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Effect of Volume Fraction and Solutions Absorption on The Properties of Epoxy/Carbon Fiber Composites

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A R T I C L E I N F O

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A B S T R A C T

The objective of this research is to study the effect of volume fraction of short carbon fibers, distilled water and diluted HCl on the mechanical properties of the composite material, and determine the diffusion coefficient. The composite material was prepared from the epoxy resin as a matrix material and the short carbon fibers as a reinforcing material at volume fractions of 3%, 5% and 7%, respectively. Bending strength, Tensile strength and Absorption Tests were carried out on the samples of the composites .The results showed that adding carbon fibers to the polymer has increased the composite material strength and consequently raised the elasticity coefficient and the tensile strength proportionally with the volume fraction. Moreover, the results showed that immersing the samples in water and acid decreased the elasticity coefficient and tensile resistance in a manner proportional to the duration of immersion, whereby the effect of acid was greater than that of water.

1. INTRODUCTION

The large scientific and technological development has required the need to find new materials to replace metals and alloys. These new materials should have the specifications of light weight, high strength, and other good features such as thermal and electrical insolation, in addition to their resistance to various environmental conditions in order to be suitable for civil and military industrial uses. These materials are called Composite Materials [1]. Composite materials consist of the matrix material, which represents the continuous phase, and reinforcement material {Reinforcement Phase} which stands most of the stress applied on the composite material, leading to improve its mechanical properties. The third phase is the interface region located between the matrix and reinforcement material [2]. Carbon fibers are widely used to reinforce the composite materials because of their properties of strength, high durability, high stability in high temperatures, resistance to chemical solutions and weather conditions. Their use in reinforcement will increase the bending strength, tensile resistance, and impact strength of the composite material, consequently improving its general mechanical properties and making it a good industrial material [3]. The composite material resistance for the applied stress mainly depends on the elasticity modulus and the strength of the reinforcement fibers. The amount of reinforcement fibers in the composite material is known by the volume fraction [4]. The bending resistance of the material is its ability to endure the vertically applied bending forces on its longitudinal axis. The stress resulting from applying the bending load combines two types of stress, compression and tensile stress, as shown in figure1[5].

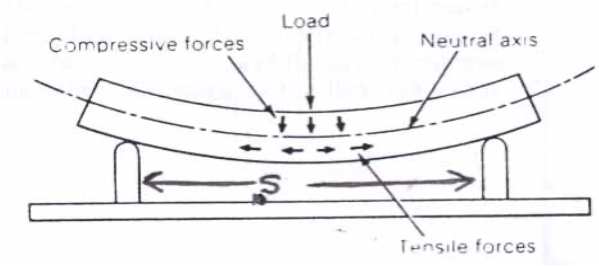

Fig.1: Analysis of effective forces on bending a simple lever.

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The maximum stress in the three points bending test which is applied on the middle of the sample can be calculated for any point on the bending curve by the torque relationship as in eq.1:

$$I = \frac{1}{12}bd^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where :

I : geometrical bending momentum (mm^4)
b : width of the sample (mm)
d : thickness of the sample (mm)

Modulus of elasticity can be determined in the three points loading system as in eq. 2:

$$E = \frac{MgL3}{48\,IS} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

E: young modulus (N/mm^2).

Mg/S: slope of primary graph straight line (Elasticity region).

L: distance between two loading point (mm).

S: deflection (mm).

Tensile test is one of the important mechanical tests for the composite materials in order to determine their geometric properties. From this test, modulus of elasticity, ductility, strain, yield point and strength of material can be estimated. There are several factors which can affect the tensile test including temperature, speed of test and degree of crosslinking[6].

Tensile strength of composite material is calculated using eq.3:

$$T.S = \frac{F_{max.}}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

T.S: tensile strength (N/m^2)
F_{max}: max. load applied at fracture (N)
A: cross section area of the sample at the fracture point (mm^2)

Polymers have the ability to absorb solutions compared with metals and ceramics. According to first Fick,s law, the amount of absorbed solution will increase linearly with the square root of immersion time, gradually and slowly until reaching the saturation state [7].

$$F_x = - D \frac{dc}{dx} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where:

F_x : flux of molecules (molc./ cm^2 .sec)
D: diffusion coefficient
dc / dx: concentration gradient

Liquid molecules pass through the composite material by direct diffusion or through the interface region between the polymer and fibers or through the cracks originally existing in the material and in the weak bonded area between the matrix and reinforcement material. Water causes swelling and raises stress in the composite material with changes inside the material such as plasticization, cracking and crazing, or hydrolysis [8], while the acid will break the bonds between polymer chains [9]. The percentage of absorbency (the weight Gain %) can be calculated from eq. 5 :

$$W.G\ \% = \left(\frac{m - m_0}{m_0}\right) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

Where :

W.G % : percentage of absorption(the weight gain)
m_0 : mass of sample before immersion (gm)
m : mass of sample after immersion (gm)

The ability of composite material to absorb solutions depends on the type of the resin, nature of solution, its temperature, and time of immersion. The second Fick's law describes the unstable diffusion state when the concentration changes with time. Diffusion coefficient can be calculated from the graphic relationship between the weight gain and the square root of time as in eq. 6 :

$$D = \pi \left(\frac{kd}{4M_\infty}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where:

K: slope of the linear part of elasticity region
M_∞: max. value of W.G

2. MATERIALS AND METHODS

2.1.Sample preparation: The sample of composites was prepared using Epoxy resin type (polyprime –EP, it is a thermoset polymer) as a matrix material and short carbon fibers as a reinforcement material with volume fractions of 3% ,5% and 7% respectively, and using a hand lay – up molding method.

2.2.Bending Test: Three point bending test was used from the graphic relationship between deviation average S and mass M where M/S represents the slope at elasticity region. Modulus of elasticity of the composite material can be calculated using eqs .1 & 2.

2.3.Tensile Test: In this test, the instron – H22 was used (ASTM –D 638-78), the samples were tested before the immersion in distilled water and diluted in HCL (0.5 N) for 12 weeks in both tensile and bending test.

2.4. Solutions absorption: The sample was weighted before and after immersion in water HCl solution, and by using

eq.6, the percentage of absorption W.G % was determined periodically by the relationship drawn between W.G% & $\sqrt{time}$ and the determination of the slope curve tangent in the elasticity region, and by using eq.7, the diffusion coefficient was calculated .

3. RESULTS AND DISCUSSION

Before immersion, it is noticed from figures (2 & 3) that modulus of elasticity (E) of the composite material increase by adding carbon fibers to the epoxy resin and the increase is proportional to the increase of the volume fraction. The higher value of (E) was for the sample of volume fraction 7 % and the least value was for the sample of volume fraction 3 % .This was due to the high strength of the carbon fibers, whereby the biggest applied stress on the composite material was generated by the carbon fibers [10]. After immersion in water and acid, a decrease of values of (E) was noticed and this decrease will continue with the length of immersion time. This happens in the case of acid more than in the case of water. The immersion has led to the penetration of water and acid through the polymer, particularly through vacancies created during the manufacturing process, and consequently the growth of vacancies between fiber bands caused swelling in the composite material. The continuation of immersion for long periods of time led to weakening the bonding forces between molecule chains accompanied with high strain rates which led to decreasing (E) as the matrix (the polymer) becomes resilient [11].

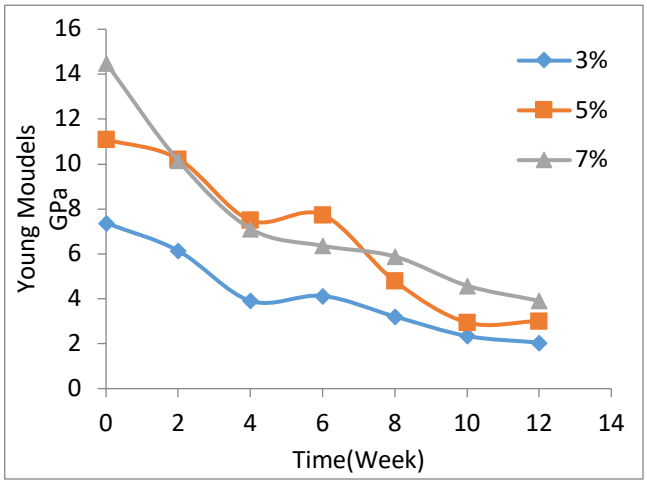

Fig.2: Variation of young modulus VS time of immersion in H_2O

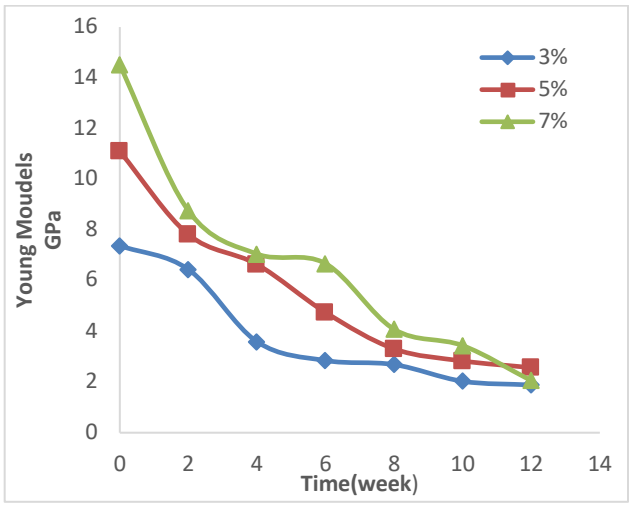

Fig.3: Variation of young modulus VS time of immersion in HCl

Figures 4 & 5 show that the sample of volume fraction 7% before immersion had the highest tensile strength (14.49 MPa) due to the fact that carbon fibers have a high tensile strength (3800 MPa), while the lowest tensile strength was for the sample of volume fraction 3 % (5.894 MPa), and the sample of volume fraction 5 % had a tensile strength of (12.65 MPa). On the other hand, the tensile strength of all samples decreased after immersion in water and acid.

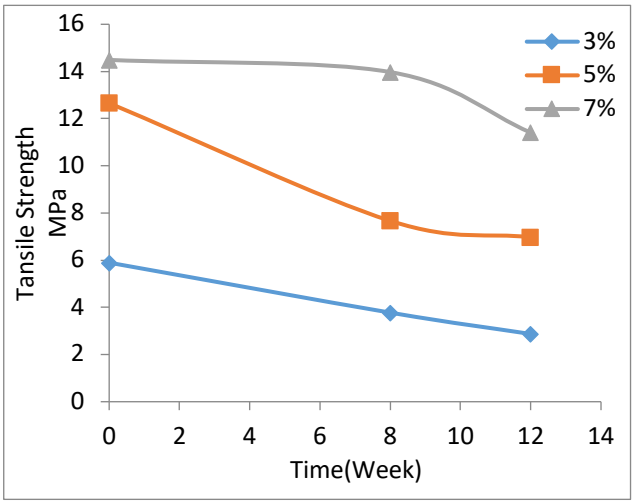

Fig.4: Variation of tensile strength VS time of immersion in H2 O

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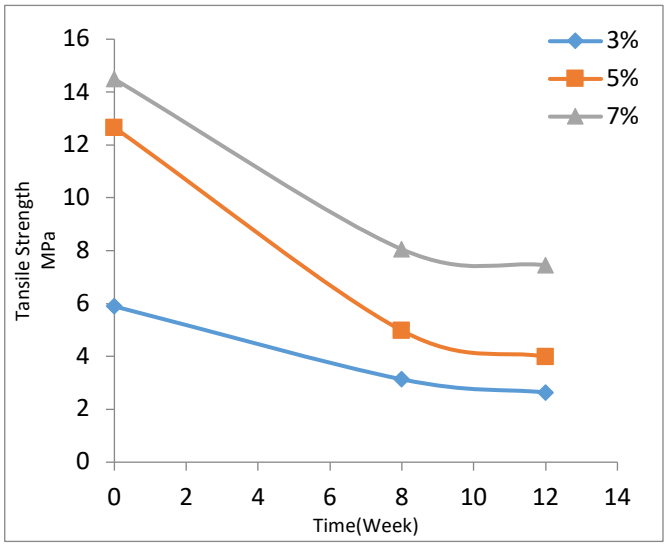

Fig.5: Variation of tensile strength VS time of immersion in HCl

Exposing the sample to immersion will affect the cohesion of the material surface molecules, whereby the effect of acid was greater than that of water because the acid is an aggressive material which affects the bonds between polymer chains in the bonding force between the matrix and the reinforcement fibers. On the other hand, the penetration of water and acid in the composite material will lead to the growth of cracks with the length of immersion period making bigger cracks [11,12].

Figures 6 & 7 show that the sample of volume fraction 3% had the highest absorption of solutions, while the sample of 7% had the lowest absorption. The adhesion between carbon fibers and the polymer depends on the ratio of fiber additive to the polymer (volume fraction)[9]. In the case of 3% volume fraction, the adhesion is weak and the voids increase and therefore the swelling increases. As a result, the permeability of the solutions increases. This leads to the spacing of polymer chains, while in case of 7% volume fraction sample, the adhesion is higher, the swelling is less, the interface region is reduced and the solutions are less effective in the composite material. The permeability of distilled water is higher than the acid because water causes hydrolysis between the polymer bonds [13]. Figure 8 shows the diffusion coefficient values of the composite samples in this study.

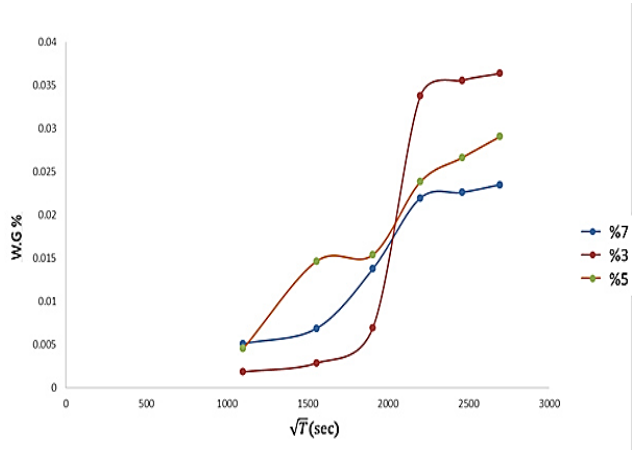

Fig.6: The Weight gain % VS Square root of time of immersion in H_2O

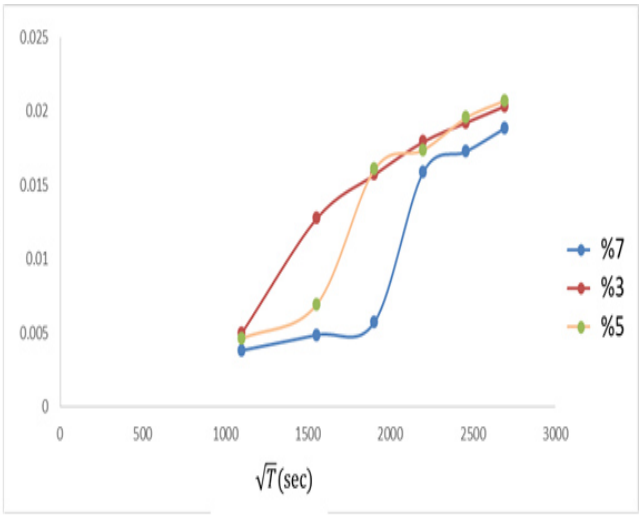

Fig.7: The Weight gain % VS Square root of time of immersion in HCl

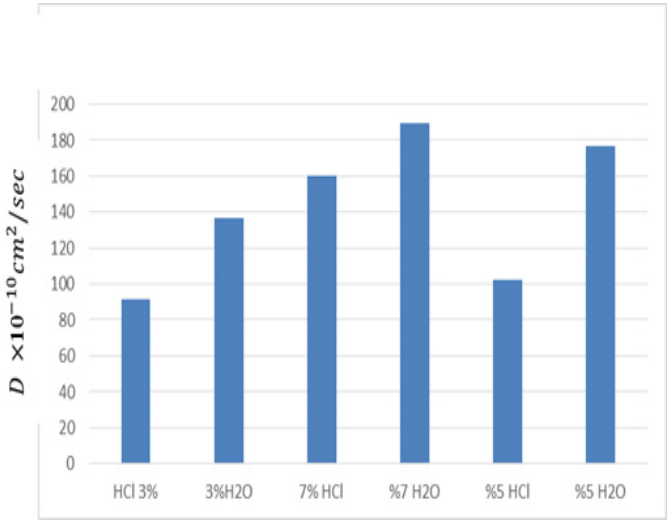

Fig.8: Values of diffusion coefficient in H_2O and HCl

4. CONCLUSIONS

1- Adding carbon fibers to the polymer improves the strength, consequently rising the elasticity modulus and tensile strength in a manner proportional to the volume fraction.
2- Exposing the composite material to water and acid negatively affects its properties in a manner proportional to the time of immersion.
3- Penetration of solutions in composite material decreases with the increase in the volume fraction of the carbon fibers.
4- The effect of solutions on the properties of composite material depends on the length of immersion period.

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تأثير الكسر الحجمي وامتصاص المحاليل على خصائص متراكبات الايبوكسي/الياف كاربون

(Epoxy/Carbon fibers)

احمد حماد مناجد الفلاحي و علي خلف عبيد و وائل ابراهيم احمد
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الخلاصة:

يهدف البحث الى دراسة تأثير الكسر الحجمي لألياف الكربون القصيرة وامتصاص الماء المقطر وحامض HCl المخفف في الخواص الميكانيكية للمادة المتراكبة وتعيين معامل الانتشار. تم تحضير المادة المتراكبة من راتنج الايبوكسي كمادة اساس والياف الكربون القصيرة كمادة تدعيم وبكسور حجمية 3%، 5% و7%. اجريت لنماذج المتراكبات فحوصات متانة الانحناء، مقاومة الشد، والامتصاصية وتعيين معامل الانتشار. اظهرت النتائج ان اظافة الياف الكربون الى البوليمرزادت متانة المادة المتراكبة وبالتالي زيادة معامل المرونة، وأن مقاومة الشد تتناسب مع مقدار الكسر الحجمي، من جهة أخرى بينت النتائج ان غمر المادة المتراكبة في الماء والحامض سبب تناقص معامل المرونة ومقاومة الشد بصورة تتناسب مع فترة الغمر، بينما كان تأثير الحامض اكبرمن الماء.

الكلمات المفتاحية: *الكسر الحجمي، الايبوكسي، الياف الكربون، الخواص الميكانيكية، الامتصاصية، المادة المتراكبة.*