat treatable alloys which reduces specific gravity and co-efficient of thermal expansion. Magnesium improves strength and hardness in Al-Si alloys during heat treatment. Common high strength aluminum-silicon compositions specify magnesium in the range of 0.4-0.7%. Beryllium reduces oxidation losses. It changes the insoluble phase morphology from script or plate to nodular form. Manganese greater than 0.5% influence internal casting soundness. It is employed to alter the response to chemical finishing and anodizing. Copper promotes solution heat treatment which enhances strength and hardness, stress-corrosion resistance, but decreases elongation. Zinc with magnesium forms $\text{MgZn}_2$ during heat treatment and increases the strength, but they are prone to stress-corrosion cracking.

1.6. **Aluminum -Silicon-Magnesium alloys:**

The research for new materials that could be used for components with complex
geometry in automotive and aircraft industries led to exploitation of Al-Si-Mg alloys. They possess excellent castability and good tensile properties. In Al-Si-Mg alloys silicon is the major alloying element, which imparts good castability, high wear resistance and hardness. Small addition of magnesium improves solution treatment and age hardening characteristics of these alloys.

1.6.1. Al-7.0Si-0.6Mg (A357) alloys:

It is categorized as cast aluminum alloy [8, 9]. These alloys can be sand cast, chill cast; can be grain refined as well as modified. The major alloying elements in A357 alloy are silicon and magnesium. Since, in a premium engineered casting, if high levels of internal soundness and micro structural refinement are desired, melting is important. Good melting equipment and the use of correct techniques are primary requisites for achieving an end product that retains desired metallurgical properties of original alloy from which it is cast. To improve the properties alloying elements are added. The most commonly alloyed elements with aluminium are copper, silicon, magnesium and manganese.

1.6.2. Composition:

The composition of A357 alloy [10] mainly consists of 92.27% of aluminum, 0.6% of magnesium, 7.0% of silicon, 0.15% of titanium, and a little amount of beryllium. Magnesium improves heat treatability, whereas silicon enhances fluidity during casting.

1.6.3. Mechanical properties of A357 (T6 sand casting at25°C) are given in Table 1.3.

1.6.4. Applications:

Aluminum is used excessively due to its many unusual combinations of
properties. A357 alloy is used in carriage components, engine casings, pump parts, fittings, transmission missile bodies, aircraft canopies and super charger, impellers, rotary casing, motor housings, cylinder heads, rocker arm, transmission cases, Connecting rod, truck trailer castings etc.

1.7. Modification:

For substantial improvement in properties, modification [11, 12, 13] is carried out by the addition of small quantities of sodium and strontium to the molten metal just before pouring in to moulds. Modification is a process of changing the shape of the second phase elements, by enhancing its growth and enhancing the property of the alloy to bring about the change in its shape certain solid agents are used. The percentage of these elements is very small and the effect is remarkable. Modification is carried out extensively in Al-Si alloys.

Modification is one of the important melt treatments because it improves the mechanical properties by changing the microstructure of the material. As cast alloys contain silicon in the form of brittle flakes which leads to poor ductility of the material. The commonly used modifiers are of strontium and sodium in Al-Si alloy industry because they are easy to handle, have good modification rate, a long incubation time and a low fading effect. The modifying effect of sodium in the development of an adequate structure is positive it vanishes with time known by a phenomenon “fading”. Alternatively extensive effort is being carried out in order to replace sodium by strontium for the modification of Al-Si eutectic alloys. One important feature of strontium is its consistency in producing castings of good quality. Some important modifiers are antimony, sodium, strontium and calcium.
1.7.1 Sodium modification:

Sodium added in the form of flux. Commercially available modifiers for eutectic or near eutectic Al-Si alloys consist of salts, like 88% of NaCl and KCl (1:1) and 12% of NaF which are in the tablet form. The manufacture of Al-Na master alloy is not possible because sodium has a very low solubility in aluminum. Modern application is that sodium is added in the form of vacuum packed cans.

1.7.2 Strontium modification:

Unlike sodium, the manufacture of Al-Sr master alloy is feasible. Common alloys are Al-with 3.5% or 5%, or 10% Sr.

1.8 Heat treatment:

Heat treatment of aluminum alloys [14, 15, and 16] is done to improve their mechanical properties and wear properties which make them more suitable for the manufacture of aircraft components.

1.8.1. Solution heat treatment:

In this process the alloy is heated to a suitable temperature and soaked for required time period. This causes the constituents to enter into solid solution, and is then cooled rapidly to retain that constituent in solution. When more than one soluble phase is present such as in Al-Si-Cu-Mg system stepped heat treatment may be required to avoid melting of lower melting temperature phases.

1.8.2. Quenching:

A quench refers to a rapid cooling. Quenching is used to prevent temperature phase transformation from occurring by only providing a narrow window of time in
which the reaction is both thermodynamically favorable and kinetically accessible. For instance, it can reduce crystalline and thereby increase toughness.

The objective of quenching is to retain the constituents with minimum distortion and minimum residual stresses. It is an instinct step in thermal practice leading to the metastable, super saturated solution heat treated condition. Rapid cooling from solution temperature to room temperature is critical, difficult and often the least controlled step in thermal processing. Specifications often define or recommended quench delay limits. Water is the quench medium of choice for aluminum alloys and its temperature has a major effect on results. The common use of water as a quenching medium is largely based on the fact that its heat extraction is greater relative other materials. It is well established that parts that have been heat treated and quenched exhibit superior properties like tensile strength, elongation and hardness to those of as-cast condition. Also the advantages of aging or precipitation hardening are obtained by additional thermal treatment after quenching.

1.8.3. Precipitation hardening or age hardening:

Precipitation hardening or age hardening is a heat treatment method used to increase the strength of soft and ductile materials. The solid solubility of some constituents in the alloy system generally changes with temperature after cooling they produce fine impurity particles. They become barriers to dislocations and increase the hardness of the material. In contrast to ordinary tempering the materials is kept at elevated temperature for several hours and allow the constituents treatment after quenching.

The two necessary conditions for age hardening are:

1. Partial solid solubility
2. Solubility should increase with temperature.
The process of hardening is accelerated by artificially aging at temperatures ranging from approximately 90 to 260° C depending on the alloy and the properties desired. The mechanism of strengthening by precipitation hardening is given by coherent lattice theory. After solutionization treatment the alloy will be in a supersaturated state with solute atoms and they precipitate during aging. During aging, these precipitates form an intermediate crystal structure, maintaining coherency with the matrix and the excess phase will have different lattice parameters than the matrix and due to this non coherency there will be considerable distortion of the matrix. Over-aging decreases strength and hardness of the alloy. There will be a boundary between the matrix and excess phase. This can be observed under microscope. The solutionization temperature and age hardening temperature are selected from pseudo phase diagram of Al-Si-Mg system.

Fig.1.1.Pseudo binary phase diagram of Al-Mg$_2$Si
The precipitation sequence can be given as supersaturated phase Guinier Preston zone intermediate precipitate structure stable phase precipitate in matrix. Magnesium silicate is the soluble phase in important alloys A356, A357 unlike the hardening that accompanies the development of coherent lattice strains; this phase increases deformation energy of the crystal lattice. Spherical zones convert to needle shaped particles at points corresponding to peak hardening. Further aging produces rod shaped particles. The transition from $\beta$ to equilibrium $\text{Mg}_2\text{Si}$ occurs without diffusion.

1.9 The Effect of Microstructure on properties of A357 alloy:

Microstructural features are product of metal chemistry and solidification conditions. The microstructure features [17], which mostly affect mechanical properties are size, form and shape of inter-metallic phases, grains, eutectic and DAS.

1.9.1 Intermetallic phases:

Controlling element concentrations and observing stoichiometric ratios required for inter metallic phase formation result in preferred microstructures for property development. Solidification rate-the rate of post solidification cooling promotes uniform size and distribution of inter-metallic and influences their morphology. Lower rates of solidification results in coarse inter-metallic and second phase concentration at the grain boundaries.

Phase formation diffusion controlled so that more rapid solidification and more rapid cooling to room temperature results in greater degrees of retained solid solution and finer dispersions of smaller constituent particles.

1.9.2. Dendrite arm spacing

In all commercial process, with the exception of semisolid forming, solidification
takes place through formation of dendrites[18] from liquid solution. The cells contained within the dendrite structure correspond to the dimensions separating the arms of primary and secondary dendrites and are exclusively controlled for a given composition by solidification rate. There are at least three measurements used to describe dendrite refinement:

- Dendrite arm spacing: The distance between developed secondary dendrite arms.
- Dendrite cell interval: The distance between centerlines of adjacent dendrite arms.
- Dendrite cell size: The width of individual dendrite cells.

The larger the dendrite arm spacing the coarser the microstructure and more pronounced their effects on properties. Finer dendrite arm spacing is desirable for improved mechanical properties. Cooling rates directly control dendrite arm spacing, which influences property development substantially improves ductility. The Table1.4.shows the approximate DAS obtained for different cooling rates and different casting processes:

1.10. Machinability of A357 alloy:

Turning [19] is a widely used cutting process to get the required finished product, where the work piece is rotated and the cutting tool removes a layer of material as it feeds into the material. The thickness of the material removed is decided by the radial movement of the tool into the work piece i.e. depth of cut. Dynamometer and cutting force indicator are generally used to find out the cutting forces involved in the operation.
1.11. Corrosive behavior of A357

Corrosion [20] is the disintegration of an engineered material into its constituent atoms due to chemical reactions with its surroundings. A357 alloys contain many needle-like shapes and beryllium addition to the alloy changes the Si morphology to small globules and reduces the amount of iron-bearing phases. This also increases the Mg$_2$Si precipitates and improves the tensile properties of A357 alloys. The corrosion resistance can be improved by reducing iron content and by modifying silicon morphology. Chemical reaction offers an advantage by the formation of protective coating on surfaces, and a film of relatively low shear strength may result which facilitates sliding. Environment plays a decisive role in determining the rate of oxidation. Thus in the presence of water, hydroxides may result whereas oxides are produced in the absence of water. The relative proportions of oxide and hydroxide determine the mechanical properties of the film formed. At comparatively low temperature metal soaps are formed which give protection to the metal surfaces whereas at higher temperature inorganic metal salts (chlorides, sulphides, phosphates) are produced by the interaction with base metal.