Effect of Particle Size on Dry Sliding Wear of Cast A356-Al_2o_3 Metal Matrix Composites

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***Abstract*- Aluminum alloy is the most commonly used matrix for the metal matrix composites. The ceramic particles reinforced aluminum composites are termed as new generation material and these materials can be tailored and engineered with specific required properties for specific application requirements. Among metal-ceramic particle composite, aluminum-graphite, aluminum-alumina and aluminum-silicon carbide particles can posses improved wear resistance, high temperature hardness and strength. In the present study, A356 with 10% Al_2O_{3p} of different particle size (23µm, 45µm, 75µm, 120µm) MMC material was fabricated using stir casting (vortex method) method. In the present work an attempt has been made to study the effect of particle size on dry sliding wear of cast A356-Al_2O_3 metal matrix composites. Dry sliding wear tests were carried out under ambient conditions (24-28 ^oC) using pin-on-disc wear testing machine. Prior to testing, the specimens were ground against a 600 grit SiC abrasive paper to make the surface flat and maintain the surface finish between 1.5 and 3µm R_a value. The wear test was conducted at different loads, with increments of 10N and varying sliding distance (up to 5000m) at constant velocity of 2 m/s. The results show the composites reinforced with all the four different particle size exhibits significantly higher wear resistance than the matrix alloy due to addition of hard alumina particles which acts as a load bearing constituent. Particle size is one of the important factor which influences wear. It can also be observed from the test result that the composite material with large size particulate reinforcements experience higher order wear compared to those with smaller size particulate reinforcement. And also observed that the wear increases with increasing sliding distance and load.**

Key words: A356, Al_2O_3, Particles, MMC's

I. INTRODUCTION

The desire of space industries for material having light weight and high strength leads to the development of new type of materials called composites. Since Aluminum Matrix Composites (AMMC's) are light in weight and having high strength to weight ratio, it is normally used in the areas where the weight is a constraint.

Pradeep K. Rohatgi [1] studied on the world-wide upsurge in metal-matrix composite research and development activities with particular emphasis on cast MMC. The potential for extensive application of cast composites is very large in India, especially in the areas of transportation, energy and electromechanical machinery; the extensive use of composites can lead to large savings in materials and energy, and in several instances, reduce environmental pollution.

Abdul Samad et.al [2] studied on wear and friction of Al- Al_2O_3 composites at various sliding speeds. This study addresses the dry wear behavior of Al_2O_3- 6061 Aluminum particulate composite under different sliding speeds and applied load using pin on- disk tribometer at room temperature. Three grades of the submicron particle composites containing 10, 20, and 30 vol. % Al_2O_3 were tested. The results illustrate that higher load and higher concentration of Al_2O_3 particles lead to higher wear rates. For 10 and 20% Al_2O_3 concentrations, the wear rate decreases with increasing sliding speed, while it increases for 30% Al_2O_3.

Takashi Moriguchi et.al [3] studied on influence of the matrix microstructure on the wear resistance of alumina continuous fiber reinforced aluminum alloy composites. In this study alumina continuous fiber of 15µm diameter was chosen to improve the wear resistance. Fiber reinforced composites were fabricated via the pressure infiltration process; continuous alumina fibers were placed in a graphite mold, then molten aluminum alloy was infiltrated into the fiber performs in a vacuum to fabricate the composites specimens with the 55 vol% fiber. The pin on ring type wear resistance test was carried out under the condition of dry and air atmosphere. The results showed that wear resistant properties of fiber reinforced composites are improved about 2 to 10 times more than unreinforced alloys.

Garcia et.al [4] studied on abrasive wear resistance of A357, A339, and A6061 aluminum matrixes reinforced with Al_2O_3 particles. The composites are prepared by using compo-casting techniques. They used different particle size and volume fraction. They reported that abrasive wear increases with decreasing particle content. Also found that abrasive wear resistance depends upon the matrix bonding with ceramic particle.

Literature review indicates that the tribological characteristics of metal matrix composites depend on amount of percentage and size of reinforcement. There is great scope for improvement with proper combination of these parameters.

II. EXPERIMENTAL DETAILS

A. *Work Material Details*

The details of the material selected for present investigation are as discussed below. Aluminum (A356) based metal matrix composite with varying particle sizes particulate aluminum oxide with volume fraction of 10% are used. α- aluminum oxide average particles sizes of 23µm, 45µm, 75µm, and 120µm has been selected for the present investigation.

1) Mechanical properties of A356:

Among several series of aluminum alloys, A356 is one of the most extensively used alloys for its excellent properties. Basically A356 is an alloy of Aluminum, Magnesium and Silicon, which is highly resistant to corrosion and exhibit moderate strength. Some of the properties of A356 are represented in Table. I

Table I. Mechanical Properties of A356

Properties	**Values**
Elastic Modulus (Gpa)	70-80
Density (g/cc)	2.7
Poisson’s Ratio	0.33
Brinell Hardness (HB500)	75
Tensile Strength in Mpa	220
Melting Temperature	660^0 C

2) Chemical composition of A356 selected: The chemical composition of the A356 is mentioned in Table.II

Table II. Chemical Composition of A356

Elements	**Percentage of contents**
Al	91.1-93.3
Cu	<=0.2
Iron	<=0.2
Mg	0.25-0.45
Mn	<=0.1
Other each	<0.05
Silicon	6.5-7.5
Titanium	<=0.2
Zinc	<=0.1

3) Mechanical properties of Al_2O_3: Table III shows the mechanical properties of reinforcement material Al_2O_3 used in the present study taken from the literature,

Table III. Mechanical Properties of Al_2o_3

Properties	**Values**
Elastic Modulus (Gpa)	300
Density (g/cc)	3.69
Poisson’s Ratio	0.21
Hardness (HB500)	1175

B. *Procedure to Fabricate Composites*

- Cleaned A356 ingot of required quantity is to be placed in the melting crucible. The furnace top is to be closed by refractory material and heater is to be switched on and set to the required temperature (800^0C). Heating is to be continued for about 3 hrs

- The 10% by weight, Al_2O_3 Reinforcement particulates are to be pre-heated to 300^0C for about 30 minutes in another closed furnace.

- Add the Slag remover to the molten metal to remove the slag.

- Chlorine based solid degassing tablet hexachloroethane – C_2Cl_6 Tablet is to be added to remove gasses entrapped during melting and Magnesium of about 0.3% is to be added to the melt to improve the wettability.

- Stirrer is to be immersed up to ¾ height of the molten metal and start the stirring action and at the same time Al_2O_3 powder is added slowly and stirring action is carried up to 5 minutes.

- After stirring the molten composite metal is poured into pre heated mould (400^0C) by opening the bottom valve of the furnace.

- After allowing the mould to cool at room temperature, the cast material is taken out, by opening the mould halves.

C. *Dry Sliding Wear Test*

Dry sliding wear tests of the specimens were conducted using pin-on- disc test apparatus conforming to ASTM G99 standards with electronic data acquisition system. EN32 hardened steel disc with a hardness of 65HRC and Ra value of 2.5–3.5 µm was used as the counter surface. The counterface disc has a diameter of 120 mm and thickness of 8 mm. The specifications of the equipment are given in the Table.IV

Fig. 1 Wear and friction test rig

Fig. 2 Wear testing pins

Table IV. Technical Specifications of Wear and Friction Test Rig

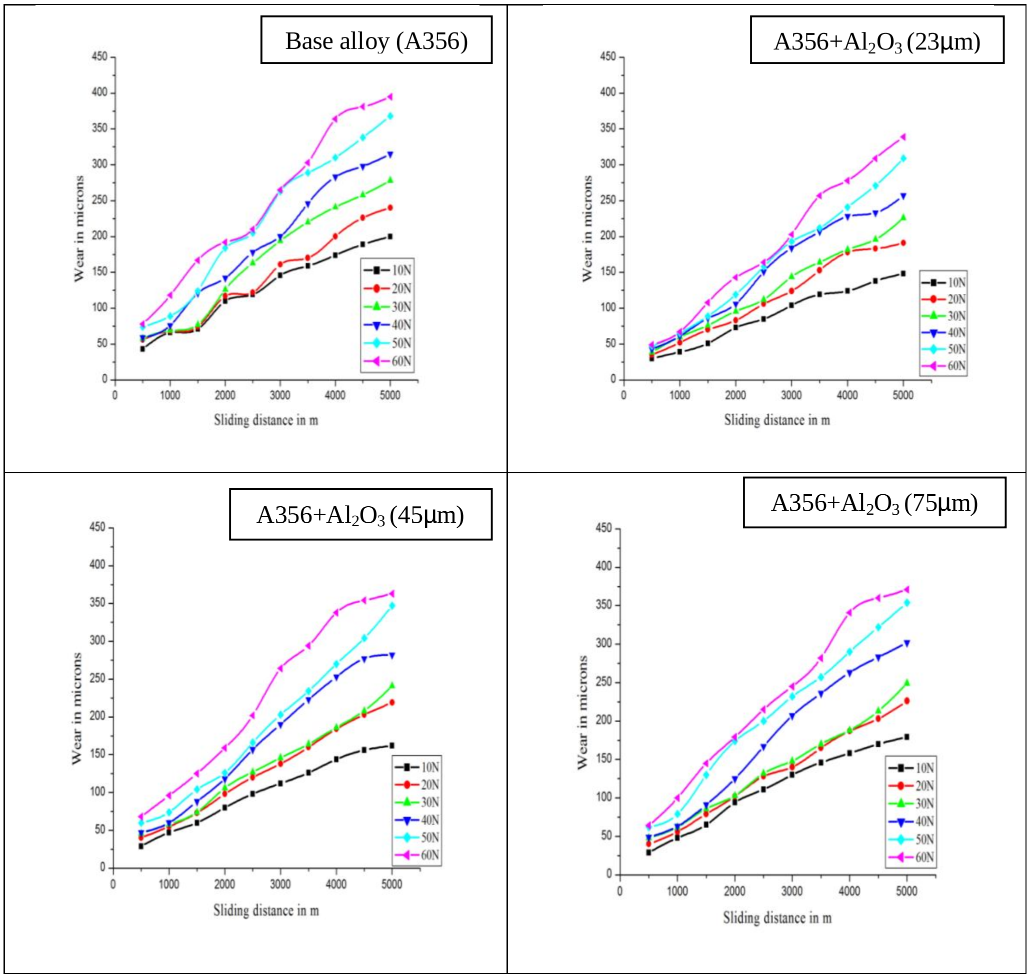
Rotational Speed	Up to 2000 rpm
Track Diameter	40mm – 118 mm
Load Range	Up to 200 N
Disc Size	Dia 120 mm ×Thickness 8 mm
Pin Size	6 to 12 mm
Wear or Displacement	±2000 microns
Frictional Force	Up to 200 N

Dry sliding wear tests were carried out under ambient conditions (24-28°C) using pin-on-disc wear testing machine.(fig.1) Prior to testing, the specimens were ground against a 600 grit SiC abrasive paper to make the surface flat and maintain the surface finish between 1.5 and 3µm Ra value. Then the specimens were thoroughly cleaned with acetone and dried. The specimens were then weighed accurately using electronic balance with 0.1 mg accuracy. The counter face disc also was cleaned with acetone to remove any oil film present. The wear test was conducted at different loads, with increments of 10N and constant velocity of 2 m/s. After every 5000m run the specimen was removed, cleaned, dried and weighed to calculate the mass loss. The friction coefficients and wear were recorded continuously.

III. RESULTS AND DISCUSSION

A. Dry Sliding Wear

1) Wear V/S Sliding Distance with Varying Load: Figure 3 indicates the wear displacement with respect to sliding distance of different test specimens at different loads. In most of cases, it can be observed that the slope of the curves is higher initially, indicating running-in wear, during which, asperity contacts take place resulting in higher wear rates. Later, as the asperities get flattened, contact area increases, with reduction in wear rate, which is indicated by the reduced slope of wear curves. With further increase in sliding distance, rate of wear increases, because of the abrasive nature of wear due to the entrapped particles between the mating surfaces.



Base alloy (A356)

A356+Al_2O_3 (23µm)

A356+Al_2O_3 (45µm)

A356+Al_2O_3 (75µm)

Fig 3.Wear V/S Sliding Distance

2) Wear V/S Load:

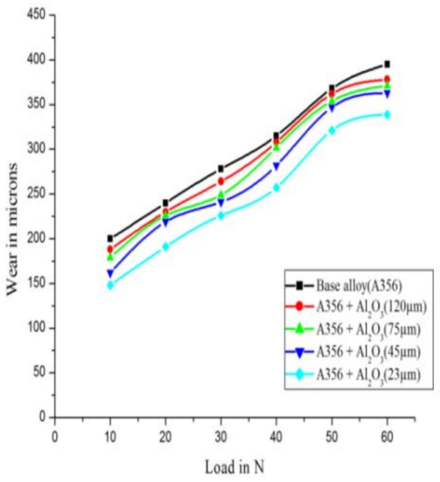


Fig.4 Wear v/s Load

3) Mass Loss V/S Load:

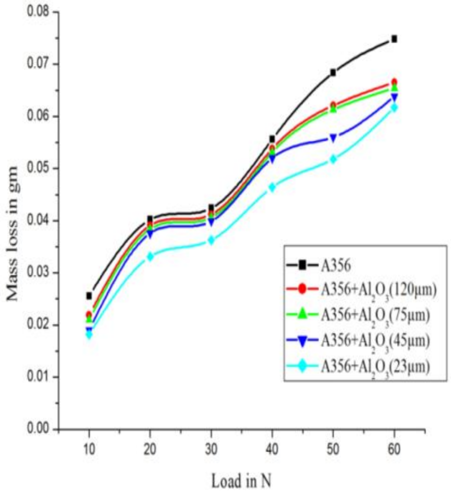


Fig.5 Mass loss v/s Load

Fig 4 and 5 illustrates the variation of dry sliding wear with load. It can be observed from the plots that the wear increases gradually with increase in load. It was observed that the composites reinforced with all the four different particle size exhibits significantly higher wear resistance than the matrix alloy due to addition of hard alumina particles which acts as a load bearing constituent. Particle size is one of the important factor which influences wear. It can also be observed from the test result that the composite material with large size particulate reinforcements experience higher order wear compared to those with smaller size particulate reinforcement.

In case of composites with small size particulate reinforcement, for the same mass percentage, the number of reinforcement particulates is larger. In case of large number of smaller particles, contact area between the matrix and the reinforcement phases will more and so is the interface between the two phases.

This increased interface region would result in better stiffening and increased strength of the composite structure resulting in reduced wear of the material. Also, when the particulates get dislodged during the process of wear, they get entrapped between the mating surfaces, causing three body type abrasion. Even in such situations, when the entrapped particulates are smaller in size, the amount of abrasive wear would be smaller when compared to those, where entrapped particulates are relatively larger.

The results of the wear test also indicate increasing trend in wear loss at lower loads, which become relatively steady in the load range of 20-30N. At smaller loads mostly asperity level contact prevail between the mating surfaces, resulting in deformation and shearing off of the asperities, resulting in higher rates of wear.

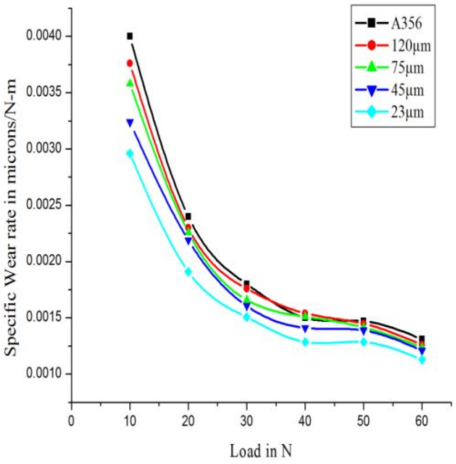
At higher loads (20-30N), the asperities get weared out faster, thereby increasing the contact area between the mating surfaces, as well as strain hardening of the surface because of increased dislocation density, this result in relatively lower rates of wear loss.

With further increase in load, a progressive increase in wear loss can be observed with load. At higher loads, the surface temperature will be more, thereby reducing the strength of the material. Also at higher loads, contact stress increases, resulting in crack initiation and propagation within the contact stress zone. At such situations, delamination type of wear is resulted, causing removal of large chunks of material in the form of flakes. This is a severe mode of wear. From the test results, it can be observed that the transition from mild to severe type of wear takes place in the load range of 30-40N.

4) Specific Wear Rate V/S Load:

Fig.6 illustrates variation of specific wear rate with load. Specific wear rate is the wear loss of the material per unit load per unit sliding distance. It actually represents the slope of the wear curves plotted with respect to normal load. It can be observed from fig.3.4 that specific wear rate decreases initially with load indicating the decreasing slope of the wear curves. After the critical load for severe wear is reached, specific wear rate becomes constant, indicating a constant slope of the wear curve, where material wear increases at a constant rate with load.

Fig .6 Specific Wears Rate V/S Load



B. Mathematical Modeling of Wear

1) Regression Analysis: Regression analysis method is used for the estimation of dry sliding wear. The objective of regression analysis is to develop a model that explains as much as possible, the variability in a dependent variable, using several independent variables. Operating parameters like load and particle size are considered as the independent parameters for constructing the regression model. The variation of measured and estimated wear with load and particle size have been presented in the form graphs for comparison.

Making use of the experimental data, a mathematical model has been developed, using regression analysis. In this analysis wear is considered as the dependent variable and load and particle size are considered as the independent variable. The first order polynomial model has been developed. The first-order polynomial is given in the equation(1)

$$Y=a_o+a_1X_1+a_2X_2 \qquad (1)$$

After regression analysis the above equation is obtained as,

$$Y=105+3.99X_1+0.396X_2 \qquad (2)$$

Where, Y= wear in microns, X_1= load in N,

X_2=particle size in µm,

a_o, a_1 and a_2 are the co-efficient of X_1 and X_2

Fig.7 shows the comparison of the modeling wear and experimental wear.

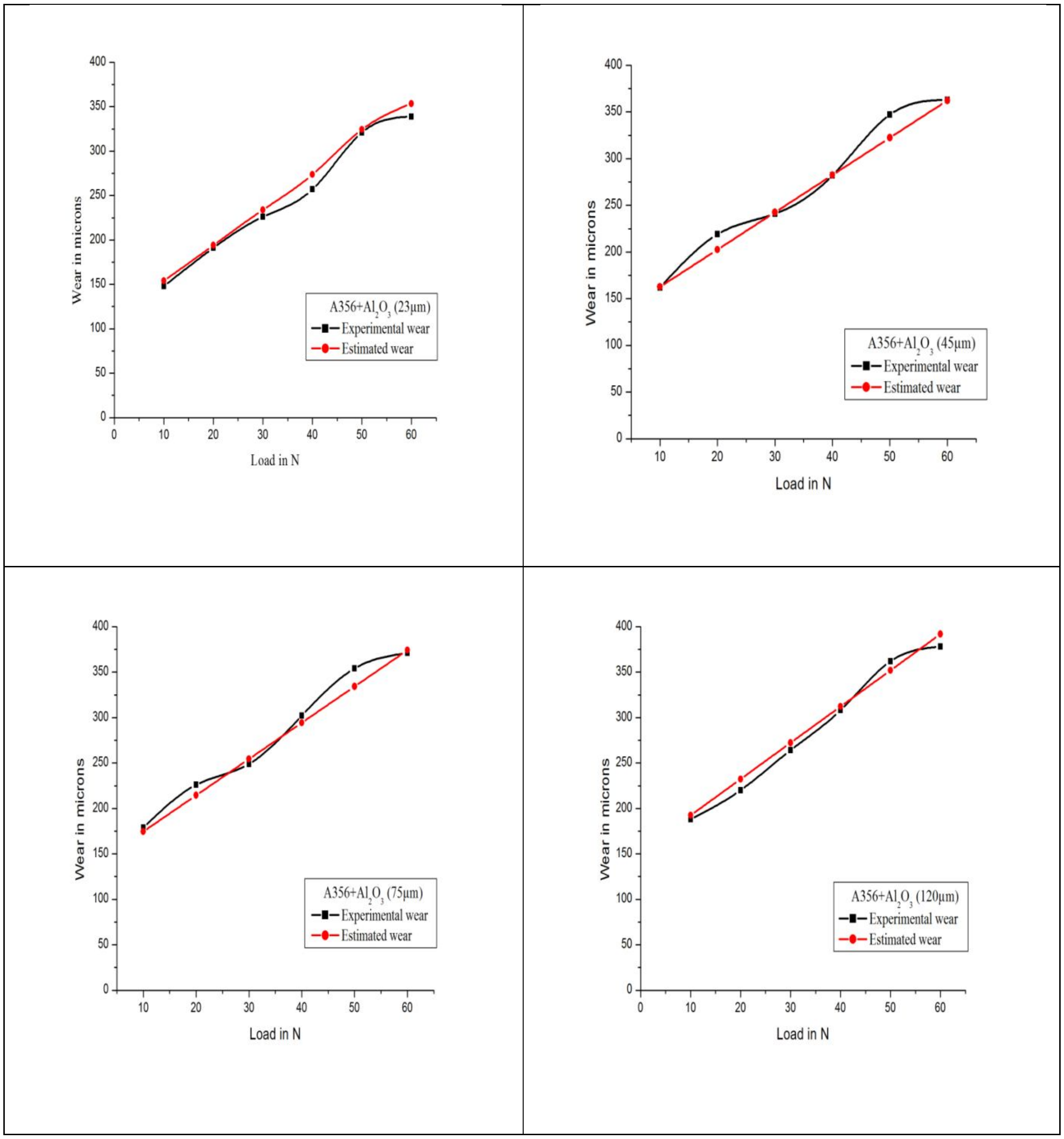


Fig.7 Comparison of Experimental and Estimated wear

IV.CONCLUSIONS

Experimental investigations conducted in the present work to study the effect of particle size of Al_2O_{3p} on dry sliding wear of A356-Al_2O_3p metal matrix composites have provided the following conclusions.

- The wear properties of the A356 alloy were considerably improved by the addition of Al_2O_3 particulates and the wear resistance of the composites was much higher than that of the unreinforced A356 aluminum alloy.
- Mass loss due to sliding is found to increase initially with load, but rate of wear is found to decrease at higher loads, mostly due to the work hardening effect on the sliding surface.
- The wear resistance of composites increased with decreasing particle size of Al_2O_3 particulates.
- Mass loss due to sliding wear increases with sliding distance, but wear rate is found to decrease with sliding distance because of flattening of asperities as well as work hardening of the surface.
- From the wear test results, it can be observed that the transition from mild to severe type of wear takes place in the load range of 30-40N.

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