Study Of Hardness And Wear Analysis In Al-Si Alloy (Al-5%Si,Al-11%Si And Al-17%Si) Along With Micro Structural Analysis

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Abstract- *In this study, there is an alloying element named as silicon is studied with its effect when varied through Al composition. As silicon is used for making alloy harder and it evident since the last few years there has been a rapid increase in the uses of aluminum-silicon alloys, particularly in the automobile industries, because it has the high strength to weight ratio, high wear resistance along with low density and low coefficient of thermal expansion. Hence, advancements in the field of application make the study of their wear and tensile behavior of utmost importance in this present investigation, Al-based alloys containing5%, 11% and 17% weight of Silicon were synthesized using casting method. Compositional analysis and hardness along with wear analysis performed for different samples of same composition have shown near uniform distribution of Si in the prepared alloys. Study of microstructure has showed the presence of primary silicon. Wear tests were carried out to check whether there will be any change in mechanical property as well as strength ie high hardness with increase in silicon percentage. Wear behavior was studied by using computerized pin on disc wear testing machine. Resistance to wear has increased with increase in silicon amount.*

I. INTRODUCTION

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 (up to 200ºC)due to excellent characteristics such as low cost manufacturing, excellent cast ability, high specific strength and recyclability [1, 2]. Cu and Mg are commonly added to improve the strength at room and elevated temperatures and enable the possibility of heat treatment [3].The microstructure of these casting alloys contains α-Al dendrites as the main constituent, which is decorated with eutectic Si particles and many intermetallic phases such as Al2Cu,Mg2Si, Fe bearing phases etc. The size, morphology and distribution of microstructural features govern the mechanical properties of theses alloys [4]. It is well-known that a refined microstructure results in improved tensile properties. The refinement of microstructure can be achieved through high cooling rate or chemical modification. Usage of Al-Si-Cu-Mg alloys at temperature above 230 ºC is however limited due to coarsening of Si particles and dissolution of Cu-and Mg-bearing phases.

Metal casting is one of the oldest of all industries on record. Its historical development can be traced back as far as 4000years B.C. The art of metal casting is fundamental to civilization and has been practiced throughout the ancient world in Europe, Central and South America, India, China, and Northern Africa. Metal casting is a process of manufacturing or fabricating a desired metal shape by pouring molten metal into a cavity called a mold, and allowing the molten metal to solidify. After solidification and cooling of the molten metal, the desired object can be removed from the mold and used or processed further. The discovery and first use of metal has been traced with some accuracy to the area north of the Black Sea in the Carpathian Mountains of Russia. Gold was the first metal used by early man to make utensils for daily use. This is because gold is malleable enough to be shaped without splitting at ambient temperatures. Later, early man discovered copper and found that copper could best be shaped by heating and hammering. With further heating it was discovered that these metals melted into liquid which would then re-solidify upon cooling. As a result, gold and copper became the first metals to be cast, and early man now had a method to obtain more complex shapes in metal. Due to the migratory nature of the people in earlier times, casting spread towards the Orient, and later, westwards into the Near East, the Mediterranean basin, and the rest of Europe. The early Chinese foundry men were able to produce intricate and delicate metal objects by using stone molds, sectional loam molds and, later, lost wax techniques. The Chinese people had apparently discovered bronze, and it is believed they had advanced knowledge of metallurgy for their time period. Figure 1-1 shows a cast bronze dating from China's Shang Dynasty (1726 to 1122 B.C.) which was produced by the lost wax process. In the Mediterranean basin, the ~gyptians put effort into improving the casting techniques used by the Chinese. In fact, credit should be given to these early

Egyptians for the discovery of the lost wax process of casting and also the use of a cope and drag, and of core molding.

General casting:

Fabrication is a process which is used to make any shape, machine and join metals. The metal which is worked in the form of an ingots obtained by smelting or refining the metal ore. The fabrication processes are basically casting, forging, welding, metal machining, metal joining and finishing. Fabrication of parts with other methods is time consuming than the casting process. Casting is a fast way to produce the required shape. Mainly three steps are involved in a casting process, 1) heating metal until it becomes molten, 2) pouring molten metal intocavity,3) allowing the metal to cool and solidify in the shape of the cavity or mould. Casting is used in the Engineering industry to produce Engine components like engine blocks, cylinder heads etc. Metal casting is very important to our economy and security. Different metals are cast by many different processes for different applications. Products cast from different metal and processes give advantages unavailable from products made by other metal forming and fabricating methods. Castings made from foundry are used in many industries like Automotive, agriculture, aerospace, mining, construction, fluid power, defense & domestic household. Few cast components like engine, cylinder block and suspension parts for automobiles. Valves, pumps, pipes, and fittings are used for hydraulic industries. To avoid the emissions there is necessity to improve the fuel efficiency and make the vehicle lighter in weight. Non ferrous metal like aluminum is lighter than steel and has density one third of that of steel. Aluminium has a lower density of 2.7 gm/cc compared to 7.8 gm/cc of steel. Aluminum and aluminum alloys are lightweight with good corrosion resistance, Strength and ductility. Aluminium castings and its process are more expensive than ferrous based castings and its process. The greater use of aluminum can reduce vehicle weight, reduce fuel cost with great performance. Casting or parts produced from Pure aluminum, gives unexpected casting features like hardness and strength because of this reason aluminium alloy castings are prepared. Silicon,copper, magnesium, Nickel, zinc, etc are the main alloying elements are added in aluminum.Aluminium silicon alloys have good casting and corrosion resistance properties. Addition of silicon used in aluminum metal to increase fluidity. The copper addition to aluminium enhance its strength and hardness. To achieve good machinability, aluminium copper alloys need to be heat treated.

Details of metal melting:

The Melting process consists of–Metal charge filled in a crucible of the furnace and the metal is allowed to melt by electrical, oil/ gas energy. The moulds are poured with the molten metal which is removed from the melting furnace. Pre heated moulds are used for permanent mold die casting process. Sand mould or metallic mould can be used for collecting the molten metal. Aluminium alloys can be melted in direct or indirect fuel fired furnaces or in electrically heated furnaces like–Tower furnace, crucible furnaces, reverberatory furnaces, pot furnaces, induction furnaces. There are various types of industrial furnaces are Oil, Gas fired and electric. The furnaces can be stationary or tilting type. a crucible is look like a metal pot which is used to hold the molten metal in a furnace. Clay graphite and silicon graphite are used to make crucible. The more famous crucible employed in industries are silicon carbide because of its higher strength and higher heat conductivity. Clay graphite crucible is cheaper than silicon carbide crucible and is used in small foundries and educational institutes. The mixtures of raw materials like graphite, silicon carbide and clays are used for making crucibles. Pitches and resins are used as binders. Crucibles are available in different sizes after it undergone of its preparation process and final firing. The main properties of a crucible should withstand the high temperatures of melting and the crucible material should have higher melting point than that of the metal to be melted. The crucibles are used for melting nonferrous metals like zinc, aluminum, brass / bronze, etc. in one foundry should not be the same. Different metals should not be melted in the same crucible as it leads to melt impurities and it will alter the properties of the castings. Moisture pick up will lead to crucible crack while heating. Few times crucibles crack and molten metal can leak and splash on the employees and it can short the coil causing damage to the furnace and injure the person dealing with it. New crucibles should be baked before being used.

Electrical heating furnaces gives good melt quality and avoid of products of combustion when oil fired furnace used. They have heating elements in the form of rounded coils or straight strips. The metallic elements are widely used in the electric resistance furnace. These furnaces are stationary or tilt type insulated with ceramic fiber. For melting of non ferrous metals, Low and high frequency induction furnaces are used. In a coreless induction furnace a graphite crucible lined with appropriate refractory is used for melting nonferrous metals. The coreless induction furnace can be tilted with a hand wheel or a motorized arrangement and the melt poured in moulds. The scrap used for aluminium alloy melting should be clean. The crucible used for melting should be cleaned after each melt. All tools used in melting must be cleaned and dried to prevent pick up of moisture by the melt. Moisture in the die or moulding sand will cause porosity in the casting. The Die must be properly dried and preheated. Combustion gases,s and, tools, etc. containing water may cause hydrogen absorption. Molten aluminium/alloys absorb gases giving a defective casting after solidification. The removal of gases is an important process in the metal casting field. Aluminium is degassed by passing nitrogen gas slowly in the melt. A flux is used in melting aluminium to remove impurities. The flux forms a protective.

Alloy

An alloy is a material that has metallic properties and is formed by combination of two or more chemical elements of which at least one is a metal. The metallic atoms must dominate in its chemical composition and the metallic bond in its crystal structure. 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 that often enhances its properties. For example, steel is stronger than iron which its primary element. The physical properties, such as density and conductivity, of an alloy may not differ greatly from those of its component elements, but engineering properties such as tensile strength and shear strength maybe considerably different from those of the constituent material[1].

Aluminium alloys

In recent years aluminium alloys are widely used in automotive industries. This is particularly due to the real need to weight saving for more reduction of fuel consumption. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. Surfaces of aluminium alloys have a brilliant lustre in dry environment due to the formation of a shielding layer of aluminium oxide. Aluminium alloys of the 4xxx, 5xxx and 6xxx series, containing major elemental additives of Mg and Si, are now being used to replace steel panels if various automobile industries. Due to such reasons, these alloys were subject of several scientific studies in the past few years[2].

Designation of Aluminium alloys

On the basis of the major alloying element, the aluminium alloys are designated according to the Aluminium Association Wrought Alloy Designation System which consists of four numerical digits[3].

Aluminium-Silicon alloy

Aluminium-Silicon alloys are of greater importance to engineering industries as they exhibit high strength to weight ratio, high wear resistance, low density, low coefficient of thermal expansion etc. Silicon imparts high fluidity and low shrinkage, which result in good cast ability and weld ability. Al-Si alloys are designated 4xxx alloys according to the Aluminium Association Wrought Alloy Designation System. The major features of the 4xxx series are:

II. LITERATURE REVIEW

Al-Si Alloy:

Hypereutectic aluminum silicon alloys are attractive candidate materials for automotive, aerospace and electronics applications due to their excellent properties, such as low weight, high stiffness, good wear resistance and low coefficient of thermal expansion. These properties can be effectively improved by further increasing the silicon content of the alloys. However, as pointed out by Hatch(1984)and Wu et al. (1995), it is difficult to produce such alloys with high silicon content by means of conventional casting processsince coarse primary silicon phase precipitates in the materials and causes reduction of mechanical properties and deterioration of workability. Hogg and Atkinson (2005)also claimed that refinement of primary silicon by adding phosphorus to the molten alloys is insufficient when the silicon content of the alloys is higher than25 wt.%.Effective primary silicon refinement can be achieved at increased solidification rates that are facilitated by high under cooling ability. Powder metallurgy seems to be an alternative route for the manufacture of hypereutectic aluminum silicon alloys since the fine powder used is usually highly under cooled and rapidly solidified. Unfortunately, the need to avoid oxidation and contamination of the powder by complex and costly processing steps hinders the cost-effective application of this process. Spray forming is a relatively new metallurgical process for the manufacture of near net shaped metallic products with enhanced material properties and performance.(2000) reported that the spray formed products are characterized by fine, uniform and macro segregation free microstructures due to rapid solidification of gas atomized molten droplets during flight and on deposition. Recent investigations by Gupta and Lavernia (1995),Ha et al. (2002),Chiang and T sao (2005) and Grant (2007)have shown that uniform distribution of refined primary silicon particles and modified eutectic phase can be obtained in spray formed hypereutectic aluminum silicon alloys. Oxidation of the alloys is significantly reduced since spray forming is usually conducted in a protective atmosphere in a single-step operation of converting molten alloy directly into a bulk material with specific shape. Therefore, spray forming is a very suitable process for the manufacture of hypereutectic aluminum silicon alloys. Despite many investigations in the field of spray forming hypereutectic Al–Si alloys, systematic study of the influence of processing conditions on the spray formed hypereutectic Al–Si alloys is rarely seen. Some uncertainties remain on how the cooling and solidification conditions in the spray and in the deposit interact to give rise to the various spray formed microstructures. In the present study spray forming was used to produce hypereutectic Al–Si alloys with different contents of silicon under different processing conditions. Calculations of the phase diagram and thermo chemical data of the alloys were made to help select spray forming parameters and interpret experimental results. The surface quality, porosity and microstructures of the spray formed alloys were investigated with emphasis on the influence of thermal condition and silicon content of the deposited materials. The formation mechanisms for porosity and silicon phases in the spray formed hypereutectic Al–Si alloys under different processing conditions are discussed and elucidated.

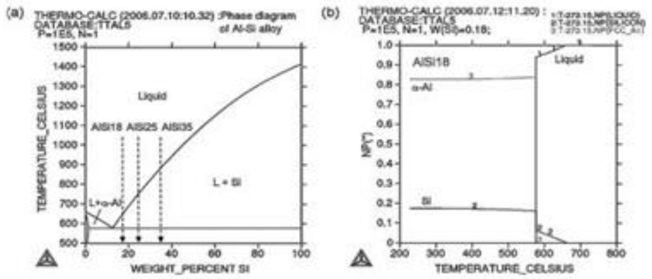


Fig.2.1(a) Phase diagram of binary Al–Si alloys and (b) phase fractions of AlSi18 alloy as a function of temperature. NP(*) denotes molar fraction of the calculated phases.

Phase Diagram:

Aluminium-Silicon system is a simple binary eutectic with limited solubility of aluminium in silicon and limited solubility of silicon in aluminium. There is only one invariant reaction in this diagram, namely L → α + β (eutectic)In above equation, L is the liquid phase, α is predominantly aluminium, and β is predominantly silicon. It is now widely accepted that the eutectic reaction takes place at 577°C and at a silicon level of 12.6%.Aluminium-Silicon (Al-Si) casting alloys are the most useful of all common foundry cast alloys in the fabrication of pistons for automotive engines. Depending on the Si concentration in weight percentage, the Al-Si alloy systems are divided into three major categories:

i. Hypoeutectic (<12 wt %Si)
ii. Eutectic (12-13 wt %Si)
iii. Hypereutectic (14-25 wt %Si).

Uses of al-si alloys:

Recent examples of aluminium applications in vehicles cover, power trains, chassis, body structure and air conditioning. Aluminium castings have been applied to various automobile parts for a long period. As a key trend, the material for engine blocks, which is one of the heavier parts, is being switched from cast iron to aluminium resulting in significant weight reduction. Aluminium castings find the most widespread use in automobile. In automotive power train, aluminium castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission (other parts-rear axle, differential housings and drive shafts etc.) For chassis applications, aluminium castings are used for about 40% of wheels, and for brackets, brake components, suspension(control arms, supports),steering components (air bag supports, steering shafts, knuckles, housings, wheels) and instrument panels. Forged wheels have been used where the loading conditions are more extreme and where higher mechanical properties are required. Aluminium alloys have also found extensive application in heat exchangers. Modern, high performance automobiles have many individual heat exchangers, e.g. engine and transmission cooling, charge air coolers(CACs), climate control, made up of aluminium alloys[8]. Al-Si is an important alloy for many commercial automotive applications (pistons, cylinder liners, etc.) duo to its unique properties.

Microstructure:

Binary Al-Si alloys, in the unmodified state, near to the eutectic composition exhibit acicularor lamellar eutectic silicon which is in the form of large plates with sharp sides and edges. Al-Si alloys containing more than about 12% Si exhibit a hypereutectic microstructure normally containing primary silicon phase in a eutectic matrix. Cast eutectic alloys with coarse acicular silicon show low strength and ductility because of the coarse plate-like nature of the Si phase that leads to premature crack initiation and fracture in tension. Similarly, the primary silicon in normal hypereutectic alloys is usually very coarse and imparts poor properties to these alloys. Therefore, alloys with a predominantly eutectic structure must be modified to ensure adequate mechanical strength and ductility. It is widely recognized that the Group IA and IIA elements(Na, Mg, Ca, Sr) are effective modifiers of Al-Si eutectic; only sodium and strontium,

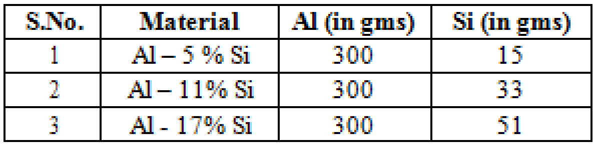
III. EXPERIMENTAL PROCEDURE

Preparation of the alloys: Al–Si alloys with varying Si percentage were prepared by melting commercially pure aluminium (99.3%) and commercially pure silicon (99.6%) in a graphite crucible in a high frequency induction furnace and the melt was held at 800°C in order to attain homogeneous composition. After degassing with 1% solid hexachloroethane, 0.1% Al–Ti master alloy was added to the melt for modification of microstructure. Each melt was stirred for 30s after the addition of the modifier, held for 5 min and then poured into a cubical graphite mould surrounded by fireclay bricks. The cast samples were of 100 mm length, 30 mm wide and 20 mm height.

Fig 3.1 Laboratory casting set up

The following table 3.1 shows the weight of Al and Sitaken, in grams, for the preparation of Al-5% Si,Al-11% Si and Al-17% Si alloys.

Table 3.1 Composition of Al-Si alloys



S.No.	Material	Al (in gms)	Si (in gms)
1	Al – 5 % Si	300	15
2	Al – 11% Si	300	33
3	Al - 17% Si	300	51

Scanning Electron Microscopy

Micro structural characterization studies were done to observe the microstructure of sample surface and also the surface after wear test. This is done by using scanning electron microscope. The Al-Si samples of different weight composition were mechanically polished using standard metallographic techniques before the examination. Characterization is done in etched conditions. Etching was done using the Keller's

Figure 3.2 JEOL JSM-6480LV scanning electron microscope

Optical Microscopy

Microstructures of the alloy samples were observed under computerized optical microscope (Model: Olympus BX51, Essex, UK). The Al-Si samples of different weight composition were mechanically polished using standard metallographic techniques before the examination. Characterization is done in etched conditions. Etching was done using the Keller's reagent (1 volume part of hydrofluoric acid(48%), 1.5 volume part of hydrochloric acid, 2.5 volume parts of nitric acid and 95 volume parts of water). The micrographs of the samples were obtained.

Fig 3.3Computerized Optical Microscope

IV. RESULTS AND DISCUSSION

Composition Analysis:

Composition of Al-Si has different types of compounds and the following table 4.1shows the weight percentage of different elements present in the prepared Al-Si samples.

Table 4.1 Weight percentage of different elements present in the Al-Si samples

	Al-5% Si (wt%)	Al-11% Si (wt%)	Al-17% Si (wt%)
Si	7.003	12.002	13.76
Fe	0.157	0.151	0.14
Cu	0.007	0.003	0.005
Mn	0.008	0.009	0.007
Mg	0.001	-	-
Zn	0.038	0.022	0.019
Ti	0.016	0.011	0.018
Ni	0.002	-	-
Ca	0.003	0.003	0.001
B	0.001	0.002	0.001
Bi	-	0.001	-
V	0.004	0.004	0.004
Co	0.001	0.001	0.001
Sb	0.001	0.001	0.001
Ga	0.015	0.015	0.015
P	0.001	-	-
As	0.002	0.002	0.002
Al	92.74	87.77	86.02

The silicon weight percentage in Al-5% Si and Al-11% Si is obtained as 5.002% and 11.004% that is very close to 5% and11% respectively. This shows that their designed cast structure is very soundable. And this can be seen that there is no loss of silicon and aluminium evaporation during operations. Hence the weight percentage of silicon in Al-17% Si is obtained as 16.25%which is still close to 17%.This kind of calculation shows some loss of silicon also.

Microstructure of all three compositions:

Microstructures obtained from Scanning electron microscopy are shown in fig 4.1to fig 4.3for Al-5%Si, Al-11% Si andAl-17% Si respectively. Figure 4.1shows an optical micrograph with SEM

(Scanning electron microscopy)of Al-5% Si alloy and it may be seen that more-or-less rounded particles of aluminium are crystallized and that are surrounded by fine eutectic silicon shown as dark area. The micrograph of Al-11% Si alloy in Fig. 4.2 shows the refinement of the eutectic silicon particles for the given composition. As it is found that the silicon has long rod like structure and it may be seen in Fig. 4.3wherethe degree of refinement of the eutectic silicon increased as the silicon content of the alloy increased above the eutectic composition. In this the primary silicon appears as coarse polyhedral particles.

As the optical microscopy gives the microstructure regarding its grain boundaries, ie it shows the structure of the resent phase which contains both flaky and merged particles and scanning electron micros copy shows flaky based structure with some others particles.

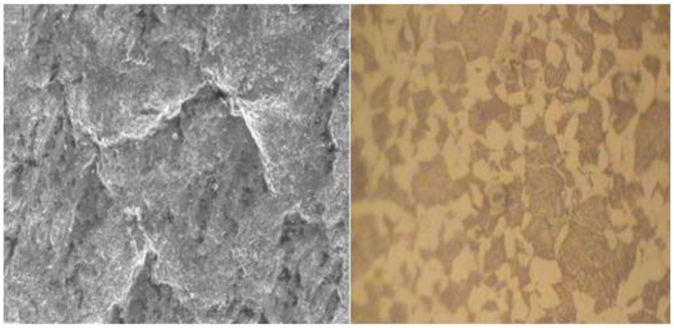


Fig 4.1 Microstructure of Al-5% Si sample

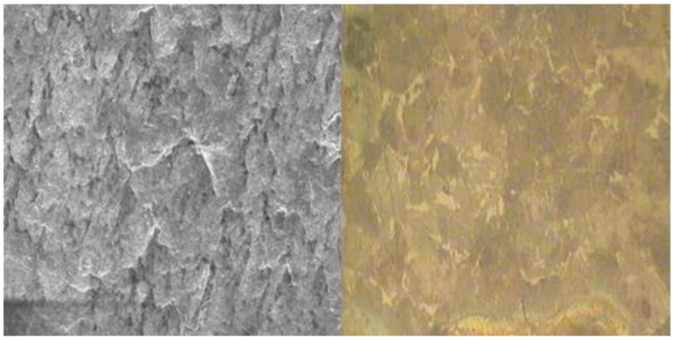
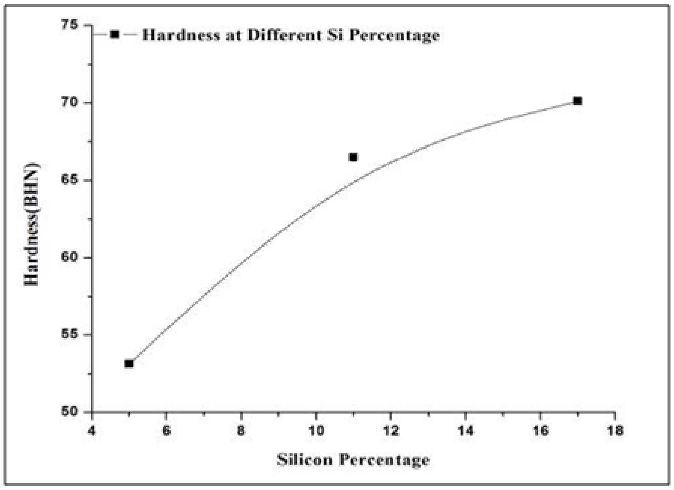


Fig 4.2 Microstructure of Al-11 % Si sample



Wear Test

For Al-Si alloys the wear tests were performed with varying applied load and sliding speed. The results are obtained from the series of tests which is done by keeping two parameters variable as load and sliding speed but keeping wear as a constant parameter.

V. CONCLUSION

The conclusions drawn from the conducted investigations are as follows:

- The prepared aluminum-silicon alloys have homogenous distribution of silicon throughout the cast.
- The amount of primary silicon increases with the increase in silicon amount in the cast.
- Yield strength and ultimate tensile strength increases with the increase of weight percentage of silicon.
- Total elongation decreases with the increase of weight percentage of silicon.
- Hardness of the Al-Si composite increases with the increase in amount of silicon present.
- The height loss due to wear decreases when the percentage of silicon increases.

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