INVESTIGATION ON MICROSTRUCTURE, MECHANICAL AND WEAR CHARACTERISTICS OF ALUMINIUM 6061 ALLOY

PROJECT REPORT

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DECLARATION

I undersigned hereby declare that the project report "INVESTIGATION ON MICROSTRUCTURE, MECHANICAL AND WEAR CHARACTERISTICS OF ALUMINIUM 6061 ALLOY", submitted for partial fulfilment of the requirements for the award of Bachelor of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of **Mr. Noushad T.T.** Assistant professor in Mechanical Engineering. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

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CERTIFICATE

This is to certify that the report entitled "INVESTIGATION ON MICROSTRUCTURE, MECHANICAL AND WEAR CHARACTERISTICS OF ALUMINIUM 6061 ALLOY" submitted by **MUHAMMED HARSHAK K.(MEA16ME074), RAMEES MUHAMMED K.(MEA16ME090), SADIQUP.(MEA16ME093), SAYED MUHAMMED FAYIZ(MEA16ME096)** to the APJ Abdul Kalam Technological University in partial fulfilment for the award of the Degree of Bachelor of Technology in Mechanical Engineering is a bonafide record of the project work carried out by him under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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ABSTRACT

Aluminium-Silicon alloys are most commonly used as piston alloys, alloyed with the elements such as Copper, Magnesium and Nickel. These alloys are widely used for the production of pistons of internal combustion engines by virtue of their low thermal expansion coefficient and high wear resistance. The present study is performed to investigate the Microstructure, Mechanical and Wear characteristics of eutectic piston alloy. Test specimens are prepared by using Wire Electro Discharge Machining. All these specimens are subjected to microstructural analysis, mechanical tests such as tensile test, hardness test and war test in order to find the property variation and grain refinement due to varying copper content in prepared piston alloys. The results of the study shows that by varying copper percentage from 6 to 8 in piston alloy, hardness values are independent in addition of copper. Hence copper concentration has no effect on hardness value. The ultimate tensile strength of the alloys decreases with addition of copper. Materials are brittle in nature and with addition of copper after the eutectic point the strength of alloys seems to be decreasing is observed. Microstructural observation expects that on heat treatment, needle shaped eutectic silicon changes to spheroidal silicon and becomes more uniform. Wear test shows that wear loss is gradually increasing with increase in load and wear rate increases with the sliding speed of the specimen on the disc.

Keywords: Al-Si piston alloy; Tilting furnace; Microstructure, Mechanical and Wear characteristics.

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CHAPTER

INTRODUCTION

An alloy is a material that has metallic properties and is formed by the combination of two or more chemical elements of which, at least one is metal. Commonly, alloys have different properties from those of the component elements. An alloy of a metal is made by combining it with one or more other metals or non-metals, which often enhances its properties. One such major application of alloys is in the automotive field, for manufacturing its components.

In an internal combustion engines, a piston is a cylindrical engine component that slides back and forth in the cylinder bore by forces produced during the combustion process and it converts thermal energy into mechanical energy. A piston is also a component of reciprocating engines, reciprocating pumps, gas compressors, pneumatic cylinders, and among other similar mechanisms. Aluminium is a metal having atomic number 13 having FCC structure. Pistons are commonly made of a cast aluminium alloy for lightweight and excellent thermal conductivity. Thermal conductivity is the ability of a material to conduct and transfer heat. Aluminium expands when heated, and proper clearance must be provided to maintain free piston movement in the cylinder bore. Insufficient clearance can cause the piston to seize in the cylinder. Excessive clearance can cause a loss of compression and an increase in piston noise.

In recent years aluminium alloys are widely used in automotive industries. This is particularly due to the need of weight reduction and hence reduction of fuel consumption. Aluminium alloys are preferred materials for pistons, due to their specific characteristics such as low density, high thermal conductivity, ease of casting and forging and better machinability, high resistance to atmospheric corrosion, high metallic luster, non magnetic and non sparking . The continuing development of modern IC engines leads to specific objectives for further piston development: reduction of piston weight, increase of mechanical and thermal load capacity, lower friction and thus improved scuffing resistance, durability, etc. These goals are achieved by high performance aluminium alloys.

The on-going improvements achieved with cast and forged aluminium alloys reveal that aluminium piston material offer optimum characteristics at elevated

of suitable alloying and heat treatment can produce alloys which suitable for many engineering applications. Addition of alloying elements is made principally to improve mechanical properties such as tensile strength, hardness, rigidity and machinability and sometimes to improve fluidity and other casting properties. Aluminium alloys are used in both the cast and wrought conditions. While the mechanical properties of them can be improved by precipitation hardening and addition of other elements.

The present study aims to understand the effect of alloying elements on a typical eutectic piston alloy by varying copper concentration and study its microstructure, mechanical properties such as tensile and hardness and wear characteristics.

CHAPTER 2
LITERATURE SURVEY

This chapter describes the study performed on the aluminium and its alloys, effects of different alloying elements, aluminium-silicon piston alloys, casting processes and heat treatments.

Aluminium denoted as Al, which is a silvery-white, soft, non-magnetic, ductile metal with atomic number 13 and standard atomic weight 26.98 g is a light weight metal with density 2.7 g/cc and having FCC structure. Its melting point is 660.32^{o}C. The young's modulus, shear modulus, bulk modulus of aluminium is 70 GPa, 26 GPa and 76 GPa respectively. It is the third most abundant element occurring (8.3%) in the Earth's crust. It is a good electrical conductor and a good radiation reflector. Metallic aluminium accepts a high polish and forms a thin, transparent, corrosion-resistant oxide layer. The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa.

2.1 ALUMINIUM-SILICON ALLOYS

Due to economic and environmental requirements, it is becoming increasingly important to reduce vehicle weight. For such an objective, Al-Si cast alloys have been widely employed to produce automotive components working at ambient and fairly high temperature and also due to excellent characteristics such as low cost manufacturing, excellent castability, high strength to weight ratio, high wear resistance, low coefficient of thermal expansion and recyclability. Copper and magnesium are commonly added to improve the strength at room and elevated temperatures.

Al-Si cast alloys are usually employed or intended for applications at temperature less than and around 230^{o}C. The alloy's microstructure strengthening mechanism will become unstable above this temperature. Mostly pistons are cast from eutectic or near-eutectic Al-Si alloys. In order to improve this near eutectic alloy, it is necessary to add required quantity of copper, magnesium, and nickel to this alloy.

Silicon is the main and most important alloying element of Al-Si cast alloy. Silicon is primarily responsible for so called “good castability”, since it imparts high fluidity and low shrinkage. i.e., the ability to readily fill dies and to solidify castings with no hot tearing or hot cracking issues. The more silicon an alloy contains, the lower is its thermal expansion coefficient. Silicon is a very hard phase, thus it contributes significantly to an alloy’s wear resistance. Silicon combines with other elements to improve an alloy’s strength. Silicon content in Al-Si based cast alloys influences tensile properties at both room and elevated temperature.

Pistons are produced from cast or forged, high temperature resistant aluminium-silicon alloys. There are three basic types of aluminium piston alloys. The standard alloy is a eutectic Al-12%Si alloy containing copper, nickel and magnesium in addition. Special eutectic alloys have been developed for improved strength at high temperatures. Alloys with 18 to 24% silicon, hypereutectic alloys, have lower thermal expansion and wear, but have lower strength.

2.1 EFFECT OF ALLOYING ELEMENTS

Alloying of aluminium plays a major role in enhancing the properties such as increased strength, hardness and resistance to wear, creep, fatigue etc. The intensity and range to which the alloying affects the properties of aluminium is specific to different alloying elements and combinations of them. Although most elements readily alloy with aluminium, comparatively very few have sufficient solid solubility to serve as major alloying additions. Among the commonly used elements, only copper, magnesium, silicon, nickel, zinc and iron have significant solubility. However, other elements like manganese and chromium with solubility below 1% confer important improvements to alloy properties. Some of the important elements alloyed with aluminium are discussed below.

2.1.1 Silicon

Silicon is primarily responsible for good castability, high fluidity, low shrinkage, improved hot tear resistance in castings. Silicon’s high heat of fusion contributes immensely to alloy fluidity. It has very low solubility in aluminium, therefore precipitates as virtually pure silicon which is hard and thereby improves the wear resistance. Silicon reduces thermal expansion coefficient of Al-Si alloys. Machinability is poor with addition of silicon in aluminium. Al-Si alloys are essentially composite materials consisting of hard and discontinuous particles embedded in ductile matrix.

2.1.2 Copper

The Al-Cu alloys in the cast and wrought form as fabricated and heat treated have contributed more than any other alloy systems. Copper is used up to 4% in wrought alloys and up to 8% in castings. Both cast and wrought Al-Cu alloys respond to solution heat treatment and subsequent ageing with an increase in strength and hardness at the expense of ductility. But copper reduces castability, ductility and corrosion resistance.

2.1.1 Magnesium

Magnesium provides substantial strengthening and improvement of the work hardening characteristics of Al. It can impart good corrosion resistance, weldability and extremely high strength. Silicon combines with magnesium to form the hardening phase Mg_2Si that provides the strengthening (Rana et al., 2012). Optimum strength in the Al-Si family is obtained by employing magnesium in the range of 0.40 to 0.70%, beyond which either no further strengthening occurs or matrix softening takes place .

2.1.2 Nickel

Nickel alloys are characterized by strength, ductility, and resistance to corrosion. Nickel enhances the thermal stability in cast alloys. The mechanical properties of Al-Si alloy varies with nickel content. When nickel is added to the Al-Si alloys it forms intermetallic compounds such as Al_3Ni, Al_3Ni_2, Al_3Ni_5, NiAl, and Ni_3Al. The NiAl compound has a higher melting point (1638°C) than Ni_3Al (1385°C).

2.1.3 Titanium and Boron

Titanium and Boron are used in aluminium and its alloys as grain refiners. Boron is more effective as grain refiner when it is used in combination with titanium in the ratio 5:1. When used alone, the effect of titanium decreases with time of holding in the molten state and with repeated re-melting. It was found that with normal titanium contents in the range of 0.015%, the grain refinement is effective. However, upon larger titanium additions to levels around 0.15% the grain structure become coarser .

2.1.4 Strontium

Strontium is used to modify the morphology of eutectic silicon in Al-Si alloy. Effective modification can be achieved at very low addition levels, but a range of recovered strontium of 0.008 to 0.04% is commonly used. Higher addition levels are associated with casting porosity, especially in processes or in thick-section parts in which solidification occurs more slowly. Degassing efficiency may also be adversely affected at higher strontium levels in the melt.

2.1.5 Manganese

It was found that as the manganese content increases over 0.5 wt. % in aluminium alloys, both yield strength and ultimate tensile strength increase significantly without decreasing ductility. Adding manganese to aluminium alloys enhances the tensile strength as well as significantly improves low-cycle fatigue resistance and corrosion resistance.

2.1.1 Zinc

Aluminium-Zinc alloys containing other elements offer the highest combination of tensile properties in wrought alloys, but hot cracking of the casting alloys and susceptibility to stress corrosion cracking of the wrought alloys curtailed their use. Effort to overcome the aforementioned limitation has been successful, and these aluminium-zinc alloys are being used commercially to an increasing extent.

2.1.2 Iron

Iron is considered to be the main impurity in aluminium alloys. It combines with aluminium, silicon and other elements to form hard insoluble phases that seriously impair ductility of the alloy. Among them β-Al_5FeSi phase form as thin platelets which appear to be acicular or flaky. They act as stress raisers resulting in reduction in strength. Their volume fraction and size are functions of not only Iron concentration, but also the solidification rate. These plates become smaller and fewer at higher solidification rate. Great care must be exercised to minimize the Iron concentration in order to produce premium quality castings.

2.2 ALUMINIUM ALLOY SYSTEMS

2.2.1 Aluminium-Copper

Copper is one of the most important alloying elements for aluminium, because of its appreciable solubility and strengthening effect. Many commercial alloys contain copper, either as the major addition or among the principal alloying elements, in concentrations of 1 to 10%. It is used frequently in combination with magnesium. The aluminium-rich end of the phase diagram is eutectic A1-Al_2Cu. The eutectic temperature is 548°C, and the composition of the eutectic liquid is Al-33.2%Cu in equilibrium with an aluminium- solid solution containing 5.7 wt. % copper. The Al_2Cu intermetallic phase has a range of composition from 52.5 to 53.7 wt. % copper at the eutectic temperature, and from 53.2 to 53.9 wt. % at 400°C, compositions slightly deficient in copper for the quoted stoichiometry.

2.2.2 Aluminium-Magnesium

Binary aluminium-magnesium alloys are the basis for an important class of non- heat treatable alloys (5XXX series alloys). Although magnesium has substantial solubility in solid aluminium, binary alloys do not show appreciable precipitation-hardening characteristics with concentrations below 7% magnesium. Magnesium, however, does provide substantial strengthening with good ductility as a result of cold work, in addition to excellent corrosion resistance and weldability. In aluminium-rich alloys, the eutectic temperature is 450°C and the concentration is 35% magnesium.

2.1.1 Aluminium-Silicon

The commercial importance of aluminium-silicon alloys is based on their high fluidity and low shrinkage in casting, brazing, and welding applications. The hardness of silicon particles imparts wear resistance. Modification with sodium or strontium results in a fine distribution of silicon particles in hypo-eutectic alloys. Alternatively, phosphorous can be added as a nucleating agent for hyper-eutectic alloys The aluminium-silicon system forms a simple eutectic with limited solid solubility at both ends. The eutectic occurs at 580°C and 12.6% silicon. At the eutectic temperature, the aluminium and silicon solid solutions contain 1.65% silicon and about 0.5% aluminium, respectively. Other intermetallic do not exist in the pure binary system.

2.1.2 Aluminium-Copper-Silicon

Several commercial aluminium based casting alloys contain both copper and silicon as major alloying ingredients. Hot shortness in casting or welding aluminium-copper-silicon alloys is strongly dependent on composition. Hot shortness is maximum at the limit of solid solubility when the amount of eutectic present is at a minimum. No ternary compounds are formed; the phases in equilibrium with aluminium are Al-Cu and silicon. An alloy of eutectic composition contains 26 to 31% copper and 5 to 6.5% silicon and solidifies at 520 to 525°C. The solid solubility of silicon in Al-Cu, or of copper and aluminium jointly in silicon, is believed to be extremely small. In an aluminium solid solution, the presence of a second dissolved element usually reduces the solubility of the first, and vice versa. Non equilibrium freezing, even by quenching from the liquid, has little effect on the structure of the alloys.

2.1.3 Aluminium-Magnesium-Silicon

The aluminium-magnesium-silicon system is the basis of a major class of heat treatable alloys used for both wrought and cast products. These alloys combine many favorable characteristics, including moderately high strength, relatively low quench sensitivity, and good corrosion resistance. The more dilute alloys are used frequently for architectural applications, usually in the form of extruded sections which are given no separate solution heat treatment before artificial ageing.

2.1.4 Aluminium-Copper-Magnesium-Silicon

Commercial alloys containing both copper and magnesium as major additions also contain sufficient silicon to give them the characteristics of quaternary alloys rather than ternary alloys. The principal precipitation-hardening reactions, however, are those of the ternary aluminium-copper-magnesium system.

2.4 Al-Si SYSTEM

Aluminium with silicon as the major alloying element is the most common of aluminium casting alloys (about 80% of the aluminium casting alloys) due to their high fluidity, high resistance to corrosion, good weldability, reduction in shrinkage and low coefficient of thermal expansion etc. As a result they are widely used in the automotive and aerospace industry. Commercial aluminium-silicon alloys are poly-phase materials belonging to 3xx.x series or 4xx.x series. 4xx.x series are not heat treatable as it does not contain precipitating elements. 3xx.x series consist of Al-Si system with copper or magnesium addition and 4xx.x series consist of Al-Si alloys. This study focuses on 3xx.x series i.e., Al-Si system with copper or magnesium.

Aluminium-Silicon alloys are divided into three groups based on silicon content:

1. Hypo-eutectic, containing 5-10% silicon.
2. Eutectic, containing 10-13% silicon.
3. Hyper-eutectic, containing 13-25% silicon.

2.4.1 Aluminium - Silicon Eutectic System

Aluminium-Silicon system is a simple binary eutectic with limited solubility of aluminium in silicon and limited solubility of silicon in aluminium. The solubility of silicon in aluminium reaches a maximum 1.65% at the eutectic temperature while solubility of aluminium in silicon is almost zero. Fig.2.1 shows Al-Si phase diagram. Eutectic point of Al-Si system is at 12.6 wt. % silicon at 577^{o}C. Alloys with silicon composition to the left of this point are termed as hypo-eutectic and alloys to the right are termed as hyper-eutectic.

The microstructure of the Al-Si cast alloys primarily consists of a primary phase (α-Al) and eutectic mixture of Al-Si. The amount of eutectic mixture in the microstructure depends on the level silicon. The wt. % of silicon varies between 5 to 23% (Puncreobutr et al., 2014). The microstructures of unmodified Al-Si alloy are in acicular or flake like shape.

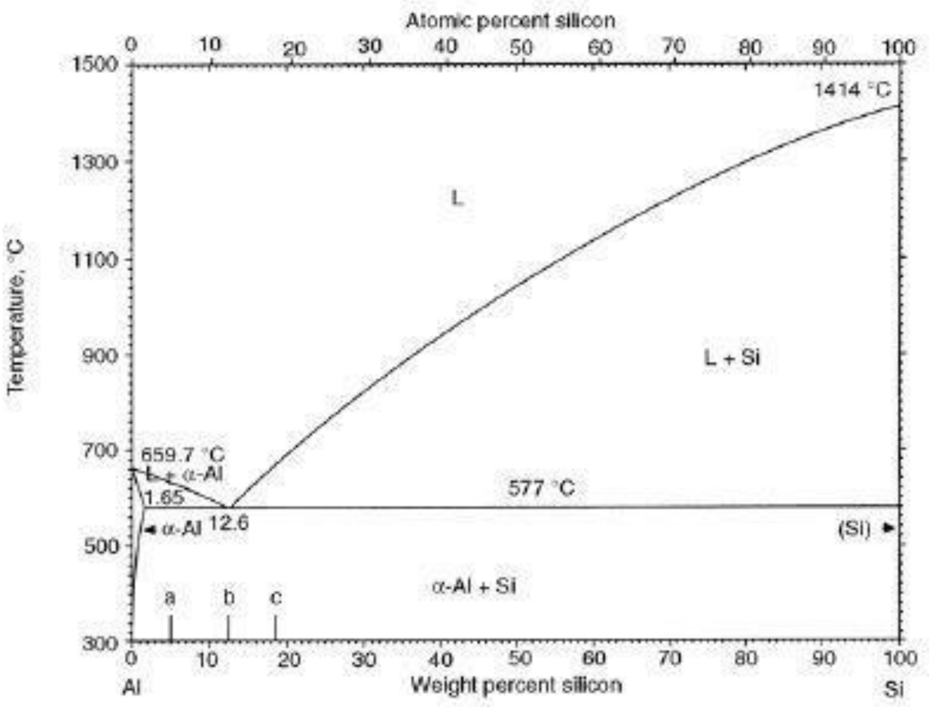


Fig.2.1 Al- Si phase diagram

2.4.2 Aluminium - Silicon Hypo-Eutectic System

In hypo-eutectic Al-Si alloy (5-10% silicon), larger fraction is primary α-Al phase and small fraction of eutectic Al-Si mixture. In hypo-eutectic Al-Si alloys α-Al solidifies dendritically and they are embedded in Al-Si eutectic (Tavitas-Medrano et al., 2010).

Hypo-eutectic alloys are used for general applications like rotors, vessels, valve bodies, large fan blade fittings etc. In the eutectic Al-Si alloy (10-13% Si) there are approximately equal volume fractions of the aluminium and silicon. The dendritic primary phase (α-Al) is absent. Eutectic alloys (11–13% silicon) are used for pistons, cylinders, blocks and heads of internal combustion engines in automobile and aeronautical industries.

2.4.3 Aluminium - Silicon Hyper-Eutectic System

Hyper-eutectic Al-Si alloy contains primary silicon phase (polygon shape) and Al-Si eutectic mixture. Hyper-eutectic alloys (13% silicon) are used in diesel engine pistons.

Mechanical properties of Al–Si alloys are largely influenced by the size, form and distribution of second phase silicon particles, porosity, eutectic morphology and the grain structures. Refinement of primary aluminium, silicon and eutectic mixture improves the mechanical properties like ductility, toughness etc. The properties of a specific alloy depend on individual physical properties of its microstructural constituents and to the volume fraction and morphology of these components. While considering this, silicon is a better candidate as an alloying element for aluminium castings because it exists in Al-Si alloy as virtually pure silicon resulting in direct effect of its aforementioned properties. But large plate like or acicular shaped silicon are detrimental to the mechanical properties. The presence of copper, magnesium and Iron in the alloy leads to formation of various intermetallic compounds in the microstructure of the alloy.

2.5 Al-Si PISTON ALLOYS

Piston alloys are a group of casting Al-Si alloys, well-known as wear resistant materials, which are widely used as the piston materials for internal combustion engines because of their low thermal expansion coefficient, high elevated temperature strength etc. when alloyed with elements such as copper, magnesium and nickel . Different grades of piston alloys contain various amounts of major and minor alloying elements. The usual ranges for some alloying elements are: 11 to 23% silicon, 0.5 to 3% nickel, 0.5 to 5.5% copper, 0.6 to 1.3% magnesium, up to 1.0% Iron and up to 1% manganese .

Most of the Al-Si cast alloys are intended for applications at temperatures of not higher than about 450°F (232°C). Above this temperature, the alloy's microstructure strengthening mechanisms will become unstable, rapidly coarsen and dissolve resulting in an alloy having an undesirable microstructure for high temperature applications. Such an alloy has little practical application at elevated temperatures because the alloy lacks the coherency between the aluminium solid solution lattice and the precipitated strengthening particles.

2.5.1 Effects of Alloying Elements in Piston Alloys

Increase in silicon content in Al-based alloys results in an increase in hardness and tensile strength accompanied by a decrease in elongation.

With the increase of silicon content the ultimate tensile strength and hardness increased, and coefficient of friction and wear resistance was increased as the silicon content increases up to eutectic level. The mechanical properties of cast component are determined largely by the shape and distribution of silicon particles in the matrix. Optimum tensile, impact and fatigue properties are obtained with small, spherical and evenly distributed particles. Silicon also imparts heat treating ability to the casting through the formation of compounds with magnesium. Elements such as nickel, molybdenum, tantalum, vanadium, scandium, copper, iron and manganese are often added in small quantities as important strengthening elements for special purpose. The addition of these elements results in the improvement in tensile properties by solid solution strengthening of α-Al matrix and formation of intermetallic. The strength and hardness of Al–Si alloys at elevated temperature can be enhanced by combining nickel with copper. The alloy is strengthened by addition of magnesium which forms the precipitation of fine Mg_2Si in the matrix. Copper can additionally strengthen the alloy by precipitation of Al_2Cu or modification of the brittle Al-Fe–Si phases. Copper and nickel are typically the alloy basis for improved mechanical properties at elevated temperature. Copper also contributes to the strengthening, matrix hardening, elevated temperature strength and machinability.

The addition of manganese to Al-Si piston alloy converts the flake like Iron bearing β-intermetallic compounds to the star-like α-intermetallic and decreases the detrimental effect of Iron. Applying high cooling rate during solidification of the alloy containing Iron and Manganese results in the formation of finer α-intermetallic compounds and improve the wear behavior of the alloy to a greater extent.

Qian, Zhao, et al., (2008) found the occurrence of manganese-bearing intermetallic phases in a low-Iron containing Al–Si piston alloy with the increase of the manganese addition . When most of the manganese exists in the dendritic Al_9FeNi phase, the elevated temperature strengthening effect is found to be good. Further increase of manganese addition can lead to the formation of plate-like manganese-bearing phase, whose strengthening effect is poor . Copper is an important alloying element in Al–Si alloys and imparts good heat treatability to castings owing to the large solid solubility in aluminium matrix. However, the amount of copper is usually controlled below 3.0 wt. % due to the worry about the formation of micro porosities which act as micro crack sources during tensile loading.

In addition, copper inclines to aggregate in the melt owing to the large density compared to aluminium and silicon, which limits the precipitation strength induced by copper from further increase inevitably. Common precipitation hardening phases such as Al_2Cu, Mg_2Si and Al_2CuMg are formed by copper and magnesium with aluminium and silicon .

The formation of Cu-containing aluminides Al_2Cu, Al_7Cu_4Ni, $Al_4Cu_2Mg_8Si_7$ and Al-Si-Fe-Ni-Cu results in the formation of a highly interconnected 3-D network of aluminides and silicon. Copper is added to aluminium mostly for improvement in tensile strength. Alloys containing copper will respond strongly to heat treatment in T5 and T6 conditions. The major step is to control the Al-Cu (Al_2Cu) compound particle size which is made to precipitate uniformly in the Al-matrix to increase strength by pinning the movement of dislocations. This mechanism would work well if these precipitate particles are very small and evenly distributed within the alloy matrix.

Al–Si–Ni–Cu–Mg alloys are used for instance for the pistons of internal combustion engines because of their superior castability, heat resistance and wear resistance and a lower thermal expansion coefficient than other aluminium alloys. However, there is a need to improve the high temperature strength of these alloys because their tensile strength decreases drastically above 200^{o}C. Solid solution strengthening by silicon, copper, magnesium and nickel alloying elements is responsible for the improvement of micro hardness and other properties.

2.6 CASTING PROCESSES

Foundry practice is the most economical and easiest way of transforming raw materials into finished products. Casting is a manufacturing process by which a liquid material is usually poured into a mould, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is known as casting, which is ejected or broken out of the mould. Different types of casting processes are used in foundry. Among these, sand casting, high pressure die casting and gravity die casting are most widely used in foundries because of cost effectiveness and high productivity.

2.6.1 Sand Casting

The most versatile method for producing aluminium products is sand casting. The process starts with a pattern that is a replica of the finished casting. In this process pattern is pressed into fine sand mixed with binders and water to form the mold into which the aluminium is poured. The melt is poured into cavity and allowed to solidify. Because of low thermal conductivity of sand, cooling rate is low resulting in a casting of less strength. As compared to die and permanent mold casting, sand casting is slow process but usually more economical for small quantities, intricate designs or when a very large casting is required.

2.6.2 Gravity Die Casting

Usually this process is applied for alloys with a low melting point like aluminium, magnesium etc. The metallic dies are preheated to about 200 – 300°C. The metal is poured into the die and forced to fill the mould under gravity and allowed to solidify. Compared to sand casting, gravity die castings provide higher strength and finer structure because of the faster cooling rate. Aluminium alloys cast by gravity die casting include Alloy 366.0, Alloys 355.0, C355.0, A357 etc.

2.6.3 High Pressures Die Casting

The process is similar to that of gravity die casting except metal is filled under pressure. The metal is forced in to the die with high pressure up to 150 MPa. The casting is held under pressure until it solidifies. Here cooling rate is much faster than gravity casting. Thus grain refinement takes place. It is a very automatic casting process for high production rates with good strength, parts with complex shapes and good dimension accuracy which can make thousands of castings every hour. Typical applications of die cast aluminium alloys include:

- Alloy A380.0 - Gears, Streetlamps housings, typewriter frames, dental equipment etc.
- Alloy A518.1 - Escalator parts, conveyor components, aircraft and hardware etc.
- Piston alloy- For high temperature applications like piston, cylinder head, valve lifters etc.

2.6.4 Squeeze Casting

Squeeze casting is a modern casting process used to obtain near net shape castings with higher mechanical properties approaching that of forged components by application of pressure during solidification. It is also known variously as liquid forging, liquid pressing, squeeze forming, pressure crystallization, extrusion casting and liquid metal stamping. Squeeze casting involves the slow, direct application of pressure to a volume of liquid metal before, during and after solidification.

The pressure applied during the process increases heat transfer between the casting and the die, reduces or eliminates porosity in the final casting and also ensures complete filling of the die. The net result of these factors, squeeze casting is considered as a highest integrity casting process currently used.

The process of squeeze casting involves the following steps:

- A pre-specified amount of molten metal is poured into a preheated die cavity, located on the bed of a hydraulic press.
- The press is activated to close off the die cavity and to pressurize the liquid metal. This is carried out very quickly, rendering solidification of the molten metal under pressure.
- The pressure is held on the metal until complete solidification. This not only increases the rate of heat flow, but also most importantly may eliminate macro or micro shrinkage porosity. In addition, since nucleation of gas porosity is pressure-dependent the porosity formation due to dissolved gases in the molten metal is restricted.

The term squeeze casting covers a variety of different processes with the common factor of the slow feeding velocity of the melt into the die and slow application of high pressure throughout all stages of solidification in the die .

2.7 HEAT TREATMENTS

The metallurgy of aluminium and its alloys offers a wide range of opportunities for employing thermal treatment practices to obtain desirable combinations of mechanical and physical properties. Through alloying and temper selection, it is possible to achieve an impressive array of features that are largely responsible for the current use of aluminium alloy castings in virtually every field of application.

Heat treatment comprises all thermal practices intended to modify the metallurgical structure of products in such a way that physical and mechanical characteristics are controllably altered to meet specific engineering criteria. The heat treatment consists of solutionizing at temperatures close to eutectic temperature, quenching and a combination of natural and artificial ageing.

2.7.1 Purpose of Heat treatment

- Relief of internal stress developed during cold working
- Harden and strengthen metals
- Improve machinability
- Change in grain size
- Soften metal for cold working

- Improve ductility and toughness
- Increase heat, wear and corrosion resistance
- Improve electrical and magnetic properties

2.7.2 Solution heat treatment

The solution treatment of the casting produces the following effects:

- Dissolves inter-metallic particles
- Homogenizes the casting
- Changes the morphology of eutectic Si

The solution treatment homogenizes the cast structure and minimizes segregation of alloying elements in the casting. The segregation of solute elements resulting from dendritic solidification may have an adverse effect on mechanical properties. The time required for homogenization is determined by the solution temperature and dendrite arm spacing.

The eutectic Si morphology plays a vital role in determining the mechanical proper- ties. Particle size, shape, and spacing are all factors that characterize silicon morphology. During heat treatment, Si particles are initially broken down into smaller fragments and gradually spheroidized. Prolonged solution treatment leads to coarsening of the particles.

2.7.3 Quenching

Following solutionizing, the castings are usually quenched in water from the solutioni zing temperature. The purpose of quenching is to suppress the formation of equilibrium intermetallic phase during cooling and retain maximum amount in solution to form a supersaturated solid solution at low temperature. The quench media and quench interval are the parameters that control the effectiveness of this treatment. In most cases, the samples are quenched in water whose temperature is in between 298 to 373 K.

2.7.4 Ageing

After solution treatment and quenching, hardening is achieved either at room temperature (natural ageing) or with a precipitation heat treatment (artificial ageing). Maintaining quenched samples at a temperature below the final artificial ageing temperature for extended periods is termed pre-ageing. This temperature may be equal to, above or below the room temperature. The enhancement of strength properties obtained during ageing treatment is primarily due to the precipitation of metastable phases from the supersaturated solid solution. In some alloys sufficient precipitation occurs in a few days at room temperature to yield stable products with properties that are adequate for many applications. These alloys sometimes are precipitation heat treated to provide increased strength and hardness in wrought or cast products. Other alloys with slow precipitation reactions at room temperature are always precipitation heat treated before being used.

Based on conventional solution treatment rule, the restrictive solution temperature to avoid local melting is 550 °C in Al-Si alloys without Cu, but solution temperature of Al- Si-Cu alloys with high Cu content are generally restricted below 495 °C. All inter metallic except the plate-like Fe phase in a Al-Si-Cu cast alloy are insoluble, during solution heat treatment at 495°C/8 h with the addition of different alloying elements, peak ageing is observed at 180 °C/5 h ageing condition.

In this work the solution treatment of the Al-Si-Cu-Ni piston alloy specimens were carried out at 500 °C (± 10 °C) for 5 h and then quenching in the cold water at 20°C. The specimens were removed from the cold water after 10 min and dried. The ageing treatment consisted of heating to 180 °C (±10 °C) for 9 h, followed by removal from the furnace.

2.8 PROBLEM DEFINITION

The continuing development of modern gasoline and diesel engines leads to specific objectives for further piston development: reduction of piston weight, increase of mechanical and thermal load capacity, lower friction and thus improved scuffing resistance, etc. In addition, the basic requirements for durability, low noise level and minimum oil consumption have to be taken into account. These goals are achieved by a targeted composition of high performance aluminium piston materials, novel piston designs and the application of innovative manufacturing technologies.

Combustion analysis from gasoline engines have shown that the unburned fuel comes mostly from a ring-shaped crevice that is formed between the combustion cylinder wall surface, the piston outside wall, and the top of the piston ring. This piston crevice is sometimes called the piston top-land clearance. Experimental results shown that the pistons crevice volume produced about 80.5 percent of the total HC emission, while the heat gasket and spark plug threads produced about 12.5 and 5 percent, respectively.

One way to minimize the pistons crevice volume is to move the top piston ring groove upward in relationship to the piston's crown. In this design, the top piston ring groove is moved upward, very close to the crown of the piston, in order to reduce the vertical length of the piston top land. Thus if the piston top land is made to be very thin, then a stronger piston alloy is mandatory to permit such design modification in order to reduce the HC emission.

The ongoing improvements achieved with cast and forged aluminium alloys reveal that aluminium piston materials still offer great optimization potential and will continue to play a dominant role as piston material in the future. For the pistons, these challenges translate into maximum strength requirements in the relevant temperature range combined with minimum weight. In gasoline engines, the thermal loads have risen significantly during the last years as a result of higher power demands. Also the stresses at average ignition pressure have increased as a consequence of the introduction of knock control, direct fuel injection and turbocharging. Moreover, high speed concepts have led to an increase in inertia load. The requirements for pistons for diesel engines are even more demanding.

Aluminium-Silicon (Al-Si) alloys are widely used in numerous applications because of their high strength, light weight, good corrosion resistance and castability. It is well established that the addition of certain elements such as calcium (Ca), sodium (Na), strontium (Sr) etc to Al-Si alloys alters or ‘modifies’ the morphology of the eutectic silicon from its acicular plate-like form to a fibrous form. This change in the silicon morphology enhances the mechanical properties of the alloy and, in particular, its ductility.

Although investigations have been carried out to study the influence of tramp elements on the microstructure and mechanical properties of Al-Si piston alloy, there is not much information available on the effect of these elements on the modification of the eutectic silicon. This project aims to investigate on the microstructure, mechanical and wear characteristics of eutectic piston alloy by varying content of copper.

CHAPTER 3

OBJECTIVES AND METHODOLOGY

This objectives of the project are presented in this chapter. The methodology of the project is also described in this chapter.

3.1 OBJECTIVES

The present study aims to investigate on microstructure mechanical wear characteristics of eutectic piston alloy.

The objectives of this project work are as follows:

1. To prepare aluminium-silicon piston alloy with the specified amount of alloying elements by varying copper content (6-8 wt%)
2. To perform Heat treatment
3. To study the following characteristics of prepared alloys
    - Microstructure analysis using Optical microscope
    - Wear properties using Pin on disc apparatus
    - Mechanical properties
    - Hardness using Rockwell Hardness Apparatus
    - Tensile strength using UTM

This project involves the preparation of Al-12.6wt%Si-(6-8wt%Cu)-2.3%wtNi eutectic piston alloys. Then microstructure analysis, various mechanical tests and wear test will be performed in order to find the impact of the alloying elements on the alloy and the results will be compared to that of common piston alloy.

3.2 METHODOLOGY

The methodology of this project includes the casting of the alloy, sample preparations and testing of the alloys. Gravity die casting technique is used for alloy preparation following which the specimens for microstructure test, tensile test, hardness test and wear test are prepared. Then the above tests are performed on specific respective apparatus shown above in objectives.

CHAPTER 4

EXPERIMENTAL PROCEDURE

4.1 INTRODUCTION

Aluminium-silicon alloys were prepared with different weight percentage of copper using Tilting furnace. Samples of different dimensions were cut for different tests after identifying the defect free areas using x-ray and ultrasound testing. Heat treatments were carried out to obtain T-6 temper conditions. The microstructures analysis conducted on the samples using optical microscope. The hardness was measured with the Rockwell hardness testing machine. The tensile properties were obtained by conducting tensile tests on universal testing machine. The wear properties were obtained by conducting wear test on Pin on disc apparatus.

4.2 PREPARATION OF ALLOYS

The following experimental procedures carried out during the processing and characterization of alloys.

- Charge calculation
- Mould preparation
- Melting the charge in Tilting furnace
- Casting of piston alloy
- Preparation of specimens for tests
- Heat treatment
- Microstructure analysis
- Tensile test
- Hardness test
- Wear test

4.2.1 Charge Calculation

Base Metal is used as A6061 and master alloys Ni, Cu and Si are used to cast the required alloy.

A6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S," it was developed in 1935.

It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose use. It is commonly available in pre-tempered grades such as 6061-0 (annealed) and tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged).

Table 4.1 Percentage composition of metals in alloys

Composition	**Al 6061**	**Si**	**Ni**	**Cu**
ALLOY-1	79.1%	12.6%	2.3%	6%
ALLOY-2	78.1%	12.6%	2.3%	7%
ALLOY-3	77.1%	12.6%	2.3%	8%

The 6xxx-group contains magnesium and silicon as major addition elements. These multiphase alloys belong to the group of commercial aluminium alloys, in which relative volume, chemical composition and morphology of structural constituents exert significant influence on their useful properties. In the technical 6xxx aluminium alloys contents of Si and Mg are in the range of 0.51.2 wt%, usually with a Si/Mg ratio larger than one. Besides the intentional additions, transition metals such as Fe and Mn are always present. If Si content in A1 alloys exceed the amount that is necessary to form Mg2Si phase, the remaining Si is present in other phases, such as Al-Fe-Si and Al-Fe-Si-Mn particles [2, 4, 6-13]. The aluminium alloys of 6xxx group have been studied extensively because of their technological importance and exceptional increase in strength obtained by precipitation hardening. The 6xxx aluminium alloys are mostly used as extruded products, as well as for construction and automotive application. The ease with which these alloys can be shaped, their low density, their very good corrosion and surface properties and good weldability are factors that together with a low price these make them commercially very attractive.

Table 4.2 Charge calculation for eutectic piston alloy

Composition	Total quantity(Kg)	Si	Cu	Ni	Al 6061
Al-12.6Si-6Cu-2.3Ni	2	0.252	0.120	0.046	1.582
Al-12.6Si-7Cu-2.3Ni	2	O.252	0.140	0.046	1.562
Al-12.6Si-8Cu-2.3Ni	2	0.252	0.160	0.046	1.542

4.2.2 Mould preparation

Mould has been fabricated using MS plate. It is a split type mould which can be separated into two pieces. It has been bolted while pouring into the mould. It has following features

- Fabricated using MS plate
- Split type mould
- Funnel shaped opening for pouring the metal
- Size 60 x 60 x 300 mm

Before pouring the mould is prepared by applying the graphite powder on the inner surfaces of the mould to avoid sticking of molten metal to the mould. It is then bolted to be an assembly which will be buried to sand, half of its portion for holding it in upright position.

4.2.1 Melting the charge in tilting furnace

The furnace uses diesel for firing. A blower is attached to the furnace for continuous supply of air. For casting the following procedure has been followed. The furnace is fired and the raw materials are charged into the crucible. The melting point of the Al-Si alloy is 950°C.Temperatue has been raised to this temperature after 6 hrs of operation.

Fig.4.1 Tilting furnace used for melting

4.2.2 Casting of Piston alloy

When the temperature of the melt decreased down to 750 °C the melt was poured into a ladle which is preheated using the furnace. Then the melt was poured to the metallic mould pre-heated to 200°C and test setup. The pouring was in a way to provide required metal in order to compensate shrinkage allowance.

After casting the mould and cast will water quenched. The cast can be removed from the die after cooling the mould. The size of the alloy material cast is 60mmx60mmx300mm.

4.2.3 Preparation of specimen for tests

The required sizes of specimens for Microstructure analysis, Tensile test, Hardness test and Wear characterization are to be cut from the casting using power hacksaw, milling machine and lathe machine.

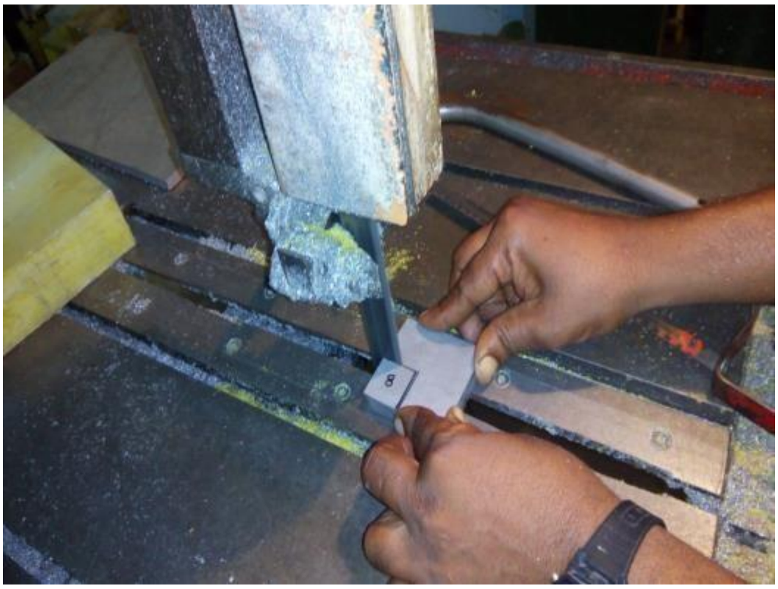


Fig.4.2 Cutting of specimen for microstructural analysis

Fig.4.3 Machining of specimen for tensile test

4.2.4 Heat treatment process

Heat Treatment is the process whereby controlled heating and cooling is used to alter the physical & mechanical properties of metals without affecting any change in the shape of the objects. Heat treatment process is used to increase material strength and also to improve machining, formability & restore ductility. Heat treatment process allows for the improvement in product performance through improvement in material characteristics.

4.2.6.1 Metallurgy of heat treatment of Aluminium alloys

Aluminum and its alloys are used in a variety of cast a wrought forms and conditions of heat treatment. Forging, extrusions, sections, etc., are examples of wrought products, while sand, gravity and pressure die castings are generally adopted casting methods.

It has been the practice of Designers to specify heat treatment to enhance mechanical properties, hardness and machinability. Only certain Aluminum alloys containing alloying elements like CU, Si, Mg and Zn in certain specific percentages can be heat treated to have desired mechanical properties. Other non heat treatable alloys can at the most be annealed to facilitate forming operations.

The various alloying elements mentioned above have limited solubility in solid state and this increase with increased temperature.

4.2.6.2 Solution heat treatment

This involves heating of Aluminum alloy to a particular temperature for sufficient time so that the alloying elements go into solid solution and forma single phase. The factors which affect the final properties of the alloy are soaking temperature, soaking time and cooling rate.

The Soaking temperature depends on various phases which are present in alloys. Each phase will dissolve in solid solution at different rates. The soaking time is based on the rate of dissolution of alloying elements into solid solution. It also depends on the conditions under which the alloy is cast. Sand cast parts have coarser structure than permanent mould casting. Hence Aluminium Sand Castings take time for dissolution of phases necessitating longer soaking time.

4.2.5 Microstructural analysis

All technological properties of materials are directly connected to their microstructure. Among these properties are their strength and deformation characteristics, their wear and high temperature behaviour, and also their corrosion behaviour and the failure behaviour under fatigue loads. Some of these properties can be changed dramatically by slight changes in the microstructure. An optical microscope is used for micro-structural investigations.

Examination of the microstructure of aluminum and its alloys requires a well-executed chain of steps carefully developed based upon scientific understanding and practical experience. In general, there are a series of steps required to prepare specimens: sectioning, mounting, grinding and polishing. In most cases, sectioning is required to obtain a small piece for examination. Mounting, in some cases, may not be needed. After grinding and polishing, it is good practice to examine the surfaces before etching. For

examination of intermetallic phases, it is common practice to etch with dilute aqueous HF solutions; a 0.5% concentration is very commonly used. This improves the image contrast and reveals little besides the intermetallic. Other etchants are used to detect segregation or cold work or reveal grain size.

4.2.7.1 Sectioning

In theory and in practice, any standard cutting technique can be, and is used, to section aluminum and its alloys. However, the damage produced at the cut surface does vary substantially with different procedures. All cutting operations produce damage, but the degree of damage and depth of damage does vary with the methods chosen. In all cases, cutting must not produce excessive temperatures that may alter the microstructure and hardness.

4.2.7.2 Grinding

Mounted or unmounted specimens can be ground either manually (i.e., by hand) or using automated devices. Silicon carbide has been the generally preferred grinding abrasive for aluminum and its alloys and it is quite effective. Specimens were ground through a series of five or more sheets of SiC with increasingly finer abrasive sizes. Grinding Carried out using Emery papers of grain sizes, 220,400,600,1000,1500,2000.

4.2.7.3 Etching

With nearly all metals and materials, and aluminum is no exception, it is always best to examine specimens after preparation, prior to etching. Numerous etchants have been developed for revealing the microstructure of aluminum and its alloys. The specimen is placed in a small beaker containing about 100 ml of the etchant, polishing face up, using tongs. Gently swirl the etchant or use the tongs to provide agitation. This promotes uniform etching. Surfaces must be properly cleaned before etching, or etching results will be impaired. Etching is halted when the proper degree of surface dulling is produced. The specimen is removed from the beaker and rinsed with running water. The specimen is then rinsed with ethanol and blown dry with warm air.

4.2.7.4 Microscopic analysis

An optical microscope is used for micro-structural investigations. The polished specimen is to be observed using Leica Optical Microscope. The images are captured at suitable magnification and recorded using computer and analyzed.

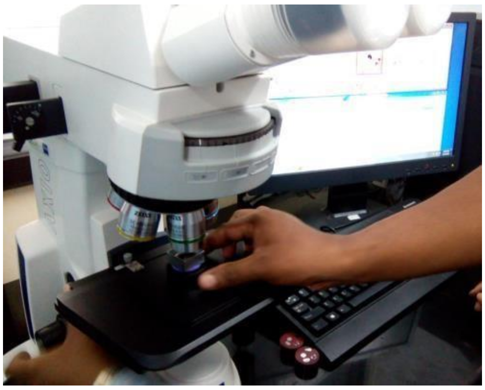


Fig.4.4 Optical microscope

4.2.6 Tensile test

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen.

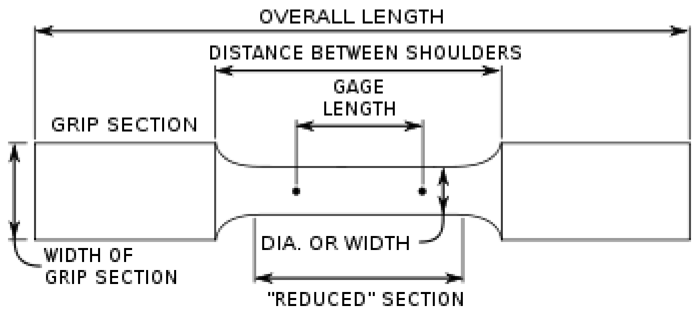


Fig.4.5 Tensile test specimen nomenclature

The strain measurements are most commonly measured with an extensometer, but strain gauges are also frequently used on small test specimen or when Poisson's ratio is being measured. Newer test machines have digital time, force, and elongation measurement systems consisting of electronic sensors connected to a data collection device (often a computer) and software to manipulate and output the data.

Tensile properties of metal are measured by gripping both ends of a test bar and pulling at a constant speed until it breaks. During the test, the force on the bar and how much it stretches is continuously measured. Metal specimen is machined into a dog bone shaped tensile bar before testing according to ASTM E-8 standards. Tensile test are carried out in the ZWICK, Germany made Universal Testing Machine.

Fig.4.6 Specimen before tensile test

Fig.4.7 Universal Testing Machine

4.2.7 Hardness test

The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, HRB, HRC, etc., where the last letter is the respective Rockwell scale.

The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number.

Details of machine which is used for hardness test:

- Machine used: Indentec, Rockwell Hardness Machine
- Load Applied: 100 Kg
- Hold Time: 3 sec.
- Calibrated by Standard test block Accuracy: ±0.5 HRB

Result is converted to BHN

BHN number of the specimen is calculated according to the format as follows:

$$BHN = \frac{L}{(\pi D/2)(D - \sqrt{D^2 - d^2})}$$

Where;

BHN = Brinell Hardness Number (N/mm^2)

L = Applied load (Kg)

D = Diameter of indenter (mm)

d = Diameter of indentation (mm)

Fig.4.8 Rockwell Hardness Testing Machine

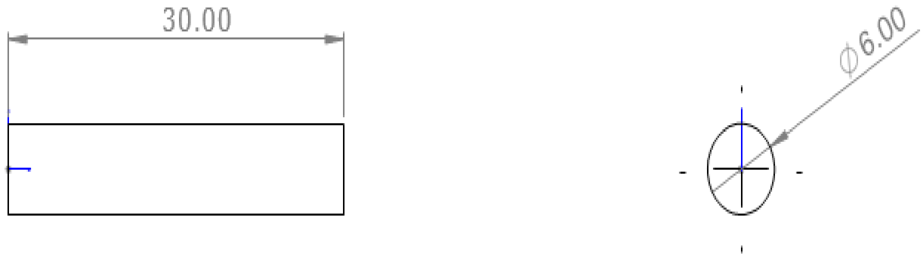
4.2.8 Wear test

Pin on disc wear test machine was used for the wear tests. The rotating disc was made of carbon steel. The samples Al-12.6Si-6Cu-2.3Ni, Al-12.6Si-7Cu-2.3Ni, Al-12.6Si-8Cu-2.3Ni were held stationary and a required normal load was applied through a lever mechanism. The test were carried out by varying one of the following three parameters and keeping other two constants:

- Applied load (15N,30N,60N,90N)
- Sliding speed (.4m/s,.6m/s,.8m/s,1m/s)
- Sliding distance (330m, always kept constant)

No lubricant is used as test is carried out in dry conditions. Care has been taken that the specimens under test are continuously cleaned with woolen cloth to avoid the entrapment of wear debris and to achieve uniformly in experimental procedure.

Fig.4.9 Pin on disc apparatus for wear test



All dimensions are in mm

Fig.4.10 Wear test specimen dimensions

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

Different tests like compositional analysis, tensile test, macro hardness test, wear test etc. on Al-Si alloys were carried out. The results obtained from these tests are reported, analyzed and discussed further in this chapter.

5.2 MICROSTRUCTURAL ANALYSIS

The variables affecting the microstructure mainly include chemical composition, casting process, solidification conditions and heat treatment. The a-Al matrix, eutectic silicon particles and other phases in the microstructure were found to play an important role in determining the tensile, wear and hardness behaviour of the alloy. The microstructure of the castings can be controlled by different melt treatments such as degassing, modification, grain refinement and cooling rate.

It can be expected that the amount of primary silicon decreases with the addition of Cu.

5.1 TENSILE TEST

The values of ultimate tensile strength (in MPa) for Cu-6%, Cu-7%and Cu-8% of Al-Si-Ni alloy can be expected in the range of Cu-6% > Cu-7%> Cu-8%

5.1 HARDNESS TEST

The macro hardness tests of all the samples were conducted using a Rockwell hardness (B Scale) testing machine with a dwell time of 3 s and applied load of 100 kgf (P) during the tests. For each composition, five indentations were taken and average value is reported.

We can expect that the hardness is improved by the addition of copper (by almost 40%).

5.1 WEAR TEST

Wear test is conducted on pin on disc apparatus. Each specimen were subjected to loads of 15N,30N,60N,90N and speeds of 0.4m/s, 0.6m/s, 0.8m/s, 1m/s at a constant sliding distance of 330 m.

It has been observed that with load increasing the wear of the material decreases and so do with increase in sliding speed. With this general trend it has been observed that for a particular combination wear is maximum for 0.4m/s speed and l5N. The wear so measured is calculated in grams as the reduction in mass of the specimen after the test.

CHAPTER 6

CONCLUSIONS

This study highlights the effect of copper addition varying (6– 8 %) to the Al-Si Piston alloy on micro structural and tensile characteristics. The conclusions drawn from the conducted investigations are as follows:

1. The alloys to be tested are prepared from the diesel fuelled tilting furnace as per the charge calculated for Al-12.6Si-6Cu-2.3Ni, Al-12.6Si-7Cu-2.3Ni, Al-12.6Si-8Cu- 2.3Ni.The prepared aluminium silicon alloys have homogenous distribution of silicon, copper and nickel throughout the cast.
2. Tensile test was conducted in UTM. The results can be expected that ultimate tensile strength decreases with increase in Cu concentration.

   Cu-6% > Cu-7%> Cu-8%

3. Hardness test were conducted on digital Rockwell hardness test apparatus.

   From the results obtained it is expected that the values are not dependent on copper concentration. Hence copper concentration has no effect on hardness value.

4. Microstructure analysis of Al-12.6Si-2.3Ni-(6-8) wt % Cu alloys were observed under high magnification optical microscope. On heat treatment needle shaped eutectic silicon changes to spheroidal silicon and becomes more uniform (expected).
5. Wear test was conducted on the pin on disc wear testing machine. From the wear characteristics of Al-12.6Si-2.3Ni-(6-8) wt % Cu piston alloys. It is expected that with respect to varying load the wear loss is gradually increasing with respect to the increase in load.

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