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Effects of Carbon Black Nanoparticles on Wear Resistance of AA7020/Carbon Black Metal Matrix Composites

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Abstract AA7020/carbon black metal-matrix composites have been prepared by stir casting method. Wear tests were conducted on a pin-on-disc wear tester. With addition of carbon black nanoparticles, the wear resistance of the composite is significantly improved, as compared with the base AA7020 alloy. The wear behavior of the composites is very sensitive to the size and distribution of the carbon black nanoparticles. From microstructural investigations, wear mechanism suggested as a combination of adhesive, abrasive, and delamination wear.

Keywords AA7020, Carbon black, Wear rate, Fracture

1. Introduction

In recent industry, it is increasingly obligatory to develop new composites, such as high resistant, alternative materials of low density in order to realize multifunctional pieces. A composite material consists of two or more nano, micro, or macro constituents with an interface separating them that differ in form and chemical composition and are essentially insoluble in each other [1-7]. The major advantage of stir casting process is its applicability to mass production. Despite its excellent properties, cast Al-SiC composites suffer detrimental effects such as segregation of particles, higher porosity level, extensive interfacial reaction due to higher processing temperature and poor wettability between molten Al and the SiC [8-11]. Experimental evidence and numerical results also demonstrated that the spatial distribution of the second phase particles played an important role on the mechanical properties and the damage mechanism of the composites [12-14].

In dry sliding, ductile materials such as aluminum alloys usually experience severe wear. For Al/SiC metal matrix composites the microstructure study of worn surfaces indicates nature of wear to be mostly abrasive [15]. In another study [16], it was reported that the wear rates increase with increase in load and sliding speed while wear resistance improves with heat treatment for Al/SiC composites. Sliding wear rate and wear behaviour were reported to be influenced by various wear parameters [17, 18]. The effects of reinforcement volume fraction, reinforcement size, sliding distance, applied load, sliding speed, hardness of the counter face and properties of the reinforcement phase which influence the dry sliding wear behavior of metal matrix composites are studied in better features [19-21]. The purpose of this paper was to analyse the fracture and wear behaviors of AA7020/carbon black metal matrix composites have been investigated.

2. Materials and Methods

The matrix material was AA7020 aluminum alloy. The reinforcement material was carbon black nanoparticles of average size 100nm. The matrix alloys and composites were prepared by the stir casting and low-pressure die casting process. The major advantage of stir casting process is its applicability to mass production [23]. The volume fractions of carbon black reinforcement were 10%, 20%, and 30%. Prior to the machining of composite samples, T6 heat treatment was given.

The heat-treated samples were machined to get flat-rectangular specimens for the tensile tests. The tensile specimens were placed in the grips of a Universal Test Machine (UTM) at a specified grip separation and pulled until failure. The test speed was 2 mm/min (as for ASTM D3039). A strain gauge was used to determine elongation. Fracture surfaces of the test samples were analyzed with a scanning electron microscope (SEM) using S-3000N Toshiba SEM to define the macroscopic fracture mode and to establish the microscopic mechanisms governing fracture.

The heat-treated samples were machined to get cylindrical specimens of 10 mm diameter and 30 mm length for the wear

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tests. The levels chosen for the controllable process parameters are summarized in Table 1. The orthogonal array, L9 was preferred to carry out wear experiments (Table 2). A pin-on-disc type friction and wear monitor (ASTM G99) was employed to evaluate the friction and wear behavior of AA7020/CB composites against hardened ground steel (En32) disc. Knoop microhardness was conducted before and after wear tests. Optical and scanning electron microscopy analyses were also carried out to find consequence of wear test AA7020/CB composite specimens.

Table 1. Control parameters and levels

Factor	Symbol	Level–1	Level–2	Level–3
Reinforcement, vf	A	0.1	0.2	0.3
Load, N	B	10	20	30
Speed, m/s	C	1	2	3
Sliding distance, m	D	500	750	1000

Table 2. Orthogonal array (L9) and control parameters

Treat No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3. Results and Discussion

Figure 1 describes the influence of volume fraction of carbon black on the tensile strength and the elastic modulus of AA7020/CB metal matrix composites. The tensile strength and elastic modulus of AA7020/CB composites increase with volume fraction of CB. Localized matrix plasticity was observed in all the composites. This implies that no truly elastic composite deformation stage existed during tensile testing, probably due to a highly inhomogeneous stress-strain distribution in the two phases. Figure 2 shows the SEM fracture surfaces of the composite after tensile testing with the volume fraction of the CB nanoparticles of 10%, 20% and 30%, respectively. It can also be seen that the CB reinforced composites show both ductile and brittle fracture characteristics. The main difference of the fracture surfaces is that increasing the volume fraction of the CB nanoparticles decreases the ductile fracture feature. Fine particles have a tendency of forming clusters.

The percent contribution indicates that the volume fraction of CB, extends 24.48% to the variation in the wear rate as given in Table 3. The normal load confers 10.06% of variation in the wear rate. The sliding speed accords 5.38% of variation in the wear rate. The sliding distance provides 60.07% of the total variation in the wear rate. The R-squared values of %reinforcement, normal load, sliding speed and sliding distance are, respectively, 0.9734, 0.9536, 0.2202 and 0.9994. The trend of mean values obtained by Taguchi techniques is same as that of R-squared values.

Examining the weight loss and wear rate obtained as a result of wear tests, it is seen from figure 3a that the weight loss decreased as the amount of reinforcement phase (CB nanoparticles) increased. Comparing these results with the hardness values given in figure 4 indicates the relationship more clearly. As the hardness of the composites increases, the weight loss measured from wear tests decreases. Wear tests were conducted with loads ranging from 10 to 30 N. All tests were conducted at room temperature. The wear rate of both unreinforced alloy and the composites increases as the applied load increases (figure 3b). The sliding speed has no effect on the wear rate (figure 3c). The variation of wear rate with sliding distance of AA7020/CB composites has been investigated at three different loads which are shown in figure 3d. It is observed that the wear rate of the composites increases with the increase in the applied load. The curve reveals greater wear corresponding to the run-in wear.

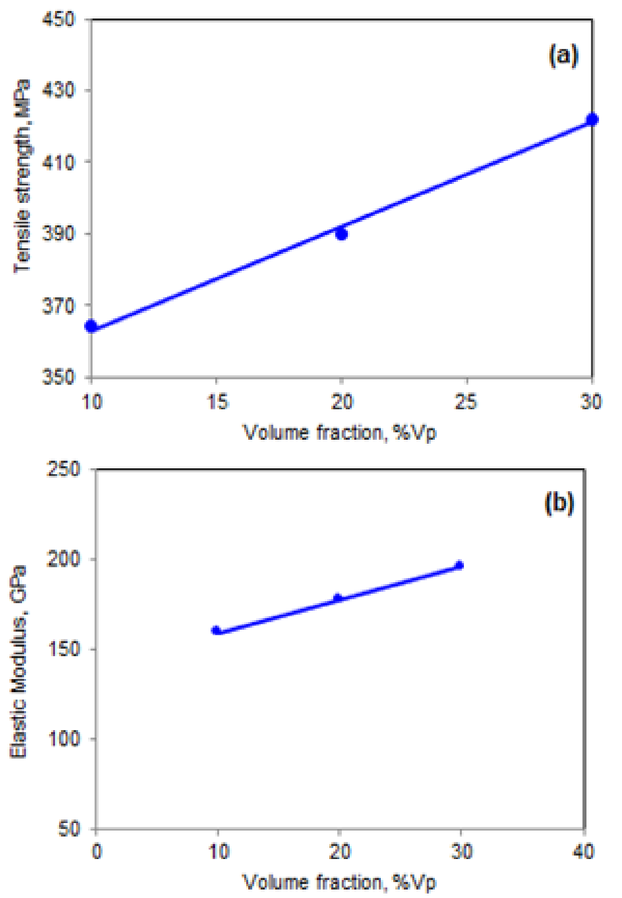

Figure 1. Effect of volume fraction on (a) tensile strength and (b) Elastic modulus

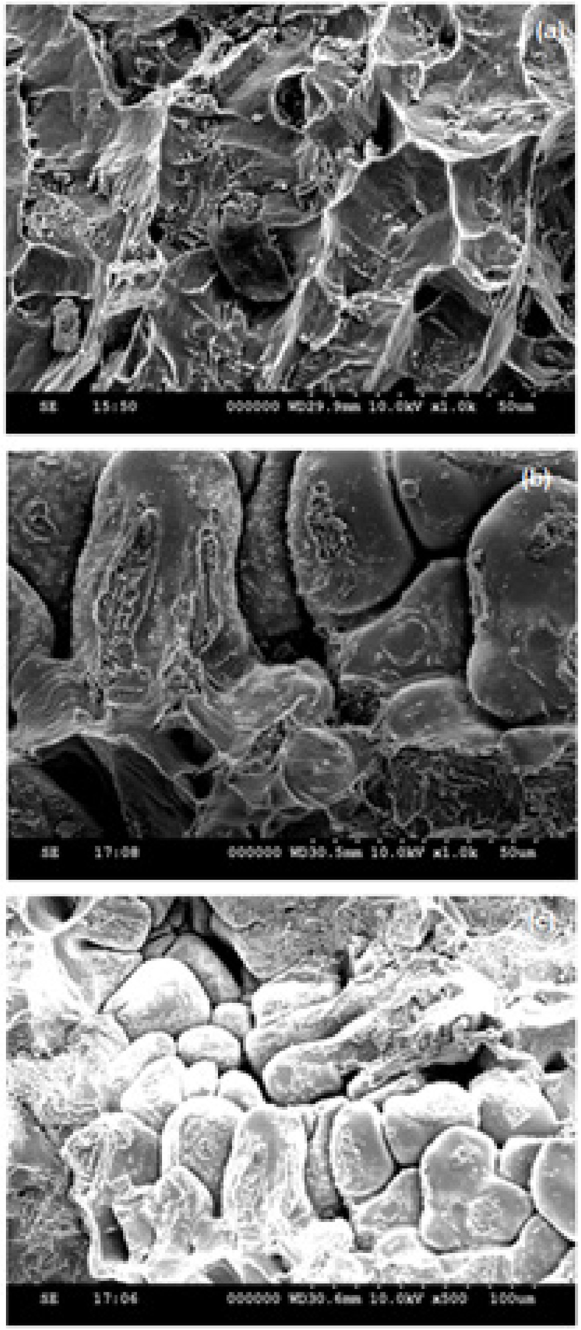

Figure 2. Fractographs of AA7020/CB metal matrix composites: (a) 10%CB, (b) 20%CB and (c) 30% CB

Table 3. ANOVA summary of the wear rate

Source	Sum 1	Sum 2	Sum 3	SS	v	V	P
A	2.29E-02	1.94E-02	1.75E-02	4.98E-06	2	2.49E-06	24.48
B	1.79E-02	2.08E-02	2.10E-02	2.05E-06	2	1.02E-06	10.06
C	1.91E-02	2.14E-02	1.92E-02	1.10E-06	2	5.48E-07	5.38
D	1.60E-02	1.23E-04	5.97E-02	1.22E-05	2	6.12E-06	60.07
e				1.08E-19	0	0.00	0.00
T	7.59E-02	6.17E-02	1.17E-01	2.04E-05	8		100.00

Note: SS is the sum of square, v is the degrees of freedom, V is the variance, P is the percentage of contribution and T is the sum squares due to total variation.

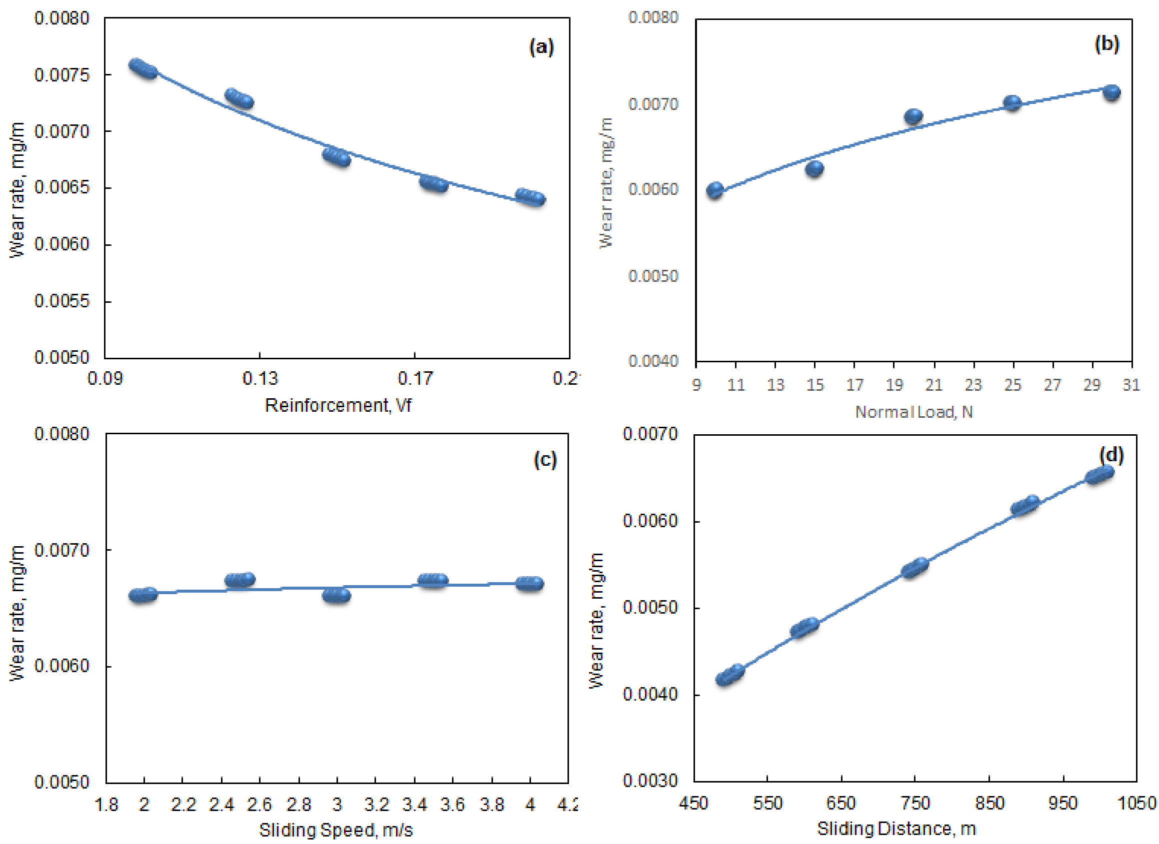

Figure 3. Variation of wear rate with (a) volume fraction of CB, (b) Normal load, (c) sliding speed and (d) sliding distance

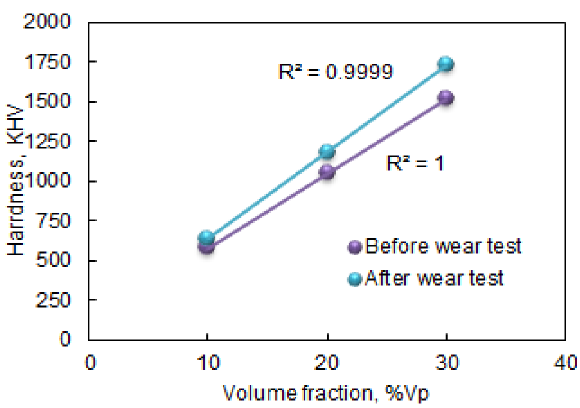

Figure 4. Function of Knoop hardness with volume fraction of CB nanoparticles

The mathematical relations between wear and volume fraction of CB content, normal load, sliding speed and sliding distance are given by

$$W_{rp} = 0.0042 v_f^{-0.2525} \quad (1)$$

$$W_{rf} = 0.004 F^{0.1729} \quad (2)$$

$$W_{rn} = 0.0066 N^{-0.0172} \quad (3)$$

$$W_{rs} = 0.0001 S^{0.6341} \quad (4)$$

where,

W_{rp} is the wear rate due to vol.% of reinforcement (vf), mg/m

W_{rf} is the wear rate due to normal load (F), mg/m

W_{rn} is the wear rate due to speed (N), mg/m

W_{rs} is the wear rate sliding distance (S), mg/m.

Rhee [24] found that the total wear of a polymer-matrix is a function of the applied load F, speed V and sliding time t according to

$$\Delta W = K F^a V^b t^c \quad (5)$$

where ΔW is the weight loss of the friction material and K, a, b and c are empirical constants. F is the applied load; v is the sliding speed; and t is the sliding time. In earlier work [20], the total wear of a metal matrix composite was defined as a function of reinforcement volume fraction, applied load, sliding speed and sliding distance according to

$$\Delta W = K F^a V^b t^c S^d \quad (6)$$

where a, b, c and d are power law coefficients of reinforcement volume fraction (vf), applied load (F), sliding speed (V) and sliding distance (S), respectively. K is the empirical constant. The values of power law coefficients a, b, c and d are, respectively, -0.2470, 0.1258, -0.2270 and 0.1471 from Equations (1) to (6). By substituting the representative values of Vf, F, N and S and their corresponding power law coefficients on the right side of Equation (6) and substituting the experimentally obtained wear rates on the left side of Equation (6), the value of K is determined. The over-all wear rate (mg/m) equation for AA6061/CB composites is given by

$$\Delta W = 1.544\, x10^{-3} F^{-0.2525} V^{0.1729} t^{0.0172} S^{0.6341} \quad (7)$$

With 10% CB nanoparticles, the worn surface appears smooth and consists of small grooves (figure 5a). The width of the groove and size of dimples on the worn surface increase with increasing load. A large deformation and cracking of the surface were observed in the specimen containing more than 20%CB nanoparticles, in which voids and particle clustering occurred, and also a large amount of plastic deformation was observed on the surface of the AA7020 matrix alloy (figure 5b and c). In the present work, the wear debris generated during the wear tests was collected. With increasing applied load and decreasing volume fraction of CB nanoparticles, the size of the platelets or flakes becomes larger and their amount increases. The similar features are observed at the low load and high volume fraction of CB nanoparticles, where the debris is composed of only fine powders.

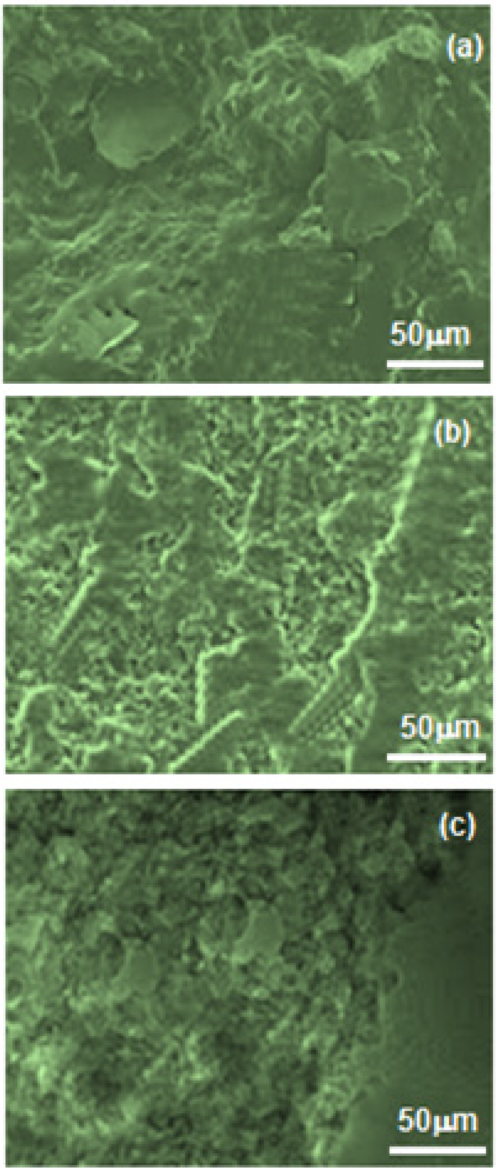

Figure 5. Worn surfaces of AA7020/CB composites: (a) 10%CB, (b) 20%CB and (c) 30%CB

4. Conclusions

In the present work experiments were conducted on AA67020/CB metal matrix composites to evaluate the fracture behavior and sliding wear. The significant parameters were volume fraction of CB and sliding distance. The sliding wear is increased with increasing sliding distance and is decreased with increasing volume fraction of CB. Maximum sliding wear of 60.07% was credited to sliding distance. A large deformation and cracking of the surface were observed in the specimen containing more than 20%CB nanoparticles. With increasing applied load and decreasing volume fraction of CB nanoparticles, the size of the platelets or flakes becomes larger and their amount increases.

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