Fick's Law Investigation and effect of water absorption on flexural strength of Epoxy reinforced with fibers

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الملخص:

يهدف البحث الحالي الى دراسة قانون انتشار Fick من خلال غمر خمس عينات مقواة بالايبوكسي تم تحضيرها بطريقة الصب اليدوي في الماء لمدة عشرين يوما، وتم قياس اوزان العينات كل ٢٤ ساعة بعد تجفيفها باستخدام الفرن ، وقد ادى الجزء الخطي من العلاقة بين (F) والجذر التربيعي لزمن الغمر الى تحسين قانون Fick وتم دراسة تأثير الماء الممتص على الخواص الميكانيكية لهذه العينات باستخدام اختبار الانحناء ،باستعمال جهاز Instron1122 وتم اخذ افضل عينه رقم ٥ لهذا الاختبار، ويعود امتصاص الماء بواسطة الراتنج الى انجذاب التجمعات القطبية لجزيئات الماء حيث تزداد نسبة الماء النافذ مع زيادة عدد هذه التجمعات ، يؤدي نفاذ الماء الى داخل الراتنج الى تقليل الروابط الهيدروجينية بين السلاسل البوليمرية مما يزيد من مرونتها، ونرى ذلك بوضح من خلال فحص العينات بعد اخراجها من الماء مقارنة بها وهي جافة .

اما بالنسبة للعينات المركبة فان الماء سيمر عبر المادة الرابطة ومن خلال الفراغات البينية بين الالياف والمادة الرابطة حيث تكون هذه الفراغات على شكل انابيب شعرية ويمر الماء من خلالها حسب الخاصية الشعرية مما يؤدي الى توليد انتفاخات (فقاعات) تؤدي الى انفصال الراتنج عن الالياف وبالتالي تقليل متانة المركبات، كما انها ستكون عرضه لانتشار الشقوق والعيوب اثناء التعرض للإجهادات الخارجية.

الكلمات المفتاحية: المواد الايبوكسية المسلحة، امتصاص الماء، اختبار الانثناء.

Abstract

Fick’s law of diffusion was investigated by immersion five Epoxy reinforced specimens that were prepared using hand lay-up method in water for twenty days. The specimen’s weights were taken every 24 hours after drying them using an oven. The linear portion from the relation between (F) and square root of immersion time improved Fick’s law. The effect of absorbed water on mechanical properties of these specimens using flexural test using an Instron 1122 were studied. The best specimen No. (5) was taken for this test.

The absorption of water by the resin is attributed to the attraction of the polar aggregates to the water molecules, as the percentage of permeable water increases with the increase in the number of these aggregates.

The penetration of water into the resin reduces the hydrogen bonds between the polymeric chains, which increases its plasticity. This was evident upon examining the samples after taking them out of the water compared to them while they were dry.

As for the composite specimens, the water will pass through the binder and through the interfacial spaces between the Fibers and the binder, where these distances will pass as capillary tubes and the water will pass through them according to the capillary property, and it will generate bulges (Bubbles) that lead to the separation of the resin from the fibres, thus reducing the durability of the composites, as it will be subject to the spread of cracks and defects during exposure to external stress.

Keywords: Epoxy reinforced materials, Water absorption, Flexural test.

Fick's law

It happens legally that the prevalence of a phenomenon across any level of success opportunities increases as the prevalence of the phenomenon increases at the backbone at the employment level.

1- Introduction:

The composite material consists of combining two or more materials, and includes mixtures and plastic reinforced, with different mechanical and physical properties. This merging process leads to obtaining a new material with engineering and physical properties that differ from the properties of the materials included in its composition.

There are several methods of reinforcement, including reinforcement with particles and reinforcement with dispersion. As for the most common reinforcement method, it is reinforcement with Fibers of all kinds, due to the great strength of these materials compared to resin materials.

The Fibers are of different types and shapes, some of which are continuous, cut, or in the form of woven braids resembling a mat.

The main objective of the Fibers reinforcement is to improve the mechanical and physical properties of the resins, where the tensile, shock and hardness resistance is greatly increased, which allows the use of these reinforced materials in many industrial fields.

The Fibers used in the reinforcement of the resin materials are considered the main responsible for bearing the external loads imposed on the superimposed upon its various uses or when subjected to a mechanical examination to test the extent to which it can withstand external stresses. Among the most common types of Fibers in the field of composite materials are glass Fibers, carbon Fibers, and Kevlar Fibers.

2- Properties of composite materials:

The general and engineering uses of composite materials depend to a large extent on their mechanical and physical properties such as tensile strength, flexibility, elongation, heat resistance, and environmental conditions such as moisture, sunlight, and other applied properties. All these properties depend very much on the molecular structure of the polymeric material used **(Groover ,2010, p67,68)**. With the many advances made in understanding the behaviour of composite materials, many Fiber-reinforced polymer composites are finding increasing use over a wide range of high-tech engineering applications. The multiplicity of composite materials, in addition to their high properties such as hardness, weight, strength, fatigue resistance, corrosion resistance and low manufacturing costs make them highly advantageous when compared to traditional metals for use in many marine and aerospace structural components and in the automotive industry (Harish**, 2015, p142).** It is possible to load a high stress rate in many applications, as you find Fiber-reinforced polymer composites nominated for use for this type of applications, and it has always been a matter of concern that the mechanical properties of composite materials may be poor at high stress rates, and therefore the study of how the mechanical properties of these changes Compounds with a stress rate are guaranteed to be able to design assemblies that do not fail before it is too late and unexpectedly at high loading rates. Determining the dynamic mechanical properties of these composites will also ensure the design of composite materials that are weight efficient and structurally sound when subjected to high dynamic loads. For the above reason, the need for dynamic characterization of FRP composites is described to understand the effects of strain rate on their mechanical properties **(Fundamentals, 2001, p54)**. The overlay materials are distinct (i.e. macroscopic, not microscopic), among the familiar overlays is concrete, which consists mainly of sand and cement. As for polymer compounds, they are plastic materials that contain embedded Fibers or particles. The well-known plastic is considered a basic material and the Fibers or particles dispersed within it are considered reinforcement materials. , and it is known as the reinforcing material, and the reinforcement is usually more solid than the base material, and therefore the reinforcement of the composite material is usually this stiffer reinforcement is placed in a certain direction within the base material, so that the resulting material has different properties in different directions, and this is usually what is being exploited to improve the design of the base material (**Michael K.Bannister, 2002,p214**). There are a large number of polymer classes that can be used in the manufacture of overlays, and the type of polymer is chosen depending on many matters, including application, cost, Fiber's type, manufacturing method, width, etc.

3- Diffusion:

The mathematical theory of the diffusion process of homogeneous substances (Isotropic substances) is built on the assumption that the rate of diffusion of atoms of one substance through the unit area of another substance depends on the extent of the decline or the rate of change of the practically measured concentration. There are two reasons for describing how liquid molecules permeate through a solid polymer **(**M. **O. Richardson1984, p265,266)**. The first, according to the scientist (Barrer), is related to the local energy of the polymer, if it is sufficient in a way that leads to the transition of the molecules that enter it and between the polymer chains, and the other was explained by the two scholars (Kumins & Kwei) by changing the local density of the polymer, which causes the occurrence of gaps (Vacances), which leads to the movement of molecules in it.

The number of molecules permeable to the polymer will be according to the possibility of forming or forming gaps in it **(**E. **J. Moran Campbell ,1977, p373)**. The atoms of the material are arranged in a way that leaves interstices that the atoms of the permeable material can enter if the conditions for diffusion are met, and then the diffusion is called ***interstitial diffusion***, as an example of this diffusion, the atoms of carbon, oxygen, nitrogen, boron, and hydrogen (C, O, N, B, H) (**L. J. Lee,1987,p793)**. As for the diffusion through gaps (Vacancies), the penetrating atoms cannot spread through the inter-atomic distances of the solid matter due to its large size, so it will wait for the occurrence of a gap resulting from an atom leaving its place and replacing it and moving from one place to another through these gaps, and the diffusion is called diffusion through the gaps (***Vacancy diffusion***) and as shown in Figure (1).

The fastest way to spread is through the grain boundary on the surface of the material or through defects such as dislocations.

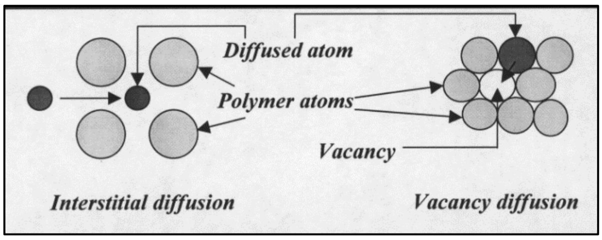


Figure (1) Interstitial and Vacancy Diffusion

The scientist (Fick) expressed his laws on the dynamics of diffusion, as the first law stated that the diffusion rate of the atoms of a substance depends on the decline or change in the concentration (C) of these atoms over the distance (x). In other words, we can express this in the following equation, which is called Fick's first law:

$$\boldsymbol{J = -D\,\frac{\partial C}{\partial X}} \ldots\ldots\ldots\ldots(\mathbf{1})$$

Where:

J = The rate of transfer per unit area of section. Or called (flux)

C = The concentration of diffusing substance.

x = The co-ordinate space measured normal to the section.

D = The diffusion coefficient.

The negative sign of the law means that the rate of diffusion is opposite to the change in concentration. The diffusion coefficient (D) depends on the following factors (Gaylond**,1974, p540)**:

1. The nature of the substance dissolved or diffused through the solid.
2. The atomic structure of this substance.
3. Change in temperature.

Where the diffusion coefficient increases when the temperature rises due to the acquisition of high thermal energy by the atoms, which gives them a greater possibility of movement from one location to another. The change of diffusion coefficient with temperature is expressed by the following relationship (**T. W. Chou,1975, p176,177)**:

$$D = D_o e^{-E_a/RT} \ \dots\dots\dots\dots (2)$$

Where:
D = Diffusion coefficient.
Do = Constant value depending on the matter.
Ea = Activation energy for diffusion, (cal./gm.mol.)
T = Temperature, (degrees kelvin).
R = Gas constant, (cal./gm. mol. K0)

By taking the integration of Fick's first law (Equation - 1), it results:

$$\int_0^L J\, dx = -\int_{c_1}^{c_2} D\, dc \ \dots\dots\dots\dots (3)$$

When the rate of diffusion is constant and does not depend on the distance (x), the product of integration will be as follows:

$$J = -\frac{1}{L}\int_{c_1}^{c_2} D\, dc \ \dots\dots\dots\dots (4)$$

The last equation (4) shows that the constant diffusion rate is inversely proportional to the sample thickness (L), and to calculate the last integration value, the change in the diffusion coefficient (D) with concentration (C) must be known. In some systems the diffusion coefficient changes with concentration because the van der Waals forces between the intermolecular particles and the polymer chains will be high, an example of this is the spread of xylene liquid through polyethylene (Al-**Rawi, 1998, p27)**.

3-1 Absorption with a constant diffusion coefficient:

In some practical experiments of water absorption in the composites, and if we consider that the concentration per unit area of the surface of the sample of thickness (d) remains constant, the amount of water molecules absorbed by the sample in time (t) will be expressed in the following equation (Campbell,**1977, p301)**:

$$\frac{M_t}{M_m} = 1 - \frac{8}{\pi^2}\sum_{m=0}^{\infty}\frac{1}{(2m+1)^2}exp(\frac{-D(2m+1)^2\pi^2 t}{d^2}) \ldots (5)$$

Where:

Mt = Moisture content at the time (t), gm.

Mm = The equilibrium moisture content taken at saturation. gm.

t = The time, sec.

D = Diffusion coefficient.

d = Specimen depth, cm.

Where the value of the diffusion coefficient (D) can be deduced from the linear part of the graphic relationship between (Mt / Mm) and (t / d2)1/2, and based on the fact that if the diffusion coefficient is constant, this curve is linear within the limits of acceptable practical errors or natural, specifically from the beginning of the curve until the value of (Mt / Mm = 0.6) at least, which will show that the materials followed Fick's law of diffusion during their absorption of water. Equation (5) is more appropriate at large time rates, and among them we find that the value of the magnitude (t/d2)1/2 corresponding to the value of the magnitude (Mt/ Mm = 0.6) is expressed in the following form (**Shirrell, 1978, p464**):

$$\frac{t}{d^2} = -\frac{1}{\pi^2 D}ln\left(\frac{\pi^2}{16} - \frac{1}{9}\left(\frac{\pi^2}{16}\right)^9\right) \ldots\ldots\ldots\ldots (6)$$

$$D = \frac{0.04919\, d^2}{t} \ldots\ldots\ldots\ldots (7)$$

3-2: Water absorption in composites:

When the composite material immersed in water, diffusion of water molecules occurs inside it and in the three dimensions through the bonding material, fibers, and interstitial spaces, which may lead to swelling of the material and a decrease in the glass transition temperature (Tg) and thus affect the mechanical properties of the superimposed (**L. J. Broutman,1980, p185**).

To identify the quantity and distribution of water absorbed by the composite, it is worth focusing on two factors:

- **Equilibrium level**, which represents the upper limit of the amount of water absorbed by the composite material.
- **Diffusion coefficient**, which gives an indication of the rate of water absorption in the material, and accordingly, the percentage of the amount of water absorbed or lost from the material can be calculated from the following equation **(ASTM, 1984, p405,407)**:

$$\%\boldsymbol{M} = \frac{\boldsymbol{W_i - W_d}}{\boldsymbol{W_d}} \boldsymbol{x\,100} \quad \dots\dots\dots\dots (\mathbf{8})$$

Where:

%M: The percentage moisture uptake or loss.
Wd: The original dry weight of the specimen.
Wi : The weight of the specimen after exposure time (t).

The diffusion coefficient (Dx) depends on the absolute temperature (T) according to the following relationship:

$$\boldsymbol{Log(D_x)} \propto (\frac{\mathbf{1}}{\boldsymbol{T}}) \quad \dots\dots\dots\dots (\mathbf{9})$$

According to Fick's second law of diffusion, this coefficient is calculated from the following equation:

$$\boldsymbol{D_x = \pi(\frac{d}{4M_m} * \frac{M_2 - M_1}{\sqrt{T_2} - \sqrt{T_1}})^2} \quad \dots\dots\dots\dots (\mathbf{10})$$

Where:

Dx = Diffusivity, cm2 sec -1
d = Thickness of the specimen, cm.
Mm = Equilibrium moisture content taken at saturation, gm.
M1 = First value of the moisture content, gm.
M2 = Second value of the moisture content, gm.
T1 = Time of M1, sec.
T2 = Time of M2, sec.

The value (M2 - M1 / t2 - t1) represents the slope of the linear part of the relationship between the amounts of water absorbed (M) and the square root of time (t). Some scientific sources study the relationship between the variable (F) and (t1/2/d) in order to achieve Fick's law of diffusion instead of the relationship between (Mt / Mm) and (t / d2)1/2, which is what was relied upon in this research, this is due to its close results to what the previous theoretical equations mentioned, where the variable (F) is calculated from the following equation:

$$\boldsymbol{F = \frac{M - M_1}{M_m - M_1}} \quad \dots\dots\dots\dots (\mathbf{11})$$

Where:

M = Moisture content, gm. At time (t).

Mm = Equilibrium moisture content taken at saturation, gm.

M1 = First value of the moisture content, gm.

It also requires that the process of absorption and desorption be according to the graphic relationship between (F, t1/2) linear from its inception to the value (F = 0.6).

4- Flexural Test:

For the purpose of studying the mechanical properties of the composites, some tests are used such as the tensile test and the flexural test, and each test has a special shape for the specimen. In the flexural test, (Fig. 3) a sample in the form of a cuboid is placed on two supports separated by a certain distance, its value is determined according to international specifications according to the thickness of the sample, and stress is applied in one direction, and let the (Y) axis, for example, be downward on a point in the centre of the sample, then its shape will begin to curve downward, and two forces will arise on the two faces of the sample, one of which is a compression force that causes compression of its upper face, and the other is a tensile force that causes expansion of its lower face. They are two opposite forces that generate the flexion moment, and this test is called the three-point test When the sample is bent or bent downward due to the force exerted on its middle (P), flexion moment is generated at both ends, which will generate compression of the particles of the part that is above the horizontal axis of the sample and the particle moving away below this axis. Therefore, the first moments of fracture occur in the particles below the axis. The amount of stress applied to the centre of the sample at the moment when the sample begins to break will be a measure of its strength and the extent of its resistance to this stress.

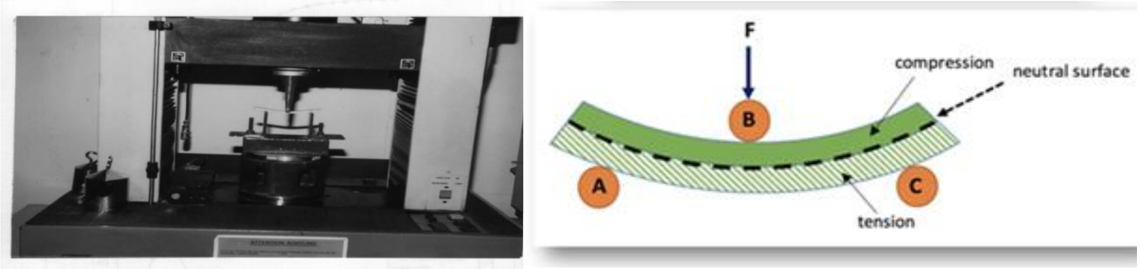


Figure (3) Flexural Test

The flexural modulus elasticity can be calculated using equation bellow:

$$\boldsymbol{E_f = \frac{L^3 m}{4bd^3}} \dots\dots\dots\dots (\mathbf{12})$$

Where:

$E_f = Flexural\ modulus\ of\ elasticity\ (\ MPa\ )$

$L = Support\ span\ (\ mm\ )$

$m = Slope\ of\ the\ initial\ straight\ line\ portion\ of\ the\ load - deflection\ curve\ (\frac{N}{mm})$

$b = Width\ of\ test\ beam\ (\ mm\ )$

$d = Depth\ of\ thickness\ of\ tested\ beam\ (\ mm\ )$

<u>5- Literature review):</u>

There have been many studies on the behaviour of polymers and their mixtures and properties through their influence on the surrounding environmental conditions.

- (Shirrell) 1968 AD - studied water absorption by epoxy composites reinforced with graphite Fibers. Among the graphs that show the amount of water absorbed, the shape of the curve was linear under the value of (0.6 = mm), which confirms the fulfilment of Fick's law in absorption, and that the experiment in the research was taken for several degrees of temperature, and it was found that the higher the temperature, the greater the amount of water absorbed. (**C. D. Shirrell, 1978,p658**).

- (Delasi & Whiteside) 1978 AD, studied the effect of water absorption of pure epoxy samples and samples of epoxy reinforced with graphite fibers. They studied the effect of the amount of absorbed water on the degree of glass transition and found that the higher the amount of absorbed water, the lower the value of the glass transition temperature. They also studied the effect of relative humidity (RH) on the maximum value of absorbed water (J. B. Whiteside, 1978,p),.
- (Whitney & Browning)**)**, 1978 AD - also took samples of epoxy mixtures and epoxy composites reinforced with graphite fibers, and exposed them to moisture at different temperatures. Diffusion across the samples was considered from three directions (d11, d22, d33), but they studied the propagation in two directions (for the composite material), one parallel and the other perpendicular to the fiber direction:

  d11 = dL, parallel diffusivity
  d22 = d33 = dT, transverse diffusivities

They found a comparison across graphs between one-way and two-way diffusion. They expressed the effective diffusion coefficient by the following equation:

d = dT [1 + h/a (1 + dL / dT)]2

From drawing the graphic relationship between (F = M/M1, t1/2), the slope is extracted in the area located below (F= 0.6), which fulfils Fick's law of diffusion, and from the slope, find the value of the effective diffusion coefficient - d from the following equation (**C. E. Browning,1978).**

$$\boldsymbol{d = \frac{\pi h^2 S^2}{16}}$$

Where:

S = Slope of the graph.
h = Depth of specimen.

- (Gillat & Broutman) 1978 AD - studied the effect of the external tensile stress imposed on the samples on the diffusion of water molecules through the composite material and on their mechanical properties. Where they experimented with different temperatures and different amounts of relative humidity and found that higher temperatures increase the maximum value of water absorbed by the samples, as well as the diffusivity and diffusion rate. They found that increasing the amount of tensile stress increases the amount of water absorbed by the sample. (**L. J. Broutman, 1978**).
- The researcher (Lee Mc. Kague) **(Lee Kague , 1978**), 1978 AD - studied the effect of water absorbed by the samples on the physical and chemical properties, and studied the phenomenon of swelling of the samples and increasing their volume as a result of water absorption, and used the relationship that links the amount of water absorbed with its maximum value and the density of the polymer and water and sample size change from the original size.

6- Experimental Part & Measurements

6-1 The practical section:

The raw materials used in the research are:

1. The polymeric Epoxy material whose specifications are mentioned in Table (1) was used with its hardener, and five samples were made of it after reinforcing it with glass Fibers in the form of a mat (00/900 woven mat) and with dimensions (15x2x1cm) to be used all of them and make a comparison between them and take The rate of adoption in the search results.

Table (1) : Specifications of the raw materials used

Materials	Hardener
Epoxy Resin	HY 953

2. Glass mould, the dimensions of which are (15 x 15 x 1.5 cm), as shown in Figure (4).
3. A graduated glass flask with a thin glass rod is used to mix the polymer mixture after adding the hardener to it.

4. Grooved aluminum roll for bonding the resin layers with the fibers.
5. A sensitive electronic scale with an accuracy (0.0001 gm.).
6. A glass container filled with water to immerse the specimens under investigation.
7. A soft brush was used to clean the specimens after taking them out of the water every 24 hours.
8. A thermal dryer to dry the specimens after taking them out of the water for the purpose of finding their weight.

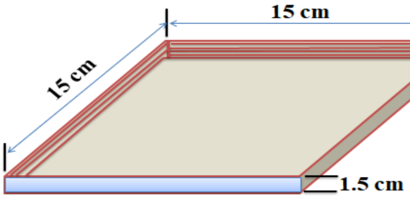


Figure (4) The glass mould used to prepare specimens

6-2: Preparation of materials:

The Hand Lay-up Method was used to prepare the specimens, which were prepared after determining the required volume of the polymeric material using a graduated glass beaker that is suitable for the size of the specimens and the template used for this purpose after calculating their weight using a sensitive balance and with the following steps:

1. The inside of the mould was coated with wax using a soft brush, because the resin did not stick to the base of the mould after casting and left to dry.

2. Pour a layer of the resin after its preparation into the glass flask and its hardener and mix it with the glass rod until complete homogeneity. Using a brush, the resin is distributed over the mould.

3. Brushing a layer of glass Fibers over the resin and then adding the resin on top of it with a suitable layer by brush and using a metal roller that was pressed for the purpose of getting rid of bubbles and defects that may arise during the casting process, which will be a source of defects affecting the calculated results from one sample to another.

4. Repeat the previous process until reaching the predetermined thickness of the samples.

5. Leave the mould for 24 hours to dry at room temperature. Raising the resin material from the mould, it was left for 72 hours before starting to cut it into samples according to the predetermined dimensions. Figure (5) shows a picture of the specimens prepared for research.

6. After cutting the mould into a group of specimens according to ASTM-D7264. The standard thickness is 4mm, and the standard specimen width is 13mm with the specimen length being about 20% longer than the support span. Five of them were used, numbered, brushed and weighed before immersing them in water. The weights were as shown in Table (2).

7. The specimens were immersed in water at room temperature in the glass container designated for this purpose.

8. The specimens were taken out of the container after 24 hours had passed, and they were cleaned and dried completely, and weighed with a sensitive scale of accuracy 0.0001 gm to calculate the amount of water absorbed.

9. The specimens were returned to the container again, and this process was repeated for twenty days, and the results were as shown in Table (3).

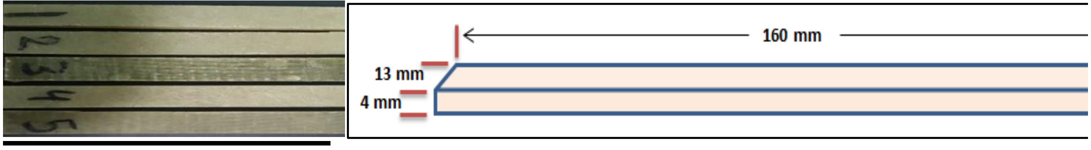


Figure (5) Specimens used in the research

6-3 Calculation of Specimen's weights:

The results of calculating the weights were as shown in Tables (2,3):

Table (2) weights of dry samples before immersion in water

Specimen no.	1	2	3	4	5
Weights (gm)	32.02	33.09	36.16	35.59	35.58

Table (3) Weights of specimens every 24 hours

Time	**Weight (gm)**

(day)	(1)	(2)	(3)	(4)	(5)
1	35.7000	35.7300	36.2700	33.3000	32.1700
2	35.7100	35.7370	36.2800	33.3200	32.1900
3	35.7200	35.7450	36.2900	33.3360	32.2000
4	35.7270	35.7500	36.3000	33.3490	32.2100
5	35.7340	35.7550	36.3100	33.3660	32.2200
6	35.7400	35.7600	36.3160	33.3800	32.2300
7	35.7460	35.7640	36.3250	33.4000	32.2410
8	35.7550	35.7700	36.3350	33.4110	32.2470
9	35.7650	35.7750	36.3450	33.4200	32.2520
10	35.7730	35.7800	36.3500	33.4310	32.2590
11	35.7780	35.7850	36.3600	33.4400	32.2650
12	35.7840	35.7880	36.3700	33.4460	32.2700
13	35.7940	35.7900	36.3800	33.4500	32.2740
14	35.8000	35.7900	36.3830	33.4500	32.2760
15	35.8050	35.7900	36.3850	33.4510	32.2778
16	35.8100	35.7910	36.3860	33.4500	32.2800
17	35.8120	35.7920	36.3870	33.4500	32.2810
18	35.8110	35.7920	36.3850	33.4520	32.2800
19	35.8110	35.7900	36.3860	33.4530	32.2800

To calculate the amount of water absorbed by the specimens during this period, their weights were subtracted from the initial weight while they were dry, and the results were as shown in Table (4):

Table (4) moisture absorbed quantities every 24 hours

Time (day)	Weight (gm)				
	(1)	(2)	(3)	(4)	(5)
1	0.1100	0.1400	0.1100	0.2100	0.1500
2	0.1200	0.1470	0.1200	0.2300	0.1700
3	0.1300	0.1550	0.1300	0.2460	0.1800
4	0.1370	0.1600	0.1400	0.2590	0.1900

5	0.1440	0.1650	0.1500	0.2760	0.2000
6	0.1500	0.1700	0.1560	0.2900	0.2100
7	0.1560	0.1740	0.1650	0.3100	0.2210
8	0.1650	0.1800	0.1750	0.3210	0.2270
9	0.1750	0.1850	0.1850	0.3300	0.2320
10	0.1830	0.1900	0.1900	0.3410	0.2390
11	0.1880	0.1950	0.2000	0.3500	0.2450
12	0.1940	0.1980	0.2100	0.3560	0.2500
13	0.2040	0.2000	0.2200	0.3600	0.2540
14	0.2100	0.2000	0.2230	0.3600	0.2560
15	0.2150	0.2000	0.2250	0.3610	0.2578
16	0.2200	0.2010	0.2260	0.3600	0.2600
17	0.2220	0.2020	0.2270	0.3600	0.2610
18	0.2210	0.2020	0.2250	0.3620	0.2600
19	0.2210	0.2000	0.2260	0.3630	0.2600
20	0.2211	0.2002	0.2257	0.3635	0.2610

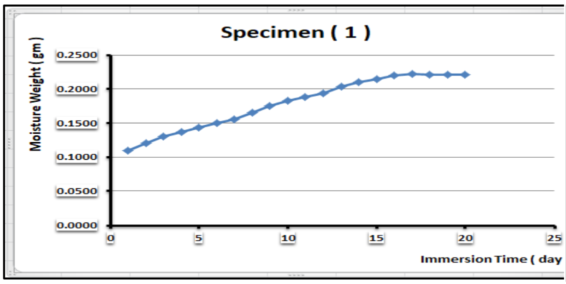
After extracting the results of the weights, the values of the variable (F) were calculated from equation (11), knowing that the thickness of one specimen was (1cm), and the results were recorded in Table (5) to be used in drawing graphs and verifying the application of Fick's law of diffusion, and the figure (6) represent the graphic relationship between the water immersion time and the amount of water absorbed for each specimen, through which the value of the saturation limit of the absorbed water was known.

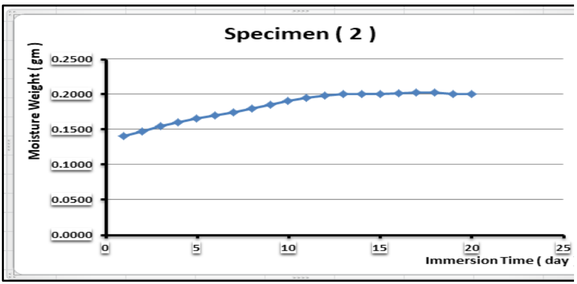
As for figures (7) they represent the graphic relationship between the variables (F) and (t1/2/d).

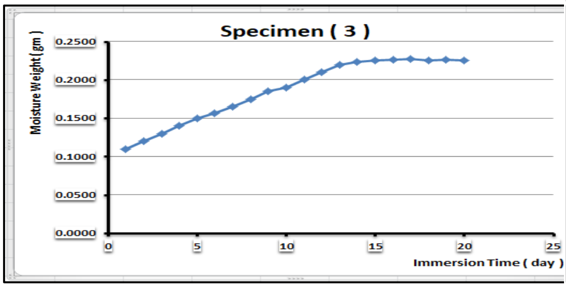
Table (5) F-values and t1/2/d

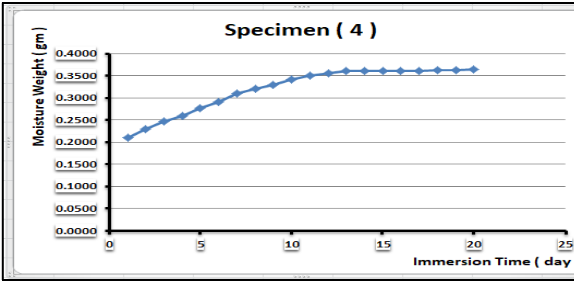
t1/2/d	***F1***	***F2***	***F3***	***F4***	***F5***
1.0000	0	0.0000	0.0000	0.0000	0.0000
1.4142	0.1	0.0875	0.0862	0.1333	0.1818
1.7321	0.2	0.1875	0.1724	0.2400	0.2727
2.0000	0.27	0.2500	0.2586	0.3267	0.3636

2.2361	0.34	0.3125	0.3448	0.4400	0.4545
2.4495	0.4	0.3750	0.3966	0.5333	0.5455
2.6458	0.46	0.4250	0.4741	0.6667	0.6455
2.8284	0.55	0.5000	0.5603	0.7400	0.7000
3.0000	0.65	0.5625	0.6466	0.8000	0.7455
3.1623	0.73	0.6250	0.6897	0.8733	0.8091
3.3166	0.78	0.6875	0.7759	0.9333	0.8636
3.4641	0.84	0.7250	0.8621	0.9733	0.9091
3.6056	0.94	0.7500	0.9483	1.0000	0.9455
3.7417	1	0.7500	0.9741	1.0000	0.9636
3.8730	1.05	0.7500	0.9914	1.0067	0.9800
4.0000	1.1	0.7625	1.0000	1.0000	1.0000
4.1231	1.12	0.7750	1.0086	1.0000	1.0091
4.2426	1.11	0.7750	0.9914	1.0133	1.0000
4.3589	1.11	0.7500	1.0000	1.0200	1.0000
4.4721	1.1110	0.7525	0.9974	1.0233	1.0091









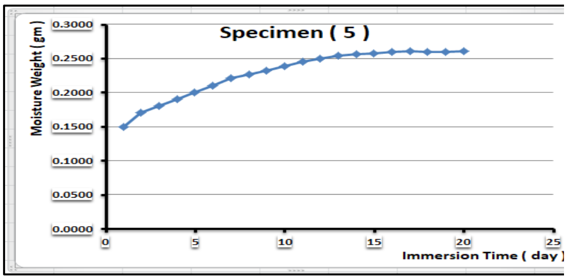


Figure (6) Relationship between five specimen's immersion time Vs. the amount of water absorbed

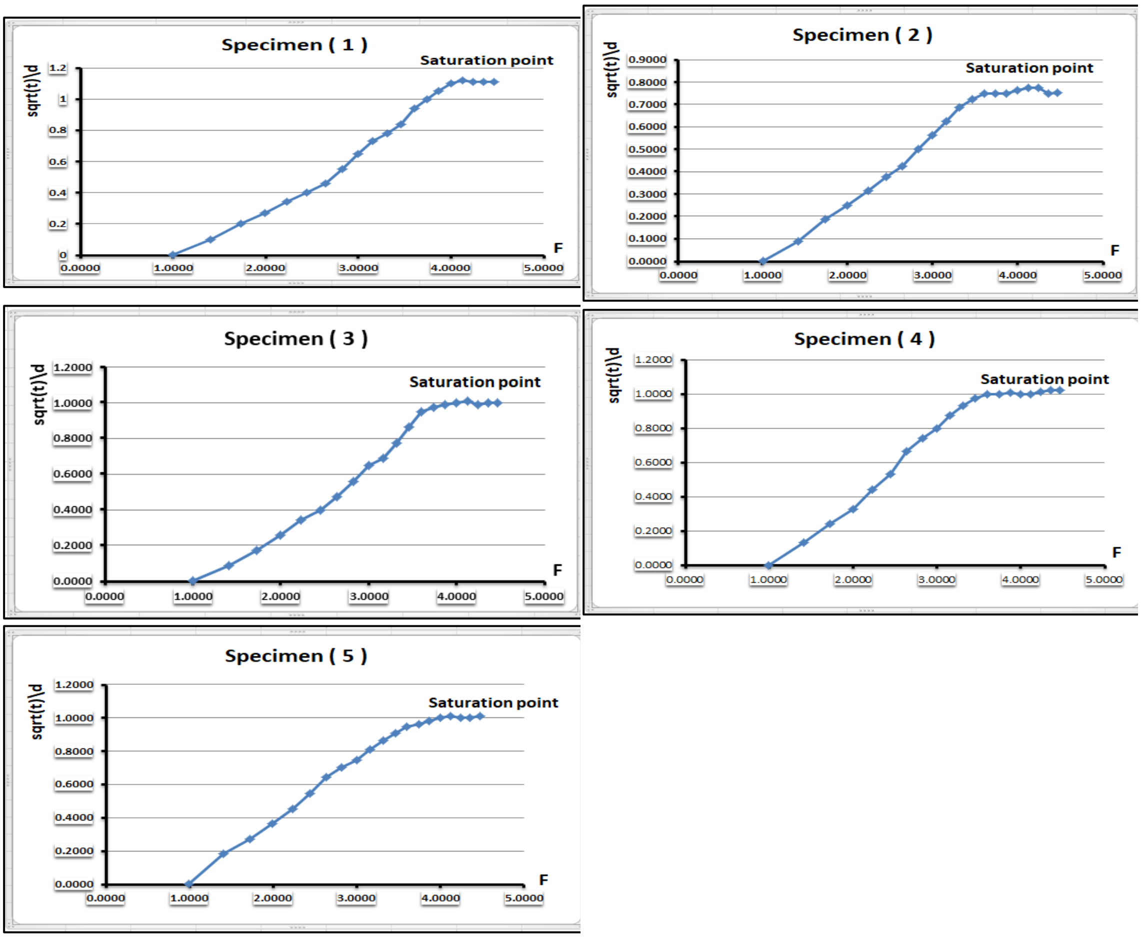


Figure (7) Relationship between (F) and (t1/2/d) for the five specimens

6-4 Three-points bending test for specimen (5)

After immersion specimens in the water for (20) days, the bending test was used to make a comparison study for the maximum flexural stress of the dry and wet specimen. The specimen number (5) was used because it is getting us the best. The results for this test as shown in table (6) and its graph as shown in figure (8).

Table (6) Three Points Bending Test for Specimen 5

Deflection (mm)	Applied Load (MPa)	
	Wet Specimen	Dry Specimen

0	0	0
1	48.56	117.6
2	91.23	244.8
3	148.8	368.6
4	180.6	484.8
5	205.2	606.7
6	210	739.2
7	217.2	870.7
8	222	926.9
9	223.2	959
10	223.2	967.2
11	223.2	956.6
12	223.2	926.4
13	222.6	885.6
14	220.8	841.9
15	219.6	787.2

To calculate flexural modulus of elasticity, the equation bellow was used, and its variables were found as shown in table (7):

$$\boldsymbol{E_f = \frac{L^3 m}{4bd^3}}$$

Table (7) Variables of wet and dry specimens for flexural test

Specimen type	**L (m)**	**m-Slope**	**b (m)**	**d(m)**	**Ef (MPa)**
Dry	**0.1**	**1.25**	**0.02**	**0.01**	**15625**
Wet	**0.1**	**0.375**	**0.02**	**0.01**	**4687.5**

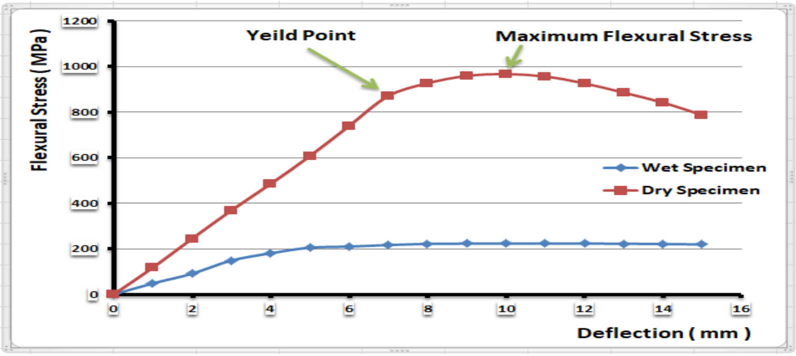


Figure (8) Bending test for Dry and Wet specimen (5)

6-5 Discussion:

Polarity is the basic property of polymer molecules, which is physically related to the density of irregular electronic distribution, which causes the appearance of dipole moments, electrostatic charges, and hydrogen bonds in large polymer molecules.

The extent to which the resin material affects water depends greatly on the polarity of the polymer molecules, and accordingly we can divide the polymers based on their ability to absorb water into:

1. High absorption.
2. Medium absorption.
3. Low absorption.

The absorption of water by the resin is attributed to the attraction of the polar aggregates to the water molecules, as the percentage of permeable water increases with the increase in the number of these aggregates. If the polymeric material contains some salt impurities, the permeable water will decompose these salts and dissolve them, generating osmotic pressure, which leaves voids inside the resin, thus, affecting its mechanical properties.

The penetration of water into the resin reduces the hydrogen bonds between the polymeric chains, which increases its plasticity. We see this clearly from examining the specimens after taking them out of the water compared to them while they were dry.

As for the composite specimens, the water will pass through the binder and through the interfacial spaces between the Fibers and the binder, where these distances will pass as capillary tubes and the water will pass through them according to the capillary property, and it will generate bulges (Bubbles) that lead to the separation of the resin from the Fibers, thus reducing of the durability of the composites, as it will be subject to the spread of cracks and defects during exposure to external stress.

1. It is clear from the previous charts that specimen (5) gave the best results, as the saturation limit was constant and clear in the last five days. Likewise, the amount of water absorbed before this point was homogeneous in terms of the increase in its value.
2. The minimum and maximum levels of water absorbed by the specimens were almost equal in the specimens (1, 2, 3, 5). As for the fourth, there is a difference in the maximum limit from the rest, and the reason may be the presence of bubbles or small gaps that permeated this piece during preparation. The reason is to absorb a larger amount of water, and this confirms the need to take care of the preparation method, as it is a manual method.
3. It is clear from Figure (7) that the graph line of fifth specimen under the value (t1/2/d = 0.8) is linear almost more clearly than the rest of the samples, which confirms the fulfilment of Fick’s law of diffusion, but this does not mean that the rest of the samples did not fulfil the law, as the graphs were also It has a linear form below this value, but not as for the fourth sample.
4. The ability of the Epoxy resin to absorb water molecules is weak, and this is evident from the measured weight values.
5. The wet specimen was lost more of its strength comparing with dry one because the water molecules which absorbed will cause a separation of Fibers from the resin, and this will decrease the resistance of specimen to the external load. Figure (8) shows that, and table (7) shows that the modulus of dry specimen is greater than its value for wet specimen, and this result showing us the effect of moisture absorption on mechanical properties of specimens.

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