International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 07, July - 2017

Influence of Titanium (Ti) Addition on Wear Properties of Aluminium-Silicon-Copper (Al-Si-Cu) Eutectic Alloy

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Abstract: **Influence of Ti content (Up to 4%) on the microstructure & hardness of near eutectic alloy Al-Si-4Cu-xTi (x = 1%, 2%, 3%, 4%) has been investigated. After melting (Al) base alloy with different Ti content melt were cast in the graphite mould (pre-heated to 200 ^{0}C) at 740 ^{0}C & solidified in the room temperature. Pin-On-Disc wear test conducted under dry sliding condition on the near eutectic Al-Si-4Cu-Ti cast alloy for various load varying from 1 Kg to 5 Kg with constant speed of 400 rpm and constant sliding time of 5 min. With increase the Ti content on the eutectic Al-Si-4Cu-Ti will increase the wear resistance and hardness increases from 102 to 132 Microhardness HV.**

Keywords— Near eutectic Al-Si-4Cu-Ti alloy, Ti content, dry sliding, wear resistance, hardness.

1. INTRODUCTION

Al–Si based alloy is the most commonly used casting alloy with high wear resistance, low coefficient of thermal expansion, excellent corrosion resistance, and improved mechanical properties at an extensive range of temperatures. These properties led to the demand of Al–Si alloys in the automotive industry, specially for cylinder heads, cylinder blocks, pistons and valve lifters [1-2]. Al-Si alloys find common application in marine casting, such as marine propellers, high rotating parts, valves, sea water pumps parts, heat exchangers, motors cars and lorry fittings & engine parts, cylinder block and heads, cylinder liners, axles and wheel rocker arms, air conditioner compressor, break drum, automotive transmission casing manifolds and jackets, piston for internal combustion engines and etc [3, 4].

Investigated the effect of Ti addition (up to 4%) on wear behaviour of as cast Al-12% Si eutectic alloy, prepared by rapid cooling and suggested that increasing the Ti content in an alloy improved the wear resistance of alloys. Conversely, these alloys showed higher wear rates compared with the binary alloy due to the tendency for embrittlement and microcracking brought about by Al_3Ti intermetallic particles. Heat treatment of the Ti containing alloys at 200 ^oC for 6 hours enhanced further their wear resistance [3]. Addition of intermetallic particles Al_3Ti, TiB_2, AlB_2 as a grain refiner and Al_4Sr modifies the nucleated silicon to fine distributed primary crystal and concealed the growth of silicon crystal within the eutectic matrix [5].

Various studies have been reported the influence of various alloying elements on wear resistance of Al–Si alloys [6-10]. The addition of 2 wt.% Ti to the rapidly solidified Al–20wt.%Si, 5wt.% Fe alloy was reported to decrease its wear rate and improving its mechanical properties, while V addition was less effective than Ti [6]. The addition of 1.5 wt.% Cu to rapidly solidified and processed Al–Si base alloys enhanced the wear behaviour at higher loads due to the precipitation of a hard-phase Al_2Cu, which inhibits further wear in these alloys [7]. Lead content from 2 to 10 wt.% in Al–Si–Pb alloys has been found to increase the wear resistance rate and load-bearing capacity of the alloys [8]. A lower friction coefficient and a higher seizure load were obtained for Al–Si–Pb alloys bearing in semi-dry sliding conditions compared with those examine for dry conditions and the addition of lead is generally found to reduce interfacial friction and enhanced the ability to resist seizure [9].

The wear characteristics of binary Al–Si alloys & a commercial LM 13 alloy have been reported in a different place [10]. It was shown that the addition of zinc, zirconium and cerium as well as subsequent heat treatment significantly improved wear resistance of the alloys. The mechanical properties of Al-Si-xCu alloys largely depend on the melt and heat treatment. Thus, the Characteristics of heat treatment play a vital role in a good combination of microstructure and mechanical properties. Cu content in Al-Si-xCu alloys affects the mechanical properties. With increasing Cu content, the hardness increases due to precipitation hardening. It is found that increasing Cu content from 3% to 5% increases the hardness from HB 55 to HB 118 [11].

Since addition of titanium to Al-Si alloys exhibit high specific strength, oxidation resistance, corrosion resistance and improved wear resistance. So to achieve the addition improvement in Al-Si-Cu alloy, an attempt will made to study the effect of Ti addition on wear properties of Al-Si-4Cu eutectic alloy. The aim of this work is to investigate the influence of Ti addition on melt Al-Si-4Cu eutectic alloy for wear properties in dry sliding against a steel counterface by using the pin-on-disk wear test.

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2. EXPERIMENTAL METHODS

Different elements were added to Al-Si alloy to improve their properties for various applications. In this work Ti will be added to Al-Si-4Cu eutectic alloy. Ti added in the intermetallic form of Al-Al_3Ti. High purity Aluminium (99.7%), Al-50Si and Al-20Cu intermetallic alloy will be melted in graphite crucible of Induction furnace and Al-10Ti will be added to melt. Alloy will be melted in the furnace at 800 ^{0}C. Melt was degassed with solid hexachloroethane (C_2Cl_6). Remove the slag and melt was stirred for 5 min by Fe rod coated with zircon. Add the cover flux wait for 5 min, the melt at 760 ^{0}C was poured into the cylindrical Graphite mould which was pre-heated to 200 ^{0}C to 250 ^{0}C and cooled in the room temperature. The mould size of 12 mm diameter and 150 mm length.

Fig. 2.1 Induction furnace for casting

Fig. 2.2 Graphite moulds

Fig. 2.3 Casted specimens

Pin-on-disc type wear and friction machine (TR-20 PHM-400 DUCOM Bangalore) is used to evaluate the wear behaviour by following the ASTM G-99 standard. A cylindrical rod of 10 mm diameter and 30 mm length with flat end are made. Polishing was done for all the pins before the wear test with the help of emery paper of 400, 800 and 1000 grade. Sample was cleaned with acetone before testing. Counter surface of disc of EN-31 steel disc (Diameter- 165 mm & 8 mm thickness) having hardness 60 HRC & 1.6 Ra surface roughness.

Fig 2.4 Wear test machine TR-20 PHM-400 DUCOM

Table 1: Details of chemical composition of alloy

Ref.	Alloy	Composition (wt %)			
		Si	Cu	Ti	Al
A1	Al-12Si-4Cu	12.45	3.96	-	Bal
A2	Al-12Si-4Cu-1Ti	12.54	3.85	0.95	Bal
A3	Al-12Si-4Cu-2Ti	12.38	3.94	1.91	Bal
A4	Al-12Si-4Cu-3Ti	12.51	3.92	2.87	Bal
A5	Al-12Si-4Cu-4Ti	12.32	3.88	3.95	Bal

The wear test were carried under varying load of 1,2,3,4 & 5 kg with a sliding speed of 400 rpm, track diameter of 110 mm and runtime of 5 min at room temperature. Pins were weighed before & after the each test in accuracy of 0.1mgs to measure the change in the weight, for wear loss calculation. Microstructure and SEM analysis is carried on EDAX (TESCAN-VEGA3)

Fig. 2.5 SEM/EDAX testing Machine TESCAN-VEGA3

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3. RESULT & DISCUSSION

3.1 Microstructure and Microhardness of alloy.

Microstructure of Al-12Si-4Cu is shown in fig. 3.1. It seen that eutectic Si is seen as a coarse needle and orientation and morphology of α-Al grains are non-uniform. In the interdendritic region $CuAl_2$ intermetallic particles are found in fig. 3.1 & needle appearance in fig. 3.2.

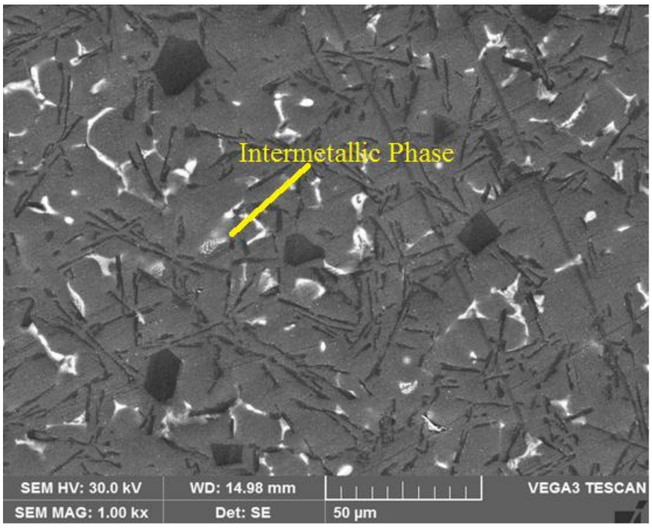

Fig. 3.1 SEM Image of Al-12Si-4Cu

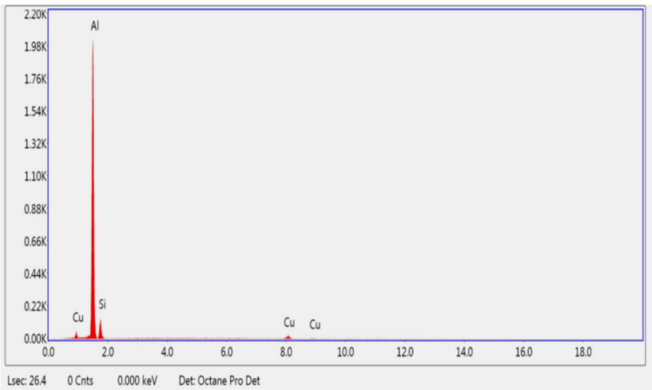

Fig. 3.2 EDAX of Eutectic Al-12Si-4Cu

Fig. 3.3 shows the microstructure of Al-12Si-4Cu-3Ti alloy having Ti wt. 3%. The addition of Ti leads to the precipitation of the Al_3Ti phase. The particles of this phase exhibit a flaky structure and are heterogeneously disperse in the structure. Increase in the Ti content leads to the rise in the volume fraction of the eutectic alloy. Fig.3.4 shows the needle appearance of the Si, Cu and Ti in the alloy A4 and having the similar needle appearance in A2, A3 & A5 alloy.

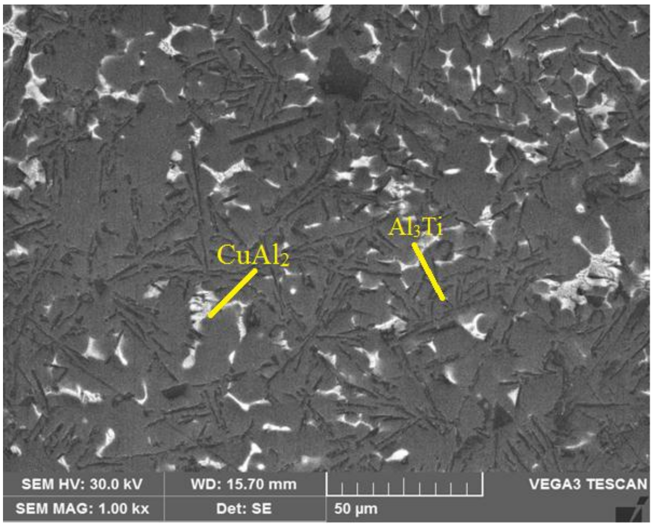

Fig. 3.3 SEM Image of Al-12Si-4Cu-3Ti (A4)

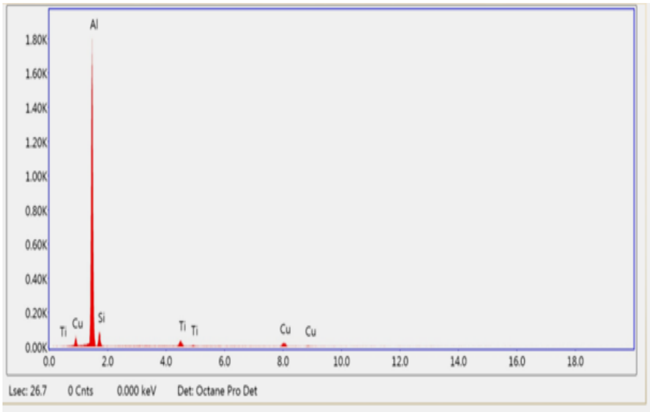

Fig. 3.4 EDAX of Eutectic Al-12Si-4Cu-3Ti (A4)

The addition of Ti up to wt. 4% will makes the changes in microstructure on wear behaviour of the alloy has been used. The effect of hardness with increase in the Ti content is shown in the fig. 3.5.

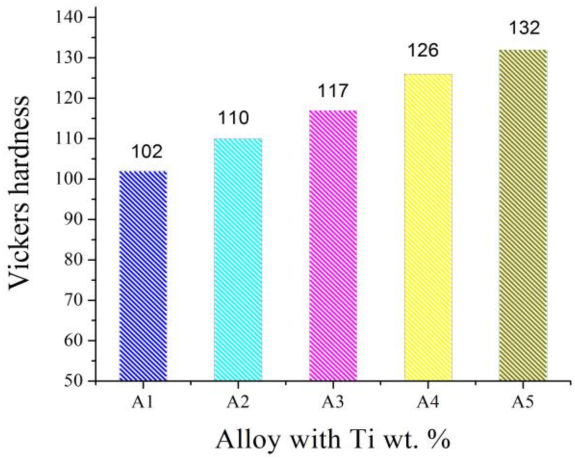

Fig. 3.5 Microhardness with increase in the Ti content

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The microhardness will increases with increase in the Ti wt. % content because of increase in the volume fraction of the relatively hard-phase Al_3Ti. Microhardness will be increase from 102 to 132 HV for alloy A5 (Ti wt. 4%). With increase in Ti wt. % content that will gradually increase the hardness of the alloy.

Fig 3.6 Vickers Microhardness testing machine

3.2 Wear behavior.

Addition of Ti as a grain refiner convert the large α-aluminium grains into fine equiaxed α-aluminium grains and fine $CuAl_2$ particles in the Interdendric region, that leads to higher mechanical properties & improved wear resistance and microhardness.

Wear test for A1 (Al-12Si-4Cu) unmodified cast alloy was carried out at different loads 1, 2, 3, 4 & 5 kg. It was observe that Seizure does not take place up to the maximum load of 5 kg. Seizure is a phenomenon of the test specimen becoming welded to the wear disc at high load & higher sliding speed of the disc due to wear. At seizure there will be more noise & vibration. For alloys A1 to A5 wear rate, specific wear rate & wear resistance under varying load is shown in the fig. 3.7, fig. 3.8 & fig. 3.9.

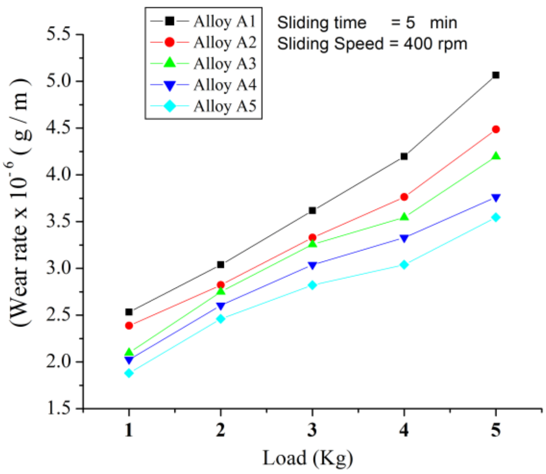

Fig.3.7 Load v/s Wear rate.

In fig. 3.7 for alloy A2-A5 as Ti content increases, the wear rate of the alloy decreases due to the increase in the microhardness as a result of the increase in the volume fraction of the relatively hard-phase Al_3Ti. From fig 3.7 it's clear that with increase in the Ti up to wt. 4 % will decrease in the ware rate from 5.0651x 10^{-6} g/m to 3.5456 x 10^{-6} g/m at load of 5 kg.

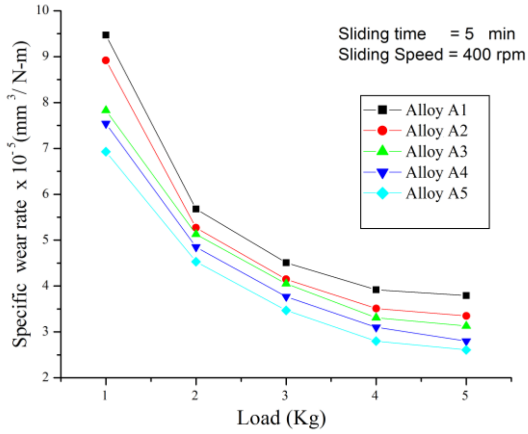

Fig. 3.8 Load v/s Specific wear rate.

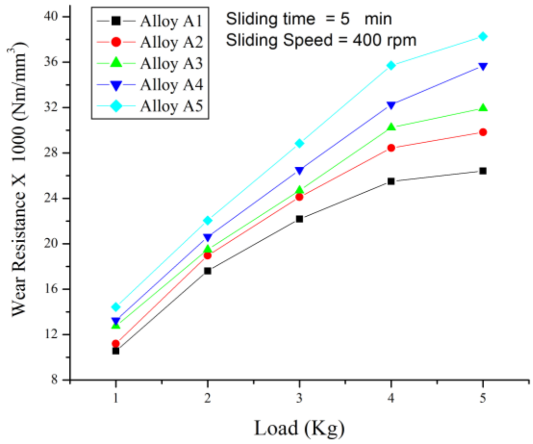

Fig. 3.9 Load v/s Wear resistance.

In fig 3.8 in spite of the higher microhardness of the Ti containing alloy (A2 - A5) compare to binary A1 alloy, the later showed the lowest specific wear rate. The specific wear rate will be decreases with increase in Ti content up to wt. 4% from 3.79X10^{-5} mm^3/N-m to 2.61X10^{-5} mm^3/N-m at load of 5 kg. This may be due to the morphology & distribution of the hard Al_3Ti particle that leads to increase in the wear resistance in the Ti containing alloy A5 from 26.41x10^3 Nm/mm^3 to 38.27x10^3 Nm/mm^3 as shown in fig. 3.9.

4. CONCLUSION

Influence of Ti as a grain refiner to the eutectic alloy Al-12Si-4Cu has been investigated & following conclusion were drawn.

- Addition of Ti to Al-12Si-4Cu eutectic phase alloy will effect in the precipitation of the Intermetallic compound Al_3Ti phase, which leads to increase in the wear resistance.

- Addition of Ti to unmodified Al-12Si-4Cu alloy convert large α-aluminium grains into fine equiaxed α-aluminium grains and $CuAl_2$ particles in the interdendric region that leads into an enhanced mechanical properties.
- With increase in Ti (Up to wt. 4%) content, the alloy will exhibit high specific strength & lesser wear rate.
- Hardness will be increases from 102 to 132 HV for the alloy A5 having wt. 4% Ti compare to alloy A1
- It may required further investigation by heat treatment to increase mechanical and wear properties of alloy.

ACKNOWLEDGEMENTS.

The author would like to acknowledge the VGST K-Fist Grant and R&D centre, Department of Mechanical Engineering, S J M Institute of Technology, Chitradurga for providing the facility for doing my research work.

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