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Effects of Different Types of Fillers on Dry Wear Characteristics of Carbon-Epoxy Composite

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Abstract

Experimental investigations had been done in this research to demonstrate the effect of carbon fiber and Ceramic fillers contents on the tribological behaviour of (15% volume fraction) carbon-epoxy composite system under varying volume fraction, load, time and sliding distance. The wear resistance were investigated according to ASTM G99-05standard using pin on disc machine to present the composite tribological behaviour. The influence of three ceramic fillers, granite, perlite and calcium carbonate ($CaCO_3$), on the wear of the carbon fabric reinforced epoxy composites under dry sliding conditions has been investigated. The effect of variants in volume fraction, applied load, time and sliding distance on the wear behaviour of polymer composites is studied by measuring the weight changes . In the experiments with wear test pin having flat face in contact with hardening rotating steel disc, sliding speed, time and loads in the range of 200 RPM, 300–900s and 40–60 N respectively was used. It is observed that the wear resistance increase with the increasing of reinforcement material volume fraction while, the wear rate increases with increasing of applied load, time and sliding distance. The results showed that the filler of granite perlite and $CaCO_3$ as filler materials in carbon epoxy composites will increase the wear resistance of the composite greatly than carbon fiber fillers epoxy composite only and granite filled CE Composite exhibited the maximum wear resistance.

Keywords*: Carbon-epoxy composite, ceramic Fillers, Sliding wear.*

1. Introduction

With our continuing quest for lighter and stronger composites, the demand for new types of composite materials is increasing. In recent years various composite materials have been used extensively in aircraft structures, space vehicles, automobiles, sporting goods, electronic packaging to medical equipment, and many consumer products[1]. The main advantage of composite materials is the potential for a high ratio of stiffness to weight, corrosion resistance, high fatigue strength etc.[2]

Epoxy resin (EP) is a thermoset resin with good thermal and environmental stability, high strength and wear resistance. This combination of properties permits the application of EP in polymer-based heavy duty sliding bearings. For these purposes, EP usually is compounded with reinforcements like glass or carbon fibers and ceramic .mineral oxides and inorganic fillers [3]. The use of fillers in polymeric composites helps to improve tensile and compressive strengths, tribological characteristics, toughness (including abrasion), dimensional stability, thermal stability, and other properties. In addition to the higher mechanical strength obtained due to the addition of fillers in polymeric composites, there is cost reduction in terms of consumption of resin material[4].

In order to obtain perfect friction and wear properties many researchers modified polymers using different fillers [5-12]. Briscoe et al.[5] reported that the wear rate of high density polyethylene

(HDPE) was reduced with the addition of inorganic fillers, such as CuO and Pb_3O_4. Tanaka[6] concluded that the wear rate of polytetrofluroethylene (PTFE) was reduced when filled with ZrO_2 and TiO_2. Bahadur et al.[7-9] found that the compounds of copper such as CuO and CuS were very effective in reducing the wear rate of PEEK, PTFE, Nylon and HDPE. Kishore et.al.[10] studied the influence of sliding velocity and load on the friction and wear behaviour of G-E composite, filled with either rubber or oxide particles, and reported that the wear loss increased with increase in load/speed. Solid lubricants such as graphite and MoS_2[11,12] when added to polymers proved to be effective in reducing the coefficient of friction and wear rate of composites. The objective of this work is to investigate the wear properties of carbon fiber epoxy composite at different volume fraction and different ceramic particulate at 15% GF chopped filled epoxy matrix composites sliding against a hardened steel counter face. As a comparison, the wear properties of plain C-E were also evaluated under identical test conditions. This work helps in understanding the function of different fillers in C-E composites.

2. Experimental Details

2.1. Materials

Three particulate reinforcing materials (granite) ,(perlite) and ($CaCO_3$) prepared from German company with grain size (10 µm) and Volume fraction (1%,2,5%,4 %, and 5% Vol.) were used here to reinforce the epoxy-carbon composite. The matrix system (Epoxy resin Quick mast 105 +and hardener Quick mast 105) was commercially obtained from (DCP) Jordan company. The details of epoxy resin illustrated in Table (1). The main reinforcement used was chopped carbon fiber used in this research with length (12mm) and diameter (10-14µm) produced by (Grace cemfiber company). The properties of carbon fiber as shown in Table (2). The properties of (granite), (perlite) and ($CaCO_3$) particles shown in Tables (3), (4) and (5) respectively, [used from sheet supplied].

2.2. Specimens Preparation

All specimens in this study were manufactured by hand layup technique. The mould that was used is made of glass with dimension of (200, 150, 10) mm as shown in Figure (1). The mould must clean and covered the inside walls of the mould with vaseline to prevent the adhesion between the mould and polymeric material. The polymeric material is present by mixing the epoxy resin with the hardener in (3:1) ratio at room temperature, the mixing was very slow, using glass rod for (15min) until it becomes homogenous, chopped carbon fibers are reinforced in epoxy resin to prepare the composite group B_1. No particulate filler is used in this composite. The volume fraction of carbon fiber in composite is kept at 2.5, 5, 7.5, 10, 12.5, 15 Vf % for samples, the other composite groups (B_2, B_3 and B_4) with particulate fillers 1, 2.5, 4, 5 Vf% of granite, perlite and $CaCO_3$ added to 15%Vf carbon fiber respectively the fillers are mixed thoroughly in epoxy resin before the carbon fibers are reinforced in the matrix body and continuously mixing until it becomes homogenous, the mixing is completed after (2min), then the mixture is poured in the mould from one side only to eliminate the entrapment of air, when the solidification process for all moulds is completed after 24 hours, the casts are released from the moulds. The mould is cut in to a standard specimen dimensions according to ASTM G99-05 standard as shown in Figure (2).

3. Sliding Wear Testing

The wear test was performed by using pin-on-Dick test instrument shown in the Figure (3). The wear rate calculated according to eq.(1) at different volume fraction, loading, sliding time and sliding distance.The disc is made of a tool steel material with hardness (385 HV), which has a rotating radius of (90 mm) and a rotating speed of (200 r.p.m.). All tests were conducted at room temperature. Wear tests were conducted with loads ranging from (40-60 N) and sliding distance range (942-1507.2m) and sliding time ranging from (300-900s). The initial weight of the specimens was measured using sensitive balance weight with an accuracy of (10^{-4} g). After the end of testing the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The differences in weight measured before and after tests gives wear of the composite specimen. The following relation is used to investigate the wear volume loss which is:

$$\text{Wear rate (volume) } (cm^3/m) = \frac{W1-W2}{S*\rho} \quad \ldots(1)$$

Where: W1: weight before testing (g), W2: weight after testing (g), ρ:density (g/cm^3) and S: sliding distance (m) calculated from the formula:

$$S=2\pi rnt \quad \ldots(2)$$

where: r: the distance from the center of the sample to the center of disc in meter, n: disc rotational speed in r.p.m, and t:time of testing in(min).

Table 1,
Physical and Mechanical Properties of Epoxy Resin[13].

Flexural strength (MPa)	**Specific heat (J/Kg.K)**	**Tensile Strength GPa**	**Density g/cm^3**	**Flexural strength** (MPa)
13	1050	20-25	1.004	13

Table 2,
Physical and Mechanical Properties of Carbon Fiber[13].

Thermal Conductivity W/m.K	**poisson's ratio**	**Tensile Strength GPa**	**Density g/cm^3**	**Young's modulus GPa**
105	**0.20**	**2.4**	**1.8**	**230**

Table 3,
Physical and Mechanical Properties of Granite Particles.

Appearance	**Diameter**	**possin's ratio**	**Density g/cm^3**	**Young's modulus GPa**
grey powder	**≥ 10µm**	**0.3**	**2.75**	**52**

Table 4,
Physical and Mechanical Properties of Perlite Particles.

Appearance	**Diameter**	**possin's ratio**	**Densit g/cm^3**	**Young's modulus GPa**
white powder	**≥ 10µm**	**0.296**	**2.04**	**46.51**

Table 5,
Physical and Mechanical Properties of $CaCO_3$ Particles.

Appearance	**Diameter**	**Density g/cm^3**	**Young's modulus GPa**
white powder	**≥ 10µm**	**2.83**	**72.36**

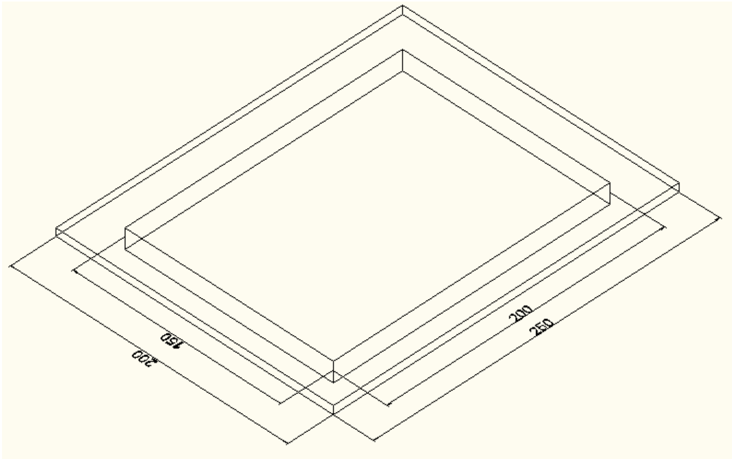

Fig. 1. The Shape of the Mould.

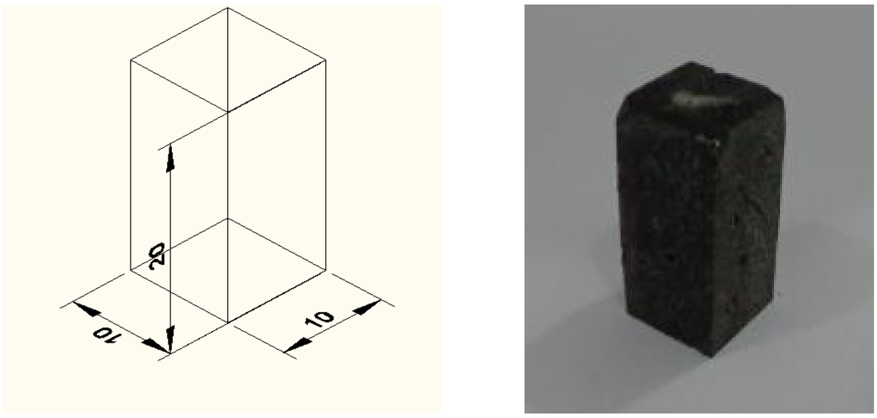

Fig. 2. Standard Wear Test Specimen[14].

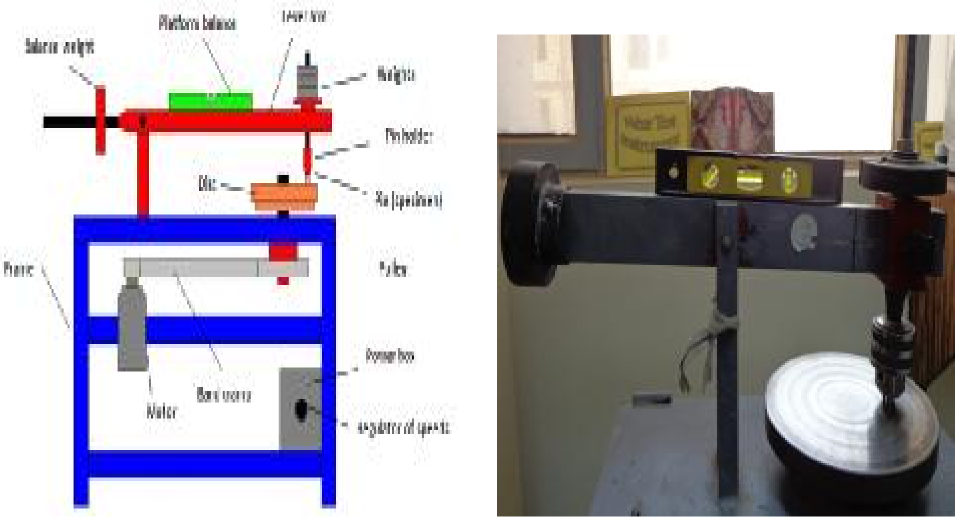

Fig . 3. Schematic of Pin-on-Disc Wear Testing Machine.

4. Result and Discussion

4.1. Wear Test

Wear test was investigated for specimens prepared from epoxy before and after adding the reinforcement materials. Wear test type pin on disc carried out for these specimens various graphs are plotted and presented in Figures (4 to 11). For different percentage of reinforcement under different test conditions. (volume fraction, Load, time and sliding distance.

4.1.1. Effect of Volume Fraction

The wear resistance of group (B_1) samples with different volume fraction of carbon fiber shown in Figure (4). When compared with the matrix material an increase represents in of 55.92% in wear resistance with the adding of 15% carbon fiber. With the adding of granite, perlite or $CaCO_3$ particles filler to 15% carbon fiber further increase in wear resistance of group (B_2, B_3 and B_4) as shown in Figure (5). At comparison to 15% glass fiber an increase represents in of 62.33%, 54.28% and 46.36% in wear resistance respectively.

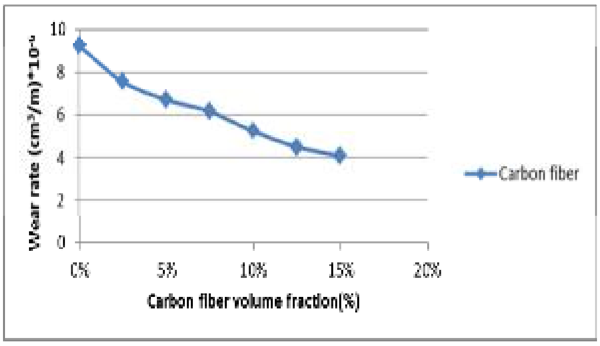

Fig. 4. Effect of Volume Fraction on Wear Rate of Carbon Fiber.

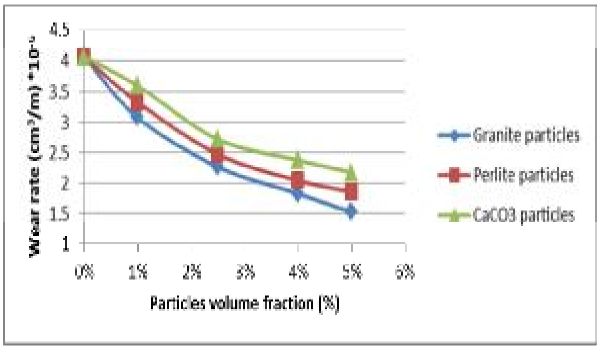

Fig. 5. Effect of Volume Fraction on Wear Rate of Granite, Perlite, CaCO3 Particles with 15% Carbon Fiber.

4.1.2. Effect of Applied Load

The influence of different normal loads on the wear rate of the un-reinforced and reinforced composites at constant parameters such as rotating disc speed 200 rpm, time 15min and sliding distance 1507.2m. the wear rate of all composite samples increases with increased normal load. This is because at higher load, the frictional thrust Increases, which results in increased deboning and fracture. A similar effect of different normal load on volumetric wear rate has been observed by Cirino et.al.[15]. As shown in Figure (6**).**

The wear rate of composite material with (5%, 10%, 15%) carbon fiber. An increase represents by (25%, 39%, 46%) respectively in wear resistance can be recognized when compared to the matrix material, in the case of carbon epoxy composite and Verma et. al. [16] for CRP composite. It has also been observed that the wear rate decreases with addition of carbon fiber up to 15vol% under all Testing condition.

With the adding of 2.5% granite, perlite or $CaCO_3$ powder with 15% carbon fiber further increase in wear resistance as shown in Figure (7). Th an increase recorded can be represented by (42.4%, 37.5%, and 29.6%) respectively in wear resistance when compared to reinforced carbon fibers only. Thus it can be conclude, addition of the ceramic particles granite, perlite and calcium carbonate.

The wear rate values are directly proportional with normal load, this fact can be seen clearly when we compare the Figures (6) to (7), and the reason of this proportional due to the increasing of the friction force which increases, when the normal load increases, because of the fraction area increasing. This lead to the increasing of loss weight, and finally the increasing of wear rate.

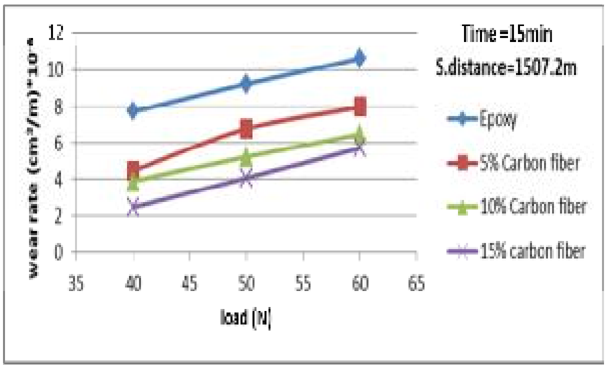

Fig. 6. Effect of Load on the Wear Rate of Carbon Fiber.

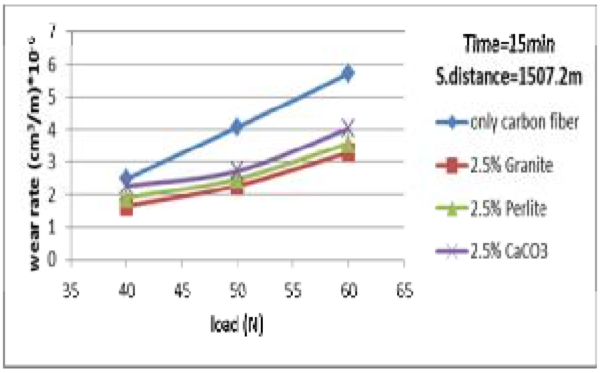

Fig. 7. Effect of Load on Wear Rate of Granite, Perlite, $CaCO_3$ with15% Carbon Fiber.

4.1.3. Effect of Sliding Time

Figure (8) shows the behaviour of wear with sliding time of the epoxy matrix specimen and reinforced by different carbon fiber volume fraction (5%, 10%, 15%) respectively, It can be seen that the wear rate of the composite pin increases with the increase of the period of sliding time similar to the case of the increasing the load, and the worst wear rate when unreinforced epoxy also it can be seen the wear rate degree when increase in volume fraction of carbon fiber and the great wear resistance at 15% carbon fiber volume fraction. At comparison with the matrix material wear resistances an increase represents by (26.7%, 43.25%, 56%).

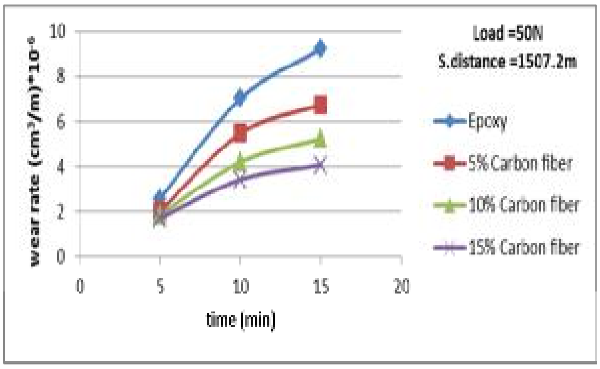

Fig. 8. Effect of Time on Wear Rate for Carbon Fiber.

From Figure (9) shows, the relationship between the sliding time and the wear volume loss of the composite pin reinforced by (15%) carbon fiber volume fraction at different ceramic particles granite, perlite and $CaCO_3$ for (volume fraction 2.5%). increase in wear resistance as shown in Figure (9). When compared to 15% carbon fiber an increase represents by (44.16%, 39%, 33%) respectively in wear resistance. It can be seen in these figures, at the beginning of the sliding time the values of wear rates for all samples under tests are high values, this behavior may be due to the separation of asperities from the sample surface.

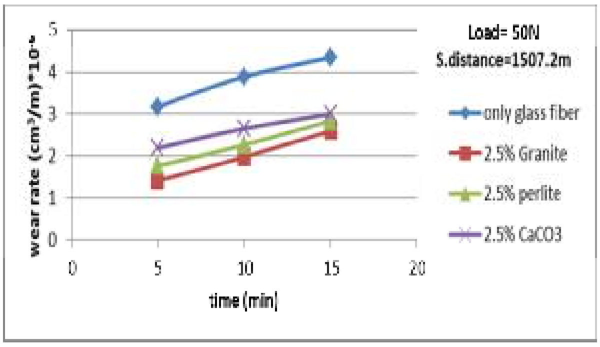

Fig. 9. Effect of Time on Wear Rate of Granite, Perlite, $CaCO_3$ Powder with 15% Carbon Fiber.

4.1.4. Effect of Sliding Distance

The assessments of wear rate with different sliding distance under the testing conditions as shown in fig (10and11). Figures(10) have been plotted to explain the variation of wear rate with sliding distance at normal load 50 N. The wear resistance of composite material with (5%,10%,15%) carbon fiber as shown in figure (10). An increase represents in of (26.7%, 43.35%, 56%) respectively in wear resistance when compared to the matrix material. It has been observed that the wear rate increases with increasing sliding distance for all the samples. It is also observed that the 15vol% carbon fiber reinforced composite shows a minimum wear rate under all testing conditions. This again reveals that the addition of carbon fiber can improve the wear resistance of composite.

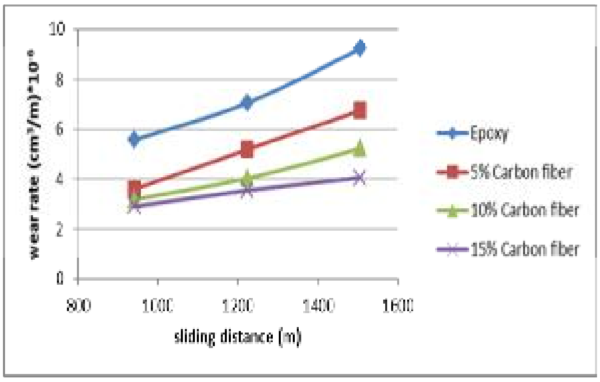

Fig. 10. Effect of Sliding Distance on Wear Rate of Carbon Fiber.

As Figure (11) show with the adding of 2.5% granite, perlite or $CaCO_3$ particles to 15% carbon fiber further increase in wear resistance as shown in figure(11). At comparison to 15% carbon fiber an increase represents in of (44.15, 39%, and 33%) respectively in wear resistance. The assessments of wear rate with different sliding , Figures-have been plotted to explain the variation of wear rate with sliding distance at normal load 50N. It has been observed that the wear rate increase with increasing of sliding distance for all the samples. It is also observed that the 15 vol% CF reinforced composite shows a minimum wear rate under all testing conditions. This again reveals that the addition of fiber can improve the wear resistance capacity of epoxy.

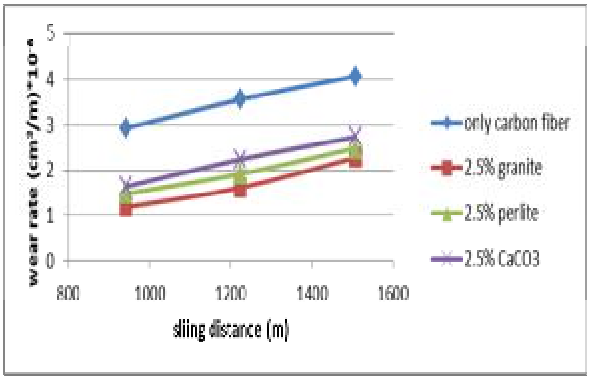

Fig. 11. Effect of Sliding Distance on Wear Rate of Granite, Perlite, $CaCO_3$ Particles with 15% Carbon Fiber.

Table 6,
List of Abbreviations and Symbols

Abbreviations and Symbols	Meaning	Units
Ep	Epoxy resin	-
HDPE	High density polyethylene	-
PTFE	Polytetroflouroethylene	-
PEEK	Polyetherether ketone	-
C-E	Carbon-Epoxy	-
ASTM	American society of testing and materials	-
W_1	weight before testing	g
W_2	weight after testing	g
s	sliding distance	m
ρ	density	g/cm^3

5. Conclusions

The primary conclusions are as follows:-

1. The wear volume loss of the reinforced epoxy specimen increases as the load, time and sliding distance increases.
2. The wear resistance of the composite system increase with the increasing of reinforcement material for all the specimen.
3. The addition of carbon fiber as a reinforcement material leads to increase the wear resistance of epoxy composite more than unreinforced epoxy.
4. 4-The adding of ceramic fillers to carbon epoxy composite leads to increase the wear resistance more than carbon- epoxy composite without ceramic fillers.
5. granite filler added to carbon-epoxy composite show better wear resistance than perlite and CaCO3 particles.
6. The highest wear resistance is that of the composite with 15% carbon fiber +5% granite particles, which is 83.4 % higher than that of the matrix material.

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تأثير الحشوات السيراميكية على خواص البلى للمواد المتراكبة للايبوكسي- كاربون

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الخلاصة

في هذا البحث تمت دراسة تأثير الياف الكاربون والحشوات السيراميكية على الخواص الترايبولوجية لراتنجات الايبوكسي المقواة بالياف الكاربون عمليا وعند كسر حجمي 15% . تم دراسة مقاومة البليان وفقا للمواصفة ASTM G99-05باستعمال جهاز المسمار مع القرص الدوار وعند احمال 40–60 N ومسافات انزلاق 942-1507.2 m وازمان مختلفة 300–900s وبعد اجراءالاختبارات لوحظ بان مقاومة البليان تزداد مع زيادة الكسر الحجمي لمواد التدعيم بينما معدل البلى بصورة عامة يزداد بزيادة الحمل المسلط والزمن ومسافة الانزلاق، ويكون معدل البليان للعينات الغير مدعمة اعلى بكثير من العينات المدعمة بالياف الكاربون فقط والعينات المدعمة بنسبة 15% الياف كاربون مع الحشوات السيراميكية المختلفة وان مقاومة البليان للعينات المحتوية على حشوات سيراميكية تكون اعلى من العينات المدعمة بالياف كاربونية فقط وان مقاومة البليان لمجموعة العينات المقواة بالياف كاربون مع كرانيت بلغت اعلى قيمة لها تليها ألعينات المدعمة بالبرلايت ثم عينات كاربونات الكالسيوم. نستنتج من ذالك اضافة الحشوات السيراميكية مع الياف الكاربون يحسن بشكل كبير من مقاومة البليان.