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Improvement the Mechanical and Physical Properties of Epoxy–Polyurethane Matrix Resin by Using Kevlar Fiber and ZnO Particles

Abstract*: This work focuses on the synthesis of hybrid polymer composite matrix materials prepared from the epoxy–Polyurethane resin (Polyprime EP) as matrix reinforced phase by using (5%, 10%, 15% and 20%) Zinc oxide particles and 5% woven roving Kevlar fiber (0^0-90^0) kind (49). Mechanical and physical tests such as tensile strength, impact strength, hardness, density, thermal conductivity, and water absorption were done. The results showed increased hardness with increasing volume fraction of ZnO for the ratios (5%, 10%, 15% and 20%). The impact strength was increased for volume fraction of zinc oxide at 15%, modulus of elasticity at 5%, thermal conductivity at 20% and density test at 10%. The stress increased at volume fraction of zinc oxide at 10% and 15%. The water absorption decreased with increasing volume fraction of ZnO additives.*

Keywords*- Epoxy–polyurethane resin, Particle zinc oxide, Kevlar, Mechanical properties, Physical properties.*

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1. Introduction

Polymers and polymeric composites have steadily reflected their importance in our daily life .The composite material however, generally possesses characteristic properties that are not possible with the individual components by themselves [1,2].
Polymers thermoset commonly used for structural matrix applications as their high; thermal and mechanical properties, excellent bonding with reinforcement, low viscosity, and low cost addition to ease manufacturing [3]. The thermoset polyurethane is a very ductile and low Tg. Rubbery resin with a high toughness. The success of polyurethane is resin because of its ability to be produced in different forms from rigid to flexible structures [4].
An epoxy resin is widely applied as high performance composites in many fields, such as; aerospace, military and sports equipment. Epoxy offer an improving in mechanical properties comparing with vinyl esters and polyesters, but on other hand it is a higher cost. Epoxies are stronger, tougher, stiffer, more solvent resistant, more durable, with higher maximum fabricating temperature and dielectric properties than polyester thermosets [5]. The polymer blends have been one of the primary areas in polymers science and technology over the past several decades. Polymer blends offer versatile industrial applications through property enhancement and economic benefits. Polymer blends are defined as any combination of two or more polymers resulting from common processing step. These blends are used to improve some thermal, physical and mainly mechanical properties of polymer. The use of polymer alloys and blends have grown so very fast as compared with other polymers materials system; mainly because of their low cost and their acceptable performance [6].
Zinc oxide has unique properties as reinforcing phase that used a plenty of researches. Various sizes and morphologies of ZnO has led to a wide range of promising applications, such as additives in paints, catalysts, optoelectronics, electronics, and many more [7]. The effect of hybridizing Kevlar fiber to carbon fiber on impact behavior of hybrid composite laminates has been studied [8]. Results indicated that hybridization of Kevlar fiber to glass fiber improved the load carrying capability, energy absorbed and damage degree of composite laminates with a slight reduction in deflection [7].
In this work, studying the effect of Kevlar 5%woven roving fiber (0^0-90^0) and zinc oxide particles (5%, 10%, 15% and 20%) addition as reinforcement to epoxy–Polyurethane (Polyprime EP) resin has been attempted on some physical and mechanical properties.

2. Experimental

I. Material and Methods

The different materials used in this study to prepare test specimens of the epoxy–Polyurethane

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resin composites: Kevlar Fiber: The Kevlar 49 fiber used in this study made by (E. I. DuPont De Nemours and Company) -U.S.A, as woven mat with fibers angle direction (0 /90) and volume fraction (5%), this type of fiber has a yellow color, (table 1) shows mechanical and physical properties of this fiber.
Epoxy –Polyurethane resin (Polyprime EP) it is provided from polybit company- UAE, It consists of a mixture of two compounds epoxy and polyurethane resin, table-2 show properties of this resin. Particle zinc oxide density (ZnO) used as reinforcement made by (China Hishine Industry Co., Ltd.) Table-3 show properties of ZnO.

II. Preparation of Composites

The mould used in this study was glass sheet in dimension (30 cm x 20 cm x 0.4 cm) and covered with a piece of nylon paper (overhead paper) to prevent the adhesion between the mould and the specimen. The mass of the reinforcement materials (zinc oxide particle) and the mass of the resin (Epoxy -Polyurethane resin) are calculated according to required volume of cast, by used one lamina from 5% Kevlar in this composites and the samples of the composite materials was synthesis by adding the reinforcing phase material (particle ZnO : 20%, 15%, 10%, 5%) to the matrix . The matrix and hardener were mixed in ratio of (2:1) at room temperature slowly and continuously. The process was continued for (5) minutes until the resin becomes homogeneous. The uniform continuous pouring is performed until the mould had filled then mixture had been left inside the mould at room temperature for (24) hrs. to solidify. Then the sample was placed inside an oven dryer for (1) hrs. at 55 ºC for drying. The specimens cut according to angle of Kevlar orientation depend upon the standard dimensions, with using different cutting tools as shown in figure (1). Each sample was tested three times and average results were reported.

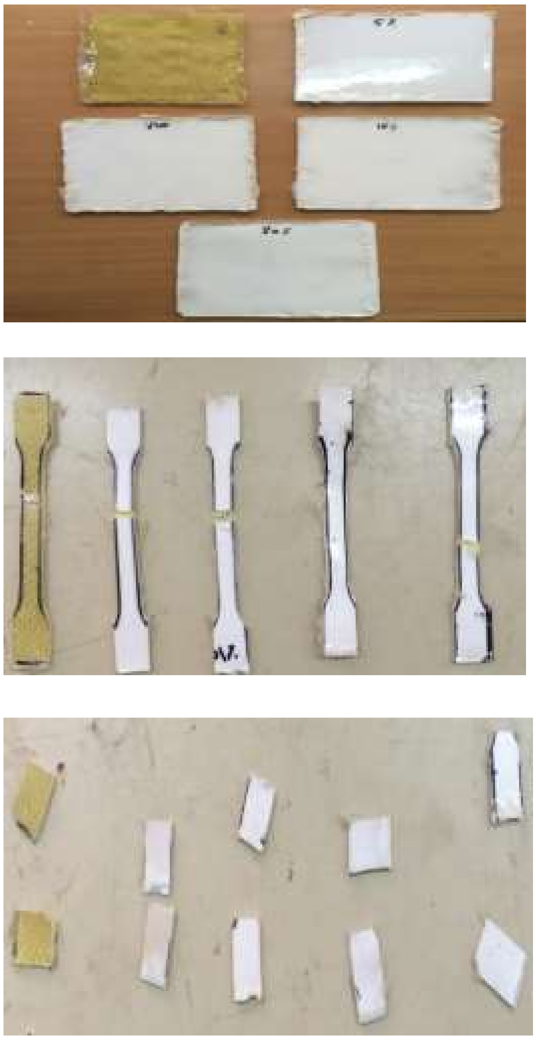

Figure 1: Specimen composites before and after cut

Table 1: Some Properties of the (Kevlar 49) Fibers used in this Study

Tensile Strength (GPa)	Young's Modulus (GPa)	Tensile Elongation (%)	Density (g/cm3)	Thermal Conductivity (W/m.k)	Specific Heat (J/kg.k)	Diameter (mm)
3.6-4.1	131	2.8	1.44	0.04-0.05	1300	12

Table 2: Some Properties of Epoxy–Polyurethane resin (Polyprime EP)

Color	Solid Content%	Initial Cure (hrs.)	Density (g/cm3)	Application temp (^{0}C)	Application Life (mints)	Water resistance
Amber	100	6-8	1.05	5 to 35	30	Very good

Table 3: Some Properties of ZnO

Molar mass g/mol	Appearance	Melting point ^{0}C	Density (g/cm3)	Solubility in water mg/100 ml (30°C)
81.38	White Solid	1,975	5.606	0.16

III. Mechanical and Physical Tests

A. Tensile test

The tensile test method was done according to ASTM 638-01. Length of the tested sample was (150) mm. The test had achieved by universal machine (capacity 5 kN), with a head speed (5mm/min) [8].

B. Impact Test

The impact value was performed according to (ISO -180) using Izod Impact test machine type is (XJU series pendulum Izod/Charpy impact testing machine). For Izod Test: the specimen clamped at one end and held vertically cantilevered beam and it has broken at impact energy of (5.5 J) of pendulum and impact velocity (3.5 m/s) [9].

C. Hardness test

This test was archived via Shore hardness instrument, according to (ASTM D2240), and preparation of specimens was at room temperature [10].

D. Density Test

The specimens was preparation depending to (ASTM D792) by using Archimedes theory. The specimens were cut into a thickness of 5 mm and a diameter of 40-mm. density can be calculated according to the following formula:

Specific gravity (SG) = $W_d / W_d - Wi$ (1)

Where: (W_d) weight of dry samples in (gm), (W_i) is weight of samples after immersing and suspended in water in (gm). (S.G) value can be converted to density by multiplying the specific gravity (SG) by (Dw) which represent the density of distilled water (0.9975) [11].

E. Water Absorption Testing

Water absorption test done depending to (ASTM D570). Samples were cut into a thickness of 5 mm and a diameter of 40 mm. The water absorption was obtained in below equation [12]:
Water Absorption percentage can be calculate by:

WA % = ($Ws - W_d / W_d$) x 100 (2)

Where W_d: is weight of the dry sample before immersing, WS: is weight of sample after immersing into distilled water at room temperature for (24 hr).

F. Thermal conductivity test:

The thermal conductivity (T_C) test was done by (Hot Disk) Thermal analyzer device type (TPS 500) Sweden. Dimensions of samples were (40mm x10mm).

3. Results and Discussion

I. Tensile strength

Figure 2 shows (stress-strain) curve for all composite specimens. The mechanical behavior of these curves depends upon the natural of matrix material and reinforced material as well as on the adhesion bond (bond strength) between the matrix and reinforced material. It can also be noticed that the initial stage of the strain stress curve is linear where the specimen behaves in an elastic manner and eventually develops into non-linear due to the deformation of specimen in plastic manner. An increase in the plastic deformation continued with increasing stress, until the fracture occurred in the specimen, at this time, the tensile strength can be estimated. It is evident that the (stress-strain) curve illustrates the stress increases with increasing volume fraction zinc oxide particles at 10% and 20%, the reasons behind such a behavior are that the strengthening mechanism of Kevlar and particle of zinc oxide reinforcing in which, the amount of these particles play an important role by impeding the increase of the slipping of epoxy-polyurethane resin chains.

II. Modulus of Elasticity

Figure 3 shows the relationship between weight fraction and modulus of elasticity of ZnO addition. It can be noticed that the values of modulus of elasticity increased with increasing of volume fraction of zinc oxide particles at ratio 5%, 10% and 20%. This may be due to the strengthening mechanism and the nature of the bonding strength and created full interface between reinforcing materials and Epoxy-polyurethane.

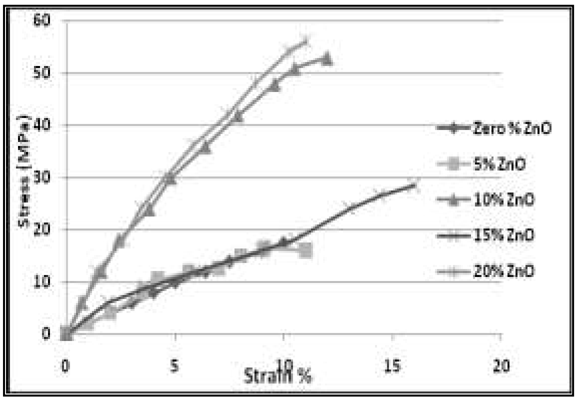

Figure 2: The (Stress – Strain) curve for composites as function of ZnO and Kevlar addition

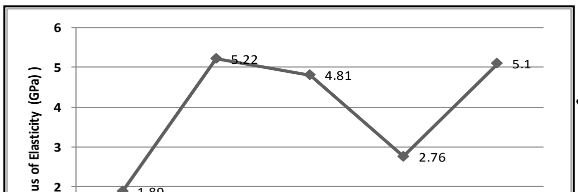

Figure 3: Relationship between modulus of elasticity of composites and weight fraction ZnO additives

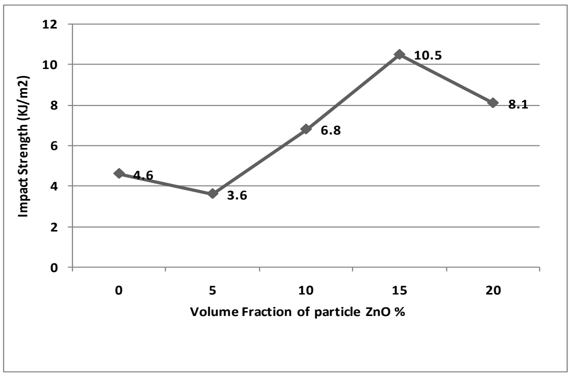

Figure 4: Relationship between Impact strength of composites and weight fraction ZnO additives

III. Impact test

The Impact test represents one of important dynamic mechanical tests, where the specimen exposed to very fast moving load. Figure 4 shows relationship between hardness and weight fraction of ZnO addition. It can be noticed value of impact strength increased with mounting of volume fraction of particles, where the maximum impact strength was recorded at 15% ZnO addition due to the reinforcements of ZnO affect positively in bearing impact load and increasing the impact energy required fracturing the specimen.

IV. Hardness Test

Figure 5 shows relation between weight fraction and hardness of ZnO addition, it can be observed hardness values increasing with increasing volume fraction of ZnO. This is may be because of high brittleness and hardness of ZnO particles as compared with epoxy-polyurethane. Furthermore, the wettability and bonding strength between these particles and matrix could make harder surface by impeding the composite motion along the stress direction. The maximum hardness was recorded at 10% ZnO addition. Furthermore a slight increase in material hardness by using percentages (15% and 5%). The results showed the hardness are getting better when using particles zinc oxide as reinforced epoxy-polyurethane resin, the reason for such important behavior may be due to the mechanisms of increasing in strength in particulate composite material by increasing in fracture surface area which results from the irregular path of crack due to particles which act as an obstacle in front of crack propagation and the need for higher energy for crack growth [13].

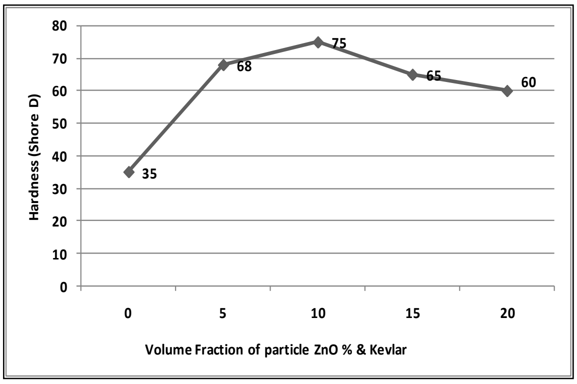

Figure 5: Relationship between hardness of composites and weight fraction ZnO additives

V. Thermal conductivity

The thermal properties depend on the frequency of interactions between the lattice atoms, particle size of the airspace and nature of bonding in solid material. It is also shown in Figure 6 that the effective thermal conductivity is higher than original polymer at 20% zinc oxide. This behavior may be explained based on structure of composite compact.

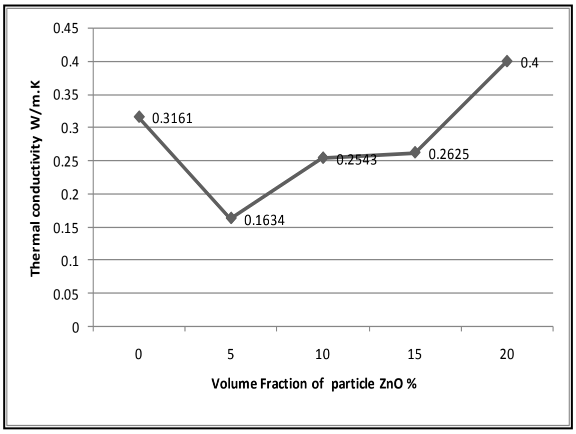

Figure 6: Relationship between thermal conductivity of composites and weight fraction ZnO additives

When the particles are added in composites, they set in the position of voids, and consequently reducing free volume into compact structure of composites, so improves thermal conductivity or thermal conduction properties of composites over the epoxy-polyurethane resin [14]. While less thermal conductivity when ratios 5%.10% and 15% because of the presence of free volume, which operate in, reverse and lead to decrease the thermal conductivity.

IV. Density Test

Figure 7 shows the relation between composites density and weight fraction of ZnO additives. It can be see the increasing density with volume fraction zinc oxide. Addition kevlar fibers at 10% decrease in other ratio of zinc oxide. This is because the particles have lower density value compared with the epoxy-polurethane matrix. In addition, the particles are cause increasing the spaces and voids inside epoxy-polurethane matrix.

VII Water Absorption

Water-soluble from polymer matrix is easily and form droplets of solutions. These droplets by sorption process lead to grow in sizes. Depending on the properties of material, these droplets might be reduced in size or grow indefinitely. This may be lead to the crack of the material, Water is a substance has relative molecular weight below those of the polymers; liquids that are added to polymers give apparently homogeneous materials that are softer and more flexible as well as having lower glass transition temperature.

Figure 8 show relation between volume fraction ZnO additives and water absorption percentage of the composites. It can be noticed that percentage of water absorption decreased with increasing of the ZnO volume fraction additives. This is because of added particles like the zinc oxide, can cause diminishing all the voids and spaces inside the epoxy-polyurethane resin which filled by these particles, in finally result the composites water absorption will be decreased the water absorption at 5% ZnO recorded the highest value among the others.

4. Conclusion

For the prepared composite material with zinc oxide, the mechanical properties like hardness were increased with increasing volume fraction of zinc oxide at (5%, 10%, 15%, 20%). The impact strength increased too for volume fraction, of zinc oxide, at 15%. Besides, the modulus of elasticity has risen to 5%, the thermal conductivity to 20% and the density test to 10%. In addition, the stress increased with increasing of volume fraction of zinc oxide to 10% and 15%. The water absorption decreased with increased volume fraction of ZnO additives.

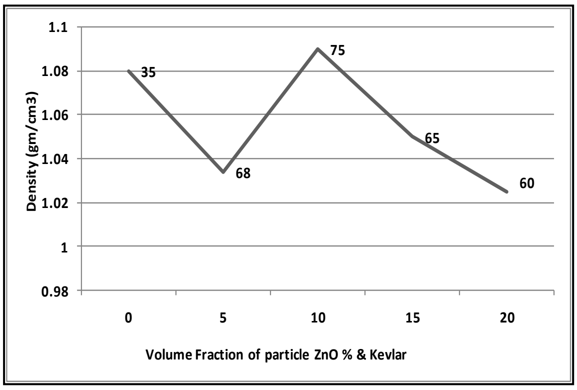

Figure 7: Relationship between density of composites and weight fraction ZnO additives

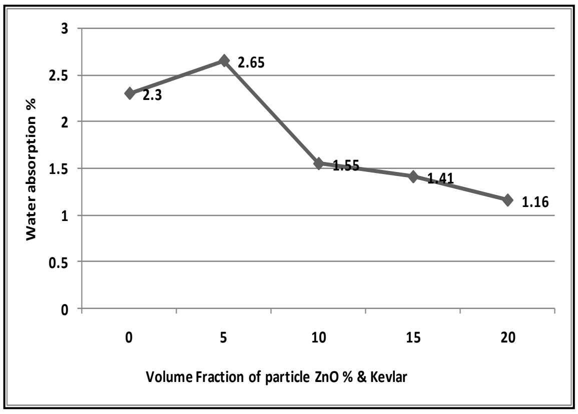

Figure 8: Relationship between water absorption of composites and weight fraction ZnO additives

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Author biography

I have big experience in the Mechanics Engineering Sciences and Manufacturing Techniques for thermoset, thermoplastic Composite materials. I got my Ph.D. degree of Engineering Sciences in Mechanics of Deformable Bodies (Manufacturing and design of Composite materials) in 2011. My dissertation research is Modeling of Physical-Mechanical Characteristics of Transversally Reinforced Laminated Composite materials. I got my MSC degree of Science in Mechanical Engineering Specialization of Aeronautical in 2001. My thesis research was conducted in The Optimum Structural Design of Aircraft Wing by Using Finite Element Method. I worked as a lecturer in Department of Materials Engineering