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Tribological Behavior of A-356/SIC/B_4C Nanoparticles

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Abstract

Objectives: The main objective of this study was to analyze the tribological behavior of aluminum alloy reinforced with SiC/B_4C nano particles. **Methods:** The composites were fabricated by mechanical and ultrasonic stirring and the reinforced aluminum composites were casted into cylindrical pins. The wear properties of the samples were then examined by using a pin-on-disc type wear testing machine under dry sliding condition and the results were tabulated. The micrograph study was also conducted to examine the agglomerates and porosity on the surface of the composites. **Findings:** The results proved that the aluminum composites with nano reinforcements have better wear resistance and lower coefficient of friction as compared with non-reinforced aluminum. The micrograph study revealed that the agglomerates and porosity on the surface of the composites were reduced by the use of ultrasonic stirring and cavitation processes. **Application:** The composites fabricated could be used in wear resistance applications and in elevated temperature applications.

Keywords: Aluminium, Composites, Nanoparticles, Reinforcement, Tribological Behaviour, Wear

1. Introduction

Composite materials are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. This overcomes the shortcoming of each of the constituents. This combination results in a newly synthesized material that has unique and useful properties for a spectrum of structural applications.

Composite materials have better endurance to wear, fatigue, fracture, heat and abrasion. So, in recent years new types of composites have been developed and used almost in all industries.

Wear is removal of material from a solid surface by the sliding action of another solid and is caused by friction, fatigue or vibration[1]. Wear causes progressive damage involving material loss and occurs on the surface of the component due to sliding. Contamination on material's surface such as debris or particles between the sliding surfaces also increase wear rate and damage to the surfaces. Wear occurs by five principal processes: adhesion wear, abrasion wear, corrosion, surface fatigue and erosion[2-4]. Earlier study[5] for SiC particles reinforced composites showed that wear was strongly dependent on the contents of reinforcement, sliding distance and speeds. In[6] presented a review of wear of metal composites. In[7] studied wear of TiC-reinforced MMCs produced by casting. They concluded that reinforced material reduces wear rate. In[8] studied wear and friction of AMCs containing 10, 20 and 30% alumina. They concluded that an increase in reinforcement decreases wear rate. They also concluded that Coefficient Of Friction (COF) decreases with increasing sliding speed. In[9] studied wear behavior of alumina particles reinforced aluminum alloy using pin-on disc type machine for wear properties measurement. They found that increase in contents of reinforcement reduces its ductility and improves wear properties. Pin on-Disc testing technique has been reported for measurement of wear of aluminum composites. Pin-on-Disc uses volumetric loss, and is evaluated from decrease in length of pin.

In this study, aluminum silicon carbide (A-356/SiC) composites and hybrids of aluminum, silicon and boron

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carbides (Al-356/SiC/B_4C) were fabricated and analyzed for their wear properties. The microstructures for various sliding distances were examined by using an optical microscope.

2. Experimental work

2.1 Materials

The reinforcements used were SiC nano powder (25–50 nm in diameter) and B_4C nano powder (30 – 60 nm in diameter). The aluminum silicon carbide (A-356/SiC) composites, with 0.5, 1, 1.5 % SiC and the hybrid (A-356/SiC/B_4C) composites with 0.5, 1, 1.5 % of equal parts of SiC and B_4C were fabricated by mechanical and ultrasonic stirring.

The effects of reinforcement nanoparticles (SiC/B_4C) on the wear property were tested using a 2.5 micrometer or better sensitivity wear measuring system, at room temperature. The specimens used for testing were cylindrical in shape. The wear measurements were found by comparing the mass and volume losses obtained from the sliding test[10].

2.2 Procedure

2.2.1 Mechanical Stirring

Mechanical stirring is a process in which a stirrer is used to mix the particles in the molten metal. It consists of a stirrer driven by an electric motor. The stirrer is made up of SS-316 metal.

2.2.2 Ultrasonic Stirring

Ultrasonic stirring is a process in which ultrasonic sound is used to disperse the particle evenly in the metal medium by the formation of cavitation. Generally, this leads to smaller particles and increased size uniformity. Also, ultrasonic cavitation improves the material transfer at particle surfaces.

2.2.3 Fabrication of Composite and Hybrid Material

Aluminum (A356) in the shape of a bar is cut into small pieces and melted in a furnace at 850^0C to ensure homogeneous melting. Silicon carbide nano powder was heated in a separate furnace to remove the moisture content and added to the molten alloy. Polyethylene glycol was used as the binder and Hexachloroethane was added to reduce the formation of slag.

The mechanical and ultrasonic stirring was carried out for 10 minutes at 600 rpm. The molten mixture was poured into the cylindrical die which was preheated at 400^0C. The inner part of the die was coated with graphite so that the cast could be taken out easily.

Similarly, the fabrication of hybrid material was done by adding equal parts of SiC nano powder and B_4C nano powder to the molten aluminum (A-356) alloy[11].

2.3 Wear Test

The wear tests were carried out for the composite and the hybrid on a pin-on-disc setup. The pin specimen is pressed against the disc at a specified load by means of an arm or lever and attached weights. When two different materials are tested, it is recommended that each material be tested in both the pin and disc positions. The amount of wear is determined by weighing both the specimens before and after the test. The mass loss value is converted to volume loss using an appropriate value for the specimen density.

Wear results are usually obtained by conducting a test for a selected sliding distance and for selected values of load. The wear properties of the composites and the hybrids were recorded under various loading conditions ranging from 10, 20 and 30 N at sliding of 1000, 2000, 3000 m respectively at room temperature under dry sliding condition. Wear results were reported as volume loss in cubic millimeters for the pin and the disc separately[12,13].

3. Results and Discussion

3.1 Sliding Wear

The reinforced nano particles decrease the wear rates of composites and hybrids compared to aluminum alloy (A-356). Also, the wear resistance increases with increase in percentage of reinforced nanoparticles. Apparently, the hybrids with two nano reinforcements (SiC / B_4C) showed better wear properties than the composites with one nano reinforcement SiC[14,15].

The wear test results of composite (A-356/SiC) are shown in Table 1, Table 2 and Table 3 respectively. Similarly, the wear test results of hybrid (A-356/SiC/B_4C) are shown in Table 4, Table 5 and Table 6 respectively.

Table 1. Wear test results of A-356/SiC at load 10N

S. No.	Sliding distance (m)	Percentage of SiC (%)	Weight before expt. (gm)	Weight after expt. (gm)	Mass loss (gm)	Volume loss (mm^3)	Wear rate (mm^3/m)	Wear coefficient (mm^3/N-m)
1	1000	0.5	6.2046	6.1868	0.0178	0.869565	0.0008696	0.00008696
2	2000	0.5	6.3041	6.2679	0.0362	14.5652	0.0072826	0.0007283
3	3000	0.5	6.3721	6.3131	0.059	18.91304	0.0063043	0.0006304
4	1000	1	6.2046	6.1868	0.0178	0.6	0.0006	0.00006
5	2000	1	6.3041	6.2679	0.0362	13.16	0.00658	0.000658
6	3000	1	6.3721	6.3131	0.059	16.96	0.0056533	0.0005653
7	1000	1.5	6.2245	6.2235	0.001	0.3846	0.0003846	0.00003846
8	2000	1.5	6.3124	6.2795	0.0329	12.461	0.00623	0.000623
9	3000	1.5	6.3837	6.3402	0.0435	16.1153	0.0053718	0.0005372

Table 2. Wear test results of A-356/SiC at load 20N

S. No.	Sliding distance (m)	Percentage of SiC (%)	Weight before expt. (gm)	Weight after expt. (gm)	Mass loss (gm)	Volume loss (mm^3)	Wear rate (mm^3/m)	Wear coefficient (mm^3/N-m)
1	1000	0.5	6.2046	6.1868	0.0178	6.8461	0.0068461	0.000342
2	2000	0.5	6.3041	6.2679	0.0362	13.8076	0.0069	0.000345
3	3000	0.5	6.3721	6.3131	0.059	22.269	0.007423	0.000371
4	1000	1	6.2046	6.1868	0.0178	7.32	0.00732	0.000366
5	2000	1	6.3041	6.2679	0.0362	14.48	0.00724	0.000362
6	3000	1	6.3721	6.3131	0.059	23.32	0.0077733	0.0003887
7	1000	1.5	6.2245	6.2235	0.001	8.21739	0.0082174	0.0004109
8	2000	1.5	6.3124	6.2795	0.0329	16.04348	0.0080217	0.0004011
9	3000	1.5	6.3837	6.3402	0.0435	25.65217	0.0085507	0.0004275

Table 3. Wear test results of A-356/SiC at load 30N

S. No.	Sliding distance (m)	Percentage of SiC (%)	Weight before expt. (gm)	Weight after expt. (gm)	Mass loss (gm)	Volume loss (mm^3)	Wear rate (mm^3/m)	Wear coefficient (mm^3/N-m)
1	1000	0.5	6.2046	6.1868	0.0178	8.269	0.008269	0.000275
2	2000	0.5	6.3041	6.2679	0.0362	15.2692	0.00763	0.000254
3	3000	0.5	6.3721	6.3131	0.059	23.538	0.007846	0.000261
4	1000	1	6.2046	6.1868	0.0178	8.8	0.0088	0.0002933
5	2000	1	6.3041	6.2679	0.0362	16	0.008	0.0002667
6	3000	1	6.3721	6.3131	0.059	24.76	0.008253	0.0002751
7	1000	1.5	6.2245	6.2235	0.001	9.7826	0.0097826	0.0003261
8	2000	1.5	6.3124	6.2795	0.0329	18.0434	0.0090217	0.0003007
9	3000	1.5	6.3837	6.3402	0.0435	27.304348	0.0091014	0.0003034

Table 4. Wear test results of hybrid (A-356/ 0.75 % SiC/ 0.75 % B_4C) at load 10N

S. No.	Sliding distance (m)	Percentage of SiC (%)	Percentage of B_4C (%)	Weight before expt. (gm)	Weight after expt. (gm)	Mass loss (gm)	Volume loss (mm^3)	Wear rate (mm^3/m)	Wear coefficient (mm^3/N-m)
1	1000	0.75	0.75	6.2032	6.2012	0.002	0.2692	0.0002692	0.000027
2	2000	0.75	0.75	6.2812	6.2477	0.033	10.8846	0.0054423	0.0005442
3	3000	0.75	0.75	6.3777	6.328	0.049	13.45294	0.0044843	0.0004484

Table 5. Wear test results of hybrid (A-356/ 0.75 % SiC/ 0.75 % B_4C) at load 20N

S. No.	Sliding distance (m)	Percentage of SiC (%)	Percentage of B_4C (%)	Weight before expt. (gm)	Weight after expt. (gm)	Mass loss (gm)	Volume loss (mm^3)	Wear rate (mm^3/m)	Wear coefficient (mm^3/N-m)
1	1000	0.75	0.75	6.2011	6.188	0.013	4.926	0.004926	0.0002463
2	2000	0.75	0.75	6.2743	6.24266	0.031	11.8962	0.0059481	0.0002974
3	3000	0.75	0.75	6.3256	6.2655	0.060	22.5954	0.0075318	0.0003766

Table 6. Wear test results of hybrid (A-356/ 0.75 % SiC/ 0.75 % B_4C) at load 30N

S. No.	Sliding distance (m)	Percentage of SiC (%)	Percentage of B_4C (%)	Weight before expt. (gm)	Weight after expt. (gm)	Mass loss (gm)	Volume loss (mm^3)	Wear rate (mm^3/m)	Wear coefficient (mm^3/N-m)
1	1000	0.75	0.75	6.2067	6.18983	0.016	6.342	0.006342	0.0002114
2	2000	0.75	0.75	6.2981	6.26092	0.037	13.978	0.006989	0.000233
3	3000	0.75	0.75	6.3089	6.24244	0.066	21.987	0.007329	0.0002776

The results of wear test for (A-356/SiC) nano composite with 0.5, 1, and 1.5% of nano SiC reinforcement and hybrid (A-356/SiC/B_4C) with 0.75% (SiC) and 0.75% (B_4C) under various loads are shown in Figure 1, Figure 2 and Figure 3 respectively.

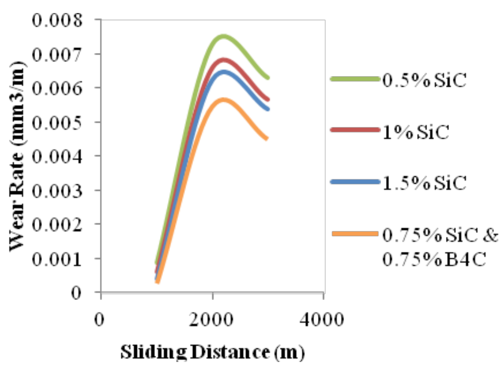

Figure 1. Wear rate comparison of composites and hybrid at load 10N.

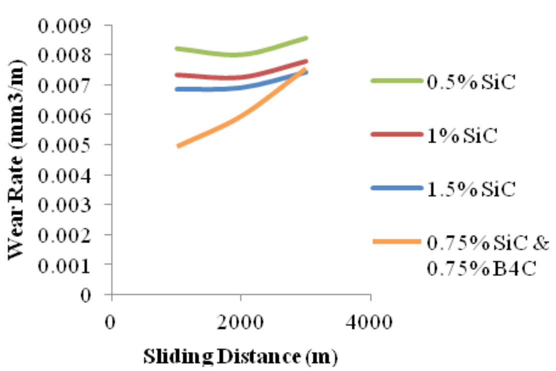

Figure 2. Wear rate comparison of composites and hybrid at load 20N.

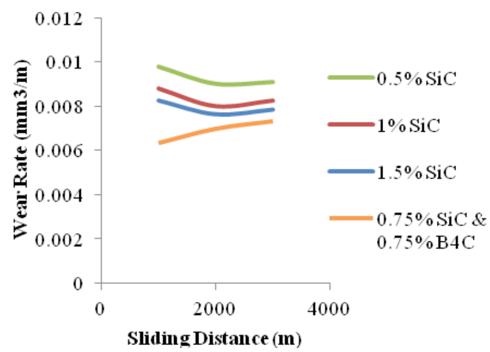

Figure 3. Wear rate comparison of composites and hybrid at load 30N.

3.2 Optical Micrographs

The composite and hybrid specimens that showed the best results after wear test were examined under an optical microscope. The wear microstructures were obtained at 1000X magnification[16].

The microstructure of the composite (A-356/SiC) with 1.5% nano reinforcement is shown in Figure 4. The microstructure of the hybrid (A-356/SiC/B_4C) with 1.5% nano reinforcement combination is shown in Figure 5.

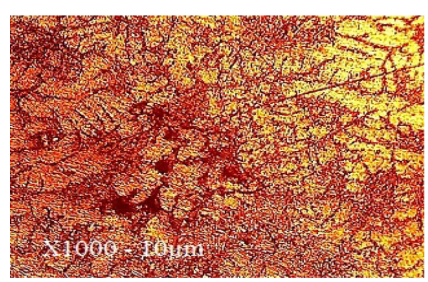

Figure 4. Micrograph of composite at Mag. X1000.

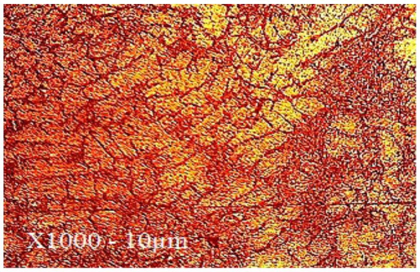

Figure 5. Micrograph of hybrid at Mag. X1000.

It can be seen from the results that the wear rates of composites and hybrids decrease with increase in weight percentage of nano SiC particles and nano B_4Cparticles. The microstructure also shows that there is less porosity on the surface of the hybrid in comparison with the composite. This comparison shows that hybrids have better wear resistance than the fundamental composites[15,16].

4. Conclusion

The wear resistance of composites and hybrids increased with increase in nano SiC and nano B_4C reinforcements. The wear rates of composites and hybrids are lower when compared with aluminum alloy indicating that wear resistance increases with increase in nano SiC and nano B_4C content. It also revealed that the coefficient of friction decreases for the composite and hybrid materials because of the nano reinforcements. Thus it is evident that the hybrid material with the highest percentage (1.5%) of nano reinforcement has better wear resistance than the other combinations.

5. References

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