Study of Mechanical Properties and Thermal Conduction of Polymer/Ceramic Nanocomposites

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A R T I C L E   I N F O

A B S T R A C T

A composite materials were prepared using a polymeric blend of epoxy resin and unsaturated polyester as a matrix material, and using a nanoceramic powder Lead Zirconium Titanate as a reinforcement material in different adding ratios(2wt % & 6wt %). Impact strength, surface hardness, thermal conductivity and solutions absorption tests were carried out for the polymeric blend and composite samples. The pre-immersion results showed that adding the ceramic powder to the polymeric blend improved the surface hardness, increased thermal conductivity as well as reduced impact strength. Immersing the samples in H2SO4 acid and kerosene caused of decrease in impact strength and surface hardness as well as increase in thermal conductivity. It was also noticed an increase in the absorption rate of acid and kerosene solutions in a manner proportional to the duration of immersion.

1. INTRODUCTION

The advanced technological and modern industrial applications require materials with distinct characteristics that are not available in one of the traditional materials such as metals, ceramic materials and polymers. The composite materials in general and the polymeric nanocomposites in particular are among the advanced materials that are widely used in various fields in our life such as manufacturing parts of automobile and aircraft structures, windmill blades, some components of laptop computers, sports equipment, orthopedics and dentistry etc., due to its good mechanical and physical properties and low cost comparing with metals, alloys and other materials [1]. The shape and size of the added particles and the way they are distributed in the matrix material are factors that influence the final properties of the composite material, as the properties of the composite material are a function of the properties of its components, quantities, shape and size of the support material particles. Studies have shown that the heterogeneous distribution of nanoparticles within the

matrix material (the polymer) does not lead to a clear improvement in some of the mechanical and physical properties of nanocomposites, while many studies have shown that the uniform and uniform diffusion of nanoceramic particles in the polymer has led to a clear improvement in those properties [2]. The composite material consists of the matrix which represents the continuous phase material, reinforcement material (reinforcement phase) which stands most of the stress applied on the composite material and leads to improving its mechanical properties, and the third phase is the interface region that is located between the matrix and reinforcement materials. The matrix material can be metals, ceramic or polymeric material, as the composite materials with a metals matrix such as iron and aluminum are distinguished by their high strength but their high density made them limited to use, the composite materials with a ceramic matrix are characterized by their tolerance to high temperatures

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but their resistance to impact is weak (brittle materials). As for the composite materials with a polymeric matrix, they are considered one of the best and most common types because of their good mechanical and physical properties (high strength, thermal and electrical insulation) [3].

Impact test is a measure of the strength of the material and its resistance to fraction under the influence of stresses at a high speed. The impact resistance represents the amount of energy absorbed during the collision of an object of a certain mass to the area of the cross section of the sample at the fraction and can be calculated from equation (1) [4].

$$I.S = U / A \qquad (1)$$

Where:

I.S: impact strength (MPa)
U: energy of fracture (J)
A: cross sectional area (mm^2)

Hardness is a characteristic of material's surface, and represents the resistance of the surface to penetration or plastic deformation such as denting and scratching, it gives a good idea on the material strength and durability, and it is also a nondestructive test. Hardness affected by many factors such as type and strength of the bond between atoms and molecules, type of surface (rough, smooth, regular, irregular, etc.). Other factors such as temperature, applied load, methods of manufacturing, heat treatment made to the material, and environmental conditions (moisture, chemicals, and radiation ,etc.) could also play important role [5].

Study of thermal properties of polymer materials and its composites are important to know the suitability of these materials for practical applications when used as a thermal insulators or any other thermal application, one of the most important properties is thermal conductivity. Polymers and its composites are considered a poor material for thermal conduction. Coefficient of thermal conductivity can be calculated using equations 2 and 3 [6].

$$K\left(\frac{T_B - T_A}{d_S}\right) = e\left[T_A + \frac{2}{r}\left(d_A + \frac{1}{4}d_S\right)T_A + \frac{1}{2r}d_S T_B\right] \quad (2)$$

e: represents the thermal energy passing through unit area in unit time (w/m^2.0k) , calculated from the following relationship:

$$H = IV = \pi r^2 e(T_A + T_B) + 2\pi r e\left[d_A T_A + d_S \frac{1}{2}(T_A + T_B) + d_B T_B + d_C T_C\right] \quad (3)$$

Where:

H: the time rate of thermal energy generated in the heater.

T_A, T_B, T_C: the temperature of the discs A, B, C, respectively (ºC).

d_A , d_B, d_C : represents the thickness of copper discs (A,B,C) (mm).

r: disc radius (mm),
dS: sample thickness (mm)
I: current passing in the circuit (A)
V: circuit voltage (V)

Polymers have an ability to absorb solutions compared to metallic and ceramic materials. Diffusion of the solutions in the polymeric composite results in an increase in the mass of the material or what is called weight gain. The percentage of mass gain for the submerged samples in the solutions is calculated by using Eq.4. The absorption of the polymers and its composites takes place when exposed to moisture or when immersed in water, and chemical solutions and according to Vick's law for diffusion, which states that the mass of water or absorbed solution increases linearly with the square root of time [7].

$$Weight\ Gain\ \% = M2 - M1/M1 * 100 \qquad (4)$$

Where:

Weight Gain %: the percentage of amount of profit in mass
M1: Sample mass before immersion (gm)
M2: - Sample mass after immersion (gm)

2. MATERIALS AND METHODS

2.1. Samples Preparation: a mixture of epoxy resin and unsaturated polyester was used, [EP 80% + UPE 20 %] as a matrix material, the epoxy used is Swiss made [type EUXIT 50 manufactured by SWISS CHEM] which is a thermosetting polymer, transparent liquid, has an adhesion property, little shrinkage, its density is approximately 1.05 g / cm^3 and it turns into a solid state by adding its hardener with a mixing ratio of 3:1 at the room temperature. The polyester used is produced by the Saudi Industrial Resins Company Limited, it is also a thermosetting polymer, in the form of a yellow transparent liquid with a density of 1 to 1.3 g/cm^3, and it can be treated to form in a solid state by adding its special hardener at a ratio of 2% at room temperature. The nanoceramic powder of Lead Zirconium Titanate [PZT] was used as a reinforcement material, its crystallite size is 10 nm and its purity is 99.99%, it has a high density (7.5 g / cm^3) and can be described as a white powder. It is manufactured by Deyang nang mater, co., Ltd. (China). Hand Lay –Up Molding

Method was used in preparing the research samples, namely: -

1-Polymeric Blend [EP 80% + UPE 20%],2- Polymeric Blend Composite with PZT 2 wt % , and 3-Polymeric Blend Composite with PZT 6 wt % .

The samples were heat treated as necessary to complete the polymerization process, it was then cut in the shapes and dimensions for each test according to the ASTM standards for impact , hardness , absorbance and thermal conductivity test according to the specifications of the Lee's Disc method.

2.2. The Tests

Impact Strength: To calculate the material resistance to impact, Charpy type shock monitor was used (Manufactured at Test Mach IND. AMITY VILLE, New York), it is described as a pendulum-mount device that has a breaking power that exceeds the energy needed to break the sample under test, a hammer weighing 2 Joules was used. The impact strength of the sample was calculated using relationship (1).

Surface Hardness: The Duroment Hardness (Type Shore-D) device manufactured at TIME GROUP ING. was used to perform a hardness test, it can be described as a device with a point stitching tool, the point stitch tool is penetrated into the surface of the material by pressing the device, the process is repeated three times in different places of the sample surface and by taking the average of these readings the surface hardness is determined.

Thermal Conductivity: To set the coefficient of thermal conductivity (K) of the samples, a Lee's Disk device manufactured by Griffen & George was used. Using the relationships 2 and 3 a value of (K) is determined.

Solutions Absorption: The mass of each sample was determined before immersion using a sensitive electronic balance (Type Denver) with a degree of sensitivity of 0.0001gm, after which the samples were submerged in kerosene and acid (H_2SO_4) and at room temperature. After certain periods of time of periodic immersion, the sample mass was determined, then the percentage change of weight gain W.G % was calculated using eq.4, and the relationship between the mass gain and the square root of time ($\sqrt{T}$) graph.

3. RESULTS AND DISCUSSION

3.1.Impact Strength

Table 1 and figures 1 & 2 show the impact strength values of the polymeric blend samples and composites. In normal conditions and at room temperature, the highest value of impact strength was for the unsupported polymeric blend sample (9.737 kJ/m^2) due to the polymeric chains possess freedom of movement and thus absorb a greater amount of energy before the fracture and this gives it a greater impact strength. As for the samples of the composite material, they had less resistance, the reason for this is that adding the ceramic particles have gained the material brittility because the particles themselves can be points for the concentration of stresses and sites for initiation of fine cracks and their diffusion within the composite material, thus, they reduce the resistance of the material to high speed shocks [4]. After immersion in kerosene and H_2SO_4 acid solutions, it was noted that the impact resistance decreased, in general of all samples, the reason for this is that the diffusion of chemical solutions leads to the occurrence of plasticity for the polymer as a result of the breaking of the hydrogen bonds between the polymeric chains. Hence, the loss of the material to its ductility attributes makes it in a state of brittleness (Embrittlement), which leads to a decrease in impact resistance, such a transformation occurs as a result of decomposition due to wet environmental conditions [8].

Table 1:Impact strength before and after immersion in kerosene & acid

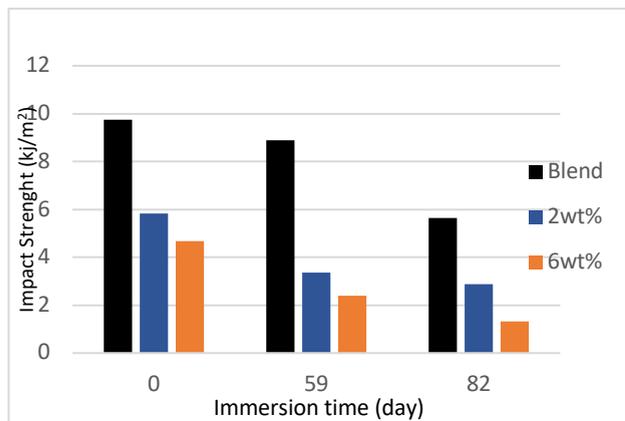| Impact Strength (kJ/m^2)					
Immersion time(day)	Kerosene			H_2SO_4		
	Blend	2wt%	6wt%	Blend	2wt%	6wt%
0	9.737	5.823	4.675	9.737	6.822	3.675
59	8.876	3.359	2.398	9.097	5.823	2.057
82	5.635	2.872	1.329	4.314	3.721	1.218

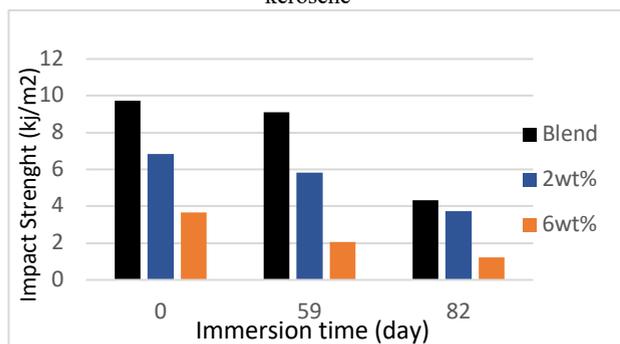Fig. 1: variation of impact strength vs immersion time in kerosene

Fig. 2:variation of impact strength vs immersion time in H2SO4

3.2. Surface Hardness

It was noted from figures 3 and 4 that adding the ceramic powder to the polymeric blend has increased the surface hardness proportionally to the addition ratio, where the hardness of 6 wt % was the highest and lowest was for the polymeric blend [9]. After immersing the samples of polymeric blend and its composites in the kerosene and acid solutions, the hardness values began to decrease in general and in proportion to the length of the immersion time, the reason for this is that the solution of kerosene is an organic solvent, so a physical or chemical interference occurs with the polymer blend particles or PZT powder atoms, and this interference may weaken the polymer chains bond (weakens the crystalline network bond energy), thereby reducing the material's strength and this results in weakening the surface hardness of the material [10]. On the other hand, the acid penetrates into the material and leads to a break in the bonds between the polymeric chains, where in corrosive solutions it leads to an increase in porosity, so the acid absorption of the substance increases, and this leads to an increase in the softness of the material. Generally,

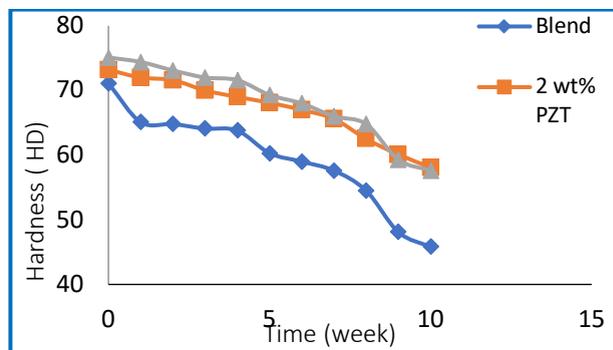increasing of immersion time increases the negative effects in most material properties [7].

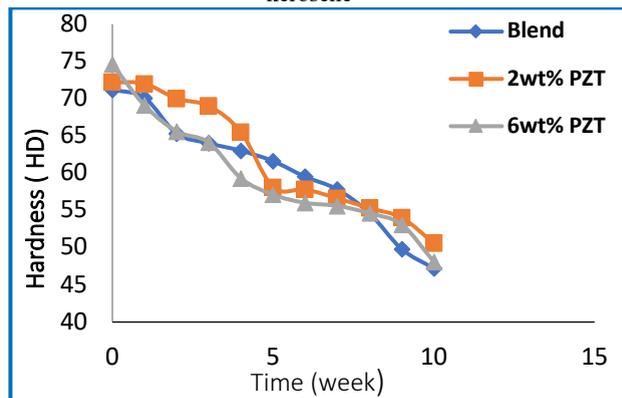Fig. 3: variation of surface hardness vs immersion time in kerosene

Fig. 4: variation of surface hardness vs immersion time in H_2SO_4.

3.3. Thermal Conductivity

Polymers are considered poor heat conductors and have a weak thermal conductivity coefficient. This is what has been observed in tests of the research samples, Phonons are the only heat carrier in them. Figures 5 and 6 show the values of the coefficient of thermal conductivity K increased after immersion in the kerosene and acid, proportionally with the time of immersion. The increase in K values for the composites was higher than in the polymeric blend, because the ceramic powders have a higher thermal conductivity than the polymers, moreover, the entry and dispersion of solutions in the composite material leads to weakening the bond of the polymer chains and thus increasing the freedom of movement of the phonons responsible for the transfer of heat energy of these materials. The chemical solutions work to break the bonds between the polymeric chains, which leads to the failure of the material and thus the increase in the coefficient of thermal conductivity in general [8]. In the

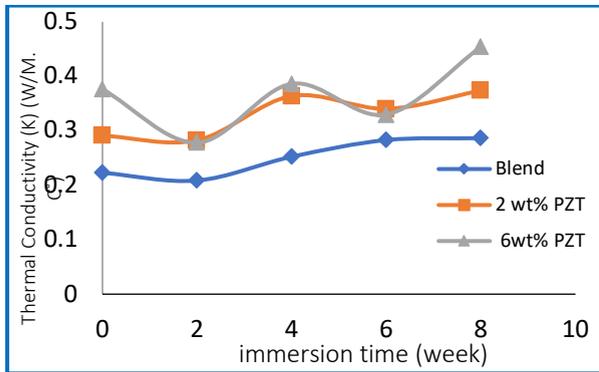eighth week, the increase in K values was the greatest in general and especially in kerosene.

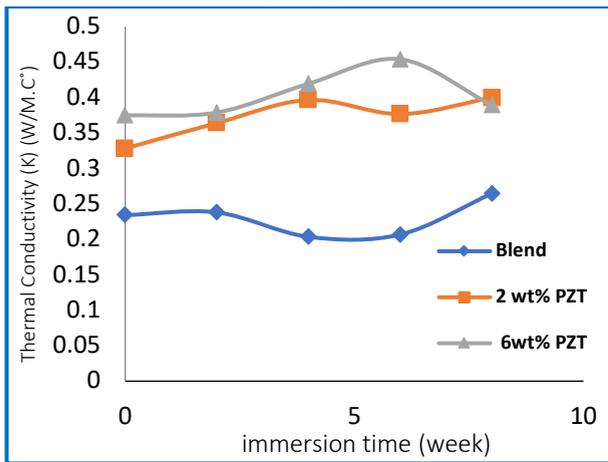Fig. 5: variation of thermal conductivity vs immersion time in kerosene

Fig. 6: variation of thermal conductivity vs immersion time in H_2SO

3.4. Absorbance

Figures 7 and 8 show the diffusion of solutions in all samples in varying proportions. In the case of kerosene, it is noted that the substance began to dissolve in the last two weeks, which means that the substance has reached the state of degradation. Ceramic materials are characterized by their having many interstitial pores and that the acid permeability is higher than kerosene because of high molecular weight of kerosene which makes its penetration inside the material slow and its effect on the surface of the material high [10]. We conclude from the above that the effect of acid and kerosene solutions is very important as it causes the weakening of the matrix material throughout the length of exposure to immersion, and that the diffusion of solutions leads to changes in the substance such as plasticizing and cracking [11].
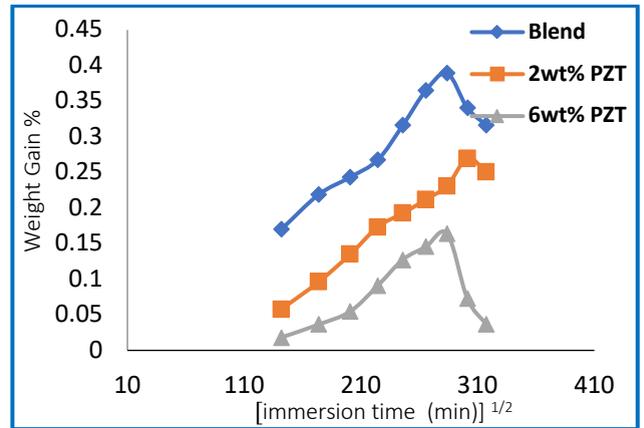

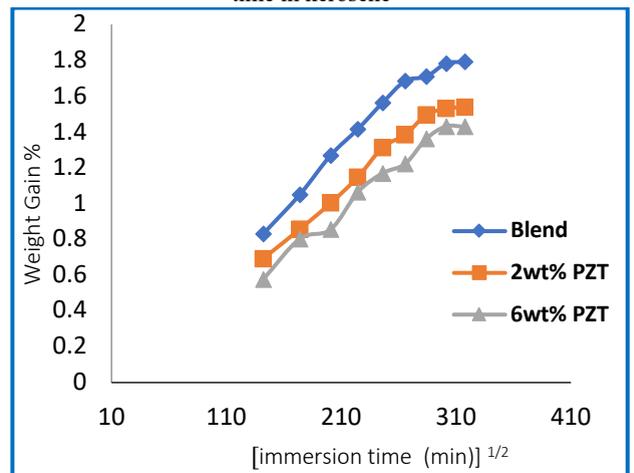Fig. 7: weight Gain percentage vs square root of immersion time in kerosene

Fig. 8:weight Gain percentage vs square root of immersion time in H_2SO_4

4. CONCLUSIONS

From the results obtained, the following can be concluded; Supporting the polymeric blend with PZT nanoceramic powder increases the surface hardness of the composite material but reduces its resistance to impact. The thermal conductivity of the composite material increases when reinforced with nanoceramic powders. The absorbance of the polymeric composite materials to solutions increases with increasing the percentage of ceramic powders addition wt % .

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دراسة الخواص الميكانيكية والتوصيل الحراري لمتراكبات بوليمر/ سيراميك النانوية

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الخلاصة

تم تحضير مواد متراكبة باستخدام خليط بوليمري من راتنج الايبوكسي والبولي استر غير المشبع كمادة اساس واستخدم المسحوق السيراميكي النانوي تيتانات زركونيوم الرصاص كمادة تدعيم وبنسب اضافة مختلفة .أجريت لعينات الخليط البوليمري والمتراكبات فحوصات متانة الصدمة ، صلادة السطح ، التوصيلية الحرارية وامتصاص المحاليل . أظهرت النتائج قبل الغمر ان اضافة المسحوق السيراميكي الى الخليط البوليمري يحسن من صلادة السطح ويزيد التوصيل الحراري بينما تناقصت متانة الصدمة . ادى غمر العينات في حامض الكبريتيك والكيروسين الى تناقص متانة الصدمة وصلادة السطح وزاد التوصيلية الحرارية ، كما لوحظ ان نسبة امتصاص محلولي الحامض والكيروسين تزداد بشكل يتناسب مع فترة الغمر .

الكلمات المفتاحية: خليط بوليمري , ايبوكسي , بولي استر , Kerosene , PZT, H2SO4 , الميكانيكي , الحراري.