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Fabrication and Experimental Investigation on Mechanical Properties of Quartz Particulate Reinforced Aluminium Composite

T.R. Vijayaram[1,*]

Abstract

Composites are processed by adding a reinforcement phase in a base metal. The base material is known as a matrix and the constituent that is added is called reinforcement. The matrix acts as a support while the reinforcements attach themselves in their respective positions which results in the synthesis of a material which has different mechanical and thermal properties compared to their raw materials. Since aluminium is used as a matrix material, it is called Aluminium Metal Matrix Composite. Aluminium matrix composites are preferred due to its light weight and high strength ratio. Such composites have low density, very high abrasion resistance, higher thermal conductivity and superior specific modulus. It has widely applied in various fields particularly in the area of automotive, marine and aerospace industries. Such composites have very high corrosion resistance. These composites are used to produce aerospace parts and have excellent applications to manufacture components for jets, missiles, cutting tools and nuclear reactors. Different reinforcement phases like Aluminium Oxide, Silicon Carbide, Zircon, Boron Carbide are added in the Aluminium matrix to attain the required mechanical properties and tribological properties. But it depends on the distribution of second phase particles reinforced in the matrix. Different technologies are available to produce Aluminium based Metal Matrix Composites. In this research work, powder metallurgical method is used to produce the samples. Powder metallurgy is an efficient method to fabricate Aluminium Metal Matrix Composite. Uniform distribution of particulates in the matrix can be obtained by controlling the process parameters like temperature, sintering time, particle size, reinforcement phase type and weight fraction of the particle reinforced in the matrix. Quartz particulate is selected as the reinforcement phase and aluminium is chosen as the base matrix metal in this experimental investigation. This research paper discusses the powder metallurgical processing and tribological testing of Quartz particulate reinforced Aluminium Metal Matrix Composite.

Keywords: Processing, powder metallurgy, hardness, tribology, wear rate, friction coefficient

***Author for Correspondence**
T.R. Vijayaram
E-mail: vijayaram.mech@bharathuniv.ac.in

[1]Professor, Department of Mechanical Engineering, BIST, SOME, BIHER, Bharath Institute of Higher Education and Research, Selaiyur, Chennai, India

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INTRODUCTION

Composite materials can be defined as a mixture of two or more physically and chemically distinct parts that have been properly arranged to obtain certain desirable properties. A composite is made by adding a constituent to an existing base material. The base material is known as a matrix and the constituent that is added is called reinforcement [1–3]. Basically, the matrix acts as a support while the reinforcements attach themselves in their respective positions which results in the synthesis of a material which has different mechanical and thermal properties compared to their raw materials. A variety of metals and their alloys can be used as matrix materials. Some of them are aluminium and aluminium alloys, Titanium and Titanium alloys, Magnesium alloys, Copper, and Intermetallic compounds [1, 4–6]. Metal matrix composites consist of a metal or alloy as matrix and the reinforcements can be a particle, short fibre or whisker [1,8]. Many processes are available to fabricate metal matrix composites. For the most, these processes involve processing in the liquid and solid state. Among them, powder metallurgy, diffusion bonding, PVD and CVD techniques are available under solid state process [1–3]. The interface region in any composite is very important in estimating the ultimate properties of the composite [1, 7]. At the interface, a variety of discontinuities can occur. The important parameters that can show discontinuities in metal matrix composites at a ceramic reinforcement or metal matrix interface are bonding, moduli, crystallographic, chemical potential and coefficient of thermal expansion [1, 8]. Some bonding must exist between the ceramic particulate reinforcement and metal matrix for load transfer from matrix to particulate to occur. Mechanical keying between the two surfaces can lead to physical bonding [1, 9]. Ceramic or metal interfaces are generally formed at high temperatures. Diffusion and chemical reaction kinetics are faster at elevated temperatures [1, 9, 10]. In this research work, powder metallurgy techniques are applied to process the test samples.

EXPERIMENTAL

Quartz Particulate Reinforced Aluminum Matrix Composite Processing Technique

The metal matrix composite processed in this research work is aluminum metal matrix reinforced with quartz particulate. Both components were obtained in powder form and the method used to produce the composites was powder metallurgy technique. This technique involves the steps: mixing the powders in the required ratio of matrix to reinforcement, blending, compacting and sintering the blended mixture in a furnace. This work deals with the study on the tribological behavior of aluminum quartz metal matrix composite of different composition of aluminum to quartz mixtures were required. For the purpose, five sets of samples were to be prepared by standard powder metallurgical processing method, each of them with different percentages of quartz reinforcement and it is shown below in Table 1.

Table 1. Percentage composition of aluminum to quartz.

Percentage of Aluminium	Percentage of Quartz
95%	5%
90%	10%
85%	15%
a80%	20%
75%	25%

The percentage of the aluminum and quartz in each mixture was determined by a simple process of weighing the powders using a digital scale. The next step was to mix each mixture to get an even distribution of the quartz in aluminum. Since both powders are in fine form it is important that the two be mixed in a proper manner. Blending is an important step in the making of the test samples. To blend the mixture, a ball milling machine was used. The powder was added to the container, placed on the rotating shafts of the machine. Speed of the machine was set to 40 rpm and mixing time was set for 15 minutes. After a duration of 15 minutes, the machine was stopped and the now homogenous mixture was removed from the machine. The mixtures were then transferred to their original containers. Compaction is the next step where the shape of the test samples take form. By containing the mixture in a preformed die and applying a high enough pressure, the powder takes the form of the die and holds the shape for the next step. In this experiment, the die that was used is cylindrical shape with a diameter of 10 mm. The compaction machine used was a manual hydraulic press. The compaction pressure set for the production of the composites in this experiment is 320 MPa. This translates roughly to 1 tonne of force in the hydraulic press. After keeping the load applied for 5 minutes the sample was removed from the die. Sintering is done to bind the quartz particles to the aluminum matrix. Sintering operation induces the interaction between the matrix and reinforcement to create a perfect composite. A sintering furnace was used to sinter the samples in this case. Since the melting point of aluminum is 660 degree Centigrade, the sintering temperature for the process is 550 C, at a heating rate of 10 degree C/ minute. Once the desired temperature was reached, the temperature was kept steady for a duration of 1 hour. This was to ensure that the heat would be uniformly distributed to all the samples.

All the samples were processed using the constant parameters such as mixing speed, compacting pressure and sintering temperature. This is because the aim of this experiment is to test the tribological aspects of the composite and to find a correlation between the variations in quartz percentages to the respective tribological properties. Although the samples were prepared using the same compaction die, due to the fine nature of the powder, it was difficult to use the exact amount in the die chamber each time before compacting. For this reason, although all the samples have the same diameter, not all of them have the same thickness, the mass of all the samples is not constant. This would not be a problem however, since the wear testing would only consider the mass lost during the test.

Hardness Testing

The Rockwell hardness machine utilized in this experiment uses a conical diamond tip with a diameter of 1.5875 mm. Te load applied to the surface of the test material was 980.7 N. To operate the instrument, the test sample was first grinded and polished using abrasive paper. This is to remove any foreign matter or oxidation on the surface. Table 2 shown below highlights the measured hardness values of the samples.

Table 2. Hardness data of the samples.

Point	**Percentage Variation of Quartz**				
	5%	***10%***	***15%***	***20%***	***25%***
1	57	81	83	64	53
2	65	85	88	66	52
3	68	86	82	80	58
4	61	84	87	87	67
Average	62.75	84	85	74.25	57.5

Tribological Testing of Samples

Standard pin on disc equipment was used to perform the tribological studies on the processed samples. The pin was measured as 51 mm and the normal load applied was 40 N. The sliding distance was set the same in all five sets of tests. Therefore the time taken for a sliding distance was calculated as 149 seconds. The machine has a strain gauge which provides a voltage reading during the course of the testing. These readings correspond to the frictional force being applied between the test specimen and the disc. Prior to the start of the experiment, a calibration chart was done by adding weights to the apparatus attached to the strain gauge. The corresponding voltmeter reading was recorded down, thereby giving a relationship between the friction force in Newtons and the strain in mV. One reason for fixing the sliding distance without varying it is that since the test samples are very small, the contact area between the sample and the disc is also very small. Due to this, there is a high amount of stress occurring at the contact point. Although the test samples are reinforced, the brittleness of the material may have increased. Therefore, it was decided that only the wear rate for one sliding distance was to be measured to avoid any possibility of the material being broken. This was also done to guard the disc from the pin holder in any case the two come in to contact unexpectedly due to the test sample being worn out completely.

RESULTS AND DISCUSSION

The results of the hardness test and wear test will be presented and discussed in this section. From these experiments, one can observe and correlate the variation of quartz in the composition to the respective parameters such as wear, friction, and hardness.

Hardness test results

The hardness was measured at four points on the surface of each test sample and it is shown below in Table 3.

Table 3. Hardness data of the samples.

Point	Percentage Variation of Quartz				
	5%	*10%*	*15%*	*20%*	*25%*
1	57	81	83	64	53
2	65	85	88	66	52
3	68	86	82	80	58
4	61	84	87	87	67
Average	62.75	84	85	74.25	57.5

The scale used was Rockwell 'B scale', with units HRB. As a reference, the hardness of aluminum was found to be 59 HRB. Figure 1 shown below explains the change in hardness over different quartz percentages in the aluminum matrix.

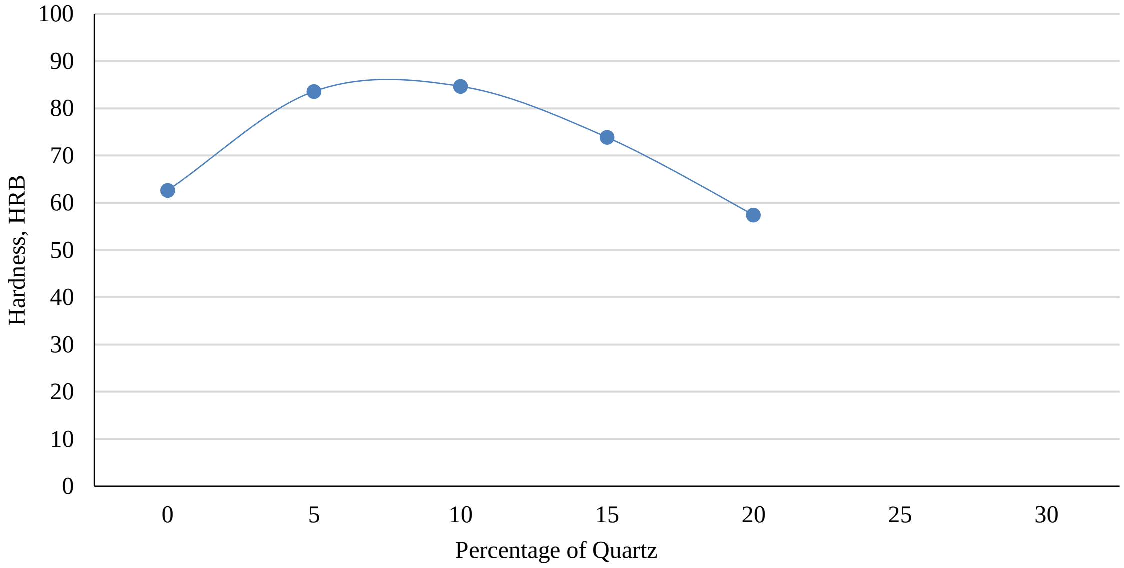

Figure 1. Hardness Vs Different quartz particulate Addition in aluminum matrix.

Figure 1 shown above depicts the variation of hardness with different quartz particulate addition in aluminium matrix. The main and most important observation is that the hardness of aluminum has been significantly decreased with the addition of the reinforcement. Pure aluminum has a hardness of 59 HRB and the hardness of quartz is 87 HRB. Therefore, by adding quartz as reinforcement we would expect to see the hardness of aluminum enhanced as the results from the Rockwell hardness test suggest. All of the test samples show a different hardness value in the range of 57–87 HRB except for the sample with 25% quartz. The second point that we can observe is that the hardness does not increase in a linear manner. One might assume that by adding more reinforcement to the matrix, the hardness will increase accordingly. However, the changes in hardness observed in this experiment may be due to a saturation effect caused by the reinforcement particles interacting with each other leading to the segregation of the particles. In other words, after a certain percentage of quartz is added, the aluminum matrix does not take any further particles as reinforcement and the remaining quartz particles are seen as excess particles. From the results obtained, the highest hardness recorded occurs at 15% of quartz. Therefore, we can consider this percentage as the optimum amount that needs to be added to gain an increase in hardness.

Tribology of Test Samples

Before the tests were carried out, calibration was done on the strain gauge relating the bending distance of the arm to the friction force developed on the pin. Figure-2 shown below explains the friction force as a function of bending distance.

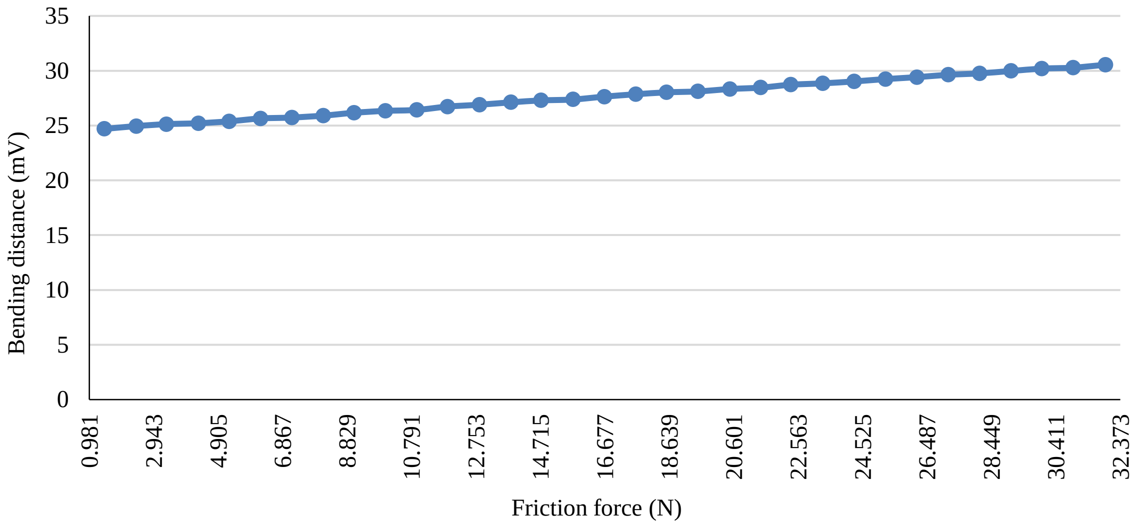

Figure 2. Friction force Vs bending distance (mv)

The wear test data is shown in Table 4 and the variation of wear rate with varying percentage addition of quartz in the matrix is shown in Figure 3.

Table 4. Wear test results.

Percentage of Quartz	Mass before Testing, m, (g)	Mass before Testing. m, (g)	Change in Mass, Am (g)	Voltmeter Reading (mV)	Wear Rate $\frac{\Delta m}{dxw}$
5%	1.1230	0.978	0.145	30.4	1.8125×10^{-8}
10%	0.940	0.797	0.143	29.2	1.7875×10^{-8}
15%	1.289	1.164	0.125	27.3	1.5625×10^{-8}
20%	1.198	1.136	0.062	27.5	7.75×10^{-9}
25%	1.229q	1.173	0.0056	27.5	7.0×10^{-10}

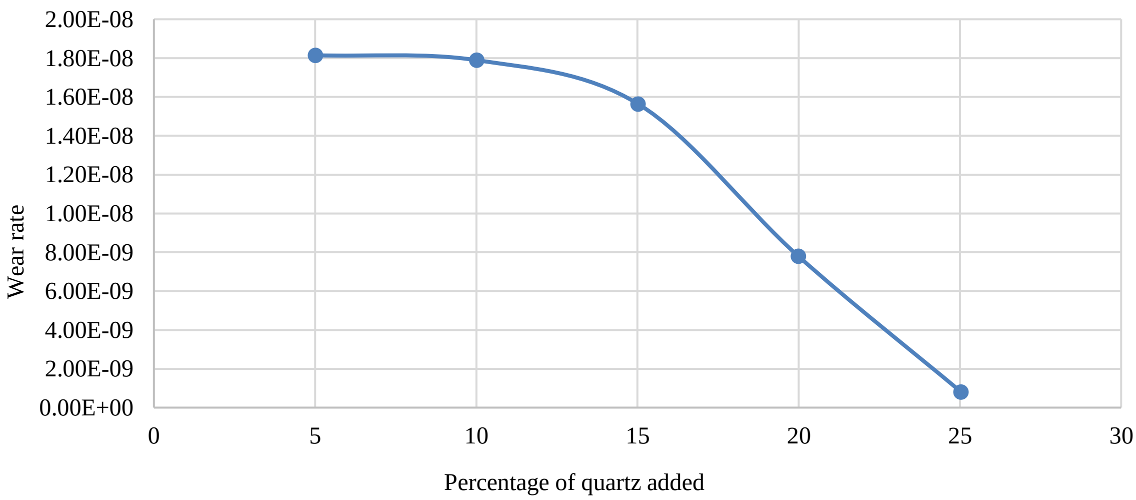

Figure 3. Wear rate Vs varying percentage of quartz addition in aluminum.

From the wear rate data, it is clear that the change in percentage of quartz added had affected the loss of material in the wear test. The change of mass drops considerably when the percentage of quartz increases as one would expect. This enforces the notion that when a ductile metal is enforced with ceramic particles, the wear resistance will increase. The type of wear observed in this experiment is mainly due to abrasive and adhesive wear due to the difference in hardness of the test sample and the disc. In theory however, since the hardness of the material was found to decrease after 15% of quartz, it would be expected to show the wear increasing. There might have been other factors which have prevented the wear in the last two test samples, such as there is a chance that they may have been compacted with less micro defects allowing them to retain more of their material, or perhaps it could have been caused by a change in the real contact area. As noted before, the test samples prepared in this experiment are very small and it is very difficult to observe whether the surface was in even contact with the disc when the test was carried out. In this respect, there is a chance that the last two samples might have had a different contact area with the disc, thereby less wear being produced.

Table 5 shown below details the variation in the friction coefficient values with varying quartz content in the matrix and the variation of friction coefficient with varying quartz percentage is shown in Figure 4.

Table 5. Friction coefficient Vs Quartz addition percentage in aluminum.

Percentage of Quartz	Voltmeter Reading, (mV)	Friction force, $F_{f(N)}$	Friction Coefficient $\mu = \frac{Ff}{W}$
5%	30.4	31.274	0.78185
10%	29.2	24.785	0.61963
15%	27.3	15.2055	0.38014
20%	27.5	15.696	0.3924
25%	27.5	15.696	0.3924

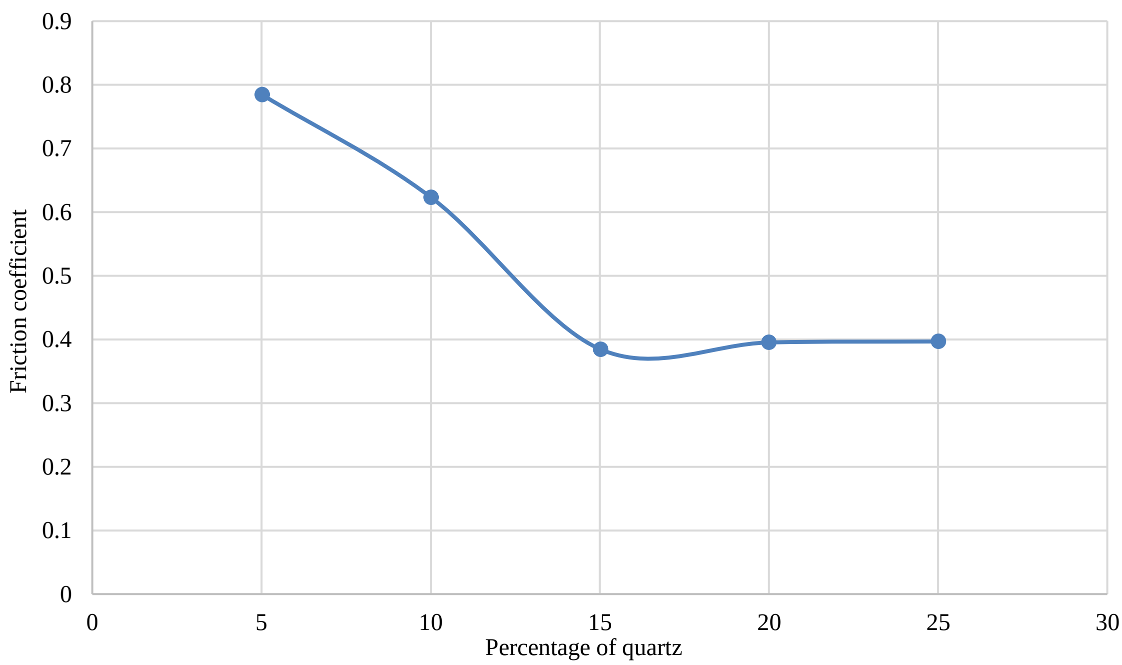

Figure 4. Friction coefficient Vs Quartz percentage additions in aluminum.

The friction coefficient is observed to be decreasing as the percentage of quartz increases. However, at 15% the test samples show a minimum amount of friction coefficient while the following two values are the same with only a slight difference from the value at 15%. Taking in to account the type of method we have used to calculate the friction coefficient, i.e. using the voltmeter to get the strain on the machine arm, it would not be wrong to suggest that these three values (at 15%, 20% and 25%) are the same. Although the voltmeter gives an accurate reading at the instant the strain is measured, the readings tend to fluctuate and the measurements in this experiment are the average of the fluctuations observed during the data collection. For this reason, we can come to the conclusion that the friction coefficient drops down to approximately 0.38 at 15% quartz and from this point onwards the friction coefficient is not affected anymore. This supports the idea from the hardness test that 15% is the ideal amount of quartz to be added and any further addition of quartz does not directly benefit the aluminum.

CONCLUSION

Powder metallurgy is the best and an effective method to produce quartz particulate reinforced aluminum metal matrix composite. From the tribological tests, it was found that the hardness, wear rate and friction coefficient is indeed affected by the adding quartz as a reinforcement material to aluminum matrix. From the hardness and friction tests, the ideal percentage of quartz to be added is 15%, since beyond this point, any further addition did not significantly improve the hardness or friction properties of the material. The wear rate was significantly improved with increasing quartz percentage. However, the tests can be further improved by using test samples with more mass and increasing the sliding distance.

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