The Effect of Water Absorption on the Creep Behavior for Polymer Composite Materials

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Abstract

In this investigation, a low cost, mechanically operated creep testing machine capable of determining the deformation property of material is developed for providing an economical means of performing standard creep experiments. Creep tests are performed to study the nonlinear viscoelastic behavior of epoxy resin and {unidirectional ($\theta=0^o$) and woven fabric ($\theta=0^o, 90^o$)) E-glass/epoxy composite materials under various environmental effects at room temperature and different values of applied stresses. Tested specimens are immersed in three different solutions {acidic water (*HCL*), *PH=5*), (distilled water (H_2O), *PH=7*}, and {Alkaline water (*NaOH*), *PH=10*}. The experimental creep data can be fitted with general power time function. This function is modified where the effect of gained moisture content, applied stress and aged time on the creep strain are suggested as variables in the creep strain equation. Results show that the creep strain increased with increasing the (*pH*) level and increased more with increasing the values of the applied stress. Also, the results show that the alkaline water "*NaOH* solution" is more effective than other solutions on the composite viscoelastic behavior. The concluded degradation rates are 36%, 57% and 62.633% for epoxy, woven fabric composite (Mat) ($\theta= 0^o,90^o$), and unidirectional composite ($\theta= 0^o$), respectively. The developed equation gives an appropriate criterion for describing long time creep strain.

Keywords: creep behavior, environmental effects, polymer composite materials.

تأثير إمتصاص الماء على سلوك الزحف للمواد المركبة المرنة

الخلاصة

في هذا البحث و بكلفة منخفضة، تم تصنيع جهاز" الزحف الميكانيكي" قادر على حساب مواصفات تشوه المادّة لتصبح من الوسائل الاقتصادية في أجراء تجارب زحف قياسية .أنجزت اختبارات الزحف لدِراسَة سلوكِ التصرف اللاخطّي المرن اللزج لمادّةِ epoxy و مركبات E-glass/epoxy تحت التأثيراتِ البيئيةِ المُخْتَلِفةِ و بتسليط إجهادات متغيرة . النماذج المُجرّبة وضعت في ثلاثة محاليل مختلفةِ {ماء حامضي (*HCL*)، *5=pH*}، {ماء مقطر (*H_2O*)، *7= pH*}، و{ماء قاعدي(*NaOH*) ، *10=pH*}. بياناتَ الزحف العملية انسجمت مع دالة الوقتِ الآسية العامةِ. هذه الدالة عدّلت بحيث أنها أصبحت بدلالة ثلاث متغيرات (محتوى الرطوبةِ المَكْتسُب ، الإجهاد المسلط والزمن اقترحوا كمتغيّرات في معادلةَ الزحف). نرى من النَتائِجُ أنه الزحف زادَ بزيَادَة *pH* و زادت أكثر بزيَادَة قِيَمِ الإجهاداتِ المسلطة. أيضاً، أثبتت النَتائِجَ بأنّ الماءَ القاعديَ (محلول *NaOH*) أكثرُ فاعلية مِنْ المحاليلِ الأخرى على سلوكِ المركّب المرن اللزج. نِسَب الانخفاض المُسْتَنْتجةِ هي 36%، 57%، 62.633% للمواد epoxy ، woven fabric

unidirectional composite ($\theta= 0^o$) ، composite على التوالي. تَعطي المعادلةُ المُطورة معاييرُ جيدةُ لوَصْف ظاهرة الزحف لوقت طويلٍ ً في هذا العملِ

الكلمات الدالة: سلوك الزحف ، التأثيرات البيئية ، المواد المركبة المرنة.

Introduction

A composite material is a material system composed of a mixture or a combination of two or more macro constituent differing in form and/or material composition from each other and that are essentially insoluble in each other. Composite materials of interest herein are polymer composites, which consist of reinforcing fibers embedded in a resin matrix binder. The fiber carry structure loads within the composite while the matrix binds the fibers together and transfers loads between them [1]. In recent years, polymer matrix composites are widely used as special engineering materials in applications of aerospace, automotive and civil engineering structure because of their high modulus and strength [2] , so it is very useful to define explicitly damage mechanisms. Damage sources are commonly: water absorption, impact, repeated impact, creep, bending, tension and mechanical fatigue [3]. Water absorption for many, but not all polymers causes swelling, plasticization, and decrease in glass-transition temperature. Plasticization is the increase in spacing between molecules so molecules mobility increases, and is a reversible process. Fiber-matrix interface damage is only partially reversible by removal of moisture. Actually, this transition takes place not at a specific temperature, but over a temperature range [4]. Glass fiber reinforced vinyl-ester resin composites incorporating varying amounts of fibers (63.5, 55.75, 48.48, 38.63 and 27.48 wt %) were characterized for their mechanical properties both as prepared and after treatment with boiling water for 2, 4, 6, 8 and 24 h. Weights of the samples were found to increase to saturation at about 8 h with boiling water treatment. The mechanical properties were relatively inferior when treated with boiling water for longer hours attributing to ingress of moisture by capillary action through the interface between the fiber and the resin matrix [5]. A three-dimensional (3D) micromechanical model was constructed to derive the effective non linear viscoelastic response of fiber reinforced plastics (FRP) laminated composites. Different experimental creep tests were used to validate the proposed model. The predicted creep responses were in good agreement with the experimental results. The proposed modeling approach was general and can easily include additional effects, such as temperature, moisture, and physical aging [6]. The effects of storage aging and concentrated *HCL* on the mechanical properties of fiber glass polyester composite were investigated in order to determine the properties of 15 years stocked GRP sheet specimens. The storage aging caused 48, 10, 16 and 10.5% reduction in tensile and flexural strength, modulus of elasticity and elongation at break of the samples respectively the storage aged samples immersed in *HCL* acid showed even more decrease in mechanical properties [7]. Creep tests under different temperature were performed to distinguish the nonlinear thermo - viscoelasticity behavior of polymer composite materials (random chopped E-

glass fiber and polyester resin). The mathematical models predicted from experimental data were derived. It was found that the extension increases with increasing temperature from 30 C^o to 60 C^o with on approximate rate of (54.3%) [8]. The present study is designed to investigate the creep behavior changes of both epoxy resin and E-glass fiber epoxy composite resulting from aging these materials in various aqueous solution as namely, distilled water (H_2O, $pH=7$), alkaline water ($NaOH$, $pH=10$), and acidic water (HCL, $pH=5$) at different stresses (pH level is defined as a negative logarithm of hydrogen concentration [9]). The results of mechanical property changes, aging conditions and exposure times are correlated by mathematical models to represent the behavior of nonlinear viscoelastic behavior for composite materials.

Experimental work

Description of the test apparatus

The creep testing apparatus used in this study is shown in figure (1). It is used to measure the variations of the longitudinal extension with time under constant load. The test rig consists of the following parts:-

1. Main frame: the main frame is used of rugged construction to provide years of trouble-free and dependable test results for the system. The principal parts of the main frame are U-channel for the frame stands and for the supporting cross members and the top and bottom plates.

a. Stand/cross U-channels: Is made of (100*50) mm mild steel U-channel cut to required sizes, bolted together to give proper rigidity and easy assembling.

b. Top and bottom plates: Are made of flat plates of 15mm thick low carbon steel to withstand stress due to bending.

2. Load application system: This comprises of load hanger, dead weights and single strand roller chain with sprockets.

3. Strain measuring system: The main mechanism for accurate measurement and recording of the longitudinal deformation of the test-piece is a dial gauge. The dial gauge is calibrated in steps equivalent to an extension of (0.001mm) and the maximum amount of extension, which can be measured is 15mm.

4. Lever (connecting rod): This rod is used to transform movement from the clipper that fix the specimen to the dial gauge. The material of this rod is carbon steel with diameter (d=6mm). The weight of this rod is small compared to the applied load and thus can be neglected.

5. Test- piece grip: The force applied from the hanger to the chain is transmitted to the material through the upper test piece holder. According to ASTM-D 2990, the test piece grip is made of carbon steel (25mm*25mm) with hole drilled on it to accommodate (7mm) diameter test piece.

6. Timer: Is used to record the subsequence time for a known deflection from the dial gauge.

The calibration of the test apparatus which was manufactured in this work was achieved for the creep tests by using the standard device shown in figure (2). Using the same specimen type at the same temperature creep was measured to compare the results with those results obtained from the manufactured device. The comparison is shown in table (1).

Materials and samples preparation

Low viscosity epoxy resin system (Quick mast 105) is presented by mixing two liquid substances (A&B). The substance (A) represents the epoxy material and (B) represents the hardener with percentage of (25%); the final solidified material is rigid. Therefore flexible die is used to prevent the specimen cracking or fracture which may occur after removing the specimen from the die. The time required to solidify this type of material which approximates with 24 hour at room temperature. Hence increasing this temperature reduces the required time for solidification. The second material is the glass fiber which is the most common material used for commercial fiber reinforced polymer composite. In this study, E-glass is used as it enjoys good mechanical properties. The types of E-glass fiber are:

1. Unidirectional oriented with ($\theta=0^o$) as shown in figure (3.a).

2. Woven fabric oriented with ($\theta=0^o$, 90^o) as shown in figure (3.b).

The specimen of composite epoxy material is manufactured by the hand lay-up method. The fiber volume fraction is (30 - 35) %. The die manufactured from plastics plate (called coupon) to give a good surface finish of the test specimen. The mechanical properties of materials are listed in table (2) [10, 11].

Preparation of creep test specimen

There are a number of creep test specimens which are used to evaluate the property of viscoelastic materials. The dimensions of a standard creep test specimen which is selected according to the ASTM - D2990 is shown in figure (4) [12]. The procedure used to execute the creep test involves reading the extension of the specimen at predetermined intervals. After this, the strain of test specimen is calculated during time interval by the following simple strain formula [8]:

$$\varepsilon(t) = \delta(t)/L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

t: the reading time (minute).

$\varepsilon(t)$: the instantaneous strain.

L: the gauge length of the specimen (mm).

Water absorption tests

The effect of water absorption on the creep behavior of composites was investigated. The samples for creep tests of *(30 - 35) %* fiber volume fractions of reinforcement were machined to a size (30cm*25cm* 1.5mm).The specimens were cut from the above size to its standard size then dried at room temperature. The dry specimens were weighed. Water absorption test were conducted by immersing the specimens in the distilled water, acidic water and alkaline water baths at *25 ^oC* for different time durations. After immersing for 24 hr, the specimens were taken out and all surfaces were dried with a clean dry cloth. The specimens were reweighed within 1 min of removing them from the water. The specimens were weighed regularly at 24, 48, 120, 168, 336, and 504 up to 1080 hr exposure. The moisture absorption was calculated by the weight difference. The percentage weight gain was measured using the following equation [13]:

$$m(t) = [(W-W_d)/W_d] * 100 \quad \ldots\ldots\ldots\ldots (2)$$

Where:

W: Weight of moist material.

W_d : Weight of dry material.

Theoretical work

Theory of nonlinear viscoelasticity

Some mathematical models (especially a power function of time) explain the main features of creep behavior of viscoelastic materials with good accuracy both in the early stage and at wide time span. For materials whose creep response may be described by a separable time-independent and time- dependent strain, the following expression has often been found to yield a good description of creep of viscoelastic materials at constant stress levels [14]:

$$\varepsilon(t) = \varepsilon(\sigma)\, t^n \quad \ldots\ldots(3)$$

Where:

$\varepsilon(\sigma)$: time- independent strain (function of applied stress).

n: exponent value(may depends on stress)

The strain functions at any time for nonlinear functions can be evaluated by determining the variables of equations (3).

Rearranging Eq.(3) and taking logarithm yields:

$$Log\, [\varepsilon(t)] = log[\varepsilon(\sigma)] + n \log t \quad \ldots\ldots(4)$$

Thus if {log (ε(t))} is plotted versus {log(t)}for simple experimental creep test data, a straight line of slope (n) is predicted. The viscoelastic behavior can be affected by water absorption and temperature. This will change the properties of the viscoelastic material such as creep compliance and relaxation modulus.

Then Eq.(3) is modified in this work as follows:

$$\varepsilon(t) = \varepsilon\, t^n \quad \ldots\ldots(5)$$

Where:

$\varepsilon(t)$: creep strain function (mm / mm); which can be evaluated from the experimental data.

ε: creep constant which may be taken as a function of creep variables.

n: creep exponent : may be considered as constant or a function of creep variables.

There are some variables affects the creep test, such as (stress, moisture, and temperature), the values of (ε , n) can be suggested in the related functions. To represent the effect of gained moisture content on the creep behavior, the values of (ε, n) in equation (5) can be proposed as a function of (m) and equation (5) will have the following form:

$$\varepsilon(t,m) = \varepsilon(m)\, t^{n(m)} \quad \ldots\ldots(6)$$

Where

ε(m): kernel function at various values of gained moisture content assumed suggest as a polynomial equation from second or third order depending on the fitting of the experimental data, such that:

$$\varepsilon(m)=A_o+A_1m+A_2m^2\ldots+A_wm^w \quad \ldots\ldots(7)$$

n(m): Exponent value depends on moisture gain content, which can be as a polynomial equation from second or third order depending on the fitting of the experimental data, such that:

$$n(m)=F_o+F_1m+F_2m^2..+F_wm^w \quad \ldots\ldots(8)$$

And to analysis the effect of applied stress, the function $\varepsilon(m)$ will be considered as a function of gained moisture content as well as applied stress. Thus it can be denoted by $\varepsilon(m,\sigma)$. That means the polynomial coefficients in equation (7) (A_o , A_1 ,…,A_w) will be written as a function of applied stress:

$$A_o = f_o(\sigma)$$
$$A_1 = f_1(\sigma)$$
$$A_2 = f_2(\sigma)$$
$$\vdots \quad \vdots$$
$$A_w = f_w(\sigma) \quad \ldots\ldots (9)$$

By plotting the coefficients of equation (7) with different values of applied stress yield appropriate equations by fitting the plotted curves. A suggested second or third order polynomial equation gives a good description of functions in equation (9):

$$A_o= f_o(\sigma)=B_o+B_1\sigma+B_2\sigma^2 \ldots+B_w\sigma^w$$
$$A_1=f_1(\sigma)=C_o+C_1\sigma+C_2\sigma^2 \ldots..+C_w\sigma^w$$
$$A_2= f_2(\sigma)=D_o+D_1\sigma+D_2\sigma^2 \ldots+D_w\sigma^w$$
$$\vdots \quad \vdots$$
$$A_w=f_w(\sigma) \ldots\ldots\ldots\ldots(10)$$

Sub equation (10) in equation (7), the following equation will be obtained:

$$\varepsilon(m,\sigma)=\{B_o + B_1\sigma + B_2\sigma^2..+B_w\sigma^w\}+\{C_o+ C_1 \sigma+ C_2\sigma^2 \ldots+C_w\sigma^w\}m +\{D_o+ D_1\sigma + D_2\sigma^2 \ldots.+ D_w\sigma^w\}m^2+ f_w(\sigma)\, m^w \ldots\ldots(11)$$

The same procedure can be used to represent the function of creep exponent (*n*), where the coefficients of polynomial equation (8) (F_o , F_1 , F_2 ,...F_w) can be plotted as a function of different values of applied stress with a polynomial equation as follows:

$$F_o= g_o(\sigma) =H_o +H_1 \sigma+H_2 \sigma^2 \ldots.+H_w \sigma^w$$
$$F_1= g_1(\sigma) =I_o + I_1 \sigma + I_2 \sigma^2 \ldots\ldots+I_w \sigma^w$$
$$F_2 = g_2(\sigma)=K_o+K_1 \sigma+K_2 \sigma^2 \ldots..+K_w\sigma^w$$
$$\vdots \quad \vdots$$
$$F_w = g_w (\sigma) \ldots\ldots\ldots\ldots (12)$$

Substituting equation (12) in equation (8) gives the exponent values as a function of gained moisture content and the applied stress:

$$n(m,\sigma)=\{H_o+H_1\sigma+H_2\sigma^2 \ldots.+H_w\sigma^w\}+\{I_o+ I_1\sigma+I_2\sigma^2 \ldots+I_w\sigma^w\}m+\{K_o+K_1\sigma+K_2\sigma^2 \ldots.K_w\sigma^w\}m^2 \ldots.+g_w(\sigma)m^w \ldots\ldots(13)$$

Furthermore, the creep strain function of equation (6) can be written as a function of time and moisture content as well as the applied stress:

$$\varepsilon(t,m,\sigma) = \varepsilon(m,\sigma)\, t^{n(m,\sigma)} \ldots\ldots\ldots(14)$$

Comparison of experimental and theoretical results

The validate of the general equations which has been derived from experimental data. Epoxy material is taken as an example when immersed in different solutions (*pH=5, 7* and *10*) at stress equals to (*12.74* MPa). The experimental creep strain data of epoxy material has been recorded directly from the experimental tests. However, the theoretical creep strain data of epoxy material has been calculated by substituting different environmental factors in the derived equations. The comparison of these results is listed in table (3).

Results and Discussion

A number of creep specimens have been tested at different values of gained moisture content which depends on the type of solution and the applied stress. The results divided into three groups:

1- Epoxy resin material.

2- Epoxy reinforced with E- glass woven fabric ($\theta=0,90^o$).

3- Epoxy reinforced with unidirectional E- glass fiber ($\theta=0^o$).

Normally increasing the gained moisture content and applied stress lead to an increase in the creep strain. Also the absorbed water content for tested specimens increased with increasing immersion time [14], [15]. Figure (5) shows the experimental creep data at different values of gained moisture content (*m= 1.35%, 1.8% and 1.98%, pH=5*) under different values of applied stress {*σ (MPa) =7.644, 12.74 and 19.11*}. Figure (6) shows the effect of gained moisture content on the creep behavior of resin (*m= 1.24%, 1.9% and 2.3%*) with three applied stresses {*σ (MPa) =*

7.644, 12.74 and 19.11}, (*pH=7*). As compared with that in figure (5), nearly the same creep behavior is observed for small moisture content value (*m=1.24%*). It can be noticed that at (m= 1.9% and 2.3%), the values of creep strain for distilled water (*pH=7*) are higher than that for acidic water (*pH=5*) for the same stress. The values of creep strain for alkaline water (*pH=10*) are higher as compared with solution at (*pH=5, 7*), {see figure (7)}. It is known that the epoxy is more affected by strong acid solution than the other solutions [1]. In this study, the creep behavior of epoxy specimens in alkaline water (*pH=10*) is affected more than those in acidic water because the acid concentration is not enough to degrade the epoxy materials. Figures (8-10) show the experimental creep data of woven fabric E-glass/epoxy composite with different values of gained moisture content, applied stresses and various types of solutions. It is noticed that the creep values increased with increasing the moisture content and the applied stress at the same time for distilled and alkaline water (*pH=7, 10*). According to a comprehensive review on moisture absorption behavior by Mei Li [16] and J. Yao et al. [17], the degradation rate for glass fiber/epoxy composite properties increased as the immersion time in distilled water increased. But G.C. Papanicolaou [18] proved the contrary state that the aging of E-glass fabric/epoxy composite immersed in water path increased with increasing the aging time for (0-24) hr while the increasing of the immersion time above (24 hr) to (504 hr) led to decrease the aging of composite. Also the results of the creep tests on the glass fiber composites obtained by Scott L. Coguill et al. [19] were concluded that the composite required a protective coating to perform well in a high alkaline environment (*pH=10*). On the other hand in acidic water, it is observed that the creep behavior increased at (*m= 1.35% & 1.8%*) while on the contrary, the creep behavior decreased at moisture content (*m= 2%*). This is because the hydrogen bond formation may reach its maximum state due to the finite number of accessible active sites available for H^+ ion. Furthermore, the formation of hydrogen bonds in the network structure caused the material to be less flexible and more rigid [1]. Similar observation was also given by Salar Baghepour et al. [7]. Figures (11-13) show the experimental creep data of unidirectional ($\theta=0^0$) E-glass/epoxy composite materials at different values of gained moisture content, applied stresses and various types of solutions (*pH=5, 7&10*). It is found that the same creep behavior is observed for both unidirectional ($\theta=0^o$) and woven fabric composite materials for small stress ($\sigma=7.644\ MPa$) while large stresses gave a higher creep strain values for woven fabric ($\theta=0^o, 90^o$) composites than that for unidirectional ($\theta=0^o$) fiber composites. Also, the effect of plasticization (the increase in spacing between molecules lead to molecules mobility increases) was greater in E-glass/epoxy composite than in epoxy materials. This probably is due to exposed edges that allow solution to diffuse easily into the composite

compared to the epoxy neat resin. Similar observation was also given by Somjai [1] and Rita Roy et al. [5]. From the experimental creep data of epoxy resin, a general equation can be derived to explain the non linear behavior by using the fitting method. At first, the experimental creep results of epoxy materials are fitted according to eq. (5). Figures (5-13) have been plotted to choose the parameters (ε, n), whereas the parameters have represented as a function of gained moisture content, $\varepsilon(m)$ and $n(m)$ as shown in equations (7 & 8). From the creep strain for each state of stress, the coefficient values of ε(m) and n(m) [(A_o ,A_1 ,A_2 ...A_w) & (F_o ,F_1 ,F_2 , ...F_w)] can be plotted to show the behavior of $\varepsilon(m)$ and $n(m)$ as a function of ($m\%$). The stress effect on those functions can be determined as in eqs. (11 & 13) which leads to final creep strain, eq.(14). The variation of $\varepsilon(m)$ function is plotted in figs. (14-22). Fitting the curve give a simple general formula of $\varepsilon(m)$ as a function of gained moisture content for each stress value and solution type. A polynomial equation satisfied the data of $\varepsilon(m)$ with good fitting. The coefficients of eq. (10) [A_o ,A_1 ,A_2,...,A_w] can be plotted to give those variations as a function of stress. Fitting those curves is expressed by polynomial equation to give the coefficients of eq.(11) [B_w ,C_w ,D_w, ...]. The coefficients of kernel strain function ε (m,σ) are listed in table (4).

On the other hand, The same procedure can be used to represent the function of strain exponent $n(m,\sigma)$, eq.(12), Depending on the experimental data. Figures (23-31) show the variation of strain exponent values with moisture content ($m\%$) at different applied stresses and types of solutions. The final resulted coefficients of strain exponent equation are listed in table (5). Hence, the coefficients of polynomial functions of the developed theoretical creep strain equation are found and listed in the above tables. This general equation give the creep strain as a function of time, moisture content and the applied stress for epoxy composite materials used in this work.

Conclusions

The following conclusions can be derived from the results of experimental and theoretical works for creep behavior of epoxy and E-glass fiber reinforced epoxy composite materials:

1.This work develop a new kernel strain equation $\varepsilon(m,\sigma)$ and strain exponent equation n(m,σ) to describe the creep strain equation $\varepsilon(t,m,\sigma)$ by using polynomial function .

$$\varepsilon(t,m,\sigma) = \varepsilon(m,\sigma)\, t^{n(m,\sigma)}$$

2-Based on the results, the effect of plasticization was greater in E-glass/epoxy composites than in epoxy materials. This is probably due to exposed edges that allow solution to diffuse easily into the composite than the neat resin.

3- The creep strain of unidirectional ($\theta=0^o$) and woven fabric ($\theta=0^o,90^o$) E-glass/epoxy composites immersed in (*HCL*) solution at room temperature initially increase in increasing moisture content ($m\%$) then dramatically decrease because the hydrogen bond formation may reach its maximum state due to finite number of accessible active sites

available for H^+ ion. Furthermore, the formation of hydrogen bonds in the network structure caused the material to be brittle.

4- The effect of (*NaOH*) and (H_2O) solutions on epoxy properties are more than (*HCL*) solution. The properties degradation rates of epoxy are about 2.31% and 1.5% for (*NaOH*) and (H_2O) solutions respectively compared to (*HCL*) solution.

5- The *pH* had different effects on woven fabric composite material in different solutions when the aging time (specimen immersion time in the different solution) increases. In the first week, the creep behavior of woven fabric composite is affected by (*NaOH*) solution more than other solutions because the degradation properties rate is approximated by 25.4%. In the second week, the creep behavior of woven fabric composite is affected by (*HCL*) solution more than other solutions because the degradation properties rate is approximated by 43.4%. In the third week, the creep behavior of woven fabric composite is affected by (H_2O) solution more than other solutions because the degradation properties rate is approximated by 58%.

6- The creep behavior of unidirectional ($\theta= 0^o$) composite material, which is resulted from the effect of different solutions, are the same in the first two weeks. In the third week, the creep behavior is affected by (*NaOH*) solution more than other solutions because the degradation properties rate is approximated by 62.633%.

7- The results showed that (NaOH) solution is more effective than other solutions on the composite viscoelastic behavior. The concluded degradation rates are 36%, 57% and 62.633% for epoxy, woven fabric composite (Mat) ($\theta= 0^o,90^o$) and unidirectional composite ($\theta= 0^o$), respectively.

8- A composite viscoelastic material showed a higher strength compared to epoxy material by 2.56% and 2.98% for woven fabric composite ($\theta=0^o,90^o$) and unidirectional composite ($\theta= 0^o$), respectively.

9- All suggested theoretical equations give a good representation to fit the experimental creep data and can be used to describe long time creep strain.

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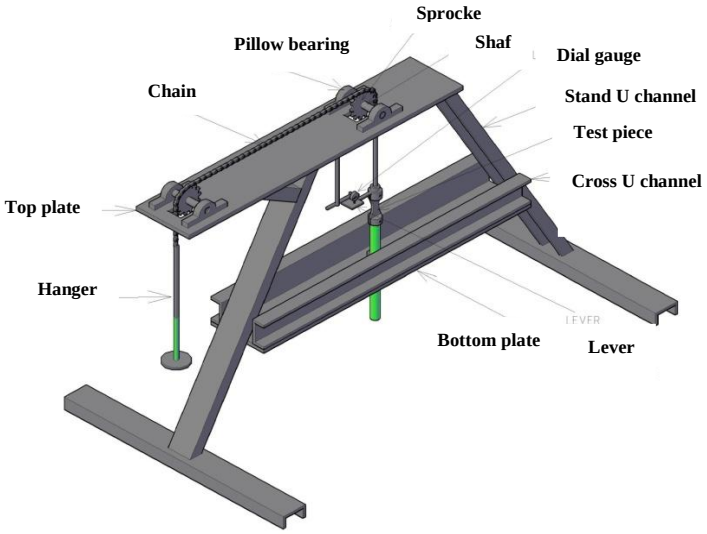


Figure (1) Manufactured creep test mach

Figure (2) Standard creep test machine

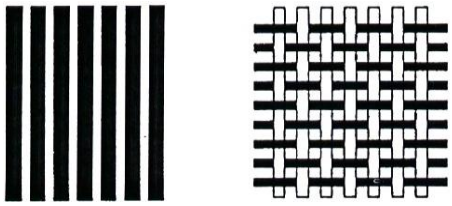
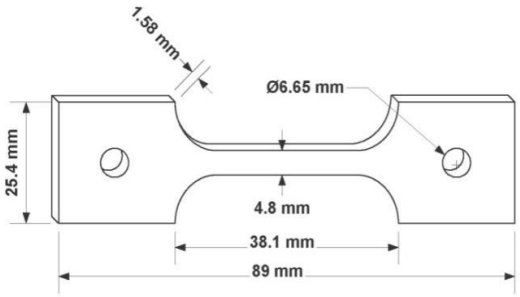


Figure (3.a&b) Unidirectional and woven E-glass fibers.



Figure(4) Standard creep test

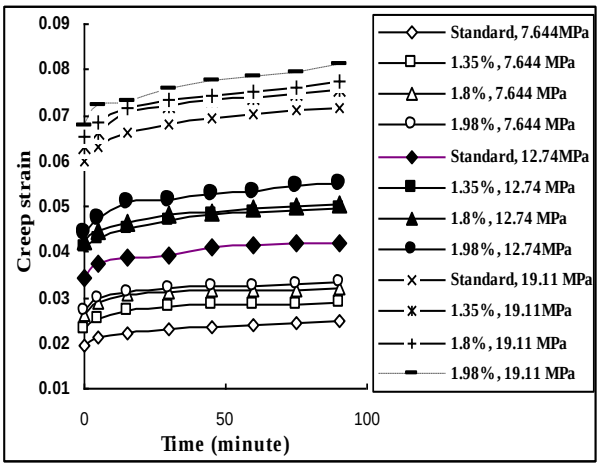


Figure (5) Experimental creep strain data of epoxy material immersed in acidic water.

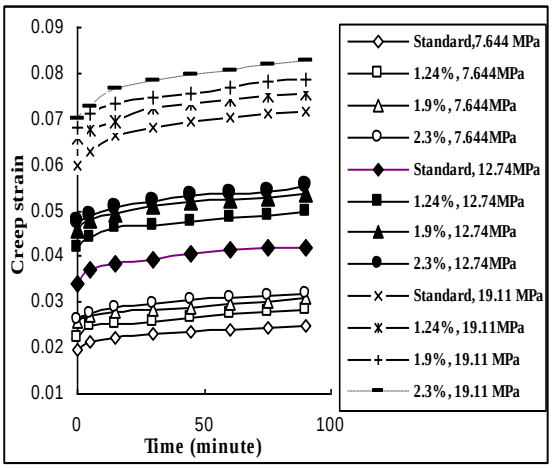


Figure (6) Experimental creep strain data of epoxy material immersed in distilled water.

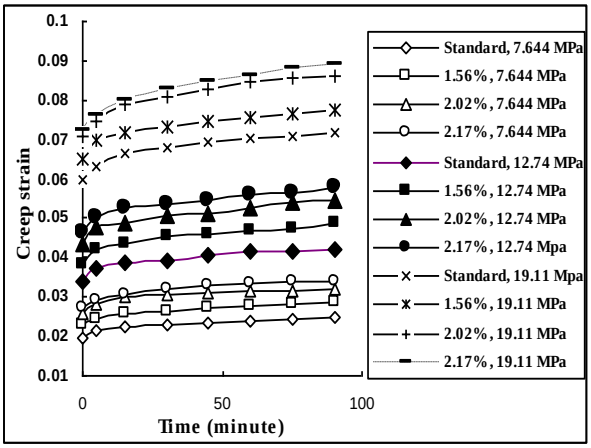


Figure (7) Experimental creep strain data of epoxy material immersed in alkaline water.

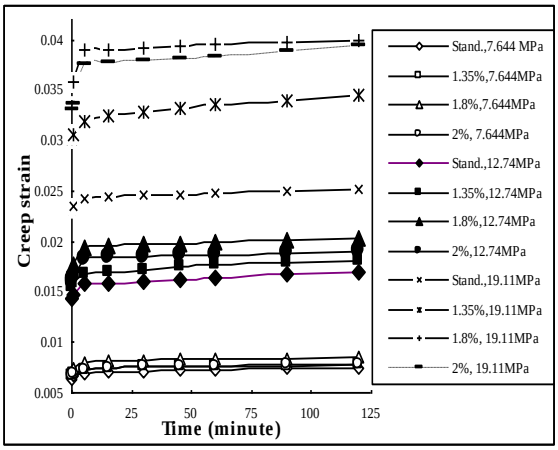


Figure (8) Experimental creep strain data of woven fabric composite immersed in acidic water.

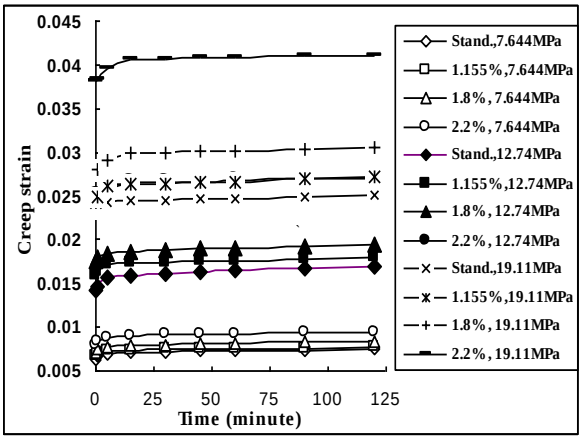


Figure (9) Experimental creep strain data of woven fabric composite immersed in distilled water.

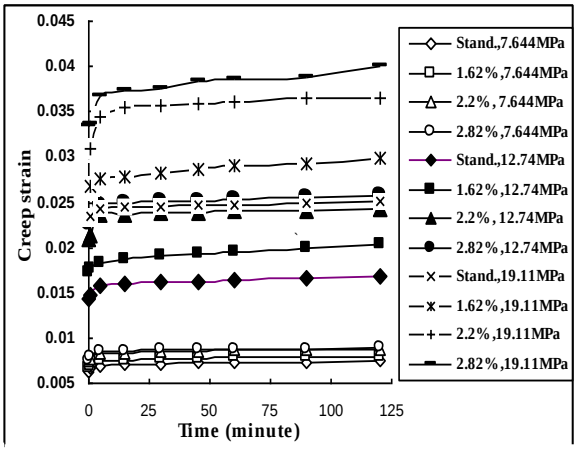


Figure (10) Experimental creep strain data of woven fabric composite immersed in alkaline water.

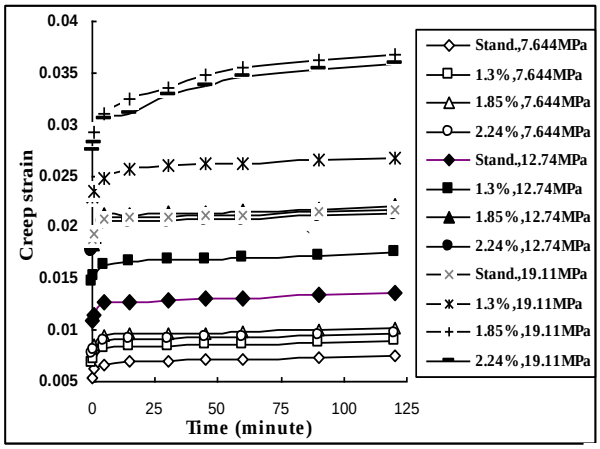


Figure (11) Experimental creep strain data of unidirectional ($\theta=0^o$) composite immersed in acidic water.

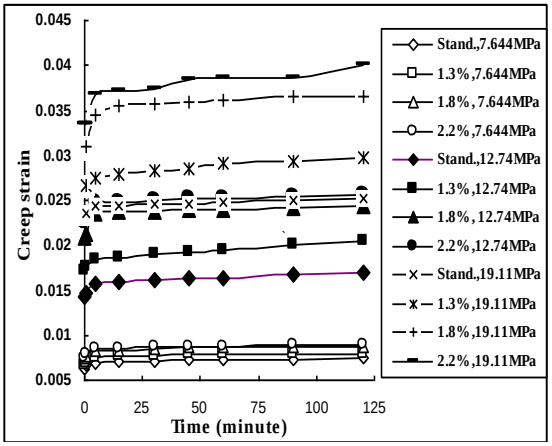


Figure (12) Experimental creep strain data of unidirectional ($\theta=0^o$) composite immersed in distilled water.

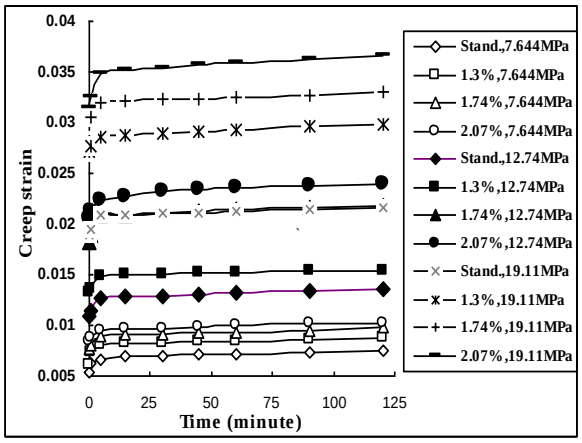


Figure (13) Experimental creep strain data of unidirectional ($\theta=0^o$) composite immersed in alkaline water.

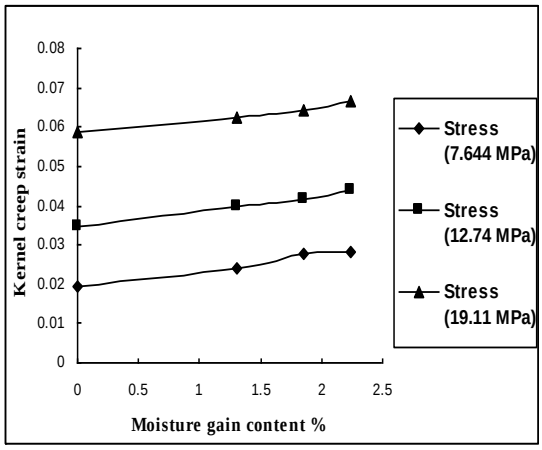


Figure (14) Kernel creep strain *ε (m)* of epoxy material immersed in acidic water.

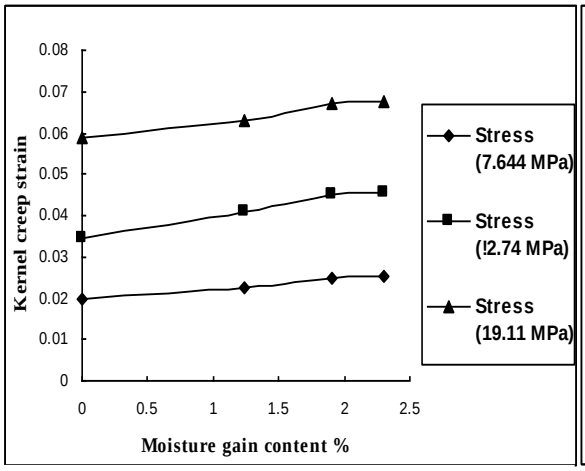


Figure (15) Kernel creep strain *ε (m)* of epoxy material immersed in distilled water.

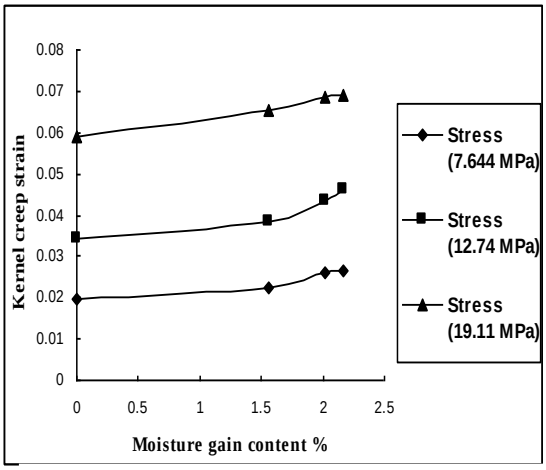


Figure (16) Kernel creep strain *ε (m)* of epoxy material immersed in alkaline water.

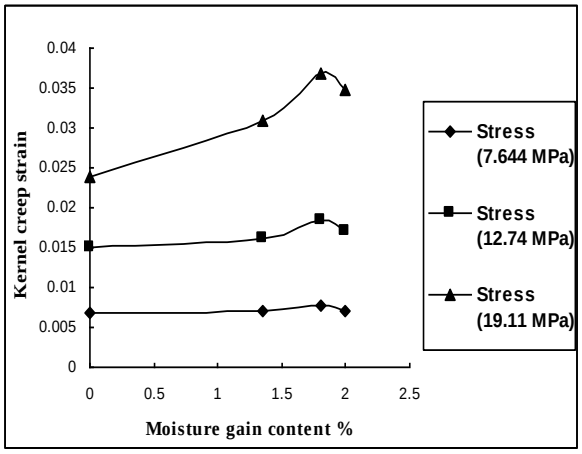


Figure (17) Kernel creep strain *ε (m)* of woven fabric material immersed in acidic water.

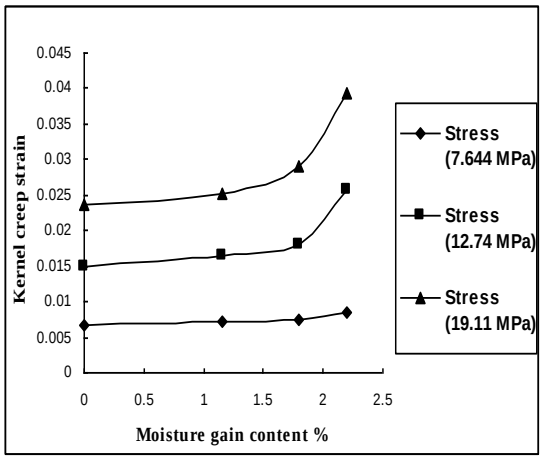


Figure (18) Kernel creep strain *ε (m)* of woven fabric material immersed in distilled water.

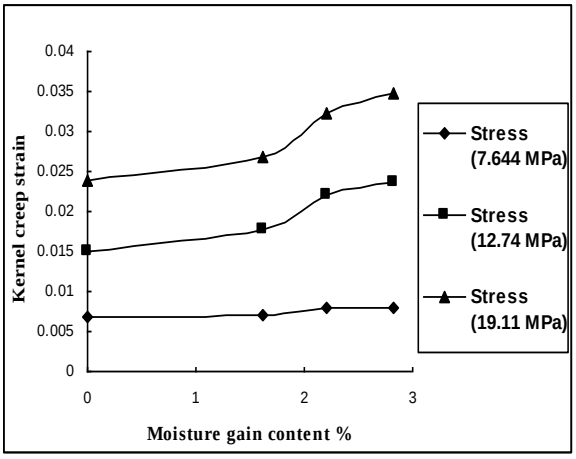


Figure (19) Kernel creep strain *ε (m)* of woven fabric material immersed in alkaline water.

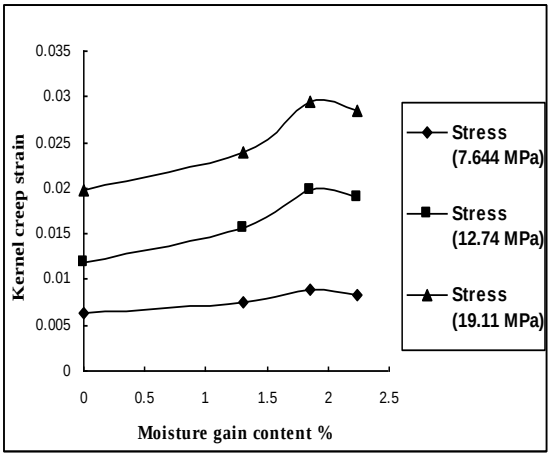


Figure (20) Kernel creep strain *ε (m)* of unidirectional material immersed in acidic water.

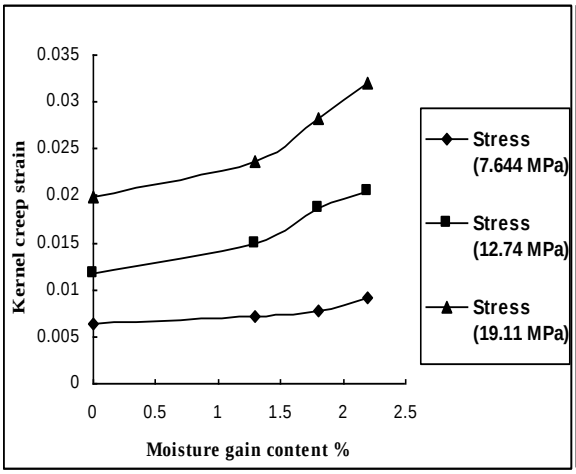


Figure (21) Kernel creep strain *ε (m)* of unidirectional material immersed in distilled water.

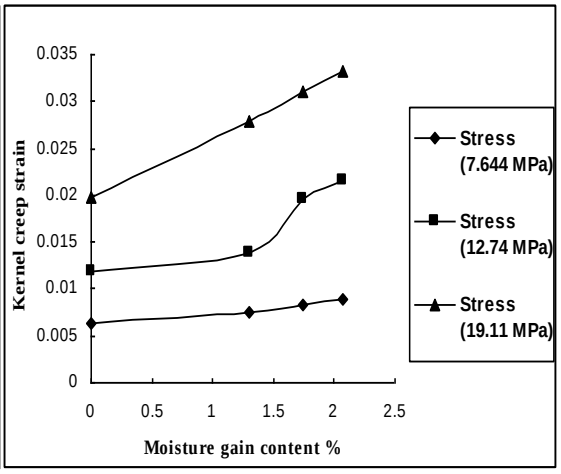


Figure (22) Kernel creep strain *ε (m)* of unidirectional material immersed in alkaline water.

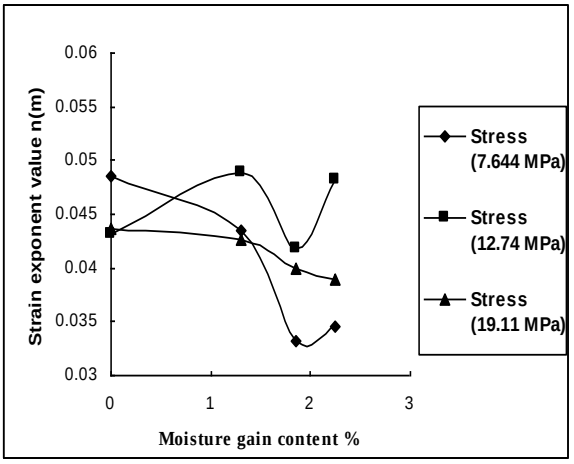


Figure (23) Strain exponent *n (m)* of epoxy material in acidic water.

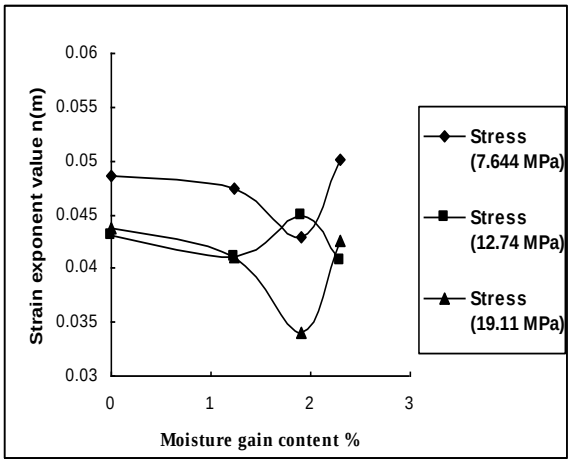


Figure (24) Strain exponent *n (m)* of epoxy material in acidic water.

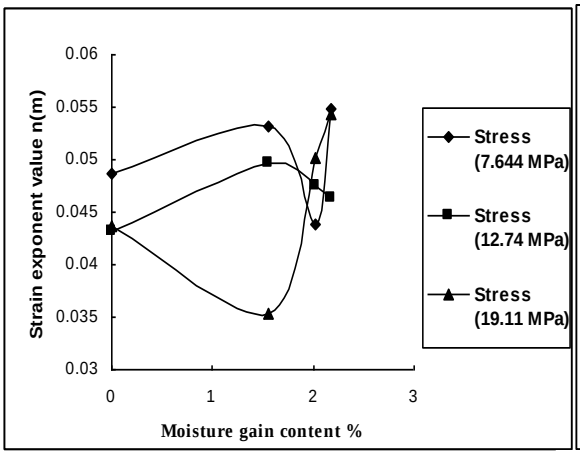


Figure (25) Strain exponent *n (m)* of epoxy material in acidic water.

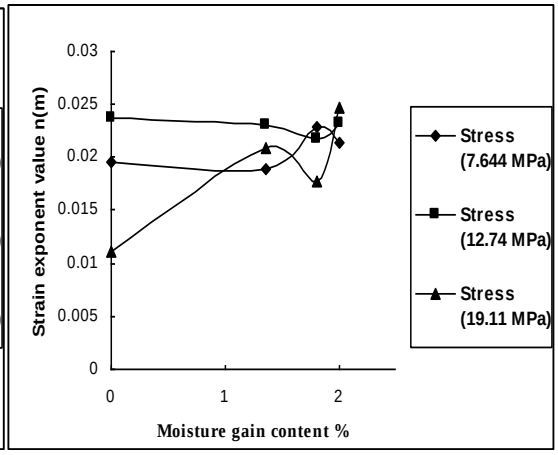


Figure (26) Strain exponent *n (m)* of woven fabric composite material in acidic water.

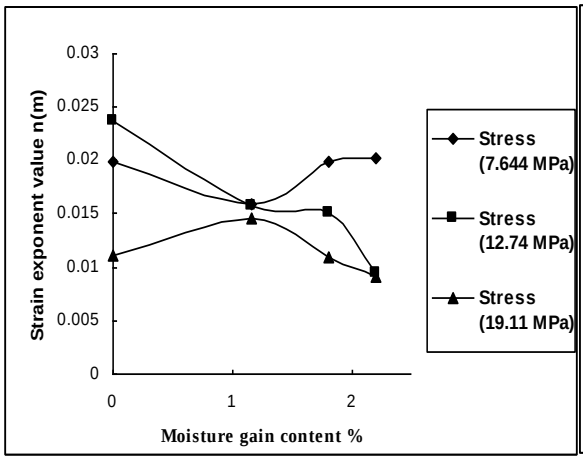


Figure (27) Strain exponent *n (m)* of woven fabric composite material in distilled water.

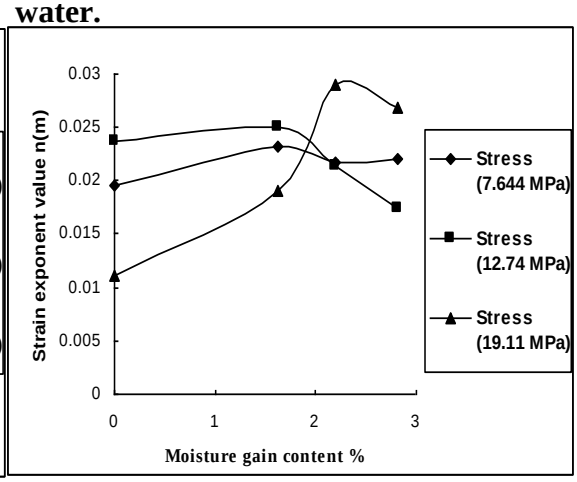


Figure (28) Strain exponent *n (m)* of woven fabric composite material in alkaline water.

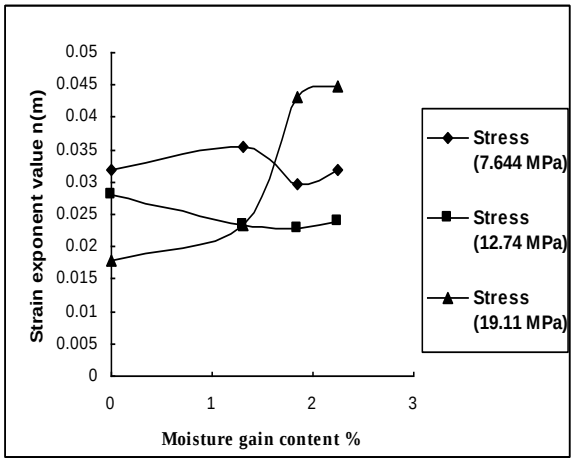


Figure (29) Strain exponent *n (m)* of unidirectional composite material in acidic water.

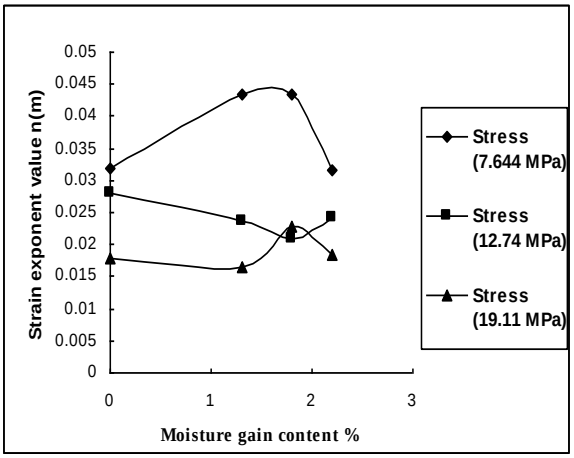


Figure (30) Strain exponent *n (m)* of unidirectional composite material in distilled water.

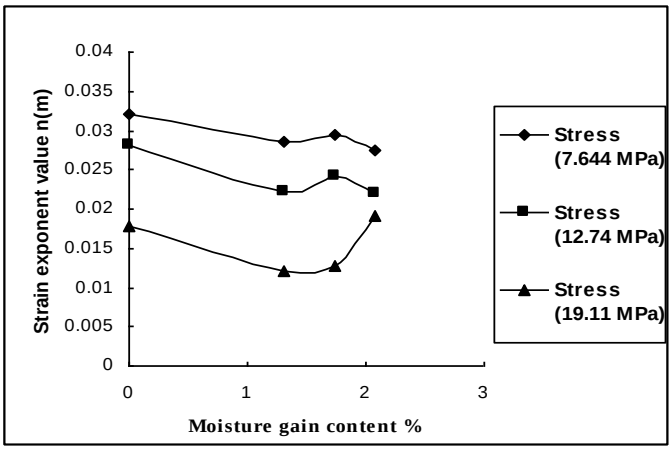


Figure (31) Strain exponent *n (m)* of unidirectional composite material in alkaline water

Table (1) The calibration of manufactured and standard device.

Time (minute)	ε (manufactured device)	ε (standard device)	Percentage of disparity%
0	0.0195	0.0202	3
5	0.0214	0.0217	1.3
15	0.0223	0.0225	0.89
30	0.023	0.0233	1.28
45	0.02354	0.02405	2.12
60	0.02392	0.02435	1.76
75	0.0243	0.0246	1.22
90	0.02468	0.02485	0.684
The average of different values			1.5

Table (2) The mechanical properties of epoxy and E-glass fiber [10, 11]

Property	Epoxy resin	E-glass	Unit
Diameter	……	2.56	μm
Density	1.04	2.56	Mg m^{-3}
Young' modulus	3-6	76	GN m^{-2}
Poisson's ratio	0.38-0.4	0.22	
Tensile strength	>25	1400-2500 (typical) 3500(freshly drawn)	MN m^{-2}
Viscosity	1.0 @35 ^{o}C	…….	poise

Table (3) The results of experimental and theoretical creep strain.

	Acidic water						Distilled water						Alkaline water					
	m=1.35%		m=1.8%		m=1.98%		m=1.24%		m=1.9%		m=2.3%		m=1.56%		m=2.02%		m=2.17%	
Time	ε_{Ex}	ε_{Th}	ε_{Ex}	ε_{Th}	ε_{Ex}	ε_{Th}	ε_{Ex}	ε_{Th}	ε_{Ex}	$\varepsilon_{Th.}$	$\varepsilon_{Ex.}$	$\varepsilon_{Th..}$	$\varepsilon_{Ex.}$	$\varepsilon_{Th.}$	$\varepsilon_{Ex.}$	$\varepsilon_{Th.}$	$\varepsilon_{Ex.}$	$\varepsilon_{Th.}$
5	0.043	0.04508	0.044606	0.0476	0.0474	0.05043	0.044	0.04368	0.048618	0.047518	0.049	0.049327	0.042	0.04156	0.0476	0.0474	0.05005	0.04973
15	0.0452	0.0475	0.0465	0.050	0.0509	0.05 29	0.04616	0.04568	0.0495	0.04991	0.0505	0.05156	0.0436	0.04395	0.0488	0.05	0.05262	0.05244
30	0.047	0.0491	0.048	0.0515	0.0514	0.05461	0.0468	0.04699	0.0513	0.05148	0.052	0.05302	0.0453	0.04553	0.05084	0.05178	0.0538	0.05423
45	0.048	0.05005	0.0489	0.0525	0.05256	0.0556	0.0476	0.04778	0.0518	0.0524	0.05314	0.053894	0.046	0.04648	0.05125	0.05283	0.05435	0.05531
60	0.0486	0.05075	0.0495	0.05317	0.0532	0.05 63	0.0485	0.04834	0.0524	0.0531	0.0538	0.05452	0.04697	0.047169	0.0526	0.05359	0.05576	0.05609
75	0.049	0.05129	0.05	0.05 37	0.05458	0.05688	0.049	0.04879	0.053	0.05363	0.0543	0.055	0.0474	0.047709	0.05388	0.054188	0.05644	0.0567
90	0.0494	0.05174	0.0503	0.05 41	0.055	0.05735	0.05	0.04915	0.0535	0.05407	0.0553	0.05542	0.04893	0.04815	0.05477	0.05467	0.05789	0.0572
Disparity %	3.66%		7.05%		5.3%		1.96%		1.48%		1.39%		1.123%		1.5%		2.31%	

Table (4): The coefficients of kernel creep strain equation $\varepsilon(m,\sigma)$,

Unidirectional ($\theta=0^o$)fiber/epoxy			Woven fabric ($\theta=0,90^o$)fiber/epoxy			Epoxy resin			material
10	**7**	**5**	**10**	**7**	**5**	**10**	**7**	**5**	***pH***
.116 328	$7.45*10^{-5}$	.237	-.007469	-.008 2579	-.007666	0.004967	-0.00360	0.004744	B_o
-.01047	.0006797	-.030312	.002	.002144	.00204	0.001320	0.001569	0.00135	B_1
.0002783	$1.83*10^{-5}$	.0009913	$-1.96*10^{-5}$	$-2.39*10^{-5}$	$-2.07*10^{-5}$	$7.83634*10^{-5}$	$6.8352*10^{-5}$	$7.751*10^{-5}$	B_2
-.079013	-.00 626	.01474	-.002848	.009233	.0117184	0.015890	-0.006 42624	-0.00109	C_o
.0001871	.001053	-.0030619	.0005458	-.0015246	-.00242	-0.00354	0.001598	0.000826	C_1
.0001902	$-3.97*10^{-5}$	$6.39*10^{-5}$	$-1.96*10^{-5}$	$3.43*10^{-5}$	$-4.25*10^{-5}$	0.000147	$-5.4962*10^{-5}$	$-3.72*10^{-5}$	C_2
-.01419	.0003127	-.02 3 44	-.001 5159	-.007 669	-.008 054	-0.008 82	-----	0.001816	D_o
.002677	$2.04*10^{-5}$	.0048713	.000257	.0013016	.0016855	0.002169	-----	-0.0002676	D_1
-.0001	$5.89*10^{-6}$	-.000113	$5.77*10^{-6}$	$-2.98*10^{-5}$	.0001212	$-8.69*10^{-5}$	-----	$1.1886*10^{-5}$	D_2
-----	-----	.0063817	-----	-----	.001915	-----	-----	-----	E_o
-----	-----	-.0013435	-----	-----	-.0004273	-----	-----	-----	E_1
-----	-----	$3.17*10^{-5}$	-----	-----	$-3.85*10^{-5}$	-----	-----	-----	E_2

Table(5): The coefficients of exponent equation $n(m,\sigma)$, eq.(13).

Unidirectional ($\theta=0^o$)fiber/epoxy			Woven fabric ($\theta=0,90^o$)fiber/epoxy			Epoxy resin			material
10	**7**	**5**	**10**	**7**	**5**	**10**	**7**	**5**	***pH***
-.0103703	-.00 8945	-.01037	.0307977	.0307977	.030 797	0.06655	0.0665792	0.0665917	***Ho***
.0005783	.0055971	.0057835	.0007148	.0007148	.0007149	-0.000312	-0.003122	-0.003 124	H_1
-.000244	-.0002382	-.000244	$-7.29*10^{-5}$	$-7.29*10^{-5}$	$-7.29*10^{-5}$	0.0001	0.0001	0.000101	H_2
-.042864	.053786	-.135906	-.077109	-.188 709	.072113	0.936701	0.301484	-0.095763	I_o
.01159	-.014636	.0115314	.019237	.0329178	-.0021832	-0.11264	-0.0 4994	0.025998	I_1
-.0005807	.0006577	$6.02*10^{-5}$	.0008315	-.001334	-.0002798	0.003132	0.001895	-0.001081	I_2
.0493208	-.04755	.17618	-.093289	.321945	-.0423903	-1.0 7759	-0.3 7539	0.071495	K_o
-.0122034	.0134309	-.016 514	.023	-.0532292	-.004 577	0.133818	0.061921	-0.02411	K_1
.0006047	-.000 6075	$4.61*10^{-5}$	-.0010197	.0020547	.0005965	-0.00388	-0.00 2355	0.001044	K_2
-.009449	.0164066	-.050 592	.0281756	-.105789	.0094426	0.30020	0.10750	-0.0 206	L_o
.0023838	-.00 415	.0047209	.006942	.0170972	.0015031	-0.03811	-0.0 1768	0.006748	L_1
-.0001213	.0001795	$-8.9*10^{-6}$	.0003126	-.0006469	-.0001662	0.001139	0.000672	-0.0 0029	L_2