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Metallurgy, Tribology and Metallography of Quartz Particulate Reinforced Aluminium Metal Matrix Composite

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. Composites may occur in natural forms such as wood, bone, or in modern times, we can see many man-made materials ranging from concrete to fibre glass. In both cases, 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. 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.

Experimental

Quartz Particulate Reinforced Aluminium Metal Matrix Composite Preparation

The composite used in this experiment is aluminium metal matrix reinforced with quartz particulate. Both materials were obtained in powder form and the method used to make the composites was powder metallurgy technique. This is a technique which involves mixing the powders in the required ratio of matrix to reinforcement, blending, compacting and sintering the blended mixture in a furnace. Since this work deals with observing the tribological behavior of aluminium quartz metal matrix composite, different composition of aluminium to quartz mixtures were required. This would give an insight of how the composite properties change with different matrix to reinforcement ratio. 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 3.1.

The percentage of the aluminium and quartz in each mixture was determined by a simple process of weighing the powders using a digital scale. For example if the total weigh of the mixture is suppose to be 10 grams and the sample number that is being prepared is number 1, the mixture would consist of 9.5 grams aluminium with 0.5 grams of quartz.

Table 3.1 : Percentage Composition of Aluminium to Quartz

Percentage of Aluminium	Percentage of Quartz
95%	5%
90%	10%
85%	15%
80%	20%
75%	25%

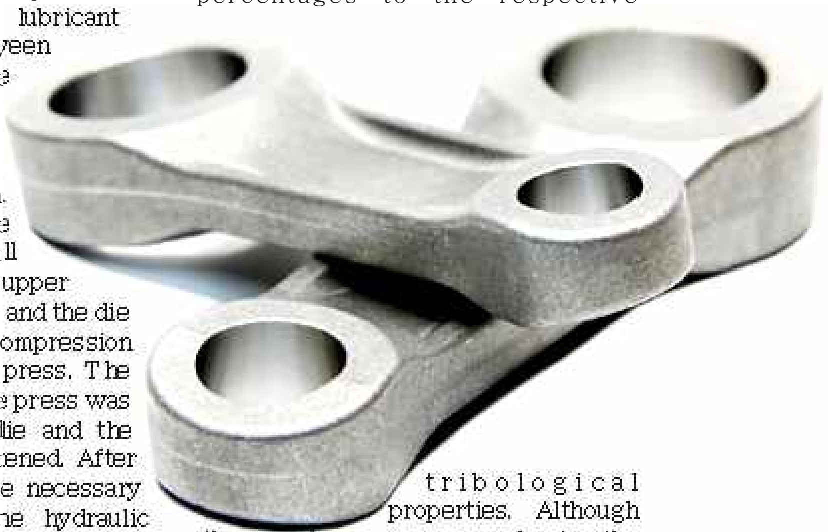
After all the samples have been weighed accordingly the next step involved was to mix or blend each mixture to get an even distribution of the quartz in aluminium. Since both powders are in a very fine form it is important that the two be mixed in a proper manner. blending is an important step in the making of the test samples. To blend the mixture, a ball milling machine was used. The machine can provide the means of grinding and blending mixtures for all types of materials used in powder metallurgy. However, since the powders used in this experiment are of a very fine nature, there was no grinding involved. 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 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 die was cleaned using a piece of cloth prior to adding the mixture. This was to ensue that the die was free from any impurities and to avoid any addition of foreign matter. The die was placed in its holding apparatus which is magnetic adapter that provides the base for the die. A lubricant film was sprayed into the hollow chamber of the die to make it easier to remove the material from the die once it has been compressed. In addition to this, the lubricant serves as a barrier between the powder and the die surface preventing any wear. The lower punch of the die was inserted followed by the addition of the mixture in to the die. Once the die is full with the mixture the upper punch was placed on top and the die was placed in the compression chamber of the manual press. The compression shaft of the press was tightened against the die and the hydraulic jack was tightened. After this, using the lever, the necessary force was applied. The hydraulic press used in this experiment is calibrated in tonnes. 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 aluminium matrix. Even though the compaction gives us a solid, it can be easily broken apart by applying a moderate force. Therefore, exposing the samples to the correct heating temperature lets the mixture come together in a true solid form. We can say that this is the most important part of the powder metallurgy process since it directly involves the interaction between the matrix and reinforcement to create that perfect composite. The chamber furnace was used to sinter the samples in this case. Since the melting point of aluminium is 660 °C, the sintering temperature chosen for the process is 550 °C (83% of the melting point), at a heating rate of 10 °C/ minute. Once the desired temperature was reached, the temperature was kept steady for 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 ergo 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 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 guage 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 guage. 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 Discussions

The results of the hardness test; metallography and wear test will be presented and discussed in this section. By using the results from these experiments, we 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 4.1. The scale used was Rockwell 'B scale', with units HRB. As a reference, the hardness of aluminium was found to be 59 HRB. Figure 4.1 shows the change in hardness over different quartz percentages in the aluminium matrix.

- The main and most important observation is that the hardness of aluminium has been significantly decreased with the addition of the reinforcement. Pure aluminium 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 aluminium 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 aluminium 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.

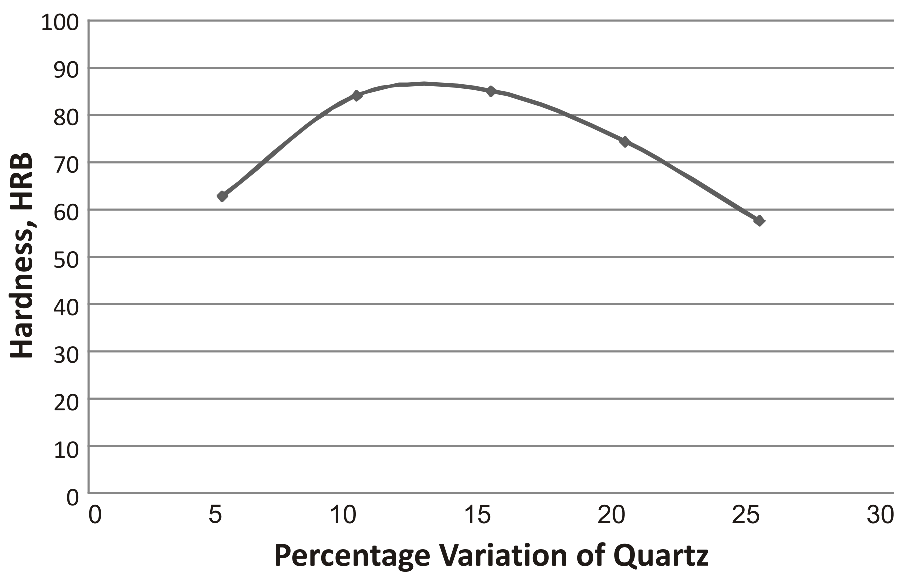
Metallography

The micrographs 4.2–4.8 shown below confirm the presence of quartz particles and how they have been distributed among the aluminium. The dark particles that we see in the micrograph are quartz particles while the shinier yellowish parts are aluminium. All the micrographs show a relatively even distribution and it can be observed that the number of quartz particles gradually increase. Particle distribution is relatively uniform, with the exception of 20% quartz content, where the micrograph shows a high amount of segregation compared to 25% quartz. There are several reasons

Table 4.1 : Hardness Data

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

Fig. 4.1 : Change In Hardness Over the Different Quartz Percentages the Data Collected Show Two Main Points for Discussion.

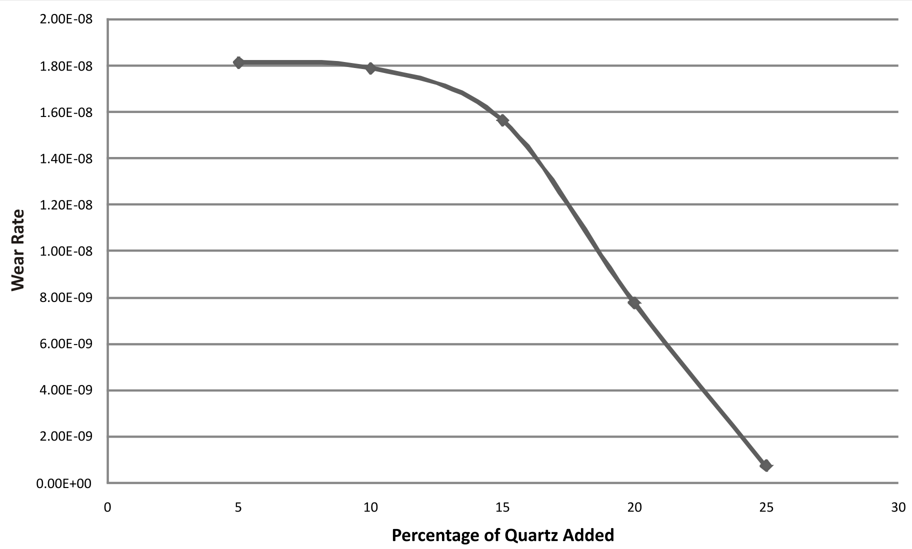


for this. The particles may have interacted with each other forming a cluster or an oxidation might have occurred during the sintering operation. The 20% quartz sample shows some degree of deformation too. This may be due to the variation in the pressure during the compaction of the samples in the powder metallurgy process.

Table 4.3 : Wear Test Results

Percentage of Quartz	Mass before Testing, m_1 (g)	Mass before Testing, m_2 (g)	Change in Mass, Δm (g)	Voltmeter Reading (mV)	Wear Rate $\frac{\Delta m}{d \times W}$
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}

Fig. 4.13 : Wear Rate with Varying Percentage of Quartz



Tribology

Before the tests were carried out, calibration was done on the strain gage relating the bending distance of the arm to the friction force developed on the pin. Figure-4.12 shows the friction force as a function of bending distance.

The wear test results are shown in Table 4.3 and the variation of wear rate with varying percentage addition of quartz in the matrix is shown in Figure 4.13. By observing the results of wear rate, it is very clear how 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.

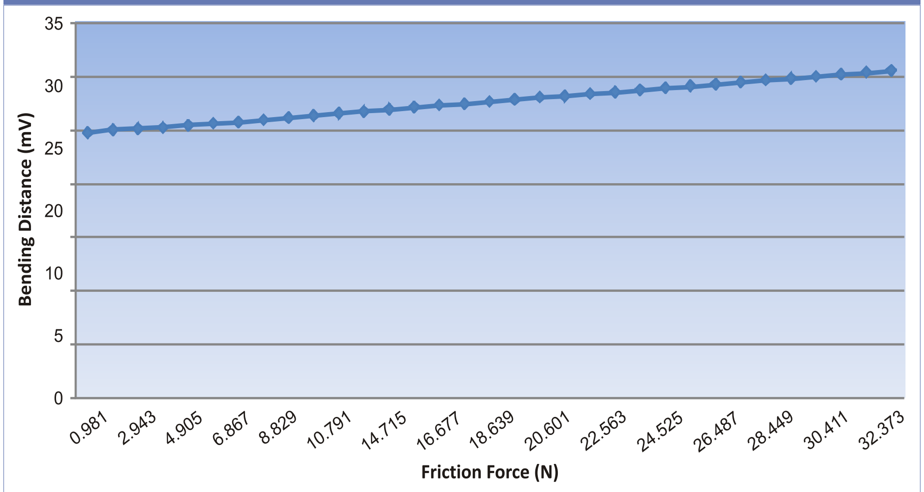
In theory however, since the hardness of the material was found to decrease after 15% of quartz, it would be expected to show the wear increasing. There might have been other factors which have prevented the wear in the last two test samples, such as there is a chance that they may have been compacted with less micro defect 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-4.5 shows 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 4.14. 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

Fig 4.12 : Friction Force as a Function of Bending Distance (mv)

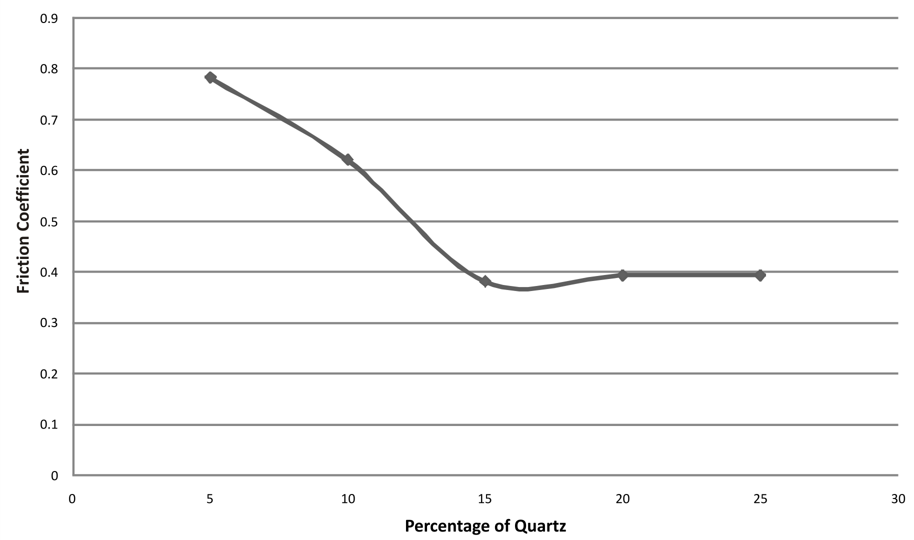


voltmeter gives an accurate reading at the instant the strain is measured, the readings tend to fluctuate and the measurements in this experiment are the average of the fluctuations observed during the data collection. For this reason, we can come to the reinforcement particles were reasonably low. From 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 aluminium matrix. From the hardness and friction

Table 4.5 : Friction Coefficient with Varying Quartz Content

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

Fig. 4.14 : Friction Coefficient with Varying Quartz Percentage



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 aluminium.

Conclusion

The first conclusion to determine from this experiment is that the method used to manufacture the samples, i.e. powder metallurgy is an effective method to produce metal matrix composites. From the results of the metallography test it was concluded The aluminium and quartz powders were very finely distributed in the test samples and segregation of tests we can conclusively say that 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. The reason for not being able to practice this during the course of this work is due to many unexpected constraints that were faced from the start to the end of the research.

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.