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Studying the Effect of Polymeric Fibers and Powders Addition on the Sliding Wear of Unsaturated Polyester Resin

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ABSTRACT

The current investigation is interested by study the effect of polymer fibers and powders such as, High Density Poly Ethylene (HDPE) fibers, Poly Vinyl Chloride (PVC) and Unsaturated Polyester (UPE) fillers, weight fraction on the sliding wear behavior of Unsaturated polyester resin, under dry sliding conditions, such as applied load, sliding speed at room temperature. The wear rate were investigated according to (ASTM-D 5963) using pin on disc machine to present the composite tribological behavior. The results showed that, when the loads increase, wear rates were enhanced when all types reinforcement materials was increased up to (3.4wt.%) and then decreased after (12.2wt.%), (9.5wt.%) for (HDPE) fibers and (PVC) powder, respectively. In the case of the sliding speed increase, the wear rate of (UPE) powder composite was decreased with powder increase, While The improvements in the wear are decrease when the additions of (HDPE) fibers and (PVC) powder to unsaturated polyester resin was increased up to (9.5 wt.%).

Introduction

Fibers and Powders reinforced are widely used in various fields of engineering, because of their various desirable properties which include high specific strength and high specific stiffness. The use of polymer fibres, powder and unsaturated polyester matrix is highly beneficial because the strength and toughness of the resulting composites are greater than those of the unreinforced plastics[1]. At present, composite materials play a key role in biomedical applications, the aerospace industry, automobile industry and other civil engineering applications, as they exhibit outstanding performance[2]. Also Polymers and composites a very important of tribological materials and are used where components are supposed to run without any external lubricants. Performance of such components, however, is generally sensitive to application conditions. It is also a well-accepted fact that no material is universally resistant to all modes of wear. Hence, during material selection for typical tribological applications it becomes imperative to know its complete spectrum of behavior in various possible wearing situations[3,4]. Interestingly, less is reported on systematic studies on wear behavior of materials in diverse wearing

situations and operating conditions, especially sliding wear conditions. Pedro et al [5] demonstrated the sliding wear behavior of polymer based composite for many tooling, and showed that the small amount of milled fibers enhance the wear resistance. Suresha et al [6] studied the influence of filler particles on the wear of glass fabrics reinforced epoxy composite under dry sliding conditions, and reported that the filler contributed significantly in reducing friction and exhibite better wear resistance properties. Jamal J. [7] investigated the wear rate of polyester reinforced with chopped glass and Kevlar fibers with different lengths and weight fractions, and showed that the wear rate of using Kevlar fiber was less than of using glass fiber. Draï A. [8] experimentally investigated the effect of reinforcements type on wear behavior of polyester resin reinforced by glass fibers under dry conditions, and reported that the high wear rate was recorded for unfilled composite in comparative with filled composite systems for all utilized fillers.

The main objective of this work, is to study the effect of selected weight fractions(1.25, 2.5, 3.7, 4.9, 6)Wt. %, of fibers such as High Density Poly Ethylene (HDPE) fibers, Poly Vinyl Chloride (PVC) and

Unsaturated Polyester (UPE) powders on tribological behavior of unsaturated polyester resin under dry sliding conditions, such as applied load, sliding speed at room temperature.

Experimental

Materials: The matrix used in this study was unsaturated polyester resin. manufactured by

accompany of(SIR Saudi Arabia), It is Viscous Liquid, transparent, pink, good mechanical properties, bonding with other materials, thermal and electrical insulation, good surface after Setting, dimension stability and it is type of thermosetting Polymer, table(1)gives some properties of unsaturated polyester resin :

Table(1): Some properties of unsaturated polyester (as receiving from Company).

NAME	DENSITY (GM/CM ³)	FRACTURE TOUGHNESS (MPA.M ^{0.5})	TENSILE STRENGTH (MPA)	PERCENT ELONGATION (EL%)	MODULUS OF ELASTICITY (GPA)	THERMAL CONDUCTIVITY (W/M.°C)	SPECIFIC HEAT(J/K G.°K)
Polyester resin	1.2	0.6	41.4 - 89.7	<2.6	2.06-4.41	0.17	710 - 920

The liquid resin converts to solid by mixing(2%)of methyl ethyl ketone peroxides(MEKP)as a hardener with(0.4%)Cobalt actuate as accelerator to solidification. This mixing is done for each(100%)of unsaturated polyester resin at room temperature.

High Density Poly Ethylene (HDPE) fibers :

The usage of High Density Poly Ethylene (HDPE) fibers for reinforcing polymer resin matrices, was chosen because it is economic filler commonly used, preferred material in industry and besides, it yields highly rigid products with a light weight and a low heat resistance property. These properties make the use of this fibers-plastic composite materials especially attractive for different applications.

In this research (HDPE) fibers used as a net , as shown in figure (1), which is immersed in the form of regular manner into the resin. (HDPE) fiber surpass

many characteristics one of these which is given in table(2)[9].

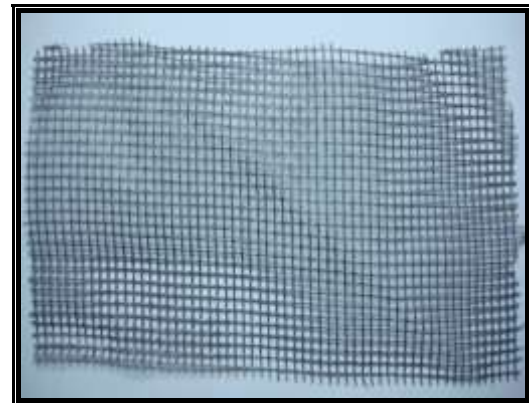


Figure (1): High Density Poly Ethylene (HDPE) fibers

Table(2): Properties of (HDPE) fibers[9]

Thermal Conductivity (W/m.k)	Flexural modulus (GPa)	Elongation at Break (%)	Modulus Elasticity of (MPa)	Tensile Strength (MPa)	Density (Kg/m ³)
0.49	1.32	100	931	32	950

Poly Vinyl Chloride (PVC) and Unsaturated Polyester (UPE) Powders :

This powders , as shown in figure (2), are used in composite materials to reduce composite costs, enhance mechanical characteristics to some extent, toughness, tribological resistance, thermal resistance, high sound and electric insulation, great chemical

resistance and in some cases to improve process ability (William,2000). This powder added to a resin, gradually and then mixed slowly with the hardener and accelerator in a beaker at room temperature. (PVC) and (UPE) Powders characteristics is given in table(3)[9].



(A)



(B)

Figure (2): (A) Poly Vinyl Chloride (PVC), (B) Unsaturated Polyester (UPE) Powders.

Table(3): some properties of (PVC) Powder[9]

Thermal Conductivity (W/m.k)	Impact Strength (KJ/m ²)	Elongation at Break (%)	Modulus of asticityE (MPa)	Tensile Strength (MPa)	Density (Kg/m ³)
0.16	1.9	16	317	57	1460

Preparation of Polymer composite Specimens:

hand-lay-up and open mould method was used in a laboratory to prepared the High Density Poly Ethylene fibers reinforced polyester composite, Poly Vinyl Chloride (PVC) and Unsaturated Polyester (UPE) Powders reinforced polyester composite.

The mould which use in this research was made from glass which was cut and cleaned, with dimensions (20×10×10) cm³ for the sliding wear tests. The internal base and internal walls of the mould were coated with thin layer of release agent in order to freely removed of samples from the mould.

The procedure of samples preparation can be described as follow:

1. Drying the High Density Poly Ethylene (HDPE) fibers reinforced polyester composite, Poly Vinyl Chloride (PVC) and Unsaturated Polyester (UPE) Powders in an electric furnace at a temperature of (60°C) for (2hrs.).

2. The weight fraction of the fiber or powder in the composite was ranging(3.4-14.8Wt.%), which was calculated according to equation :

$$\text{Wt. \% of the fibers or powder in the composite} =$$

$$\frac{\text{Weight of fibers or powder}}{\text{Weight of polyester+ weight of fibers or powder}}$$

$$\times 100\%$$

3. The(HDPE)were impregnated with resin by pouring the resin on the fibers from one corner to the mould after putting fibers into the mould to avoid the bubble formation which causes cast damage and the uniform pouring was continued until the mould was filled to the required level. Care was taken as we can to evenly distribute the fibers in the mould to ensure a uniform sample and to prevent the clump and tangle the fibers together during pouring the resin.

4. The (PVC) and (UPE) powders and the matrix (including the accelerator and the hardener) were mixed at room temperature continuously and slowly to avoid bubbling during mixing .The process was

continued for (5) minutes until the mixture became homogeneous, then The mixture was poured from one corner into the mould to avoid the bubble formation which causes cast damage and the uniform pouring was continued until the mould was filled to the required level.

5. Samples was then pressed in a (0.3 MPa) left in the mould for (24) hrs at room temperature to solidify, then, removed from the mould and leave in the air for another(24)hrs, then heat treatment in oven in (55 °C) at (1 hr.) to complete polymerization.

6. whole assembly then released and allowed to cure for a 7 days at room temperature.

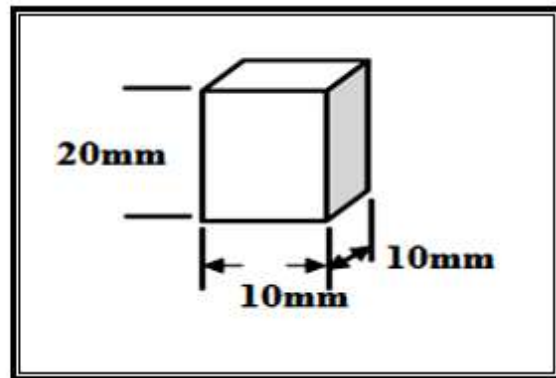
Tribological Test :

In order to characterize the effect of polymer fibers and fillers on the tribological behavior of unsaturated polyester, the pin-on-disk abrasive wear machine was used, which consist of aluminum rotating disc, as shown in figure (3), with friction surface of (400#).



Figure(3): Pin-on-Disc Aperture

The prepared samples are of rectangular cross sections of size (20×10×10)mm² according to (ASTM D 5963), as shown in figure (4).



Figure(4) : Testing Samples

The tests are carried out on the selected parameters by varying the load or velocity for all samples, as in table (4).

Table(4) : Selected Testing Parameters

At Increasing Load			At Increasing Velocity		
Particulars	Testing Parameters		Particulars	Testing Parameters	
	No.	Units		No.	Units
Loads	16,20,24,28,32	N	Loads	16	N
Sliding Speed	120	Cycle/min	Sliding Speed	60,90,120,150	Cycle/min
Sliding Distance	0.025	m	Sliding Distance	0.025	m
Friction Surface	400	#	Friction Surface	400	#
Time	300	sec	Time	300	sec

The weight loss of the sample was measured by noting the difference between the initial and final weight readings which is recorded using the electronic balance of accuracy (0.0001) mg after cleaning of the sample. The surface of samples and the disc are cleaned using acetone before performing the test. After fixing the sample inside the sample holder, the normal load through a pivoted loading lever or different velocities to the rectangular sample was applied. As the test time is finished, the rotating disc was stopped. the weight of the sample is measured and then cleaned with acetone and weight again. Care has been taken after each test to avoid entrapment of wear debris in the specimen. The specimens were cleaned by using atheline to remove the debris which adheres to the specimens. The difference in the initial weight and final weight gives the rate of wear of the samples at different loading conditions.

Five samples were run for each combination of the test parameters employed to ensure the taken data while the results reported are the average of the five readings.

The wear rate is evaluated using the following relations[10-12] :

$$W.R = \Delta W / S_D \dots\dots (1)$$

$$\Delta W = W_1 - W_2 \dots\dots (2)$$

$$S_D = 2\pi r N_r t \dots\dots (3)$$

Where :

ΔW : Is the weight loss of the specimen before and after the wear test (gm).

S_D : Is the sliding distance (cm).

r : The radius from the center of sample to disk center.

N : Is the no. of revolutions of the rotating disc (rev. /min).

t : Is the sliding time (min).

The sliding velocity is evaluated from the following relationship[7] :

$$V_s = \pi D N / 60 \dots\dots (4)$$

Where:

D : Is the circular sliding diameter (cm).

Result and discussion

The variation of wear rate with the applied normal load of Unsaturated polyester resin before and after reinforced with different weight fractions of (HDPE) fibers and (PVC, UPE) powders is shown in figure (5).

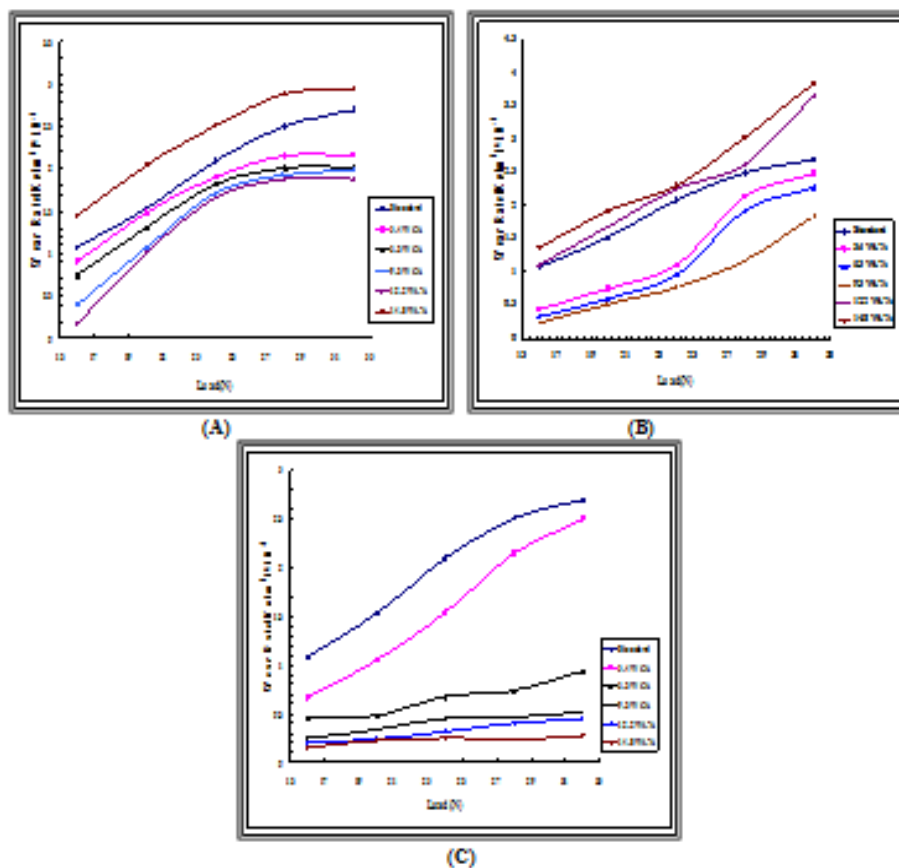


Figure (5): Relationship Between the Wear Rate and Normal Load of the Polyester Reinforced by : (A) HDPE, (B) PVC, (C) UPE.

It was observed from these figure(5) that the wear rates for all tested specimens increases with increase of applied load. This is due to the deeper grooving and more material removal from the sample with increasing load. The neat unsaturated polyester shows the highest wear rate because abrasive particles from friction abrasive paper penetrate deeper into the softer matrix forming a series of tracks, as shown in figure (6). which is similar to that presented in references [8][13].

Also from figure (5), can be seen the wear rate decreases with increasing weight fraction of polymer

fibers and powders. This behavior may be due to when the addition of fibers and particles into the matrix increase the average hardness of the composites and also increases reinforcement-matrix adhesion which reduces the material removal. It is also clear that the wear behavior of (UPE) composite have been showed a considerable the best improvement in comparison with the (HDPE) and (PVC), which the increase of the weight fraction more than of (12.2Wt.%) and (9.5Wt.%), respectively, lead to rapidly increase in the wear rate.

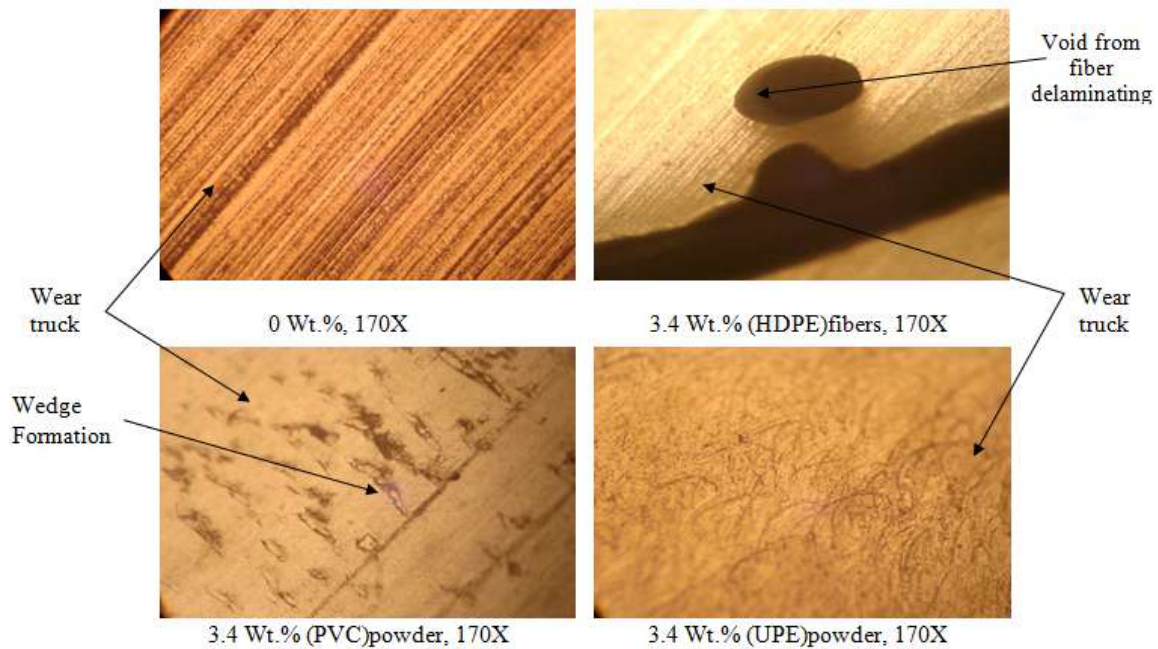


Fig.(6) : microstructure of standard and different weight fractions of polymer fibers and powders composites samples tested for different applied loads.

The incorporation of (HDPE) fibers, (PVC) and (UPE) powders into the polyester with different weight fractions at (load = 16 N, speed = 0.25 m/sec. and sliding time = 300 sec.) is shown in figure(7),

which appear the comparison of the sliding wear resistance improvement between and unsaturated polyester resin unreinforced and reinforced with different reinforcing materials.

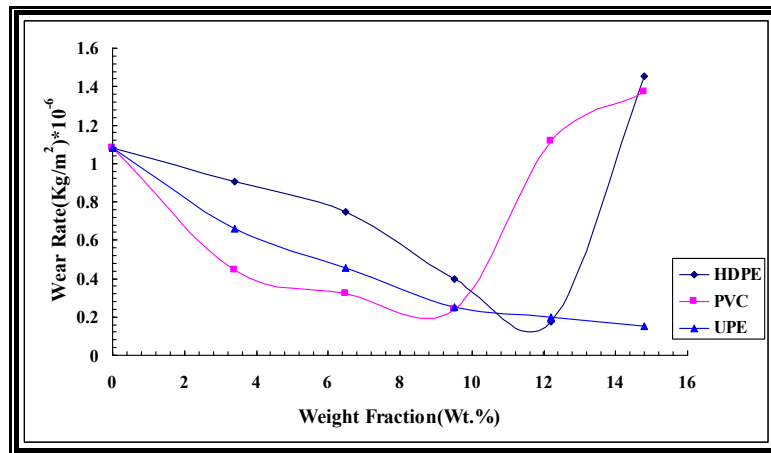
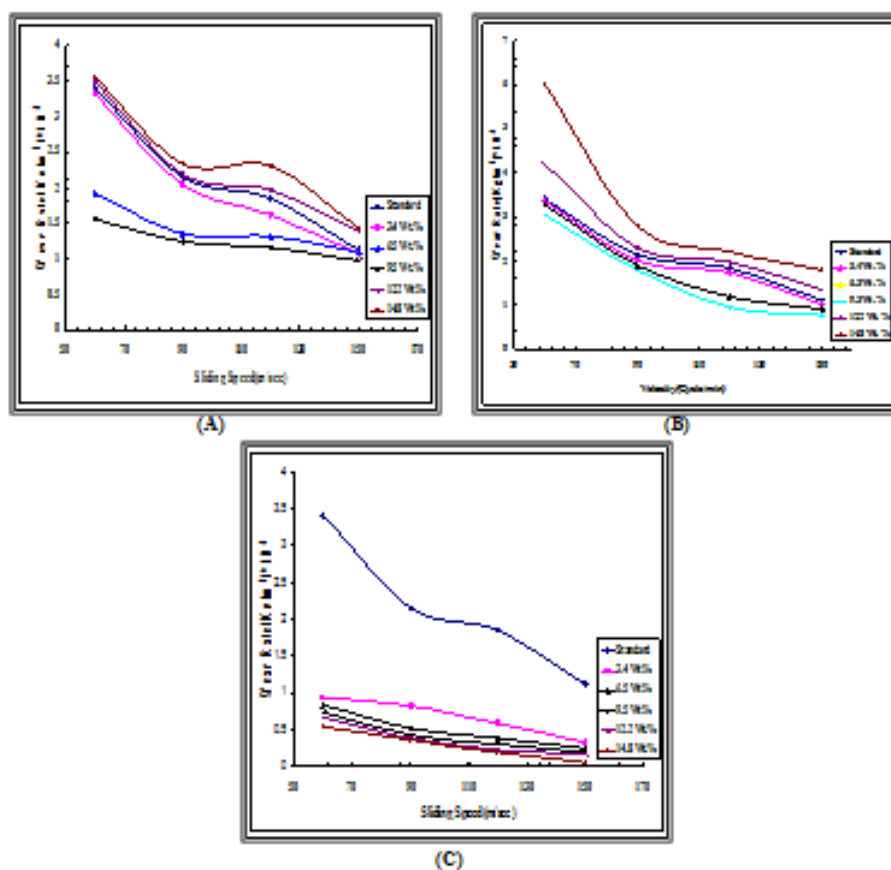


Figure (7): Relationship Between the Weight Fraction and the Wear Rate of the Polyester Reinforced by : (A) HDPE, (B) PVC, (C) UPE.

The wear rate of the composite pin changes in nonlinear relationship from $(1.0812 \times 10^{-6} \text{ Kg/m}^2)$ for unreinforced pin to the $(1.4534 \times 10^{-6} \text{ Kg/m}^2)$, $(1.3749 \times 10^{-6} \text{ Kg/m}^2)$ and $(0.1537 \times 10^{-6} \text{ Kg/m}^2)$ at weight fraction (14 Wt.%) for reinforcing (HDPE) fibers, PVC and UPE powders respectively. It is clear that the wear behavior of these (UPE) composites have been showed a considerable the best improvement with the increasing of the weight fraction of the reinforcement material. this improvement approach to (14.21%) than the standard sample at weight fraction (14 Wt.%). This

improvement is due to the presence of the (UPE) powder makes a layer of solid lubricant, that reduces the friction and hence decreases wear. In contrast with the (HDPE) and (PVC), which the increase of the weight fraction more than of (12.2Wt.%) and (9.5Wt.%), respectively, lead to rapidly increase in the wear rate.

Figures (8) shows the effect of polymers fibers and powders content on the wear rate with different sliding velocity at working condition (load = 14N, and sliding time = 300 sec.)



Figure(8): Relationship Between the Wear Rate and Sliding Speed of the Polyester Reinforced by : (A) HDPE, (B) PVC, (C) UPE.

It was observed that the wear rates were high at the sliding velocity of (60 m/sec) then decreases to its lowest value at (150 m/sec), for all types of reinforcement materials, this is due to reduce in contact time between composite specimen and counter face of Pin-on-disc tribometer. This is similar

to reference [14]. Also the amounts of the wear of the composites decrease with filler content increase, except in case of (12.2Wt.% , 14.8 Wt.%) (HDPE) fibers and (PVC) powder, which the wear rate increase respectively, as shown in figure(9).

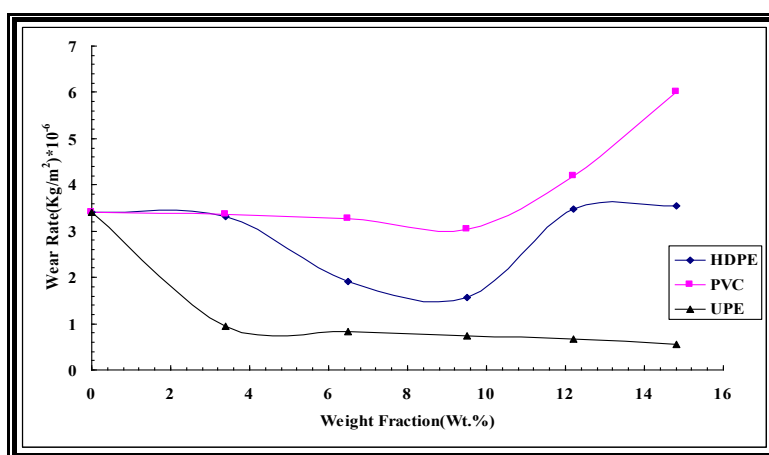


Figure (9): Relationship Between the Weight Fraction and the Wear Rate of the Polyester Reinforced by : (A) HDPE, (B) PVC, (C) UPE.

This result is corresponding with the study [15] which was indicated that when the material is in the elastic deformation range, the bond breakage and subsequent crack propagation does not occur and thus the wear loss is very small. When the material enters into

plastic deformation region either due to the increased normal load or due to the rising sliding velocity, then cracks grow via atomic bond rupture and therefore wear loss become significant. This variation in the

behavior may be related to nature of crack propagation within the material as mentioned above. The photomicrographs of (3.4Wt.%) filler weight fraction of different polymer composites samples tested for different sliding velocities are shown in Figure (10). The micrographs showed the formation

of pits, debris and parallel grooves on the wear surface of the composite indicating the abrasion phenomenon. Heat generation by friction softens the resin [16] and also due to lower specific wear value of the composite [17] leads to ploughing grooves at the worn out surface of the sample.

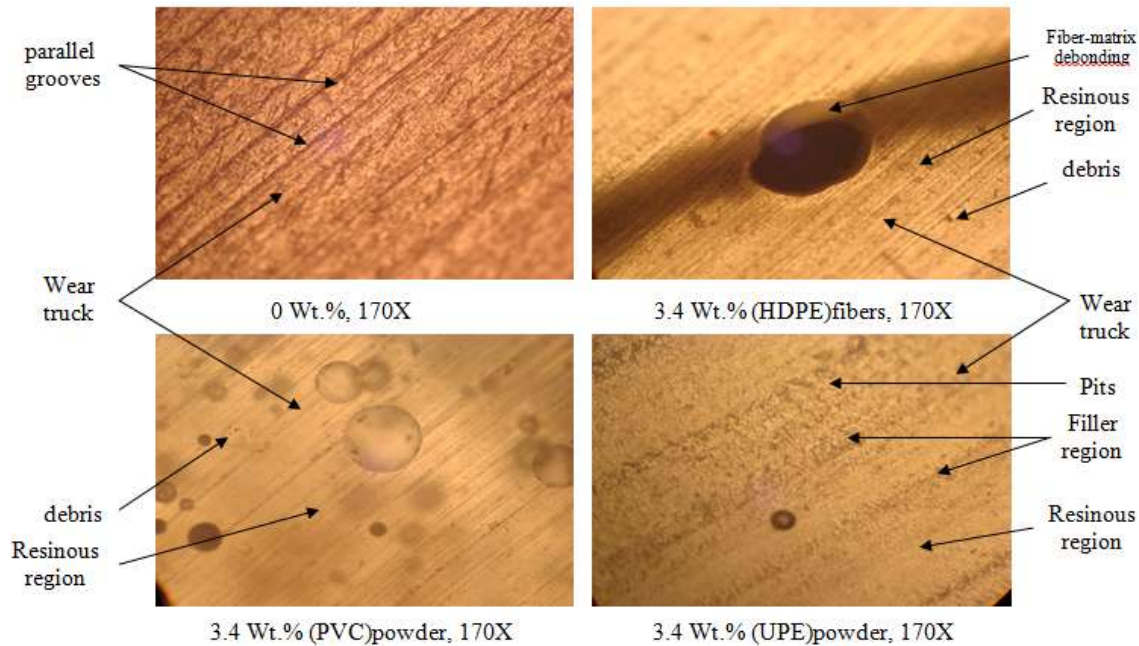


Fig.(10) : microstructure of standard and different weight fractions of polymer fibers and powders composites samples tested for different sliding velocities.

Figure (10) also show, the resinous and filler regions as in case of (UPE)composite, which results in the lesser wear rate because the filler covers the maximum matrix region. While in the cases of (HDPE, PVC) composite, the resinous covers the maximum matrix region. This leads to increases the wear rates of these composites.

Conclusions

The main conclusions of this search are :

1. The wear rate of all composite materials increased with increased time applied load, and decreased with increased weight fraction of all types of reinforcement, except in the case of reinforcement by (12.2Wt.% PVC) and (14.8Wt.% HDPE,PVC).

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2. The wear rate of all composite materials decreased with increased time applied sliding velocity, and decreased with increased weight fraction of all types of reinforcement, except in the case of reinforcement by (12.2 Wt.%, 14.8Wt.% HDPE, PVC).

3. Under the load and the sliding velocity changing, The wear test shows that the unsaturated polyester powder composite with the weight fraction of (14.8Wt.%) is a better choice for frictional application a sit has exhibited lowest wear rate of ($0.1537 \times 10^{-6} \text{ Kg/m}^2$) and ($0.5421 \times 10^{-6} \text{ Kg/m}^2$), respectively in comparison with other types of composites.

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دراسة تأثير إضافة الألياف والمساحيق البوليمرية على البلى الانزلاقي لراتنج البولي استر غير المشبع المقوى

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الملخص

يهتم بحثنا الحالي بدراسة تأثير إضافة الألياف والمساحيق البوليمرية مثل ألياف البولي ايثيلين عالي الكثافة (HDPE)، ومسحوق بولي كلوريد الفايثيل (PVC) والبولي استر غير المشبع (UPE)، على سلوك البلى الانزلاقي لراتنج البولي استر غير المشبع تحت ظروف الانزلاق الجاف، كالحمل المسلط، سرعة الانزلاق عند درجة حرارة الغرفة. اجري اختبار البلى وفقاً لنظام (ASTM-D5963) باستخدام جهاز المسمار على القرص، للحصول على سلوك البلى للمترابكات. أظهرت النتائج أن معدلات البلى تزداد بزيادة الحمل المسلط لكل الأنواع من مواد التدعيم لأعلى من (3.4Wt.%) وتتنخفض عند زيادة التركيز لأعلى من (12.2Wt.%)، (9.5Wt.%)، لكل من ألياف البولي ايثيلين عالي الكثافة ومسحوق بولي كلوريد الفايثيل، على التوالي. أما في حالة زيادة السرعة الانزلاقية، وجد أن معدلات البلى تقل بزيادة مسحوق البولي استر غير المشبع، بينما وجد أن هنالك تحسناً عند زيادة التراكيز لأعلى من (9.5Wt.%) لكل من ألياف البولي ايثيلين عالي الكثافة ومسحوق بولي كلوريد الفايثيل المضافة الى راتنج البولي استر غير المشبع.