Effect of Al_2O_3 particles on the Tribological and Mechanical properties of Al6082 Metal matrix composites fabricated by powder metallurgy technique

Anil kumar[1], J. Satheesh[2], Praveen kittali[3], T. Madhusudhan[4]

1Associate Professor, Mechanical Department, SJB Institute of Technology, VTU, Belagavi, Karnataka, India
[2] Professor, Mechanical Department, SJB Institute of Technology, VTU, Belagavi, Karnataka, India
[3] P.G. Scholar, Mechanical Department, SJB Institute of Technology, VTU, Belagavi, Karnataka, India
4Professor, Mechanical Department, SJB Institute of Technology, VTU, Belagavi, Karnataka, India

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Abstract – *This work deals with the effect of Al_2O_3 particles on tribological and mechanical behavior of Al6082 metal matrix composites fabricated by powder metallurgy technique. Four different weight percentage (0%, 5%, 10%, and 15%) of reinforcements were utilized and also the samples were sintered at four different sintering temperatures (420°C, 450°C, 480°C and 510°C). Various properties such as wear, hardness, porosity and density were investigated with variation of reinforcement content. Microstructural observations was made to study the particle distribution and porosity. The results obtained for density and porosity shows an increase in density of composite with increase in sintering temperature and also decrease in percentage of reinforcement but Porosity increased with decrease in sintering temperature and increase in reinforcement content. Rockwell hardness test results showed an increase in hardness value with wt.% of Al_2O_3 and with sintering temperature. Wear test was conducted by considering a constant speed of 100rpm and distance of 200m at three different loads of 9.81N, 14.72N and 19.62N.*

Key Words: **AMCs, Al_2O_3, Al6082, Sintering temperature**

1.INTRODUCTION

Aluminium matrix composites (AMCs) used in various industries such as automotive, defense, and aerospace because they exhibit high electrical conductivity, light weight, good corrosion resistance, and high strength to weight ratio. Aluminum matrix composites can be utilized for the automobile products, for example, cylinder liner, brake disc and engine piston. Among engineering alloys, Aluminum alloys are most used next to steel. Al alloys exhibit low wear resistance and low yield strength. Addition of hard ceramic particles to soft Al alloys improves wear resistance and strength at both elevated and ambient temperatures.

It is necessary that the reinforcements should be uniformly distributed in composites to achieve excellent mechanical and tribological properties. Components produced using zinc based Al alloy materials showing strength of nearly 80% of that of components produced using steel. Addition of lithium as primary alloying element to aluminium gives rise to unique characteristics of combination of low density (ρ) and high elastic modulus (E). Powder metallurgy is the common method for production of metal matrix composite because it produce near net shape with minimal material loss.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

In the present study, Al6082 alloying elements (Mg 0.6-1.2 wt.%, Si 0.7-1.3 wt.%, Cr 0.25 wt.% max, Fe 0.5 wt.% max, Cu 0.1 wt.% max, Zn 0.2 wt.% max, Mn 0.4-1.0 wt.%, Ti 0.1 wt.% max and balance Al) were used as the matrix material with a mesh size of 300. Alumina (Al_2O_3) particulates with a mesh size range of 100-200 were used as reinforcements. The melting temperature of Al6082 is 555°C.

2.1 Blending

Planetary ball mill was used to perform blending of powders. Milling speed was maintained at 200 rpm and milling time was 2h. Mixing was done by using 25 steel balls of 10mm diameter.

2.2 Compaction and sintering

Compaction of powder was done with the help of 200KN capacity compression testing machine. The die was fabricated using EN24 steel material according to required dimensions. Matrix and reinforcement particulates were poured into the die and pressed at a constant load of 18KN. Cylindrical specimens of size Φ10 × 8mm were prepared. The compacted specimens were sintered at four different (420°C, 450°C, 480°C and 510°C) sintering temperatures for 2h in a sintering furnace. The sintered specimens were allowed to cool in sintering machine only. The schematic of Compression testing machine and sintering machine are shown in Fig. 1a and 1b respectively.

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(a) (b)

Fig-1: Equipments (a) Compression testing machine (b) Sintering furnace

2.3 Density and porosity measurement

The sintered density of samples was measured by dividing the mass of samples with volume. The samples were weighed using an electronic weighing balance with an accuracy of ± 0.0001g. Theoretical density was calculated using rule of mixture. Porosity of prepared composite samples was calculated by using both theoretical and measured sintered densities.

2.4 Hardness

Hardness measurement of samples were performed using Rockwell hardness testing machine. The hardened steel ball of 1/8" was pressed against the specimen by applying 100 Kgf load and wait for 30 seconds before release the load. The B- scale reading in the dial indicate the hardness value. Perform the test by changing the location of indentor on the specimen and take 3-4 readings. The average value of all the readings is the hardness of the specimen which is noted as Rockwell hardness number (RHN).

2.5 Wear test

Two-body abrasive wear test was conducted by using a pin-on-disc machine. The surface of the sample (Φ10 × 8mm) glued to a pin of dimensions 7 mm diameter and 25 mm length, which comes in contact with water proof 220 grade Aluminum oxide (Al_2O_3) abrasive papers. The Al_2O_3 paper is glued on a steel disc by using a suitable adhesive. The abrading distance was taken as 200m. The abrasion wear test was conducted on a track of 90 mm diameter. The composite specimens were abraded against 220 grit Al_2O_3 papers at load of 9.81N, 14.72N and 19.62KN, and at a constant speed of 100rpm. Here the composite reinforced with 10 wt.% of Al_2O_3 sintered at four different sintering temperatures were taken for wear test. The difference between weight of specimens before and after wear was noted.

Fig-2. Schematic of Pin-on-disc wear test machine

2.6 Microstructural studies

Microstructural studies were conducted to determine the presence and distribution of reinforcement, and interfacial integrity between matrix and reinforcement. The scanning electron microscope is used to get the microstructure.

3. Results and discussion

3.1 Density and porosity measurement

Table -1: Theoretical and measured sintered densities

Sl. No	Composition	Theoretical density(ρ_{th}) gm/cm^3	Densities of sintered composites (gm/cm^3)			
			420 °C	450 °C	480 °C	510 °C
1	Al 6082	2.70	2.5483	2.5537	2.5712	2.5862
2	Al6082 + 5wt% Al_2O_3	2.7434	2.5294	2.5432	2.5536	2.5758
3	Al6082 + 10wt% Al_2O_3	2.7882	2.4967	2.5125	2.5192	2.5372
4	Al 6082 +15wt% Al_2O_3	2.8345	2.4499	2.4515	2.4674	2.4896

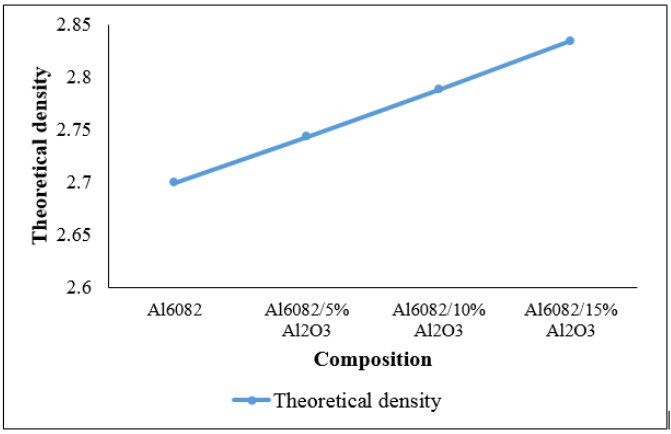

Fig-3: Theoretical density variation with composition of composite

Variation of theoretical densities with composition of composite are shown in Fig-3. Theoretical densities of composite increases with increase in aluminium oxide. The density of Al_2O_3 is 3.95g/cm^3 and aluminium density is 2.7 g/cm^3. Here reinforcement density is greater than aluminium alloy density hence with the addition of reinforcement the theoretical density of composite increases. Theoretical density is maximum for 15% addition of reinforcement compared to 5% reinforced composite.

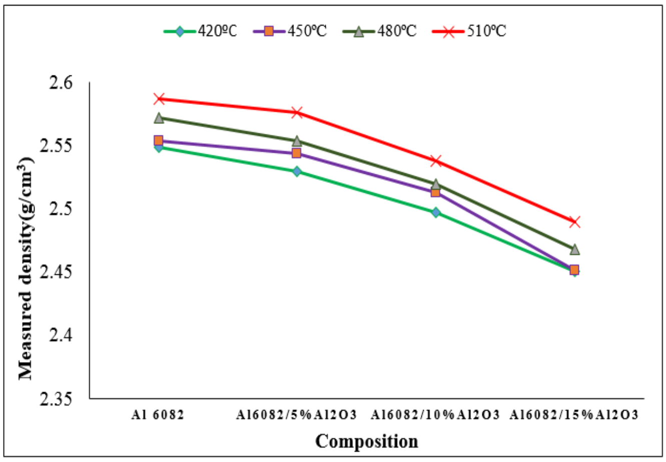

Fig-4: Variation of measured density with composition of composite

Theoretical density of composite is more than actual measured sintered density. Fig-4 show that the density of composite increases with increase in sintering temperatures. As temperature increases, bonding strength between particles also increases hence particles are densly packed in the composite so the density increases with sintering temperatures. As addition of reinforcement increases, the actual sintered density decreases. For pure Al6082, the sintered density is maximum but it is minimum for 15% of Al_2O_3. Theoretical density of Aluminium without reinforcement is 2.7 g/cm^3 but for 15% reinforced composite is 2.8345 g/cm^3. The maximum sintered density is observed in pure Aluminium sample which is sintered at 510°C. Aluminium oxides are hard particles hence these particles opposes the compaction of powder and they have high melting temperature compared to Aluminium 6082 alloy. The bonding between Aluminium and Alumina particles reduces because the samples are sintered at low temperatures compared to melting point of alumina hence sintered density decreases with increase in weight percentage of Alumina reinforcement.

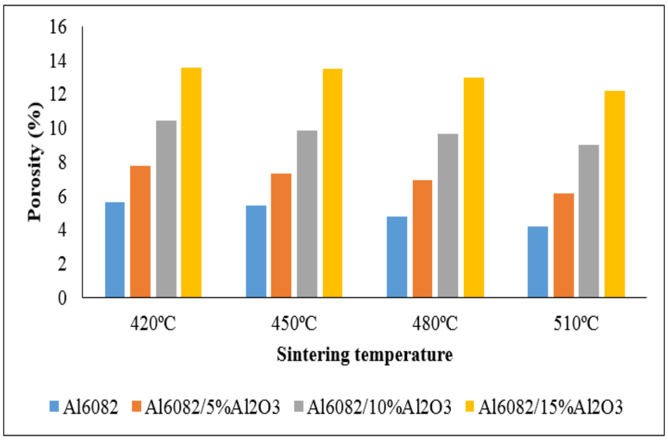

Fig-5: Variation of porosity with sintering temperature

From Fig-5 we can observe decreasing porosity with increase in sintering temperature, and also increasing porosity with increase in weight percentage of reinforcement. Air voids decreases with temperature hence porosity decreases. At 15% of Al_2O_3 the porosity is more because of weak bonding between reinforcement and matrix particles. Maximum porosity is obtained in a composite reinforced by 15% Al_2O_3 which is sintered at 420°C and minimum porosity is observed in a composite made of pure Al6082 alloy sintered at 510°C.

3.2 Hardness

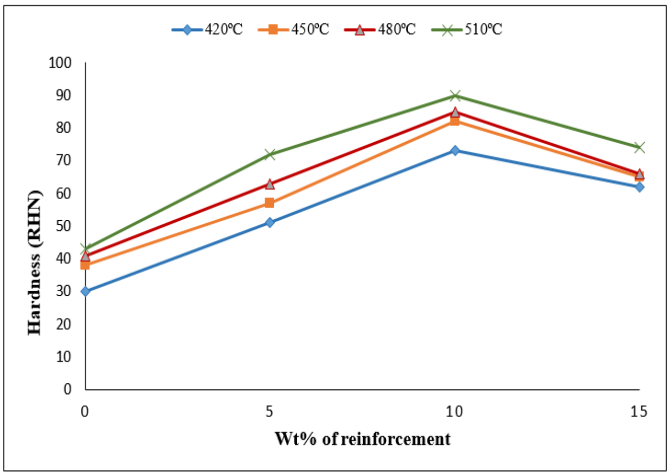

Fig-6: Comparison of Hardness number with weight percentage of reinforcement

Hardness value goes on increases with sintering temperatures. At 510°C, Hardness value is more compared to other sintering temperatures. Maximum hardness obtained is 90 RHN at 10% of reinforcement. Hardness is more for reinforced composites compared to unreinforced alloy. Fig-6 shows an increase in hardness upto 10% of Al_2O_3 but further increase in reinforcement decrease the hardness i.e. hardness value reduced for 15% of reinforcement. The reduction in hardness value is because of clustering of reinforcement particles in Al6082 matrix. The strength of composites reduces if reinforcement particles are not distributed uniformly throughout the matrix.

3.3 Two body abrasive wear test

The specimens containing 10% Al_2O_3 have high hardness, hence they were used to examine the wear rate. Here, abrading distance and speed were taken as 200m and 100rpm respectively for every trial of the experiment. The wear rate obtained for different loads is shown in Fig-7.

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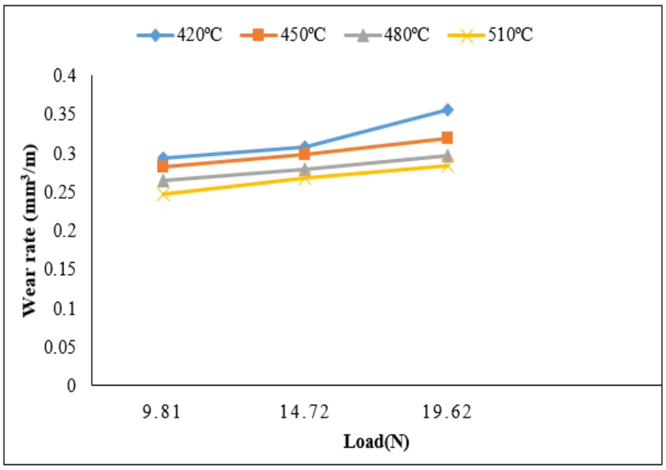
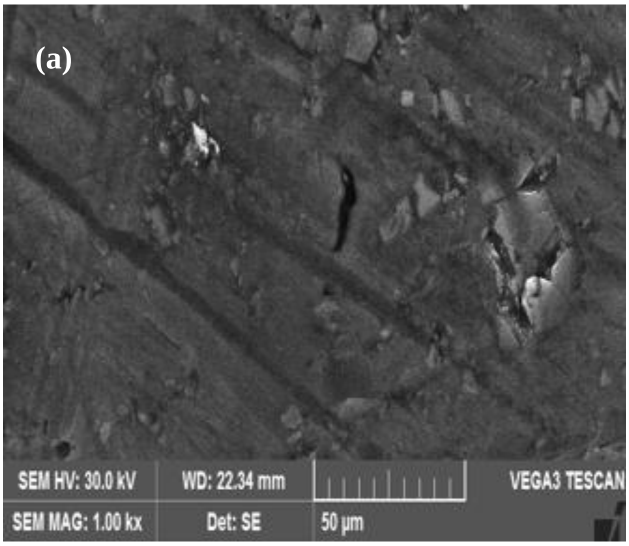


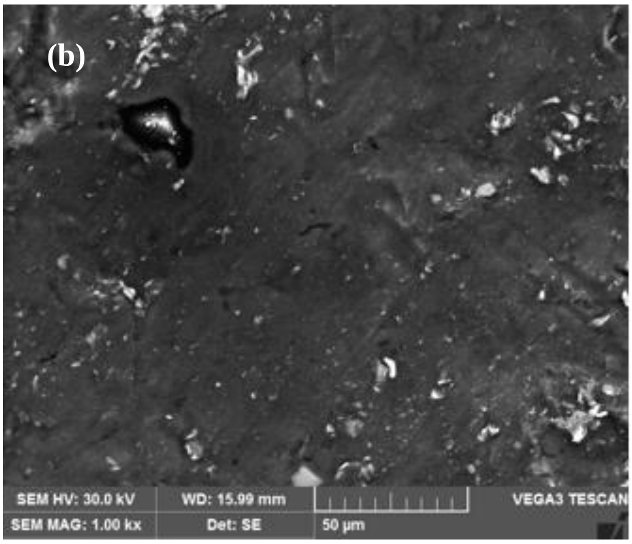
Fig-7: Variation of wear rate with load

The wear rate increased with increase in load and decreased with increase in sintering temperature. As load increases, the coefficient of friction increases and size of wear debris also increases, hence results in more wear loss at higher loads. The wear rate at a load of 19.62N was 21.5% higher than at 9.81N load for a sample sintered at 420 °C and wear rate is about 14.9% higher when a sample sintered at 510 °C is loaded by 19.62N compared to 9.81N . As sintering temperature increases, the wear rate decreases i.e. wear rate of sample sintered at 510 °C is 15.6% lesser than a specimen sintered at 420 °C under a constant load of 9.81N, similarly there is 20.2% reduction in wear rate from 420 °C to 510 °C temperature at 19.62N load.

3.4 Microstructure observation

Composite samples sintered at 510°C were used for microstructure observation. From SEM diagrams the distribution of aluminium oxide particles and porosity present in the material can be observed.





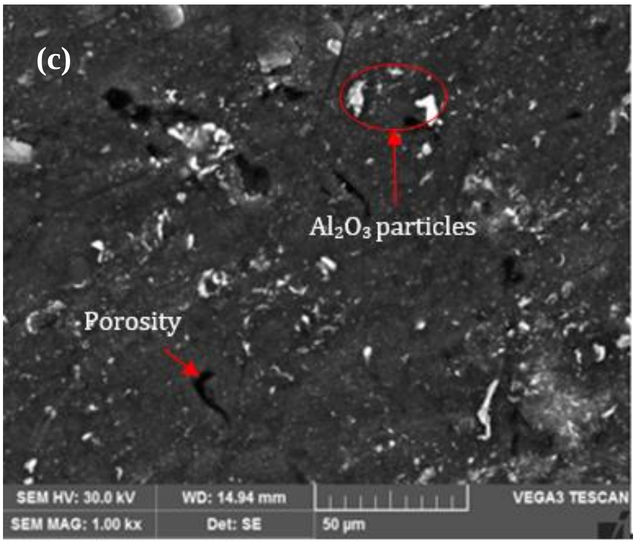


Fig-8: SEM Images of composites reinforced by (a) 5% Al_2O_3 (b) 10% Al_2O_3 and (c) 15% Al_2O_3

4. CONCLUSIONS

An attempt was made to investigate properties of AMCs reinforced with Aluminum oxide. Powder metallurgy (P/M) technique was employed for composite fabrication. Different weight fractions of Aluminum oxide were reinforced with Al6082. Sintering temperatures were taken as 420°C, 450 °C, 480°C and 510°C. The following are the inferences of this study:

1. Hardness test results revealed that the hardness of fabricated composite increased with an increase in reinforcement content from 0% to 10% and then decreased at 15% of reinforcement due to clustering of reinforcement particles. The hardness

of composite is more compared to the hardness of Al6082 alloy matrix.

2. Hardness test results also showed the increase in hardness of fabricated composite with increase in sintering temperature because of strong bonding between particles at high temperatures. Maximum hardness was observed in a sample reinforced by 10% Al_2O_3 and sintered at 510°C.
3. Density studies revealed that the theoretical density of composite increased with increase in reinforcement content and Sintered density decreased with increase in reinforcement. The aluminium oxide particles are very hard compared to aluminium 6082 particles hence these particles opposed the compaction of powder so the sintered density decreased with increase in aluminium oxide particles.
4. Porosity of composite increased with increase in weight percentage of reinforcement and it decreased with increase in sintering temperature. Porosity values are less at 510°C compared to porosity at 420°C for all combination of composite.
5. The results obtained in abrasive wear test showed that the wear rate decreased by 20.2% from 420 °C to 510 °C sintering temperatures at a constant load of 19.62N and similarly 15.6% reduction in wear rate at 9.81N load because of strong bonding between particles at higher temperatures.
6. The wear rate increased with increase in applied load because of increase in coefficient of friction and size of wear debris.

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