Mechanical and Tribological Behavior of Glass-Polyester Composite System Under Graphite Filler Content

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ABSTRACT

Experimental investigations had been done in this work to demonstrate the effect of graphite filler contents on the mechanical and tribological behavior of (30% volume fraction) glass-polyester composite system. The stress-strain relations, modulus of elasticity, yield stress, ultimate tensile strength and ultimate compression strength were studied according to ASTM-D 638-87and ASTM-D 695 to present the composite mechanical behavior. The wear rate and wear resistance were investigated according to ASTM-D 5963 using pin on disc machine to present the composite tribological behavior. The results showed that the mechanical and tribological properties behavior was improved when the graphite filler content was increased up to 7.5% and then decreased after that. At 7.5% filler content the modulus of elasticity, yield stress, ultimate tensile strength, ultimate compression strength and wear resistance increased by (41%, 64%, 24%, 60% and 38%) greater than unfilled composite, while the wear rate was decreased by 27% less than the unfilled one.

Keywords: stress-strain, tensile strength, wear rate, composite material, graphite fillers.

تاثير كمية دقائق الكرافيت على السلوك الميكانيكي والترايبولوجي لراتنجات البولي استر المقوى بالياف الزجاج

الخلاصة

في هذا البحث تمت دراسة تأثير كمية الكرافيت على السلوك الميكانيكي والترايبولوجي لراتنجات البولي استر المقوى بالياف الزجاج عمليا وعند كسر حجمي 30%. تم اختبار علاقة الاجهاد - الانفعال و معامل المرونة و اجهاد الخضوع ومقاومة الشد والانضغاط الاعظم للمادة المتراكبة وفقا (ASTM-D 638-87 و ASTM-D 695) لبيان تاثير كمية الكرافيت على السلوك الميكانيكي. ولمعرفة السلوك الترايبولوجي تم اجراء اختبارات معدل البلى ومقاومة البلى وفقا ASTM-D 5963. بينت نتائج الاختبارات ان الخواص الميكانيكية والترايبولوجية تزداد بزيادة كمية الكرافيت الى اعلى قيمها عند 7.5% ومن ثم تنخفض بزيادة الكرافيت. عند كمية كرافيت 7.5% فان معامل المرونة واجهاد الخضوع ومقاومة الشد والانضغاط ومقاومة البلى تزداد بنسبة (41%, 64%, 24%, 60% and 38%) اكثر

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منها بدون الكرافيت في حين معدل البلى يقل عنها بمقدار 27% .

الكلمات المرشدة:الاجهاد -الانفعال، مقاومة الشد، معدل البلى، مواد متراكبة، الكرافيت.

Symbols

D Diameter (µm)
E Modulus of Elasticity (GPa).
F_n Applied load (N).
F_T Fracture toughness (MPa-m$^{0.5}$).
R Electrical resistance (Ω).
S_d Sliding distance of material removal (mm).
T_S Tensile strength (GPa).
Vr Volume of removed material (mm^3)
Wc Wear rate of composite (mm^3/mm)
Wr Wear resistance (N.m/m^3).
e Elongation at maximum tensile strength (%).
α Coefficient of thermal expansion (C°)$^{-1}$.
Δm Weight loss (gm).
Γ Thermal conductivity (w/m.K).
λ Specific heat (J/kg.K).
ρ Density (gm/cm^3).
σ_{uc} Ultimate compression strength (MPa).
σ_{ut} Ultimate tensile strength (MPa).
σ_y Yield stress (MPa).

INTRODUCTION

Liquid epoxy resins exhibit a good mixture and processing ability with reinforced materials in granular or fiber form. The results of these mixtures are composite materials with intermediate properties depending on the combined action of the components. Fiber and/or filler reinforced epoxy matrix composites are known for their high specific mechanical properties and are therefore used in numerous light weight engineering applications ranging from sports goods to automobiles and aircraft [1].

The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. The matrix isolates the fibers from one another in order to prevent abrasion and formation of new surface flaws and possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distributive stress concentration [2]. The use of inorganic fillers dispersed in composites is increasing, since fillers do not reduce the cost only but also improve the performance requirements which could not be obtained by using reinforcement and resins only[3,4]. Due to the importance of this problem, the main objective of this work is to investigate the effect of filler on mechanical and tribological behavior of composite materials.

Pedro et al [1] demonstrated the tribological behavior of epoxy based composite for rapid tooling, and showed that the small amount of milled fibers enhance the wear resistance. Suresha et al [5] 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. Qahtan A. [6] studied the mechanical and physical properties for polymer matrix composite materials at 10% weight fraction, and showed that the particle volume fraction affects the mechanical and physical 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. Drai A. [8] experimentally investigated the effect of fillers type on tribological 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. Monika et al [9] had an experimental results showed that ASTM D 638 type tension specimens failed at a location where the straight gage section of the specimen ends and the curved transition region begins.

EXPERIMENTAL PROCEDURES

MATERIALS

The material used in this investigation was woven roving glass fiber made of 360 gsm, containing E-glass of 8-14µm diameter. The matrix system used was unsaturated polyester resin known commercial by TOPAZ -1110 TP medium reactive based on Phthalic Anhydride (KSA made) and a room temperature hardener (Methyl Ethyl Kenton Peroxide (MEKP)). The filler used was graphite powders (no. 7782-42-5 Merck index 10, 4410 Swiss). The technical and mechanical characteristics of the raw materials are presented in tables 1, 2 and 3.

SPECIMENS PREPARATION

All the composite specimens were manufactured by dry hand lay up procedure. E-glass weave roving fibers, which is compatible to unsaturated polyester resin, was used as the reinforcement. The unsaturated polyester resin was mixed with the hardener in the ratio 100:2 by weight. The stacking procedure of glass-polyester composites was constructed by placing the E-glass fiber ply one above the other with the resin mixed well to spread between the plies by using mould of (250x250x20) mm. This process was repeated till all the 18 ply were completed with a fixed volume fraction of (30%). The whole assembly was then pressed in a (0.3 MPa) then released and allowed to cure for a 7 days at room temperature. To prepare the filled composites, graphite powders filler was mixed with known amounts of unsaturated polyester resin. The product is a composite plate of

(250x250x20) mm. The details of composites are shown in table-4. To produce the test samples, the plate was cut into the appropriate dimensions using a tipped cutter. A 250x30x20 mm plate was machining using CNC vertical milling machine to produce the tensile test samples according to ASTM-D 638-87 as shown in figure-1. Cylinders of 10mm diameter and 20 mm length shown in figures-(2&3) are produce from 250x20x20 mm composite plates using CNC lathe machine. Theses samples were produced for the compression and wear tests according to ASTM-D 695 and ASTM D 5963 respectively.

MECHANICAL AND TRIBOLOGICAL TESTS

In order to characterize the effect of graphite filler on the mechanical and tribological behavior of glass-polyester composite system, the following tests were performed:

1. Tensile test: An Instron Tensile test machine is used. The test was done with 1000 kg applied load and strain rate of (2mm/min). The test results present the stress strain relationship shown in figure-5, and modulus of elasticity, yield stress, and ultimate tensile strength of the composite shown in table (5).
2. Compression test: The Instron Tensile test machine was also used for the compression test. The test was done with 1000kg applied load and a strain rate of (2mm/min).
3. Wear test: The Pin-on-disc machine shown in figure-4 was used. The cylindrical surface sample of (10 mm diameter) and 20 mm length to form a Pin assembly design for standard wear tests described in ASTM D 5963. This mounted composite sample was made to come in contact with rotating hardened (HRC 62) alloy steel disc counter surface of 200 mm diameter and 8 mm thickness. The dead weight loaded 0.5-2.2 kg (normal load 5 to 22N).The mounting arrangement of the samples was made in such a way that the thickness side of the laminate is made to come in contact with the disc. The sample surfaces were polished with fine SiC paper.

The initial weight of the pin assembly was measured in each test using suitable weighing balance of 10^{-4} gm. The test parameters are normal load, sliding velocity and sliding distance. After the completion of each test the pin assembly was weighed accurately again using the same balance. The weight changes due to wear runs of the specimen were recorded. 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. Load 5–22 N, sliding velocity 2.67 - 5.34 m/sec and sliding distance ranges 1920 - 3850 m, were chosen. The weight loss of the sample was determined by noting the difference between the initial and final weight readings of the sample. Three 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 three readings. The wear resistance W_r is evaluated on the basis of the following equation [10]:

$$\mathbf{W_r = F_n\, S_d / \Delta m / \rho} \qquad \ldots\ldots (1)$$

While the wear rate is calculated using the following relations:

$$Wc = V_r / S_d \quad \ldots\ldots (2)$$

Where the composite's density is obtained by water displacement technique [11] and their values are listed in table-4.

RESULTS AND DISCUSSIONS

Experimental investigations were done to present the effect of graphite filler content on the mechanical and tribological behavior of 30% volume fraction glass-polyester composite system. In mechanical behavior study the stress-strain relation, modulus of elasticity, yield stress, ultimate tensile strength and compression strength, using tensile and compression tests performed on ASTM B 557-02a and ASTM-D 695 specimens respectively. While, for tribological behavior the wear rate and the wear resistance were found, using a Pin-on-disc machine according to ASTM D 5963.

Figure (5) illustrates the stress-strain behavior of the tensile test with graphite filler content. The behaviors of stress strain relation in the five conditions have the same behavior but differ in magnitude. While figure (6) shows the effect of graphite filler contents on the behavior of stress strain under compression tests. Also the behaviors of the five conditions are the same but differ in magnitude. As the filler content was increased the mechanical properties of the composite generally increased as shown in table (5). The modulus of elasticity was increased by (13%, 16%, 41% and 23%). The yield stress was increased by (36%, 43%, 64%, and 38%). The ultimate tensile strength was increased by (2%, 16%, 29% and 24%). While the ultimate compression strength was increased by (30%, 43%, 60% and 52%), when using (2.5%, 5%, 7.5% and 10%) graphite filler content respectively, as compared with the unfilled composite system. Because the filler acts with the fiber and resin in resisting the load and the graphite has a greater strength than the fiber and resin. There is also compatibility between the filler and fiber and between filler and resin. The maximum values of mechanical properties at 30% volume fraction of glass-polyester composite system, was found at 7.5% graphite filler contents. But the mechanical properties decreased when the filler content was increased more than 7.5%. This is because the resin becomes more viscose with increasing filler which leads to a problem in the resin flows, and gets lower adhesion force with more defects.

Figure (7) shows the effect of filler content on wear rate with different applied loads at 3.23 m/sec sliding velocity. It was observed that when the applied load is low, the wear rate is quite small for filled or unfilled, which increases with the increase in applied load. This is similar to that presented in reference [8]. In general with the graphite filler content increase the wear rate decrease as compared with unfilled system. Because the graphite makes a layer of solid lubricant, that reduces the friction and hence decreases wear. The wear rate at 15 N applied load was decreased by (4%, 8%, 27% and 21%) with using (2.5%, 5%, 7.5% and 10%) graphite filler content respectively, less than unfilled composite system. Figure (8) shows the effect of filler content on the wear rate with different sliding velocity at 15 N applied load. It was observed that the wear rates were high at the sliding velocity of 2.5 m/sec then decreases to its lowest value at 5 m/sec sliding velocity. This is similar to references [1and 8]. Also the amounts of the wear of the composites decrease with filler content increase for the same reasons. The composite system wear rate at 3.74 m/sec sliding velocities decrease by (11%, 18%, 23% and 16%), with using (2.5%, 5%, 7.5% and 10%) graphite filler content respectively, less than unfilled composite system. So, figures (7&8) show that the 7.5% graphite filler content of 30% volume fraction glass-polyester composite system have the minimum wear rate value. Figure (9) represents the effect of graphite filler content on wear resistance with different sliding velocities. The wear resistance generally increased with the sliding velocity. This is identical to the results presented from figure (8) when the wear rate decreased with sliding velocity increase. The wear resistance of the filled composite system increases more than that of unfilled one due to the composite strength increase. The wear resistance of the system at 5 m/sec sliding velocity increase by (7%, 19%, 38% and 33%) at (2.5%, 5%, 7.5% and 10%) graphite filler content respectively, more than the unfilled composite system.

CONCLUSIONS

The following conclusions can be drawn:

1. The stress-strain of filled and unfilled glass-polyester composites have the same behavior but differ in values.
2. The mechanical properties of the composite system increase with the filler content increase up to 7.5%. At 7.5% graphite filler content the modulus of elasticity, yield stress, ultimate tensile strength and ultimate compression strength increase by (41%, 64%, 24% and 60%) as compared with the unfilled composite.
3. The wear resistance of the composite system increase and the wear rate decrease with the filler content increase up to 7.5%. At 7.5% graphite filler content the wear resistance increase by (38%), while the wear rate decrease by (27%) as compared with the unfilled one.

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Table (1) Mechanical and physical properties of E-glass fiber [12].

E (GPa)	ρ gm/cm^3	D μm	T_S MPa	e %	α 10^{-6}/C°	γ w/m.K	λ J/kg.k
72.5	2.58	8-14	3450	4.3	5	1.3	810

Table (2) Mechanical and physical properties of unsaturated polyester resin [12].

E (GPa)	ρ gm/cm^3	F_T MPa-$m^{0.5}$	T_S GPa	e %	α 10^{-6}/C°	γ w/m.K	λ J/kg.k
2.06-4.41	1.2	0.6	41.4-89.7	<2.6	100-180	0.17	710-920

Table (3) Mechanical and physical properties of graphite powders [12].

E (GPa)	ρ gm/cm^3	T_S MPa	R Ω	α 10^{-6}/C°	γ w/m.K	λ J/kg.k
11.7	1.78	31-69	$(10-18)10^{-6}$	2.2-6	130-104	830

Table (4) Samples detail

Sample	Matrix	Reinforcement 30% Wt	Filler	Weight%	ρ_c kg/m^3
A	Unsaturated polyester resin	E-Glass	None	0%	1388
B	Unsaturated polyester resin	E-Glass	Graphite powder	2.5%	1521
C	Unsaturated polyester resin	E-Glass	Graphite powder	5%	1600
D	Unsaturated polyester resin	E-Glass	Graphite powder	7.5%	1728
E	Unsaturated polyester resin	E-Glass	Graphite powder	10%	1840

Graphite %	E (Gpa)	S_y (Mpa)	S_{ut} (Mpa)	S_{uc} (Mpa)
0%	2.551	57	127	46
2.5%	2.883	78	130	60
5%	2.976	82	148	66
7.5%	3.616	94	165	74
10%	3.140	79	158	70

a-before test

B-after test

Figure (1) tensile test sample according to ASTM-D 638-87.

Figure (2) Compression and wear test samples preparation.

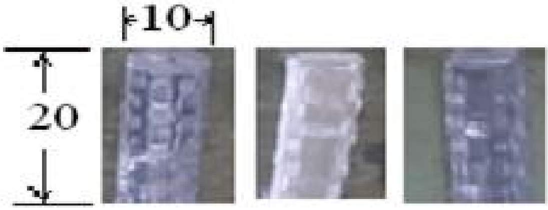

Figure (3) Compression and wear test samples according to ASTM-D695 and D5963 respectively.

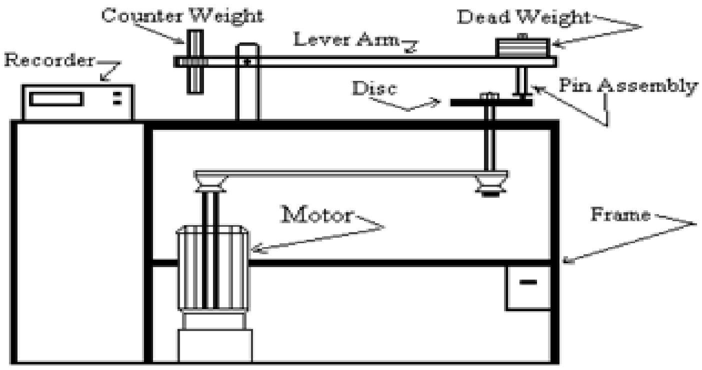

Figure (4) Layout of the Pin on disc wear testing machine.

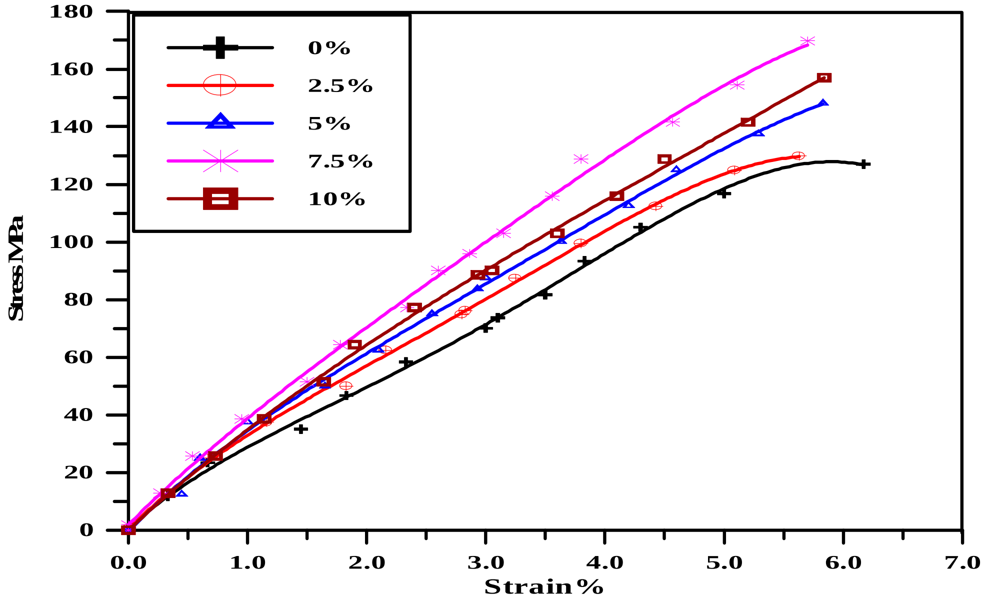

Figure (5) Effect of graphite filler content on the Stress-strain behavior of tensile test.

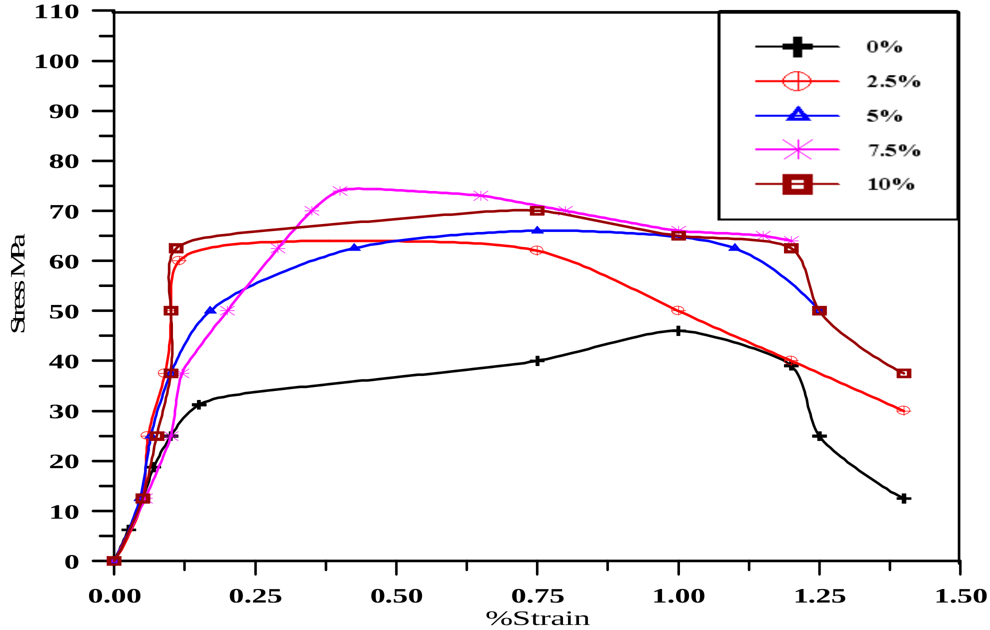

Figure (6) Effect of graphite filler content on the Stress-strain behavior of compression test.

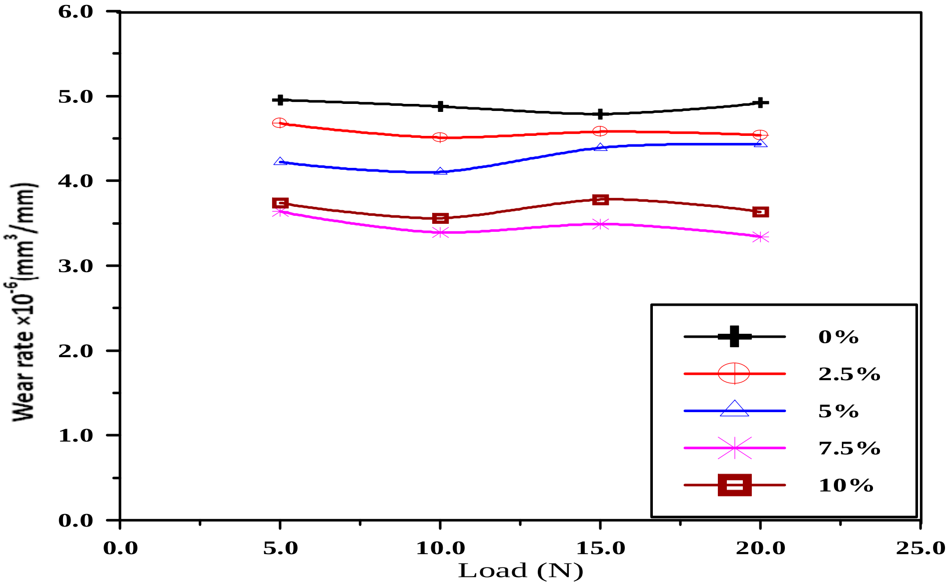

Figure (7) Effect of filler content on wear rate with different load at 3.23 m/sec sliding speed and 1938m sliding distance.

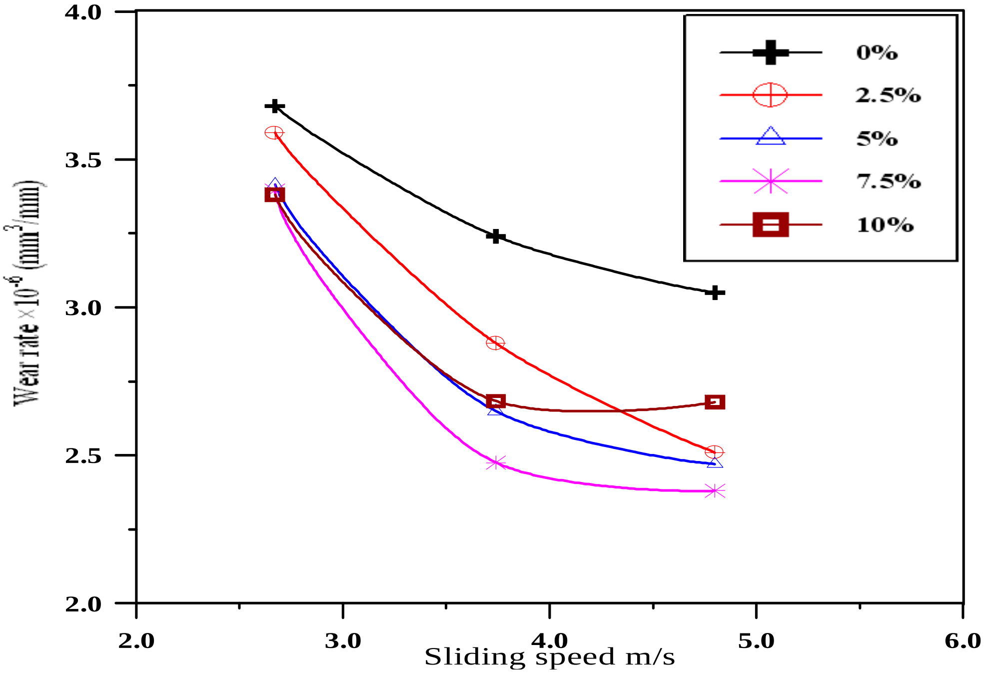

Figure (8) Effect of filler content on wear rate with different sliding speed at 15 N applied load.

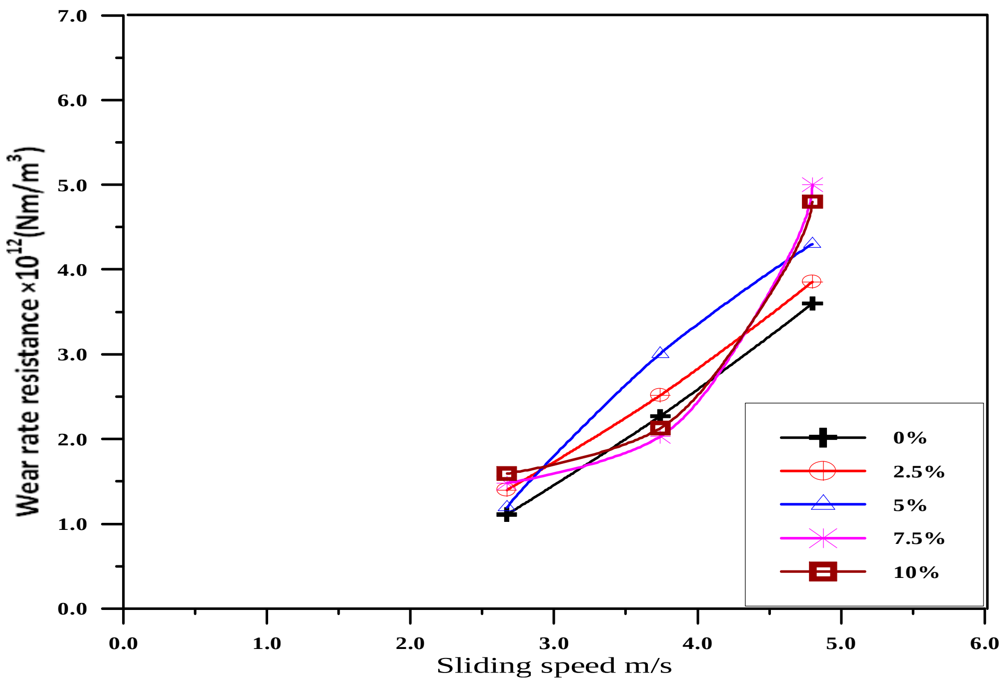

Figure (9) Effect of filler content on wear resistance at different speed and 15 N applied load.