Investigation on Mechanical and Tribological properties of Al-Si Alloy based MMC

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Abstract— In the present study aluminium-silicon alloy (LM6) composites containing 10 and 15 vol. % of fly ash particles have been fabricated. Some mechanical and the dry sliding wear behavior of unreinforced alloy and Metal matrix composites are studied using Pin-On-Disc machine at a load of 30 N at a constant sliding velocity of 1 m/s for 1000sec.Charpy impact test and compression test are considered for mechanical properties study. Results show that the Metal matrix composite prepared with 15 vol% of fly ash exhibit better wear and mechanical property compared to unreinforced alloy as well as Metal matrix composite (MMC) prepared with 10 Vol% of fly ash. Fly ash particle size and its volume fraction significantly affect the wear and friction properties of composites. Microscopic examination of the worn surfaces, sub surfaces and debris has been done.

Keywords— Al-Si alloy, Fly ash, Reinforcement, MMC, Dry wear, coefficient of friction etc.

I. INTRODUCTION

Metal matrix composites (MMCs) represent a new generation of engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties including specific strength, specific stiffness, wear resistance, excellent corrosion resistance and high elastic modulus\cite{1,2}. Over the past two decades metal matrix composites (MMCs) have been transformed from a topic of scientific and intellectual interest to a material of broad technological and commercial significance\cite{3,4}. MMCs combine metallic properties of matrix alloys (ductility and toughness) with ceramic properties of reinforcements (high strength and high modulus), leading to greater strength in shear and compression and higher service-temperature capabilities. Thus, they have significant scientific, technological and commercial importance\cite{5,6}. During the last decade, because of their improved properties, MMCs are being used extensively for high performance applications such as in aircraft engines and more recently in the automotive industry \cite{7,8}. MMCs offer a unique balance of physical and mechanical properties. Aluminium based MMCs have received increased attention in recent decades as engineering materials with most of them possess the advantages of high strength, hardness and wear resistance\cite{9,10}. Fly ash particles are potential discontinuous dispersoids used in metal matrix composites, since they are low-cost and low-density reinforcement available in large quantities as a waste by-product in thermal power plants\cite{10,11}. The fly ash contains the most important chemical constituents like SiO\textsubscript{2}, Al\textsubscript{2}O\textsubscript{3}, Fe\textsubscript{2}O\textsubscript{3} and CaO. It constitutes quartz, mullite, magnetite, hematite, spinel, ferrite and alumina\cite{12}. Addition of fly ash particles in to Al matrix improves the hardness, wears resistance, damping properties, stiffness and reduces the density\cite{13}.The ductility of the composite decreases with increase in the weight fraction of reinforced fly ash and decreases with increase in particle size of the fly ash. However, for composites with more than 15% weight fraction of fly ash particles, the compressive strength is reported to be decreasing\cite{14,15}.

Most of the previous studies carried out on processing of aluminium–fly ash composites have utilized different size of reinforcement, different amount of reinforcement. But very little work has been reported on different amount of reinforcement in analysis of wear and physical test. To overcome that situation, in this present investigation, we have casted two types of metal matrix composites by vary the volume fraction of fly ash, as to wear resistive or not. And further we have compared the mechanical and tribological properties of the metal matrix composites with the base alloy.

II. EXPERIMENTAL PROCEDURE

II.1 MATERIAL

Eutectic Al–Si alloy LM6 containing 12.25% Si was used as a matrix. The composition of the alloy is given in Table 1. Cenospheres of fly ash were used as a reinforcement material in this investigation. They were formed in the temperature range of 920–1200 °C (32). In this experiment we have used fly ash whose composition is as shown in the table-2.

| Table-1: Composition of Al-Si alloy [wt. %] designated as a base alloy |
|----------------------|-----|-----|-----|-----|-----|-----|-----|
| Si | Co | Fe | Mn | Ti | Zn | Ni |
| 12.25 | 0.02 | 0.43 | 0.16 | 0.06 | 0.09 | 0.03 |
| Cu | Al | V | Ca | Sn | Cr | Sn |
| 0.06 | 0.09 | 0.01 | 0.01 | 86.76 | 0.08 |
**Table-2: Chemical composition of Fly Ash**

<table>
<thead>
<tr>
<th>Compound</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>CaO</th>
<th>MgO</th>
<th>Na$_2$O</th>
<th>K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Wt. %)</td>
<td>63.34</td>
<td>24.60</td>
<td>4.97</td>
<td>1.23</td>
<td>0.56</td>
<td>0.11</td>
<td>0.64</td>
</tr>
</tbody>
</table>

II.2 PREPARATION OF ALUMINIUM-SILICON ALLOY BASED METAL MATRIX COMPOSITE BY STIR CASTING.

After cleaning Al-Si ingot, it is cut to proper sizes, weighed in requisite quantities and were charged into a vertically aligned pit type bottom poured melting furnace (Fig.1).

![Fig.1: Bottom Pouring Furnace](image)

Fly ashes were preheated to 650°C±5°C before pouring into the melt of Aluminium-Silicon Alloy. This was done to facilitate removal of any residual moisture as well as to improve wetability. The molten metal was stirred with a BN coated stainless steel rotor at speed of 400-450 rpm. A vortex was created in the melt because of stirring where preheated fly ash was poured centrally in to the vortex. The rotor was moved down slowly, from top to bottom by maintaining a clearance of 12mm from the bottom. The rotor was then pushed back slowly to its initial position. The pouring temperature of the liquid was kept around 700°C. Casting was made in rectangular metal mould (250x20x45 mm$^3$). For comparison purpose two composites were prepared with 10 and 15 vol% of fly ash.

II.3 Mechanical Properties

II.3.1 IMPACT STRENGTH TEST

Impact Strength tests were performed by Charpy V Notch pendulum impact testing machine as shown in Fig 2. The square bar test specimens were placed as simply supported beams. Specimens were prepared by square cross section 10 mm x 10mm and 55 mm in length with 45-degree v notch at the centre as shown in Fig. 3. Single blow of hammer was given at mid span of specimen. The sufficient blow was applied to bend or break the specimen at centre. The striking energy was measured as 310 ±10 joules.

![Fig.2 Impact testing machine (Charpy test)](image)

![Fig.3 Specimen before impact test](image)

![Fig.4 Specimen after impact test](image)
II.3.2 COMPRESSION STRENGTH TEST

Compression test was done in the Universal Testing Machine (UTM) shown in Fig5. The cylindrical test specimen was mounted on the base plate of the UTM. The specimen here used had same diameter as that of height of the specimen shown in Fig6. The load was applied on the specimen gradually until the sample was compressed until its height reduced by 50%. As the application of load increased the displacement also increased, then the displacement reduced drastically as it cannot be compressed more. The photograph of used UTM and test specimens is shown in Fig below.

II.4 Wear test

Wear tests were carried out on a pin-on-disc type machine (TR201LE) Fig8 under atmospheric condition. The test samples having the dimensions of 8 mm diameter and 40 mm length Fig9 were slid against the low alloy steel disc (material EN-31-HRS 60 W 61 equal to 4340) of dia 215 mm, and Hardness Rc 62. Weight loss was measured with electric sensor weighing machine. Coefficient of friction and wear were measured continuously with an electric sensor attached to the machine and are recorded. The worn out samples were cleaned with acetone and are weighed in the balance.
III. RESULT AND DISCUSSION

III.1 MECHANICAL PROPERTIES

Charpy Impact data for the three materials i.e. Al-Si alloy, MMC with 10% fly ash and MMC with 15% fly ash were depicted in Table 3. It was observed that the amount of energy absorbed by MMC prepared with 15% fly ash is higher in comparison to the other two materials i.e. LM6 alloy and MMC prepared with 10% fly ash. The compressive test result was listed in Table 4. Data from compression test had also shown the highest strength value for MMC prepared with 15% fly ash than the other two materials. From the table-4, it can be observed that the compressive strength increased with an increase in the weight percentage of fly ash particles. This is due to the hardening of the base alloy by fly ash particles.

Table-3: Impact Strength of LM6, MMC with 10% fly ash and MMC with 15% fly ash.

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Sample name</th>
<th>Trial no.1</th>
<th>Trial no.2</th>
<th>Trial no.3</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.</td>
<td>LM-6</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>02.</td>
<td>MMC with 10% fly ash</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>03.</td>
<td>MMC with 15% fly ash</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Table-4: Compressive Strength of LM6, AMC with 10% fly ash and AMC with 15% fly ash.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>No. of trials</th>
<th>Sample Name</th>
<th>Compressive Strength in N/mm²</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>01.</td>
<td>TRIAL NO.1</td>
<td>Base alloy</td>
<td>461</td>
<td>462</td>
</tr>
<tr>
<td>02.</td>
<td>TRIAL NO.2</td>
<td>MMC with 10% fly ash</td>
<td>479</td>
<td>478</td>
</tr>
<tr>
<td>03.</td>
<td>TRIAL NO.3</td>
<td>MMC with 15% fly ash</td>
<td>482</td>
<td>481</td>
</tr>
</tbody>
</table>

III.2 WEAR BEHAVIOR OF THE COMPOSITES

Based on the results, various graphs were plotted and presented in Fig.[11and12] for different Percentage of reinforcement under identical test conditions. Our test conditions were sliding speed at 1 m/s, sliding time 1000 sec and load 30N. In this paper we measured two output parameters i.e Co-efficient of friction by the sensor available in wear test machine (DUCOM) and wear loss by electronic sensor weighing Machine. Fig.11 shows the variation of Co-efficient of friction (COF) along with sliding time. Similarly Fig.12 represents the wear loss along with sliding time. It was seen from the plot that with addition of fly ash particles the wear as well as Co-efficient of friction (COF) of the composite decreases and further decreases with increasing filler volume %.

III.3 DISCUSSION ABOUT SEM IMAGE OF WORN SURFACE.

Fig. 13 (a-c) shows the scanning electron micrograph of worn surfaces of (a) Al-Si Alloy (b) MMC prepared with 10% fly ash and (c) MMC prepared with 15% fly ash.

To have more information about the variation in wear behavior due to the addition of the fly ash, morphologies of the worn pins' surfaces were examined by SEM at an identical magnification Figs.(13a-c). The main features on the worn surface of the Al-Si alloy are severe damage characterized by the disintegration of the top surface, wear debris and deep
grooves in the sliding direction (Fig. 13a). Al-Si alloy of the size of micrometers detach and leave small craters behind. These alloys, which might be captured between the counterface and the pin sample, abrade the sample surface leading to even more substantial loss of material. In the case of MMC prepared with fly ash, the appearances are completely different and become rather smooth. Although the ploughing grooves are still visible on the sample surface, the groove depths are shallower on MMC with 10% fly ash (Fig. 13b) and at some region, the grooves are simply invisible. It seems the low filler loading is sufficient and can bring about significant improvement in wear resistance. Very fine scratches are visible resulting from the fly ash fillers pulled out of the matrix (Fig. 13c), and then further moved across the surface by scratching and rolling. Large matrix fragments are not found. During sliding, a rolling effect of fly ash could reduce the shear stress, the friction coefficient and the contact temperature. The matrix damages in the interfacial region were reduced by this rolling effect. In the present work, the wear-resistant of fly ash composite transferred well to the counterface and its transfer film was thin, uniform and adhered strongly to the counter face. Thus the improvement in the tribological behavior of Fly ash reinforced composite is related to the improved characteristics of the transfer film. The other reason for lower wear rate in composites is their high hardness as compared to pure aluminum resulting in lower real area of contact and therefore lower wear rate.

IV. CONCLUSION

The stir casting method used to prepare the composites could produce uniform distribution of the reinforced fly ash particles. Al-Si alloy matrix composites have been successfully fabricated with fairly uniform distribution of fly ash particles. Dispersion of fly ash particles in Al-Si alloy matrix improved the hardness of the matrix material and also the wear behavior of the composite. The degree of improvement of wear resistance of MMC is strongly dependent on the kind of reinforcement as well as its volume fractions. The effect was the increase in interfacial area between Al-Si alloy matrix and fly ash particles leading to the increase in strength appreciably. Coefficient of friction decreased as the vol % of reinforcement increased. Wear coefficient tend to decrease with increasing particle volume content. It also indicated that fly ash addition is beneficial in reducing wear as well as mechanical properties of the Al-Si fly ash composite. Wear resistance and mechanical properties of the composite increased due to addition of fly ash particles. However there existed an optimum filler volume friction which gave maximum wear resistance to the composite. The physical characteristics of the Al-Si Alloy matrix also increased with the addition of flyash particles which ultimately enhanced the mechanical property.

REFERENCES

Figure 11. Graph representing the Coefficient of Friction of the 3 samples

Figure 12. Graph representing the Wear of the 3 samples