Development of Wear Resistant Al-Si-Ce Metal Matrix Composites Using Gr as Reinforcement

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Abstract- In the present investigation wear resistant of Aluminium Matrix Composites (AMCs) were developed by using Graphite as reinforcement and Cerium as a grain refiner. Al-Si-Ce alloys and Al-Si-Ce-Gr AMCs were casted using stir casting metallurgy techniques and the castings were T6 heat treated. Cerium was added from 0.15 wt% to 0.3 wt% and Graphite of 4 wt% was added as reinforcement in the manufacture of AMCs. Wear tests were conducted as per ASTM G-99 test standards. The experiments were conducted with two different speeds and loads of 100 rpm - 500 rpm and 10 N – 50 N. From the wear testing analysis, it was found that at higher speed and lower load wear loss and coefficient of friction was minimum in all the investigating alloys and composites. Maximum wear loss was observed at lower speed (100 rpm) with highest (50 N) load.

Keywords – Cerium, Aluminium Alloys, Metal Matrix Composites, Wear Behavior.

I. INTRODUCTION

Composite materials can be defined in many ways. Some improved or desired properties can be obtained in Composite materials. The Matrix is a dispersed phase(s), dispensed in continuous medium and should maintain its uniqueness even after processing, during service or reprocessing [1]. They have heterogeneous composition. Metal Matrix Composites of Aluminum have extensive use in automotive, aerospace and defense industries because of their light weight, high strength to wear ratio, stiffness, and good wear resistance and enhanced electrical and thermal properties [2-3]

Graphite particles dispersed in Aluminum alloys are known as potential materials for tribological applications [4-7]. Aluminum alloy matrix yields at low stresses and deforms. This improves the deformation and fragmentation of the surface and sub-surface graphite particles. It provides a continuous film of graphite, which prevents metal to metal contact and seizure.

Rohit Sharma et al [8] analyzed dry sliding behavior of Aluminum alloy LM6 reinforced with dual hybrid titanium dioxide and graphite particles. With increase in reinforcement percentage, wear rate decreased linearly and with above 15% reinforcement levels, wear rate started increasing. Wear rate increased at higher loads with decrease in COF. Also, presence of reinforcement improved the micro hardness. Ravindran et al [9] used technique to study the wear behavior of hybrid aluminum composites. The loss of material and COF were influenced by the applied normal load and sliding distance. Wear resistance of 5% SiC + 5% graphite reinforced hybrid composite was more compared to 5% SiC reinforced composites. Soft graphite with hard carbides increased wear resistance. Anru et al [10] published that the strength of the alloy increases by adding Ce at room and high temperature. It also helps to refine Eutectic structure, harden by dispersion, decrease ductility, and influence the rate and precipitation of solid phases. The solubility of Ce in Aluminum increases with increasing temperature. Secondary intermetallic phases forms during solidification and heat treatment for decrease in solubility from high concentrations at high temperatures to relatively low solubility.

Anasyida Abu Seman et al [11] studied the effect of cerium addition on the Microstructure and Microhardness of Al-12.5Si-4Mg alloy. With the addition of 0.5 to 3.0 Wt% of cerium dispersed fine cells having a mixture of α-Al, Eutectic Si and intermetallic Al4Ce phase was formed in Al-matrix. With increase in Ce content Microhardness of as cast alloy increases due to precipitated phase. Diffusion of Si and Ce induced by ageing at 2000C lead to clustering of Si and Precipitation of fine Al4Ce phase resulted in increase of the microhardness of as cast alloy. Vivek Babu et al [12] evaluated the hardness of LM6 (aluminum)/Gr (Graphite) particulate metal matrix composite. With the addition of Gr particle up to a particular limit, the hardness value of LM6/Gr composite increased and then suddenly decreased. For around 4% Gr composition Maximum value of hardness was found. Wear loss analysis of 18% silicon-based Aluminum alloy was studied by Anirudh Biswas et al [13], wear rate reached maximum value at 15N and decreased as applied load increased to 20N. At higher loads work-hardening of matrix due to plastic deformation helped in reduction of wear. Temperature increases appreciably at higher loads, lowers the strength of materials in contact and results in increase in contact area and COF. A.S.Anasyida et al [14] studied the wear behavior of as-cast Al-4Si-4Mg alloys with cerium addition. Cerium addition to Al-4Si-4Mg resulted in
intermetallic phase formation of Al-Ce and Al-Si-Ce. Enhanced wear resistance and lowered friction coefficient of as-cast alloy was obtained with increase of cerium up to 5Wt%. Amro M. Al-Qutub et al [15] studied Al2O3/6061 Aluminum particulate composite for dry wear behavior. Higher concentration of Al2O3 and higher load lead to higher wear rates. Friction coefficient had negligible effect due to Al2O3. S. Srivastava et al [16] used Al-Sn-based alloy with different amount of Graphite for tribological properties at different normal loads and sliding speeds. Mechanical properties and tribiological properties due to presence of graphite in the matrix Improved. Increase of Graphite content increased the ductility of composite materials. With increase in Graphite content the COF decreases. Wang and Rack [17], recorded that higher wear resistance is exhibited by overaged composites compared to underaged. Straffelini et al [18] also concluded that higher wear resistance is exhibited in over aged composites than under aged one in extruded and also in forged condition. From the above literature survey, it was found that still scope exhists to work on Aluminum Metal matrix composites. In this investigation Graphite is reinforced in Al-Si-Ce alloys and its wear behaviour has been evaluated.

II. MATERIALS AND METHODS
Based on the necessity mechanical properties of the Metal Matrix composites and alloy, the method of casting process varies. The properties of the casting primarily depend upon alloying elements, melting, casting operations, and heat treatment. The properties attained from one particular combination of these factors may not be same to those obtained with the same alloy in a different metal casting facility. Molten aluminum has many characteristics that can be controlled to maximize casting properties. It is susceptible to picking up hydrogen gas and oxides in the molten state. It is very sensitive to minor trace elements. Tight control of melt and specialized molten metal processing techniques produce improved mechanical properties. The composition of the alloy used in casting is as shown in the Table 1. In the process of casting, permanent dies of size 300 mm x 200 mm x 18 mm were used. The alloy which is used as a matrix consisted of pure aluminum, copper, nickel, magnesium etc.

<table>
<thead>
<tr>
<th>Material</th>
<th>Cu</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Mn</th>
<th>Ni</th>
<th>Zn</th>
<th>Pb</th>
<th>Sn</th>
<th>Ti</th>
<th>Al</th>
<th>Ce</th>
<th>Gr</th>
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<tbody>
<tr>
<td>Alloy – 1</td>
<td>0.1</td>
<td>0.1</td>
<td>10</td>
<td>0.6</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
<td>0.2</td>
<td>Rem</td>
<td>0.15</td>
<td>-</td>
</tr>
<tr>
<td>AMC – 1</td>
<td>0.1</td>
<td>0.1</td>
<td>10</td>
<td>0.6</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
<td>0.2</td>
<td>Rem</td>
<td>0.15</td>
<td>4</td>
</tr>
<tr>
<td>Alloy – 2</td>
<td>0.1</td>
<td>0.1</td>
<td>10</td>
<td>0.6</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
<td>0.2</td>
<td>Rem</td>
<td>0.3</td>
<td>-</td>
</tr>
<tr>
<td>AMC – 2</td>
<td>0.1</td>
<td>0.1</td>
<td>10</td>
<td>0.6</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
<td>0.2</td>
<td>Rem</td>
<td>0.3</td>
<td>4</td>
</tr>
</tbody>
</table>

Melting was carried in an induction furnace in a graphite crucible up to a temperature of 7200 C. After degassing, master alloy of cerium was added for grain refinement. The melt, stirred for 30 sec with a stirring speed of 140-160 rpm after adding the grain refiner and graphite, held for 5 min and poured to dies. The dies were heated up to 2500C before pouring the molten metal, to avoid the sudden cooling of the melt.

III. HEAT TREATMENT
Aluminum-Silicon alloys having other elements like Mg, Si etc., offer the highest combination of high temperature resistant properties in cast/ wrought form. Heat treatment is a process to change the mode of occurrence of the soluble alloying elements, especially Copper, Magnesium, Silicon and Zinc, which can combine with one another to form inter metallic compounds. Different heat treatment processes include quenching, solution heat treatment, precipitation hardening or aging, cold working and tempering. Solution heat treatment alludes to a thermal hardening process. Material is immersed at fairly high temperature for a number of hours. During which the alloying elements are put into solid solution. Usually the temperature is rapidly lowered (quenched) which leaves an unstable structure. During aging at room temperature the internal structure stabilizes itself. This is also called T6 Heat treatment is as shown in Fig. 1.
Generally, the cracks are developed in components due to stresses produced during the structural transformation with its accompanying increase in volume. Many heat treatment processes will soften the material. The scale formation is another problem of heat-treated materials. The fracture toughness of the heat-treated materials depends primarily on the method of the heat treatment and the temperature.

IV. SLIDING WEAR TEST

Wear tests were carried using computerized Pin on Disc Tester of Ducom make. Tests were carried at ambient temperature. In the present dry sliding wear investigation of heat treated (T6) Alloy-1, Alloy-2, AMC-1 and AMC-2 was conducted according to ASTM G-99 standard testing procedure. Experiment was conducted using a computerized Pin-on-Disc Tester to find mass loss, Volume loss, frictional force and coefficient. The machine had wear disc of specification EN31 with wear track diameter 10-120 mm. The Cylindrical specimens of 8 mm diameter and height 25 mm were used. Test was carried out at track diameter of 100 mm for a sliding distance of 3.142 km. The specimens were weighted before and after the experiment and the corresponding weight loss, volume loss, wear loss and coefficient of friction were calculated. During conduction of each test both disc and specimen were cleaned thoroughly with silver nitrate liquid and dried in order to avoid the contamination.

An instrument used was DUCOM make. Test rig was Wear and Tear Monitor, TR-20L, with Electronics controller, Winducom 2010 software and computer of Pentium 4, 512 MB RAM, 2GB. Wear test was conducted out on Pin-on-Disc tester to evaluate the Weight loss, Volume loss, Specific wear loss, COF properties. The tests were conducted for the following material system. The following material system is used in the sliding wear test analysis (Table 2).

Table 2 List of investigating alloys and AMCs

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Material Composition</th>
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<tbody>
<tr>
<td>Alloy – 1/T6*</td>
<td>Al-Si-1.5%Ce</td>
</tr>
<tr>
<td>Alloy – 2/T6*</td>
<td>Al-Si-3.0 %Ce</td>
</tr>
<tr>
<td>AMC – 1/T6*</td>
<td>Al-Si-1.5%Ce-Gr</td>
</tr>
<tr>
<td>AMC – 2/T6*</td>
<td>Al-Si-3.0 %Ce-Gr</td>
</tr>
</tbody>
</table>

*Heat treatment

Four sets of experiment were conducted for a combination of different load and speed i.e. a minimum speed of 100 rpm and a maximum speed of 500 rpm along with a minimum load of 10 N and a maximum load of 50 N. The specimens were weighted before and after the experiment and the corresponding weight loss, volume loss, wear loss and coefficient of friction were calculated. During conduction of each test both disc and specimen were cleaned thoroughly with silver nitrate liquid and dried in order to avoid the contamination.

V. EFFECT OF LOAD AND SPEED ON WEIGHT LOSS

All the specimens were tested with four different combinations of load and speed as shown in Fig. 2. From the analysis it was found that at a speed of 100 rpm with an applied load of 10 N, wear loss progressively decreased with the increase of percentage of cerium in both the alloys and composites.
At an applied load of 50 N with a speed of 500 rpm the wear loss was increased in all the alloys and composites. The weight loss was increased in AMC-1/T6 when compared with Alloy-1/T6 and then it reduced progressively with the increase in cerium percentage. At an applied load of 50 N with a speed of 100 rpm the highest wear loss was observed in Alloy-2/T6 when compared with all other alloys and composites. At an applied load of 10 N with a speed of 500 rpm wear loss was uniform in all the alloys and composites and also minimum wear loss was observed in all the composites and alloys when compared with other speed and load conditions.

VI. EFFECT OF LOAD AND SPEED ON HEIGHT LOSS
From the analysis (Fig. 3) it was found that at an applied load of 10 N with 100 rpm height loss was progressively reduced with the addition of graphite and increase in percentage of cerium. At an applied load of 50 N with 500 rpm height wear loss was observed in Alloy-1/T6 when compared with other alloys and composites and also at different loads and speeds height loss was decreased.

At high load (10 N) and low speed (100 rpm) the height loss is more in all the alloys and composites. Whereas at high speed (500 rpm) and low load height loss is minimum when compared with all other testing conditions.

VII. EFFECT OF LOAD AND SPEED ON VOLUMATRIC LOSS
From Fig. 4. it is observed that at low load (10 N) with low speed (100 rpm) volumetric loss was very high in Alloy-1/T6 and progressively reduced in other alloys and composites. At high load and high speed and also at low speed and high load volumetric loss was high are all the alloys and composites when compared with other loads and speeds. Whereas at high speed (500 rpm) and low load (10N) volumetric loss was very less in all the alloys and composites.
VIII. EFFECT OF LOAD AND SPEED ON COEFFICIENT OF FRICTION

Frictional coefficient was calculated from the recorded frictional force and the applied load. From the Fig. 5 it was found that the coefficient of friction in Alloy-1/T6 and Alloy-2/T6 is lesser than AMC-1/T6 and AMC-2/T6 at low load (10 N) and speed (100 rpm), the presence of graphite particles in the matrix increased the COF. The coefficient of friction is lower at 0.15 wt% Ce mixed alloys and composites when compared with 0.3 wt% cerium mixed alloys and composites at high speed and low load. At low speed and high load AMC-1/T6 and AMC-2/T6 coefficient of friction is lesser than the investigating alloys. At high speed and low load, the coefficient is progressively increased in Alloy-1/T6, Alloy-2/T6, AMC-1/T6 and decreased in AMC-2/T6.

From the analysis it was found that the coefficient of friction was decreased at higher speed and lower load in alloys and composites with 0.3 wt% Ce. The Gr particulates were found to act as bearing material between specimens and rotating disc. Wear worn surface consists of wear debris includes coarse metallic particles of the surfaces and Gr particles, which act as abrasive particles between the specimen and disc. The oxide film formed on the wearing surface prevents the metal to metal contact. The hard-brittle oxide formed on aluminum provides protection against wear. The oxide layer formed is harder than the base material which reduces the friction and wear of the specimen. According to Rohatgi et al. [19] at large volume fractions of graphite the composites showed very low wear rates with independent of sliding velocity. This is due to graphite film stability. The existence of graphite in the matrix enhances its oil spreadability over the contact surface, thus decreasing the tendency to score or seize. Graphite has carbon atoms arranged in a layer like structure. It shows a very low COF while sliding on another clean surface [20]. Ramesh et al. [21] reported that the coefficient of friction was decreased with the increase in percentage of reinforcement in Al6061-Ni-P-Si3N4 hybrid composites [49], due to the improvement in anti-frictional behaviour of reinforced particles which behaves as a load bearing element [22, 23]. Liu et al. [24] studied friction and wear behaviour of Aluminum – Silicon alloy matrix composites with graphite particles. The coefficient of friction and wear were considerably lower in MMHCs, as compared to MMCs due to the formation graphite film formation between the rubbing surfaces.
IX. CONCLUSION
The experiments were conducted for all the investigating alloys and composites and the following conclusions were drawn on the wear behaviour. Wear volume was progressively reduced and coefficient of friction was increased at low speed and low load in all the investigating alloys and composites. At high load and high-speed highest wear loss was observed when compared with all other loading conditions. At low speed and high load higher wear loss and higher coefficient was observed in alloys when compared with composites. At high speed to low load wear loss was minimum in all the investigating alloys and composites. Also, high coefficient of friction was observed in alloys when compared with composites.

X. REFERENCES