# Mechanical Behavior for Polymer Matrix Composite Reinforced By Copper Powder

**Mohammed Abdulsattar Mohammed**
**Assistant Lecturer**
**Mechanical Engineering Department**
**College of Engineering /Nahrain University**
**M1976sj@Yahoo.Com**

## Abstract

The mechanical properties of commercial epoxide resin type conipox 77Z have been investigated both unfilled and filled with varying weight fraction of copper particles.

The values of Young's modulus, modulus of rigidity, yield stress, tensile strength, shear strength, flexural strength, fracture energy, impact strength, coefficient of friction and the S/N curves and the fatigue strength or fatigue limit have been studied at room temperature (25°C) to a certain the influence of weight fraction of copper powder to epoxy resin (0%, 5%, 10% and 15%) and found that increasing the weight fraction of copper powder to epoxy for different particle sizes leads to an increase in modulus of elasticity (E), modulus of rigidity (G), tensile yield stress and ultimate tensile strength but at the same time will decrease the compression yield stress, fracture energy and the impact strength.

Finally the reinforced epoxy with (15%) was found to be improving the mechanical properties for composite material, where the modulus of elasticity and the modulus of rigidity increased and the coefficient of friction of the composite material to steel decreased.

**Keyword**: PMC, Reinforced copper, fatigue, tensile.

## Introduction:

Mankind has been aware of composite materials since several hundred years before Christ and has applied innovations to improve the quality of life.

Although it is not clear as to how man understood the fact that mud bricks made sturdier houses if lined with straw, he used them to make buildings that lasted.

Ancient Pharaohs made their slaves use bricks with straw to enhance the structure integrity of their buildings, some of which testify to the wisdom of the dead civilization even today [1].

As a result of modern technology, there are need new materials that have a lightweight, high modulus, toughness and stable against the environment in instead of using metals and alloys in different industries in the world.

Contemporary composites resulting from research and innovation from the past few decades have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range of other applications.

Composite materials can be defined as a material consisting of two or more physically and/or chemically distinct phases suitably arranged or distributed. A composite material usually has characteristics that are not depicted by any of its components in isolation [2].

The reinforcing phase or reinforcement is in form of fibers, sheets or particulate and it is impeded into another material, the matrix.

In principle, any two materials could be combined to make a composite and they might be mixed in much geometry [3]. Generally, the continuous phase is referred to as the matrix, while the distributed phase is called the reinforcement. Three things are the characteristics of a composite; the reinforcement, the matrix and the interface between them [2].

The reinforcements are typically hard, stiff materials usually of glass, ceramics or metals [3]. The matrix materials are generally ductile and tough like polymers but brittle matrices are also used.

Composites can be classified according to morphology of reinforcements (fiber, particulate reinforced and laminate composite) or to matrix materials (metals, ceramic, polymer matrix composite). By a selection of reinforcement, matrix material, composition, volume or weight fraction and arrangement of reinforcements, a very wide range of microstructures (and therefore set of properties) can be obtained including anisotropic and isotropic behavior, too [3].

Microstructures of metal and ceramics composites, which show particles of one phase strewn in the other, are known as a particle reinforced composites.

Square, triangular and round shapes of reinforcements are known, but the dimensions of all their sides are observed to be more or less equal.

Fibers or particles embedded in the matrix of another material would be the best example of modern day composite materials.

Particle reinforced composite usually depends on the diameter or mean diameter of the particles, the inter particle spacing, and the volume fraction of the reinforcement. The matrix properties influence the behavior of the particulate composite too [1].

The study of copper particles reinforced epoxy resin is mostly modern and whiles the studies of the past few decades were interested in fibers and laminates composite. The use of copper powder as a reinforcement with epoxy resin is a new trend in particulate composite investigation.

## Literatures Survey: -

The strength properties of poly (Vinyl chloride)-copper composites studies by **Swapan K. Battacharyya** according to the influence of volume fraction and the size of particles and found that strength properties have a linear relation ships with ($d_m^{0.5}$)where ($d_m$) is the mean free path between the filler particles [4, 5].

But **A. C. Molony** studied the influence of volume fraction of filler, particle size and the filler aspect ratio on the mechanical properties of silica filled epoxy resin such as tensile strength, tensile modulus, flexural strength, flexural modulus and compressive yield stress which are increase with the decreasing of particle size and increasing the volume fraction and aspect ratio [6].

**J. Jancar** studied the influence of filler particle shape on the Young's and shear modulus of PP/$CaCO_3$ and PP/Mg(OH) composites at volume fraction >50%, (PP is a polypropylene). Calcium Carbonate had irregular, approximately spherical particles and Magnesium Hydroxide had particles either in the form of hexagonal plates or micro-needles. He conclude that the elastic module of PP/CaCO3and PP/Mg(OH)composites with different shapes of particles increased at constant volume fraction of fillers with increasing aspect ratio and specific surface area in the sequence CaCO> Mg(OH)plates > Mg(OH)needles [7].

In 2002, **Husam Alwan Kereem** studied the influence of nickel powder as reinforcement to a thermosetting epoxy resin matrix. The mechanical properties included the Tensile strength, Compression strength, Bending, Wear, Hardness and Impact. The composite material parameters included the volume fraction and particle size of the reinforcement. The volume fraction ranged from zero, epoxy resin on its own up to 15% volume fraction reinforcement. The particle size covered the ranged from less than 10μm to over than 45μm.

The modules of elasticity and yield strength have shown an increase in their value with an increase in volume fraction of the particle. Also the increase in particle size improved these properties up to a certain size namely 32μm. However the mechanical properties deteriorated with elevated temperatures; namely above 50?C [8].

Also in 2002, **Abdul – Hakem Al – Zangna** studied the effect of adding the Iraqi ceramic raw materials (Bauxite + Kaolin) on the mechanical properties of polymers concerning the parameters: -

- Particle size (d <10, d <28 and d <32μm).
- Particle filler weight fraction (0, 25, 35 and 45%).
- Temperatures (0, 30 and 50°C).

The polymer matrix particulate has been prepared by adding the ceramic powder (Bauxite + Kaolin) to the epoxy of type (CY223) as an example to the thermosetting polymer. The experimental results have been obtained and it is concluded that the best particle size is smaller than (10μm), the best weight fraction is (35%) and the best temperature is (0°C) [9].

The authors found that: -

- The strength properties have linear relation ship with $d_m^{0.5}$ where ($d_m$) is the mean free path between the filler particles.
- Tensile strength, Tensile strength, Flexural modulus, Flexural strength and compressive yield stress are increased with the decrease of particle size and increase of volume fraction and aspect ratio.

In 1979, David J.Green studied the fracture process in a model brittle composite containing nickel spheres in a glass matrix. Fracture measurements showed that there were slight decreases in Young's modulus values and fracture strength as the volume fraction of nickel increased and by using ultrasonic fractography to illustrate the nature of the local interaction between the crack front and the particles which clearly impede the crack and change the crack- front configuration [10].

But in 1983, A.C.Molony studied the fracture properties of two commercial epoxide resins which have been investigated both unfilled and filled with varying volume fraction of silica, alumina and dolomite particles and found that increasing volume fraction leads to increase in fracture toughness [11].

In 1984, **A.C.Molony** and **H.R.Stieger** studied the fracture properties of two commercial epoxide resins filled with glass beads untreated form and treated with CPO3 "Coupling agent" with volume fraction (0-60%) and particle size (1-100μm) and concluded that epoxide resins may be toughed by the addition of rigid particulate fillers and improved fracture properties by treating the particles with coupling agent [12].

To study the effect of particle size and orientation on the impact fracture toughness of a filled and plasticized polymeric material, **C.W.Fong** made experimental study with filler alignment, is either to be parallel to the specimen bar axis, (or the

extrusion direction) or to be transverse to the specimen axis, which is perpendicular or parallel to the notch of specimen. Testing was carried out in a three points bend mode under impact conditions and it was concluded that particle size and orientation have a great influence on the facture toughness, where the resistance to fracture along the axis of direction is higher than that of a right angle direction [13].

In 1986, **R.A. Pearson** studied the toughing mechanisms of elastomer- modified epoxies with volume fraction (1-35%) and concludes that rubber particles improved fracture toughness [14].

But in 1989, **James D. Miller** studied the fracture surfaces of glass sphere- filled polyethylene model composites with varying degrees of interfacial modification, by scanning electron microscopy which demonstrate that the interfacial modifications have large effects on the locus of fracture failure amount of bound polyethylene, and the composite properties [15].

And in 1990, **W.J. Cantwell** studied a series of short- term fracture tests on silica- filled epoxy resin in order to examine the processes of damage initiation, development and fracture in a particulate filled polymer and found that there are three distinct regions on the fracture surfaces. Around the defect many of particles were often debonded as a result of the sub-critical growth of the crack. At the onset of instability, the fracture surface becomes very smooth and the particles remain well bonded to the matrix. Beyond this zone the fracture surface becomes very rough exhibiting extensive crack bifurcation, here the crack is propagated at the limiting velocity and much energy is being dissipated in creating multiple fracture surfaces [16].

In 1977, **Biing- Lin lee** studied the temperature dependence of the dynamic properties of filled polymer and developed a theory to explain the jump in the relative modulus of filled polymers near the glass transition temperature $T_g$ and the subsequent decrease in relative modulus at temperatures above the glass transition temperature. This theory is based upon the concept that there are some particle- particle contacts in doublets and in agglomerates containing a large number of particles. Below (T), the motion of particles at the contact points is possible because of the high modulus of polymer. At higher temperatures the mismatch in the coefficients of expansion allows some motion to occur at points of contact and slippage may occur at the polymer particle interfaces, so the modulus decreases. It is shown theoretically and experimentally that both the elastic modulus and the mechanical damping depend upon the nature of the surface of the particles [17].

But in 1978, **K. Iisaka** and **K. Shibayama** studied the dynamic mechanical properties of poly (methyl methacrylate) (PMMA) filled with mica flaks or glass beads were investigated as functions of particle size, and they concluded that the dynamic modulus slightly decreases for glass beads system, while it increases rapidly at first and then approaches the limiting value for mica flacks system [18].

In 1976, **Jack C. Smith** discussed a calculation of the elastic constants of a particulate composite material in terms of the elastic constants of the filler and the matrix. The theories of **Kerner** or **Hashin** and **Shtrikmam** the equivalent theories of **Budiansky** and **Hill**, and a generalized **van der Poal** type theory are presented and discussed. The **van der Poal** theory provides the best agreement and gives good values for volume fractions of filler up to 35% [19].

**In this paper we are study the influence weight fraction of copper powder of (0%, 5%, 10% and 15%) which filled an epoxy resin type conipox 77Z to the mechanical properties of tensile, compression and flexural modulus, tensile and compression yield stress, tensile and flexural strength, fracture energy, impact strength, coefficient of friction, and fatigue strength or fatigue limit of composite material from the S-N curves.**

**Theoretical Part**

The most common epoxy resins are glycidyl ethers of alcohols or phenolics. Liquid epoxy resin is the diglycidyl ether of bisphenol A (DGEBA) and represents greater than 75% of The particle strengthening of composite is similar to the dispersion strengthening but it differs in that particle size is larger and volume fraction is greater where the particle diameter is larger than 1μm and volume fraction is greater than 25% and the matrix mean free path is greater than 1μm, the resin used in industrial applications. In particle strengthening, the load is shared by both the matrix and the particles where the particle initially impedes deformation of the matrix [9, 20].

Generally, the properties of particle strengthening also depends on the form, size, direction of particle distribution in the matrix and the bonding between the particles and the matrix, also the interface in composite has a great influences on the properties of the composite material.

The particles of metal powder have various shapes such as spherical (carbonyl iron; lead), rounded or droplet (atomized copper; zinc; tin), angular (mechanically disintegrated Sb; cast iron), Flakes (ball milled copper; aluminum) [24].

Many researchers' studies this type of reinforcement and all of them agreed on these methods to calculate the modulus of elasticity and rigidity [8].

1- The particles randomly distributed in the matrix.

2- The particles are the same size.
3- The particles are bonded with the matrix strongly.
4- The particles and the matrix are isotropic.

**The law of mixtures [9, 21]:** -

The mass ($m_c$) of composite is made up of the masses of the matrix ($m_m$) and the filler particle ($m_f$),

$$m_c = m_m + m_f \quad (2\text{-}1)$$

Since the mass is volume time's density then equation (2-1) can be written as follows: -

$$v_c \rho_c = v_m \rho_m + v_f \rho_f \quad (2\text{-}2)$$

And so: -

$$\rho_c = \frac{v_m}{v_c}\rho_m + \frac{v_f}{v_c}\rho_f \quad (2\text{-}3)$$

($v_m/v_c$) is the volume fraction ($V_m$) that is the matrix and ($v_f/v_c$) is the volume fraction (V) that is the filler particle.

$$\rho_c = V_m \rho_m + V_f \rho_f \quad (2\text{-}4)$$

Note that since $v_m = v_c - v_f$ it must have: -

$$v_m = 1 - v_f \quad (2\text{-}5)$$

By substituting equation (2-5) in equation (2-4), we will get

$$\rho_c = \rho_m(1-V_f) + \rho_f V_f = \rho_m + V_f(\rho_f - \rho_m) \quad (2\text{-}6)$$

Also the mass of the matrix and the mass of reinforcement material can be calculated as shown below: -

Since,

$$V_f = \frac{v_f}{v_c}$$

$$\text{then } V_f = \frac{m_f}{\rho_f * v_c} \quad (2\text{-}7)$$

$$\text{then } m_f = v_c \quad V_f \quad \rho_f \quad (2\text{-}8)$$

$$m_m = v_c \rho_m (1 - V_f) \quad (2\text{-}9)$$

**Bounds on the modulus [9, 25]: -**

The simplest cases have two bounds for predicting the tensile modulus. The upper bound is: -

$$E_c = (1 - V_f)E_m + V_f E_f \quad (2\text{-}10)$$

This assumes equal strains in the two phases under elastic deformation, and this equation contains only the variable composition and is often called the mixture rule and is known as the series model. If the stresses of the two phases are assumed equal, the lower bound of the modulus is governed by the parallel mode.

$$E_c = \left(\frac{1-V_f}{E_m} + \frac{V_f}{E_f}\right)^{-1} \quad (2\text{-}11)$$

Equations (2-10) and (2-11) have been applied to various physical properties e.g. the coefficient of thermal expansion, thermal conductivity and shear and bulk module Ishai and Cohen equation depends on Paul equation by assuming the producing strain due to applied stress at composite material be constant so that the composite moduli can be developed as follows:

**Haplin-Tsai equation [9, 25]: -**

This is a simple empirical expression reduced from Herman's solution containing a geometric fitting parameter A, obtained by fitting with numerical solutions, formal elasticity theory composite moduli, can be put in the form

$$\frac{E_c}{E_m} = \frac{1 + ABV_f}{1 - BV_f} \quad (2\text{-}12)$$

$$B = (E_f/E_m - 1)/(E_f/E_m + A)$$

where: -

$A = 2l/d$ for tensile modulus. The ratio $l/d$ is the aspect ratio.

**B-Paul equation [9]: -**

B-Paul equation has been effectively developed by assuming a good adhesion between the particles and the matrix. The tensile modulus of elasticity of the composite is given by:

$$E_c = \left[\frac{1 + (m-1)V_f^{2/3}}{1 + (m-1)(V_f^{2/3} - V_f)}\right] \quad (2\text{-}13)$$

$$m = \frac{E_f}{E_m}$$

**O. Ishai and L. J. Cohen equation [9]: -**
Ishai and Cohen equation depends on Paul equation by assuming the producing strain due to applied stress at composite material be constant so that the composite moduli can be developed as follows: -

$$E_c = E_m\left[1+\frac{V_f/m}{(m-1)-V_f}\right] \quad \text{2-14}$$

Generally, the difference in theoretical and practical results of the filler system depends not only on the material properties of the two components and the volume fraction but also on the size, shape orientation and the state of adhesion between the filler and the matrix.

## Mechanical properties: -

Mechanical properties are important considerations in the design of a structure or a machine, and these, enable the design to serve its function safely and well.

Mechanical properties are usually expressed in terms of quantities that are primarily functions of stress or strain, but they are occasionally expressed in terms of other quantities such as time and temperature [26].
These properties include strength, stiffness, hardness, ductility, and toughness.

## Impact strength: -

Impact tests are used to measure the value of strength of material under high rates of loading. Some ductile and brittle materials are weak under impact loads.
Charpy tests are ordinarily conducted to assess impact strength. As with metals, polymers may exhibit ductile or brittle fracture under impact loading conditions, depending on the temperature, specimen size, strain rate and mode of loading [27].
So the Impact strength is equal to [9]: -

$$G_c = \frac{U_c}{BD\phi} \quad \text{2-15}$$

Where: -
$U_c$=Fracture energy.
B= Breath of impact specimen.
D= Depth of specimen.
φ=Geometry function= $0.135\left(\frac{a}{D}\right)^{-0.77}$
For only S/D =4
a= notch depth.
S= Distance between supports.

## Torsion: -

The problem of transmitting a torque from one plane to a parallel plane is frequently encountered in the design of machinery [28].
For rectangular shafts, however, with longer side D and shorter side B, it can be shown by experiment that the maximum shearing stress occurs at the center of the longer side and is given by [29]: -

$$\tau_{max} = \frac{T}{K_1 DB^2} \quad \text{2-16}$$

Where $K_1$ is a constant depending on the ratio D/B and given in table (1) below:

Table (1): - Table of $K_1$ and $K_2$ values for rectangular sections in torsion [29].

| D/B | 1.0 | 1.5 | 1.75 | 2 | ∞ |
|---|---|---|---|---|---|
| $K_1$ | .208 | .231 | .239 | .246 | .333 |
| $K_2$ | .141 | .196 | .214 | .299 | .333 |

The essential difference between the shear stress distributions in circular and rectangular members is illustrated in figure (1) where the shear stress distribution along the major and minor axes of a rectangular section together with that along a "radial" line to the corner of the section are indicated. The maximum shear stress is shown at the center of the longer side, as noted above, and the stress at the corner is zero.

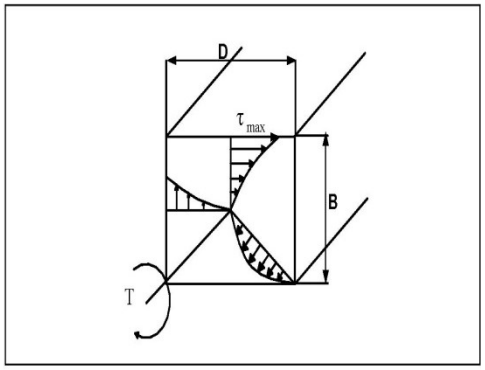


**Figure (2.5): -** Shear stress distribution in a solid rectangular shaft [29].

The angle of twist per unit length is given by: -

$$\frac{\theta}{L} = \frac{T}{k_2 DB^3 G} \qquad (2\text{-}17)$$

$K_2$ being another constant depending on the ratio D/B also was given in table (1).
It is possible to reduce the above equation from the absence of table (1) to the following

forms:

$$T_{\max} = \frac{T}{DB^2}\left[3 + 1.8\frac{B}{D}\right] = \frac{T}{db^3}\left[3D + 1.8B\right] \qquad (2\text{-}18)$$

$$\theta = \frac{42TLJ}{GA^4} = \frac{42TLJ}{GD^4B^4} \qquad (2\text{-}19)$$

Where is the cross section area of the section (=BD) and

$$J = (DB/12)(B^2 + D^2)$$

## Fatigue

Fatigue failures can and often do occur under loading conditions where the fluctuating stress is below the tensile strength and, in some materials, even below the elastic limit. Because of its importance, the subject has been expensively researched over the last one hundred years but even today one still occasionally hears of a disaster in which fatigue is a prime-contributing factor [29].

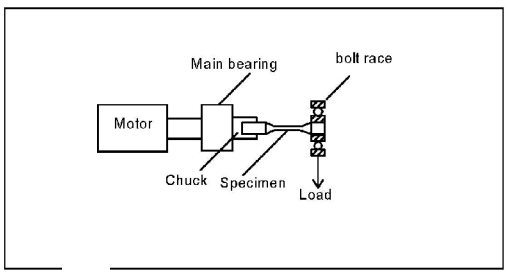


**Figure 1** - Single point load arrangement in a Wohler machine for zero mean stress fatigue testing [29].

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## The S-N curve: -

Fatigue tests are usually carried out under conditions of rotating – bending and with a zero mean stress as obtained by means of a Wohler machine. Figure (1) illustrates that the top surface of the specimen, held (cantilever fashion) in the machine, is in tension, whilst the bottom surface is in compression. As the specimen rotates, the top surface moves to the button and hence each segment of the surface moves continuously from tension to compression producing a "stress – cycle" as shown in figure (2).

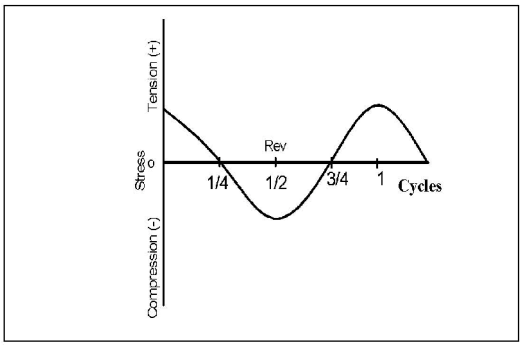



**Figure ( 2): -** Simple sinusoidal (zero mean) stress fatigue curve, " reversed – symmetrical) [29].

The stress cycle curve is shown in figure (3) and from this diagram, it can be seen that [27 29]: -

Stress range= $\sigma_r = 2\sigma_a$

The stress cycle curve is shown in figure (3) and from this diagram, it can be seen that [27 29]: -

Stress range $\sigma_r = 2\sigma_a$ (2-20)

Mean stress $\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}$ (2-21)

Alternative stress amplitude,

$$\sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2} \qquad (2\text{-}22)$$

Finally, the stress ratio R is just the ratio of minimum and maximum stress amplitudes.

$$R = \frac{\sigma_{\min}}{\sigma_{\max}} \qquad (2\text{-}23)$$

by convention, tensile stresses are positive and compression stresses are negative for example, for reversed cycle the value of (R= –1), [27].

The most general method of presenting the results of a fatigue test is to plot a graph of the stress amplitude as ordinate against the corresponding number of cycles to failure, the amplitude being varied for each new specimen until sufficient data have been obtained. These results in the production of the well– known S-N curve– figure (4).

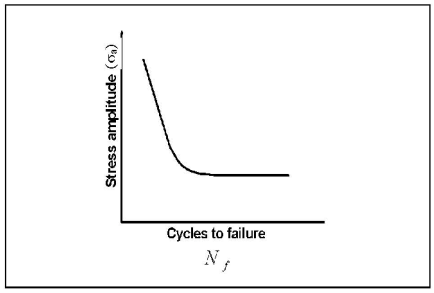



**Figure ( 4): -** Typical S-N (fatigue life) curve [29].

In using the S-N curve for design purposes it may be advantageous to express the relationship between $\sigma_a$ and $N_f$ the number of cycles to failure. Various empirical relationships have been proposed but, provided the stress applied does not produce plastic deformation, the following relationship is most often used:

$$\sigma_r^n N_f = k \qquad 2\text{-}24$$

Where (n) is a constant, which varies from 8 to 15 and is a second constant depending on the material [29].

Finally, most nonferrous alloys and polymers, do not have a fatigue limit, so that the S-N curve continues its downward trend at increasingly greater N value, figure (5) thus, shows that fatigue will ultimately occur regardless of the magnitude of the stress. For these materials, the fatigue response is specified as **fatigue strength**, which is defined as the stress level at which failure will occur for some specified number of cycles (between 7 10to 8 10cycles) as demonstrated in figure (5), [27].

## Experimental work

This section includes the experimental part that explains the types of materials (matrix and reinforcement materials) that are used to make samples for tests in his paper oxy was used as the matrix material and a copper powder as the reinforcement material epoxy sins form thermosetting materials are being combined with a hardener, which enables cross- links to be established between the epoxy molecules and to produce a thermoset material.

The epoxy that was used for this paper is type conipox 77Z that is produced by conica technik AG and it consists from two components of a high grade, low viscosity, colorless materials, and the density at 20°C is approximately 1.09gr/cmand has a mixing ratio of 100:45 based on weight, and on application time of 30 min at approximately 20°C and after the solidification process, it demonstrates low density (1.13328 gr/cm) and high electrical resistance.

The reinforcing material used is copper powder with a particle size of (d≤25μm) and 73.2% purity (after checking).

To produce samples for the tests (Tensile, Bending, Impact and Friction), one sample for each test is prepared from pure epoxy with standard dimensions and then these samples are used to make the moulds.

The moulds are produced from paste of panes, rolled out and then the shape of each sample is formed on it.

To produce samples for the tests (compression, Fatigue), a plastic pipe with a diameter (D=12.7mm, L= 25.4mm) for compression test mould and (D=12.7mm, L=90mm) for fatigue test mould are used and then the finishing processes are applied (turning and cutting) to get the standard dimensions.

Finally, these processes for mould preparation are simple and can be applied to get the required shape for each sample with low cost.

The steps of specimen preparation are brief as explained below: -

1- The mould was coated with a wax to prevent adhesion between the samples and the moulds.

2- The resin and the hardener were mixed at room temperature (25°C) at a ratio 100:45 according to weight, the mixing process was continued for 15 minutes until the mixture became homogenous and its temperature was raised.

3- The mixture was poured to the mould slowly and carefully to prevent forming cavities until the mould is filled.

4- The mixture was left in the mould for about (16 hours) at room temperature (25°C) to solidify.

5- To produce the composite material, copper powder was mixed with epoxy resin according to specified weight fraction. The mixing process was continued until the mixture became homogeneous and then the hardener was added to mixture (copper powder+ resin). The ratio of resin: hardener equaled to 100:45 according to weight. The mixing process of (hardener) to (copper powder+ resin) must continue for 20 minutes until it became homogeneous before the curing process. It is important for the mixture to have a high viscosity to prevent depositing copper powder. Finally the mixture was poured to the

mould according to the same steps that were explained in points 3 and 4.

6- Grinding process was applied to the specimens using a waterproof silicon carbide paper, grade 600 and 1000, to obtain the required surface finish.

Tensile test specimens have been produced according to (ASTM D638-99) for pure and reinforced epoxy with weight fraction (5, 10 and 15).

Compression test specimens have been produced according to (ASTM-D695) where the length to diameter ratio is approximately 2:1.

Impact test specimens have been produced according to (ASTM-E23).

Flexural test specimens have been produced according to (ASTM D790-89) with a length to depth ratio equal to 32:1, [depth (3.2mm), width (25mm) and a length (127mm)] .

Fatigue test specimens of pure and reinforced epoxy have been produced according to ASTM E466 M-82

Torsion test specimens have been produced as prismatic bars with a width of 8mm, depth of 6mm and length 130mm.

## Experimental Results and Discussions:

Experimental results of each test by curves which are discussed to clear the change and differences of adding a copper powder to epoxy with different weight fraction to the mechanical properties; tensile, compression, fatigue, and others. The data is obtained from the mean results of five standard specimens for all tests except the fatigue tests were the numbers of specimens were ten at each weight fraction [31].

**Tensile testing: -**

Tensile testing is one of the most used methods for determining the modulus of elasticity; yield tensile stress, ultimate tensile strength and ductility of a material. The test involves an axial tensile load being applied to a standard specimen of rectangular cross section with a constant strain rate at about (0.075- 0.08 min^-1) by hydraulic means and this causes the specimen to elongate and finally fractured.

The curve of tensile test for pure epoxy at room temperature is shown in figure (6) and can be noted that the initial part of the plot, is linear and the specimen behaves in an elastic manner which the specimen will return to its dimensions when the load is released and the slope of the line attachment in this region complies to Young's modulus E.

Just beyond the limit of proportionality, the specimen may undergo sudden extension without a corresponding increase in load and this is referred to as yield point.

Beyond yield stress the stress- strain curve deviates due to the specimen deforming in plastic manner.

After appreciable plastic deformation has occurred the stress- strain curve reaches a maximum value. At this point the specimen has started to undergo localized plastic deformation, or necking down as it is usually called, the reduced cross section area in the necking region, means further deformation occurs at reduced load and hence the stress- strain curve now falls until failure finally takes placed and the ultimate tensile strength can be calculated.

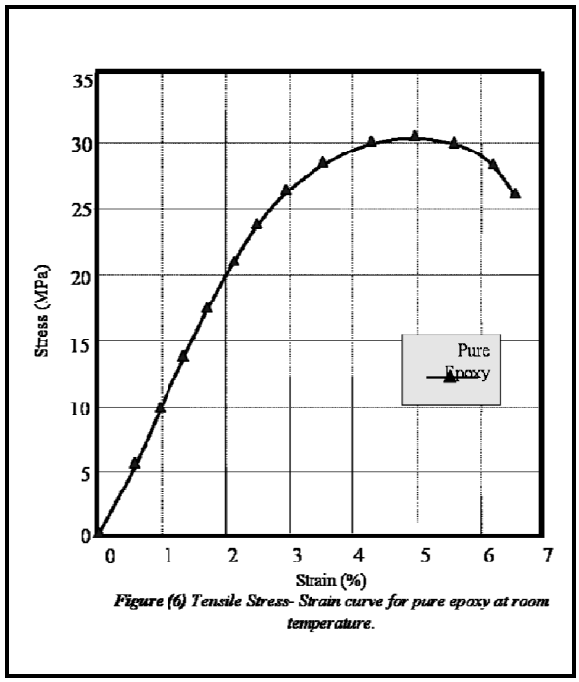



*Figure (6) Tensile Stress- Strain curve for pure epoxy at room temperature.*

Tensile test results have been achieved for reinforced epoxy at room temperature with weight fraction 5%, 10% and 15% as shown in figures (7)

Figures (7) show that the initial part of the plot is linear and the specimens behave in an elastic manner and the slope of the line in this region complies with Young's modulus (E), which has increased due to the increase in the weight fraction due to higher elastic modulus of copper than that of pure epoxy which leads to an increase in the elastic modulus of reinforced epoxy with increasing the weight fraction of copper to epoxy.

The tensile yield stress for pure and reinforced epoxy of figure (7) can be defined as the stress required to produce a specified amount of plastic deformation and is determined by drawing a line parallel to the elastic part of the graph which is offset by an extension corresponding to 0.1% of strain [32].

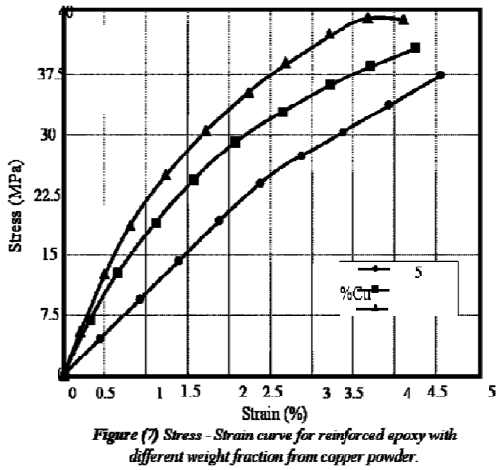



*Figure (7) Stress - Strain curve for reinforced epoxy with different weight fraction from copper powder.*

Finally, figures (8, 9 and 10) shown below illustrate the change in values of Young's modulus; yield stress and ultimate tensile strength due to the change in weight fraction of copper powder.

It can be noted that Young's modulus is increased with the increase in weight fraction of copper powder to epoxy due to increase the number of copper particles in unit volume and then decreased the movement of particles (i.e decreasing strain in specimen) which leads to increase modulus of elasticity, Also the tensile yield stress and ultimate tensile strength are increased with increase in weight fraction of copper due to increase the boundary grains of copper, which leads to increase the strength of composite materials, the percentage of reduction area for pure epoxy is higher than that for reinforced epoxy.

## Compression testing: -

Compression testing is one of the most used methods for determining the modulus of elasticity and compression yield stress of a material. The test involves an axial compression load being applied to a standard specimen of circular cross section with a constant strain rate at about (0.1-0.15 min^-1) by hydraulic means and this causes the specimen to compressed.

The curve of compression test for pure epoxy at room temperature is shown in figure (11) and can be noted that the initial part of the plot has low slope (low elastic modulus) corresponding to the uncoiling of molecules (overcoming weak, secondary bonds). The high modulus region corresponds to the elongation of extended molecules (stretching primary, covalent bonds) [33], and the specimen behaves in an elastic manner, in which the specimen will return to its dimensions when the load is released, and the slope of the line in this region complies with Young's modulus E.

Just beyond the limit of proportionality the specimen may undergo sudden compression without a corresponding increase in load and this is referred to as the yield point.

Beyond yield stress the stress- strain curve deviates due to the specimen deforming in a plastic manner.

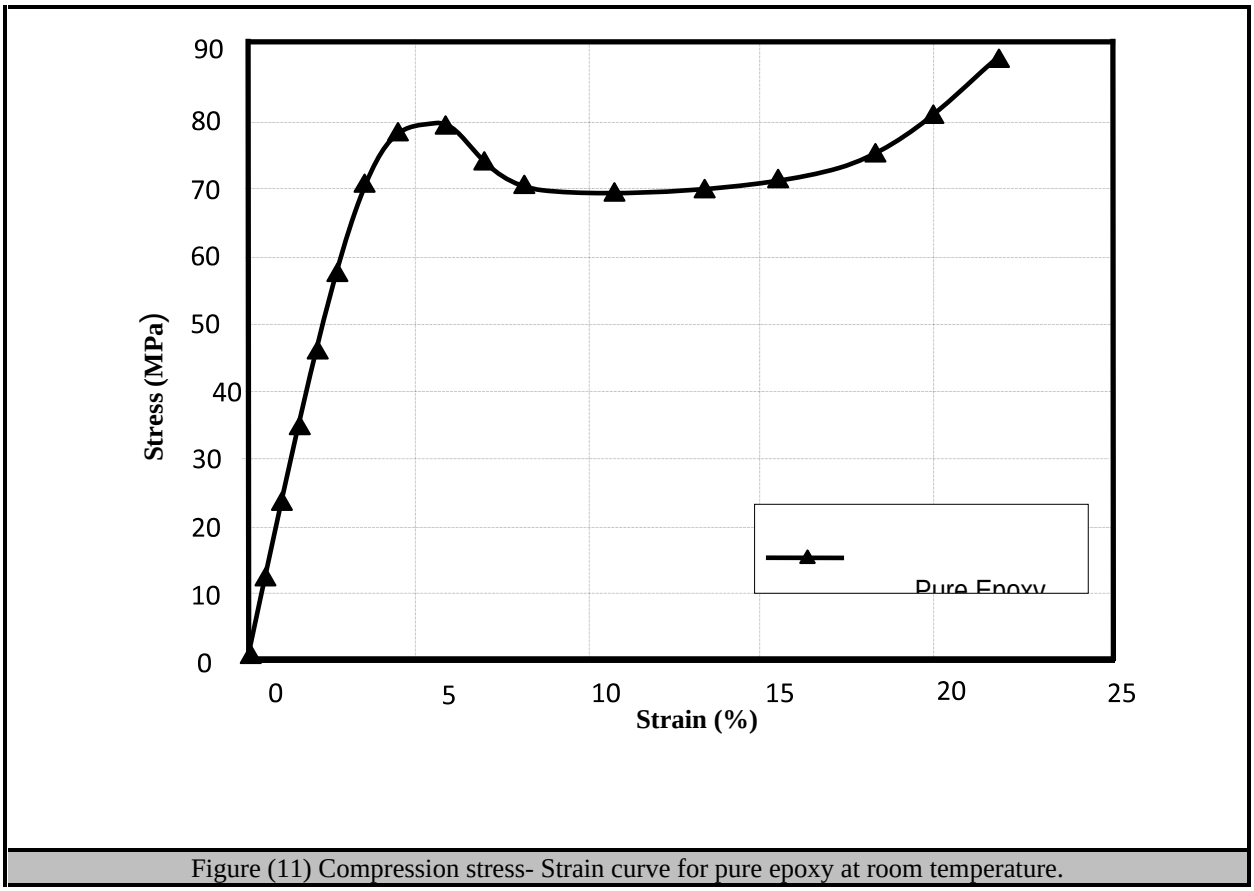



Figure (11) Compression stress- Strain curve for pure epoxy at room temperature.

Compression testing results have been achieved for reinforced epoxy at room temperature with weight fraction 5%, 10% and 15% as shown in figure (12).

The initial parts of the plots have low slope (low elastic modulus) corresponding to the uncoiling of molecules (overcoming weak, secondary bonds). The high modulus region corresponds to the elongation of the extended molecules (stretching primary, covalent bonds) [33]. While the initial part of plots for reinforced epoxy with (15%W) specimens behave in an elastic manner and the slope of the line in this region complies with Young's modulus (E), which is increased according to the increase in weight fraction. Finally, the modulus of elasticity with weight fraction curves are shown in figure (4.13) and it illustrates that the modulus of elasticity is increased according to the increase in weight fraction for each particle size due to increase the number of copper particles in unit volume and then decreased the movement of particles (i.e decreasing strain in specimen) which leads to increase modulus of elasticity.

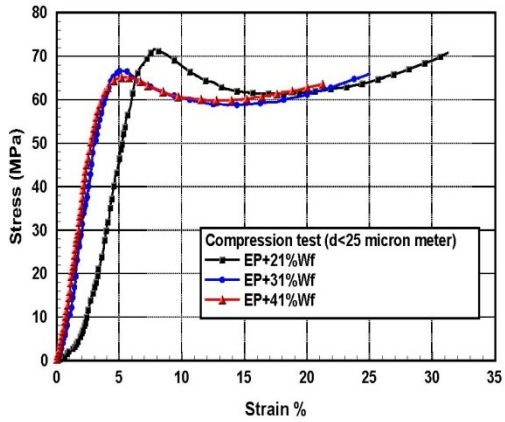



**Figure (12) Stress - Strain curve for reinforced epoxy with different weight fraction from copper powder**

The compression yield stress in figure (12) can be defined as the stress at the slope of stress- strain curve equal to zero which is decreased due to the increase in weight fraction of copper powder to epoxy as shown in figure (4.14) as the influence of friction between copper particles and the matrix causes the slipping between particles at compression test, while the compression yield stress will be increased as the particle size of

copper powder is decreased due to the increased wettablity of copper particles by epoxy resin which increases transmitting stresses from matrix to copper particles. Also, decreasing particle size leads to increase in boundary grains of copper in composite material, which leads to increase the compression yield stress of composite materials.

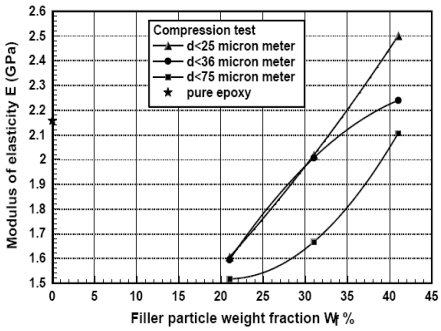
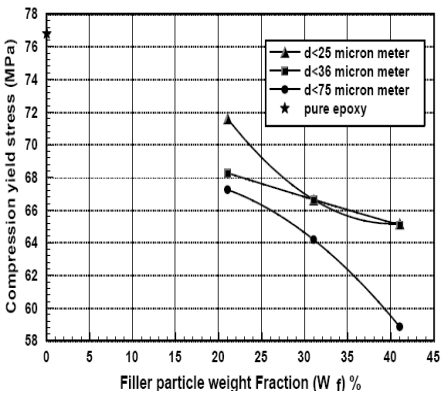



**Figure (4.13):** - Modulus of elasticity (GPa)– filler particle weight fraction % curve for different particle size.




## 4.4 Impact testing: -

Many materials are prone to fracture in a brittle manner as very little plastic deformation takes place before failure. Crack growth during brittle fracture absorbs very little energy. It is also extremely rapid and occurs without any warning.

The Charpy test is used for testing the impact on specimens that are supported as a simple beam, in which the specimen is struck from a position behind the notch.

### 4.4.1 Impact testing for pure and reinforced epoxy: -

Impact testing results have been obtained for pure and reinforced epoxy at room temperature with particle size (d=25, 36 and 75μm) and weight fraction 21%, 31% and 41%.

In the figures (4.16 and 17), the fracture energy and Impact strength with filler particle weight fraction curves illustrate that the fracture energy and Impact strength for pure epoxy are higher than that for reinforced epoxy with copper powder as a result of less ductility of reinforced epoxy than that for pure epoxy.

But for reinforced epoxy with copper powder, it can be noted that any increase in weight fraction leads to an increase in fracture energy and Impact strength for each particle size of copper powder (dμm) due to increase the number of copper particles in unit volume which impede crack propagation, (i.e. increase in the absorb energy). Also, it can be noted that the fracture energy and Impact strength are increased as the particle size is decreased for each weight fraction due to increasing wettability of the copper particles by epoxy resin which causes an increase in transmitting stresses from matrix to copper particles. Also, decreasing particle size leads to increase in boundary grains of copper in composite material, which leads to increase the strength of composite materials.

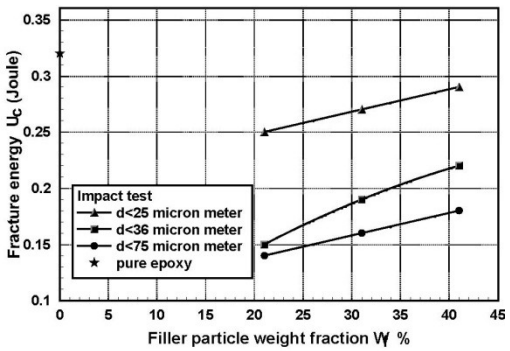



**Figure (4.16): - Fracture energy (J) – filler particle weight fraction % curve for pure and reinforced epoxy with copper powder and different particle size.**

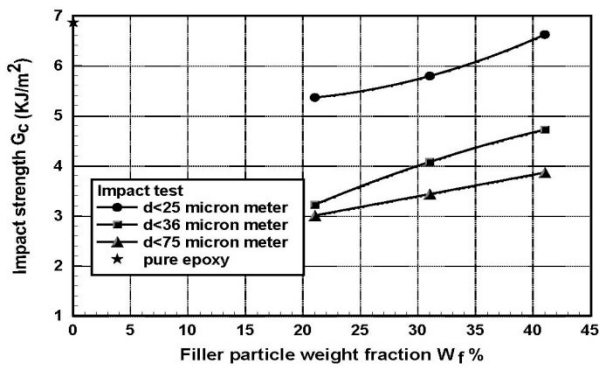



**Figure (4.17): - Impact strength (KJ/m)- weight fraction % curve for pure and reinforced epoxy with copper powder and different particle size.**

Figure (4.19) shows that modulus of elasticity (E) of reinforced epoxy is increased with the increase in weight fraction of copper due to increase the number of copper particles in unit volume and then decreased the movement of particles which leads to increase modulus of elasticity, also it can be noted that the modulus of elasticity for each weight fraction is increased with a decrease in particle size (dμm) as a result of increasing wettability of copper particles by epoxy resin (small interface region) which cause an increase in the transmitting stresses from matrix to copper particles. Also, decreasing particle size leads to increase in boundary grains of copper

## 4.5 Bending test: -

The bending test is one of the most used methods for determining the modulus of elasticity and flexural strength of materials. The test involves an axial load being applied to a simply supported standard beam of rectangular cross section with a constant strain rate and causes the specimen to deflect and finally fractured.

### 4.5.1 Bending test for pure and reinforced epoxy: -

Bending test results have been obtained for pure and reinforced epoxy at room temperature with particle size (d=25, 36 and 75μm) and weight fraction 21%, 31% and 41%.

$\leq 25, 36 \text{ and } 75$ in composite material, which leads to increase the modulus of elasticity of composite materials.

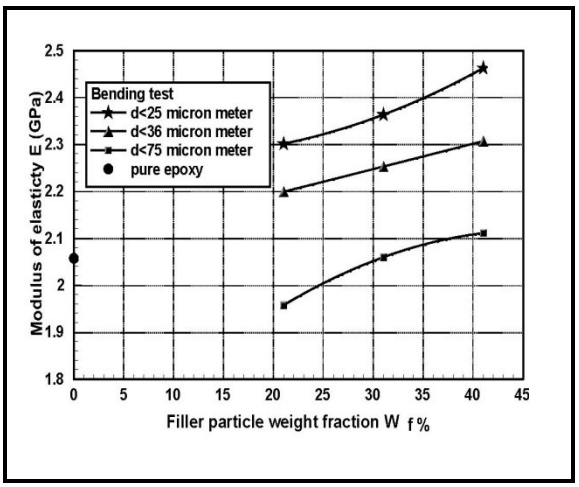



Figure (4.20) illustrated that the flexural strength for reinforced epoxy with particle size (dμm) is less than flexural strength for pure epoxy because the ductility for pure epoxy is higher than that for reinforced epoxy.

Also it is noted that flexural strength for reinforced epoxy is decreased with the increase in weight fraction for each particle size due to friction between particles which increase the deformation (slipping bands) between particles, but flexural strength is increased with the decrease in particle size as a result of increasing wettability of copper particles by epoxy resin (small interface region) which cause an increase in the transmitting stresses from matrix to copper particles. Also, decreasing particle size leads to increase in boundary grains of copper in composite material, which leads to increase the strength of composite materials.

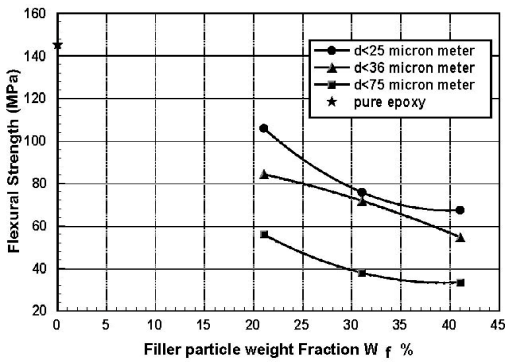



**Figure (4.20): - Flexural strength (MPa) – filler particle weight fraction % for reinforced epoxy with different particle size.**

## 4.6 Torsion testing: -

Torsion testing is one of the most used methods for determining the modulus of rigidity and shear strength. The test involves a torque being applied to a prismatic bar of rectangular cross section with a constant strain rate by mechanical means and this causes the specimen to twist and finally fractured.

### 4.6.1 Torsion testing for pure and reinforced epoxy: -

Torsion test results have been achieved for pure and reinforced epoxy at room temperature with particle size (d 25, 36 and 74μm) and weight fraction 21%, 31% and 41%.

Figure (4.22) is a plot for maximum shear stress-shear strain curve for pure epoxy, and figures (4.23, 24 and 25); are for maximum shear stress-shear strain curve for reinforced epoxy with particle size (dμm) and different weight fractions. All of these show that the initial part of the plots is linear, and the specimen behaves in an elastic manner, which the specimen will return to its initial state when the torque is released, and the slope of the line in this region complies with the modulus of rigidity.

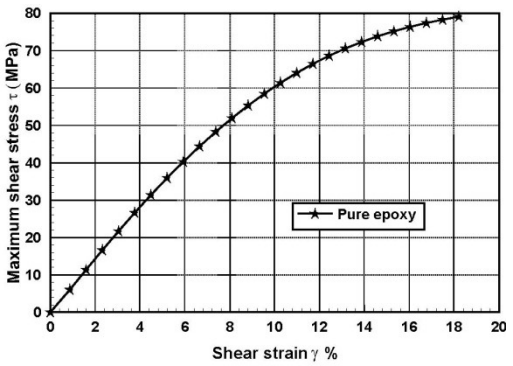



**Figure (4.22): - Maximum shear stress (MPa)- shear strain % curve for pure epoxy.**

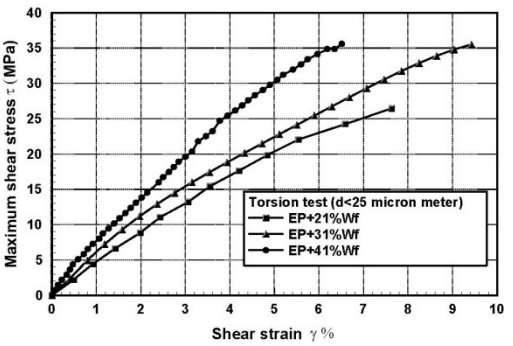



**Figure (4.23): - Maximum shear stress (MPa)- shear strain % curve for reinforced epoxy with copper powder (d=25 micron meter) and different weight fraction**

Also, figure (4.26) illustrates that modulus of rigidity is increased with the increase in the weight fraction of copper powder for each particle size (dμm) to epoxy due to increase the number of copper particles in unit volume and then decreased the movement of particles (i.e decreasing deformation in specimen) which leads to increase modulus of rigidity.

Also it can be noted that the modulus of rigidity for reinforced epoxy is increased with the decrease in particle size for each weight fraction as a result of increasing wettability of copper particles by epoxy resin (small interface region) which cause an increase in the transmitting stresses from matrix to copper particles. Also, decreasing particle size leads to increase in boundary grains of copper in composite material, which leads to increase the modulus of rigidity of composite materials.

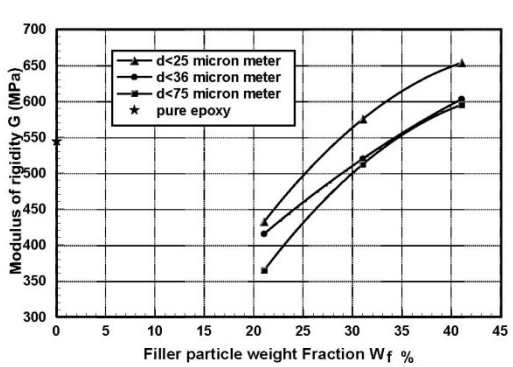



Figure (4.26): - Modulus of rigidity (MPa)- filler particle weight fraction % curve for reinforced epoxy with different particle size.

Figure (4.27) for shear strength in (MPa) against filler particle weight fraction percent curves shows that the shear strength for pure epoxy is higher than that for reinforced epoxy with particle size (dμm) and different weight fraction because the reinforced epoxy is more brittle than pure epoxy.

But for reinforced epoxy with particle size (dμm) and different weight fraction, the shear strength is decreased with the increase in weight fraction due to the influence of friction between particles, which increase deformation (slipping bands). Also the shear strength is increased with the decrease of particle size as a result of increasing wettability of copper particles by epoxy resin (small interface region) which cause an increase in the transmitting stresses from matrix to copper particles. Also, decreasing particle size leads to increase in boundary grains of copper in composite material, which leads to increase the strength of composite materials.

Finally, figure (4.28) shows torsion test specimens after failure. It failed at 45°, which means that this material is brittle [30].

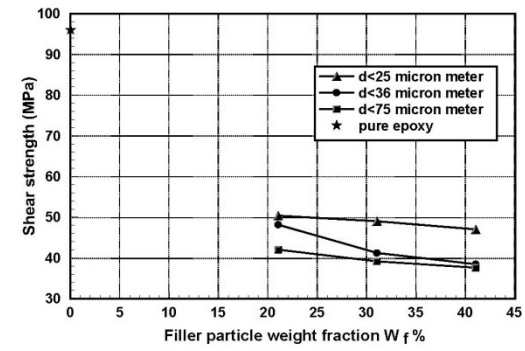



**Figure (4.27): - S**hear strength (MPa)- filler particle weight fraction % curves and different particle size

## 4.7 Fatigue testing: -

[

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses. Under these circumstances it is possible for failure to occur at a stress level considerably lower than the tensile or yield strength for a static load.

Polymers are susceptible to this type of failure. Furthermore, it is catastrophic and insidious, occurring very suddenly and without warning.

Fatigue test has been achieved for pure and reinforced epoxy with a stress ratio (R=-1) at room temperature for particle size (d= 25**)** and weight fraction 21% and 41%.

### 4.7.1 S-N curves for pure and reinforced epoxy: -

A series of tests are commenced by subjecting a specimen to the stress cycling at relatively large maximum stress amplitude, the number of cycles to failure is counted. This procedure is repeated on other specimens at progressively decreasing maximum stress amplitudes. Data is plotted as stress amplitude sversus the logarithm of the number of cycles to failure N

The S-N behaviors for pure and reinforced epoxy are shown in figures (4.29 and 30) as these plots indicate, the higher the magnitude of the stress,

$_f$ for each specimen. the smaller the number of cycles the material is capable of sustaining before failure. The S-N curves for pure and reinforced epoxy did not show the fatigue limit and the S-N curves continued the downward trend at increasingly greater N values. Thus, fatigue will ultimately occur regardless of the magnitude of the stress, therefore, the fatigue response is specified as fatigue strength, which is defined as the stress level at which failure will occur at a number of cycles between ($10^7$ -$10^8$ cycles) [27].

The fatigue behavior represented in figures (4.29 and 30) may be classified into two domains. One is associated with relatively high loads that produce not only elastic strain but also some plastic strain during each cycle. Consequently, fatigue live is relatively short: this domain is termed low- cycle and occurs at less than about 10to 10 cycles. For lower stress levels wherein deformations are totally elastic, longer lives result. This is called high-cycle fatigue inasmuch as relatively large numbers of cycles are required to produce fatigue failure. High cycle fatigue is associated with fatigue lives greater than about 10to 105 cycles [27].

Figure (4.30), illustrates that behavior of the S-N curve for reinforced epoxy with particle size (dμm) and 21% W, is close to that for polymers (pure epoxy) which have a

**fatigue strength**, but for reinforced epoxy with particle size (dμm) and 41% W, the behavior of the S-N curve is close to that for metals which have a

**fatigue limit** due to the influence of increasing weight fraction of copper powder to epoxy resin.

Finally, figure (4.31) shows fatigue test specimens after failure.

$$_a = 83.436 N_f^{-0.13214}$$

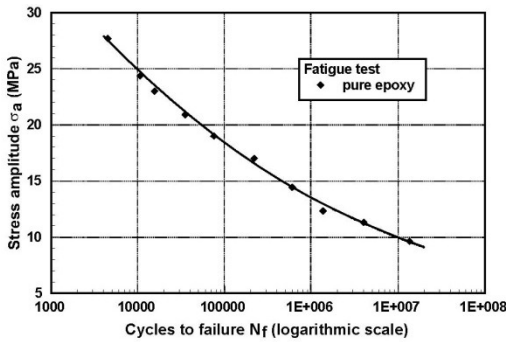



Figure (4.29): - The S-N curve for pure epoxy

(Fatigue strength at $10^7$ cycles equal to 10.5 MPa), (s ).

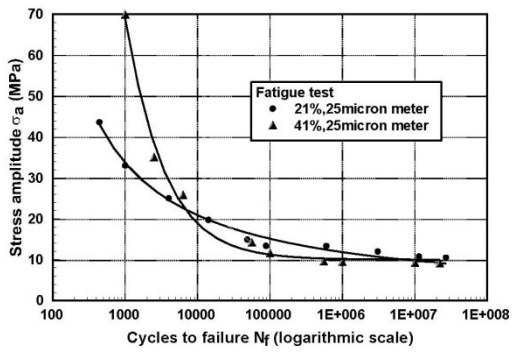



**Figure (4.30): -** The S-N curve for reinforced epoxy with particle size (dμm) at 21% and 41% W, (Fatigue strength for 21% Wat $10^7$

cycles equal to 10 MPa), but the Fatigue life for 41% Wequal to 10 MPa).

## 4.8 Friction testing: -

When a body slides or trends to slide on another body, the force tangent to the contact surface which resists the motion, or the tendency toward motion, of one body relative to the other is defined as friction.

The friction test is one of the most used methods for determining coefficient of friction. The test involves contacting disks of pure or reinforced epoxy to a steel wheel and working out values of normal force at the disks and the value of torque, applied to the wheel, from which the coefficient of friction can be determined.

### 4.8.1 Static coefficient of friction for pure and reinforced epoxy to steel: -

The coefficient of static friction μ is defined as the ratio of the magnitude of the maximum static frictional force , to the magnitude of normal force, between the two surfaces. In mathematical form,

$$\frac{F_r}{F_n}$$

The static coefficient of friction is an experimentally determined constant, which depends on the materials from which the contacting bodies are made. Figure (4.32) shows, the relationship between the coefficient of friction and the filler particle weight fraction for different particle size. It is noted from this figure that the static coefficient of friction for reinforced epoxy is less than that for pure epoxy to **steel** due to the influence of copper particles as a lubricant, also it is noted that static coefficient of friction for reinforced epoxy with particle size (dμm) is constant for increasing filler particle weight fraction (21%, 31% and 41%) but for reinforced epoxy with particle size (dμm), it is noted that the static coefficient of friction decreases with the increase in weight fraction up to 31% and then constant for any additional increase in filler particle weight fraction (i.e. larger than 31%).

Finally, figure (4.33) shows photograph of pure and reinforced epoxy test specimen.

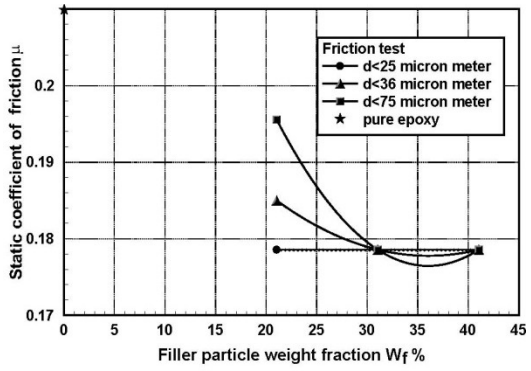



**Figure (4.32): - Static coefficient of friction– filler particle weight fraction for pure and reinforced epoxy to steel for different particle size.**

# Conclusions And Recommendations

## 5.1 Conclusions: -

The most important conclusions that can be drawn from this work are as follows:

1- Particular composite is a modern type of composite materials, which can be used for manufacturing prcesses because of easy casting of different shapes.

2- Particulate composite of copper powder-reinforcing epoxy is a new material, which can be used in different fields.

3- Experimentally, increasing a weight fraction of a copper powder to epoxy for different particle size leads to increase in modulus of elasticity (E), modulus of rigidity (G), tensile yield stress and ultimate tensile strength at room temperature (25°C).

4- Decreasing, compression yield stress, fracture energy, impact strength due to increasing weight fraction of copper powder to epoxy with different particle size (dμm) at room temperature (25°C).

5- The increasing modulus of elasticity (E), modulus of rigidity (G), tensile yield stress, ultimate tensile strength, compression yield stress, fracture energy, impact strength, Flexural strength and shear strength as a result of decreased particle size of copper powder (dμm) for each weight fraction (21, 31 and 41%) at room temperature (25°C).

6- Decreasing static coefficient of friction for reinforced epoxy with particle size (dμm) as a result of increased of weight fraction (0% and 21%) and then will be constant at weight fraction (31% and 41).

7- Decreasing static coefficient of friction for reinforced epoxy as a result of decreased the particle size (d=μm) with weight

fraction (21%), but constant, at weight fraction (31% and 41%).

8- The best weight fraction is 41% for particle size (dμm), with a high modulus of elasticity, modulus of rigidity, tensile yield stress and ultimate tensile strength.

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# السلوك الميكانيكي للمواد المركبة البوليمرية المدعمة بمسحوق النحاس

**محمد عبد الستار محمد**
**مدرس مساعد**
**قسم الهندسة الميكانيكية**
**كلية الهندسة/جامعة النهرين**
M1976sjn@yahoo.com

## الخلاصة

الخواص الميكانيكية لراتنج الايبوكسي التجاري conipox 77 قد درست في حالة التدعيم بدقائق النحاس بكسور وزنية مختلفة وفي حالة عدم التدعيم.
قيم معامل المرونة،معامل الجساءة، اجهاد الخضوع، اجهاد الشد، اجهاد القص، اجهاد الانحناء، طاقة الكسر، مقاومة الصدمة، معامل الاحتكاك، منحنى S/N و اجهاد الكلل قد درست عند درجة حرارة الغرفة (٢٥س) لمعرفة تاثيرالكسر الوزني لمسحوق النحاس الضافة الى الايبوكسي بمقادير (٠%،٥%،١٠% و١٥%). ووجد ان الزيادة في الكسر الوزني لمسحوق النحاس الى الايبوكسي و لاحجام مختلفة لجزيئات النحاس قد ادت الى زيادة في معامل المرونة،الجساءة،اجهاد الخضوع، اجهاد الاقصى ولكن في نفس الوقت ادت الى تقليل اجهاد الخضوع ، طاقة الكسر و طاقة الصدمة.
اخيرا الايبوكسي المدعم بنسبة (١٥%) ادى الى تحسين الخواص الميكانيكية للمواد المركبة مع تقليل لمعامل الاحتكاك.