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The Tribological Behaviour of Epoxy Matrix Composite Reinforced by Ceramic Carbides

Mohammed J. Kadhim[1,*], Hamza M. Kamal[1], Amer Hameed Majeed[1]

[1] Materials Engineering Department, Mustansiriyah University, Baghdad, Iraq

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ABSTRACT

In this effort, the tribological behavior of epoxy resin filled with treated ceramic carbides fillers has been investigated. The epoxy matrix composite was prepared with different weight fraction (0, 5, 10 and 15%) separately for both silicon and boron carbides ceramic particles using hand-lay methodology. The wear characteristics represented by weight loss and coefficient of friction at different average load (30, 40, 50 N) with two sliding velocity (2.5, 5 m/s) and constant sliding distance. It was noticed from the acquired results, there is obvious improved in the wear behavior of epoxy resin when filled with treated ceramic carbide particles (especially boron carbides) related to unfilled epoxy resin and theses enhancement increased with increasing the weight fraction of fillers.

Keywords:
Epoxy resin; Boron carbide; silicon carbide; tribological behavior; wear

1. Introduction

The Tribological properties of polymer matrix composite play a critical role in different kinds of application range from bearings, brakes, gears, seals and artificial joints where wear and friction are the most significant considerations [1]. Composite materials are often favoured due to their low density, easy of manufacturing, chemical resistance and the high strength-to-weight ratio [2]. So that, there is an urgent necessity to improve the tribological behavior of polymer matrix composite by incorporation of ceramic filler particles which enhance the wear resistance and reduce the coefficient of friction of epoxy resin [3]. Bazrgari *et al.,* [4] studied the tribological performance of epoxy resin when reinforced with nano alumina particles; it was observed that the dispersion of nano Al_2O_3 into epoxy resin matrix at a low ratio (1%) resulted in a significant reduction in coefficient of friction and wear rate of epoxy resin. Abenojar *et al.,* [5] study the influence of nano nano-silica particles on wear and mechanical properties of epoxy resin, it was found that the wear properties and the cavitation erosion are reduced by nano-particles addition and the best ratio obtained at (3%) of nano-silica powder. Sarkar *et al.,* [6] investigate the tribological characteristics of aluminium powder reinforced

* *Corresponding author.*
E-mail address: moh_materials@yahoo.com (Mohammed J. Kadhim)

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glass-epoxy composites, it was noticed with (5 wt.%) aluminium the hybrid composite has the lowest frictional and wear properties while composite displays the highest friction and wear values at (15 wt.%) of aluminium powder. Silicon carbide whiskers have been incorporated into ceramic materials for improving their fracture toughness [12]. Polymers and polymer composites have been used increasingly as engineering materials for technical applications in which tribological properties are of considerable importance. In general, fillers (e.g., glass, carbon, asbestos, oxides, and textile fibers) are incorporated for improving the composites' tribological performance [13]. One of the most extensively used polymers as the matrix of composites is Epoxy resin. However, the major drawback of epoxy resins is their poor wear resistance. Because of their extensive use in the anti-wear applications [14]. Also, modifications to the specimen preparation process can significantly alter the tribological behavior to a point that excludes the necessity of nanotube pre-treatment [15]. Besides, the tribological properties of epoxy composites filled with wax-containing microcapsules and silica nanoparticles were examined methodically. Results exhibited a remarkable decrease in the specific wear rates and the coefficient of friction for silica/wax microcapsules /epoxy ternary nanocomposites [7]. On the other hand, the influence of molybdenum disulphide, fly ash and Hanumantharaya *et al.,* [8] examine ceramic fillers on the tribological and mechanical behavior of epoxy matrix composite, the obtained results show significant decreasing in the wear rate when composite filled with 10% MoS2, 5% ceramic filler and 15% of fly ash. So, this study aims to a tribological behavior of epoxy resin filled with treated ceramic carbides fillers has been investigated. The epoxy matrix composite was prepared with different weight fraction separately for both silicon and boron carbides ceramic particles using a hand-lay methodology.

2. Experimental Details

2.1 Matrix Phase

In this study, epoxy resin type (LY556+HY951) system that provided from "Advanced Materials India Pvt. Ltd." was used as a matrix phase in polymer composite preparation. It is a very versatile resin system, allowing for abroad range of properties and processing capabilities. It exhibits low shrinkage as well as excellent adhesion to variety of substrate materials. The specification and the properties of epoxy resin that used in this work listed in the Table 1.

Table 1
Properties of LY556 and HY951 epoxy resin

Specification	LY556	HY951
Aspect	Clear, pale yellow liquid	Clear liquid
Viscosity at 25° C [mPa s]	10000-12000	10-20
Density at 25° C [g/cc]	1.15-1.20	0.98
Mixing ratio [parts by weight]	100	10

2.2 Reinforcing Phase

Two classes of ceramic carbides fillers (represented by silicon carbide and boron carbide powders provided from DINES PLASTICS, LTD, England) are used as reinforcing phase in this effort. The properties of ceramic carbides fillers used are listed in the Table 2.

Table 2
Properties of ceramic carbides fillers

Specification	B_4C	SiC
Particle size	(0.1-20) µm	(0.1-25) µm
Density ($g.cm^{-3}$)	2.5	3.2
Melting Point (˚C)	2450	2600
Young Modulus (GPa)	480	480
Hardness (Vickers) 100g	3200	2600
Fracture Toughness ($MN\ m^{-3/2}$)	3.5	4
Ultimate Tensile Strength (GPa)	6.5	3
Color	Black	Gray

2.3 Surface Modification of Ceramic Carbides

To modify the adhesion properties between the epoxy resin and ceramic carbides fillers, a silane-coupling agent was used in this effort. This treatment enhances the surface of particles and the bonding characteristics at the interface. The carbides fillers were treated with (1%) dilute fresh silane solution and stirred for (5) min followed by a drying time at 100 0C for 10 hours.

2.4 Procedure

Utilizing hand lay-up route, epoxy resin matrix filled with ceramic carbides fillers are prepared in this effort. Epoxy resin with its hardener by (10:1) ratio are filled with different weight fraction of two types of ceramic carbides fillers (0, 5, 10, and 15% respectively) and investigate its mechanical properties denoted by hardness and wear tests.

The treated ceramic carbide particles are incorporated into epoxy resin with its hardener and mixed manually until the uniform distribution of ceramic carbide particles in the matrix are obtained and gel-like paste was achieved. In this procedure, the major problem is the precipitation of particles in the base of the matrix; so, to avoid this problem, the particles should be added before the gelation forming to prevent the precipitation of particles in the base of the sample. After mixing, the mixture poured in a mold for (24-hour) to cure the composite and then we obtain well-shaped hard disks composite materials.

2.5 Mold Preparation

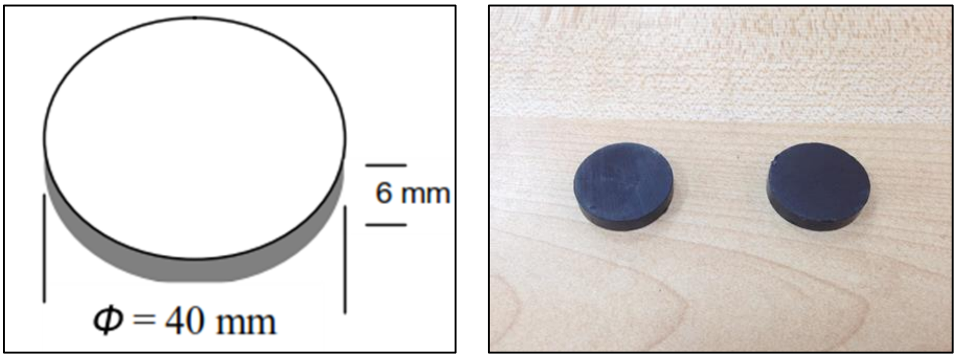
In this research, cylindrical mold made from acrylic plastic with a dimension of (10 mm) diameter and (20 mm) thickness proper to wear test and (40 mm) diameter and (10 mm) thickness proper to hardness test was used. Before the pouring process, the mold was cleaned and lubricated the inside walls of the mold with (Vaseline) to prevent the adhesion between the mold and polymeric material.

3. Characterization

To investigate the required properties, three samples are prepared for each test into the required geometry according to (ASTM) standard and applying the route for each required test.

3.1 Hardness Measurements

Shore hardness (D) device (provided from the "W-Tester Amsler Durometer (DIN 53505-ISO P858))" [9] was used to determine the hardness values of the epoxy resin and the prepared composite. Figure 1 shows the hardness test samples.



(a) (b)

Fig. 1. Hardness test geometry (a): Schematic (b): Prepared samples

3.2 Wear Measurements

Wear characteristics of epoxy and epoxy filled with ceramic carbides fillers were evaluated using "pin-on-disc wear test apparatus according to (ASTM G99)". The disk with (61) HRC hardness, 165 mm diameter, 8 mm thick and 1.3 mm surface roughness made from steel are used in this work. Before the examination, the disc and the specimen were cleaned with a soft cloth soaked in acetone.

The wear behavior of the prepared specimens were conducted at different loads (30, 40, and 50 N) with two sliding velocities (2.5 and 5 m/s) respectively and the wear values were expressed as weight loss results from the difference between the initial and the final weights by using an electronic digital scale with an accuracy of 0.0001 g. (type Mettler Toledo manufactured by Switzerland Company.

Besides weight loss measurements, another parameter (represented by coefficient of friction) is also calculated to evaluate the tribological behavior of epoxy resin. It was measured by dividing the frictional force with normal load [11]. The frictional force was verified from the control unit of the instrument and the coefficient of the friction was determined. This parameter was calculated with the same conditions that used in weight loss measurement from the applied load and sliding distance. Figure 2 show the prepared samples of the epoxy resin and epoxy resin filled with ceramic carbide fillers for wear test measurements.

(a) (b) (c)

Fig. 2. Wear test samples (a): Epoxy resin (b): Epoxy with SiC (c): Epoxy with B_4C

3.3 SEM Examination

"TESCAN Vega II XMU SEM characterization" used in this effort, which are given high-resolution images. At least (3) small samples from each specimen to ensure homogeneity structure. After that, the specimens are cleaned, dried and finally fixed on a stub of metal with adhesive, coated with (40-60) nm of gold.

4. Results and Discussion

Figure 3 shows the influence of treated silicon and boron carbide particles on the hardness values of the epoxy resin with different weight fraction (5, 10, and 15%) respectively. It was observed from Figure 1, the hardness values of epoxy resin increased significantly with increasing the weight fraction of ceramic carbide particles and the best value is obtained at (15% wt.).

The enhancement in the hardness values is ascribed to the well dispersion of treated ceramic carbide particles within epoxy resin, which results in strengthening the epoxy matrix by inhibiting the crack propagation as shown from the SEM images in the Figure 4 and Figure 5. In addition, the surface treatment of the carbide particles with silane solution enhances the bonding properties at the interface region between ceramic carbide particles and epoxy resin that led to more stress transformation from the matrix to the reinforcing particles. Furthermore, the boron carbides filled epoxy resin showed high hardness values compared to silicon carbides filled epoxy and this due to the high tensile strength and hardness of boron carbide particles.

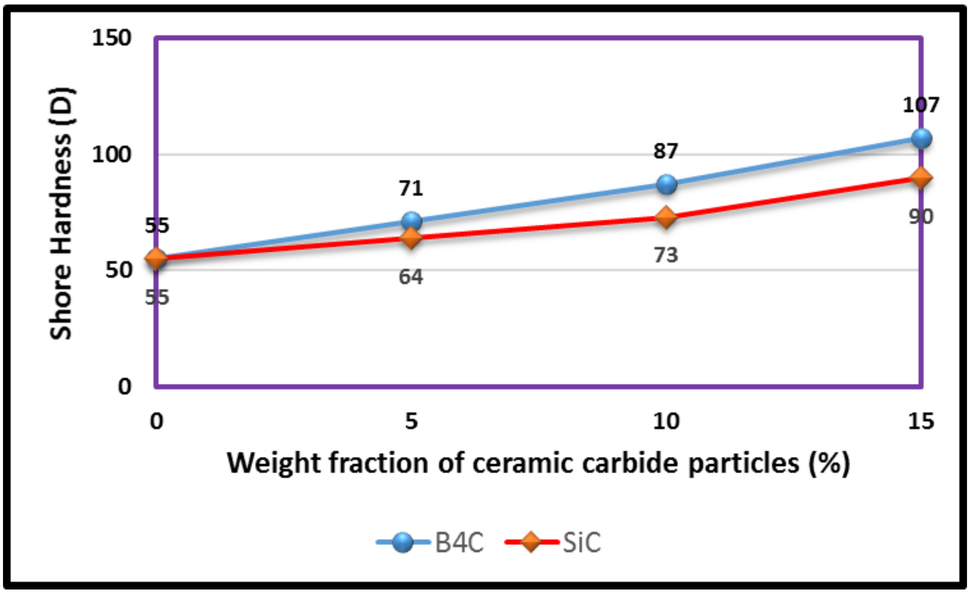


Fig. 3. Effect of ceramic carbide particles with different weight fraction on the hardness values of epoxy resin

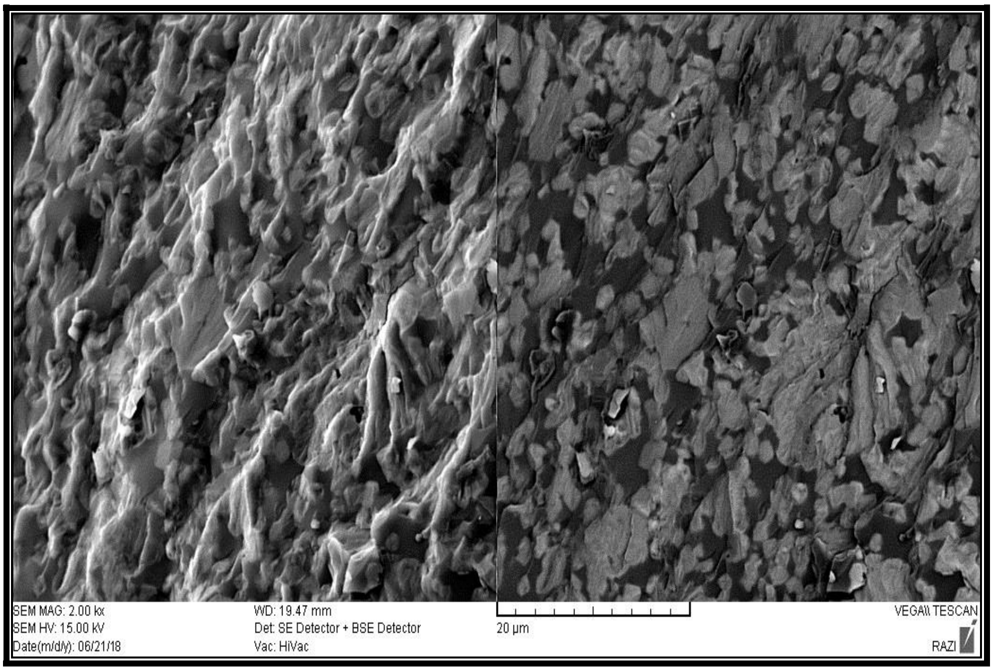


Fig. 4. SEM image of epoxy resin filled with (15%) SiC particles

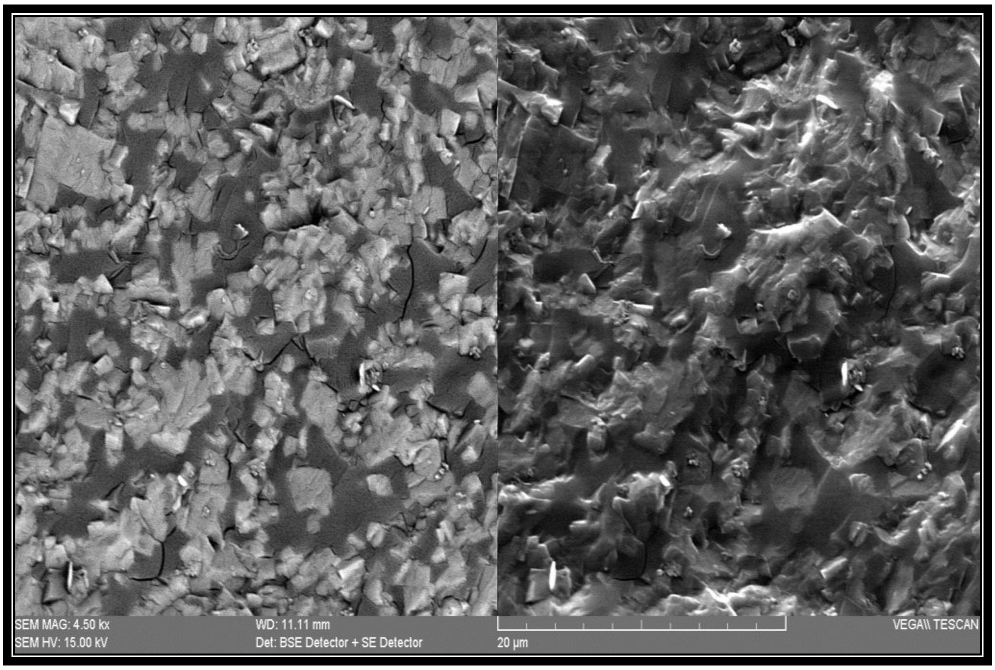


Fig. 5. SEM image of epoxy resin filled with (15%) B_4C particles

To describe the influence of normal loads (30, 40, and 50 N respectively) at different weight fraction (5, 10, and 15%) of ceramic carbides, the wear loss is plotted via the normal loads for silicon and boron carbides filled epoxy resin in Figure 6 to Figure 11 for different sliding velocities.

It was observed from the obtained data, and in all cases, the wear loss of composite increases with increasing the average load and the sliding velocities, and the rate of wear loss dramatically decrease when epoxy filled with ceramic carbides fillers compared to unfilled composites. This enhancement in the wear properties when epoxy filled with ceramic carbides especially boron carbide is ascribed to the unusual wear characteristics and hardness properties of these fillers.

On the other hand, the surface treatment of particles has improved the wear behavior of epoxy by modifying the surface of the particles and interfacial bonding leading to better transfer of stress from the resin to these particles. Moreover, this treatment improves the hydrophobicity to inhibit moisture infiltration and cause a more efficient distribution of the fillers in the resin.

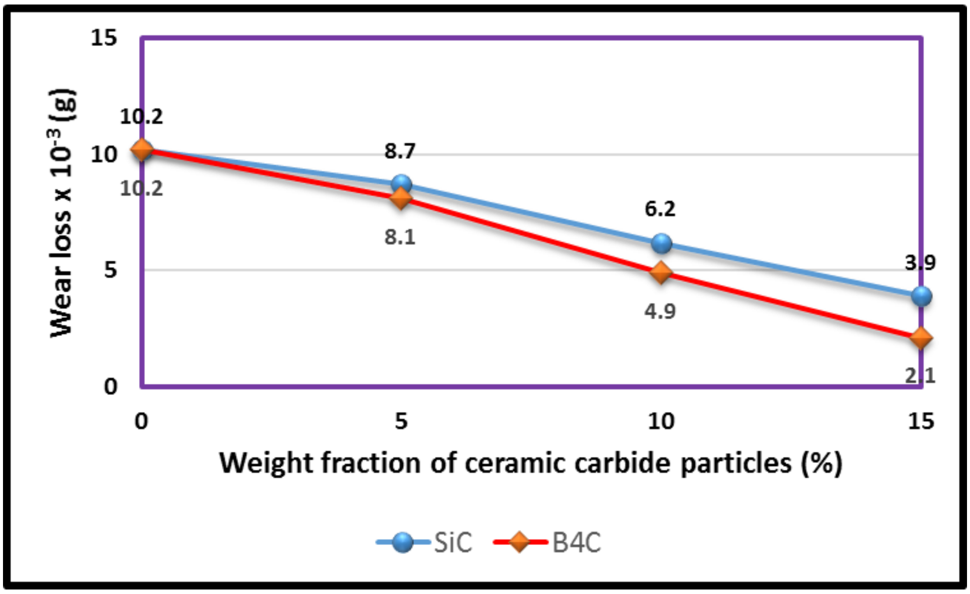


Fig. 6. Wear loss of epoxy resin versus weight fraction of ceramic carbides at (30 N) load and (2.5 m/s) sliding velocity

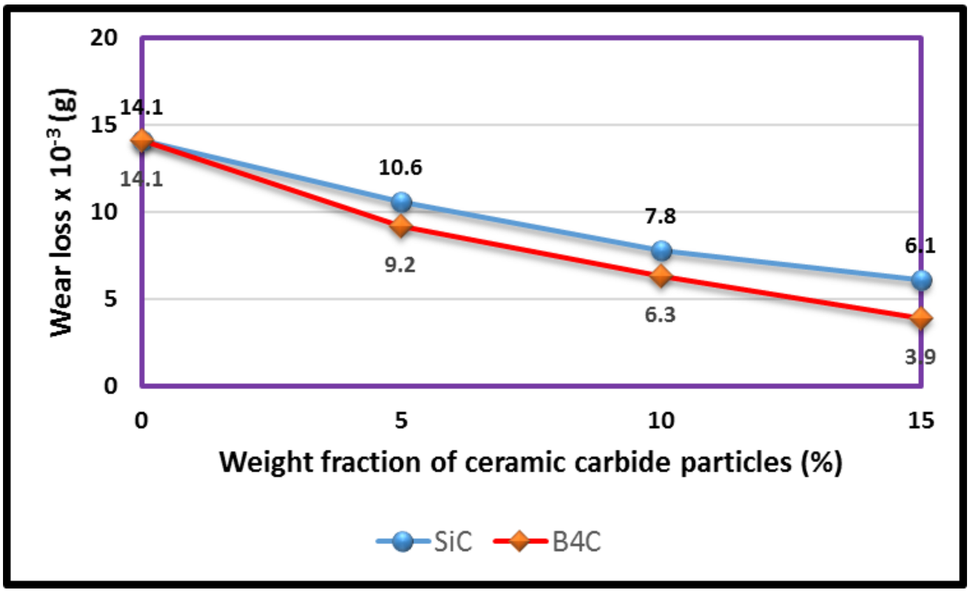


Fig. 7. Wear loss of epoxy resin versus weight fraction of ceramic carbides at (40 N) load and (2.5 m/s) sliding velocity

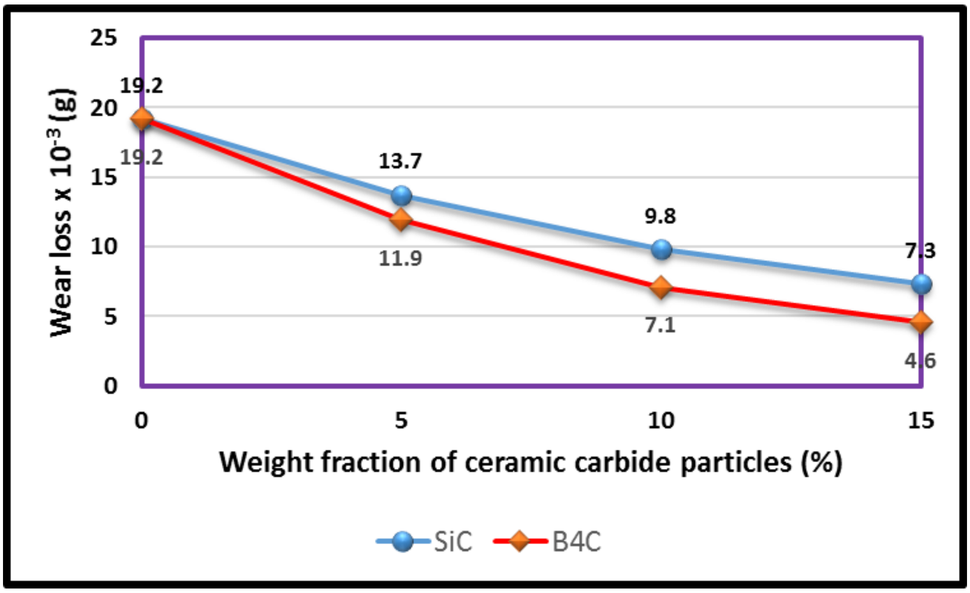


Fig. 8. Wear loss of epoxy resin versus weight fraction of ceramic carbides at (50 N) load and (2.5 m/s) sliding velocity

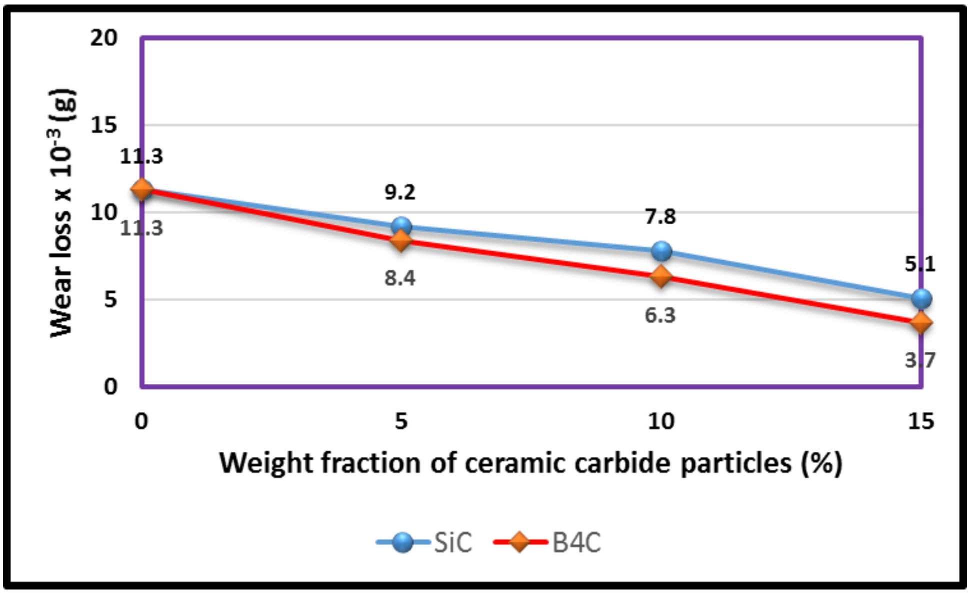


Fig. 9. Wear loss of epoxy resin versus weight fraction of ceramic carbides at (30 N) load and (5 m/s) sliding velocity

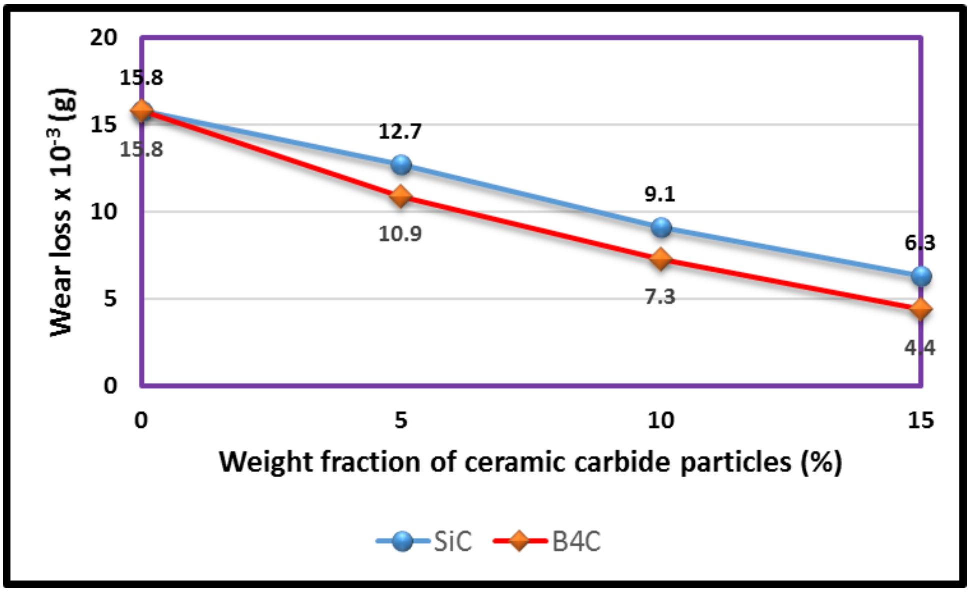


Fig. 10. Wear loss of epoxy resin versus weight fraction of ceramic carbides at (40 N) load and (5 m/s) sliding velocity

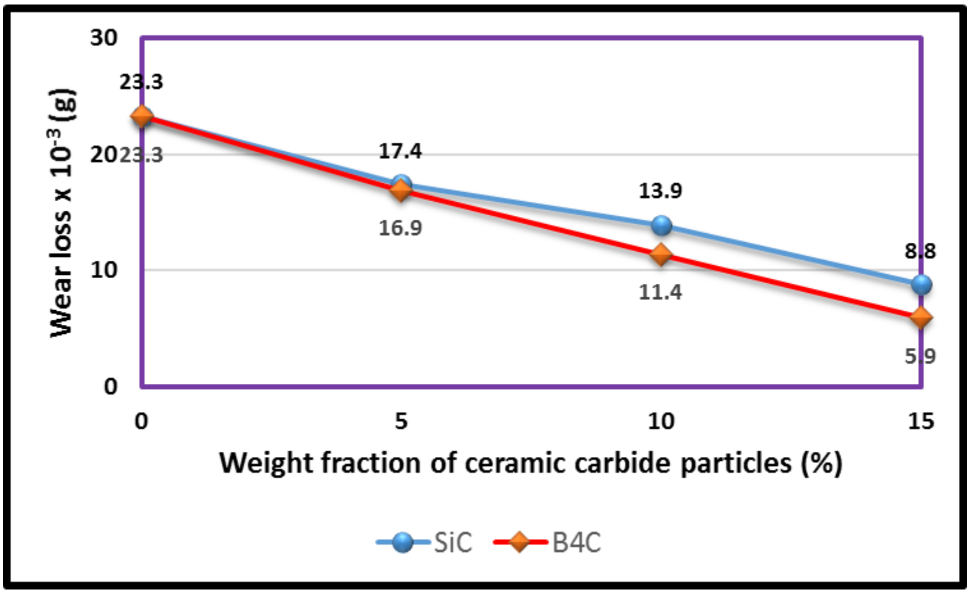


Fig. 11. Wear loss of epoxy resin versus weight fraction of ceramic carbides at (50 N) load and (5 m/s) sliding velocity

Figure 12 to Figure 17 display the effect of the weight fraction of fillers on the coefficient of the fraction of epoxy resin by applying different normal loads (30, 40, and 50 N) with two sliding velocities (2.5 and 5 m/s) at a constant sliding distance.

Similar to the weight loss measurement, the filled epoxy resin with ceramic carbides exhibited a lower coefficient of friction than unfilled resin. Conversely, as the normal load increases for all sliding velocities, the interaction pressure at the line between the disc and the specimen also increases, which increases the interface temperature, leading to increase in the frictional force. Therefore, the ceramic carbides fillers play a critical role in decreasing the generated temperate at the interface region between the disc and the specimen because of the heat resistance properties of carbides fillers leading to remarkable improvement in the coefficient of friction values of epoxy resin.

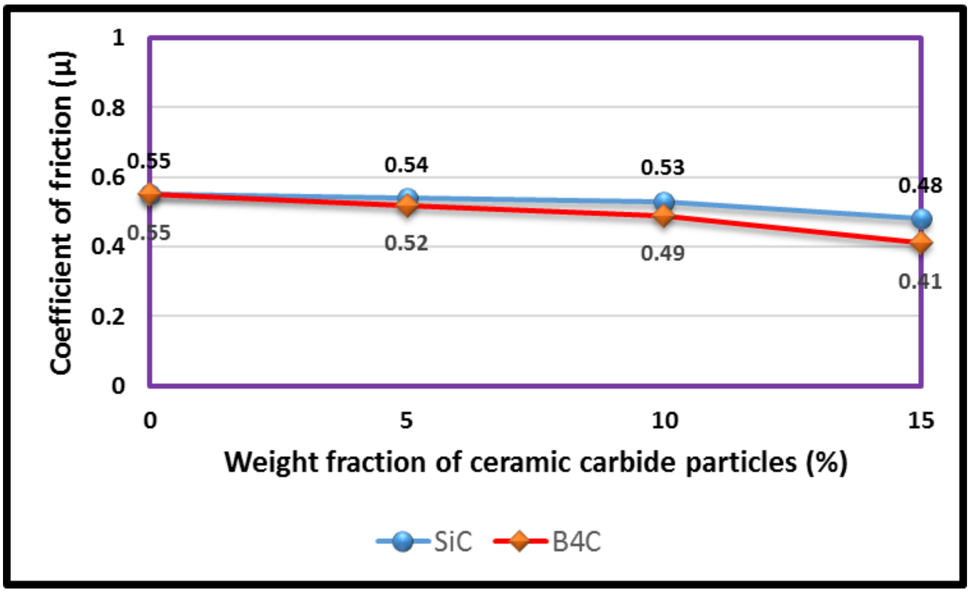


Fig. 12. Coefficient of friction of epoxy resin versus weight fraction of ceramic carbides at (30 N) load and (2.5 m/s) sliding velocity

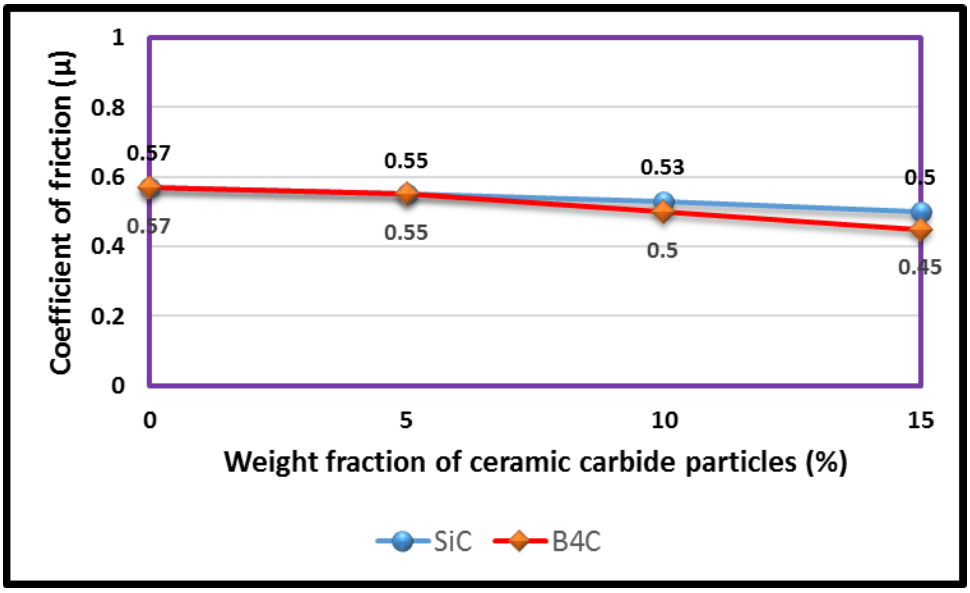


Fig. 13. Coefficient of friction of epoxy resin versus weight fraction of ceramic carbides at (40 N) load and (2.5 m/s) sliding velocity

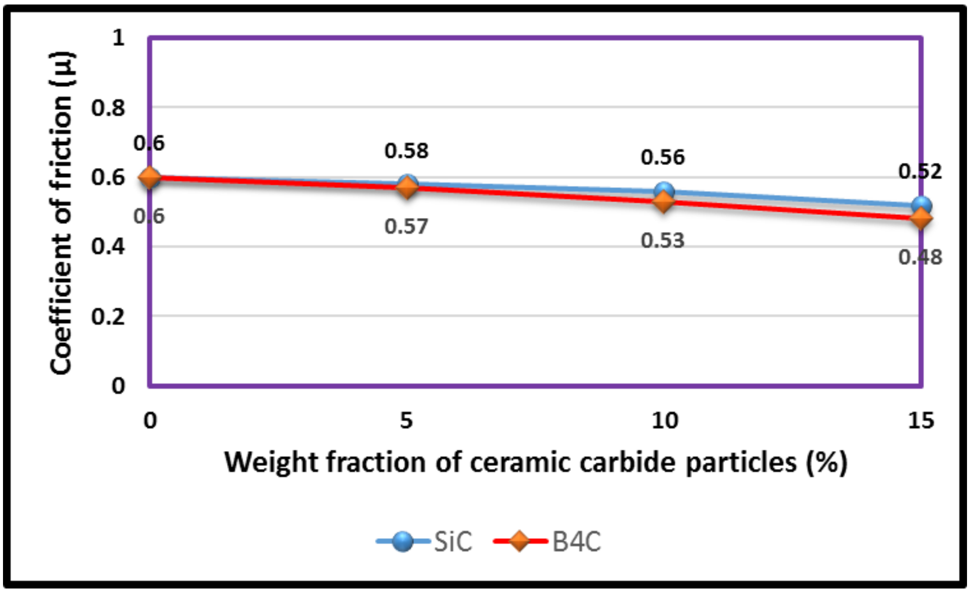


Fig. 14. Coefficient of friction of epoxy resin versus weight fraction of ceramic carbides at (50 N) load and (2.5 m/s) sliding velocity

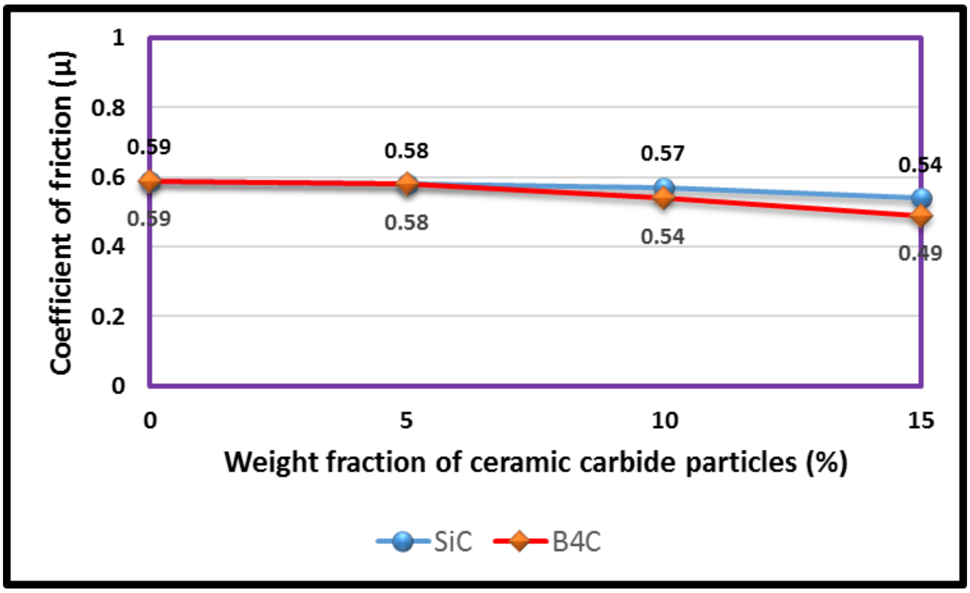


Fig. 15. Coefficient of friction of epoxy resin versus weight fraction of ceramic carbides at (30 N) load and (5 m/s) sliding velocity

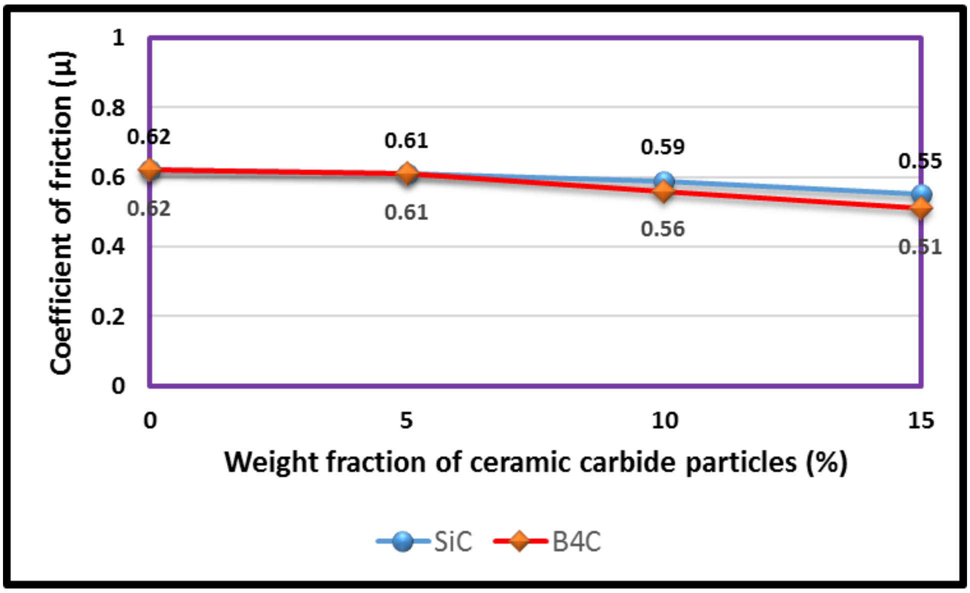


Fig. 16. Coefficient of friction of epoxy resin versus weight fraction of ceramic carbides at (40 N) load and (5 m/s) sliding velocity

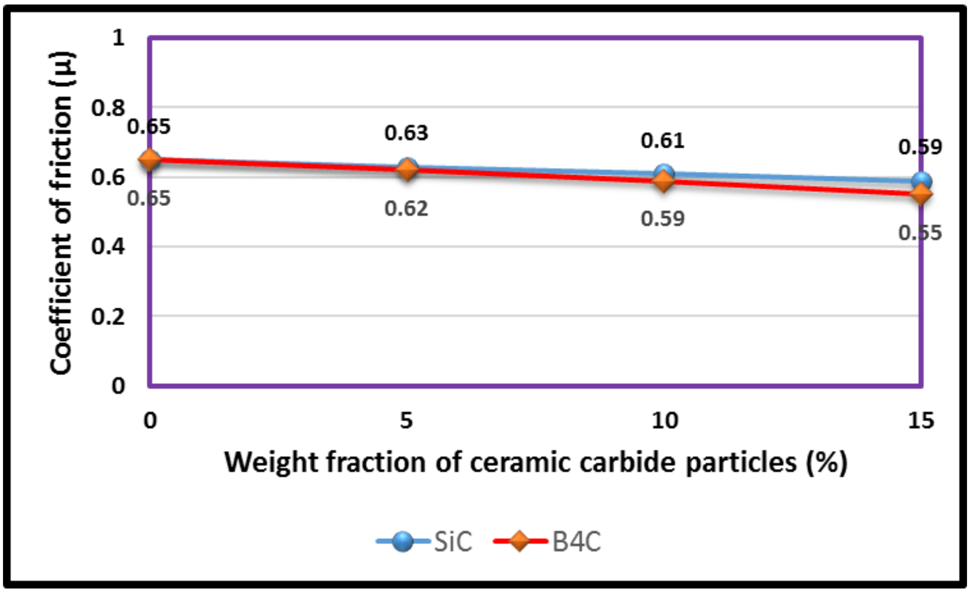


Fig. 17. Coefficient of friction of epoxy resin versus weight fraction of ceramic carbides at (50 N) load and (5 m/s) sliding velocity

5. Conclusions

The influence of SiC and B_4C fillers with different weight fraction on the wear loss and friction properties of the epoxy resin matrix has been examined in this study. The wear behavior of the composite was studied under different normal loads and sliding velocities. It is concluded from experimental data, there is increasing in the wear parameters and this increment increased with increasing the normal load at all sliding velocities. On the other side, the wear loss and coefficient of friction of all the composites noticeably enhanced when epoxy filled with treated SiC and B_4C fillers related to unfilled epoxy resin and these augmentations increased with increasing the weight fraction of fillers. Finally, the epoxy resin filled with B_4C ceramic particles demonstrates better wear performance than SiC particles.

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