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Comparison of Dry and Wet Sliding Wear Behavior of Squeeze Cast Aluminum Alloy

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ABSTRACT

LM25 aluminum alloys are extensively used to produce castings with superior mechanical properties. It is, in practice, the general purpose high strength casting alloy which exhibits fair resistance to corrosion. Its potential uses are increased by its availability of various conditions of heat treatment in both sand and chill castings. Consequently, LM25 finds application in the food, chemical, marine, electrical, and many other industries and above all in road transport vehicles where it is used for cylinder blocks and heads and other engine and body castings. Even thin castings can be produced which are leak tight and free from hot tearing. Hence, this investigation makes an attempt to analyze the dry and wet sliding wear behavior of squeeze cast LM25 aluminum alloy for the varying load, speed, and sliding distances. Further, to determine the effect of each input parameter on the wear rate, ANOVA analysis using Minitab - 17 is carried out. Microstructural studies were carried out to analyze patterns of wear mechanisms on the worn surfaces using an optical microscope and scanning electron microscope.

Key words: *LM25, Squeeze casting, Dry and wet sliding wear, OM and scanning electron microscope studies.*

1. INTRODUCTION

Aluminum alloys get more and more importance as structural materials, but for many applications, it is necessary to improve wear resistance. In particular, uses of aluminum alloys in automotive applications have been limited by their inferior strength, rigidity and wear resistance, compared with ferrous alloys. Particulate-reinforced aluminum composites offer reduced mass, high stiffness and strength, and improved wear resistance. Specifically, the possibility of substituting iron-base materials for Al metal-matrix composites (MMCs), in automotive components, provides the potential for considerable weight reduction [1]. Sliding wear behavior of aluminum/ $Be_3Al_2(SiO_3)_6$ (Beryl) composites using Pin-on-disc apparatus was assessed and also the Taguchi approach was employed to acquire data through an orthogonal array, signal-to-noise ratio, and analysis of variance. The mathematical model was obtained to determine the wear of the composite and confirmation tests were conducted to verify the experimental results [2]. An attempt has been made to determine the wear rate for different materials such as steel, aluminum, and brass under the effect of sliding speed, time, and different loads. A mathematical model has been made for all cases by using least squares method [3]. Effect of SiC content on aluminum matrix in sliding wear behavior was established for varying process parameters, and the results revealed that as the SiC content increases the wear rate and temperature decreases, but reverse trend has been observed for the coefficient of friction [4]. Aluminum (A 380) composites containing fly ash, fabricated using stir casting technique were tested for three different fly ash particles size ranges (50-75 µm), (75-103 µm), and (103-150 µm) for dry abrasive wear behavior. Results showed that composites reinforced with coarse fly ash particles exhibit superior wear resistance than fine fly ash particles. On the other hand, the abrasive resistance decreased with increase in load and speed. Wear rate of composites decreased with increase in fly ash particles for all size ranges [5]. Thus, interest in aluminum-based MMCs continues to grow, especially from the transport industries, where component weight reduction is a key objective. While to an extent this has been successful, where a critical load exists during dry sliding, above which a ceramic based composite offers little improvement in wear resistance compared to an unreinforced sample. Indeed, it was found that hard ceramics can actually increase the wear rate of the mating counter face, due to their abrasive action, and thus reduce the overall wear resistance of the tribosystem [6]. Particulate reinforced Al-MMCs exhibits better mechanical properties and improved wear resistance over other conventional

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alloys. The composites of Al6061 containing 2-6 wt.% SiC prepared using liquid metallurgy route exhibited increased density, hardness, and ultimate tensile with increased SiC content but with the expense of ductility [1,7]. Hot compression and wear resistance as well as hardness of powder metallurgy (P/M) aluminum MMC were investigated by adding Al_2O_3 and Al_4C_3. The addition of 4% Al_4C_3 improved the wear resistance of composites while its existence decreased the braking percent [8]. Aluminum alloy composites have been extensively investigated for use in tribo-contact applications. However, little-detailed literature exists on the sub-surface microstructural evolution as a result of lubricated sliding wear. Two un-reinforced alloys 2124 and 5056 and identical alloy composites, reinforced with 15 vol.% $MoSi_2$ intermetallic particles were produced by a powder metallurgy route and subject to lubricated sliding at initial hertzian contact pressures of 0.9-1.2 GPa. Results indicated that the depth of deformation was minimal in the alloys, evidence of surface erosion by solid particle impact was also observed, with wear debris generated as a result of material exceeding the ductility limit. Reinforcement fracture was observed both at the worn surface and in areas further away in the bulk, for particles which were in direct contact with each other. Thus, intermetallic reinforcements may have potential to replace reinforcements that are more abrasive to counter faces, such as SiC or Al_2O_3, while still providing adequate wear resistance for the aluminum alloy [9]. The relationship between the tribological properties of the lubricants and their chemical reactivity with aluminum was also found [10]. Experimental program using ball-on-cylinder tester has been conducted to investigate the effects of temperature, normal load, sliding speed, and type of lubricating oil on sliding wear mechanism. The worn surfaces and debris have been examined. Surface examination of the samples using scanning electron microscope (SEM) was used to study the wear surfaces. The results show that the temperature of the oils affects the probability of adhesion, oxidation, wear rates, and friction coefficient. At room temperature and under lubrication conditions, friction, and wear decrease with increase of the running time. The phosphorated oil SAE 90 was superior in minimizing friction and wear as compared with other oils. The results have shown that the lubricant temperature has a significant role in wear mechanism [11].

Hence in this regard, the research work aims at arriving at beneficial sliding wear behavior of Aluminum alloy in both dry and lubricated situations through squeeze cast technique so that the results are compared with the traditional stir casting method to identify the significance of densification achieved through squeeze casting in enhancing the wear resistance of LM25 alloy.

2. EXPERIMENTAL

The material used in the experimental investigation is an Al alloy LM25 (Si - 7%). It has iron - 0.05%, copper - 022%, manganese - 0.13%, magnesium - 0.40%, and nickel - 0.12%.

2.1. Processing

This research work has utilized Stir - squeeze cast approach for the production of MMC. Around 2-3 kg of LM25 - 7% Si alloy ingots were thoroughly cleaned and melted using three-phase electrical resistance furnace. Degassing of the super-heated molten metal was carried out by adding finely powdered tablets of hexachloroethane at a temperature of about 780°C. Further, the degassed melt was poured with the help of ladle into the graphite paste coated, cylindrical die cavity of the 20-T hydraulic squeeze press. The densification of the casting was achieved by descending punch at the predetermined squeeze pressure of 50 kg/cm^2 and for the squeeze time of 15 min. The melt was allowed to solidify in the mold, and the casting was allowed to cool so as to reach the room temperature gradually. Then cylindrical specimen of about 8-10 mm diameter and 30 mm length were prepared from the castings obtained to carry out the sliding wear studies.

2.2. Dry and Lubricated Sliding Wear Tests

Two body dry sliding wear tests were carried out by using a computerized Pin on the disc wear testing machine by varying parameters such as normal load, sliding speed, and sliding distance (SD) for the metal LM25. Two body lubricated sliding wear tests were carried out by using a computerized Pin on disc test rig with respect to the same process parameters for the metal LM25 for comparison purpose. The lubricant used was SAE 20 W 50 and the flow rate 75 ml/min is kept constant throughout. The specimen were weighed before and after the experiment by thoroughly cleaning using hexane to remove oil completely and the weight loss was recorded. Experiments were framed using Taguchi technique, standard L27 orthogonal array full factorial type. The output studied was wear in terms of grams with the objective of “Smaller is the better” type quality characteristic. Minitab - 17 software is used to analyze the contribution of each input parameters such as load, speed, and SD on the output factor wear rate in mg and also the interactions between them. The load (L) was varied between 0.5, 1.0, and 1.5 kg, the speed (S) was varied between 200, 400, and 600 rpm and the SD was varied between 1, 2, and 3 km, respectively.

3. RESULTS AND DISCUSSION

Table 1 represents the full factorial results for sliding wear tests conducted for LM25 in both dry and wet conditions. It is observed that in both situations, results clearly indicate that increase in load, speed, and SDs increase wear output correspondingly. The wear rate in the dry sliding test is comparatively very low when compared with the castings produced by vortex method since more densification due to squeeze casting [12]. The Figures 1-4 represent the main effects plot and interaction plot for wear in terms of weight loss with respect to input variables such as load, speed and sliding distance for dry sliding wear and lubricated sliding wear respectively. The ANOVA analysis carried out using Mini Tab - 17 statistical tool for dry sliding wear test (Table 2) signifies that the speed factor contributes around 41%, the SD factor contributes around 34% and load factor contributes around 11% for the output factor wear. However, in the case of lubricated sliding wear test, for the ANOVA analysis, F-value of the of Table 3 is compared with the table of critical values for the F- distribution.

Table 1: Summary of dry and wet sliding wear test results for LM25.

L kg	S rpm	SD km	Wear in terms of weight loss (g) LM25	
			Dry	Wet
0.5	200	1	0.0029	0.00059
0.5	200	2	0.0076	0.00068
0.5	200	3	0.0109	0.00075
0.5	400	1	0.0075	0.00061
0.5	400	2	0.0106	0.00072
0.5	400	3	0.0113	0.00078
0.5	600	1	0.0104	0.00065
0.5	600	2	0.0189	0.00074
0.5	600	3	0.0283	0.00080
1.0	200	1	0.0059	0.00064
1.0	200	2	0.0106	0.00085
1.0	200	3	0.0164	0.00099
1.0	400	1	0.0105	0.00071
1.0	400	2	0.0120	0.00078
1.0	400	3	0.0160	0.00087
1.0	600	1	0.0124	0.00070
1.0	600	2	0.0247	0.00076
1.0	600	3	0.0350	0.00083
1.5	200	1	0.0089	0.00069
1.5	200	2	0.0136	0.00089
1.5	200	3	0.0218	0.00093
1.5	400	1	0.0125	0.00075
1.5	400	2	0.0132	0.00090
1.5	400	3	0.0210	0.00099
1.5	600	1	0.0154	0.00082
1.5	600	2	0.0290	0.00093
1.5	600	3	0.0392	0.00124

SD=Sliding distance

There it signifies that load and the SD parameters are statistically significant with respect to the output parameter wear whereas the speed factor is not at all significant. This is because as speed increases, it tries to lift the specimen from the contact surface or a thin film of lubrication will be maintained throughout thereby decreasing the wear rate [13].

Further SEM image analysis was carried out to analyze the microstructure of worn surfaces. Figure 5 clearly indicates the surface delamination of aluminum matrix material under dry condition whereas Figure 6 represents only the formation wear grooves for the same situation but lubricated condition. Similarly, severe surface deformation with the formation of pits was observed in dry condition for increased load and speed (Figure 7) whereas mild delamination of the surface was observed for the same situation but under lubricated condition (Figure 8). This clearly indicates that lubricant absorbs heat that was generated at the specimen disc interface and also reduces friction to the greater extent. Hence, the amount of wear is very low in case of lubricated sliding situation compared to dry sliding situation, or it is almost negligible. This result will be helpful in automotive industries where it comprises of good number of aluminum parts.

4. CONCLUSION

- LM25 aluminum alloy was synthesized successfully using squeeze cast method.
- The sliding wear resistance of squeeze cast aluminum was found out in both dry and lubricated condition. Wear rate has increased with increase in load, speed, and SD due to the surface delamination and formation of pits & masses of the aluminum alloy under dry condition.

Table 2: ANOVA for dry sliding wear test

Source	DF	Adj SS	Adj MS	F value	p value
Load	2	2.44×10^{-4}	1.22×10^{-4}	10.43	0.001
Speed	2	8.58×10^{-4}	4.29×10^{-4}	36.69	0.001
SD	2	7.16×10^{-4}	3.58×10^{-4}	30.65	0.000
Error	20	2.34×10^{-4}	1.2×10^{-5}		
Total	26	2.051×10^{-3}			

SS=Sums of squares, MS=Mean squares, SD=Sliding distance

Table 3: ANOVA for lubricated sliding wear test.

Source	DF	Adj SS	Adj MS	F value	p value
Load	2	0.0000	0.0000	20.13	0.000
Speed	2	0.0000	0.0000	1.42	0.266
SD	2	0.0000	0.0000	24.76	0.000
Error	20	0.0000	0.0000		
Total	26	0.000001			

SS=Sums of squares, MS=Means squares, SD=Sliding distance

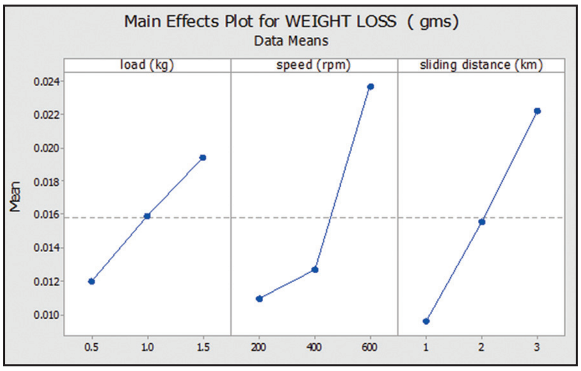

Figure 1: Effect of load, speed and sliding distance on wear for dry sliding.

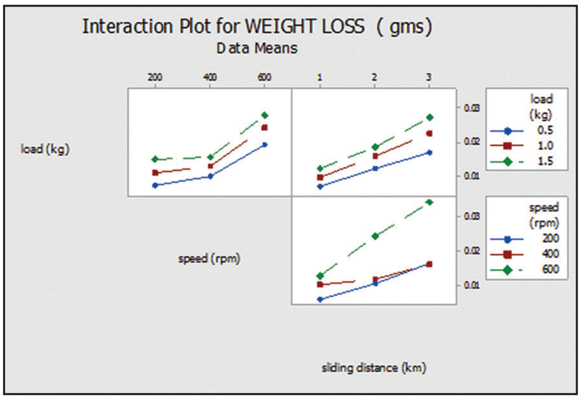

Figure 2: Effect of interactions of load, speed, and sliding distance on wear for dry sliding.

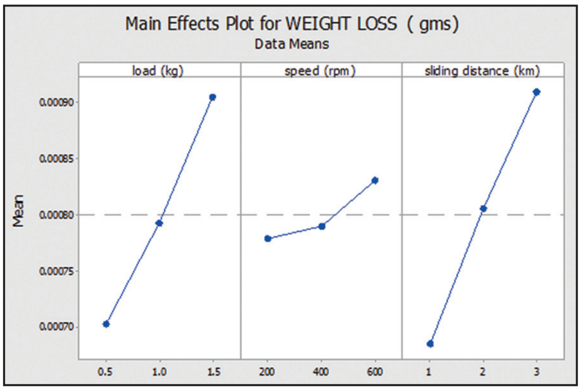

Figure 3: Effect of load, speed, and sliding distance onwear for wet sliding.

- The sliding wear resistance under lubricated situation showed the same trend, but the wear rate was comparatively very low for the same parametric conditions as that of the dry situation. It was featured in terms of micro grooves and a small amount of delamination of the aluminum surface.
- Influence of input parameters on the wear rate was estimated. It was found that contribution of applied load is about 11%, the speed is about 41%, and the SD is about 34%, and the interaction between all three input factors on the output is about 14% for dry sliding wear situation.

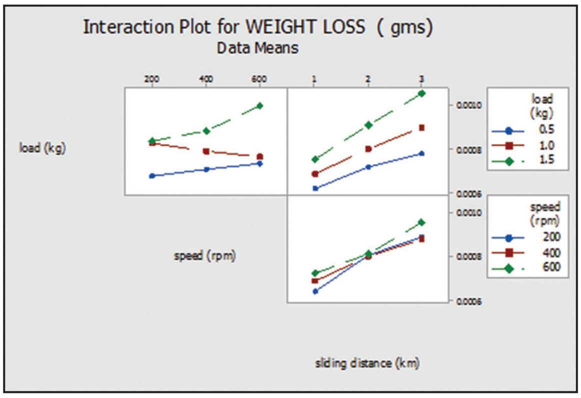

Figure 4: Effect of interactions of load, speed, and sliding distance on wear for wet sliding.

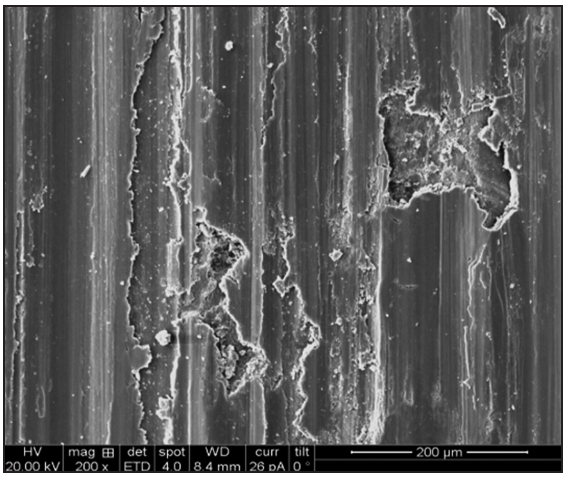

Figure 5: Scanning electron microscope image of LM25 under dry sliding wear behavior for 0.5 kg load, 200 rpm, and 3 km sliding distance.

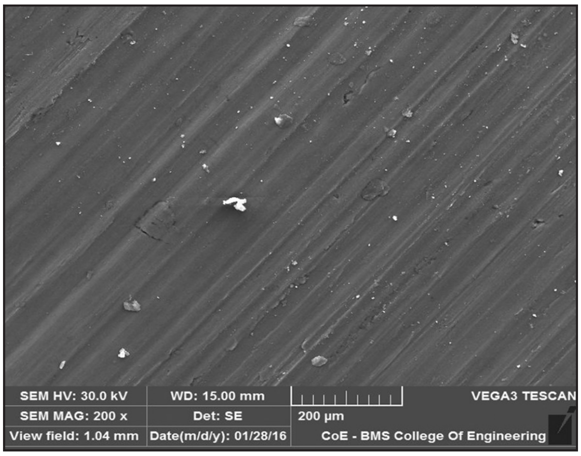

Figure 6: Scanning electron microscope image of LM25 under wet sliding wear behavior for 0.5 kg load, 200 rpm and 3 km sliding distance.

- In the case of lubricated wear condition, load, and SD factors dominate on the wear rate whereas speed factor is almost negligible.
- Hence, this investigation concludes that whenever

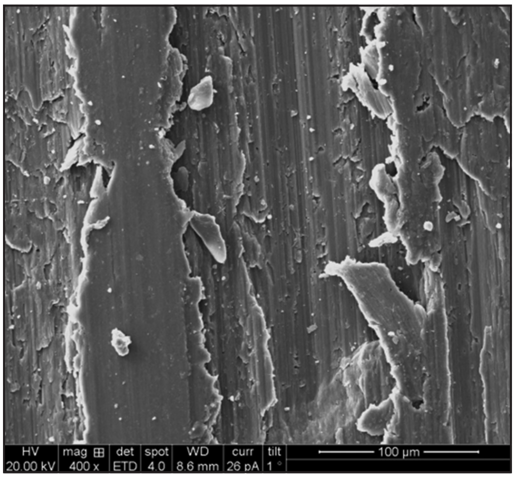

Figure 7: Scanning electron microscope image of LM25 under dry sliding wear behaviour for 1.0 kg load, 600 rpm and 2 km sliding distance.

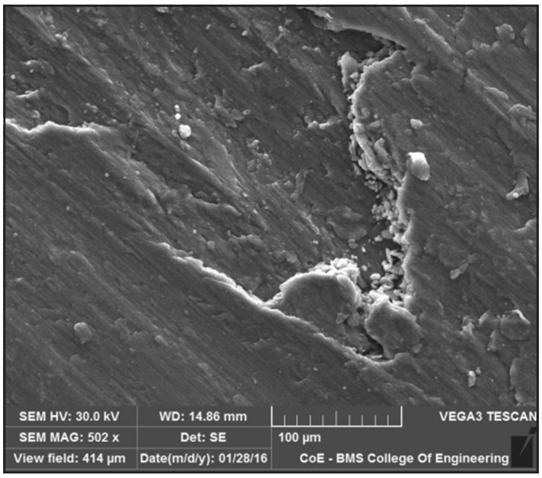

Figure 8: Scanning electron microscope image of LM25 under wet sliding wear behavior for 1.0 kg load, 600 rpm and 2 km sliding distance.

application demands high load, speed, and SDs between sliding contacts, such situations can be well managed by introducing appropriate lubricant so as to reduce heat and friction and hence wear rate.

5. ACKNOWLEDGMENTS

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***Bibliographical Sketch**

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