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# A Comparison Between The Wear Rate Behavior Of Polyester Reinforced By Glass And Kevlar Fibers

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**Abstract**

In this research the wear rate of the polyester reinforced by chopped glass fibers and chopped Kevlar fibers with length (1-2.5 mm) and weight fraction (4, 8, 12, 16 WT %) has been investigated. A Pin -on- Disc wear testing machine of variable speed has been used. Flat against flat sliding surfaces under variable working parameters conditions have been tested.

The results of flat sliding surfaces show that the wear rate of the specimens depends heavily on the working condition. It increases with the increase of the load and sliding speed, and the wear rate decreases with the increase of the weight fraction.

The results also show that the wear rate for polyester reinforced by Kevlar fiber was less than the polyester reinforced by glass fiber. The optimum value of wear rate was ($2.75*10^{-6}$ $mm^3/mm$) happened at weight fraction (16 WT %) when reinforced by Kevlar fibers.

**مقارنة سلوك معدل البلى للبولي استر المقوى بألياف الزجاج والياف الكفلر**

**الخلاصة**

في هذا البحث تمت دراسة سلوك البليان للبولي أستر المقوى بألياف الزجاج وألياف الكفلر المتقطعة بطول (1-2.5 mm) وكسر وزني (4, 8, 12, 16 WT %) . لقد استخدم جهاز قياس البلى ( المسمار - على - قرص ) ذو السرع المتغيرة. أجريت الدراسة على سطح مسمار مسطح – على قرص مسطح تحت معالم وضروف مختلفة.

بينت نتائج الاسطح المنزلقة بان معدل البلى للعينات يعتمد بصورة كبيرة على ضروف العمل. حيث يزداد معدل البلى مع زيادة الحمل المسلط والسرعة الانزلاقية ويقل مع زيادة الكسر الوزني.

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كذلك بينت النتائج بان معدل البلى للبولي أستر المقوى بألياف الكفلر اقل من المقوى بألياف الزجاج. وان أفضل قيمة لمعدل البلى كانت ($2.75*10^{-6}mm^3/mm$) حصلت عند كسر وزني (16 WT %) عند التقوية بألياف الكفلر.

## Introduction

In recent times, there has been a remarkable growth in the large-scale production of fibrous composite materials. As advanced engineering materials, the fiber composites are used in many applications where high wear resistance is required; these include electrical contact brushes, brake disc, cams, clutches, cylinder liners, artificial joints, helicopter blades, many bearing applications and bio-medical applications.

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.

Most of the machine parts suffer from friction and wear at the interface of the sliding surfaces. 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 [1].

The aim of this work is to study the effect of the weight fraction and type of reinforcing fibers (glass and kevlar) on the wear rate characteristics of the polyester at different working condition. Wear studies; have therefore become so important in order to decrease costly losses of equipments and machinery and to increase the life of tribological components.

Many studies had investigated wear rate and attempted to find the effect of volume (or weight) fraction, type, and other parameters such as the applied load, sliding velocity, abrasive grit size and sliding time.

El-Sayed et al. studied the tribological properties of unsaturated polyester reinforced by jute fibers. It was found that the increase of fiber volume fraction to (33 %) decreased its wear rate by about (95 %) [2].

Harsha and Tewari investigated experimentally the abrasive wear of polytherketone (PEK) and its glass fiber reinforced composites by using pin on disc machine under various experimental conditions such as sliding distance, load, abrasive grit size. It was observed that incorporation of glass fiber results in an increase in wear rate under different types of loading [3].

Suresha et al. investigated the tribological properties of the carbon-epoxy (C-E) composite and glass-epoxy (G-E) composite by using pin-on-disc. The tests are conducted by subject (C-E) and (G-E) samples sliding against a hard steel disc (62 HRC) under different sliding speed and loading conditions. The results illustrated the (C-E) composite show lower friction and lower slide wear loss compared to (G-E) composites irrespective of the load or speed employed [4].

David et al. evaluated the wear characteristics of fiber-reinforced dental composite by using glass fiber with different fiber length and different weight fraction added to the dental resin. It was found that the specimen with (5.7 WT %) fiber and fiber length of (3 mm) performed better wear volume in compared to all other fiber-reinforced specimens under all load conditions [5].

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 influenced by the fiber orientation [6].

Suresha et al., studied the wear loss of epoxy matrix reinforced by glass fiber at different load ranged by (3-5 N) and different sliding speed ranged by (30-70 m/sec.) by using a pin-on-disc wear tester. It was found that the wear loss increase with the increasing the sliding speed and the applied normal load [7].

El-Tayeb and Yousif investigated the wear behavior of chopped strand materials (CSM) 450-R-glass fiber reinforced polyester (CGRP) by using pin-on-ring configuration with (SiC) abrasive paper (1500, 1000, and 400) at different normal loads (5-25 N) and rotating speed (100 & 50 r.p.m.). 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 [8].

**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 rule of mixtures which are based on two simplified equations, the first of which, the inverse rule of mixtures, was introduced for two-phase composites by Khruschov [9]:

$$\frac{1}{K_c} = \frac{V_m}{K_m} + \frac{V_f}{K_f} \qquad (1)$$

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.

Equation (1) is based on the assumption that the components of the composite wear are at an equal rate. Since the wear rate of the harder reinforcement is typically much smaller than that of the matrix, this relationship predicts that the abrasive wear behavior of a composite will be governed primarily by the reinforcement.

The second wear equation for multiphase materials, introduced by Zum-Gahr to explain experimental data, is the linear rule of mixtures, here; the wear behavior of a composite is not dominated by a single phase [10]. Instead, the contribution from each component is linearly proportional to its volume fraction in the composite.

$$K_c = V_f \cdot K_f + V_m \cdot K_m \qquad (2)$$

It is noted that the abrasive wear rate of the composite decreases linearly with the increase of volume fraction of the reinforcement.

These equations theoretically represent the upper and lower limits of abrasive wear rates in a composite.

Abrasive wear occurs when there is friction between one body under stress and a harder body or grain [11].

Abrasive wear may be prevented or minimized by selecting alternative materials such as replacing the softer material by harder one [12].

## Experimental Work

Experiments were run on an open rotating Pin -on- Disc wear testing machine (see figure 1) within a conditioned laboratory environment. The weighing method was used to determine the mass loss of the test specimens. This method is the simplest way of detecting wear rate of the test specimens, where the specimens after cleaning were weighed before and after running, and the weight loss, during the experiment, was used to calculate the wear rate. The experimental conditions were done under variable load within the range of (2 - 8 N) and a sliding speed within the range of (0.5 - 2.6 m/sec.) and sliding time of (600 sec.).

The following relation is used to investigate the wear rate which is [13]:

$$K_c = \frac{V_r}{X} \qquad (3)$$

Where,

$$V_r = \frac{\Delta m}{\rho_c}$$

And $X = V_s \cdot T$

Therefore

$$K_c = \frac{\Delta m}{r_c \cdot V_s \cdot T} = \frac{m_2 - m_1}{r_c \cdot V_s \cdot T} \quad (mm^3/mm) \quad (4)$$

Where:

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

$V_r$ -Volume of removed material $(mm^3)$.

$X$ -Sliding distance of material removal (mm).

$\rho_c$ -Density of the test specimen $(gm/mm^3)$.

| | |
|---|---|
| $\Delta m$ | -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.). |

**Preparation of the Specimens**

The composite specimens were made from ( unsaturated polyester ) as a matrix and short fiber (glass and kevlar) as the reinforcement with length (1-2.5 mm) at different weight fractions of (4, 8, 12 and 16 WT %) by mixing the short reinforcing fibers in liquid unsaturated polyester followed by casting in an open mould. The mixture was cured for 7 days at room temperature. Some samples and the dimension of the specimen was 9.5 mm diameter and 20 mm length as shown in figure (2) based on the standard wear tests described in ASTM standard D5963-97a [14].

Table (1) illustrates some properties of the polyester, glass fiber and Kevlar fiber that used in this investigation [15].

**Instrumentation**

1- Balance weight: - It is used to measure the weight loss in the specimens with accuracy $1*10^{-4}$ gm.
2- Tachometer: - It is used to measure the angular speed of the specimen with range (0 - 5000 r.p.m.)
3- Stop Watch: - It is used to measure the sliding Period of each test.

**Results**

Figures (3 and 4) show, the variation of wear rate with the applied normal load of the unreinforced and reinforced polyester with a weight fraction of (4, 8, 12 and 16 WT %) and working condition (speed = 1.9 m/sec. and sliding time = 600 sec.) for both reinforcing fibers (glass and kevlar fibers) respectively.

It can be seen that as the applied load increases the wear rate of the reinforced and unreinforced polyester increases at different rates for all values of weight fractions and for both reinforcing fibers. The wear rate of the unreinforced polyester is more than that of the reinforced polyester 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. The incorporation of glass fibers and Kevlar fibers into the polyester with different weight fractions improves the sliding wear resistance as compared to the unreinforced polyester. This results agreement with the results obtained by [3, 4 and 7].

Figures (5 and 6) show the relationship between the sliding speed and the wear rate of the polyester reinforced by fibers, for different weight fraction of (0, 4, 8, 12, and 16 WT %) at working condition (load = 4.5 N, and sliding time = 600 sec.) and for both reinforcing fibers (glass and Kevlar) 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.

Figures (5 and 6), also show that the wear rate of the reinforced polyester was lower than that of the unreinforced polyester. This 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.

The increase of the wear rate with increasing sliding speed was found by some of the previous studies [4 and 7]

Figure (7) shows the variation in the wear rate versus different weight fraction of the glass fiber and Kevlar fiber at the working condition (load = 4.5 N, speed = 1.9 m/sec. and sliding time = 600 sec.).

The wear rate of the composite pin decreases in nonlinear relationship from (9.3 $*10^{-6}$ $mm^3/mm.$) for unreinforced pin to the (5.25 $*10^{-6}$ $mm^3/mm$) and (2.75 $*10^{-6}$ $mm^3/mm$) at weight fraction (16 WT %) for both reinforcing fibers (glass and Kevlar) respectively. A decrease in wear rate with increasing fiber weight fraction in the composites has been observed by a number of researchers [2 and 5]

Figure (8) illustrates the variation of wear rate with weight fraction of reinforcing fibers at working condition (load = 4.5 N, speed = 1.9 m/sec. and sliding time = 600 sec.). From this figure it is obvious that when the polyester reinforcing by Kevlar fibers give the lowest wear rate compared to other reinforcing by glass and unreinforced polyester. Due to the hardness and bonding force (i.e. nature of the interface between fibers and matrix) of the polyester when reinforced by Kevlar fibers was higher than that when reinforced by glass fiber and unreinforced polyester.

The optimum value of wear rate was ($2.75*10^{-6}$ $mm^3/mm$) at weight fraction (16 WT %) when reinforced by Kevlar fibers, and the percentage of improving the wear resistance was (118 %) as compared with that at weight fraction (4 WT %) when reinforced by the same fibers.

**Conclusions**

In this study, the wear rate of the polyester reinforced by (glass and Kevlar) fibers was investigated, and the following inferences are drawn from the above study.

1- There has been an observed marked improvement in wear resistance as seen in reinforced polyester compared to unreinforced polyester.

2- Wear rate of the polyester reinforced by Kevlar fibers was lower than that when the composite reinforced by glass fibers.
3- Wear rate decreases with the increase of weight fraction.
4- In the present investigation, the (16 WT %) weight fraction of reinforcing fibers exhibited better wear resistance than the other combinations for both reinforcing fibers.
5- For the polyester reinforced by Kevlar fibers the percentage of improving the wear resistance was (118 %) at weight fraction (16 WT %) compared with that at weight fraction (4 WT %).

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Table (1): Some Properties of Fibers and Matrix [15].

| | | Density g/cm$^3$ | Modulus of Elasticity GPa. | Tensile Strength MPa. | Percentage Elongation % |
|---|---|---|---|---|---|
| Matrix | Polyester | 1.2 | 2.8 | 65 | < 2.6 |
| Fibers | Glass | 2.58 | 72.5 | 3450 | 4.3 |
| | Kevlar | 1.44 | 131 | 3800 | 2.8 |

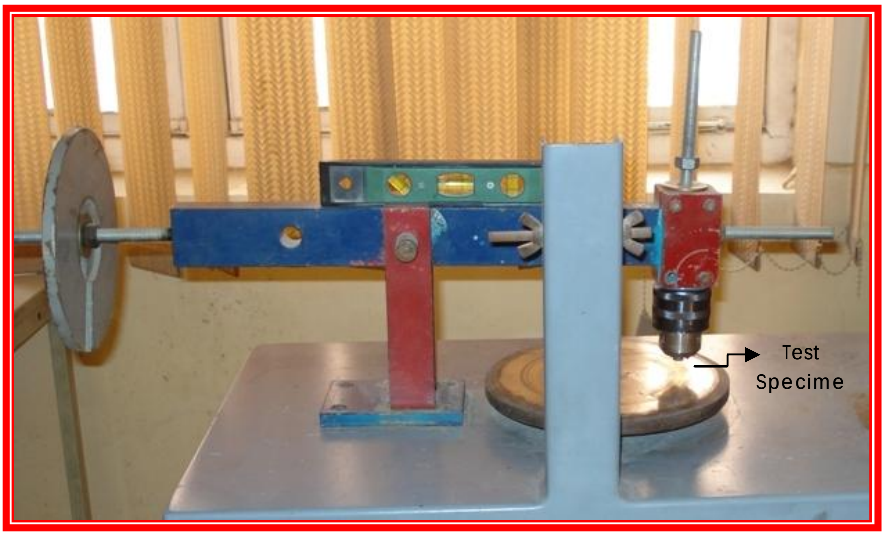


Figure (1): Pin -on- Disc Wear Test Apparatus.

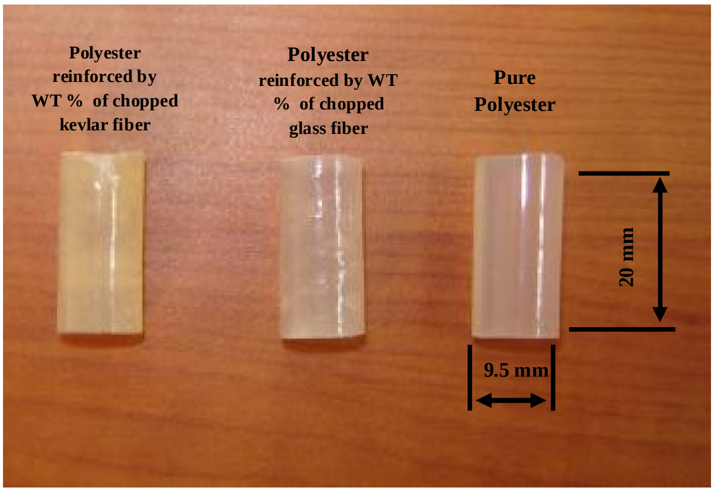


Figure (2): Samples and Dimensions of the test specimens.

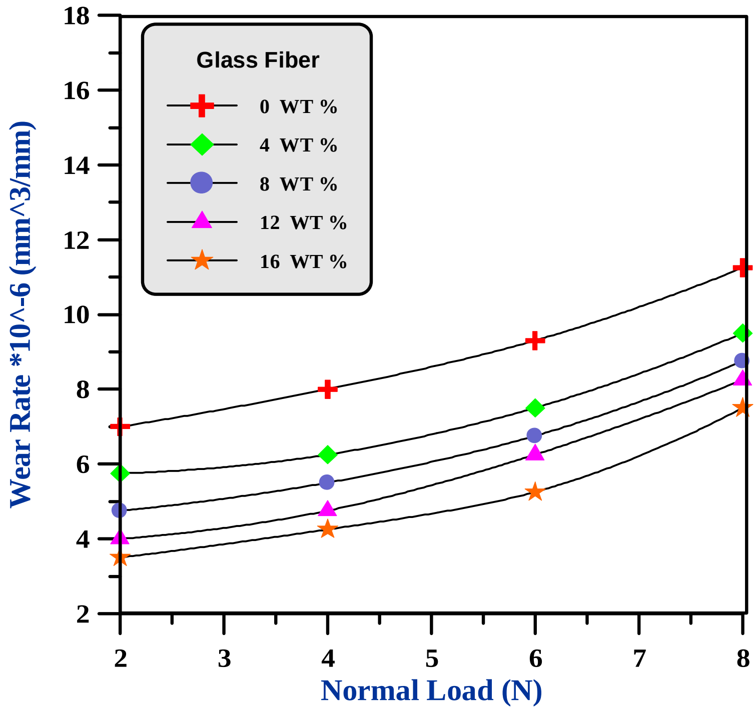


Figure (3): Relationship Between the Normal Load and the Wear Rate of the Polyester Reinforced by Glass Fiber at Working Conditions ($V_s$= 1.9 m/sec., and T= 600 Sec.).

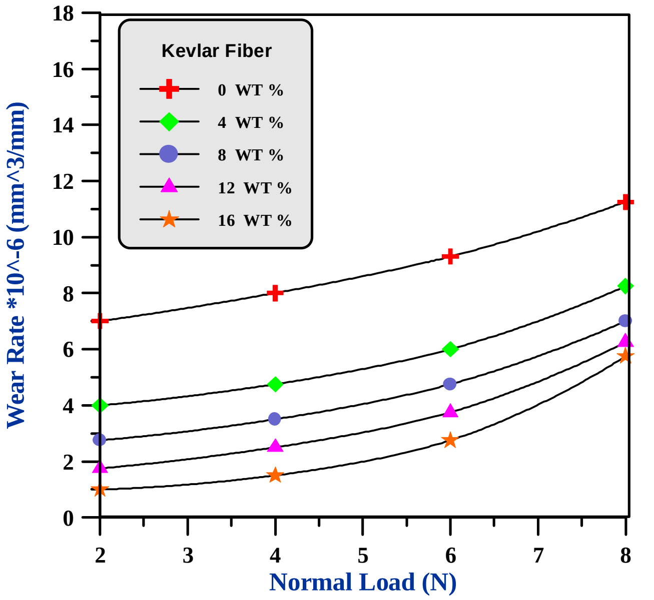


Figure (4): Relationship Between the Normal Load and the Wear Rate of the Polyester Reinforced by Kevlar Fiber at Working Conditions ($V_s$= 1.9 m/sec., and T= 600 Sec.)

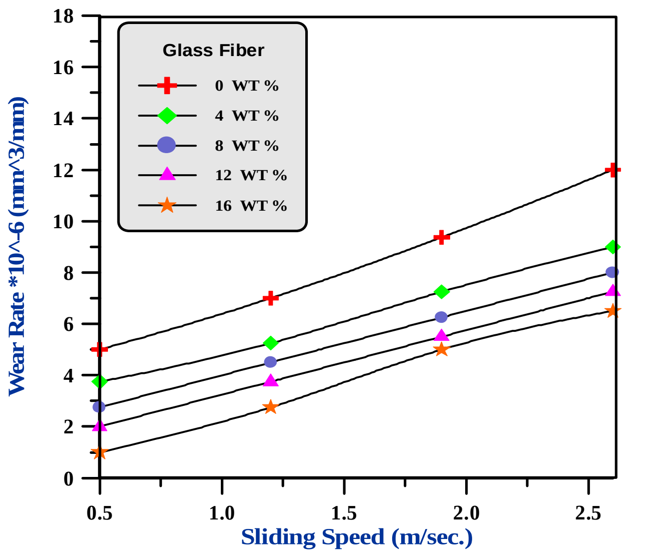


Figure (5): Relationship Between the Sliding Speed and the Wear Rate of the Polyester Reinforced by Glass Fiber at Working Conditions (W=4.5 N, and T= 600 Sec.).

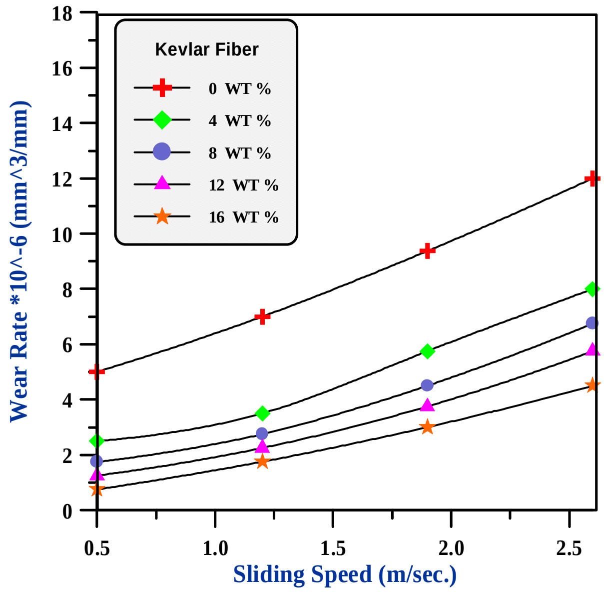


Figure (6):Relationship Between the Sliding Speed and the Wear Rate of the Polyester Reinforced by Kevlar Fiber at Working Conditions (W=4.5 N,and T= 600 Sec.).

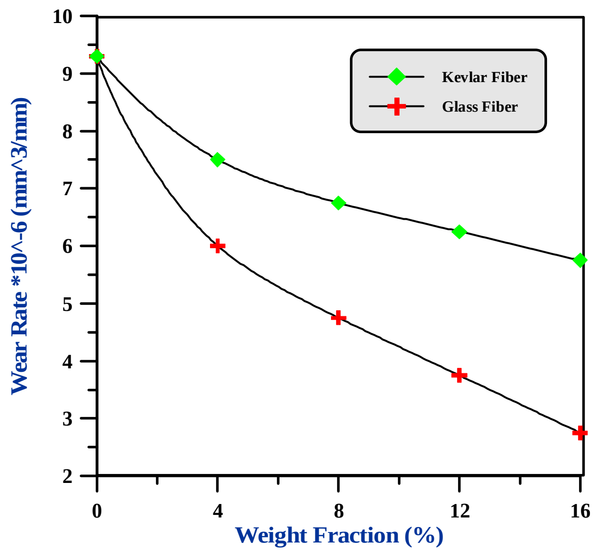


Figure (7): Relationship Between the Weight Fraction and the Wear Rate of the Polyester Reinforced by Glass and Kevlar Fibers at Working Conditions ( W=4.5 N, $V_s$= 1.9 m/sec., and T= 600 Sec.).

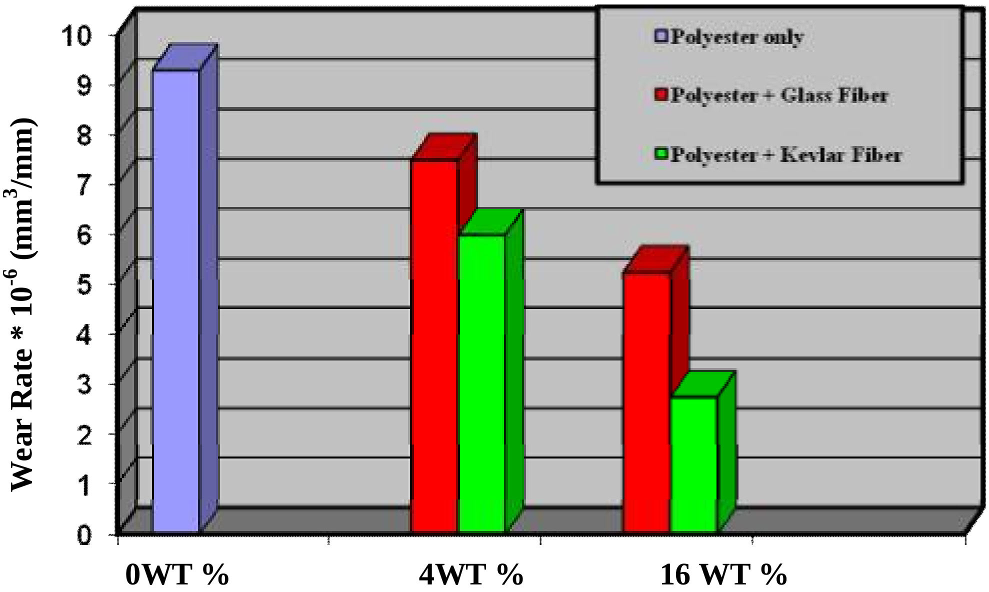


Figure (8): Relationship Between the Weight Fraction of Reinforcing Fibers and the Wear Rate at Working Conditions ( W=4.5 N, $V_s$= 1.9 m/sec., and T= 600 Sec.).