Study The Effect Of The (Al) And (Al_2O_3) Particles Reinforcing On The Wear Volume Loss Characteristics Of Epoxy

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Abstract

This study investigated experimentally the wear volume loss of the epoxy reinforced by (Al) and (Al_2O_3) particles of grain size (≤ 30 μm) with different four volume fractions of the reinforcements which are (3 %, 6 %, 9 %, and 12 % Vol.). Pin-on-Disc wear test were conducted to exam the wear volume loss behavior of the composite specimens. The wear test results indicated that the wear volume loss of the specimen increases with the increase of the applied load and sliding time, while it decreases with the increase of the volume fraction of the reinforcing material. Also the results show that the average volume loss of the epoxy reinforced by (Al) was higher than reinforced by (Al_2O_3) by the value was (45 %) at volume fraction (= 6 %), sliding speed (V_s =2 m/sec.) and sliding time (T =300 sec.)

دراسة تأثير التقوية بدقائق (Al) و (Al_2O_3) على خصائص خسارة حجم البلى للأيبوكسي

الخلاصة

هذه الدراسة بحثت عمليا" خسارة حجم البلى للأيبوكسي المقوى بدقائق (Al) و (Al_2O_3) ذات الحجم الحبيبي (≤ 30 μm) عند أربعة كسور حجميه مختلفة لمادة التقوية (12 %, 9%, 6 %, 3%).

أستخدم جهاز البلى نوع (مسمار – على – قرص) للتوصل إلى طبيعة خسارة حجم البلى للعينات المتراكبة المستخدمة. بينت النتائج بان خسارة الحجم للعينات تزداد مع زيادة الحمل المسلط وزمن الانزلاق بينما تقل مع زيادة الكسر ألحجمي لمادة التقوية. كذلك بينت النتائج بان معدل خسارة حجم البلى للأيبوكسي المقوى بــ (Al) أعلى من المقوى بــ (Al_2O_3) بنسبة (45 %) عند كسر حجمي (6 %) وسرعة أنزلاق (2 m/sec.) وزمن أنزلاق (300 sec.).

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Introduction

In recent times, there has been a remarkable growth in the large-scale production of filler reinforced epoxy matrix composite. Because of light weight, high performance, high specific stiffness, high specific strength, normal thermal expansion coefficient and superior dimensional stability. They are extensively used for a wide variety for structural applications. Therefore the polymer matrix composite used in the industrial applications such as (gear, wheel, brakes, clutch, ball bearing, cages, journal bearing, cams, seals for shafts…….etc) and for bio-medical applications such as (valves, hip joints, knee joints and pump components ……..etc) [1, 2]. The term of wear is inevitable, when two surfaces undergo sliding under load. The ability to reduce the volume loss has long been a major factor for increasing the efficiency and working life of machines and moving parts. Although it will be impossible to prevent the wear process, it must be try to control or minimize it [3].

To improve wear resistance of the composite, additional phase can be introduced to the matrix material. However, the required mechanical properties of the reinforcement and the role of the reinforcement will be different in ductile Vs. brittle matrices. For a ductile matrix, a hard secondary phase is need to reduce wear, such that the presence of the hard reinforcement increases the effective hardness of the matrix, thereby reducing the penetration of the abrasive medium. Consequently, increasing the effective hardness acts to reduce the a mount of material removed [4, 5] The sliding of abrasives on a solid surface results in volume removal. The mechanism of wear depends on the mechanical properties of the solid. In a ductile solid, the primary wear mechanism is related hardness of the material is a key parameter in governing the amount of material removal [6, 7].Tanaka [8] concluded that the wear rate of polytetrofluroethylene (PTFE) was reduced when filled with ZrO_2 and TiO_2.

S. Basavarajappa et al. [9] investigated the dry sliding wear behavior of Al 2219 alloy, reinforced with SiC particles in (0-15 wt %). The results showed that the wear rates of the composites are lower than that of the matrix alloy and further decrease with increasing SiC content.

B. Suresha et al. [10] studied the effect of the fillers (silicon carbide and graphite particulates) on the wear rate characteristics of glass-epoxy composite system. It was found that for the increased load and sliding velocity situations, higher wear loss was recorded and SiC filled G-E composite exhibited the maximum wear resistance.

Kishore et al. [11] studied the influence of sliding velocity and applied load on the friction and wear behavior of G-E composite, filled with either rubber or oxide particles, and reported that the wear loss increased with increase in load/speed.

P. Bhimaraj et al. [12] study the effect of the grain size and the weight fraction of alumina nanoparticles on the wear rate of poly (ethylene) terephthalate (PET). They found that the wear resistance increases with increase of the weight fraction.In the view of the above description, an attempt has been made in this study to reduce the wear volume loss behavior of the epoxy reinforced with (Al) and (Al_2O_3) particles at different loads, sliding time and volume fraction, such that it will be more relevant and appropriate for severe environments.

Therefore the objective of this work is to investigate the wear volume loss properties of particulate filled-epoxy matrix sliding against a hardened steel counterface.

Experimental Work

Two particulate reinforcing materials (Al) and (Al_2O_3) prepared from (RIEDEI-DE HAENAG) German company with grain size (≤30 μm) and Volume fraction (3%, 6 %, 9% and 12% Vol.) were used here to reinforce the epoxy prepared from (SIR) Saudi company. The detail of these particles and epoxy illustrated in Table (1).

Hand-Lay out method was used to prepare the composite specimens with the dimension of (9.5 mm) diameter and (20 mm) length based on the standard wear test described in ASTM standard D5963-97a [13]. The sample of the test specimens illustrated in figure (1).

Pin-on-Disc test apparatus figure (2) was used to investigate the wear volume loss characteristics of these composite specimens. The disc is made of a tool steel material with hardness (385 HV), which has a rotating radius of (70 mm) and a rotating speed of (276 r.p.m.). All tests were conducted at room temperature. Wear tests were conducted with loads ranging from (2.5-12.5 N) and sliding speed (2 m/sec.) and sliding time ranging from (150-750 sec.).

The initial weight of the specimens was measured using sensitive balance weight with an accuracy of (10^{-4} gm). After the end of testing the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The differences in weight measured before and after tests gives wear of the composite specimen. The following relation is used to investigate the wear volume loss which is: [14]

$$K = \frac{\Delta m}{r_c} \qquad ..... \quad (1)$$

where:

Δm : difference in the weight of the specimen before and after wear test (gm).

ρ_c : density of the composite specimen (gm/cm^3).

The density of the composite estimated from the law of rule of mixtures: [1,2]

$$r_c = V_p \cdot r_p + V_m \cdot r_m \qquad ....(2)$$

where

ρ_p and ρ_m : Density of the particles and matrix respectively (gm/cm^3).

V_p and V_m :Volume Fraction of the particles and the matrix respectively (%).

The volume fraction of the particles reinforcement and the matrix may be estimated from the following equations: [1,2]

$$V_p = \frac{r_c}{r_p} \cdot W_p \cdot 100\% = \frac{r_c}{r_p} \cdot \frac{w_p}{w_c} \cdot 100\% \qquad .....(3)$$

$$V_m = \frac{r_c}{r_m} \cdot W_m \cdot 100\% = \frac{r_c}{r_p} \cdot \frac{w_m}{w_c} \cdot 100\% \qquad .....(4)$$

where:

ρ_c : Density of the composite (gm/cm^3)

W_p and W_m : Weight fraction of the particles and the matrix respectively.

ω_p, ω_m and ω_c : Weight of the particles, matrix and the composite respectively (gm).

The effect of the volume fraction of the reinforcing materials on the density of the composite is illustrated in table (2).

Results

The results obtained from the experimental work are discussed here. Figures (3 and 4) show the relationship between the applied normal load and the wear volume loss of the composite pin reinforced by (Al) and (Al_2O_3) particles respectively, for different particulate volume fraction (0%, 3 %, 6 %, 9 %, and 12 % Vol.) at working condition (speed = 2 m/sec., and sliding time = 300 sec.).

It is clear from these figures that the wear volume loss of the composite pin increases with the increase of the applied normal load at different rates.

Also, figures (3 and 4), show that the wear volume loss of the reinforced composite pin was lower than that of unreinforced composite pin. Because at these values of loading the particles acted as a load bearing element between the contact surfaces. These particles have higher hardness than the matrix (epoxy).

Figure (5) shows, the relationship between the applied normal load and the wear volume loss of the composite pin reinforced by (Al) and (Al_2O_3) particles for (volume fraction = 6 %, speed = 2 m/sec., and sliding time = 300 sec.).

It is clear from these figure that the average wear volume loss of the composite pin reinforced by (Al) particles was higher than that of the average volume loss of the composite pin reinforced by (Al_2O_3) by the value of (45 %) that due to hardness of the composite pin reinforced by (Al_2O_3) particles was higher than that when reinforced by (Al) particles.

Figures (6 and 7) show the behavior of wear volume loss with sliding time of the composite pin reinforced by (Al) and (Al_2O_3) particles respectively, for different volume fraction (3%, 6%, 9% and 120% Vol.).

It can be seen that the wear volume loss of the composite pin increases with the increase of the period of sliding similar to the case of increasing the load, also it can be seen that the worst wear volume loss when unreinforced epoxy.

Figure (8) shows, the relationship between the sliding time and the wear volume loss of the composite pin reinforced by (Al) and (Al_2O_3) particles for (volume fraction = 6 %, speed = 2 m/sec., and load = 7.5 N).

It is illustrated from this figure that the average wear volume loss of the composite pin reinforced by (Al) particles was higher than that of the average wear volume loss of the composite pin reinforced by (Al_2O_3) by the value of (38.4 %). This is due to the hardness of the composite pin reinforced by (Al_2O_3) particles was higher than that when reinforced by (Al) particles.

Figure (9) shows, the relationship between the volume fraction of the reinforcing materials and the wear volume loss of the composite pin reinforced by (Al) and (Al_2O_3) particles.

It is clear from this figure that the wear volume loss decreases with the increase the volume fraction of the reinforcing materials, from value of ($13.3*10^{-3}$ mm^3) for unreinforced epoxy to ($4*10^{-3}$ mm^3 and $2.4*10^{-3}$ mm^3) at 12 % Vol. For (Al) and (Al_2O_3) respectively at working conditions (load= 7.5 N, speed = 2 m/sec., and sliding time = 300 sec.). The wear volume loss of the composite pin reinforced by (Al) particles was higher than for the composite pin reinforced by (Al_2O_3) particles for all values of volume fraction.

Conclusions

The primary conclusions are as follows:-

1- The wear volume loss of the reinforced epoxy specimen increases as the load and sliding time increases.

2- The average volume loss of epoxy reinforced by (Al) particles was higher than that when reinforced by (Al_2O_3) particles by the value (45 %) at (volume fraction = 6 %, speed = 2m/sec., and sliding time = 300 sec.)

3- The wear volume loss of the epoxy reinforced by (Al) and (Al_2O_3) decreases with the increase of the volume fraction.

4- The value of wear volume loss of unreinforced epoxy was ($13.3*10^{-3}$ mm^3), while for the epoxy reinforced by (12 %) of (Al) and (Al_2O_3) was ($4*10^{-3}$ mm^3 and $2.4*10^{-3}$ mm^3) respectively at working conditions (load= 7.5 N, speed = 2 m/sec., and sliding time = 300 sec.)

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Table (1) Some Properties of the Matrix and the Reinforced Materials [1,15].

Material Type	Density (gm/cm^3)	Modulus of Elasticity (GPa.)	Tensile Strength (MPa.)	Fracture Toughness MPa.Öm	Thermal Conductivity W/m.°C
Epoxy	1.11-1.40	2.41	27.6-90	0.6	0.19
Al particles	2.7	71	60	40	247
Al2O3 particles	3.72	304	282-551	4.2-5.9	39

Table (2) Variation of the Density of the Composite with the Volume Fraction if the Reinforcement.

V_f of (Al) particles %	Density of the composite (gm/cm^3)	V_f of (Al_2O_3) particles %	Density of the composite (gm/cm^3)
0	1.2	0	1.2
3	1.245	3	1.276
6	1.29	6	1.351
9	1.335	9	1.427
12	1.38	12	1.502

3 % Vol. | 6 % Vol. | 9 % Vol. | 12 % Vol.

Epoxy Reinforced by (Al) particles

Epoxy Reinforced by (Al_2O_3) particles

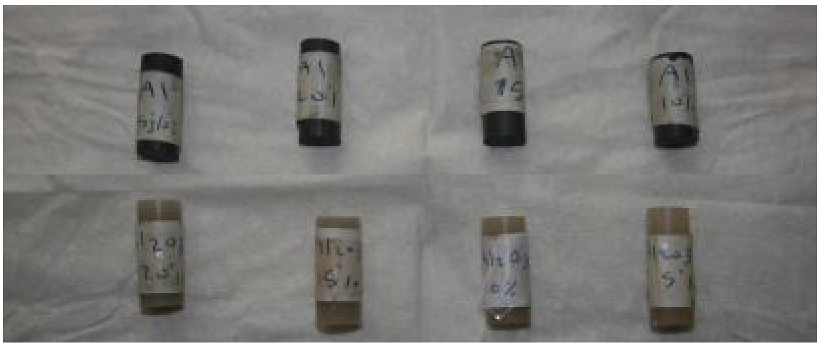

Figure (1) Sample of the Test Specimens.

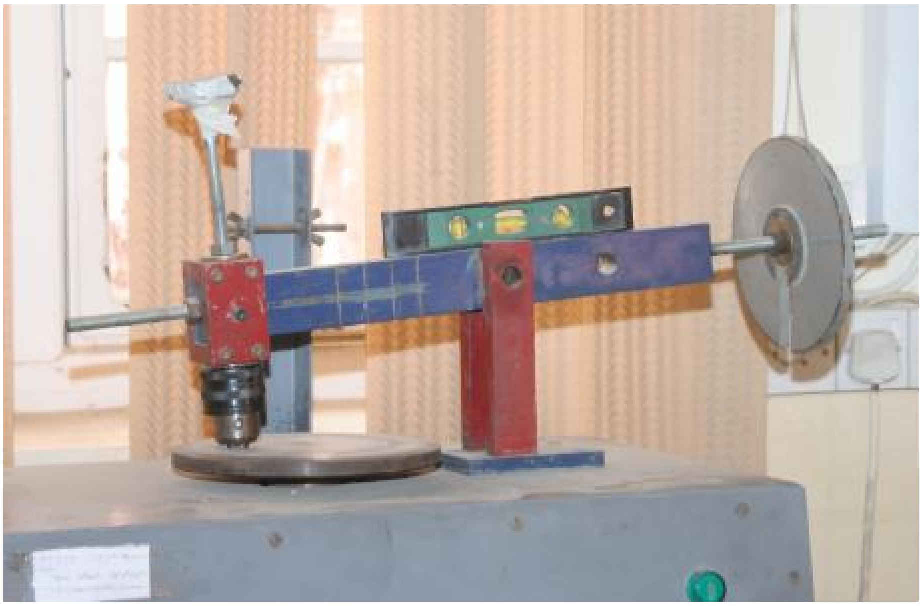

Figure (2) Pin – on – Disc Wear Test Apparatus.

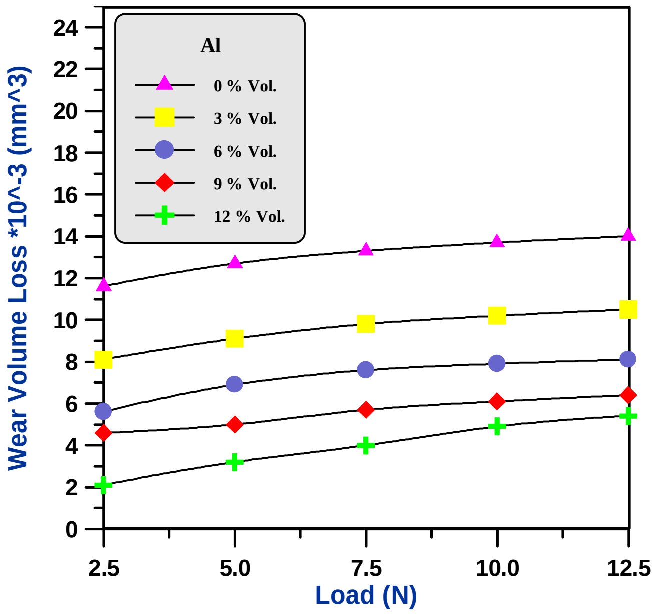

Figure (3) Relationship Between the Normal Load and the Wear Volume Loss of the Composite Pin Reinforced by (Al) particles at (V_s= 2 m/sec., and T= 300 sec.).

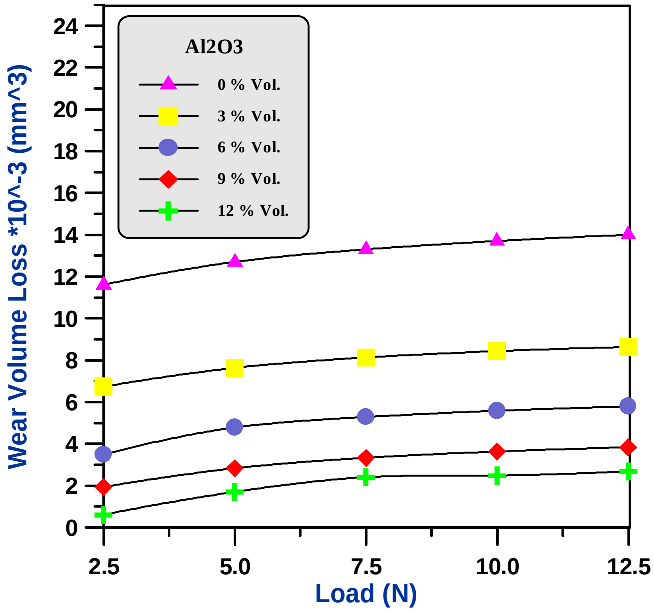

Figure (4) Relationship Between the Normal Load and the Wear Volume Loss of the Composite Pin Reinforced by (Al_2O_3) particles at (V_s= 2 m/sec., and T= 300 sec.).

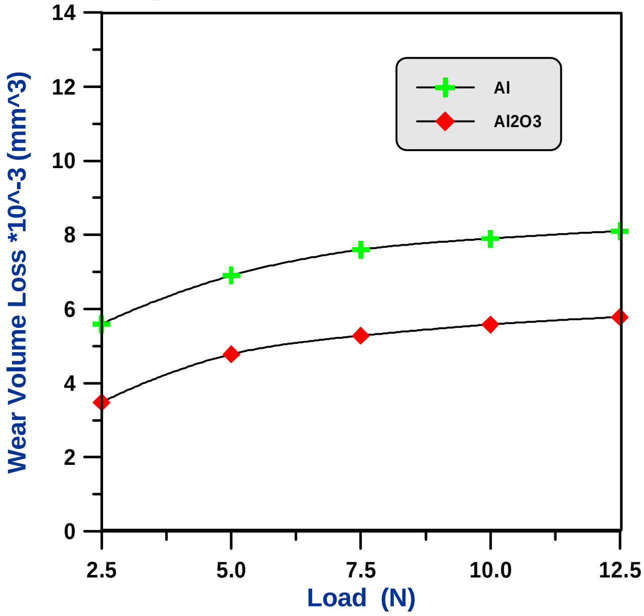

Figure (5) Relationship Between the Normal Load and the Wear Volume Loss of the Composite Pin Reinforced by 6 % Vol. of (Al) and (Al_2O_3) particles at (V_s= 2 m/sec., and T= 300 sec.).

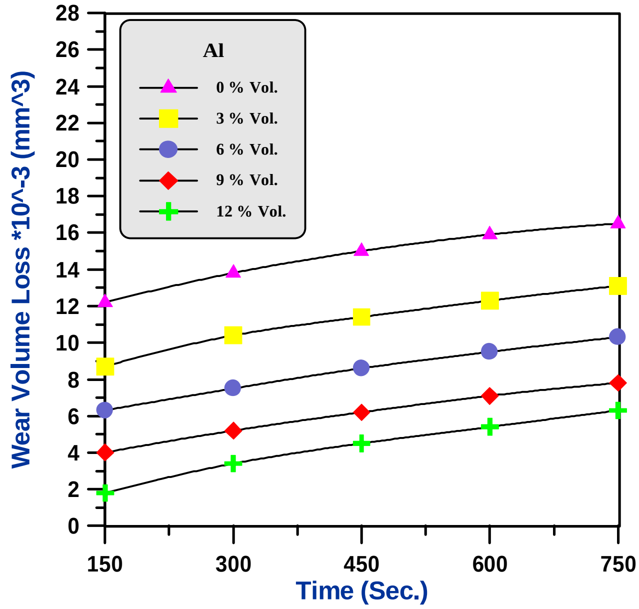

Figure (6) Relationship Between the Sliding Time and the Wear Volume Loss of the Composite Pin Reinforced by (Al) particles at (V_s= 2 m/sec., and W = 7.5 N).

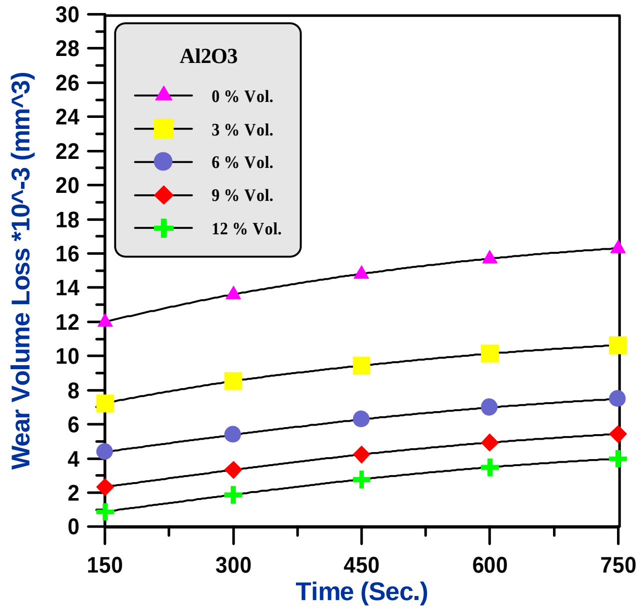

Figure (7) Relationship Between the Sliding Time and the Wear Volume Loss of the Composite Pin Reinforced by (Al_2O_3) particles at (V_s= 2 m/sec., and W = 7.5 N).

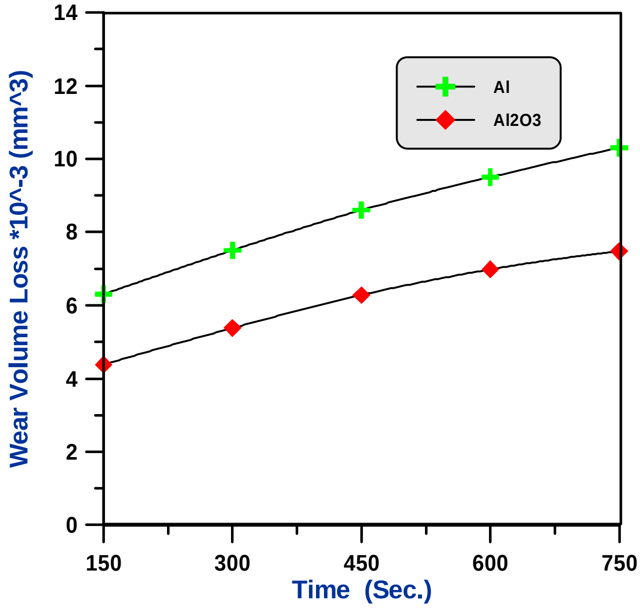

Figure (8) Relationship Between the Sliding Time and the Wear Volume Loss of the Composite Pin Reinforced by 6 % Vol. of (Al) and (Al_2O_3) particles at (V_s= 2 m/sec., and W = 7.5 N).

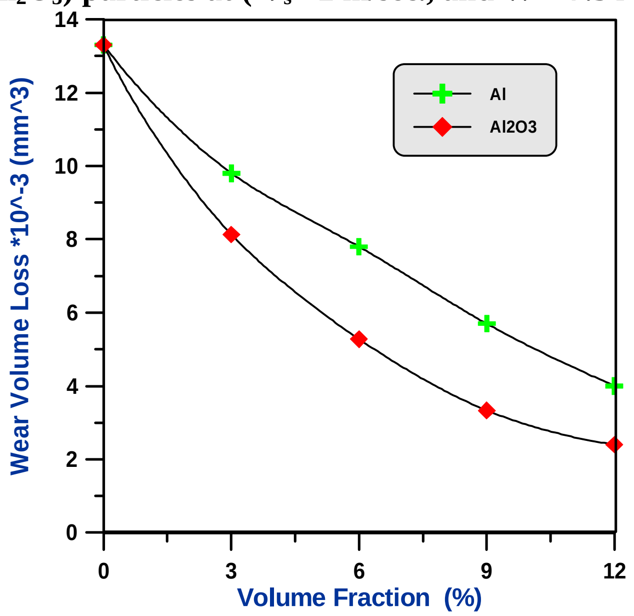

Figure (9) Relationship Between the Volume Fraction and the Wear Volume Loss of the Composite Pin Reinforced by (Al) and (Al_2O_3) particles at (V_s= 2 m/sec., W = 7.5 N and T= 300 sec.).