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Wear characteristics of thixoformed hypoeutectic Al-Si-Cu alloy with Mg addition

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ABSTRACT – The effect of magnesium addition on dry sliding wear characteristics of thixoformed Al-Si-Cu aluminum alloy was investigated. A pin-on-disc tribometer was used to carry out wear tests at 49N, 1m/s speed and 9Km distance. It was observed that increasing in Mg content up to 1.5 wt.% improves wear resistance and hardness of the thixoformed alloys. Addition of more than 1.5 wt.% Mg, however, led to increase in hardness, but resulting in a lower wear resistance. The dominant wear mechanism is a combination of abrasion and adhesion at low Mg content alloys and delamination with some abrasion at high Mg alloy.

1. INTRODUCTION

Al–Si casting alloys are well recognized candidate materials for automotive and aerospace applications. These alloys are considered to be promising light weight material to replace the use of cast iron and steel, owing to its attractive properties e.g., high strength to weight ratio, excellent castability, low coefficient of thermal expansion, good corrosion resistance, high thermal conductivity and recycling potential [1].

Aluminum silicon alloys can be divided into three categories: hypoeutectic, eutectic, and hypereutectic alloys. Hypoeutectic alloys consist of less than 11% Si, whereas eutectic alloys consist of 11-13% Si, and hypereutectic alloys consists of more than 13% Si. Among the hypoeutectic alloys, A319 (Al–Si-Cu) have received a significant attention for applications in automotive industry such as engine crankcases, cylinder heads, cylinder blocks, gasoline and oil tanks and oil pans. The main limitation of this alloy is, however, its relatively low wear resistance compared to ferrous materials. In such cases, there is a need for some improvements. Addition of minor alloying elements including magnesium, copper and zinc is one of the major methods used to improve the quality of cast aluminum alloys. The alloying additions may modify the wear performance of cast Al-Si alloys due to solid solution strengthening and precipitation hardening [2].This alloy is commonly produced by conventional casting methods. Although the conventional casting process promises high production rate, the microstructural features with a dendritic morphology of the primary phase, non-uniformly distributed coarse and acicular Si particles, segregated microstructures and porosity, necessitate alternative processing to reach desired properties. As an alternative method of production, thixoforming offers the possibility of fabricating cast Al-Si alloys with fine globular microstructure, near net shaping capabilities, uniform distribution of fine Si particles as well as reduction of segregation and porosity [3].

Therefore, this work will exploit the advantages of thixoforming process to synthesize Al–Si–Cu-(*X* Mg) alloys and to investigate their wear characteristics.

2. METHODOLOGY

Four Al-Si-Cu- (*X* Mg) alloys (*X*= 0.3, 1, 1.5and 2 wt. %) were fabricated by conventional casting process which are coded as alloys A319, A, B and C respectively (Table 1). Cooling slope casting method was employed to produce the thixoforming feedstock [4].Differential scanning calorimetry (DSC) was used to estimate the liquid fraction profile to be used in cooling slope and thixoforming process. The details of thixoforming set up and process have been described in previous study [4].

Table 1 Chemical composition of studied alloys (wt. %).

Alloy	Si	Cu	Mg	Mn	Zn	Fe	Al
A319	6.26	2.91	0.30	0.16	0.71	0.53	bal
A	6.26	2.86	0.96	0.15	0.54	0.53	bal
B	6.31	2.84	1.48	0.11	0.71	0.45	bal
C	6.15	2.88	2.01	0.10	0.66	0.48	bal

Wear tests were conducted on all thixoformed alloys and on the as cast A319 for comparison using a pin on disc machine as per ASTM: G99. The counterpart disc was M2 tool steel having a hardness of 62HRC. Tests were carried out at a 49 N applied load, 1 m/s sliding speed, and in steps of 1800m up to a sliding distance of 9000m. The worn surfaces were then examined by scanning electron microscope (SEM).

3. RESULTS AND DISCUSSION

Figure 1a shows the microstructure of as-cast A319 aluminum alloy. It can be seen that the microstructure composed of the typical primary dendritic α-Al phase surrounded by an eutectic matrix of acicular Si and some intermetallic phases such as θ-(Al_2Cu), α-($Al_{15}(Mn,Fe)_3Si_2$) and β-(Al_5FeSi). The thixoforming was carried out at a liquid fraction of approximately 50%, which corresponded to 571 °C, 568 °C, 562 °C and 560 °C for the alloys A319, A, B and C respectively. Figure 1b shows the microstructure of thixoformed alloy C (2% Mg). Thixoformed samples revealed a uniform distribution of globular α-Al grains, and no pores. The addition of Mg was found to lead to the precipitation of intermetallic phases ($Al_5Cu_2Mg_8Si_5$, Mg_2Si) and transforming some of β-Al_5FeSi phase to π-$Al_8FeMg_3Si_6$. The hardness values of all alloys are given in Table 2.

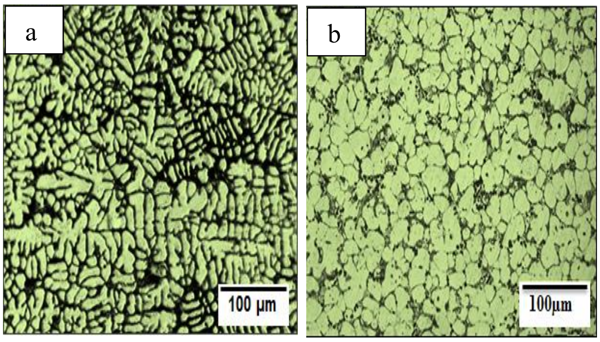

Figure 1 Optical micrographs of (a) as-cast A319 alloy, (b) thixoformed alloy C.

Table 2: The hardness values of studied alloys.

Alloy	Hardness (HRB)
As A319	35±2.5
Thixoformed A319	43±3.5
Thixoformed A	65±2
Thixoformed B	69.3±2.3
Thixoformed C	74.3±2

Figure 2 shows the relationship between wear volume loss and the sliding distance of the as-cast A319, thixoforming A319, A, B, C alloys at 5N applied load. The volumetric wear loss increases almost linearly with the sliding distance for all alloys. Also, the extent of wear is lower in thixoformed A319 than in as-cast A319. This improvement in wear resistance is attributed to the decreasing in the grain size of the matrix, the uniform distribution of eutectic silicon and a reduction in microporosity. Volume loss of thixoforming alloys initially decreased with increasing Mg up to 1.5 wt% (alloy B), above which it increased. The initial decrease in volume loss may be attributed to an increase in the hardness as a result of the increase in the quantity of hard intermetallic phases. This unexpected change in the wear behaviour of alloy C may be related to its microstructure. The large Mg_2Si phase renders its interfacial bonding to the matrix alloy and may have acted as crack nucleation sites resulting in a stress concentration leading to sub micro crack. Also attributed to the presence of the brittle π-$Al_8Mg_3FeSi_6$ inter-metallics which under go cracking during deformation.

In order to investigate the wear mechanism, the worn surfaces were examined under SEM. Figure. 3 shows the SEM morphologies of the worn surfaces of the thixoformed A319 and thixoformed alloy C. The worn surface of the thixoformed A319 is characterized by adhesive wear (craters) and abrasive scoring marks. In contrast, in the thixoformed alloy C the predominant wear mechanism changed to delamination with some abrasive.

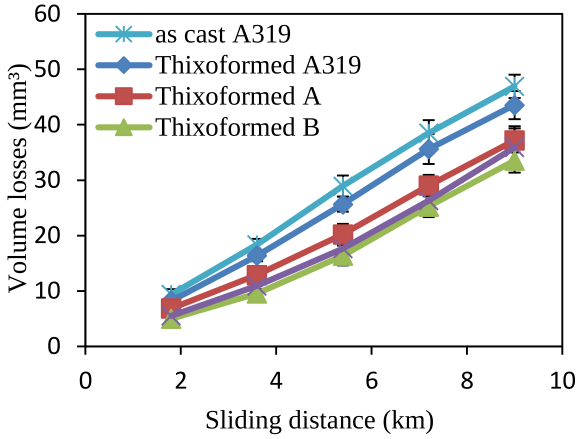

Figure 2 Volumetric wear loss as a function of sliding distance for as-cast A319, thixoformed alloys.

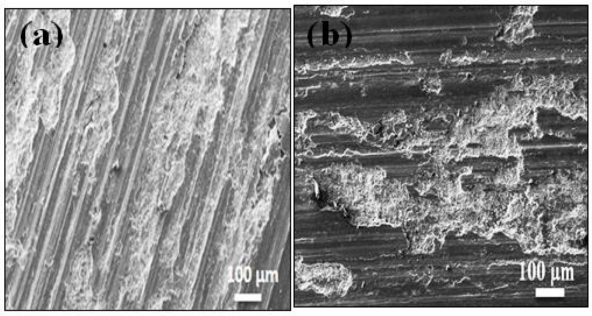

Figure 3 SEM morphologies of worn surfaces of a) thixoformed A319, b) thixoformed alloy C.

4. CONCLUSIONS

In this work, the effect of Mg addition on the wear properties of thixoformed Al-Si-Cu aluminium alloy was investigated. The volume loss of Al–Si–Cu alloys decreases with increasing Mg content up to 1.5%, but above this level the trend reverses. These changes in wear volume of the alloys with Mg content are related to the microstructure. Adhesion, abrasion and delamination observed to be the operative wear mechanisms.

5. REFERENCES

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