Effect of Silicon Content on wear and Hardness of Al-Si Alloys

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Abstract. In the current work the Al-Si composite is prepared using stir casting method with variation in the percentage (4%, 6% and 8%) of the Si particles in it. stir casting method is one of the cheapest method for production of Al alloys. The prepared composites of different percentages of Si are investigated for it wears behaviour using Pin-on-Disk machine and other properties like hardness. Characterization of Worn surface of the composite is done using SEM. Among the metallic matrices, the aluminum-based matrix remains the most studied metal matrix material for the production of MMCs. This is largely due to the large variety of properties provided by aluminum-based matrix composites at low manufacturing costs. While many Metal Matrix Composites (MMCs) are desirable for use in various industrial applications, Aluminum Matrix Composites (AMCs) are the most commonly used in specialized applications because they combine reasonable strength, low density, durability, machinability, availability, performance and price. In aerospace applications, the excellent tribological characteristics of Al-Si and Al-Sn alloys have led to their widespread use, especially in plain bearings, cylinder liners and internal combustion pistons. It is seen that Si is uniformly distributed in the Al matrix and hardness increases to 71BHN with 8%Si in Al matrix. Further analysis revealed that the microstructure homogeneity of the samples is strongly affected its hardness and Wear rate decreases with increase in Si.

1. Introduction

As of late aluminium composites are generally utilized in car businesses. This is especially because of the genuine need to weight putting something aside for more decrease in fuel utilization. The common alloying components are Cu, Mg, Mn, Si and Zi. The surfaces of aluminium combinations have an outstanding dry polish due to the arrangement of a protective coating of aluminium oxide [1-5]. Aluminum composites of 4xxx, 5xxx and 6xxx, containing significant basic added substances of Mg and Si, are currently being used to substitute steel boards in numerous automotive firms. Because of such reasons, these combinations were subject of a few logical investigations in a previous couple of years. Aluminum alloys are characterised by their principal elements in alloy[6-10]. As its main casting alloy part, silicon is found in the 4xxx group. Silicon in metallic alloys is perfect. It increases the fluidity of the melt, decreases the temperature of the melt, decreases shrinkage during
solidification, and is very economical as a raw material. Density of the silicon is low (2.34 g cm\(^{-3}\)), which will help to minimise the cast component's overall weight. Silicone has a low aluminium solubility, precipitates like almost pure silicone, and is strong and thus increases the resistance to abrasion. Aluminum-silicon alloys form a eutectic with a silicon content of 12.6 wt. % and a eutectic temperature of 577 °C. That refers to a standard casting alloy composition since its melting temperature is as low as possible [11-14].

Aluminum-Silicon alloys are a higher priority for the manufacturing sector. Since they have a high ratio of strength to weight, high wear resistance, low hardness, low coefficient of thermal expansion, etc. Due to low shrinkage and high fluidity, which results in increased ability for casting and welding. In compliance with the Aluminum Association Wrought Alloy, Al-Si alloys are numbered 6xxx alloys.

The 6xxx series has two main uses, welding of filler alloys and forging. The excellent flow properties given by the presence of a relatively high silicon material are attributed to these two applications. The effect of silicon in Al-Si alloys is as follows: i. Presence of silicon reduces the heat transfer ii. Magnetic properties are going to reduce slightly iii. Silicon diminishes the lattice parameter dramatically iv. Due to the hardness of the silicon, the surface finish is low, but there are several literatures and it is obvious based on the previous section that there is an increased potential for further study of Al-Si alloys, particularly their mechanical properties [15-17].

Al-Si is an essential alloy for many transportation components (pistons, cylinder liners, etc.) due to its special characteristics. Al-Si casting alloys are by far the most durable of all casting alloys in the manufacture of automotive components specially engine pistons. Since they are the hardest Al alloys to be cast and machined due to higher Si content, industrial applications for hypereutectic alloys are comparatively limited. Once Al is alloyed with a high Si material, it adds a large amount of heat that needs to be drained from the alloy to solidify it during the casting operation. There are significant variations in the size of the primary Si particles within the various areas of the casting system, resulting in major changes in the sample's mechanical properties. Si’s primary crystals can be refined to increase tolerance to wear and hardness properties. Hypereutectic alloys are not very cost-effective to produce for these purposes because they have a large range of solidification that contributes to poor casting efficiency and needs additional processing methods to monitor the microstructure [18-20].

2. Experimental

2.1 Preparation of Composites

In the present, the samples examined were MMCs based on 6061 aluminium alloy (having 0.4 per cent Mg and 0.75 per cent Si) and containing graphite particles. In preparing the composite for the first set a known quantity of Al6061 as matrix, Silicon in varying proportions as reinforcement i.e. 4%, 6%, 8% by weight and specimens are prepared under stir casting method figure 1. In order to produce the composite Al6061 was heated in the induction furnace and the temperature raised to 700°C and then the mixture was stirred with a suitable speed using stirrer coated with zirconium. After certain time specific quantity of silicon was added to the vortex figure 2 as a set of composite mean while stirring was continued and mixed isothermally. Finally, stirrer was removed from the slurry and the molten mixture was poured into metallic mould figure 3 which were preheated earlier. After solidification set of composites were removed from the metallic mould.
Machining of composites to ASTM specifications for conducting dry sliding wear test on pin-on-disc machine by applying parameters such as load, speed, distance and microstructures studied under SEM.

2.2 Preparation of Specimen for testing and parameters

The specimens that undergo dry sliding wear test is conducted by using pin on disc machine (modal; wear and friction monitor TR-20). The pin on disc machine, the disc is made up of EN32 steel disc the pin was held against the counter face of a rotating disc track diameter 120mm. Normally the load consider was 1kg, 5kg and the sliding distance was 754m for (Al6061/ Si). Initially the specimen was polished with the 600grit emery paper to obtained flat surface. Initial weight w1 will be taken by the electronic balance machine. Fix the pin on disc with 60mm track diameter. Put the load 1kg and start the machine and speed and velocity will be calculated and set the machine. The frictional force readings take by every minute. After completing of the 1000 distance final Wight w2 was taken and volume loss will be calculated by, w1-w2 =delta w. Volume loss =delta (w)/density, Density=mass/volume. The test will be repeated for remaining specimen.

In the present work wear test is carried out by Subsequent variables

1. Load
2. Sliding speed
3. Sliding distance

In this present experiment the parameters are as in Table 1.

| Table 1. Parameters Considered for wear test |
|-----------------|---------|---------|
| Load (N)        | Speed V (m/s) | Distance (M) |
| 9.81            | 2.5      | 754     |
| 49.05           | 2.5      | 754     |
Al-Si samples of various weight configurations were mechanically polished using standardized metallographic procedures prior to examination.

3. Results and Discussion

Tests like Hardness test & wear test are carried on Al-Si alloys. Microstructure analyses are also carried out on worn surface specimens. The outcomes of these experiments are recorded, analysed and debated.

3.1 Wear test

Wear tests of Al-Si alloys were conducted with differing applied loads, sliding speeds and sliding distances.

3.1.1 Calculation.

Wear rate = volume loss / sliding distance
Force friction (ff) = Enter (n)
Coefficient friction (CoF) = Frictional force / load

At 2.5m/s
V = πDN / 60
N = 400rpm
Time = 5min

| Load (N) | Distance (M) | Speed (rpm) | W₁ (gm.) | W₂ (gm.) | Delta W | Density | Vol. loss | Wear | ff | CoF |
|---------|--------------|-------------|--------|--------|--------|--------|----------|------|----|-----|
| 9.81    | 754          | 2.5         | 3.758  | 3.306  | 0.452  | 0.003  | 133.09   | 0.176| 5.1| 0.519|
| 49.05   | 754          | 2.5         | 3.306  | 2.197  | 1.108  | 0.003  | 326.21   | 0.432| 27.1| 0.552|

Table 2. 96% Aluminium and 4% silicon composite wear rate, force friction (ff) and coefficient friction

Table 3. 94% Aluminium and 6% silicon composite wear rate, force friction (ff) and coefficient friction

Table 4. 92% Aluminium and 8% silicon composite wear rate, force friction (ff) and coefficient friction

Calculation of the Volume loss, wear rate and coefficient of friction for 96% Aluminium and 4% silicon composite. Similarly it is calculated to other composites:

1) vol loss = delta / density.
   = 0.452 / 0.003
   = 133.09

2) wear rate = vol loss / distance.
   = 133.09 / 754
   = 0.176

3) coefficient of friction = friction force / load
   = 5.1 / 9.81
   = 0.519
The details of the wear tests on all samples with different loads (9.8, 49.05 N) are shown in Table 2, 3 and 4 and the activity of all samples is shown in Fig. 4. It is noted that as the percentage of silicon increases, the drop in height due to wear decreases. For Al-4% of Si load alloy 49.05N, the volume loss is 326.21mm$^3$, while for Al-6% of Si load alloy 49.05N, the volume loss is 239.41mm$^3$ and for Al-8% of Si load alloy 49.05N, the volume loss is 207.18mm$^3$. Linked volume failure trends for all other loads are found. The addition of hard silicon particles applied to the alloy may be attributed to reduced height loss of a growing percentage of silicon. [21] have studied the effect of grain refiner and or modifier on the wear behavior of hypoeutectic (Al–0.2, 2, 3, 4, 5 and 7Si) and eutectic (Al–12Si) alloys using a Pin-On-Disc apparatus under dry sliding conditions. It is important that Al-Si alloys solidify with fine equiaxed α-Al in hypoeutectic/fine primary Si particles in hypereutectic and fine eutectic Si.

![Figure 4. Wear at various loads](image)

### 3.2 Brinell Hardness test

Hardness, which is defined as a amount of the resistance of a material to external indentation, can be thought of as a function of the stress required to create certain specific forms of surface deformation. The hardness test for all samples is performed using the Brinell hardness test.

| Table 5. Brinell hardness number of different Al-Si alloys |
|------------------------------------------------------------|
| **Composition**   | **Avg BHN** |
| Al-4%Si           | 53          |
| Al-6%Si           | 63          |
| Al-8%Si           | 71          |
Figure 5 indicates the Brinell hardness number of Al-4% Si, Al-6% Si and Al-8% Si with a silicon percentage.

![Brinell hardness number of Al-4% Si, Al-6% Si and Al-8% Si](image)

**Figure 5.** Brinell hardness number of Al-4% Si, Al-6% Si and Al-8% Si

The Brinell hardness values are found to be 53, 63 and 71, respectively, for Al-4% Si, Al-6% Si and Al-8% Si. This indicates that Al-Si hardness improves with an improvement in the silicone percentage. This may be because of a hard increase in the volume of silicon.

### 3.3 Worn morphology

Samples of alloys from the maximum wear examination. 49.05 N load, 25 rpm sliding velocity and 754 m sliding distance are obtained and their worn surfaces are investigated by an electron scanning microscope. Figure 6 shows micrographs with high magnification, respectively.
The worn out surfaces of the samples were observed under scanning electron microscope to examine the mechanism of wear. Micrograph magnification with low SEM, Fig. 6, show the points for the right grade. The score depth in the case of the Al-4 % Si alloy is greater compared to Al-6 % Si and the lowest in Al-8 % Si. This indicates that the wear rate is the highest in Al-4% Si and the lowest in Al-8% Si. The appearance of the mark can be due to the trapped abrasion of the particles, the rugged asperity of the hardened steel counter face, or the hardened deposits of the counter face. During wear, hard-distributed particles or damaged materials are more likely to be dislodged. The pinholes thus created serve to nucleate and grow as possible sites for cracks. As cracks expand and get intertwined, a surface is lost. These are indicated using arrow marks in the figure 6.

**Conclusion**

The conclusions obtained from the examinations conducted are as follows: Aluminum-silicon alloys prepared have a homogeneous silicon distribution in the casting. The Al-Si composite hardness increases with an increase in the quantity of silicon present. For an increase in the silicon percentage, volume loss due to wear decreases. Wear is seen to increase at higher sliding speed and at higher applied load. Wear behavior is dependent on applied load, sliding speed mainly.

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