

Studying The Mechanical And Electrical Properties Of Polyester Resin Reinforced With Silica Particals

Asst. Lecture. Shayma. H. Mohammad
Technical college/Baghdad

Abstract :

A study has been made on mechanical properties of polyester resin matrix reinforced with weight fraction (10,20, 30&40) % of silica particles. The specimens were subjected to tensile test bending test (three point method), and hardness test .The experimental results indicate that the tensile strength of the matrix material were found to be significantly higher than those of the composite material (36%,36.1%,52%,57.5) while the young modulus of matrix material were found to be less than of composite material (% 14,% 33,42%, 45%). Test result also indicate that the flexural strength of the matrix material were found to be significantly higher than those of the composite material (6%,27%,29%,51) while the young modulus of matrix material were found to be less than of composite material(41%,50%,57.6%, 63%) . hardness of the composite materials are significantly higher than those of the matrix material (20%,28.6%,34%,43%) the enhancement in these properties are found to be directly proportional to the weight fraction of reinforcement materials. Test results also indicate that the electrical conductivity increased with increasing the silica concentrationsn.

Keywords: ceramic filled polymer composite, polyester resin, electrical properties, mechanical properties

دراسة الخواص الميكانيكية والكهربائية لراتنج البولي استر المدعم بدقائق السليكا

م .م شيماء حميد محمد
مدرس الكلية التقنية – بغداد

الخلاصة :

تم في هذا البحث دراسة الخواص الميكانيكية والكهربائية لراتنج البولي استر المدعم بدقائق السليكا وبنسب وزنيه (10، 20، 30 & 40) . تعرضت العينيات إلى اختبار الشد وجساءة الانحناء (ثلاثي النقاط) والصلادة حيث أظهرت النتائج إن متانة الشد للمادة الأساس أعلى من المادة المركبة بمقدار (36.1%,36%,52%,57.5) إما معامل المرونة للمادة الأساس أقل من المادة المركبة بمقدار (14% ,33%,42%, 45%) . إما في اختبار الانحناء أظهرت النتائج إن متانة الانحناء للمادة الأساس أعلى من المادة المركبة بمقدار (6%,27%,29%,51) إما معامل المرونة للمادة الأساس أقل من المادة المركبة بمقدار (41% ,50%,57.6%, 63%) . إما نتائج اختبارات الصلادة أظهرت إن صلادة المواد المركبة أعلى بكثير من المادة الأساس (20%,28.6%,34%,43%) وان التحسن في الخواص يتناسب طرديا مع الكسر الوزني للمواد المدعمة إما بالنسبة لاختبار التوصيل الكهربائي فقد أظهرت النتائج إن خاصية التوصيل الكهربائي للمادة المركبة اعلى من المادة الأساس وتزداد بزيادة النسبة الوزنية لدقائق التدعيم .

Introduction

A composite is a heterogeneous substance consisting of two or more materials which do not lose the characteristics of each component. This combination of materials brings about new desirable properties . Polymer composites consist of a polymer resin as the matrix , A polymer is simply a very large molecule formed by joining many small molecules known as monomers the polymer can be classified into three types (thermoplastic ,thermo set & elastomer). The importance of polymers is mainly because polymers are still regarded as a cheap alternative material that is manufactured easily Due to the combination of more than one material, the properties of composites are influenced by many factors such as Matrix Material, Reinforcement Material and Interface and Bonding^[1].

Composite materials are widely used in many fields of industry. Depending on required properties. Mechanical and electrical properties of composite materials are important for nearly all applications in industry.

Polyester resin is a thermosetting polymer , polyester resins have a series of valuable properties suitable viscosity, ability to solidify at both room and high temperatures, high strength and dielectric ratings, high chemical stability and they do not release volatile substances. The coefficient of light refraction of the unsaturated polyester resins is close to that of the glass; therefore the obtained polymer materials are transparent^[2].

Particulate composite differs from the fiber and flake types in that distribution of the additive constituent is usually random rather than controlled. Particulate composites are therefore usually isotropic. The particles in particulate composites are discrete, and, by definition, they do not combine chemically with the matrix. The geometrical characteristics of the particles their structural arrangement in the matrix largely determine the properties of the composite. These characteristics include particle size and shape, the spacing between the particles, the amount or volume fraction of particles, and the manner in which the particles are distributed in the matrix . The particles ranging in size from microscopic to macroscopic^[3&4].

Many important ceramic engineering materials are based on silica (SiO_2),Silica is very widespread in nature even in pure form . The fundamental structural unit for silica and all silicates is silicon – oxygen tetrahedron in which the silicon atom is surrounded by four oxygen atoms places at the corner of a tetrahedron .Silica exists in several different polymorphic forms: quartz, tridymite and cristobalite . Silica is mechanically strong and has a high melting point of 1710 °C, because of strong primary bonds between silicon and oxygen atoms^[5,6& 7].

B. Hussien study the electrical properties of (PMMA- Al_2O_3) composite and he found that the electrical conductivity increased with increasing the alumina concentrations and temperature^[8].

P.L. Electrical conductivity results revealed that increasing in conductivity with increasing in filler loading. Percolation concentration was found at filler content of 20 vol. %. Increasing the amount of filler content led to a decreased in flexural strength and a corresponding increase in flexural modulus of elasticity. It was observed that the hardness of

composites nonlinearly increased with increasing amount of filler. Thermo gravimetric analysis (TGA) study showed an increment in thermal stability after the addition of recycled copper filler in polyester resin composites^[9].

S. P. Deshmukh and A. C. Rao. In this research mica filled PVC composites of different concentrations were prepared using untreated and surface treated water ground mica of different particle size. Mica filled PVC composites were compounded for various compositions and test samples were prepared using compression moulding process. These samples were tested for electrical insulation and mechanical properties. The results shows enhancement in dielectric properties with improvement in Young's modulus, stiffness, reduction in elongation at break and slight increase in shore D hardness of composites. Scanning electron microscopy was used to test the morphology of the samples which has shown proper distributions and adhesion of the filler mica in PVC matrix. There was some effect of surface treatment of mica on its mechanical and dielectric properties of the composite^[10].

Ali – Zangna, studied the influence of adding Iraqi ceramic raw materials (kaolin , Bauxite) on the mechanical properties of epoxy resin type (CY 223) , the weight fraction of the particles are (25, 35, 45).The results indicate improvement in the mechanical properties with addition of ceramic powders. The results show a decrease in tensile strength, and increase in elastic modulus with increasing the weight fraction of the ceramic particles. The fracture toughness, the hardness, and compressive strength increase when the epoxy resin reinforced with ceramic powders, while the flexural strength and wear rate decrease with increasing the weight fraction of the ceramic particles ^[11].

The aim of this research is studying the mechanical and electrical properties of polyester reinforced with silica particles.

Experimental Work

- Materials:
 1. SiO₂ particles .
 2. polyester & its hardener
- Equipment's:
 - 1- Instron universal testing machine
 - 2- Universal testing machine for plastic & rubber, model 2005.
 - 3- Brinell hardness test the equipment used is type Ley Bold Harris No.36110

Experimental Setup

- 1- Silica particles with different weight fraction (0,10,20,30&40%).
- 2- polyester resin and its hardener were added and mixed to ensure complete melting at approximate 2%.

- 3- Silica particles were added.
- 4- The mixture was mould and the sample of polymer composite were cutting with (2& 0.5) cm dimension for electrical test . **Figure (1)** shows the schematic diagram of current measurement apparatus.

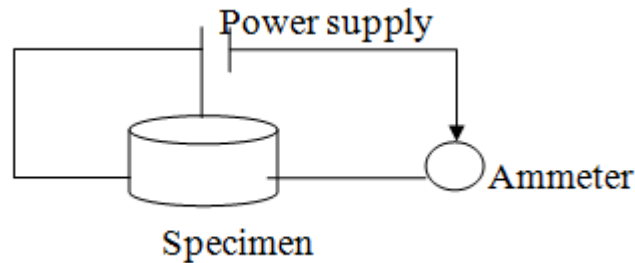


Fig.(1): schematic diagram of current measurement apparatus

$$R = \frac{V}{I} \quad \dots\dots\dots(1)$$

Where :

R: resistance V: voltage I: current

$$\sigma = \frac{d}{R.A} \quad \dots\dots\dots(2)$$

Where:

σ : *electrical conductivity* ($S\text{cm}^{-1}$)

d: diameter of specimen, cm

R:electrical resistance, Ω/cm

A:cross-section area, cm^2

- 5- The dimensions of the bending specimen (three point method) for flexural test are (length 160mm , thickness 4mm and width 10) according to ASTM-D790 ^[12] . as show in **Figure (2)**.

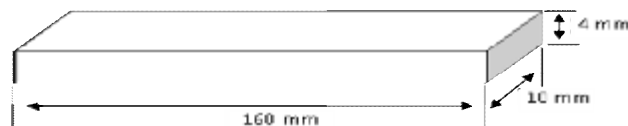


Fig.(2): bending test specimen

- 6- The dimensions of the specimen for tensile test are (length 60mm the thickness 4mm and the width is 10mm) according to the ASTM-D638^[13] . as shown in **Figure.(3)**.

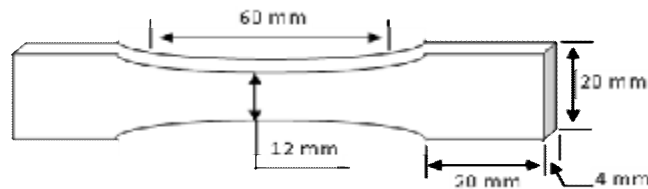


Fig.(3): tensile test specimen

- 7- The speed of which the stress is applied in tensile test is (2mm/min) at room temperature.
- 8- Young modulus for tensile test is calculated from slop of stress strain curve
While the young modulus of bending test calculate from following equations

$$E = \frac{\text{mass} \cdot g \cdot L^3}{\text{deflection} \cdot 48 I} \quad \dots\dots (3)$$

Where:

(Mass/ deflection) is representing the slope which is calculated from mass/ deflection curve.

g : acceleration of gravity ,9.81 m/s⁻²

L: length of the specimen, 100 mm

I: momentum of the bending, mm⁴

$$I = \frac{bd^3}{12} \quad \dots\dots (3)$$

b: width of the specimen, mm

d: thickness of the specimen, mm

and flexural strength is calculated from the following equation

$$F. S = \frac{3PL}{2bd^2} \quad \dots\dots(4)$$

where :

P: the load at fraction (N)

Results And Discussion

Tensile test result :

The tensile test of material specimens was carried out on an Instron Universal Testing Machine Type 1195 as explained in **Figure (4)**.

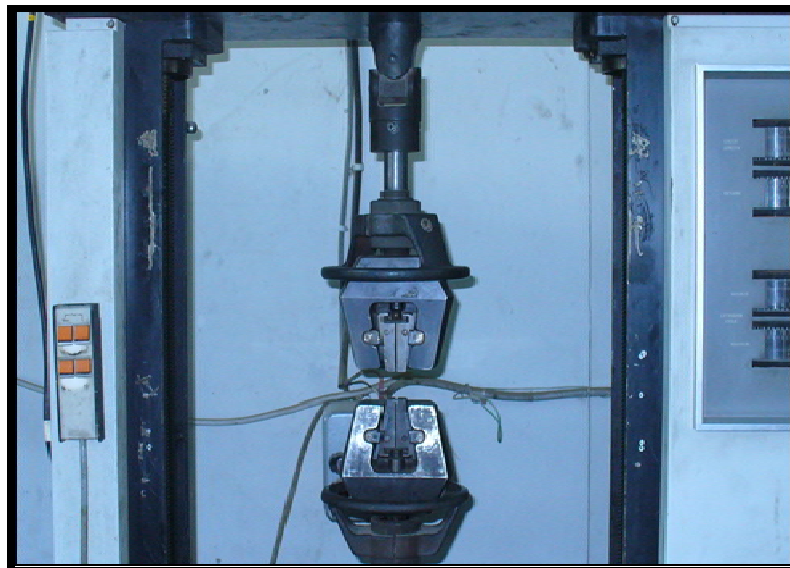


Fig. (4) Tensile Test Instrument.

Tensile stress-strain curves of the matrix material and the four types of composite materials are shown in **Figure (5)**.

The ultimate tensile strength and tensile modulus of elasticity of these materials are given in **Table (1)**, and **Figures (6&7)** show the relation between Wight fraction and ultimate tensile strength ,and between weight fraction and young modulus .

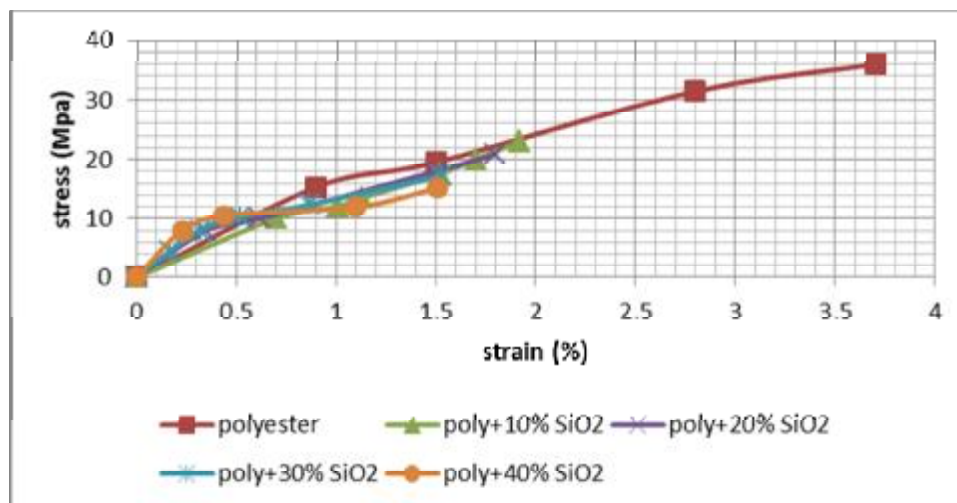


Fig (5): Tensile stress-strain curves of the matrix material and the four types of composite materials

Table (1) Tensile strength and Modulus of elasticity of Materials

Materials		Particle Weight Fraction %	Tensile Elastic Modulus Gpa (E)	Tensile Strength Mpa T.S
Matrix	Reinforcement Particle			
Polyester	0	0	1.67	36
Polyester	Silica	10	1.94	23
Polyester	Silica	20	2.5	20.9
Polyester	Silica	30	2.9	17.2
Polyester	Silica	40	3.05	15.3

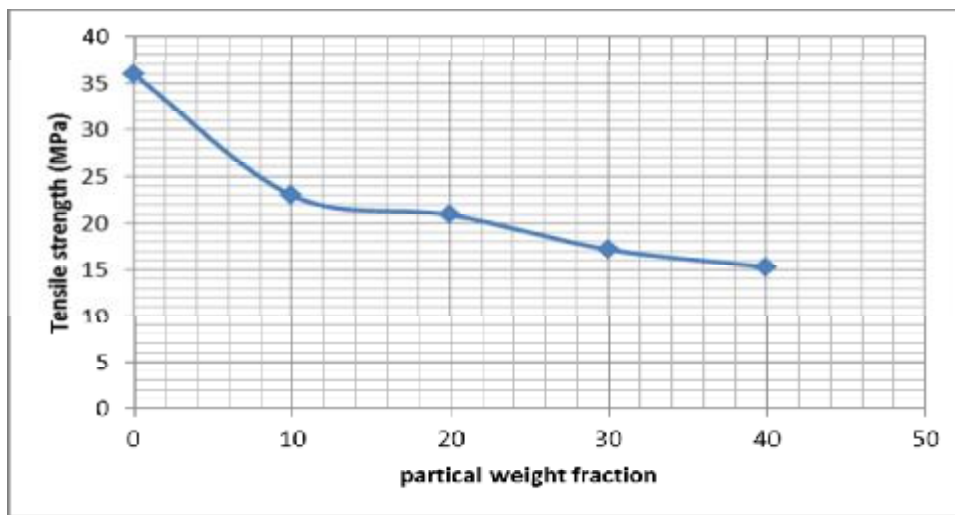


Fig. (6): The Effect of the Silica Particle Weight Fraction on the Tensile Strength.

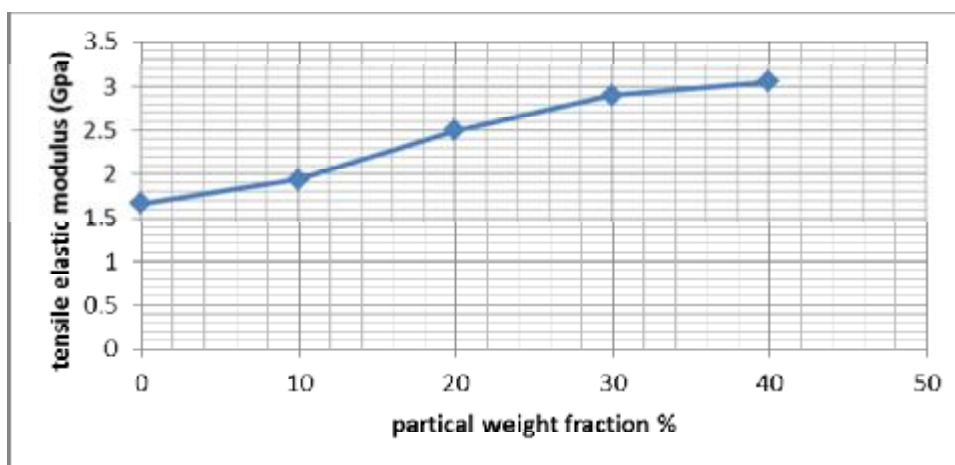


Fig. (7):The effect of the Silica Particle Weight Fraction on the Tensile Elastic Modulus.

it is noted that the ultimate tensile strength of the matrix material is higher than those of the composite materials, while its tensile modulus of elasticity is lower. This indicates that adding silica to the polyester resin decreases the tensile strength and increases the modulus of the elasticity.

This behaviour can be explained as follows; the strength of ceramic particles is higher than that of metals because of their atomic bonding. The atomic bonding in ceramic are covalent and ionic bonding and the one of most important properties of these bounds that are rigid and does not permit slip under stress and are stronger than metallic bonding. while metallic bonding has the advantage that it allows for slip, the basic mechanism by which metals deforms plastically when subjected to high stresses. The inability to slip makes it much more difficult for ceramics to absorb stress ^[14], the modulus of elasticity is evidence of interatomic bonding, and as a result, the ceramic has the higher modulus of elasticity.

Bending Test Result:

The flexural test adopted in this work was the three-point test in accordance with ASTM D-790 standard .In this the test, the specimen was simply supported on two cylindrical bars 100mm apart and the load was applied at midspan via a third cylindrical bar fitted to the Instron's grip as explained in **Figure(8)**.

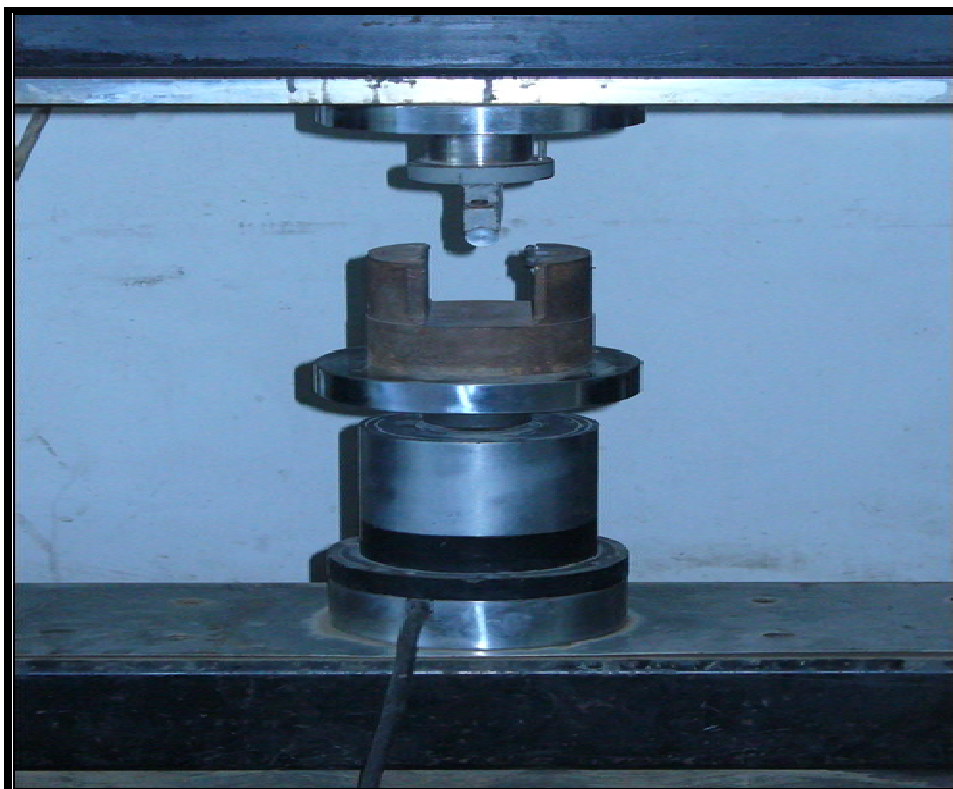


Fig. (8) Flexural Test Instrument.

Typical flexural stress-strain curves of the matrix material and the four types of composite materials are shown in **Figures (9)**.

The ultimate flexural strength and flexural stiffness (flexural modulus) of these materials are given in **Table (2)**, and **Figures (10&11)** show the relation between Weight fraction and ultimate flexural strength ,and between weight fraction and flexural elastic modulus .

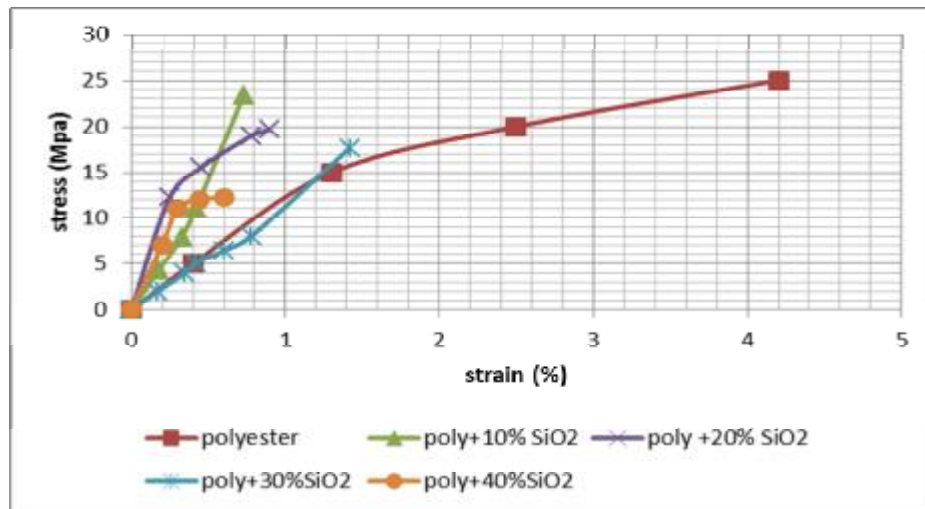


Fig (9): flexural stress-strain curves of the matrix material and the four types of composite materials.

Table (2) Flexural Strength and Stiffness of Materials

Materials		Particle Weight Fraction %	Flexural Elastic Modulus Gpa (E)	Flexural Strength Mpa T.S
Matrix	Reinforcement Particle			
Polyester	0	0	1.4	25
Polyester	Silica	10	1.98	23.34
Polyester	Silica	20	2.8	19.7
Polyester	Silica	30	3.3	17.68
Polyester	Silica	40	3.8	12.24

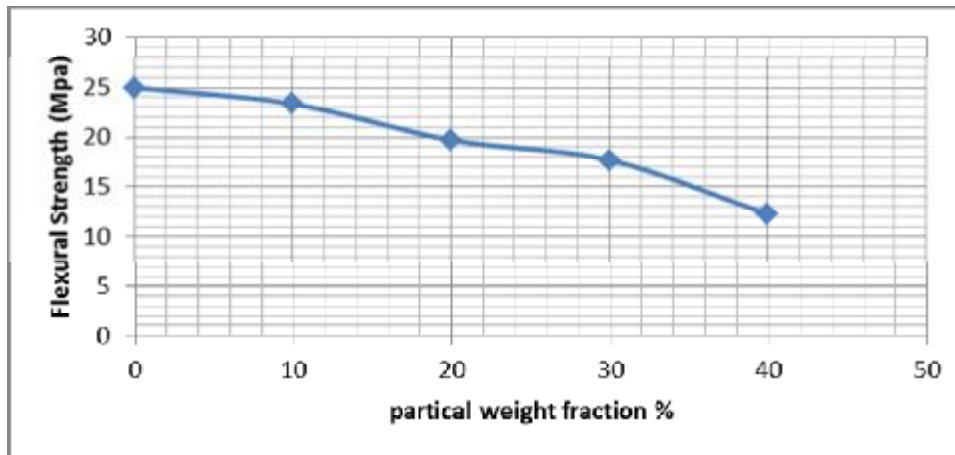


Fig (10): The Effect of the Particle Weight Fraction on the Bending Strength.

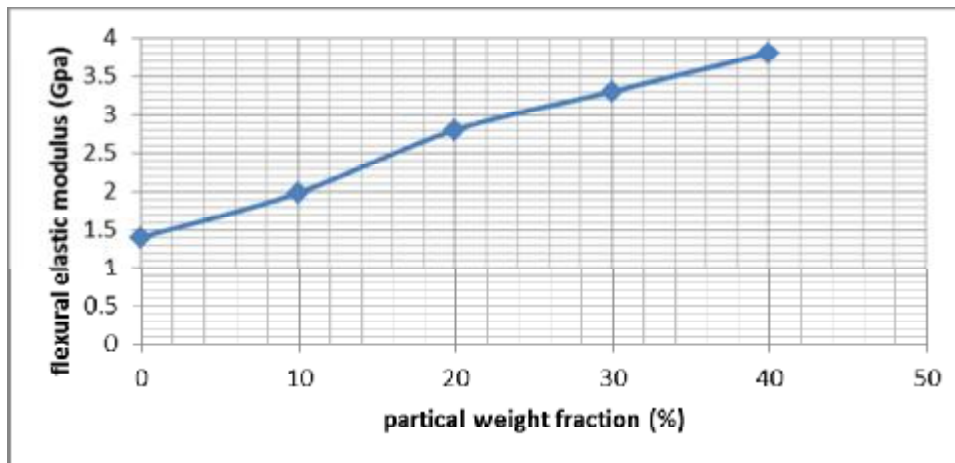


Fig (11): The Effect of the Particle Weight Fraction on the Bending Modulus

In general, it is noted that the ultimate bending strength of the matrix material is higher than those of the composite materials, while its bending modulus of elasticity is lower. This indicates that adding silica particulate to the polyester resin decreases the ultimate bending strength and increases the modulus of the elasticity.

The decrease in flexural strength with increase SiO_2 concentration this related to that the bound between matrix and SiO_2 particles are weak and the other reason to this behaviour that the voids produce between particle and the voids content increase with increase in SiO_2 concentration.

The flexural modulus increase as SiO_2 concentrations increases. This is related to the increase in the stiffness of composites resulting from the increase in filler concentration ^[15]. Adding a fine particle will increase the stiffness or flexural modulus of a polymer system. Generally, the higher the filler loading is, the greater the increase in the flexural modulus ^[16].

Hardness Test Result :

Brinell hardness test set was used to determine the hardness of the specimens. The equipment used is type Ley Bold Harris No.36110 is shown in **Figure (12)**

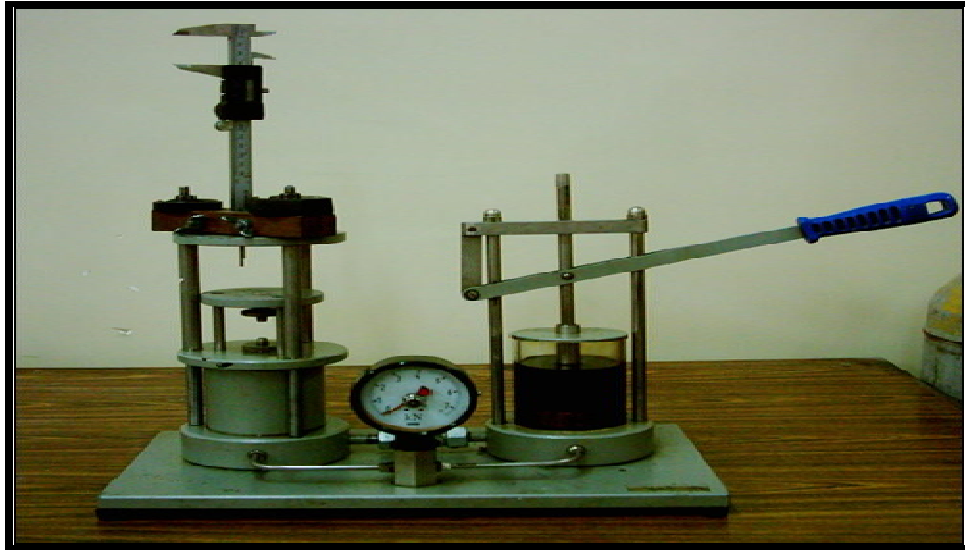


Fig. (12) Hardness Test Instrument.

Hardness test results are given in **Table(3)** . It is noted that all composite materials have significantly hardness than the matrix material; these increase the hardness because the silica particles have very high hardness and the strengthening occurs due to the load-carrying of the particles ^[17].

In addition to that it is clearly evident that the increase hardness is a function of reinforcement material content and that the hardness is directly proportional to the reinforcement content. The effect of silica content on the hardness is shown in **Figure (13)**. This figure indicates that the hardness increases at almost constant rate with the increase in reinforcement material content. From the testing of flexural modulus, it was found that there was an increased in the stiffness of composites resulting from the increase in filler concentration. The hardness results are aligned with the flexural stiffness.

Table(3) The Hardness of the four Types of Materials.

Materials		Particle Weight Fraction %	Hardness BHN (Kg/mm ²)
Matrix	Reinforcement Particle		
Polyester	0	0	18.134
Polyester	Silica	10	22.63
Polyester	Silica	20	25.43
Polyester	Silica	30	28.7
Polyester	Silica	40	31.95

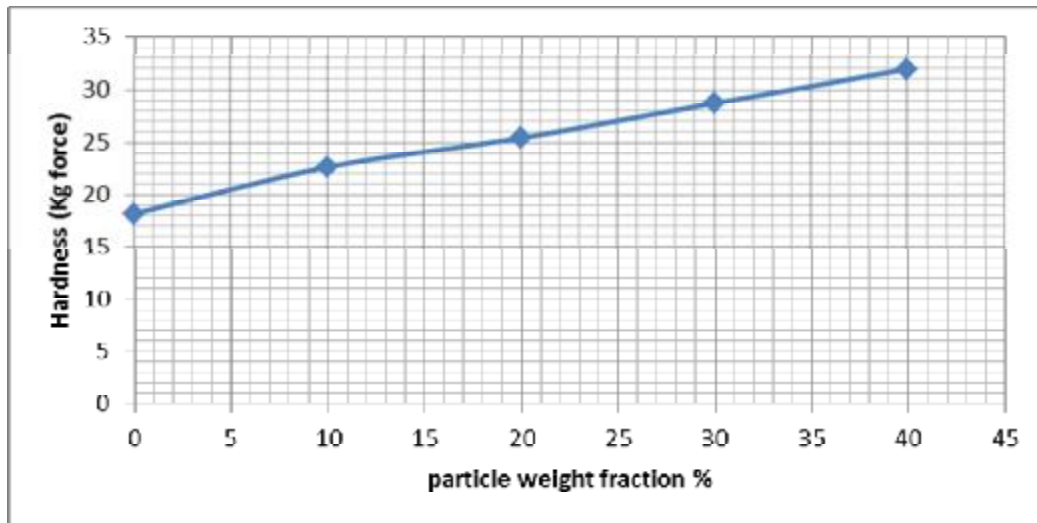


Fig.(13): The Effect of the Particle Weight Fraction on the Hardness.

Electrical conductivity result:

Electrical conductivity is used to specify the electrical character of a material and is indicate of the ease with which a material is capable of conducting an electric current . Solid materials exhibit an amazing range of electrical conductivities, extending over 27 orders of magnitude; probably no other physical property experiences this breadth of variation. In fact, one way of classifying solid materials is according to the ease with which they conduct an electric current; within this classification scheme there are three groupings: conductors, semiconductors, and insulators. The dependence of the electrical conductivity of polyester filled with SiO₂ particle composites on the particle weight fraction is shown in **Figure (14)**. The results show the expected trend of increasing in conductivity with increasing in particle weight fraction . when the material is placed in an electric field as shown in **Figure. (1)** the electrical resistance can be calculate from equation (1) the result show that the electrical resistance decrease with increase the SiO₂ concentration because when electric current move through the matrix material a conductive net work is formed and this permits the movement of charge carries of the particle through the matrix. As a concentration of SiO₂ increase the number of conductive paths increase and the distance between the conductive particle becomes smaller so the resistance of the composite decrease ^[18] and depending on **equation (2)** the electrical conductivity of material increase with decrease in material resistance so the electrical conductivity increase with increase SiO₂ concentration.

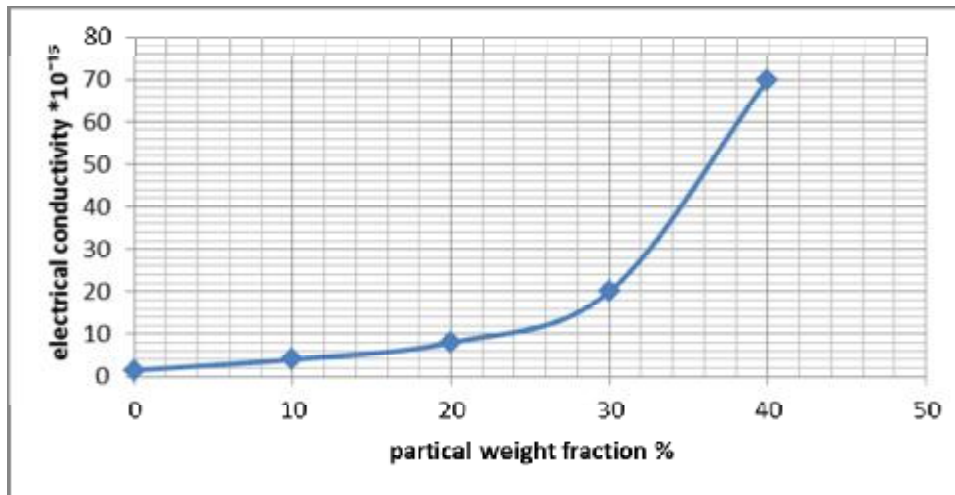


Fig (14): Electrical conductivity of SiO₂ filled polyester composites at different weight fraction

Conclusions

- 1- The results exhibited that decreasing in tensile strength and increasing in tensile modulus with increasing in particle concentration .
- 2- Decreasing in bending strength and increasing in bending modulus with increasing in particle concentration.
- 3- Increasing in hardness of composite material with increase in particle concentration .
- 4- Increasing in electrical conductivity with increase in particle concentration .

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