

Tribological Behaviour of Aluminum Silicon Carbide Functionally Graded Material

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Keywords:

Powder metallurgy
Functionally graded materials
Tribology
Pin-on-disc
Wear volume loss
Coefficient of friction.

ABSTRACT

Al based Functionally graded materials (FGMs) are appropriate for wider range of applications in various sectors such as structural, aircraft and automotive industries. They are highly conductive, ductile, light in weight and have high strength to weight ratio. In this research, the tribological behavior of Al-X wt.% SiC (X = 0,3,7 and 10) functionally graded composites are fabricated using powder metallurgy (PM) route. All specimens were prepared by blending, pressing and sintering methodology. The sintered specimens are characterized by optical microscope and Scanning Electron Microscope (SEM). Properties such as hardness, wear/wear volume loss and coefficient of friction are measured. The wear tests are carried out using a pin-on-disc setup. Coefficient of friction (COF) and wear volume loss (WVL) are measured by sliding the pin specimens on to a grey cast iron counter disc rotating at a constant speed of 500 rpm. Synthetic hard ceramic particulates are incorporated in the aluminum matrix to accomplish reduction in both wear and coefficient of friction. The experimental results reveal that the hardness of the composite increased by increasing the SiC wt.%, on the other hand, low wear volume loss and lower coefficient of friction values are noticed.

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1. INTRODUCTION

The development of functionally graded materials (FGMs) revolutionized the manufacturing sectors of mechanical parts, especially in automotive, aviation and biomedical fields [1]. There are various processing routes available to get functionally graded materials which includes powder compacting, centrifugal and stir casting [2]. Among all PM is the simplest and cost effective route due to its good control capability on the

composition, microstructure and reliable shape forming capability [3-5]. Owing to their high strength to weight ratio, good resistance to wear aluminium based metal matrix composites are very popular. These composites show more desirable mechanical properties over conventional metals/alloys [6]. The reinforcement constituent embedded in this metal/metal alloy matrix is usually non-metallic in nature. Some examples for reinforcement constituents are SiC, C, Al₂O₃, SiO₂, B, BN and B₄C [7]. In comparison to composites alloy undergo

high wear rate independent of load and abrasive size. Composites manufactured by the reinforcement of SiC in aluminium using powder metallurgy exhibit good abrasion wear resistance [8]. In automobile and aerospace engineering fields, for wear resistant applications, budget friendly functionally graded materials are the best fit. For example, in a ceramic metal combination such a material would comprise of a hard-ceramic face on the exposed side, a tough metal face on the other side forming a graded composite. Such a gradation will improve the toughness of the ceramic face and simultaneously prevents the breaking of ceramic-metal bonds. In such a material, high wear resistance and high toughness are uniquely combined [9]. The two important characteristics, namely wear and coefficient of friction are taken into consideration to study the tribological behavior of FGM [10]. This research investigates strength to weight ratio, wear resistance and tribological characteristics of Al-SiC FGMs keeping in view their applications in flywheels, racing car brakes and composite piping systems.

2. EXPERIMENTATION

2.1 Materials and Experimental Procedure

The work undertaken is the fabrication of pure Al-SiC functionally graded material using powder metallurgy and its tribological study. Pure Aluminium (Al) is taken as matrix and, SiC as reinforcement and powder metallurgy is used as the manufacturing method. The following properties are tested:

- Wear Volume loss(WVL) and
- Coefficient of friction (COF).

The SiC particles with a density of 3.21 g/cm³ are used in experimentation for reinforcement with three different weight percentages (3, 7 and 10 %).

Table 1. Composition of pure Aluminum.

Composition	Assay	Arsenic	Lead	Iron
Weight %	99.5	0.0005	0.03	0.5
Density	2.68 g/cm ³			
Purity	99.5 %			
Particle size	200 Mesh			

1 kg of pure aluminum powder is procured from Unique traders, Hyderabad. 500 gms silicon carbide is procured from Bombay through CEC Chemicals, Hyderabad. The composition of the aluminum is specified by the manufacturing company itself on the bottle as shown in Table 1. The particle sizes of aluminum and silicon carbide are 200 mesh (74 microns) and 220 mesh (70 microns) respectively.

2.2 Specimen Preparation

Four specimens are manufactured with varying SiC content. The weight percentages of SiC in different specimens are mentioned in the Table 2. Different mixtures of aluminum and silicon carbide are prepared as per weight fractions mentioned in the Table 2, weight of each sample is 2 gms. Composition of each sample is calculated and constituents are mixed to obtain uniform composition.

Table 2. SiC composition in each sample.

Specimen	wt.% of Al	wt.% of SiC
1	100 %	0 %
2	97 %	3 %
3	93 %	7 %
4	90 %	10 %

After mixtures are prepared, the next step is to fill the die. Different mixtures are poured into the die. Stearic acid was used as binding agent. Stearic acid solution was prepared by mixing approximately 3 gms of stearic acid with 10 ml of acetone. The stearic acid solution is stirred continuously for 2 min to get uniform solution.



Fig. 1. Universal testing machine.

The above solution acts as a binder for aluminum–silicon carbide mixture. The amount of binder added to the above mixture is based on trial and error method. After the die is filled with Al-SiC mixture, it is then cold pressed by applying 6 kN force using universal testing machine (Fig. 1). Green specimens are obtained at the end of the process.

Sintering is a process where the material is heated in a standard atmosphere preferably argon atmosphere which will give good results. The sintering temperature should be in the range of 70 to 90 percentage of the melting point of Aluminum. Usually, Sintering time depends upon the specimen dimensions and type of the metal. The optimum sintering temperature is 560 °C with 3 hours of heating and a holding time of 1 hour in muffle furnace (Fig. 2) [7].



Fig. 2. Muffle furnace.



Fig. 3. Sintered specimens with SiC wt.% (3, 7 and 10).

After furnace cooling, specimens (Fig. 3) are taken out and the surface finishing operation is performed on specimens. The microstructure analysis is done through SEM. Rockwell hardness test is carried out using the following specifications:

- Ball indenter size: 1/16-inch,
- Applied load: 100 kg,
- Dwell time: 20 sec.

Hardness test is performed at room temperature and readings are taken at three different places on each composite to obtain the mean value of hardness [11,12]. Tribological properties are tested for all specimens and results obtained are discussed in the following section.

3. TRIBOLOGICAL EXPERIMENTATION

ASTM standard test is conducted for determining the wear of material during sliding. The coefficient of friction is determined using pin-on-disc wear test, two components are required, one pin is placed perpendicular to the other component, which usually is a flat circular disc. The test machine causes the disc or the pin specimen to rotate about the center of the disc. In either case, the sliding path is a circle on the disc surface. The pin specimen is pressed against the disc at a specified load, usually by means of an arm or lever and attached weights. Wear results are reported as wear volume loss (mm^3) for the pin and disc separately.

The pin-on-disc apparatus is used to investigate the dry sliding wear characteristics of the composites as per ASTM G99-95a standards. The ends of wear specimen (pin) which is 8 mm in diameter and 15 mm in height are polished with abrasive paper of grade 120. The sliding ends of the pin and disc surface are cleaned with acetone before each test. The initial weight of the specimen is measured in a single pan electronic weighing machine with a least count of 0.0001 g.



Fig. 4. Pin on disc apparatus.

During the test, the pin is pressed against the grey cast iron counter disc which is shown in Fig. 4, by adjusting various parameters as per the experimental plan. After rotating the disc against pin for a fixed time, the pin is removed from the lever and the weight of the sample is checked again. The weight loss obtained from difference in weights is converted into wear volume loss. The results for the wear volume loss and coefficient of friction for all the specimens are presented in the Tables 4-6.

3.1 Formulas

The density of FGM sample can be defined as the ratio of weight of the material to the volume of the material and is expressed as ρ_c :

$$\rho_c = \frac{1}{\frac{W_{Al}}{\rho_{Al}} + \frac{W_{SiC}}{\rho_{SiC}}} \quad (1)$$

$$W_L = W_i - W_f \quad (2)$$

$$WVL = \frac{W_L}{\rho_c} \quad (3)$$

where:

- W_{Al} Weight fraction of Aluminum
- W_{SiC} Weight fraction of Silicon Carbide
- ρ_{Al} Density of Aluminum g/cm³
- ρ_{SiC} Density of Silicon Carbide
- W_i Initial weight before test
- W_f Final weight after test
- W_L Weight loss in grams
- WVL Wear volume loss in mm³
- COF Coefficient of friction

4. RESULTS AND DISCUSSION

The results obtained in the above experiments are listed in the Tables 3-6. Results are analyzed and conclusions have been drawn. A magnification of 150x is used for SEM images shown in Figs. 5-7.

Table 3. Hardness values of specimens.

S. No	Specimen (SiC%)	Hardness(RHN)
1	0	23
2	3	25
3	7	28
4	10	30

Table 4. WVL and COF Results of Test 1.

Sample	Sliding Speed (rpm)	Load (Kg)	WVL mm ³	COF
1	500	1	10.44	0.107
2	500	1	6.634	0.202
3	500	1	3.595	0.234
4	500	1	1.4577	0.371

Table 5. WVL and COF Results of Test 2.

Sample	Sliding Speed (rpm)	Load (Kg)	WVL mm ³	COF
1	500	1.5	19.26	0.252
2	500	1.5	13.93	0.261
3	500	1.5	5.465	0.249
4	500	1.5	1.822	0.299

Table 6. WVL and COF Results of Test 3.

Sample	Sliding Speed (rpm)	Load (Kg)	WVL mm ³	COF
1	500	2	22.88	0.153
2	500	2	15.18	0.166
3	500	2	6.89	0.327
4	500	2	2.0043	0.219

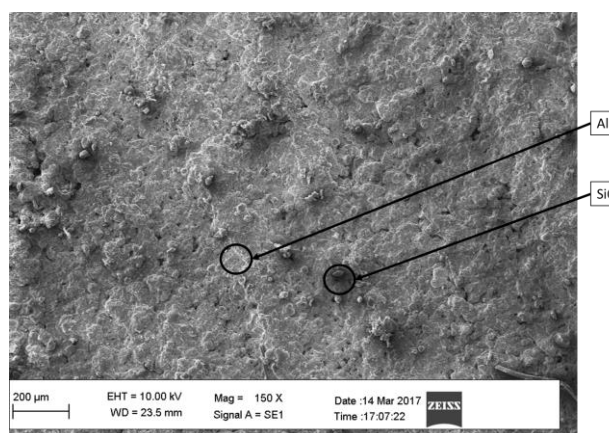


Fig. 5. Microstructure of al-SiC (3 %).

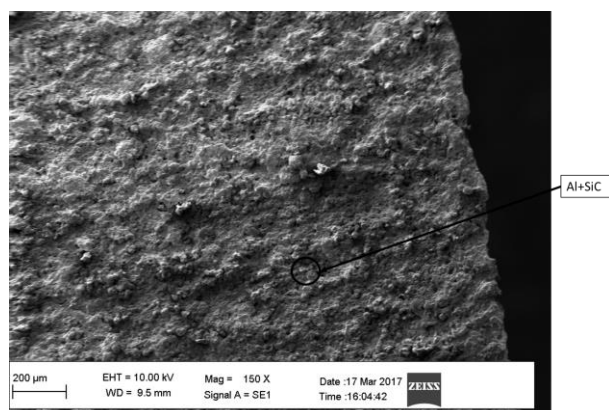


Fig. 6. Microstructure of al-SiC (7 %).

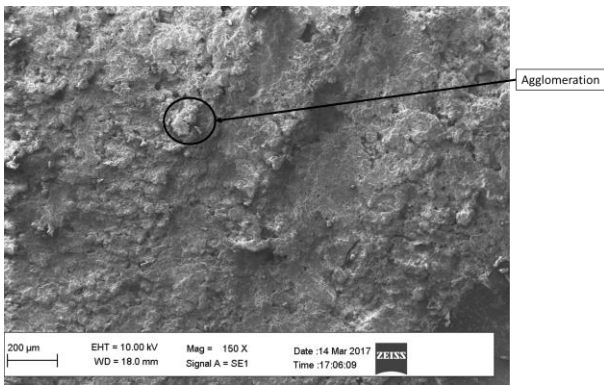


Fig. 7. Microstructure of al-SiC (10%).

Figures 5, 6 and 7 show the microstructures of different specimen at 3 %, 7 % and 10 % SiC respectively. The black coloured portion is SiC and white coloured portion is aluminium. It is observed that there is a uniform distribution of black and white portions in Figs. 5 and 6 whereas a small amount of agglomeration which signifies increase in SiC content is identified in Fig. 7. Apart from the small agglomeration identified in Fig. 7, there is a homogenous distribution of reinforcement in the rest of the specimen.

The hardness values for the specimens are tabulated in Table 3. An increase in hardness number can be seen with an increase in SiC percentage.

Table 4 gives the relationship between wear volume loss, coefficient of friction and SiC percentage for a sliding time of 10 min at a load of 1 kg. It is observed that wear volume loss is very high for pure aluminum and very less for Al-10 % SiC composition. The wear volume loss decreases gradually as the SiC content increases. Co-efficient of friction value is less for pure aluminum and it increases gradually with increasing SiC percentage. At 10 % SiC, highest COF value of 0.371 is recorded as SiC particles are abrasives and rigid.

Table 5 gives the relationship between wear volume loss, coefficient of friction and SiC percentage for a sliding time of 10 min at a load of 1.5 kg. It is observed that the wear volume loss is highest (19.26 mm³) and lowest (1.822 mm³) for Al – 10 % SiC sample. Co-efficient of friction value is less for pure aluminum and it increased gradually with increase in SiC content except for 7 % SiC sample, where COF value was less than that of pure aluminum. At 10 % SiC, it

recorded highest COF value of 0.299 as SiC particles are rough particles which contribute to more friction at the interface.

Table 6 gives the relationship between wear volume loss, coefficient of friction and SiC percentage for a sliding time of 10 min at a load of 2 kg. It is observed that wear volume loss is highest for pure aluminum and lowest for Al-10 % SiC composition. It is seen that the wear volume loss decreases gradually as the SiC content increases. Co-efficient of friction value is less for pure aluminum and it increases gradually with increase in SiC content. At 6 % SiC, it recorded highest COF value of 0.327 which is more than that of 10 % SiC. The above obtained results and data are represented graphically in Figs. 8 and 9.

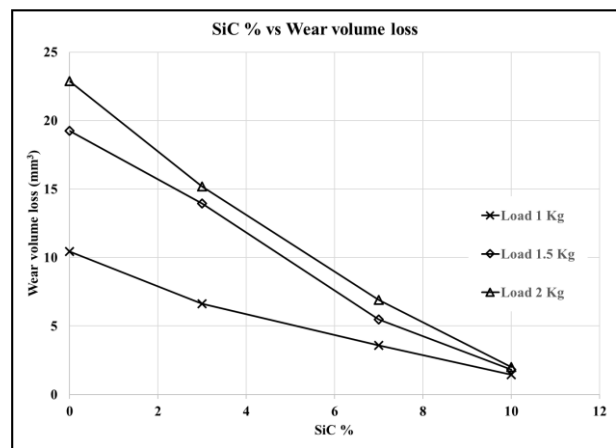


Fig. 8. SiC % vs Wear volume loss graph.

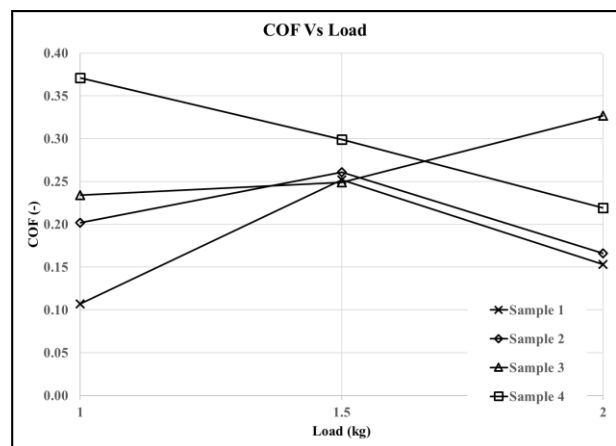


Fig. 9. COF vs load.

Figure 8 shows the graphical representation of wear volume loss and percentage of silicon carbide at various loads as shown in Table 4, Table 5 and Table 6. All the curves follow the same trend and no discrepancy is found. Were as in Fig. 9 the COF which normally is expected to decrease with

increasing normal load is varying [13]. For the sample with 10 % SiC, due to the rough and rigid nature of SiC particles the trend is as expected. But for pure aluminium, due to the lack of presence of SiC particles the trend is otherwise. If we observe the trend of COF from pure aluminium to 10 % SiC, the curve changes from continuous positive slope to continuous negative slope.

5. CONCLUSION

The experimental results, reveals that SiC reinforced aluminum matrix composites exhibit higher wear resistance than that of unreinforced aluminum matrix materials. From the SEM morphology, the SiC particulates are uniformly distributed throughout the aluminum matrix.

As the SiC wt.% increases the hardness values also increase, but the failure of specimens occurred when SiC content was increased beyond 10 %. This is due to high brittleness and less bonding of aluminum-aluminum particles. It can be concluded from the experimental results that, optimal filler capacity for SiC in Pure Al is 10 %.

From the above results, it is observed that pure aluminum specimen has undergone more wear volume loss as it is a soft material and has poor wear resistance. Wear volume loss also increases with increase in applied normal load. As the applied load increases more heat is produced thus making the material softer and vulnerable to high wear loss.

It is also observed that COF value is dependent on the combination of %SiC and applied load. The roughness of SiC particles contributes to more frictional force.

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