Effect of Water on Bending Strength for Epoxy Reinforced with Particles by Using Cantilever Bending Test.

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ABSTRACT.

This research includes the study of bending strength for the polymer composite materials. The first of all, the hand lay-up technology is used to prepare slates of the composite materials, epoxy resin was used as matrix for the reinforced materials that consist of artificial powders (aluminum oxide and copper) for reinforcing. The slates made of composite materials for both volume fractions 20% and 40% from the reinforced materials; all these slates were cut into samples with measurement (10x 100 mm) in order to carry out the bending strength test for samples by using cantilever bending test for both volume fractions 20% and 40%.

The results and laboratory examinations for these samples shows increase in the bending strength and modulus of elasticity for composite materials when the volume fraction increase from 20% to 40% for reinforced materials, and these values decrease when the samples were immersion in distilled water for (30) days.

Key words: Polymer, Epoxy, Composite materials, bending strength.

1. INTRODUCTION.

About 30% of all polymers produced each year are used in the civil engineering and building industries. Polymer offer many advantages over conventional materials including lightness resilience to corrosion and ease of processing. They can be combined with fibers or particles to form composite materials which have enhanced properties. Theoretically, any material that is not a pure substance and contains more than one component, may be classified among the composite materials, enabling them to be used as structural members and units polymer composites can be used in many different forms ranging form structural composites in the construction industry to the high technology composites of the aerospace and space satellite industries. Polymer composites were first developed during the 1940's, for military and aerospace applications. Particles- reinforced plastics have been used in many other applications including pressure pipes, tank liners and roofs. In the last decade, polymer composites have found application in the construction sector in areas such as bridge repair, bridge design, mooring cables, structural strengthening, and stand-alone components [1-3]. In polymer composites, the matrix may be thermoplastic or thermoset materials. Epoxy resin is thermoset materials, there are a varicly of hardeners or curing a gents generally used for epoxy resins. The amine type compounds are often used in structural application. The hardening effect is achieved through the formation of cross-links between the resin polymer chain and the hardener, or by directs linkage among the epoxy groups [4, 5]. Reinforced plastics based on epoxy resins have better mechanical strength, chemical resistance, electrical insulating properties and environmental stability than those made with conventional unsaturated polyester [6- 10].

Particle filled polymer composites have become attractive because of their wide applications and low cost. Incorporating inorganic mineral fillers into plastic resin improves various physical properties of the materials such as mechanical strength, modulus of elasticity and thermal stability. In general, the mechanical properties of particulate filled polymer composites depend strongly on size, shape and distribution of filler particles in the matrix polymer and a good adhesion at the interface surface [11].

For most composites, the particulate phase is harder and stiffer than the matrix. In essence, the matrix transfers some of the applied stress to the particles, which bear a fraction of the load. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix –particle interface. For effective reinforcement, the particles should be small, evenly distributed throughout the polymer matrix, and must form a strong adhesive bond with the matrix [12].

2. FLEXURAL PROPERTIES.

The stress- strain behavior of polymer in flexure is of interest to a designer as well as a polymer manufacturer. Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. The stresses induced due to the flexural load are a combination of compressive and tensile stresses; this effect is illustrated in **fig. (1)**. Flexural properties are repor-ted and calculated in terms of the maximum stress and strain that occur at the outside surface of the test bar. Many polymers do not break under flexure even after a large deflection that makes determination of the ultimate flexural strength impractical for many polymers. In such cases, the common practice is to report flexural yield strength when the maximum strain in the outer fiber of the specimen has reach five percent. For polymeric materials that break easily under flexural load, the specimen is deflected until a rupture occurs in the outer fibers. The beam is typically $(\frac{1}{8} x \ \frac{1}{2} x \ 4)$ inches, although this size can vary from different materials [13].

There are three basic methods that cover the determination of flexural properties of plastics. Method (1) is a three- point loading system utilizing center loading on a simple supported beam as shown in **fig. (1)**. Method (2) is four- point loading system utilizing two load points equally spaced from their adjacent support one- third of the support span.

In this method, the test bar rests on two supports and is loaded at two points, each on equal distance from the adjacent support point. Method (3) is two- point cantilever loading system is illustrated in **fig.(2)**. For the cantilevered specimen, the maximum tensile stress develops on the occlusal surface or the surface that is becoming more convex, the upper surface became more convex or stretched (tensile region) and the opposite becomes compressed [14, 15].

The bending modulus (E_b) from method (3) is determined by using the following [16]:

$$E_b = \frac{4l^3}{wh^3} \ x \ \frac{F}{D} \quad (1)$$

Where (l) is length, (w) is width, (h) is thickness and (D) is the deflection of specimens respectively, so that (F) is the applied load.

3. INFLUENCE OF WATER ON COMPOSITES.

Water enters the composite by diffusion through the resin and by capillary action along the fiber matrix interface. The surface damage and cracks produced as a result of weathering further facilitate the entrance of water. The effect of water on the resin which causes swelling and plasticization- hydrolysis of resin is not considered to be an important process under the conditions encountered outdoors. In the epoxies there are three important functional groups which can associate with water; the hydroxyl groups formed when curing agents add across epoxide groups, the phenelin ether groups which are present in all bisphenol A or novolac based resins and the amino groups of the curing agents. The weight gain in a specimen was expressed as a percentage of the original dry weight using formula [17]:

$$M = \frac{(W_{wet} - W_{dry})}{W_{dry}} \times 100\% \qquad (2)$$

Where (M) is the percentage weight gain or loss after a time (t), (W_{dry}) is the original dry weight of the specimen and (W_{wet}) is the weight of the specimen after a time (t).

4. EXPERIMENTAL PROCEDURE.

Epoxy resin was used to fabricate the samples and the hardener material was added in order to solid it. This mixture are used to made the matrix, more over synthetic aluminum oxide and copper powder were used in order to reinforce the matrix to produce composite materials which are ready for bending test. Hand lay-up was used to produce the slates of composite materials. We reinforced the resin by aluminum oxide and copper powder with different volume fractions like 20% and also 40%. All these slates were cut into samples with the dimensions of (100 mm) for the length, (10 mm) for the width and (2.5 mm) for the thickness in order to carried out the bending strength test for both volume fractions 20% and 40%. **Fig. (3)** shows bending test samples.

5. RESULT AND DISCUSSION.

Bending test for dry samples.

In this test, the tests were carried out both volume fractions 20% and 40% on dry specimens with length of the test piece shall be equal to the distance between the supports plus (80 mm). Macroscopic examinations of the specimens showed that increasing in the deflections when the applied loads on the specimens increase as shown in the **tables (1, 2)** and **figs.(4,5)**. that because most of polymer materials specially epoxy having long molecular chains which cross linked with each other when it become hard. The resistance of these materials depends on direction, regularity and cross linkage degree for molecular chains. The external forces play active role in the effect on cross linkage chains strength. Applied the external load on epoxy materials will effect on nature and direction the cross linkage polymer chains and that causing broken the polymer chains when high loads applied.

Moreover, when the external loads increase, the deflection increase too and that depend on longitudinal the chains clearly, on the other hand the applied load on the samples cause applied inner stress on the molecules chains for polymer materials. The increase in the applied loads cause increase the effect range for tension and compression forces, that will accelerate formation of primary cracks in polymers because the high increasing in the inner energy, so the collapse occur in the samples have thermal inconstancies energy higher than chemical bonds energy.

Furthermore the epoxy specimens reinfo-rced with copper and aluminum oxide powders for both volume fractions 20% and 40% have deflections less than unreinforced specimens at the same loads as shown in **table (2).** That is, the reinforced samples have elasticity less than the elasticity of the unreinforced samples, because of nature, shape and size of copper and aluminum oxide powder molecules. So that the cross linkage process between powder and polymer materials will be high and that lead to the specimens elasticity will be little for both volume fractions 20% and 40%. The flexibility will decrease and modulus of elasticity increase in these specimens when reinforced materials ratio increase from 20% to 40% as shown in **table (3)**.

Influence of water on specimens.

In order to study the influence of water on the properties of particles reinforced epoxy resins, test specimens were immersed in distilled water for 30 days. The tests were carried out for both volume fractions 20% and 40% of wet specimens with length of the test piece shall be equal to the distance between the supports plus (80 mm). At the same time, the water absorption of the specimens was determined from the **figs. (6, 7, and 8)**.

Absorption test of the immersed samples in distilled water was carried out in laboratory temperature, the **figs.(6, 7, and 8)** shows that all samples (reinforced and unreinforced samples) are increased in weight at immersion start in distilled water for both volume fractions 20% and 40%. From the figures, notice that the weight increases until it reaches to constant value, which means that the samples will reach to the saturation state. The samples differ in the saturation state and that depend on several factors such as matrix type, the reinforced materials, water temperature, the immersion time and the volume fractions for reinforced materials. The absorbed water has negative effect on the mechanical behavior for the composite materials with polymer base as shown in **tables (4 and 5)**. Water causes decreasing in the mechanical properties values because of weak bonds between the matrix and the reinforced particles.

The diffusion coefficient independent of time and moisture concentration can be calculating from the Fickian diffusion curves **(figs. 6, 7, and 8)**. The diffusion coefficient (*D*) is determined from the initial linear region of the Fickian diffusion curve using the following [18, 19]:

$$D = \frac{\pi}{16}\left(\frac{h(M_2 - M_1)}{M_\infty(\sqrt{t_2} - \sqrt{t_1})}\right)^2 \qquad (3)$$

Where (M_∞) is the equilibrium moisture concentration (or content), (M_1) is the moisture uptake after time (t_1), (M_2) is the moisture uptake after time (t_2) and (h) is the thickness.

The influence of water on deflections and modulus of elasticity are shown by **figs. (9, 10)**, the values after (30) days immersion in distilled water are additionally listed in **tables (4,5)**.

It is observed from the **figs. (9, 10)**, the results in **table (4)** and laboratory examinations the flexibility for immersed samples in distilled water for both volume fractions 20% and 40% for (30) days higher than the flexibility for dry samples.

Notice that, the deflections of the immersed samples in distilled water are higher than the deflections of dry samples with the same applied loads. That is because water molecules diffuse into the polymer samples and centering among the polymer chains and that causes swelling of the samples. Moreover water causes to increase the movement of the polymer chains because water works as a lubricant among the polymer chains and that facilitate its movement, so that the modulus of elasticity for immersed samples in distilled water are lower than the modulus of elasticity for dry samples.

6. CONCLUSION.

The main conclusions of this work can be summarized as follows:

1- The epoxy resin is a good adhesive material which can use as a binder.
2- Increasing in the deflections when the applied loads on the specimens increase for both volume fractions 20% and 40%.
3- Reinforcing the epoxy with particles would lead to a dramatic increase in mechanical properties, such as bending strength and modulus of elasticity.
4- Increasing in the deflections of specimens when immersion it in distilled water for (30) days.

5- Increasing in modulus of elasticity for samples when the volume fractions increase.
6- The flexibility for all samples increases when the samples are immersed in the distilled water for (30) days because of absorption of water.
7- The modulus of elasticity for immersed samples in distilled water is lower than the modulus of elasticity for dry samples.
8- Increase in distilled water absorption for samples when the volume fractions for reinforced materials increase from 20% to 40%.

7. REFERENCE.

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Table (1): shows load and deflection of dry and wet unreinforced (EP) samples.

Load (N)	***Deflection of EP samples (mm)***	
	Dry EP sample	***Wet EP sample***
1	1.05	1.23
2	2.21	2.79
3	3.19	3.70
4	4.58	4.88
5	5.33	6.26
6	6.54	7.21
7	7.19	8.81
8	8.51	10.0

Table (2): shows load and deflection of dry samples for both volume fractions.

Load (N)	***Deflection of dry samples (mm)***			
	EPCu sample (V_f=20%)	***EPCu sample (V_f=40%)***	***EPAl sample (V_f=20%)***	***EPAl sample (V_f=40%)***
1	0.97	0.82	0.79	0.49
2	1.94	1.66	1.68	1.22
3	2.73	2.43	2.35	1.83
4	3.90	3.25	3.13	2.4
5	4.98	4.15	3.91	3.12
6	5.81	4.87	4.73	3.58
7	6.76	5.46	5.36	4.19
8	7.80	6.57	6.30	4.80

Table (3): shows bending modulus of dry sample for both volume fractions.

Samples	*Volume fraction %*	*Bending modulus (E_b) (GPa)*
EP	---	12.386
EPCu	20%	13.408
EPCu	40%	16.240
EPAl	20%	16.869
EPAl	40%	21.627

Table (4): shows the load and deflection of wet specimens for both volume fractions.

Load (N)	*Deflection of wet samples (mm)*			
	EPCu sample (V_f=20%)	*EPCu sample (V_f=40%)*	*EPAl sample (V_f=20%)*	*EPAl sample (V_f=40%)*
1	1.25	1.05	1.34	1.27
2	2.23	2.10	2.67	2.26
3	3.37	3.14	4.20	3.38
4	4.50	4.18	5.42	4.50
5	5.51	5.16	6.73	5.65
6	6.78	6.38	8.16	6.78
7	7.85	7.31	9.44	8.05
8	9.00	8.40	10.95	9.15

Table (5): the weight gain, diffusion coefficient and bending modulus for immersion specimens in distilled water for (30) days.

Samples	*Volume fraction %*	*Weight gain (M %)*	*Diffusion coefficient (D) $m^2.sec^{-1}$ $x10^{-12}$*	*Bending modulus (E_b) (GPa)*
EP	---	1.41586	1.0107	10.577
EPCu	20%	1.32752	0.9810	11.717
EPCu	40%	1.02396	0.7849	12.478
EPAl	20%	1.65232	0.7826	9.633
EPAl	40%	1.37201	0.9412	11.508

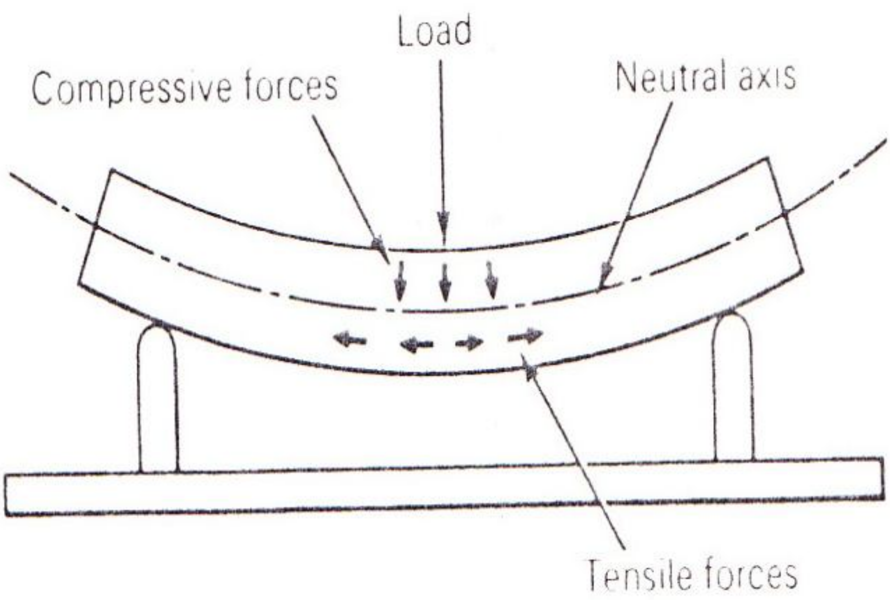

Figure (1): forces involved in bending a simple beam [13].

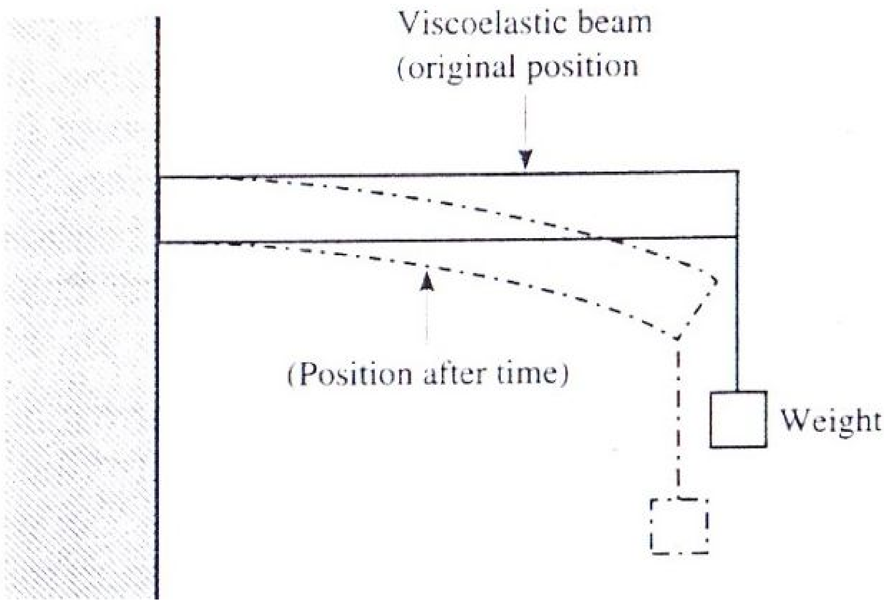

Figure (2): two- point cantilever loading system [15].

Figure (3): bending test samples.

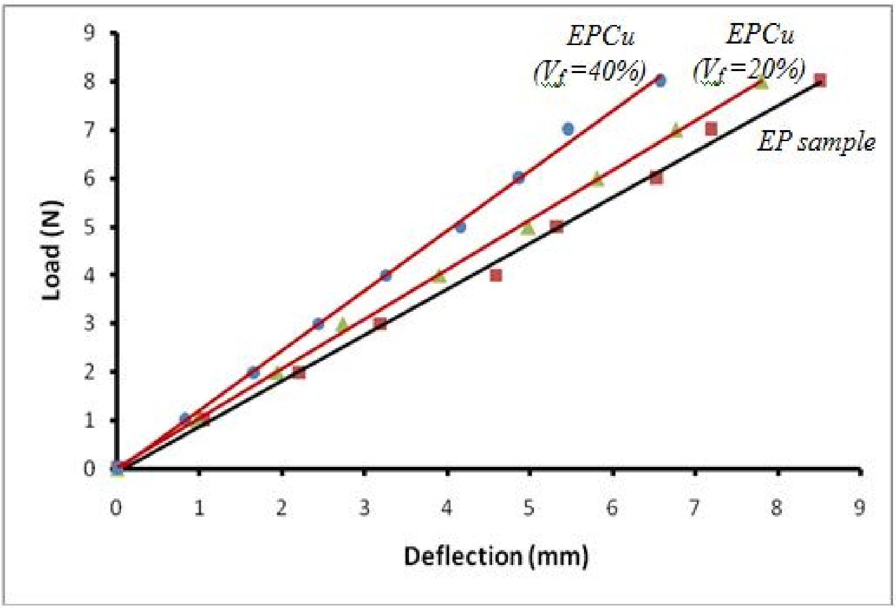

Figure (4): shows load versus deflection for dry (EP and EPCu) samples**.**

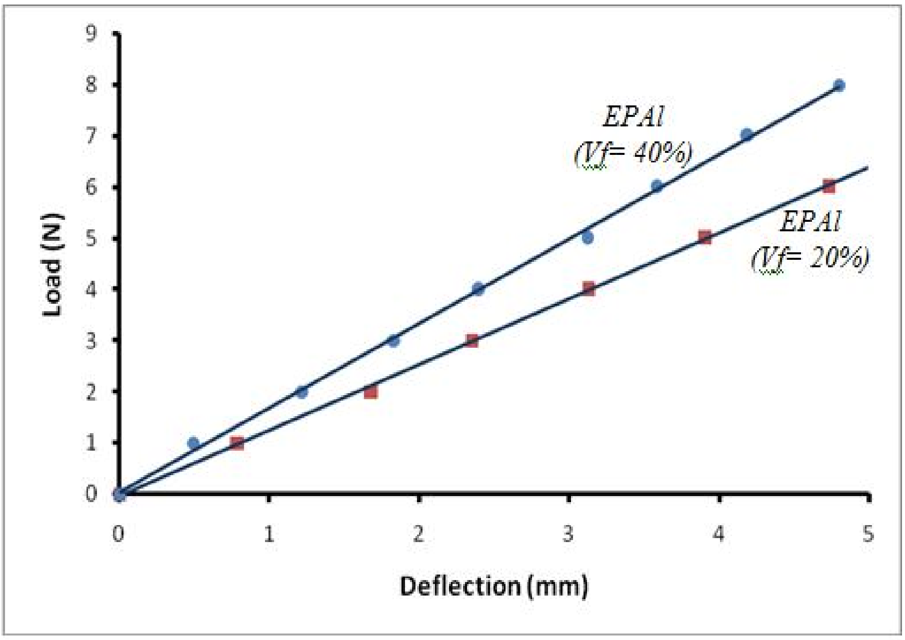

Figure (5): shows load versus deflection for dry (EPAl) samples.

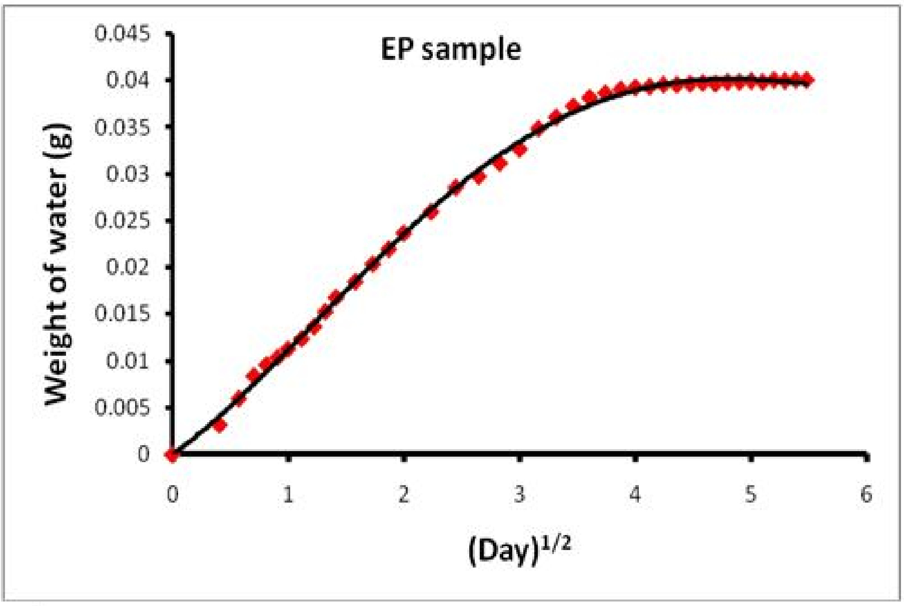

Figure (6): shown absorption curve for wet unreinforced epoxy sample.

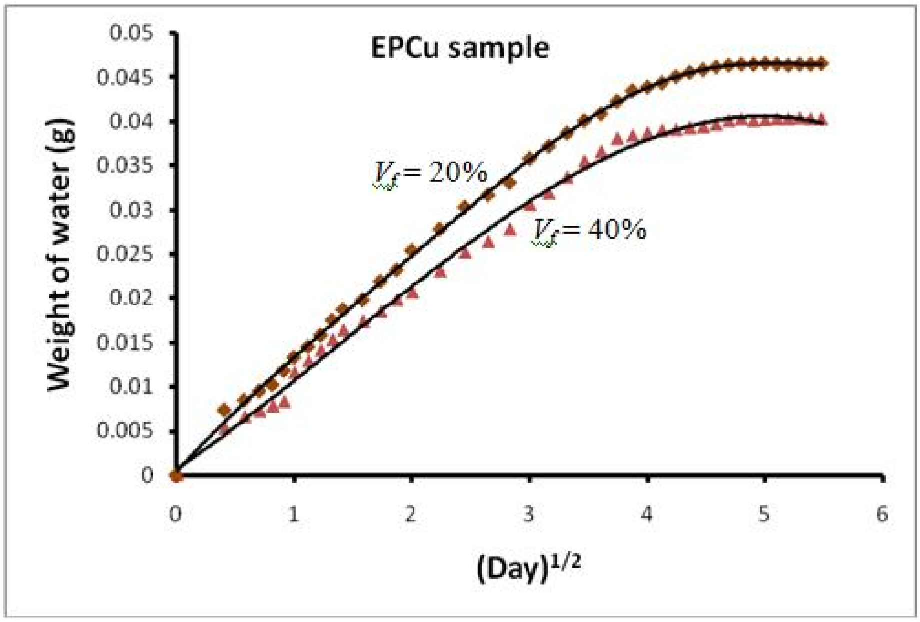

Figure (7): shown absorption curve for wet (EPCu) samples for both volume fractions 20% and 40%.

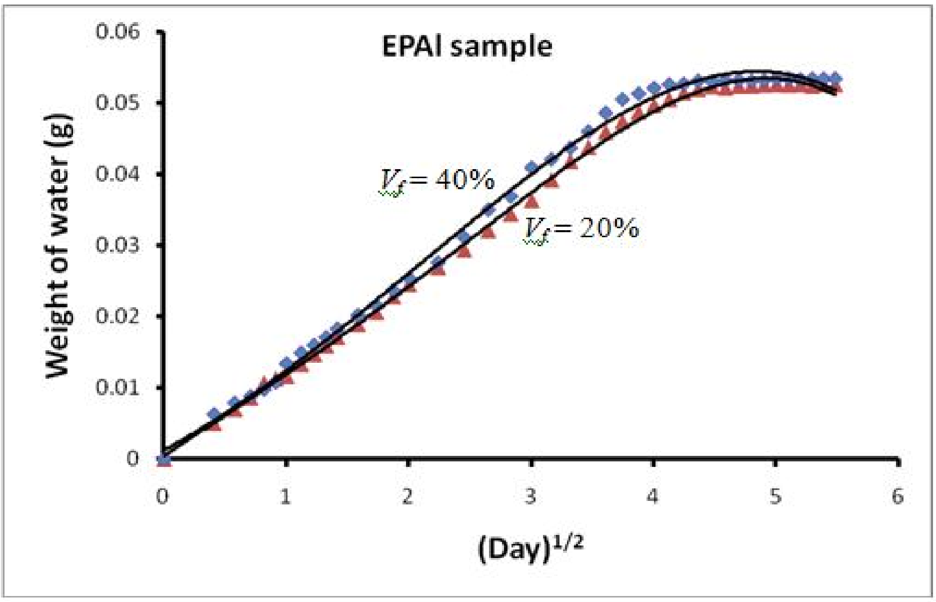

Figure (8): shown absorption curve for wet (EPAl) samples for both volume fractions 20% and 40%.

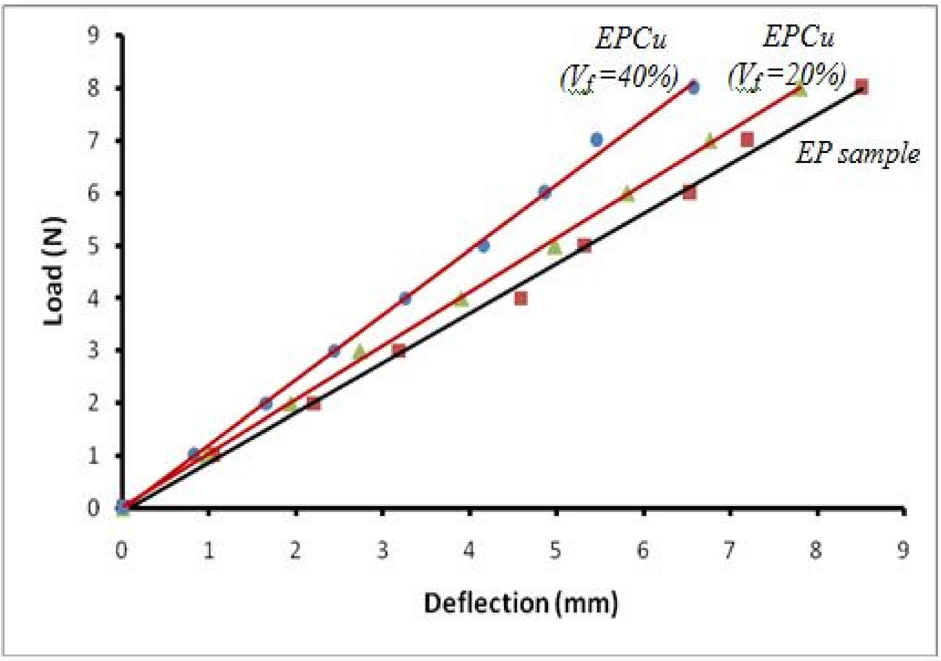

Figure (9): shows load versus deflection for wet (EP and EPCu) samples.

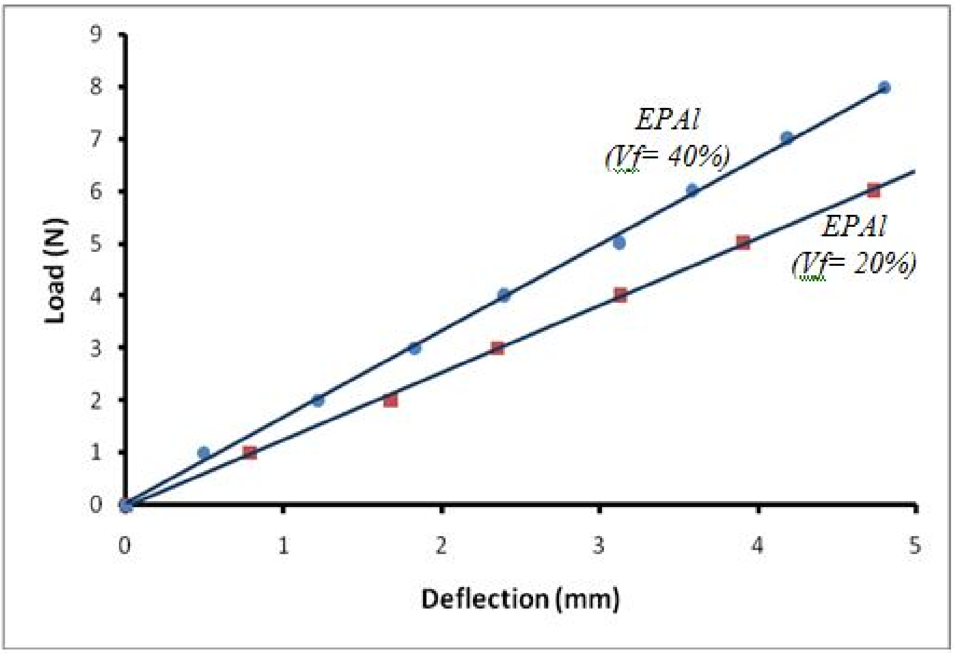

Figure (10): shows load versus deflection for wet (EPAl) samples.

تأثير الماء على متانة الأنحناء للايبوكسي المدعم بالجسيمات بأستخدام أختبار الأنحناء للعارضة المثبتة من طرف واحد.

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الخلاصـة.

تضمن هذا البحث دراسة متانة الأنحناء للمواد المتراكبة البوليمرية المسلحة بالجسيمات. أستخدمت تقنية التصنيع اليدوي في تصنيع ألواح من المواد المتراكبة، حيث استخدم راتنج الايبوكسي كمادة رابطة لمواد التسليح والمتكونة من مسحوقي أوكسيد الألمنيوم والنحاس. صنعت ألواح من المواد المتراكبة بكسرين حجميين 20% و 40% من مواد التسليح وكل هذه الألواح تم تقطيعها إلى عينات بالقياسات (100×10 ملم) لكي يتم بعد ذلك إجراء اختبار متانة الأنحناء للعينات بأستخدام أختبار الأنحناء للعارضة المثبتة من طرف واحد ولكلا الكسرين الحجميين 20% و 40%.

أظهرت النتائج والاختبارات المختبرية لهذه العينات إن هناك زيادة في متانة الأنحناء ومعامل المرونة عند زيادة الكسر الحجمي لمواد التسليح من 20% إلى 40% وان هذه القيم تتناقص عند غمر العينات بالماء المقطر لمدة (30) يوما.

الكلمات الرئيسية: بوليمر، ايبوكسي، المواد المتراكبة، متانة الانحناء