Research Article

# Tribological Characteristics of Silicon Carbide – Epoxy Nanocomposites

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**Abstract**
The applications of epoxy nanocomposites have been increased in fast, in technological applications and engineering materials for seal and sliding components in many machines, devices, tools and variance vehicles. In this research friction and wear coefficients of epoxy reinforced by nanoparticles silicon carbide in terms of variance volume fractions have been tested. Mechanical – layup method with ultrasonic technique for the dispersion of the nanoparticles within the epoxy are used. Wear and friction coefficients tests are created out using pin -on-disc technique. The results showed significant improvement in wear resistance and low coefficient of friction for 10 Vol. % nanocomposites compared with the epoxy alone. It can be concluded from scanning electron microscopy results before and after the tests that the wear was transformed from the severe to the moderate.

**Keywords**: Friction, Wear, Epoxy Composites, Pin on disc, and SiC nanoparticles.

**الخلاصـة**
أزدات تطبيقات المتراكبات الايبوكسي النانوية بسرعة، في التطبيقات التكنولوجية والمواد الهندسية للمكونات المنزلقة والمحكمة في المكائن المتعددة والأجهزة والمعدات والمركبات المتنوعة. أختبيرت في هذا البحث معاملات الاحتكاك والبلى للايبوكسي المدعم بمسحوق كاربيد السيليكون النانوي بدلالة تغير الكسور الحجمية. استخدمت طريقة القولبة الالية مع تقنية الموجات فوق الصوتية لتشتيت الدقائق النانوية ضمن الايبوكسي. نفذت أختبارات معاملات الأحتكاك والبلى باستخدام تقنية Pin –on- Disc . بينت النتائج التحسن الكبير في مقاومة البلى وانخفاض بمعامل الاحتكاك للكسر الحجمي 10 Vol.% مقارنة بالايبوكسي منفردا. يمكن الأستنتاج من خلال نتائج المجهر الألكتروني الماسح قبل الأختبارات وبعدها تحول البلى من الحاد إلى المعتدل .

## Introduction

The problems of materials which is used for industry and technology can be summarized in two major phenomenon caused the failure of these materials; it is wear and fatigue. Wear of materials is dealing with long life while fatigue is dealing with sudden broken when materials are in performance service. We know that wear is one of the three parameters of tribology which is the science and technology of friction, lubrication and wear. Increased attention has been paid in recent years to researches on polymer nanocomposites in particular from the point of view of their potential uses in tribological, mechanical, electrical and thermal applications. Much researches has been carried out on tribology of polymer nanocomposites and its application purpose increasing and extending into even more new areas [1] [2] [3] and [4]. Many of modern technologies require materials with non-usual combination of properties that can be met by the conventional metals, alloys, ceramics and polymeric materials. That can be achieved *via* nanocomposites. Sumita, Shizuma, Miyasaka, and Ishikawa hab been studied the effect of reducible properties of temperature, rate of strain, and filler content on the tensile yield stress of nylon 6 composites filled with ultrafine particles where they were suggested that "with diminishing filler measurements or expanding filler content a huge enhance in the contact territory between the filler and matrix, and thus it would significantly and viably enhance the exchange of the heap between the fillers and the polymer" [5]. Wang had introduced in their paper an investigation of the friction and wear properties of nanometer $Si_3$ $N_4$ filled PEEK and through their studies they reached " the inorganic nanofillers, ranging from 1 to 50 nm, were successfully incorporated into the polymeric matrix to strengthen and improve the ductile polymer to be more stiff and resistant for abrasion" [6]. Scanlon and Cammarata mention in their paper "mechanical properties of nanocomposite granular metal thin films" that "large numbers of tribological studies have been reported to display properties not quite the same as their miniaturized scale partners. In view of this, they would be required to give distinctive tribological properties" [7]. Lu and Friedrich as well as Voort and Bahadur were concluded that "wear resistance relies on upon the change of polymer composites by the particulate filler material" [8] [9]. Bahjat B. Kadhim and his coworkers mention that "novel properties of nanocomposites can be acquired by productive giving of the characteristics of parent constituents to a lone material" [10].

Through a research group the researchers confirmed that "polymer nanocomposites are widely used in many situations where machine components are subjected to tribological loading conditions" [11] [12] [13] [14] [15] [16]. In view of this, many researchers are interested to study the wear properties at different loadings and found that, different inorganic fillers show distinct effect on the wear behaviors of polymer nanocomposites, so the mechanism of filler in reducing wear has been largely focused [17] [18] [19] [20] [21].

The objective of this work is to investigate the friction and wear properties of epoxy reinforced by nanoparticles SiC to prepare nanocomposites specimens sliding against a hardened stainless steel counter face. As a comparison, the friction and wear properties of plain SiC were also evaluated under identical test conditions. This work helps in understanding the function of different fillers in SiC nanocomposites.

Exactly when the polymeric materials are reaching in tribological connects with, it is to a great degree accommodating and routinely the lubricant is excessive.

For polymeric materials grip, scraped area and weariness wear are the predominant components. In spite of the fact that, there is just minimal adhesion between ceramic materials and polymers, much of the time a film of exchanged material can be framed on the earthenware surface (the hardest material) and accordingly bond can be more grounded [22].

According to the conditions of the pin on disc machine the specific wear rate are calculated according to [23]:

$$W_S = \frac{W_V}{L \times SD} \tag{4}$$

Where: $W_V$, is the wear volume loss of the specimen before and after the wear test (mm$^3$), $L$ is the normal load (N), and $SD$**:** is the sliding distance (m). Wear rate can be calculated as:

$$W_R = \frac{\Delta W}{SD} \tag{2}$$

Where: $\Delta W$, is the wear weight loss of the specimen before and after the wear test (gm). Wear coefficient can be calculated using the *Archard's equation* [24]:

$$k = \frac{W_V . H_v}{SD.L} \tag{3}$$

Where $k$ is wear coefficient, $W_v$ is wear volume, $L$ is the normal load, $SD$ is the sliding distance, and $H_V$ is the hardness.

$$W_V = \frac{\Delta W}{\rho} \tag{4}$$

$HV$ **,** Vickers hardness (N / mm$^2$), $\Delta W$, wear weight loos (gm), $\rho$, density (kg/m$^3$ ) and $L$, load (N). According to the conditions of Pin – on – disc machine, the coefficient of friction can be calculated by using the following relationship:

$$\mu = \frac{Q}{r \times L} \tag{5}$$

Where $\mu$ is coefficient of friction, $Q$ is friction torque in (mN), $r$ is the radius of pin revolution on counter face steel disc in (m), and $L$ is the applied normal load in (N). The friction torque value is obtained from the integrating disc counter before and after the test.

## Materials and Methods

The nano silicon carbide (nano-SiC) is used for reinforced the epoxy. Nanocomposites are prepared by dispersing (nano–SiC) by kinematic ultra-sonication technique. To achieve better state of dispersion, first the nanoparticles were treated with alcoholic medium (acetone) for the deagglomeration of the particle bundles. The treated particles are then added to the epoxy resin and sonicated for 2h at room temperature. Then the mixture is cured under vacuum at (363K) for 10h followed by hardener addition by using simultaneous magnetic stirring (100 rpm) for one hour to homogenization. The prepared specimens are treated at (353K) for 6h in the oven to remove the moisture contents of the specimens. To prepare the nanocomposite specimens, molds are made from Teflon. The mold smeared by wax before the mixture is poured into the mold after homogeneity. Wear tests have been conducted in the pin-on-disc machine, against hardened ground stainless steel disc with hardness (55HRC). It is necessary to mention that the surface of all specimens under study were cleaned and grinded to become smoother (without scratches) before the test.

## Results and Discussion

Experimental data on the slide wear loss of filled and unfilled SiC nanocomposite specimens are shown in Figures 1, 2, and 3 for different loads (5, 10 and 15)N, sliding velocities (1.5 m/s) and sliding time 5 second. Tables 1, 2, and 3 show the results demonstrate the outcomes relating to the coefficients of erosion and wear of filled and unfilled SiC nanocomposite. It can be observed from the Figures and Tables that there is a strong inter-dependence between the friction coefficients and wear loss irrespective of the loads and sliding velocities employed. The best value of wear rate, wear coefficient, and friction of coefficient at 10 Vol.% of nano-silicon carbide because high resistance wear and high value hardness of SiC.

Table 1: Data of wear rate and friction coefficient values.

| ***Data*** | **Code sample** | **ΔW** | **$W_R$x$10^{-7}$** | ***k*** | **μ** | **$H_{v.}$ MPa** |
|---|---|---|---|---|---|---|
| ***Time=5min*** | 0% SiC | 0.0008 | 17.8 | 0.0160 | 0.16 | 23.6 |
| ***Load 5 N*** | 5% SiC | 0.0004 | 8.9 | 0.0190 | 0.20 | 48.0 |
| SD=447.45 | 10% SiC | 0.0003 | 6.7 | 0.0173 | 0.17 | 58.0 |
| $V_S$=1.5 m/s | 15% SiC | 0.0005 | 11.1 | 0.0366 | 0.4 | 73.8 |

Table 2: Data of wear rate and friction coefficient values.

| ***Data*** | **Code sample** | **ΔW** | **$W_R$ x$10^{-7}$** | ***k*** | **μ** | **$H_{v.}$ MPa** |
|---|---|---|---|---|---|---|
| ***Time=5min*** | 0% SiC | 0.0013 | 29.05 | 0.0153 | 0.15 | 23.6 |
| ***Load 10N*** | 5% SiC | 0.0009 | 20.11 | 0.0216 | 0.22 | 48.0 |
| SD=447.45 | 10% SiC | 0.0001 | 2.235 | 0.0029 | 0.03 | 58.0 |
| $V_S$=1.5 m/s | 15% SiC | 0.0006 | 13.40 | 0.0221 | 0.24 | 73.8 |

Table 3: Data of wear rate and friction coefficient values.

| ***Data*** | **Code sample** | **ΔW** | **$W_R$ x$10^{-7}$** | ***K*** | **μ** | **$H_{v.}$ MPa** |
|---|---|---|---|---|---|---|
| ***Time=5min*** | 0% SiC | 0.0009 | 20.11 | 0.007 | 0.07 | 23.6 |
| ***Load 15N*** | 5% SiC | 0.0007 | 15.64 | 0.011 | 0.13 | 48.0 |
| SD=447.45 | 10% SiC | 0.0002 | 4.470 | 0.003 | 0.03 | 58.0 |
| $V_S$=1.5 m/s | 15% SiC | 0.0004 | 8.940 | 0.009 | 0.10 | 73.8 |

The examinations of select combinations of filled and unfilled nano - SiC specimens subjected to slide wear are shown in Figures 1, 2, and 3 respectively. The wear properties are examined for 5 Vol.%, 10 Vol. %, and 15 Vol.% nano-SiC filled matrix and illustrated in the figure below. It is observed that, the wear rate of epoxy decreased from (17.8 x $10^{-7}$ ) gm/cm to (8.94 x $10^{-7}$) gm/cm at a load of 5N, time 5min by reinforcing 15 Vol.% of SiC nanoparticles. After this latter, the wear rate increased to (17.8 - 29.05) x$10^{-7}$ gm/cm for epoxy and decreased to (20.11 x$10^{-7}$) gm/cm for nanocomposites respectively at 15N load, time 5min as illustrated in Table 3. It is observed that the composite filled with 15 Vol.% SiC nanoparticles exhibits lowest wear rate in comparison with the wear rate of pure epoxy. After increasing the volume fraction of SiC nanoparticles, wear rate of nanocomposite is increased. The same trend is observed for (5 N, 10 N and 15 N) load as shown in the Figures below. This indicates that the filler content played a key role in the wear property of epoxy nanocomposites. From the SEM examinations (Figures 4, 5, 6, and 7) of SiC nanocomposites, it is clearly observed that the 5 Vol.% and 10 Vol.% SiC nanoparticles are mixed thoroughly in epoxy matrix without any aggregation of SiC nanoparticles. The surface is also smooth for 5 Vol.% and 10 Vol.% SiC nanocomposites. From the SEM images (Figure 7), it is observed that there is an aggregation of SiC nanoparticles in the epoxy matrix by reinforcing 15 Vol.% based on this examination. It can be inferred that SiC at low volume fractions distributed uniformly on the subsurface of the nanocomposite, which reduces the destruction of matrix during wear process. Also it can be observed, the higher volume fractions of SiC nanoparticles in the epoxy matrix leads to aggregation.

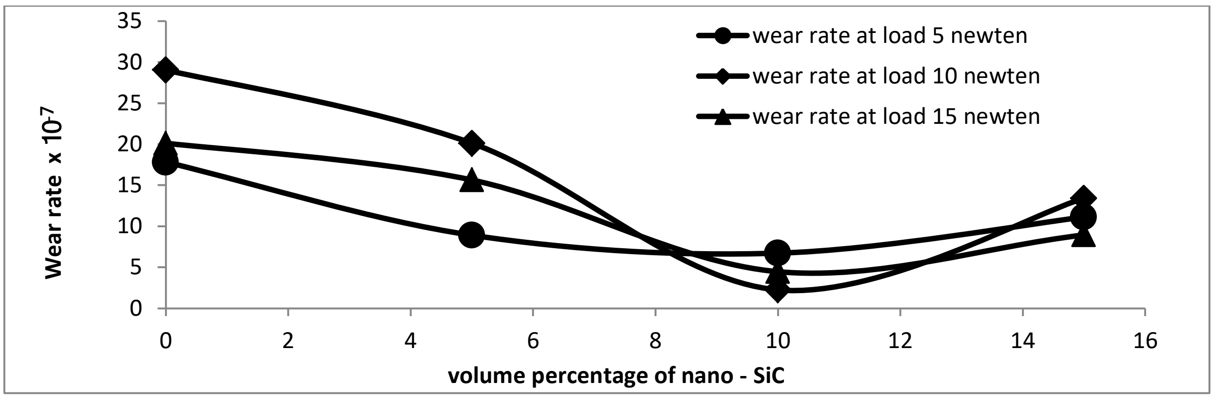


Figure 1: Wear rate at different condition.

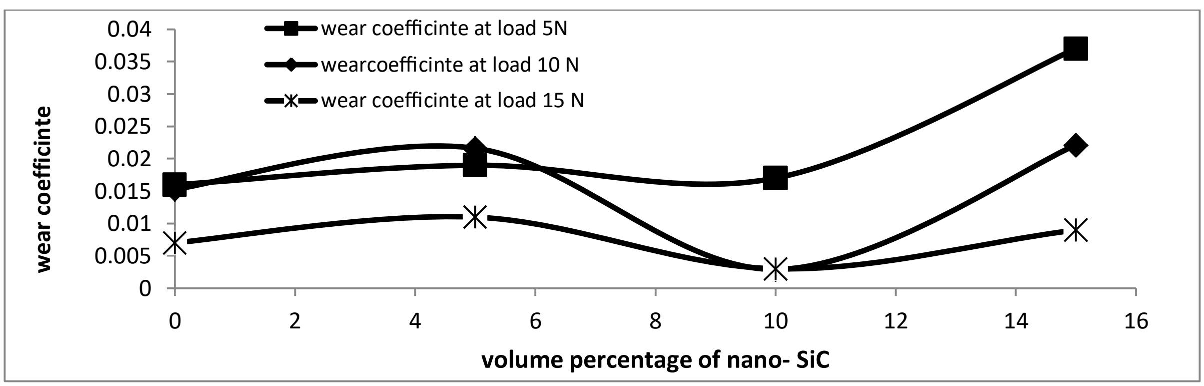


Figure 2: Wear coefficients at different condition.

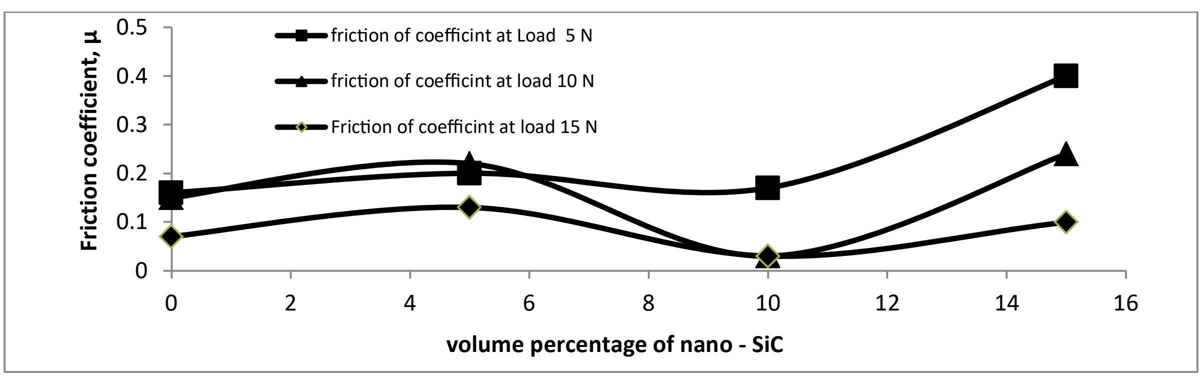


Figure 3: Friction of coefficients at different condition.

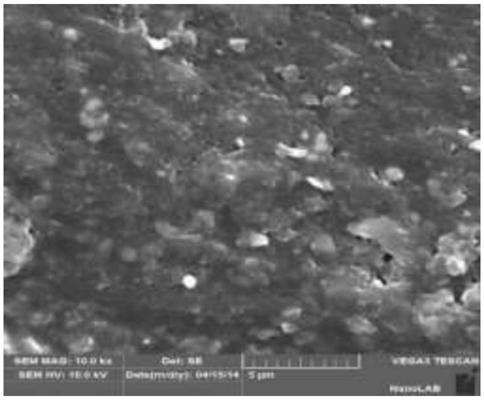

Figure 4: SEM image of 0%SiC.

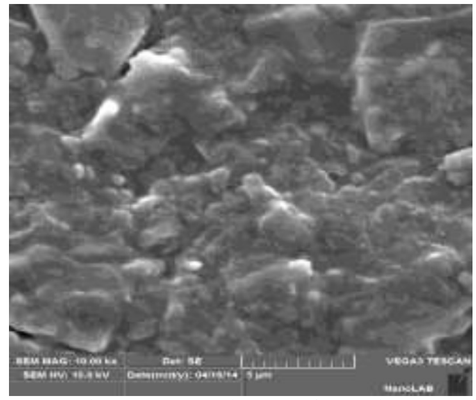

Figure 5: SEM image of 5%SiC.

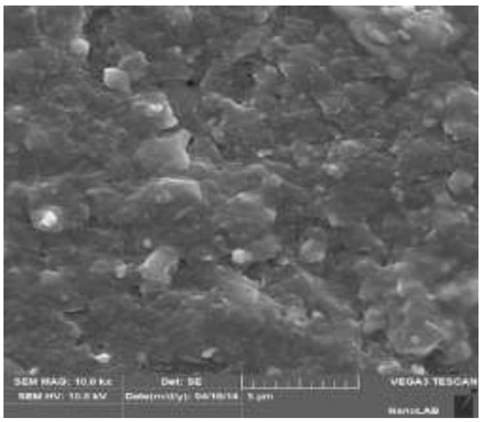

Figure 6: SEM image of 10%SiC.

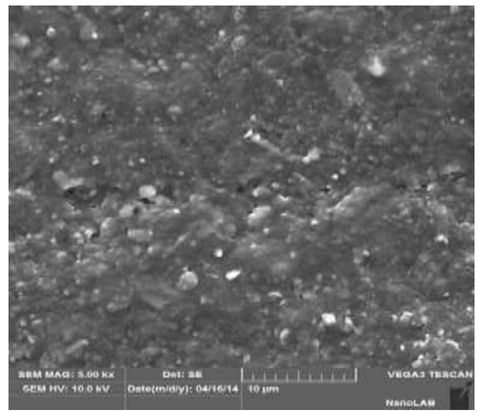

Figure 7: SEM image of 15%SiC.

## Conclusions

It can be concluded from the present study that although the coefficient of friction of the SiC – epoxy nanocomposites is moderate, which obviously not very suitable as bearing material; it can be however be safely used in seal and contact regimes. The wear and friction coefficients decreased with low volume fractions of nano–SiC.

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