Mechanical Properties and Wear Characteristics Al-ZrO2-SiCp and Graphite Hybrid Metal Matrix Composites

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Abstract: Development of Aluminum Metal Matrix Composites (AMMCs) has been one of the major requirements in engineering applications due to their excellent mechanical properties, light weight and high strength. In the present investigation, Stir casting technique has been used for fabrication of composites, taking Aluminum as parent metal, Silicon Carbide (SiCp) of 7 vol. % of 220 mesh size and 1.75 vol. % of graphite as reinforcements. The Zirconia content was varied as 2.75, 4.5 and 6 vol. % to fabricate three different types of hybrid composites. The tensile strength and hardness were measured in UTM and Vickers hardness tester respectively and the wear characteristics were studied in a pin on disc friction monitor under dry sliding condition against steel counter face. The tensile strength was found to be 90 MPa, 120 MPa, 130 MPa and hardness 80.25 VHN, 103.22 VHN, 103.77 VHN for 2.75, 4.5 and 6 vol. % of Zirconia respectively. From the above investigation, it is recommended that composition with Al, 7 % - SiCp, 1.75 % -Gr and 6 vol %-ZrO2 showed better mechanical properties i.e. high tensile strength (130MPa) and reasonably good hardness (103.77 VHN). The composite with Al, 7 % - SiCp, 1.75 % -Gr and 6 % -ZrO2 is good for short run frictional application and the composite with Al, 7 % - SiCp, 1.75 % -Gr and 4.5 % -ZrO2 may be used for long run frictional application after testing.

Key words: Composites of Al-SiCp-Gr-ZrO2, Strength, Hardness and Wear

1. Introduction

Available monolithic materials have limitations with respect to achievable combinations of strength, stiffness, and density. In order to overcome these shortages and to meet the increasing engineering demands of modern technology, metal matrix composites are gaining importance. The areas of applications of composite materials are growing rapidly and have even found new markets [1-3]. The current objective is to make them durable in tough conditions to replace other materials. Basically, Composites are the combination of two or more dissimilar materials (different in composition, characteristics and sometimes inform) which exist in different phases and are insoluble in each other. One or more discontinuous phases are, therefore, bound in a continuous phase to form a composite. Among the phases one is the matrix phase which contains the reinforcements in order to improve its own properties. The aluminium composites are widely used in the fields of Automotive Industry (Body, Brake pads, Drive shafts, Fuel tanks, Hoods, Spoiler, clutches), Aerospace (Nose, doors, struts, fairings, out board and inboard flaps etc), Sports (Tennis, Bicycles, Badminton), Constructions, marine industries and biomedical applications etc.[4-6]. Therefore in the present investigation the aluminium matrix reinforced with different volume % of SiCp, Graphite and Zirconia has been considered. These reinforcement materials have been chosen because of their better mechanical as well as tribological properties. Zirconia is one of the important ceramic which is used as a biomaterial that has a bright future because of its high mechanical strength and fracture toughness. Graphite and Silicon carbide have low densities. Silicon carbide has high strength, high hardness and excellent thermal shock resistance. Both graphite and Zirconia have high wear.
resistance also [7-8]. In this investigation the mechanical as well as wear behaviour of these hybrid composites are evaluated in order to distinguish the best material for suitable engineering applications.

2. Experimental Details

In the present investigation Aluminium is considered as the matrix material and Zirconia, Silicon Carbide and Graphite were used as reinforcement materials. All the reinforcements used are in particulate form. Graphite and Silicon Carbide used are of 71 µm and Zirconia particles are of size 40µm at an average. The amount of reinforcement particle Silicon Carbide and Graphite are kept constant i.e. 7 and 1.75 vol. % respectively and the vol. % of Zirconia is varied as 2.75, 4.5 and 6 vol. % respectively.

Ingots of pure aluminium (900gms) are first melted in a muffle furnace in clay crucible at 850ºC and after that the pre heated reinforcements are added to the liquid aluminium and the temperature is maintained for 20 minutes. The mixture is poured into a sand mould and left for 24hrs at room temperature to solidify in order to get the desired castings.

2.1 Characterization

2.1.1 Tensile Test

Tensile test samples (Fig.1) have been prepared by machining the cast samples to the desired sizes as per ASTM E8 standard. The tensile strength of the specimens was evaluated in the Universal Testing Machine (Fig-2) of model BSUT- 40-JD and having capacity 400kN.

2.1.2 Hardness test

For the hardness test three specimen are prepared (shown in fig.3 ) with varying vol% of ZrO₂ (2.75, 4.5 and 6 vol. %) and the test was conducted in a micro vicker’s hardness testing machine by considering a load of 1 kgf and dwell time of 15 sec. in the test the The square based diamond pyramid was used as indenter. The hardness values were measured in three locations over the sample and the average length of the diagonals of the indentation were calculated. Then the Vickers Hardness Number (VHN) of the samples was obtained.
Fig. 3 Specimens used for hardness testing

2.1.3 Wear Testing

The wear test of the specimens was carried out in the dry sliding condition in a pin-on-disc tester (Fig.5). The short run wear tests were carried out to find out the coefficient of friction and wear behaviour. The wear tests were conducted in two phases, in the first phase the pins (Fig.4) were made to slide on the steel disc at 1, 1.5, 2 and 2.5 m/s respectively considering a constant load 5 Kg and constant time 4 min and in the second phase the pins were made to slide on the pins for 1, 2, 3 and 4 minutes respectively considering a constant load 5 Kg and constant speed 2 m/s.

For short run wear tests the pins of the composites were prepared by machining the cast samples to 10 mm in diameter and 32 mm length (Fig.4).

3. Results and discussion

3.1 Tensile Test

The results obtained from the tensile test were represented in the graphical form below (Fig.6). From the result it is clear that the composite consisting of 2.75 vol.% of Zirconia shows highest tensile strength (132.008 MPa) whereas the composite with 4.5 vol.% of Zirconia shows lower tensile strength (91.263 MPa).

For short run wear tests the pins of the composites were prepared by machining the cast samples to 10 mm in diameter and 32 mm length (Fig.4).

Fig- 6 Tensile Stress Strain curve of the composites Fig.7 Hardness of the composites
3.2 Hardness test results

The hardness of the composites obtained from the micro Vickers hardness tester are represented in a bar graph as shown in Fig.7. From the results it is observed that the composite with 6 vol.% Zirconia is the hardest among the three and the hardness value is 103.77 and the composite with 2.75 vol.% Zirconium exhibits least hardness i.e 80.25 in the Vickers scale.

3.3 Analysis of wear test results

3.3.1 Co-efficient of friction (COF)

The C.O.F test of the composites is under the short run test category. In this test the composites are allowed to slide for a constant time period 1 minute with varying the load from 1 Kg to 4 Kg with an increment of 1. The coefficient of friction of the composites obtained at different load conditions are represented in Table 1

| Load(Kg) | Specimen-1 2.75% ZrO₂ | Specimen-2 4.5% ZrO₂ | Specimen-3 6% ZrO₂ |
|----------|------------------------|-----------------------|---------------------|
| 1        | 0.67                   | 0.385                 | 0.49                |
| 2        | 0.48                   | 0.32                  | 0.524               |
| 3        | 0.38                   | 0.28                  | 0.53                |
| 4        | 0.26                   | 0.279                 | 0.47                |

The graphical representation of the above data is shown in Fig.8. From the obtained data it is seen that the C.O.F of specimen-1 and 2 decreases with the increase in load whereas the C.O.F of specimen-3 first increases and then decreases with the increase in load.

![Fig.8 Co-efficient of friction vs. load](image1)

![Fig.9 wear vs. sliding speed](image2)

3.3.2 Wear vs. Sliding speed

The test is carried out by changing the sliding speed of the composites. The other parameters like time (4 minute) and load (5 Kg) are kept constant. The different sliding speeds considered are 1, 1.5, 2 and 2.5 m/s respectively. The wear data obtained with respect to the sliding speed of the composites are represented in Table 2.
Tab.2 Wear of composites with respect to sliding speed

| Sliding speed (m/s) | Wear (micron) |
|--------------------|---------------|
| Specimen-1         | Specimen-2    | Specimen-3    |
| 2.75% ZrO2         | 4.5% ZrO2     | 6% ZrO2       |
| 1                  | 38.769        | 75.126        | 152.858       |
| 1.5                | 36.807        | 68.894        | 136.102       |
| 2                  | 153.007       | 53.472        | 229.471       |
| 2.5                | 61.843        | 30.203        | 368.644       |

From the obtained data we can conclude that the wear of Specimen-1 and 3 first decreases and then increases with the increase in sliding speed whereas the wear of specimen-2 decreases with the increase in sliding speed. However, the wear of the specimen-2 is comparatively lesser than the other two which is shown in fig.9.

3.3.3 Wear vs. Time

The time of sliding of the specimen were varied from 1 minute to 4 minute. The other parameters like sliding speed (2m/s) and load (5Kg) are kept constant. The wear data obtained with respect to time of sliding of the composites are represented in Table 3.

Table 3. Wear of composite with respect to time

| Time in minute | Wear (micron) |
|----------------|---------------|
| Specimen-1     | Specimen-2    | Specimen-3    |
| 2.75% ZrO2     | 4.5% ZrO2     | 6% ZrO2       |
| 1              | 13            | 24            | 17            |
| 2              | 15            | 18            | 28            |
| 3              | 17            | 23            | 35            |
| 4              | 34            | 28            | 48            |

Fig.10 wear vs. time

From the above obtained data and the graph it is clear that in each case the wear increases with the increase in time, however the wear of specimen -3 is higher than the other two. Probably the wear will stabilize after running for a longer period.
4. Conclusions

From the present investigations the conclusions obtained are the followings:

1) The composite with 2.75 vol. % of Zirconia shows highest tensile strength (132.008 MPa) whereas the composite with 4.5vol. % of Zirconia shows lowest tensile strength (91.263MPa).

2) Addition of Zirconia to the composite increases the hardness of the composite. The highest hardness value obtained is 103.77 in Vickers scale which is obtained from the composite of 6 vol. % Zirconia.

3) The specimen-3 shows better C.O.F in all load conditions for which this may be used for frictional applications more effectively than the others.

4) Specimen-3 also exhibits highest wear with the increase in both the sliding speed as well as the time whereas the wear of specimen-2 changes within a certain range without fluctuating. Thus the specimen-2 can be proposed as a better composite than the other two for short run wear applications.

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