WEAR RATE BEHAVIOR OF CARBON/EPOXY COMPOSITE MATERIALS AT DIFFERENT WORKING CONDITIONS

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ABSTRACT

A Pin -on- Disc wear testing rig of variable sliding speed with varying load and sliding time has been used in this research to measure the wear rate of the carbon/epoxy composite specimens at dry and wet working conditions.

In this research the composite specimens made from the epoxy used as a matrix and the carbon fiber with length ≤ 3mm and volume fraction (3, 6 & 9 vol. %) as reinforcement.

The results show that the wear rate of composite specimens increase in nonlinear relationship with increase the applied load, sliding speed and sliding time and decrease in nonlinear relationship with increase the volume fraction of carbon fiber.

The results also show that the wear rate for the epoxy reinforced by carbon fibers for dry working conditions was higher than the wear rate for wet working conditions. The maximum percentage reduction in wear rate was 30% for wet working conditions and 18.5 % for dry working conditions at 9 % Vol. of carbon fibers when compared with the neat epoxy.

Key word: epoxy, carbon fiber, wear rate, volume fraction

سلوك معدل البلى لمادة متراكبة ايبوكسي/الياف كاربون عند ضروف عمل مختلفة

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الخلاصة

لقد استخدم جهاز قياس البلى (المسمار – على – قرص) ذو السرع المختلفة مع تغير الحمل وزمن الانزلاق لقياس معدل البلى لعينات متراكبة مصنوعة من الايبوكسي المقوى بالياف الكاربون عند ضروف عمل جافة ورطبة.

في هذا البحث العينات المركبة مصنوعة من راتنج الايبوكسي كمادة اساس مقواة والياف الكاربون المتقطعة بطول ≤ 3mm وبكسر حجمي (3, 6 & 9 vol. %) كمادة تقوية. بينت النتائج بان معدل البلى للعينات المركبة يزداد بعلاقات لاخطية مع زيادة الحمل المسلط والسرعة الانزلاقية والزمن الانزلاقي ويقل بعلاقات لاخطية مع زيادة الكسر الحجمي لالياف الكاربون. وكذلك بينت النتائج بان معدل البلى للايبوكسي المقوى بالياف الكاربون عندالضروف الجافة اعلى من معدل البلى عند الضروف الرطبة لنفس الكسر الحجمي. وان اقصى نسبة انخفاض في معدل البلى للايبوكسي المقوى بالياف الكاربون بكسر حجمي (9 Vol.%) كانت (30 %) عند العمل في الضروف الرطبة و (18.5 %) عند العمل في الضروف الجافة مقارنة مع الايبوكسي الغير مقوى بالياف الكاربون.

INTRODUCTION

Wear was defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between contacting surfaces. The five main types of wear were abrasive, adhesive, fretting, erosion and fatigue wear, which were commonly observed in practical situations. Abrasive wear was the most important among all the forms of wear because it contributes almost 63% of the total cost of wear [1].

The application of carbon fibers/polymer composite has continuously resin the last decade, especially in car and aerospace industry, robots, sports goods,……etc. due to the improvement of mechanical properties. Carbon fibers posses exceptional specific strength and stiffness and hence they find important applications in structural composites. The performance of such composites depends on the properties of the fibers and surrounding matrix, but also on the interface between them [2 & 3].

Wears are not intrinsic material property but are characteristics of the engineering systems. Wear problems especially abrasive and adhesive type often lead to replacement of components and assemblies in engineering due to changes in dimensions of the mating parts [4].

Therefore Wear studies become so important in order to decrease costly losses of equipments and machinery and to increase the life of tribological components.

The wear properties can be varied substantially through changes in the microstructure, the morphology, volume (or weight) fraction and mechanical properties of the reinforcing phase, and the nature of the interface between matrix and the reinforcement.

Vasconcelos et al. used epoxy resin based composites containing aluminum particles and milled glass fibers to investigate the wear resistance for rapid tooling and found that the epoxy resin reinforced by glass fiber have lower wear rate than the neat epoxy [5].

Lee et al. investigated the effect of wear debris on wear characteristics of carbon/epoxy composites with and without micro-groove for the specimens by dry sliding test and found that the wear rate of grooved specimens was lower than that of flat specimens at different working conditions [6].

The investigation of the friction and wear loss of the carbon-epoxy composite and glass-epoxy composite by using pin-on-disc were made by suresha et al. conducted the samples sliding against a hard steel disc under different working conditions. The results illustrated the composite show lower friction and lower slide wear loss compared to composites irrespective of the load or speed employed [7].

Quintelier et al. used pin-on-disc rig to test wear and friction of poly phenylene sulfide reinforced by carbon fibers, and found that the wear behavior is strongly dependent on the weft-warp direction, where the 90º disc position (parallel fiber orientation with the weft direction) and the 0º disc position (indicated via the line in the middle of the disc) orientation have an earlier wear through the top layer of PPS than 45º, and perpendicular to the weft direction (0º disc position) has an earlier wear through than the parallel (90º disc position) [8].

The investigated of the wear behavior of chopped strand glass fiber reinforced polyester by using pin-on-ring configuration with silicon carbide abrasive paper with different grade at different normal loads and rotating speed. The results illustrated the wear rate of the composite specimens increases substantially with increasing the size of the abrasive grits and rotational speed, where as it leads to decrease with increasing the applied normal load [9].

The aim of this work is to study the effect of the volume fraction of chopped carbon fibers on the wear rate characteristics of the epoxy at dry and wet working condition.

THEORY

Wear is one of the most commonly encountered industrial problems leading to the replacement of components and assemblies in engineering.

In general there is great enthusiasm for wear resistant of the polymer, in order to obtain the optimal wear rate without compromising the beneficial properties of the matrix material, an accurate prediction of the wear of the composites is essential by using the linear rule of mixtures which introduced by Zum-Gahr to explain experimental data, the contribution from each component is linearly proportional to its volume fraction in the composite [10].

$$K_c = V_f \cdot K_f + V_m \cdot K_m \tag{1}$$

Where:

K_c, K_m and K_f : Wear rate of the composite, the matrix and the reinforcement (fibers) respectively.

V_m and V_f : Volume Fraction of the matrix and the reinforcement (fibers) respectively.

Here; the wear behavior of a composite is not dominated by a single phase but depend on matrix phase and reinforced phase. It is noted that the abrasive wear rate of the composite decreases linearly with the increase of volume fraction of the reinforcement [10].

Abrasive wear may be prevented or minimized by selecting alternative materials such as replacing the softer material by harder one or by use lubricant between the two sliding surfaces like oil or water [11].

EXPERIMENTAL WORK

The composite specimens were made from (epoxy) as a matrix and short carbon fiber as the reinforcement with length ≤ 3 mm at different volume fractions of (3, 6 and 9 vol. %) by mixing the short reinforcing fibers in liquid epoxy followed by casting in an open mould (Hand Lay-out method). The specimens were cured in oven for 30 min. at temperature = 70 ºC. The dimension of the specimen was 9.5 mm diameter and 20 mm length based on the standard wear tests described in ASTM standard D5963-97a [12].

Table (1) illustrates some properties of the epoxy and carbon fiber that used in this investigation [13].

The rotating Pin -on- Disc wear testing machine within a conditioned laboratory environment. The weighing method was used to determine the mass loss of the test specimens before and after the test. The experimental conditions were done under variable load within the range of (4 - 16 N) and a sliding speed within the range of (0.4 – 1.6 m/sec.) by using different belts and pulleys and sliding time within the range of (5 – 20 min.) at dry and wet (continuous water between pin and sliding disc) working conditions between the composite pin and steel disc.

The following relation is used to investigate the wear rate which is [14]:

$$K_c = \frac{\Delta m}{\rho_c \cdot V_s \cdot T} = \frac{m_2 - m_1}{\rho_c \cdot V_s \cdot T} \qquad (mm^3/mm) \qquad (2)$$

Where:

K_c -Wear Rate of the composite (mm^3/mm).

ρ_c -Density of the test specimen (gm/mm^3).

Δm -Weight loss (gm).

m_1 -Weight of the specimen before test (gm).

m_2 -Weight of the specimen after test (gm).

V_s -Sliding speed (mm/sec.).

T -Sliding Time (sec.).

RESULTS AND DISCUSSION

The effect of applied normal load on wear rate of the unreinforced and reinforced epoxy with a volume fraction of (3, 6, and 9 Vol. %) of carbon fiber at speed = 0.8 m/sec., sliding time = 10 min.) for both dry and wet working conditions represented in figures (1 and 2) respectively.

These figures illustrated that with the increasing the applied load the wear rate of the reinforced and unreinforced epoxy increases at different rates for all values of volume fractions and for both dry and wet working conditions. The wear rate of the neat epoxy is more than that of the reinforced epoxy for all values of load. This is due to presence of reinforcing fibers that lead to increase the average hardness of the composite. Moreover, as the percentage of reinforcement increases, the wear rate of the composite decreases [7].

Figures (3 and 4) show the relationship between the sliding speed and the wear rate of the reinforced and unreinforced epoxy by fibers, for different volume fraction of (3, 6, and 9 Vol. %) at working condition (load = 12 N, and sliding time= 10 min.) and for both dry and wet working conditions respectively.

It is clear from these figures that the wear rate of the composite pin increases in nonlinear relationship with the increase of the sliding speed at different rates.

These figures also show that the wear rate of the reinforced epoxy was lower than that of the unreinforced epoxy. These results may be expected due to the fact that the adhesion (bonding) between the fibers and matrix deteriorates when sliding occurs at high speed leading to easier peeling or pulling out of fibers from matrix [7].

The effect of sliding time on wear rate of the unreinforced and reinforced epoxy with a volume fraction of (3, 6, and 9 Vol. %) of carbon fiber at speed = 0.8 m/sec., applied load = 12 N) for both dry and wet working conditions represented in figures (5 and 6) respectively.

Also it can be seen from these figures that the wear rate of the composite pin increases in nonlinear relationship with the increase of the sliding time at different rates for both dry and wet working conditions.

Figure (7) illustrates the variation of wear rate with volume fraction of carbon fibers at working condition (load = 12 N, speed = 0.8 m/sec. and sliding time = 10 min.). From this figure it is obvious that wear rate decrease with increase the volume fraction of carbon fiber that due to the hardness and bonding forces (i.e. nature of the interface between fibers and matrix).

The percentage of reduction in wear rate between the neat epoxy and reinforced epoxy by 9 Vol.% of carbon fiber was 18.5% for dry condition and 30 % for wet condition that due to the wet case which work as a lubricant in contact surface area between the pin and disc.

CONCLUSIONS

The following conclusions can be drawn from the results of this study.

1- There has been an observed marked improvement in wear resistance as seen in reinforced epoxy by carbon fibers compared to unreinforced epoxy.
2- Wear rate of the composite specimen decreases with the increase of weight fraction and for dry working conditions was higher than that at wet working conditions.
3- In the present investigation, the (9 Vol. %) volume fraction of reinforcing fibers exhibited better wear resistance than the other combinations for both dry and wet working conditions.
4- The maximum percentage reduction in wear rate was 30% for wet working condition at 9 Vol. % of carbon fibers.

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Table (1): Some Properties of Fibers and Matrix [13].

Property	Units	Matrix	Fibers
		Epoxy	Carbon
Density	g/cm^3	1.25	1.78
Modulus of Elasticity	GPa.	2.41	230
Tensile Strength	MPa.	60	4000
Percentage Elongation	%	4.5	2
Thermal Conductivity	W.m/ºC	0.19	11

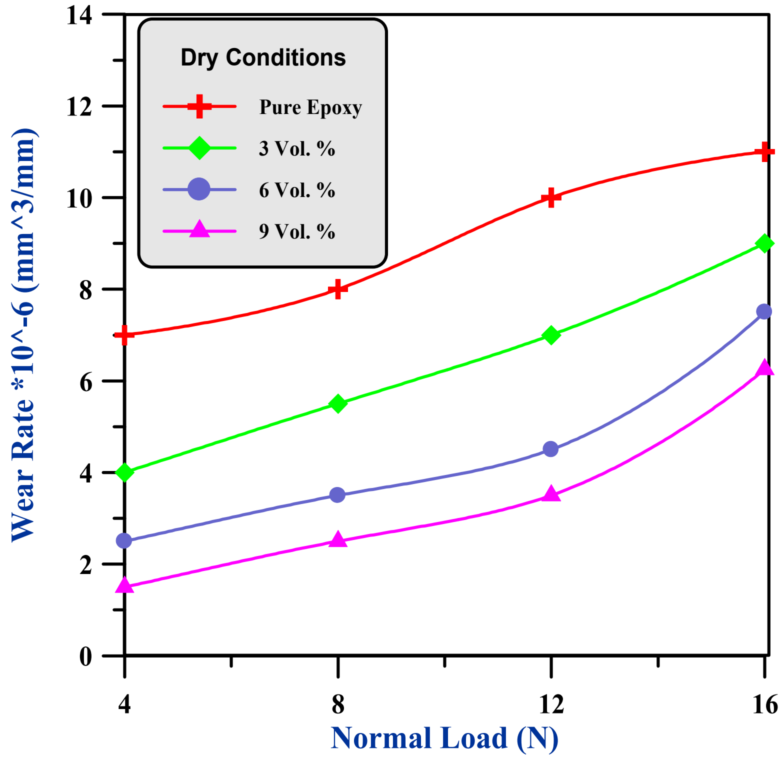

Figure (1): Relationship Between the Normal Load and the Wear Rate of the Epoxy Reinforced by Carbon Fiber at Dry Working Conditions (V_s= 0.8 m/sec., and T= 10min.).

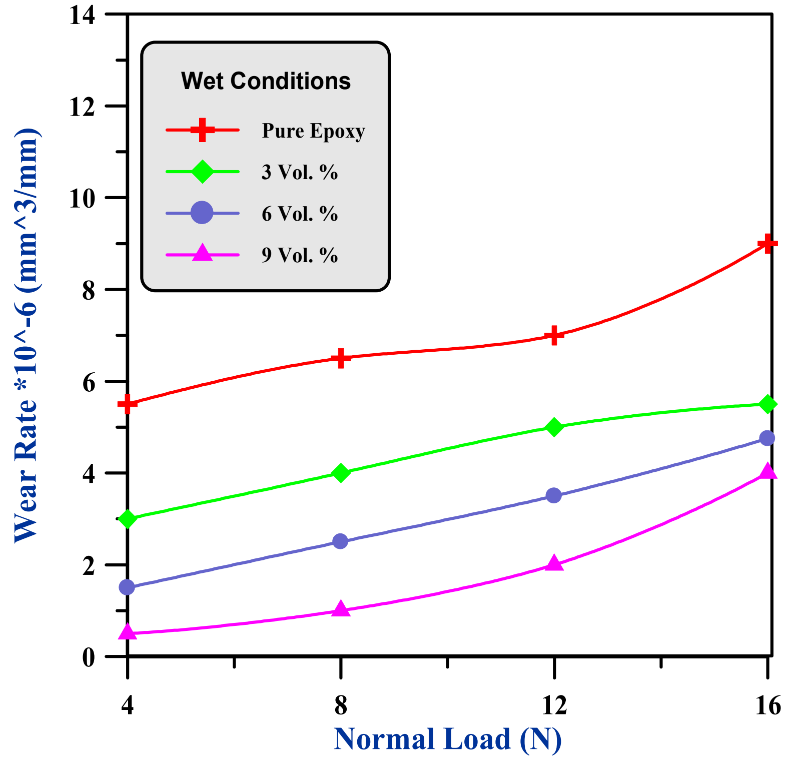

Figure (2): Relationship Between the Normal Load and the Wear Rate of the Epoxy Reinforced by Carbon Fiber at Wet Working Conditions (V_s= 0.8 m/sec., and T= 10 min.).

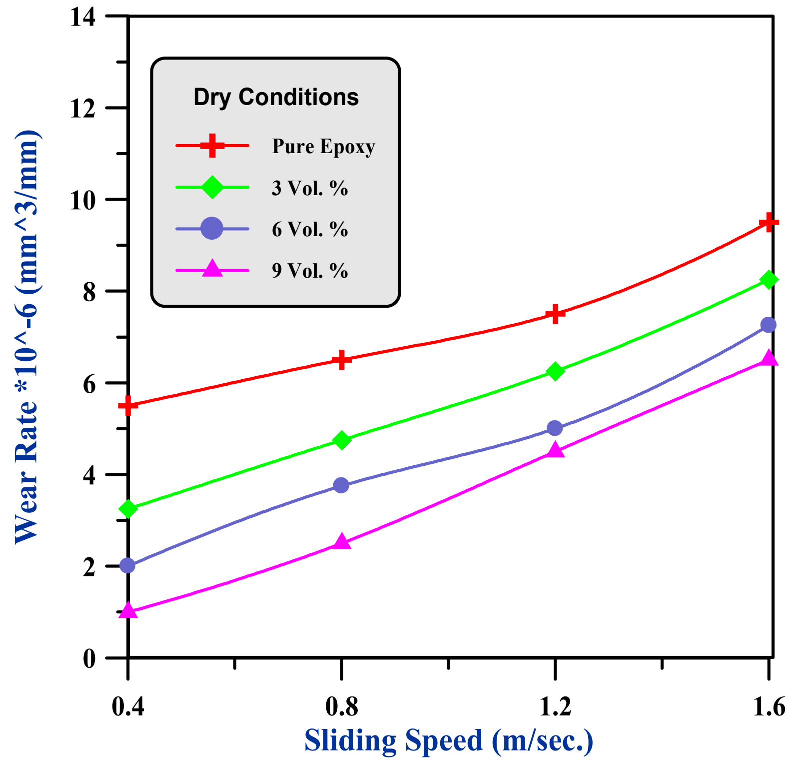

Figure (3): Relationship Between the Sliding Speed and the Wear Rate of the Epoxy Reinforced by Carbon Fiber at Dry Working Conditions (W=12 N, and T= 10 min.).

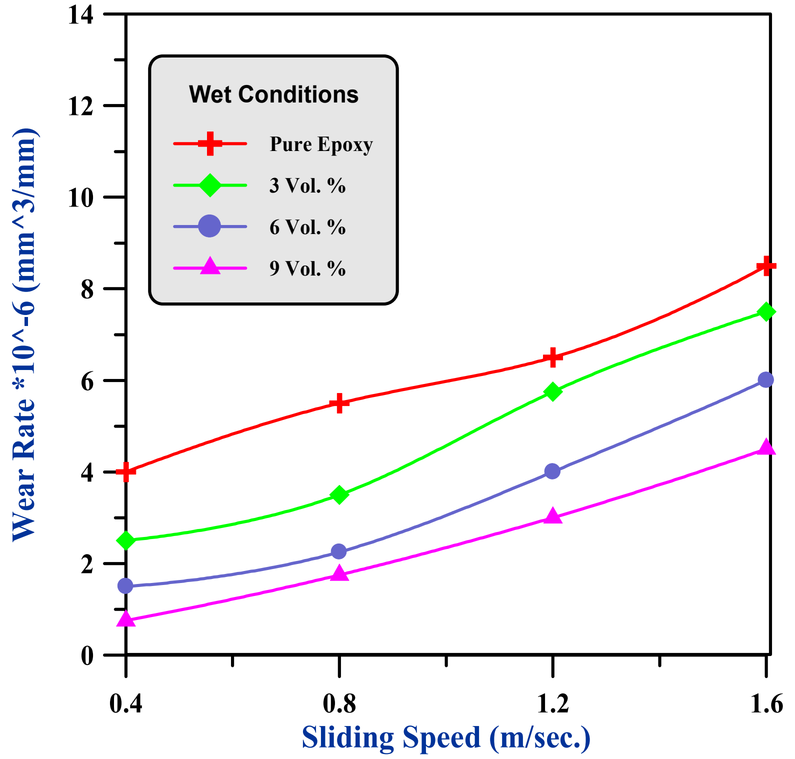

Figure (4): Relationship Between the Sliding Speed and the Wear Rate of the Epoxy Reinforced by Carbon Fiber at Wet Working Conditions (W=12 N, and T= 10 min.).

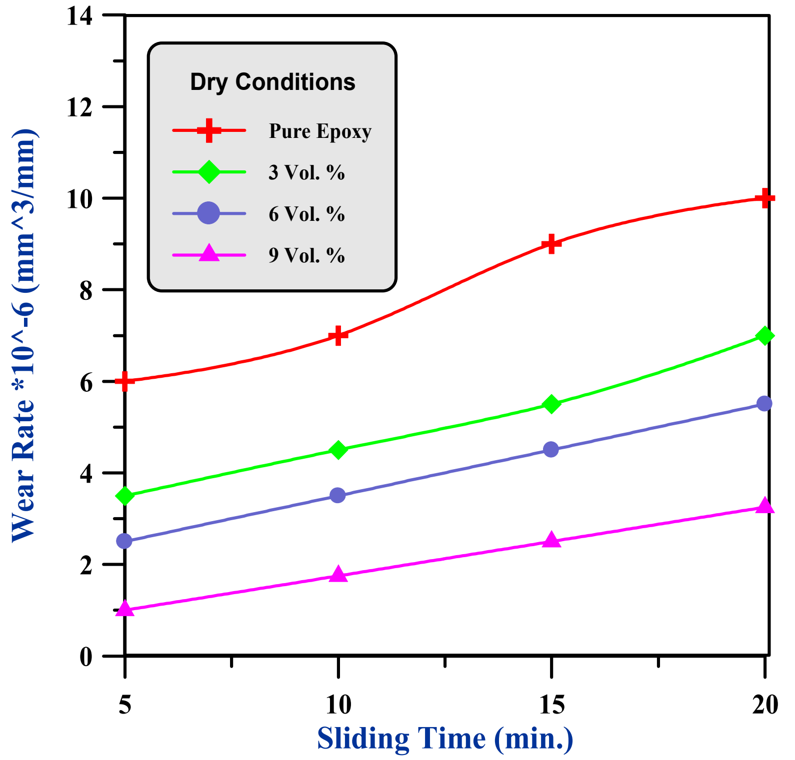

Figure (5): Relationship Between the Sliding Time and the Wear Rate of the Epoxy Reinforced by Carbon Fiber at Dry Working Conditions (W=12 N, and V_s = 0.8 m/sec.).

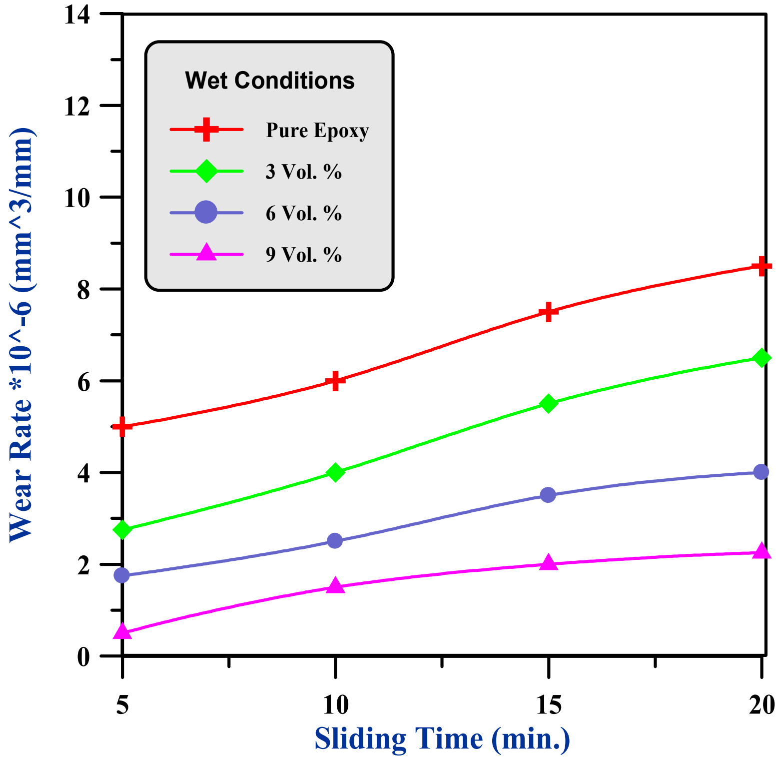

Figure (6): Relationship Between the Sliding Time and the Wear Rate of the Epoxy Reinforced by Carbon Fiber at Wet Working Conditions (W=12 N, and V_s = 0.8 m/sec.).

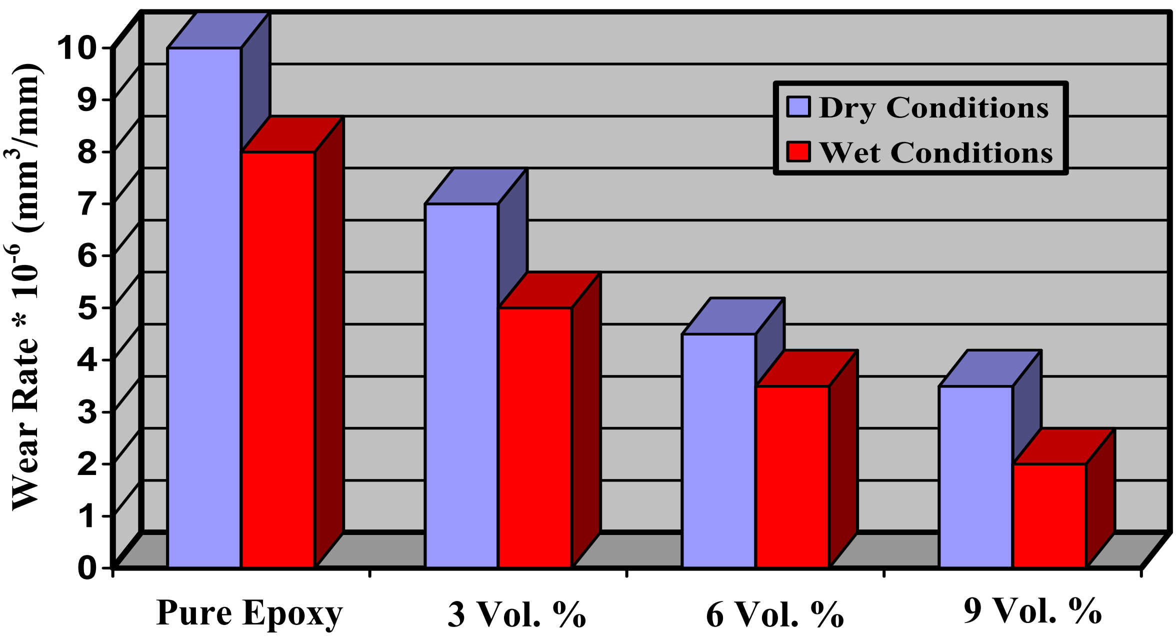

Figure (7): Relationship Between the Volume Fraction of Reinforcing Fibers and the Wear Rate at Dry and Wet Working Conditions (W=1.2 N, V_s= 0.8 m/sec., and T= 10 min.).