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Research paper

Study of Mechanical and Wear Properties of Stir-Cast Al-Si-Cu alloy

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Abstract

The present work deal with an investigation of the mechanical and wear properties of eutectic Al-12.8%Si-2.5%Cu under as cast and homogenized conditions. The alloy was melted in a ceramic crucible, stirred and gravity poured into a metal mold and was then cooled under atmosphere. The stirring parameters include a stirrer speed of 400rpm at a melt temperature of 750^{0}C for about 10 minutes. The cast specimens were homogenized in a nitrogen atmosphere crucible at a temperature of 350^{0}C for 8 hours and furnace cooled to room temperature. The microstructure of as cast and homogenized specimen were studied under SEM. The results of SEM study showed that the Si particles were more evenly dispersed around the α-Al matrix after homogenization. This even dispersion of Si particles led to an increase in the hardness and ultimate tensile strength of the alloy. The dry sliding wear behavior was studied using a pin-on-disc machine. It is seen that the wear rate reduced with increase in sliding speed. The EDAX analysis of worn surface showed the phenomenon of lamination. It is concluded that the oxide layer formation was also a reason for increase in wear resistance of the material.

Key words: *Al-Si-Cu alloy;EDAX;Homogenization;SEM;Stir casting.*

1. Introduction

Al-Si alloys showed an increase in usage nowadays in many industries because of their high wear characteristics, low thermal coefficient and good strength. They are light weight alloys with good corrosion properties and their density is lower compared to other such alloys. The addition of silicon increases the micro structural level flow ability of the alloy. Then again Silicon is a hard material so it helps in increasing the overall mechanical and tribological properties of the alloy. Various works have been conducted to understand the wear behavior of Al-Si alloy. At dry sliding condition, adding upto 13% silicon showed an increase in the wear behavior of the alloy, i.e. the alloy shows trend of lower wear rate till 13% or decreased wear rate but wear rate is gradually increasing when over 20% silicon is added. Normally at as-cast conditions adhesive wear is happening but heat treatment showed an increase of wear resistance of the alloy[1][2][3]. It is always important to understand and control the properties of these alloys as they have a wide range of use in the industrial sense.

Many research have been carried out aiming at bettering the mechanical and wear properties of the alloy. One of the ways is to add various other elements to the alloy to improve the microstructure of Silicon phase and also make the alloy heat treatable (precipitation hardening).Common elements like Cu, Fe, Pb, Sn, Zn and high melting point elements like Ti, Ni,Co[4]. Copper addition showed a significant effect in improving the wear resistance of the material and made the alloy heat treatable by forming intermetallic compounds[5]. Ti addition helped the alloy in increasing wear resistance due to formation of Al_3Ti compounds but a higher wear rate was experienced by these alloys due to micro-cracking of Al_3Ti particles[6]. Lead and Tin showed the lowest improvement for alloying with the Al-Si alloy while Cobalt alloying provided with highest hardness[4]. Iron addition was significant for further improving the tribological characteristics of the alloy. But nowadays standard alloys include in small quantities most of the elements mentioned above[7]. A combination of all these elements helps in changing the structure of the primary and eutectic Silicon from coarse needle like of plate to a globular form. As we all know a spherical microstructure provides with a better hardness or tensile property. Even rare earth metals like Scandium is being tried to alloy with Al-Si alloys[8]. Neodymium was proved to be useful in improving the characteristics of the alloy at high temperatures[9].

Grain refining and Modification has become important nowadays as to control the microstructure of any alloy. Especially iron based and aluminium alloys are treated with these methods to improve the microstructure of those alloys. Modification of Al-Si alloy is done by adding Sodium, Strontium etc. in small quantities during casting which helped in changing the microstructure of silicon phase from needle like to fine globular form[10]. Grain refining is made out by adding usually Al-Ti master alloys and it effects the $\alpha-$aluminium dendrites and make dendrites equi-axed. Optimum casting or process parameters (e.g.- cooling rate) play an important role in controlling the grain structure of Silicon which is the major reason for better properties of the Al-Si alloys. Heat treatment or precipitation hardening is always important when considering any Aluminium alloy[11][12]. Al-Si alloys are either T6 treated or precipitation hardened involuntarily to improve their mechanical and tribological properties. Addition of elements like Cu, Zn etc. is very important when considering heat treatment as the main reason behind improving hardness is through formation of intermetallic compounds[13][14][15]. Solutionizing is usually carried out at 500-600^{0}C for 8 hours and aging temperature between 130-180^{0}C[16].

This paper deals the study of Al-Si alloys that has been processed through stir casting.

2. Experimental setup

Here Bottom pour type Stir Casting is used with a Ceramic crucible and Average melt temperature up to 900^0C. It's an Al/Mg casting equipment. The crucible was preheated to 250^0C and impurities or previous melts were removed with the help of tongs and stick.
After cleaning, Aluminium was placed in the crucible and the temperature was increased to 800^0C.The top lid is closed and is left for melting. Silicon and Copper was preheated to 300^0C to remove moisture and other impurities. Silicon and Copper is then added to the melted Aluminium and is left as such. After an hour or more of holding at 800^0C, the Aluminium , Silicon and Copper will be melted. Then the stirrer is moved downwards into the melt .The temp was lowered to 750^0C and the stirrer was made to rotate at a speed of 400 rpm for around 10 minutes. The die of size 30 Diameter and 250mm Length is preheated up to 250^0C and was placed at the bottom of the stirrer.
After melting of materials and stirring the molten metal is taken out by bottom pouring technique as shown in figure. A metal die is used here. After solidification of molten metal in the metal mold, it is then taken out and we get the specimen as shown in figure.

Homogenization of Al-Si alloys were mainly done to ensure that the elements are properly mixed throughout the cast part and also to change the microstructure.

Table 1: Homogenization Parameters

Heat treatment	Homogenization
No. of components	3
Temperature (^{0}C)	350^0C
Duration	8 hours
Type of cooling	Furnace cooled
Atmosphere	Nitrogen atmosphere

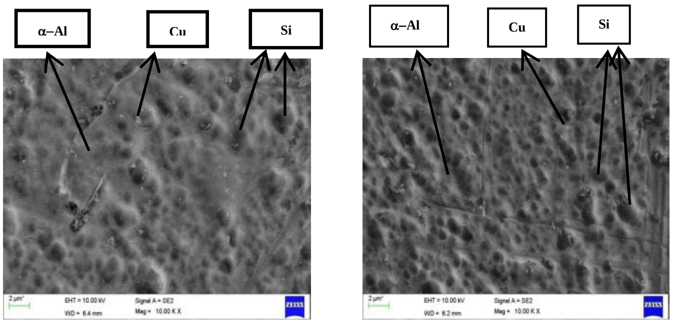
The specimens were tested for hardness using Vicker's Microhardness Tester. Both Cast and Homogenized specimens were grinded for clear visibility of the indentation when observed through microscope. The ultimate tensile strength (UTS) of the alloy is measured using Tinus Olsen H25KT computerized universal testing machine. The specimens for the test are prepared as per ASTM E8M – 04 standards. The Homogenized alloy was tested for the wear rate analysis with a Pin on disk apparatus. The specimen prepared was a cylindrical specimen of 10mm diameter and length of 40mm with both of the ends being hemi-spherical.

Table 2: Wear parameters

Sl.No.	Load (N)	Velocity(m/s)	Sliding distance (m)
1	5	0.5	298.45
2	10	1	596.90
3	15	1.5	895.35
4	20	2	1193.8

3. Result and discussion

3.1. Microstructure analysis



(a) (b)

Fig 1: Microstructure of specimen.(a) As cast condition , (b) Homogenized condition

Microstructure of as cast and homogenized specimens at 10000X magnification is shown above. It is seen that at Cast condition the Si particles are having an almost plate like structure. The primary Si particles are unevenly distributed around the Al matrix as shown in figure. The Aluminium matrix, primary silicon phase and Cu content are marked in the fig at both as cast and homogenized conditions. It was observed that after homogenization the primary Si particles are more evenly distributed around the α–Aluminium matrix.

3.2. Mechanical properties of Al-Si-Cu alloy

3.2.1 Microhardness study

Hardness of as-cast and homogenized specimen were found out. There was an increase in hardness after homogenization. This is due to the evenly distribution of Si and Cu particles around the aluminium matrix.

Table 3: Hardness value for the alloy.

Al-12.8Si-2.5Cu	**Vicker's Hardness**
As cast	69hV
Homogenized	83hV

3.2.2 Tensile strength and percentage elongation

The table below shows the Tensile strength and percentage elongation of the alloy at homogenized conditions.

Table 4: Tensile strength and Percent elongation.

Al-12.8Si-2.5Cu	**Ultimate Tensile Strength(MPa)**	**Percenatge elongation (%)**
Homogenized	154.8	6.9

3.3 Wear behavior

Wear test was conducted on a pin on disc wear machine. The results of the test were shown in the table below. The graphs for Wear vs Load and Specific wear vs Load was also drawn and shown below. It seems that Al-Si-Cu alloy tested here is a good wear resistant material. At the start when 95 rpm was the speed, as load increased the wear showed an increase at first and then gradually decreased. Just like that, for 186 rpm also the wear rate was showing a sudden spike from 5N to 10N and then gradually became constant or almost constant. When speed was changed to 286 rpm the wear rate seems almost constant ie there was not much change induced when load was increased. The lowest wear rates were discovered at speed of 381 rpm where even though there is a gradual increase in wear when load changed from 5N to 20N but it was still only a small increase. From these results it is seen that as Speed was increased there is a gradual reduction in the wear rate. The time is kept constant at 10 minutes. And the track radius was also kept constant at 50mm.

Table 5: Wear rate and Specific wear rate of the homogenized specimen.

S	L (N)	S.p (rpm)	S.d (m)	W (mm^3/m)x10^{-3}	S w r (m^3/Nm)x10^{-4}
1	5	95	298.45	2.11	4.23
2	5	190	596.90	1.85	3.7
3	5	286	895.35	1.25	2.86
4	5	381	1193.8	0.528	1.06
5	10	95	298.45	2.98	2.98
6	10	190	596.90	2.29	2.29
7	10	286	895.35	1.39	1.4
8	10	381	1193.8	1.02	1.03
9	15	95	298.45	2.23	1.48
10	15	190	596.90	1.93	1.29
11	15	286	895.35	1.42	0.952
12	15	381	1193.8	1.04	0.69
13	20	95	298.45	2.03	0.715
14	20	190	596.90	1.81	0.90
15	20	286	895.35	1.39	0.695
16	20	391	1193.8	1.12	0.56

Note: S-Sample;L-Load;S.p-speed;W-Wear rate;S.w.r-Specific Wear rate

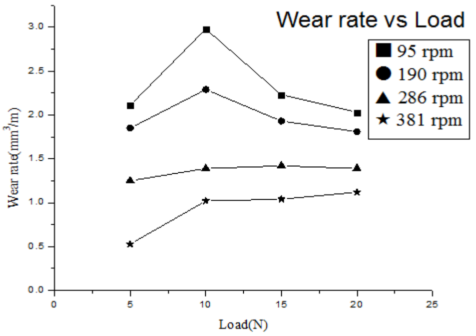


Fig. 2: Wear rate vs. Load.

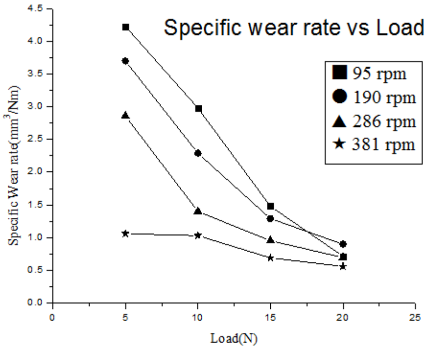
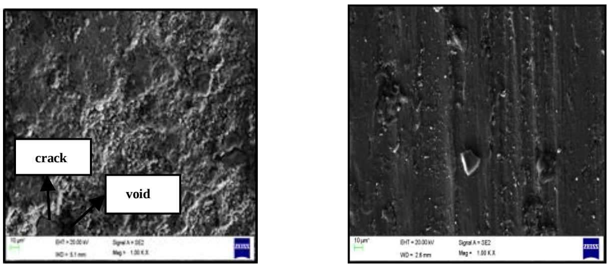
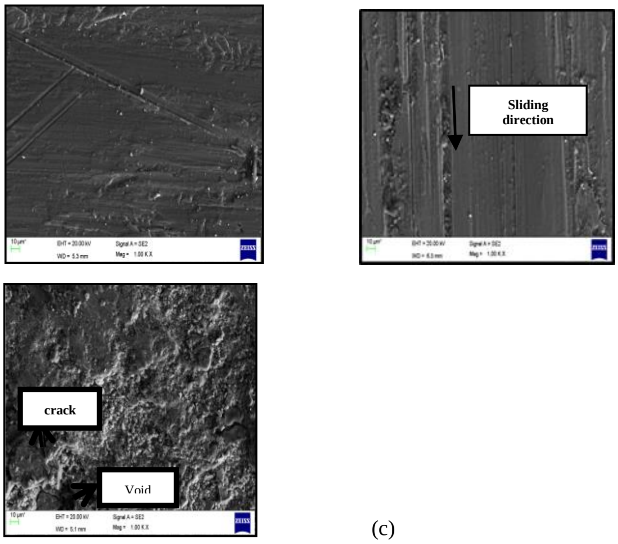


Fig 3: Specific wear rate vs Load.

3.3.1 SEM analysis



(a) (b)



(c)

(d)

Fig 3: Microstructure of worn surface at:(a) At load 20N and speed 95rpm:(b) (b) At load 20N and speed 190rpm(c) At load 20N and speed 286rpm:(d) At load 20N and speed 381rpm.

The SEM image of worn surface at 4 different speeds (95rpm, 190rpm, 286rpm and 381rpm) and constant load(20N) is shown above. It is seen that as speed is increasing there is a decrease in wear rate ie the surface seems smoother at higher speed. Fig 4a is showing a highly worn surface with cracks and voids. But as speed is increasing the surface seemed clearer and there is lower material removal rate. This indicates that speed up to a level is inversely proportional to wear rate at constant loads.

3.3.2 Energy Dispersive X-ray analysis of worn surface

The EDAX analysis was done for the load 20N and speed 386 rpm. The work surface was analyzed and it was seen that, there were presence of various kinds of elements .The presence of Carbon and Iron is due to diffusion of C and Fe from the surface of Steel plate of the wear machine to the wear sample. The presence of Oxygen proved the formation of oxide layer at the worn surface. Oxide layer formation is due to the reaction between the wear sample surface and the oxygen present in atmosphere during the wear test. This oxide layer is hard, and thus it reduces the wear of the total surface as during further sliding movement, first this oxide layer needs to be broken. Only after this oxide layer is broken, further wear can happen to the alloy surface. Thus this phenomenon of formation of oxide layer is called as **Lamination**. And this Lamination helps in increasing the wear resistance of the material or alloy. The breaking of the oxide layer induces wear to the sliding or moving surface. The breaking of the oxide layer is called as **De-lamination**. At constant load and changing speed lamination phenomenon is the reason for reduction is wear rate. At constant speed and increasing load, the wear rate increases due to de-lamination.

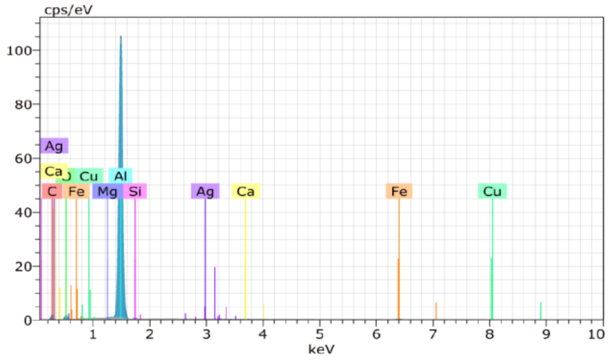


Fig 5: EDAX analysis of worn surface.

4. Conclusion

The following conclusions were made from the study

- The addition of copper to the binary Al-Si alloy increased the mechanical properties of the alloy. The more copper is added , better will be the hardness
- The microstructure of the alloy showed that homogenization helped in evening out the Si particles around the bulk of the alloy.
- The hardness and Tensile strength increased after homogenization treatment was carried out.
- The wear test showed a decrease in wear rate as the speed is increased at constant load. This is due to the formation of oxide layer at the surface of the sliding layer. This phenomenon of formation of oxide layer is called as Lamination. The laminated layer is hard and helps in preventing further wear of the sliding surfaces. But after some time the oxide layer will be broken and shown in the graphs.ie as load in increased at constant speed the wear is having a slight increase, this is due to breaking of oxide layer or called as De-lamination.
- The result shows that increasing speed helps in lamination phenomenon and thereby reducing wear rate.
- When load is increased wear rate is being increased thus load induces the delamination or breaking of oxide layer.
- The parameters have varied effect on the wear behavior of the alloy. Load is directly proportional to wear rate. While speed is inversely proportional to wear rate as per the result showed.

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