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The Influence of the Addition of 4.5 wt.% of Copper on Wear Properties of Al-12Si Eutectic Alloy

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Abstract

The influence of 4.5 wt.% copper addition on wear behavior of as-cast Al-12Si alloy prepared by gravity casting is investigated in dry sliding against a steel counterface using a pin-on-disk apparatus. The microstructures of test alloys and worn surfaces were examined by scanning electron microscopy and energy dispersing X-ray spectroscopy. The addition of copper to the binary Al-12Si alloy led to the precipitation of CuAl2 phase. Copper addition resulted in a refinement of α-Al and a minor modification of eutectic Si. The Al-12Si-4.5Cu alloy showed a higher wear resistance as compared to Al-12Si binary eutectic alloy.

Keywords: *Eutectic alloy; Effect of Cu addition; Microstructure; Wear*.

1. Introduction

Al-Si alloys are widely used in automotive industry as they offer a high wear resistance, a low thermal expansion and a good corrosion resistance [1]. These alloys are used in manufacturing Cylinder blocks, cylinder heads, pistons and valve filters [2]. These applications require excellent wear properties of the alloys. The effect of adding Si content on wear characteristics of Al-Si alloys were studied [3]. The wear characteristics of the material depend on the structural features of the material, such as shape, size and distribution of micro constituents in the matrix apart from operating conditions, such as sliding speed, load, temperature and distance [4]. Many authors investigated the influence of alloying elements on tribological properties of Al-Si alloys [5,6]. Studies conducted to investigate the influence of adding Al-1Ti-3B (grain refiner) and Al-10Sr (modifier) master alloys to eutectic Al-Si alloys reported an improved wear resistance after the modification and grain refinement [7]. The studies on the wear behavior of Al-12Si alloy reinforced with TiB_2 particles showed that these particles played a vital role in reducing the size of Si particles and minimizing the subsurface crack propagation resulting in an improved wear resistance [8]. The addition of grain refiner (Al-1Ti-3B), modifier (Sr) and modifier (P) to Al-15Si-4Cu cast alloys resulted in an improvement in the wear resistance due to grain refinement, and fine $CuAl_2$ particles found in the interdendritic region [9]. The wear behavior of hypereutectic Al–Si–Cu–Mg casting alloys with 6 wt % and 10 wt% Mg was investigated using a dry sand rubber wheel and it was found that alloys with high Mg content showed an improved wear resistance [10]. Microstructural investigations indicated that the intermetallic Mg_2Si particles in alloys with 6% and 10% Mg addition are more solidly bonded to the matrix compared to the coarse primary silicon particles. The effects of pressurized solidification on copper containing Al-Si alloy were studied. The micro structural studies indicated that microstructure of non-pressurised specimen contained course dendrites and the pressurized specimen showed a fine microstructure with modified eutectic Si particles. These structural changes resulted in an improved wear behavior of the pressurized cast samples [11]. The studies were carried out to understand the evaluation of the microstructure and dry sliding wear behavior of thixoformed A319 aluminium alloy [12]. The thixoforming process resulted in uniformly distributed Si and intermetallic compounds of the test alloy. The enhanced microstructure was found to play a major role in improving wear performance.

Copper is another important alloying element in aluminium alloys among the elements used in production. It imparts heat treatability to castings through the formation of Al_2Cu and enhances the mechanical properties remarkably [13]. Al–Si–Cu alloys, with up to 4.5 wt.% copper, are satisfactory for the ordinary

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conditions of service. The addition of just 1% copper in these alloys increases the transition load by 3-4 times by increasing the strength and stability of protective surface layer [14]. The effect of adding 1, 2 and 4 wt.% Cu to Al-12Si-20Mg cast alloys on their wear and corrosion properties were studied [15]. Studies showed that the addition of Cu led to the formation of $CuAl_2$ phase. Adding Cu to Al-12Si-20Mg alloy increased hardness values. The role of adding copper in optimizing the tensile properties of Al-11Si-0.3Mg alloy was studied [16]. Studies reported a slight coarsening of α-Al dendrites due to the addition of copper. However, copper addition had an insignificant effect on the size and morphology of eutectic Si particles. The effect of adding Cu on the wear behavior of Al-18Si-0.5Mg alloys was investigated [5]. The study showed that the wear rate is not appreciably affected with the addition of Cu. However, the addition of copper increased the transition load at 2.0 m/s sliding speed. Further addition of Cu (more than 2%) did not show any effect on the transition load. The study that investigated the influence of the combined action of grain refiner and modifier on dry sliding wear of Al-12Si alloy and Al-12Si-3Cu alloy showed that the treated Al-12Si-3Cu alloy offered the best wear resistance at higher loads [17]. The experimental studies on the effect of copper addition on dry sliding wear behavior of A356 alloy reported an increase in wear resistance due to the increase in the strength and hardness of the alloy after copper addition . The formation of oxide layers on the surface is found to be one of the causes of improving the sliding wear performance [18].

The objective of the present work is to investigate the influence of the addition of 4.5 wt.% Cu on wear properties of as cast Al-12Si alloy in dry sliding using pin-on-disk wear tests.

2. Experimental Work

The chemical compositions of Al-12Si and Al-12Si-4.5Cu alloys, as determined by optical emission spectrometer, are given in Table 1.

Table 1. Chemical composition of experimental alloys

Alloy	Composition (wt.%)					
	Si	Cu	Fe	Mn	Mg	Al
Al-12Si	12.09	0.04	0.16	0.02	0.01	Balance
Al-12Si-4.5Cu	12.06	4.46	0.18	0.04	0.03	Balance

The eutectic Al-Si alloys were melted in clay-graphite crucible at 720±5°C. Before pouring the melt into steel moulds, 1 wt% of hexachloroethane (C_2Cl_6) was added to degas the melt. For Al-12Si alloy, pre determined amount pure copper was added for getting Al-12Si-4.5Cu alloy. For optical microscopy, the samples were mechanically polished and etched with Keller's reagent (1.5 ml HNO_3, 2.5 ml HCl, 1.0 ml HF, and 95 ml H_2O). SEM was carried out using FEI Netherlands make Quanta-200 SEM.

Dry sliding wear studies were carried out following ASTM-G-99 standard and using pin-on-disc apparatus at a speed of 2m/s using variable loads. The wear pins were cylindrical rods (10 mm diameter and 25mm long) with flat ends. The specimens of the experimental alloys were held against a rotating steel disc of 98 BHN. The sliding wear tests were conducted on pin-on-disc (TR-20 LE, DUCOM, Bangalore) test machine. The wear test arrangement is shown in Figure 1.

Figure 1. Dry sliding wear test arrangement

3. Results and Discussions

3.1. Microstructure of the Alloys

SEM images of Al-12Si binary alloy and Al-12Si-4.5Cu alloy are shown below. The microstructure of Al-12Si alloy, as seen in Figure 2 (a), consists of large primary α-Al grains and eutectic Si with needle like morphology (actually, plate like or flake like in three dimension) well dispersed throughout the matrix. EDX of Si needle is shown in Figure 2 (b).

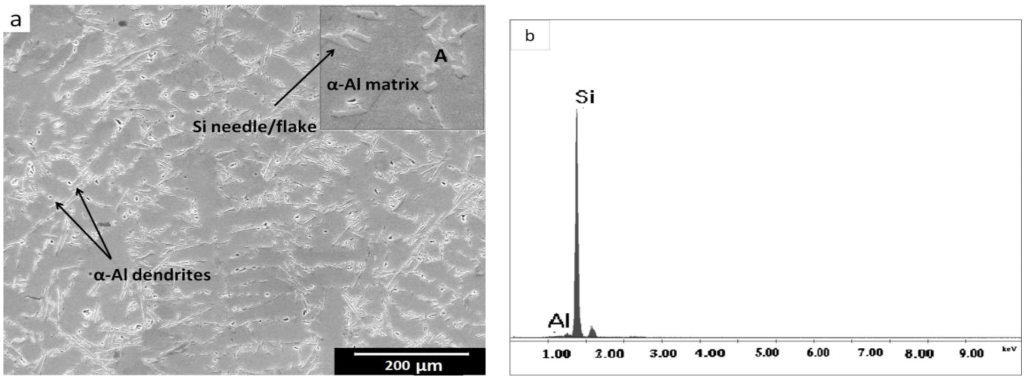

Figure 2. (a) SEM image of Al-12Si alloy (b) EDX of Si needle (marked 'A')

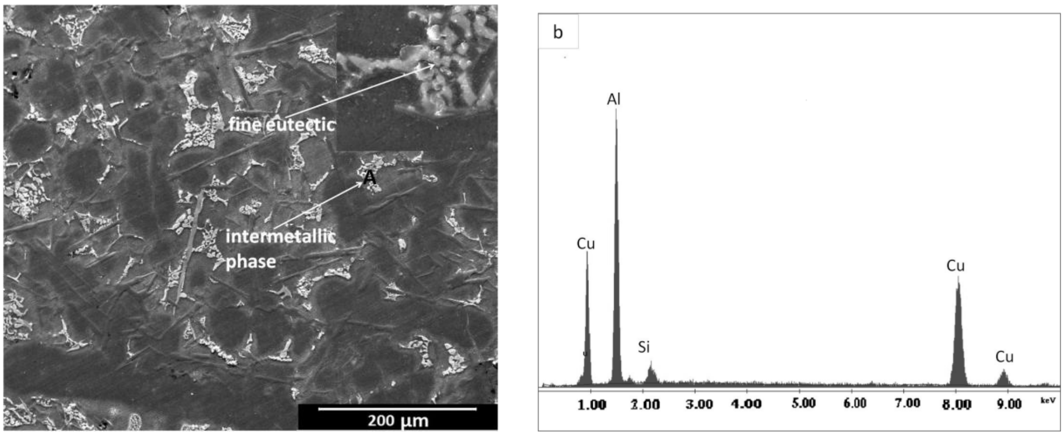

Figure 3. (a) SEM image of Al-12Si-4.5Cu alloy (b) EDX of $CuAl_2$ (marked 'A')

The change in microstructure with the addition of 4.5 wt. % of Cu is shown in Figure 3 (a). It can be seen that the eutectic Si is seen as coarse needles and orientation and morphology of α-Al grains is non uniform. In the inter-dendritic region $CuAl_2$ intermetallic particles are found. EDX of $CuAl_2$ intermetallic is shown in Figure 3 (b).

The effect of changes in microstructure due to the addition of 4.5 wt.% of Cu on wear behavior of the alloy was studied.

3.2. Wear Behaviour

Figure 4 shows the sliding wear of Al-12Si and Al-12Si-4.5 Cu alloys at different normal loads of (10, 20, 30, 40 and 50N) with a constant sliding speed of 2.0 m/s and a constant sliding distance of 1500 m. As the normal load on the test specimen is increased, the actual area of the contact increases resulting in an increased frictional force between the sliding surfaces. The results demonstrate that the increase in the load is responsible for the wear loss of the investigated samples. The addition of 4.5% Cu to Al-12Si alloy shows a lower wear rate when compared to that of Al-12Si alloy.

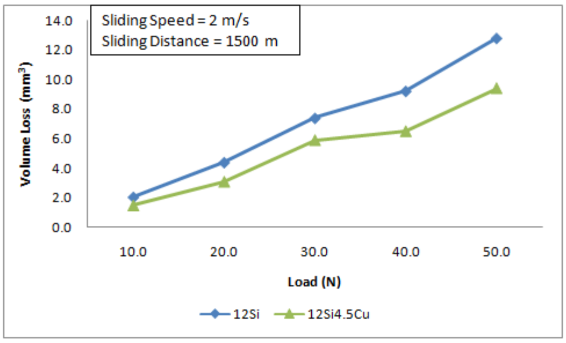

Figure 4. Variation of Volume loss with different loads

Figure 5(a) shows SEM image of the worn surface of Al-12Si alloy. A number of long, deep unidirectional ploughing grooves can be observed. A unidirectional action during sliding takes place and fragments come out of its surface and form debris. This depends on the critical shear stress of both mating surfaces. However, at 40 N load, Al-12Si base alloy witnessed a significant material removal or a high level of surface damage. These damages are mostly due to the low hardness of base alloy (64 HB).

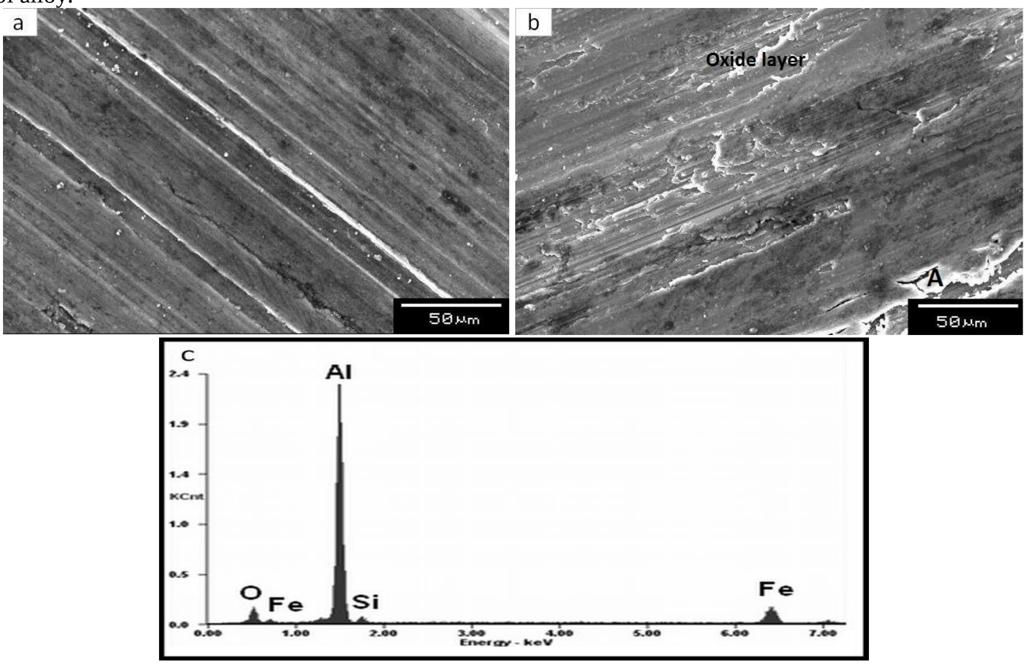

Figure 5. SEM of worn surface of Al-12Si alloy at load (a) 10 N (b) 40 N (c) EDX of oxide layer (Marked A)

From a close observation of Figure 5(b), it can be explained that the wear during sliding is mostly oxidation and metallic in nature. The tensile stress at the asperity increases with the increase in friction and results in the formation of oxide layer [19]. EDX, shown in Figure 5(c), confirms presence of the oxide layer.

Figure 6 (a) shows the wear track observed for Al-12Si-4.5Cu alloy. It can be observed that the wear grooves are smooth and not much deeper as compared to Figure 5 (a). This clearly demonstrates that the copper addition to the Al-12Si alloy results in a better sliding wear performance. Further, the presence of copper in Al-12Si makes the material hard (85 HB) and, as a result, it makes the depth of the sliding abrasive grooves low.

These results can be compared with Figure 4 where the wear loss for the Al-12Si-4.5Cu alloy exhibited low wear rates as compared to the Al-12Si base alloy.

Wear debris were collected at 50 N load at a sliding speed of 2m/s and Figure 7 shows the SEM of the wear debris of the experimental alloy. Figure 7 (a) depicts the wear debris of Al-12Si, whereas Figure 7 (b) depicts the debris of Al-12Si-4.5Cu alloy. Various shapes and sizes of wear debris were formed as a result of a dry sliding test. The shape and sizes of wear debris varied from fine particles to coarse flakes. The average size of wear debris of Al-12Si alloy and Al-12Si-4.5Cu alloy are about 300 microns and 80 microns, respectively. The higher size of wear debris of Al-12Si alloy was due to the delamination of particles from the wear surface. Fine wear debris of Al-12Ai-4.5Cu was due to a mild oxidative wear. Changes in the morphology of the wear debris were found to be consistence with the severity of the worn surface.

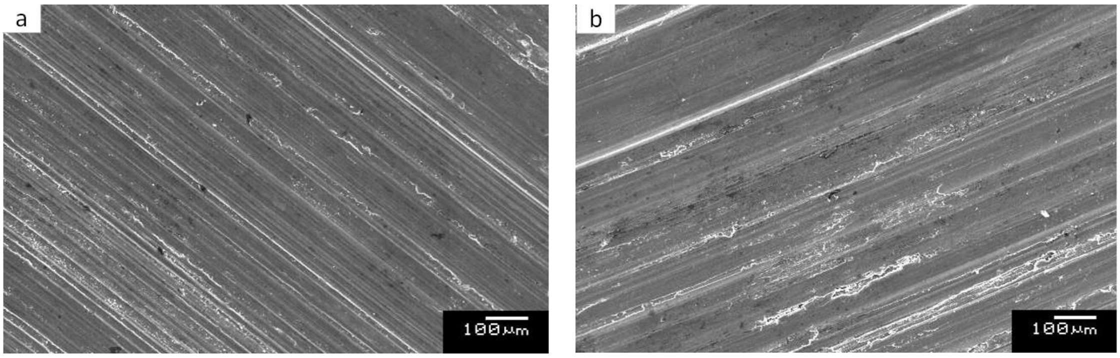

Figure 6. SEM of worn surface of Al-12Si-4.5Cu alloy at Load (a) 10 N (b) 40 N

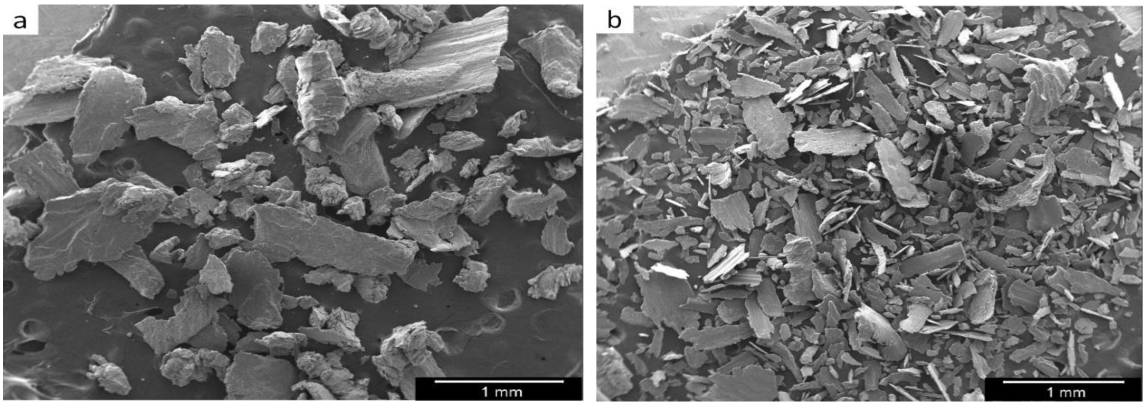

Figure 7. SEM of wear debris of (a) Al-12Si alloy (b) Al-12Si-4.5Cu alloy

4. Conclusions

Al-12Si alloys are widely used for automobile applications. A large number of experiments are made for the enhancement of the wear properties of these alloys. The present investigation aimed at improving the wear performance of Al-12Si alloy by the addition of 4.5 wt.% Cu. The copper addition resulted in the refinement of α-Al and a minor modification of eutectic Si. From the results obtained, the following conclusions are drawn:

- The microstructure details of as cast Al-12Si alloy clearly depict large primary α-Al and plate like eutectic Si. These structural details were responsible for the inferior sliding wear properties.
- The addition of 4.5 wt.% Cu to Al-12Si alloy resulted in improved hardness and sliding wear properties. The presence of $CuAl_2$ particles in Al-12Si-4.5Cu alloy was responsible for the improved wear properties.
- In general, the increase in the wear is observed with an increase in the load and sliding distance for both the test alloys.

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