A STUDY OF WEAR RATE BEHAVIOR OF POLYESTER REINFORCED BY SILICA (Sio_2) Particles

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ABSTRACT

In this research the wear rate of one type of the thermosetting polymer (polyester) reinforced by ceramic particles (silica) 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.

Statistical and mathematical analyses were used to the processing of the experimental data. A mathematical model was done which shows the wear rate of composite materials as a function of grain size and weight fraction.

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.

The results also show that the wear rate decreases with the increase of the weight fraction and the decrease of the grain size of the reinforcing particles. The optimum wear resistance of the reinforced polyester was at weight fraction of (20 %) and grain size of (25 μm).

دراسة سلوك معدل البلى للبولي أستر المقوى بدقائق السليكا (Sio_2)

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الخلاصة

في هذا البحث تمت دراسة سلوك البليان لأحد انواع البوليمرات المصلدة بالحرارة (البولي أستر) المقوى بدقائق سيراميكية (السليكا). لقد استخدم جهاز قياس البلى (المسمار – على – قرص) ذو السرع المتغيرة. أجريت الدراسة على سطح مسمار مسطح – على قرص مسطح تحت معالم وضروف مختلفة.

استخدمت التحليلات الرياضية والإحصائية لمعالجة القيم العملية .تم عمل موديل رياضي يبين علاقة معدل البلى للمادة المركبة كداله للحجم الحبيبي والكسر الوزني لدقائق (Sio_2).

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

كذلك بينت النتائج بان معدل البلى يقل مع زيادة الكسر الوزني ونقصان الحجم الحبيبي لمادة التقوية. وان أفضل مقاومة للبلى للبولي أستر المقوى بدقائق (Sio_2) كانت عند كسر وزني (% 20) وحجم حبيبي (25 μm).

Keyword: wear rate, polyester, Sio_2 , grain size, weight fraction,

INTRODUCTION

As advanced engineering materials, composites are used in many applications where high wear resistance is required; these include electrical contact brushes, cylinder liners, artificial joints, helicopter blades and many bearing applications [W. D. Callister 2003].

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 [K-H Z Gahr 1987].

The tribology of the composite is of significant interest because of the ability of the particles to alter the properties of the matrix and the surfaces involved while remaining as small defects in the matrix [K.H. Zum-Gahr 1987].

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 [Halling, J. 1976].

The aim of this work is to study the effect of the weight fraction and the grain size of (Sio_2) particles on the wear rate characteristics of the polyester. 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 fraction, type, particle size and other parameters such as the applied load, sliding velocity, surface roughness and sliding time.

A.A. Cenna et al. [2001] measured the abrasive wear rate of polymer surface reinforced by different values of volume fractions (5%, 10%, 15%, 20%, and 30%) of graphite powder. They found that the calculated dimensionless wear rates depend on the volume fraction of particles in resin matrix.

Q.M. Jia et al. [2006] used pin -on- disc rig to test the friction and wear loss of pure EP and EP nanocomposites, and found that the nanofillers with different shapes play different roles for improving the wear resistance of EP nanocomposites.

S. Badhak et al. [2008] studied the wear resistance of high-density polyethylene (HDPE) reinforced by various ceramic fillers, like alumina and hydroxapatite (Hap). It was found that the generation of wear debris particles be reduced for various compositionally modified polymer composites, in comparison to unreinforced HDPE, and record the low wear depth of (3.5 - 4) μm.

A.K Pogosyan et al. and B. Wetzel et al. [2002] studied the influence of type, shape, volume content and particle sizes of the fillers on the tribogical properties of polymers composite. The results demonstrated the best improvement in wear resistance of the epoxy was at a nano-particles content of 4 Vol % TiO_2.

L.Yu et al. [2000] studied the wear mechanism of the polyoxymethylene (POM) filled with copper particles, and found that the wear mechanism in the composite filled with micron sized particles was primarily scuffing and adhesion, while wear of the nanoparticle – filled composite occurred by plastic deformation.

P. Bhimaraj et al. [2005] studied the friction and wear properties of poly (ethylene) terephthalate (PET) filled with alumina nanoparticles. The results showed that the addition of nanoparticles can increase the wear resistance by nearly 2X over the unfilled polymer and the average coefficient of friction also decreased in many cases.

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 and Babichev [1985]:

$$\frac{1}{K_c} = \frac{V_m}{K_m} + \frac{V_p}{K_p} \qquad (1)$$

Where:

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

V_m and V_p : Volume Fraction of the matrix and the reinforcement (particle) 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 K.H. Zum-Gahr [1987] to explain experimental data, is the linear rule of mixtures, here; the wear behavior of a composite is not dominated by a single phase. 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 [A.D. Sarkar 1980].

Abrasive wear may be prevented or minimized by selecting alternative materials such as replacing the softer material by harder one [A.A. Reda et al. 1975].

The following relation is used to investigate the wear rate which is [Dowson, D. 1998]:

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

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

And $X = V_s \cdot T$

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

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 (1.5 N - 6 N) and a sliding speed within the range of (0.5 m/sec. - 3.05 m/sec.) and sliding time of (300 sec.).

Preparation of the Specimens

The composite specimens were made from (unsaturated polyester) as a matrix and silica (Sio_2) as the reinforcement with different weight fractions of (5%, 10%, 15% and 20%) and two different grain sizes (25 μm and 125μm) by mixing the ceramic particles in liquid unsaturated polyester followed by casting in an open mould. The mixture was cured for 7 days at room temperature. 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 [ASTM International 2001].

INSTRUMENTION

1- Balance weight: - It is used to measure the weight loss in the specimens with accuracy $1*10^{-4}$ N.
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 AND DISCUSSION

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 (5%, 10%, 15% and 20% WT) working condition (speed = 2.2 m/sec. and sliding time = 300 sec.) for both particle size of Sio_2 (25 μm and 125μm) 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 grain sizes. The wear rate of the unreinforced polyester is more than that of the reinforced polyester for all values of load. This is because at these values of loading the particles acted as a load bearing element between the contact surfaces. Moreover, as the percentage of reinforcement increases, the wear rate of the composite decreases. The incorporation of Sio_2 particles into the polyester with different weight fractions and different grain size improves the sliding wear resistance as compared to the unreinforced polyester. The improvement resistance accompanying the presence of ceramic particles in polyester matrix is due to the increase in average hardness of the composite.

Figures (5 and 6) show the relationship between the sliding speed and the wear rate of the polyester reinforced by (Sio_2) particles, for different particulate weight fraction of (0%, 5 %, 10 %, 15 %, and 20 % WT) at working condition (load = 4.5 N., and sliding time = 300 sec.) and for both particle size of Sio_2 (25 μm and 125μm) 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.

Figure (7) shows the variation in the wear rate versus different weight fraction of the reinforcing materials (Sio_2) at different grain size at the working condition (load = 4.5 N, speed = 2.2 m/sec. and sliding time = 300 sec.).

As the weight fraction increases from (0 % WT) to (20 % WT), the wear rate of the composite pin decreases in nonlinear relationship from ($10.37 *10^{-6}$ mm^3/mm.) to the ($3.25 *10^{-6}$ mm^3/mm) and ($5 *10^{-6}$ mm^3/mm) for both of the grain size of Sio_2 (25 μm and 125μm) respectively.

Figure (8) illustrates the variation of wear rate with particle size under working condition (load = 4.5 N, speed = 2.2 m/sec. and sliding time = 300 sec.). From this figure it is obvious that a particle size of (25 μm) was optimum for improving the wear rate compared to other size (125 μm) and unreinforced polyester. Due to the presence of these fine particles which act as a load bearing element between the contact surfaces while the coarsing of Sio_2 particles, increase the pre-existing crack sizes, resulting in the ease of crack propagation and linking with other cracks.

The optimum value of wear rate on the other hand was ($3.25*10^{-6}$ mm^3/mm) at (20 %) weight fraction and (25 μm) grain size, and the percentage of improving the wear resistance was (100 %) as compared with that at (5%) weight fraction and (25 μm) grain size.

Mathematical Model

The regression analysis method is mostly used to obtain an equation in various engineering fields, which includes the experimental investigations, mathematical methods and statistical analysis. In this research the relationship between independent variables or parameters to determine the coefficients of independent variables which will obtain the optimal solution for objective function of the wear rate. The regression coefficients determined in the beginning are estimated by using the experimental data. In this study, multiple polynomial (least square fitting) regression analysis was used to establish a mathematical model among the experimentally obtained parameters. Multiple regression analysis techniques were applied to relate the wear rate to weight fraction and grain size of Sio_2, the best form of the relationship between the wear rate, grain size and weight fraction of Sio_2 parameters was chosen in the form:

$$K = a_o + a_1 \cdot X + a_2 \cdot Z + a_3 \cdot X^2 + a_4 \cdot Z^2 + a_5 \cdot XZ \quad (5)$$

Where:

K: Wear Rate (mm^3/mm).
X: Weight Fraction of Sio_2 (% WT).
Z: Grain Size of Sio_2 (μm).
a_o, a_1, a_2, a_3, a_4 and a_5: Regression Coefficients.

The statistical analysis of the experimental data was done by using the (MATLAB) program package to perform the multiple polynomial regression analysis with the model proposed by eq. (5) above to determine the coefficients of this model. The final model of the wear rate at working conditions (W=4.5 N, V_s= 2.2 m/sec., and T= 300 Sec.) is represented by the following equation:

$$K = 10.37 - 19.1446X - 0.15072Z - 2.3824X^2 + 0.0011Z^2 + 0.0076XZ \quad (6)$$

CONCLUSION

In this study, the wear rate of the polyester reinforced by (Sio_2) particles was investigated, and the following inferences are drawn from the above study.

1- Wear rate increases as the applied load and sliding speed increase.
2- There has been an observed marked improvement in wear resistance as seen in reinforced polyester compared to unreinforced polyester.
3- Wear rate decreases with the increase of weight fraction and the decrease of the particle size of the reinforcing materials.
4- In the present investigation, the (20 %) weight fraction and (25 μm) grain size of (sio_2) reinforcing particles exhibited better wear resistance than the other combinations.
5- For the same grain size (25 μm) the percentage of improving the wear resistance was (100 %) at weight fraction (20 %) compared with that at weight fraction (5%).
6- A mathematical model was done which shows the wear rate of composite materials as a function of grain size and weight fraction.

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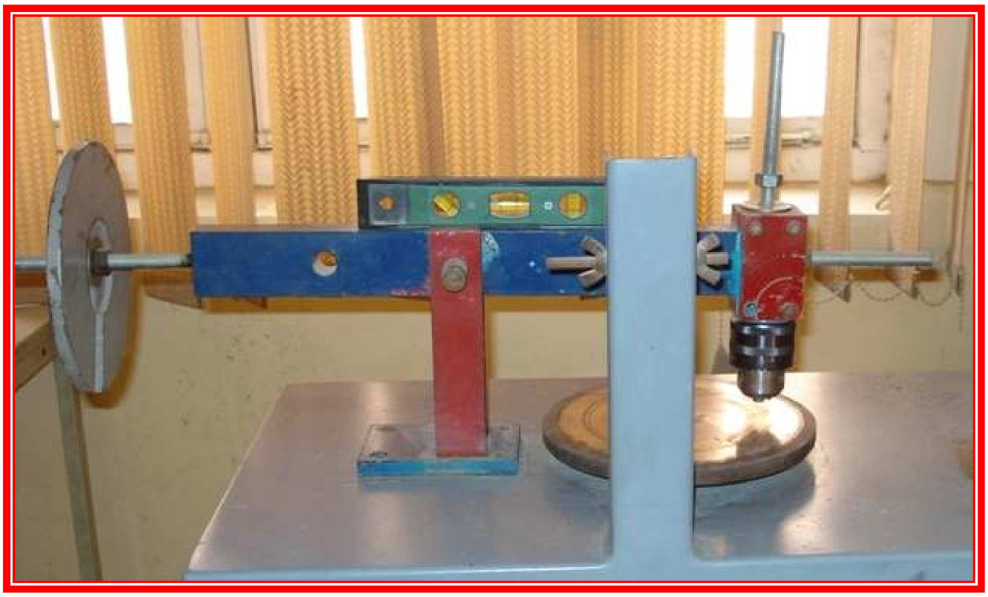

Figure (1): Pin -on- Disc Wear Test Apparatus.

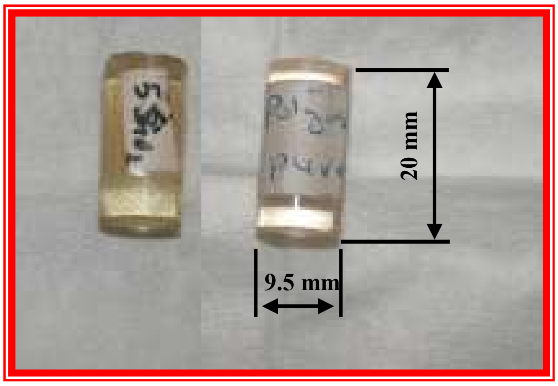

Figure (2): Samples and Dimensions of the test specimens.

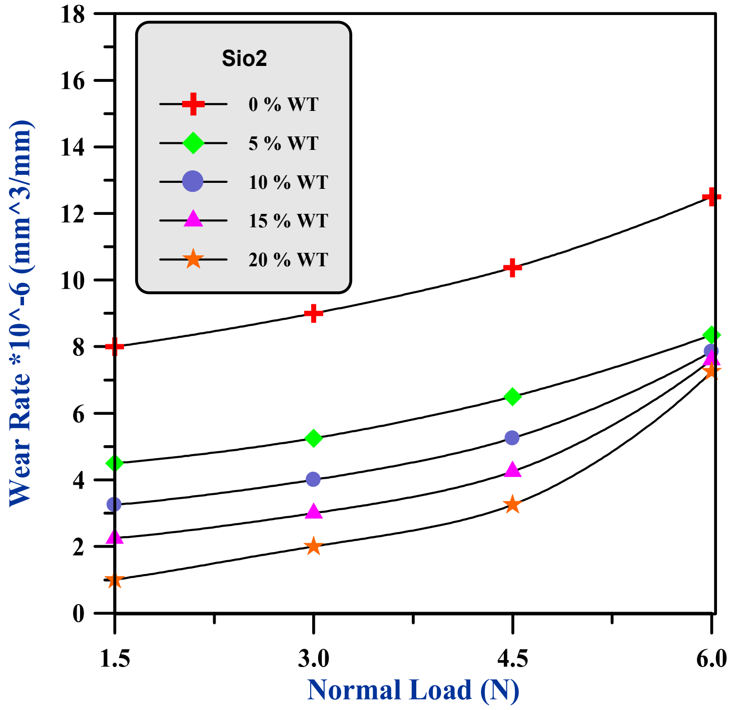

Figure (3): Relationship Between the Normal Load and the Wear Rate of the Polyester Reinforced by (SiO_2) Particles with Grain Size (25 μm) and Working Conditions (V_s= 2.2 m/sec., and T= 300 Sec.).

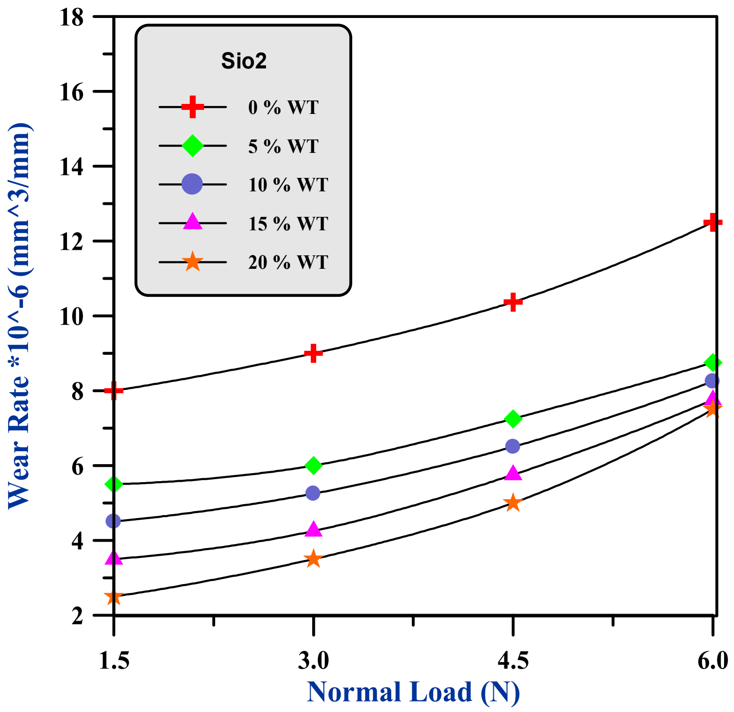

Figure (4): Relationship Between the Normal Load and the Wear Rate of the Polyester Reinforced by (SiO_2) Particles with Grain Size (125 μm) and Working Conditions (V_s= 2.2 m/sec., and T= 300 Sec.).

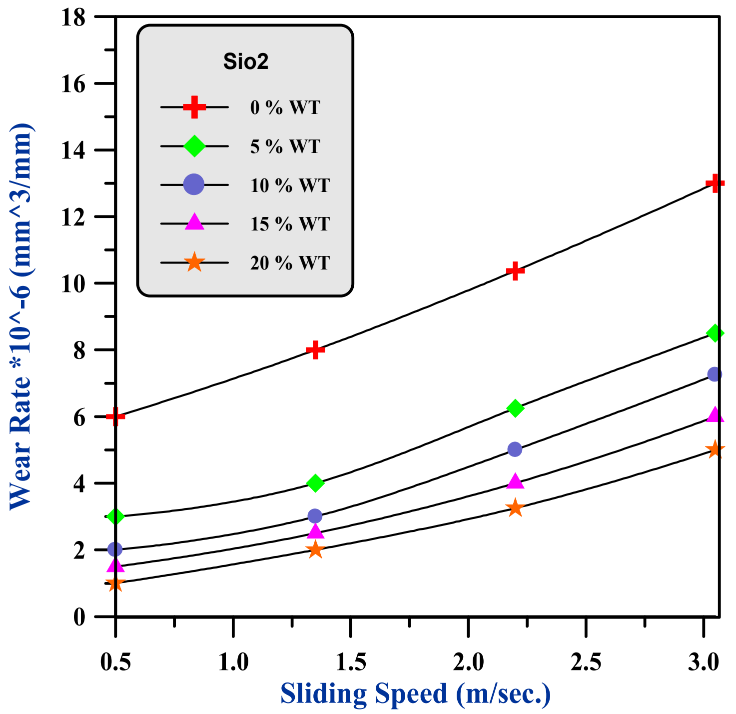

Figure (5): Relationship Between the Sliding Speed and the Wear Rate of the Polyester Reinforced by (SiO_2) Particles with Grain Size (25 μm) and Working Conditions (W=4.5 N, and T= 300 Sec.).

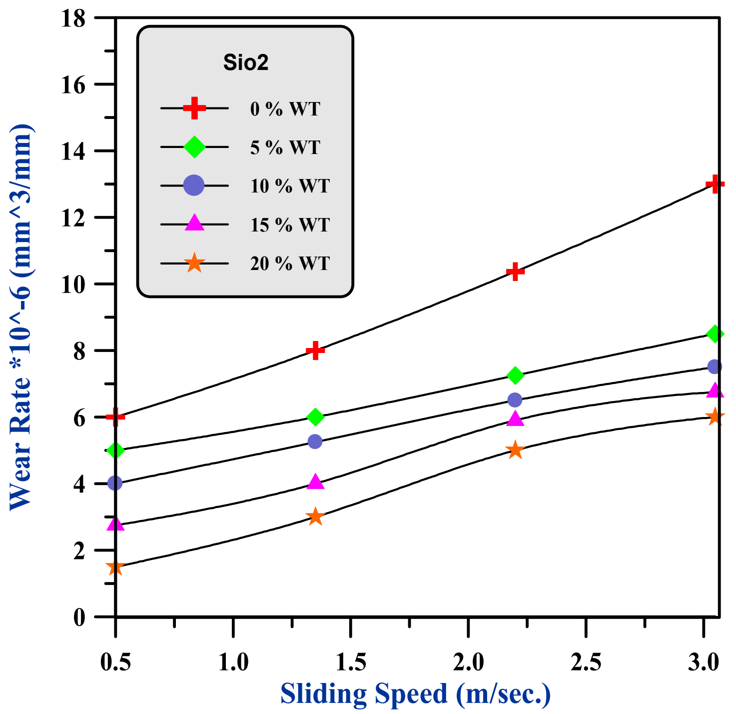

Figure (6): Relationship Between the Sliding Speed and the Wear Rate of the Polyester Reinforced by (SiO_2) Particles with Grain Size (125 μm) and Working Conditions (W=4.5 N, and T= 300 Sec.).

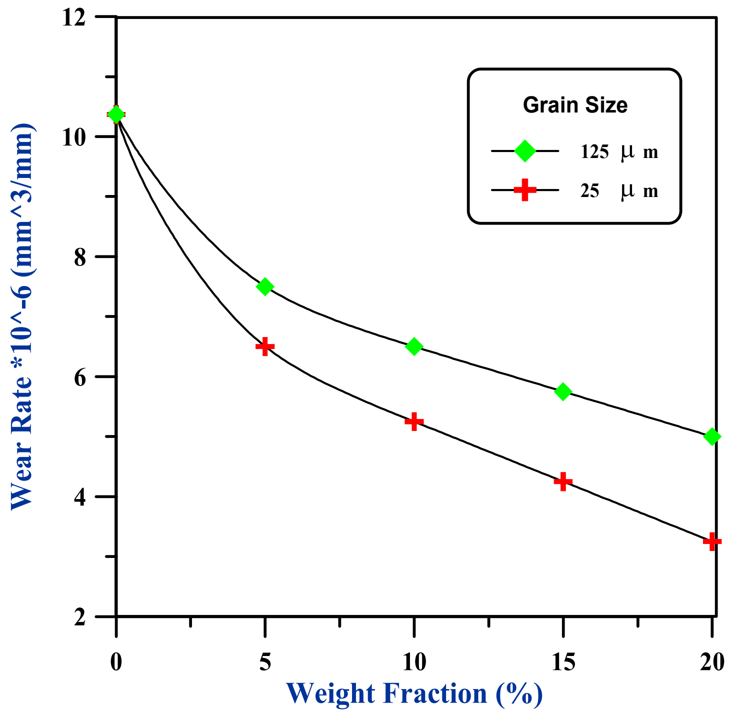

Figure (7): Relationship Between the Weight Fraction and the Wear Rate of the Polyester Reinforced by (SiO_2) Particles with Different Grain Size and at Working Conditions (W=4.5 N, V_s= 2.2 m/sec., and T= 300 Sec.).

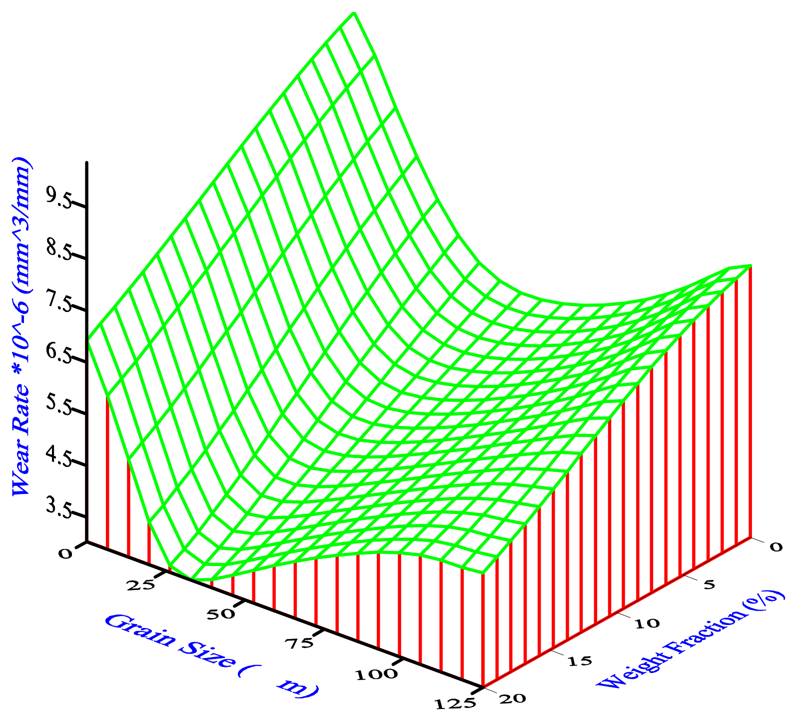

Figure (8): Relationship Between the Grain Size and the Wear Rate of the Polyester Reinforced by (SiO_2) Particles with Different weight fraction and at Working Conditions (W=4.5 N, V_s= 2.2 m/sec., and T= 300 Sec.).