THE EFFECT OF WATER ACIDITY LEVEL AND MOISTURE PERCENTAGE ON THE CREEP BEHAVIOR OF COMPOSITE MATERIAL +

تأثير النسبة المئوية لمستوى الحموضة والرطوبة على تصرف الزحف للمادة المركبة

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Abstract:

The creep behavior for unidirectional and bidirectional fiber composite material has been studied experimentally under the effect of different water acidity level (pH=5,7&10) and moisture percentage (m= 1.24, 2.02 & 2.65%). It has been observed that the creep strain increase when the moisture percentage increased and decreased with increasing the acidity level. Different values of the applied stresses are tested which gave an increasing in the creep strain values with increasing the stress. The experimental creep data can be fitted with the general exponent creep equation. This equation is modified where the effect of moisture percentage and the applied stress on the creep strain are suggested as variables in the creep strain equation. The suggested equation gives a good criteria to be used to describe long time of creep strain in this work.

***Key word*: creep, acidity level, moisture, composite material.**

المستخلص:

تم دراسة تصرف الزحف للمواد المركبة ذات الياف أحادية وثنائية الاتجاه عمليا" تحت تأثير مستويات حامضية (pH=5,7&10) ونسب رطوبة مختلفة (m= 1.24, 2.02 & 2.65%). لوحظ زيادة بأنفعال الزحف بزيادة نسب الرطوبة ونقصانه بزيادة المستوي الحامضي. استخدمنا قيم مختلفة من الاجهاد المسلط والذي اعطى زيادة بقيم انفعال الزحف بزيادته. قيم الانفعال العملية يمكن ان توافق مع معادلة الزحف الأسية العامة. هذه المعادلة عُدلت حيث تم اقتراح متغيرات نسب الرطوبة و الاجهاد المسلط في معادلة انفعال الزحف. المعادلة المقترحة اعطت معيار جيد استخدم لوصف انفعال الزحف لمدى طويل من الزمن في هذا البحث.

Introduction:

Creep is the time-dependent plastic strain at constant stress and temperature.One of the unique improvements in polymer nanocomposites has been detected. It was found out that the nanoparticles contributed to a remarkable reduction of the creep rate under various

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constant loads at both temperature levels.[1]. It was found that the creep resistance of nanocomposites was significantly enhanced by nanoparticles without sacrificing the tensile properties[2]. Observed enhancement of creep resistance, which are: (1) fairly good interfacial strength between MWNTs and polymer matrix, (2) increasing immobility of amorphous regions due to nanotubes acting as restriction sites, and (3) high aspect ratio of MWNTs. DSC results showing crystallinity changes in the specimens before and after creep deformation present evidence to confirm these mechanisms[3]. presents a model using finite element method to study the response of a typical commercial corrugated fiberboard due to an induced moisture function at one side of the fiberboard. The results generated from the finite element model showed an excellent agreement with the experimental [4]. An ultrasonic guided wave scan system was used to nondestructively monitor damage over time and position in a C/enhanced SiC sample that was creep tested to failure at 1200^{o}C in air at a stress of 69 MPa (10 ksi). The use of the guided wave scan system for mapping evolving oxidation profiles (via porosity gradients resulting from oxidation) along the sample length and predicting failure location was explored [5]. The long-term creep behavior and creep-rupture properties were investigated for two systems of E-glass reinforced polymer composites: E-glass/polyurethane composite and E-glass/epoxy composite. The two composite systems showed similar short-term mechanical properties, however their long-term creep properties were quite different [6]. By comparison between the applied techniques it seems reasonable to assume that the "diffusional" technique due to its inherent icroscopic mass transport processes in form of H2O molecules diffusion and therefore its ability to "detect" microstructural detects on a much lower scale can give a better approach to the damage accumulation phenomena[7]. It was observed that water uptake have an effect on the creep behaviuor of glass-epoxy composite material[8]

(2)Experimental work

(2-1)Specimen preparation

The material used in this work is made from composite material which consists of:

i. matrix: polyester
ii. fiber: fiber glass and included:

- Unidirectional fiber as in figure (1-a).
- Bidirectional fiber as in figure (1-b).

Hence two type of composite material used to make the specimens of creep test. The first is of unidirectional fibers and the second of bidirectional fibers. Figure (2) shows the standard creep test specimen.

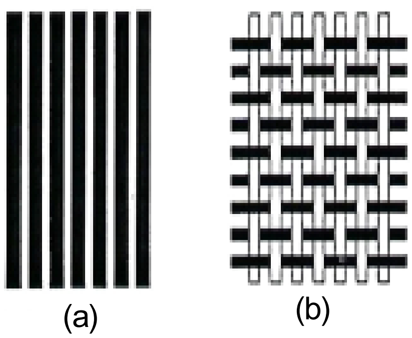


Fig.(1) (a) unidirectional and (b) bidirectional fibers.

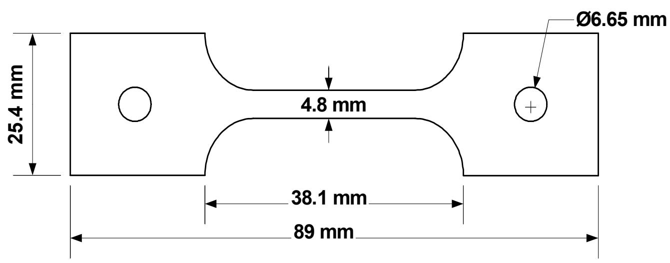


Fig.(2) Standard creep test specimen[9]

(2-2)Specimen moisture:

A finite number of creep specimens have been immersed in three type of liquid (have different acidity, pH.) so as to study the effect of moisture percentages on the creep behavior of composite material. The moisture absorption was calculated by the weight difference. The percentage weight gain of samples was measured for three type of liquid with different pH listed in table (1) as follows:

Table (1) level of acidity

Liquid type	Acidic water	Polish water	Alkaline water
pH	5	7	10

The moisture percentages used in this work for each liquid type are presented in table (2):

Table (2) moisture percentages

m%	1.24	2.02	2.65

(2-3)Creep test:

Each specimen has been tested under constant load, where the instantaneous deformation (□) is recorded. The creep strain at any time is calculated by divided the instantaneous deformation by the original specimen length (L).
Figure (3) shows the creep test equipment.
The deformation increased during time under the constant applied load such that the deformation and the creep strain will be as a function of time.
Three values of the applied stress are used to study those effect on the creep behavior (σ_1=10.192 MPa, σ_2=12.74 MPa, σ_3=16.564 MPa). Those values are calculated by divided the applied load by the cross sectional area. The specimens of unidirectional fiber are made such that the fiber in the direction of the applied stress.

Fig.(3) creep test equipment

(3)Theoretical analysis:

A different equation type has been suggested to fit the experimental creep strain data [10]. One of the most creep strain equation which give a good criteria to describe the creep behavior is:

$\varepsilon(t)=\varepsilon\, t^{n}$ (1)

Where:

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

$\varepsilon(t)=\delta(t)/L$ (2)

$\delta(t)$: the instantaneous deformation at each recorded time (mm).

L: the original length of standard creep strain specimen(mm).

ε: creep constant and may be take as a function of creep variables.

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

If the stress and moisture give an effect on the strain and exponent, the theoretical formula of strain and exponent will be as a function of stress and moisture as follow:

(3-1)The suggested functions for (ε, n):

To analysis the effect of moisture percentage on the creep behavior, the values of (ε, n) in equation (1) are suggested as a function of (m) and equation (1) will have the following form:

$\varepsilon(t,m)=\varepsilon(m)\ t^{n(m)}$ (3)

In this work, the function $\varepsilon(m)$ is suggested as a polynomial third order equation, such that:

$\varepsilon(m)= c_o+c_1m+c_2m^2+c_3m^3$ (4)

And to analyses the effect of stress, the function $\varepsilon(m)$ will be considered as a function of moisture percentage as well as the applied stress $\varepsilon(m,\sigma)$.

That means each constant in eq.(4) (c_o,c_1,c_2,c_3) will be as a function of stress:

$c_o= f_o(\sigma)$

$c_1= f_1(\sigma)$

$c_2= f_2(\sigma)$ (5)

$c_3= f_3(\sigma)$

Plotting the constants (c_o,c_1,c_2,c_3) against the applied stress will give those equations with simple curve-fitting.

A suggested 2nd order polynomial equation is assumed for equation (5):

$c_o(\sigma)= f_o(\sigma)=A_o+A_1\sigma+A_2\sigma^2$

$c_1(\sigma)= f_1(\sigma)=B_o+B_1\sigma+B_2\sigma^2$

$c_2(\sigma)=f_2(\sigma)=D_o+D_1\sigma+D_2\sigma^2$ (6)

$c_3(\sigma)= f_3(\sigma)=E_o+E_1\sigma+E_2\sigma^2$

sub eq.(5) in eq.(4) gives:

$\varepsilon(m,\sigma)=f_o(\sigma)+f_1(\sigma)m+f_2(\sigma)m^2+f_3(\sigma)m^3$ (7)

Sub the functions $(f_o(\sigma),f_1(\sigma),f_2(\sigma),f_3(\sigma))$ from eq.(6) in eq.(7) gives:

$$\varepsilon(m,\sigma)=A_o+A_1\sigma+A_2\sigma^2+\{B_o+B_1\sigma+B_2\sigma^2\}m+ \{D_o+D_1\sigma+D_2\sigma^2\}m^2+\{E_o+E_1\sigma+E_2\sigma^2\}m^3 \quad (8)$$

The values of constants ($A_o,A_1,A_2,B_o,B_1,B_2,D_o,D_1,D_2,E_o,E_1$ and E_2,) in eq.(8) are calculated by curve-fitting method.

The same above suggested procedure can be used to give the function of creep exponent (n). Plotting the values of exponent (n) versus the moisture percentages (m) values can be give the variation of (n) with (m) and the fitting function n(m) will suggested for smooth fitting. In this work the suggested formula has a linear equitation:

$$n(m)=F_o+F_1m \quad (9)$$

Where the values of (F_o, F_1) can be found as a function of stress with 1st and 2nd order polynomial equation respectively as follows:

$$F_0(\sigma)=g_1(\sigma)=G_o+G_1\sigma$$
$$F_1(\sigma)=g_2(\sigma)=H_o+H_1\sigma+H_2\sigma^2 \quad (10)$$

Substituting eq.(10) in (9) gives the exponent as a function of moisture and the applied stress :

$$n(m,\sigma)=\{G_o+G_1\sigma\}+\{H_o+H_1\sigma+H_2\sigma^2\}m \quad (11)$$

On the other hand, the creep strain function eq.(3) can be written as a function of moisture percentage and the applied stress as well as the instantaneous time:

$$\varepsilon(t,m,\sigma)=\varepsilon(m,\sigma)\ t^{n(m,\sigma)} \quad (12)$$

Sub equation (8 &11) in (12), the general suggestion creep strain equation in this work will have the following form:

$$\varepsilon(t,m,\sigma)=[A_o+A_1\sigma+A_2\sigma^2+\{B_o+B_1\sigma+B_2\sigma^2\}m+\{D_o+D_1\sigma+D_2\sigma^2\}m^2+\{E_o+E_1\sigma+E_2\sigma^2\}m^3]*t^{\{Go+G1\sigma+G2\sigma2\}+\{Ho+H1\sigma+H2\sigma2\}m} \quad (13)$$

(4)Results:

Creep specimens test results is divided into two groups:

- Composite material specimens with unidirectional fibers, fig. (4-12).
- Composite material specimens with bidirectional fibers, fig. (13-21).

The effect of applied loads, moisture percentages and the liquid type (pH number) has been studied.

Figure (4) shows the effect of moisture percentage on the creep behavior for unidirectional fiber with stress (σ_1=10.192 MPa), (pH=5). In general, the creep strain rate have a large value ($4*10^{-4}$ mm/min) at the initial creep time and decreased sharply to ($2.5*10^{-5}$ mm/min) for the other time of creep test. Increasing the moisture percentages results in increase the creep value for the same time value. And this phenomena increase more as the moisture percentage increased as comparing the strain at (m=1.24%, 2.02% and 2.65%).

Normally, increasing the applied load results in increase the creep strain as it has been shown in fig. (4,5&6) for each moisture values.

Fig.(7) shows the effect of moisture percentages on the creep behavior for unidirectional fiber with stress (σ_1=10.192 MPa), (pH=7). As comparing with those of fig.(4), nearly the same creep behavior for small moisture values (m=1.24%, 2.02%). It has been observed that at (2.65%) the values of creep strains are higher for (pH=5) than that for (pH=7) for the same stress.

The same behavior has been shown in the other values of stress as in fig. (8&9) compared with that of fig.(5&6).

The values of creep strain are observed lower for (pH=10) as comparing with (pH=5&7) for the same stress, figs. (10, 11 &12).

Fig.(13-21) shows the creep behavior for bidirectional fiber with different moisture, stress and Ph. The creep values increase with increasing the moisture percentage and the applied load at the same time for each liquid type.

Approximately, the same creep behavior is observed for both samples unidirectional and bidirectional fibers for small stress. But, large stress gives a higher creep strain values for bidirectional fiber than that for unidirectional fibers.

All curves in each figure (4-21) have been fitted according to eq.(1) which gives a good fitting formula. Those curves can be formulate with a union equation by named the constants in eq.(1) initially as a function of moisture percentage , *ε(m)* and *n(m),* eq.(4 &9). From the creep strain for each state of stress, the constants values of *ε(m)* and *n(m)* can be plotted in a figure to show the behavior *ε(m)* and *n(m)* as a function of (m) and then find those functions. And then find the stress effect on those function as in eq.(8 &11) which leads to final creep strain equation(12).`

The variation of *ε(m)* function is plotted in figures(22-27). Fitting the curve give a simple general formula of *ε(m)*as a function of moisture percentage for each stress value and liquid type. A third order polynomial equation satisfied the data of *ε(m)* with smooth fitting. The constants of eq.(6) can be plotted in another curves to give those variation as a function of stress. figs.(28-31) represent the variation of constants (C_n) with stress. Fitting those curves gives the constants of equation(8).

The constants of strain function *ε(m,σ),* eq.(8), are listed in table(3) below:

Table (3): constants of equation (8)

Fiber	pH	A_o	A_1	A_2	B_o	B_1	B_2	D_o	D_1	D_2	E_o	E_1	E_2
Unidirectional	5	**-.72**	**.114**	**-.004**	**.157**	**-.027**	**.0012**	**-.97**	**.156**	**-.006**	**.33**	**-.053**	**.002**
	7	**-.003**	**.014**	**-.0006**	**-1.02**	**.12**	**-.003**	**1.4**	**-.18**	**.006**	**-.36**	**.046**	**-.001**
	10	**-.003**	**.014**	**-.0006**	**2.88**	**-.43**	**.015**	**-2.83**	**.42**	**-.015**	**.66**	**-.099**	**.0035**
Bidirectional	5	**.356**	**-.038**	**.00125**	**1.03**	**-.14**	**.005**	**.356**	**-.038**	**.0012**	**.332**	**-.048**	**.0016**
	7	**.356**	**-.038**	**.00125**	**-.07**	**-.004**	**.0005**	**.02**	**.008**	**.0006**	**-.01**	**-5e-4**	**9e-5**
	10	**.356**	**-.038**	**.00125**	**1.26**	**-.17**	**.006**	**-1.4**	**.193**	**-.007**	**.32**	**-.044**	**.0015**

On the other hand, to evaluate the exponent function, *n(m),* each value of the exponent (n) found from the experimental data, figures(4-21) show the strain rate against the moisture percentage for each stress value, figures (32-37), in which a linear relationship as presented as in eq.(9). The constants of the previous equation (F_o & F_1) are plotted in figures (38 &39) respectively with the variation of stress to find those functions as a function of stress. As it has been observed from the previous figures, the first constant, F_o, give a first order equation and the other, F_1 give a second order polynomial equation as the suggested equation, eq.(10).

Using the curve-fitting method, the constants of eq.(10) for the exponent function, *n(m,σ),* eq.(11) are listed in table (4)

Table (4) constants of equation (11)

fiber	pH	G_o	G_1	H_o	H_1	H_2
Unidirectional	**5**	**-6.2**	**.12**	**.778**	**-.114**	**.005**
	7	**-6.48**	**.138**	**-.339**	**.0784**	**-.0033**
	10	**-6.43**	**.135**	**1.054**	**-.117**	**.0035**
Bidirectional	**5**	**-6.19**	**.121**	**1.836**	**-.25**	**.00916**
	7	**-6.15**	**.12**	**.29**	**-.016**	**.00024**
	10	**-6.13**	**.118**	**1.3888**	**-.162**	**.0054**

Hence, the constants of the suggested theoretical creep strain equation are found and listed in the above tables. This function gives the creep strain along any time as a function of time, moisture percentage as well as the applied stress for the composite material used in this work. Approximately, the slope of curves(strain rate) for each values of (m) at a certain time have the same value in figs(4-21).

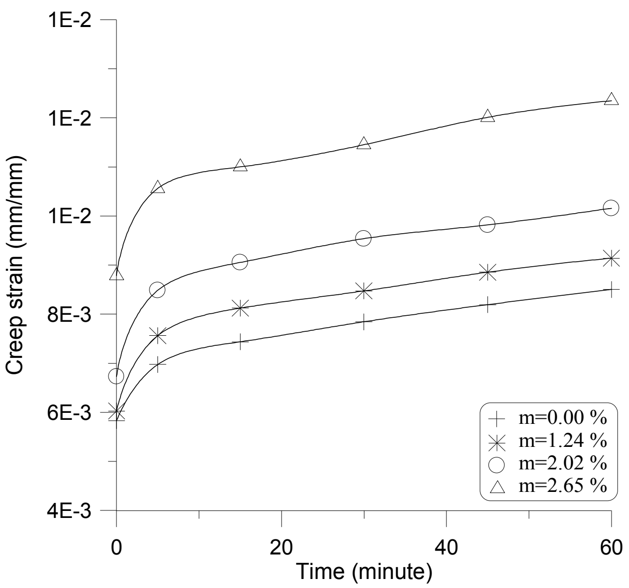


Fig.(4) creep strain for unidirectional fiber- Acidic water and σ_1=10.192 MPa.

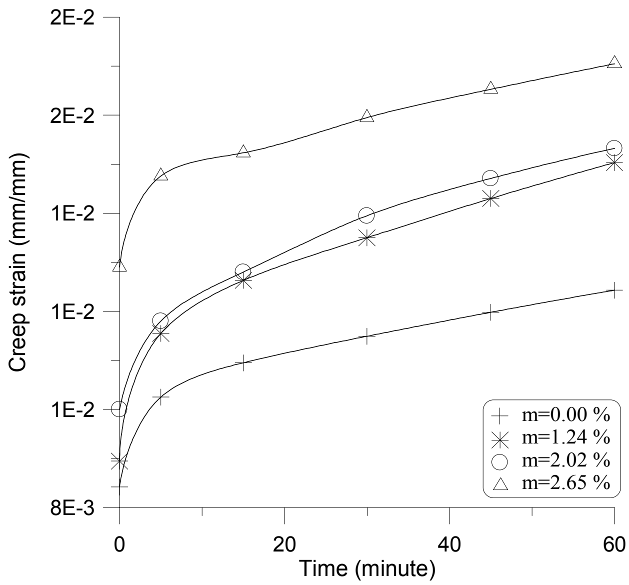
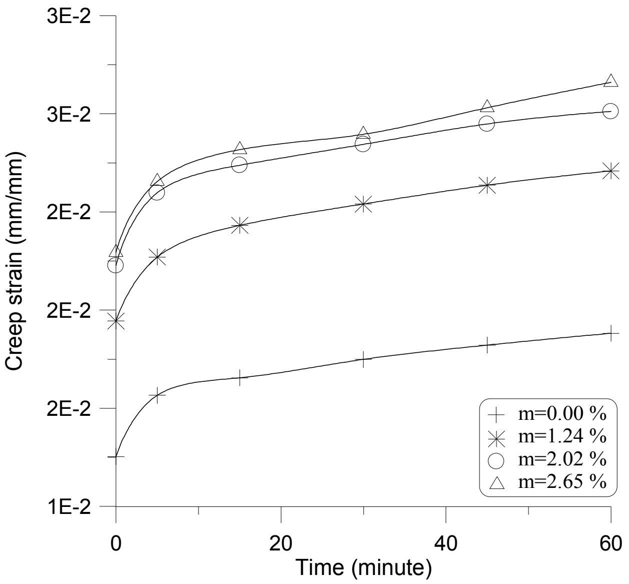
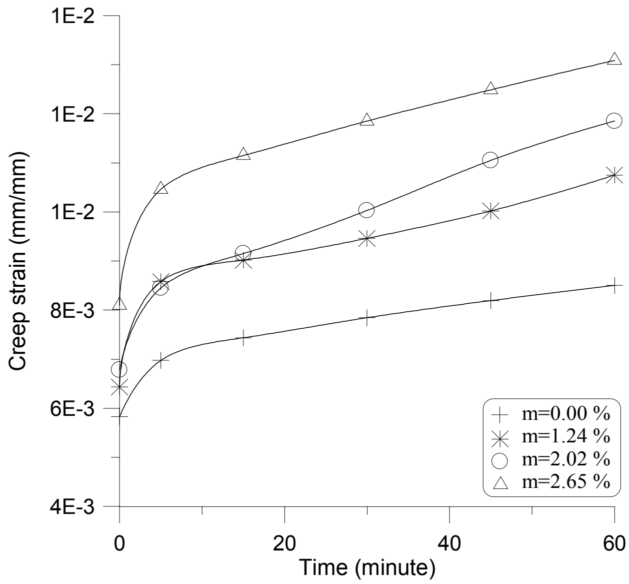


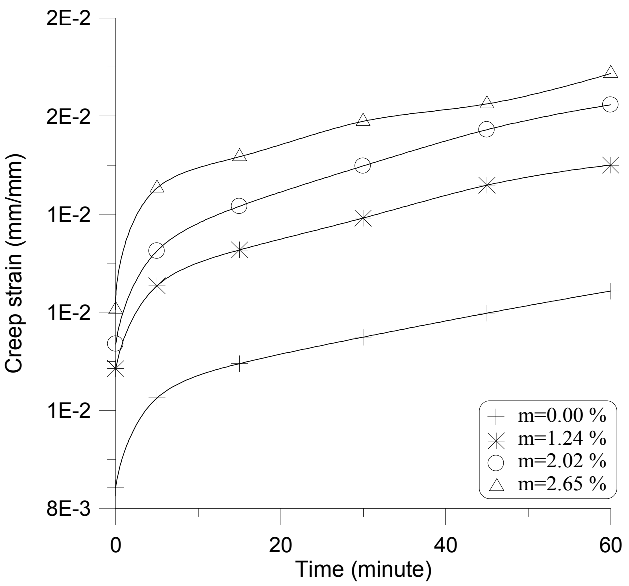
Fig.(5) creep strain for unidirectional fiber- Acidic water and σ_2=12.74 MPa.



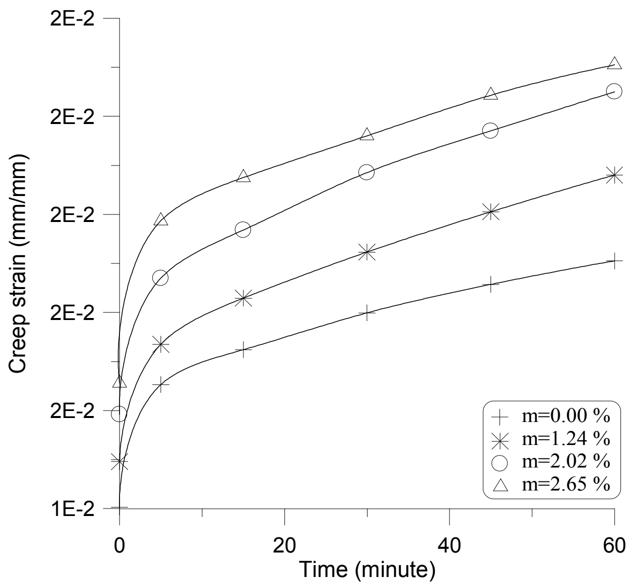
<u>Fig.(6)</u> creep strain for unidirectional fiber- Acidic water and σ_3=16.564 MPa.



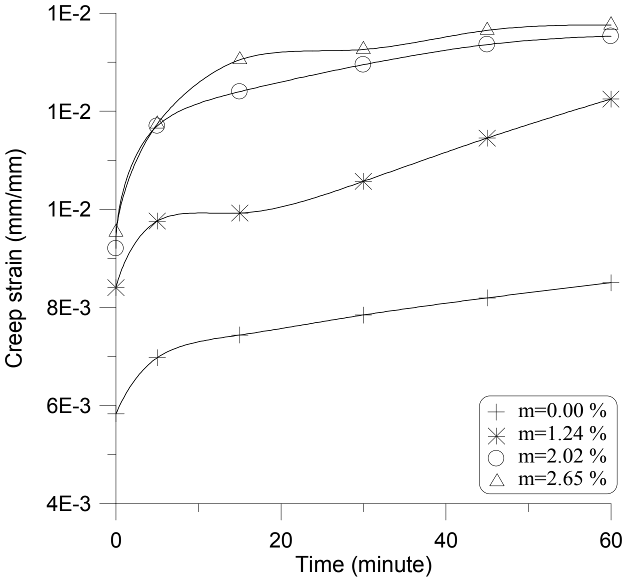
<u>Fig.(7)</u> creep strain for unidirectional fiber- fiber- Polish water and σ_1=10.192 MPa.



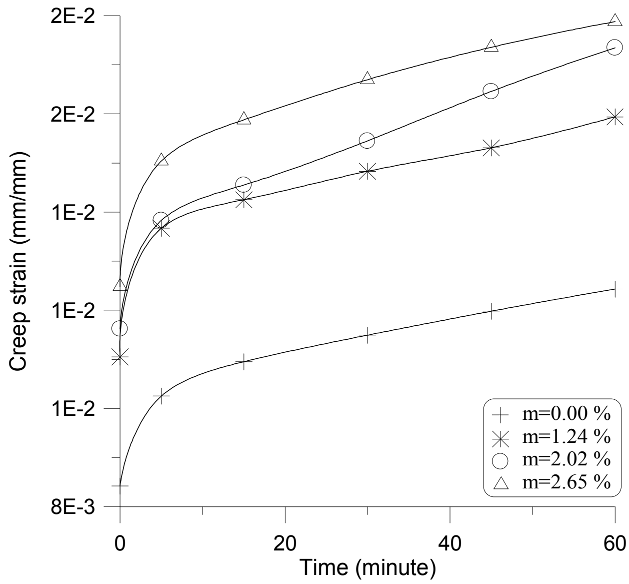
<u>Fig.(8)</u> creep strain for unidirectional fiber- Polish water and σ_2=12.74 MPa.



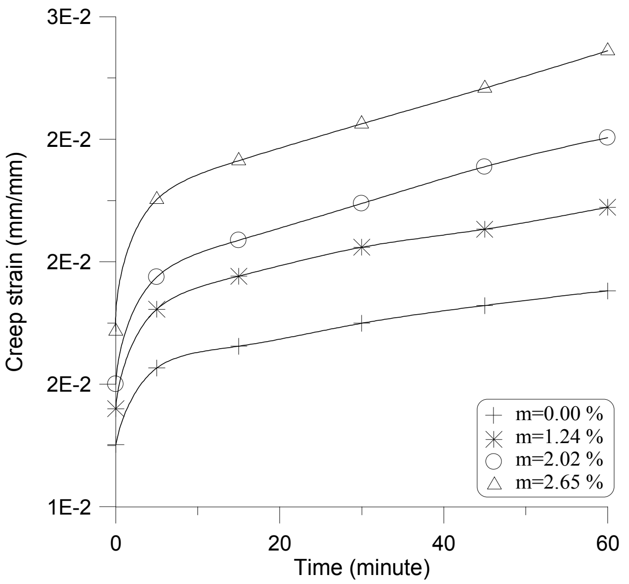
<u>Fig.(9)</u> creep strain for unidirectional fiber- Polish water and σ_3=16.564 MPa.

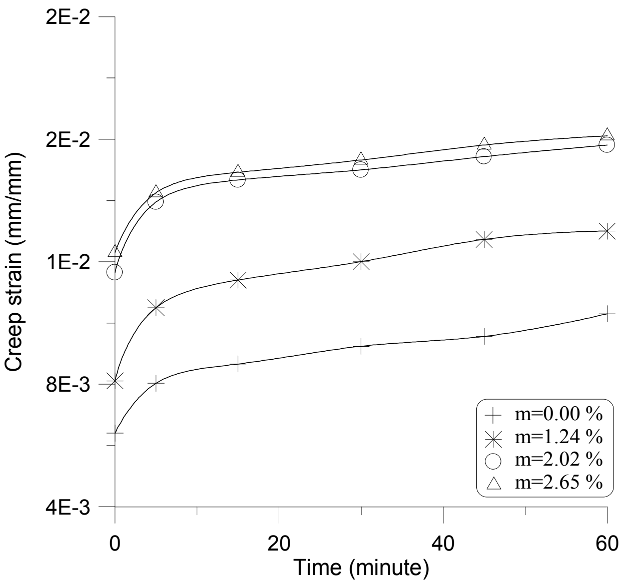


<u>Fig.(10)</u> creep strain for unidirectional fiber-Alkaline water and σ_1=10.192 MPa.



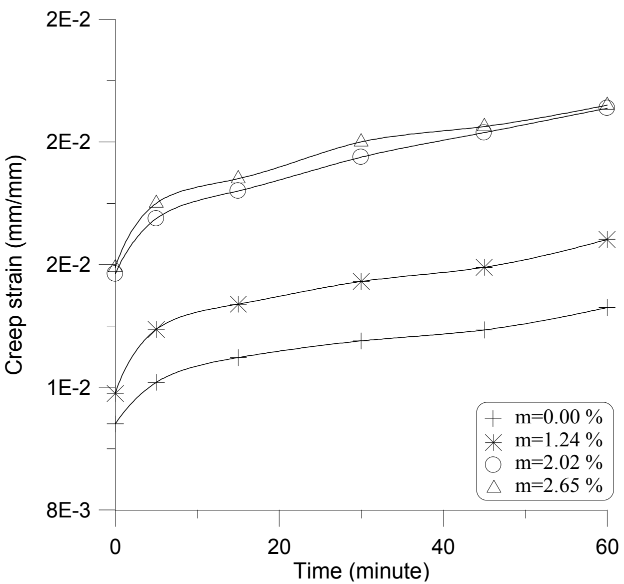
<u>Fig.(11)</u> creep strain for unidirectional fiber- Alkaline water and σ_2=12.74 MPa.

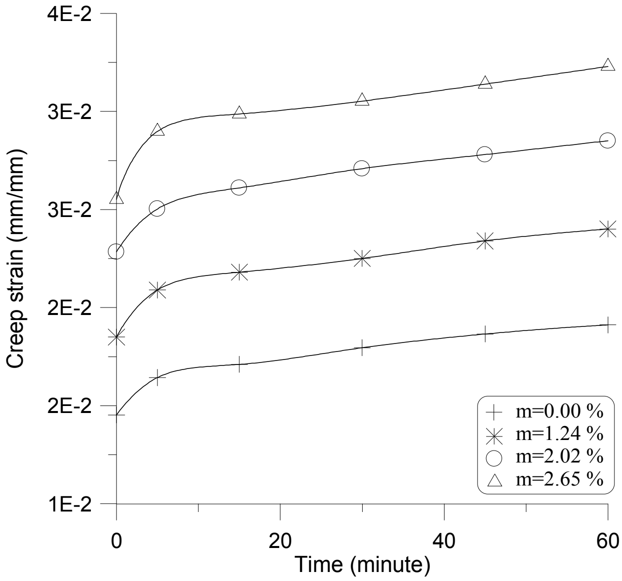




<u>Fig.(12)</u> creep strain for unidirectional fiber-Alkaline water and σ_3=16.564 MPa.

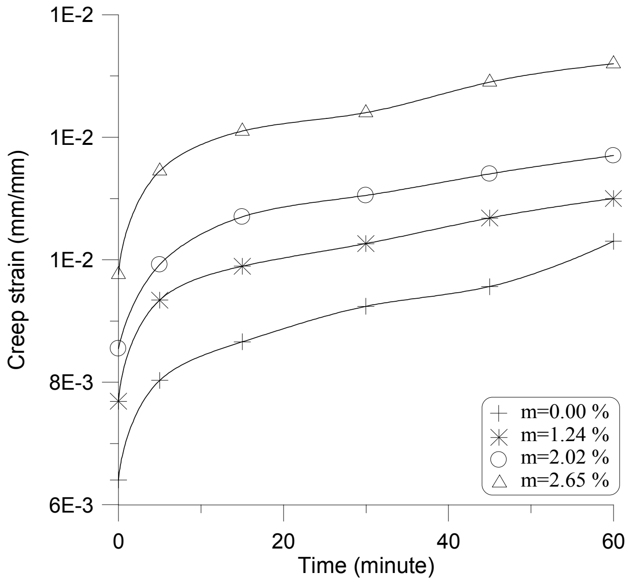
<u>Fig.(13)</u> creep strain for bidirectional fiber- Acidic water and σ_1=10.192 MPa.



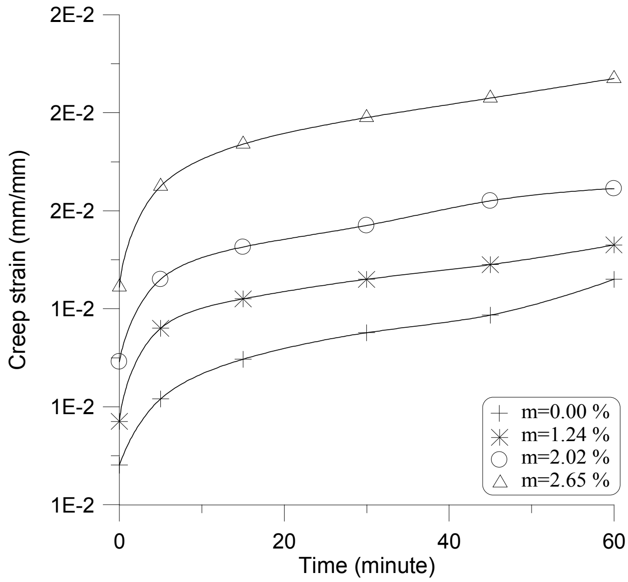


<u>Fig.(14)</u> creep strain for bidirectional fiber- fiber- Acidic water and σ_2=12.74 MPa.

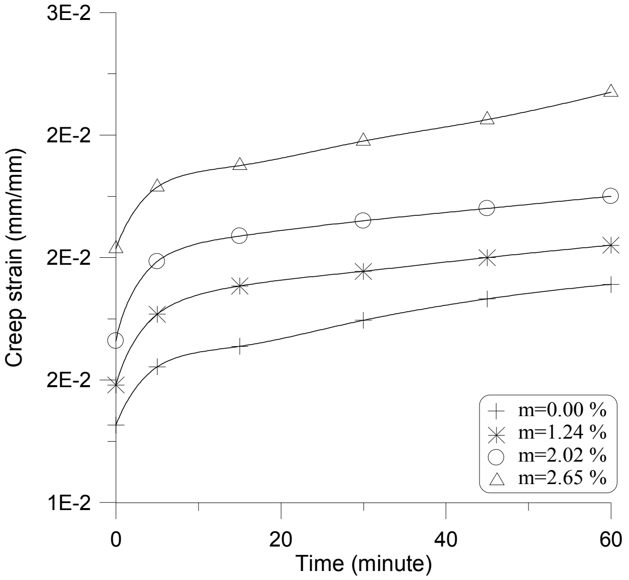
<u>Fig.(15)</u> creep strain for bidirectional fiber- Polish water and σ_3=16.564 MPa.

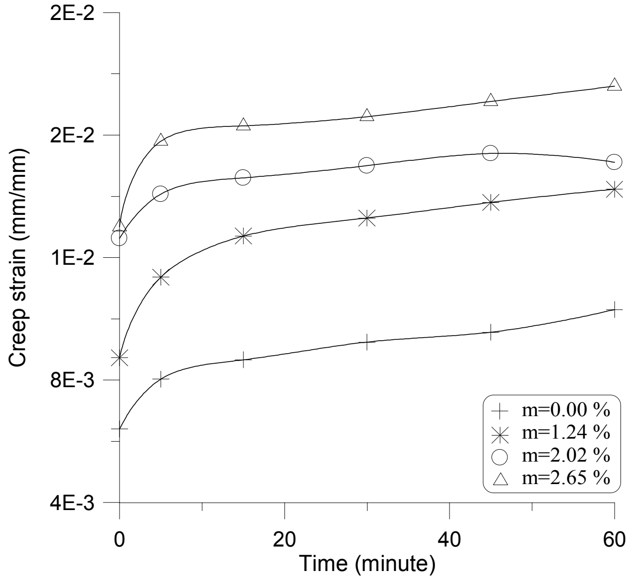


<u>Fig.(16)</u> creep strain for bidirectional fiber- Polish water and σ_1=10.192 MPa.



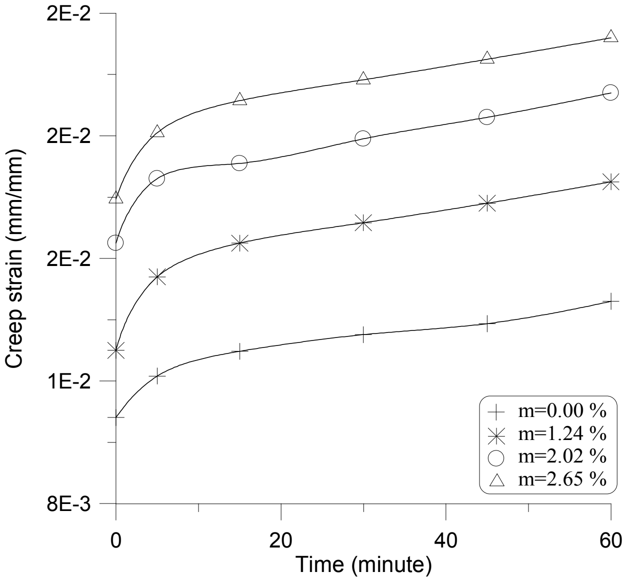
<u>Fig.(17)</u> creep strain for bidirectional fiber- Polish water and σ_2=12.74 MPa.

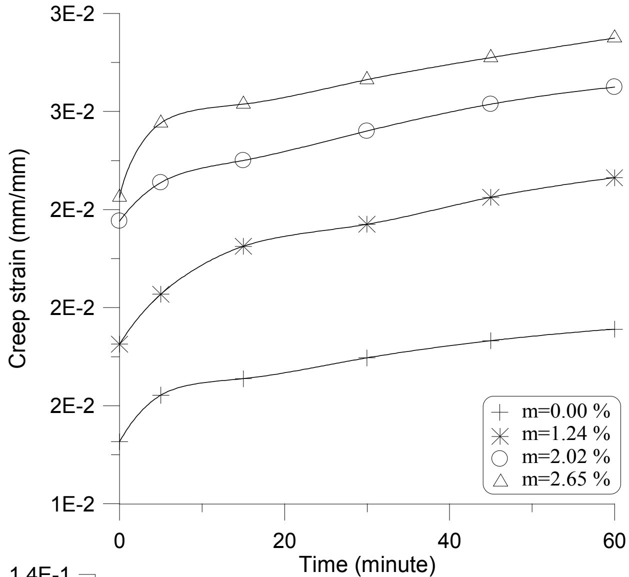


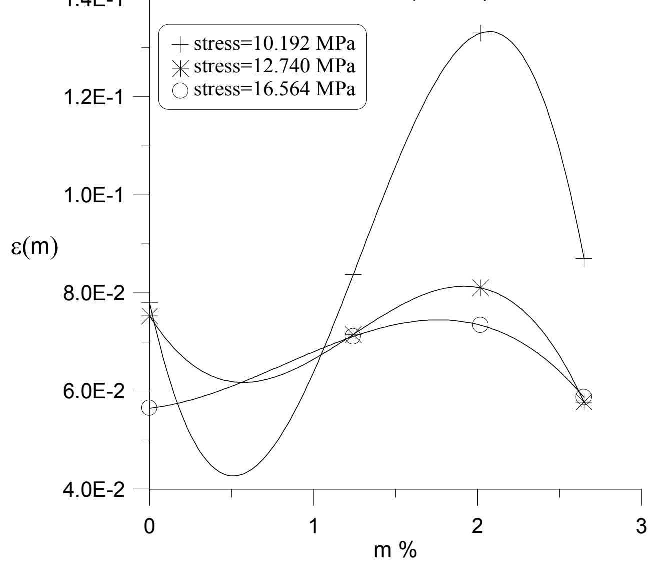


<u>Fig.(18)</u> creep strain for bidirectional fiber- Polish water and σ_3=16.564 MPa.

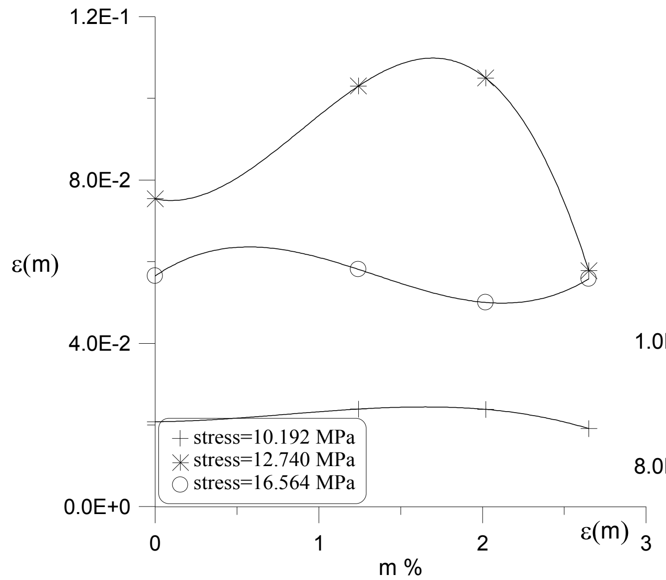
<u>Fig.(19)</u> creep strain for bidirectional fiber- fiber- Alkaline water and σ_1=10.192 MPa.



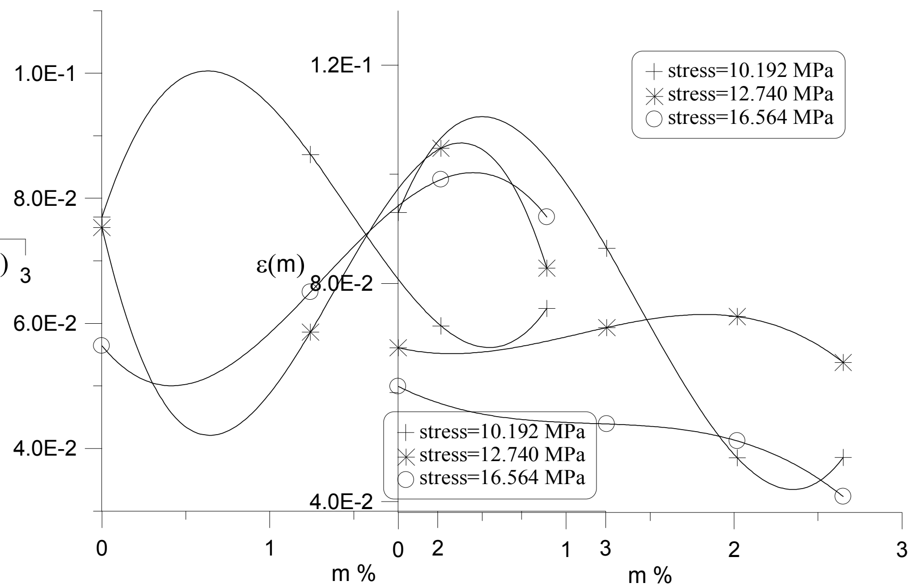




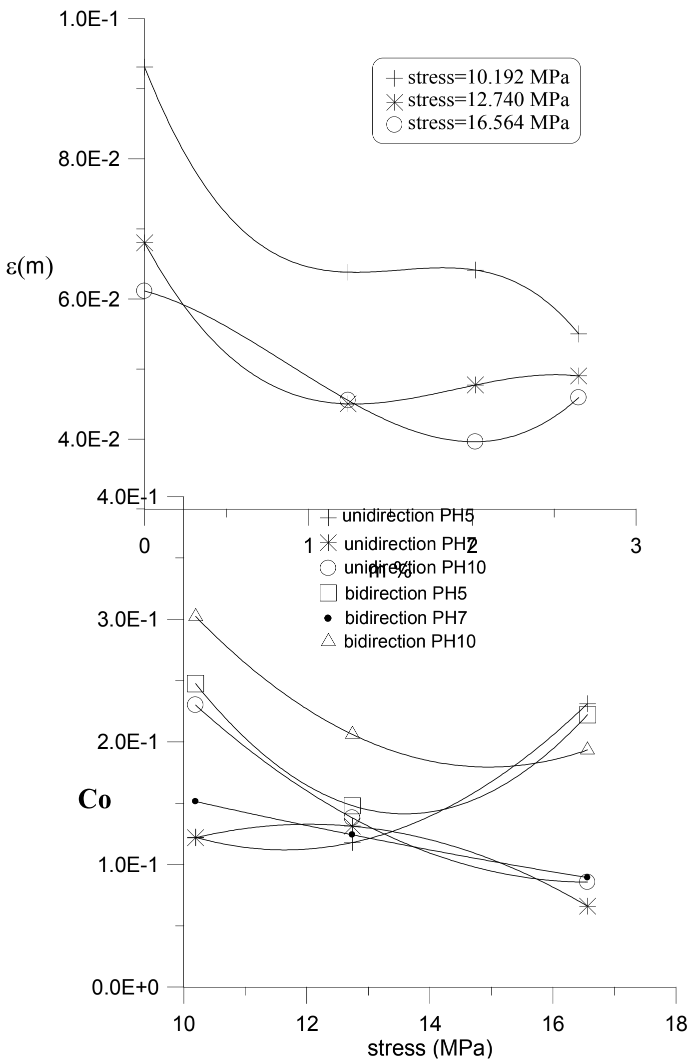
<u>Fig.(20)</u> creep strain for bidirectional fiber-
<u>Fig.(21)</u> creep strain for bidirectional
Alkaline water and σ_2=12.74 MPa.
fiber- Alkaline water and σ_3=16.564 MPa.

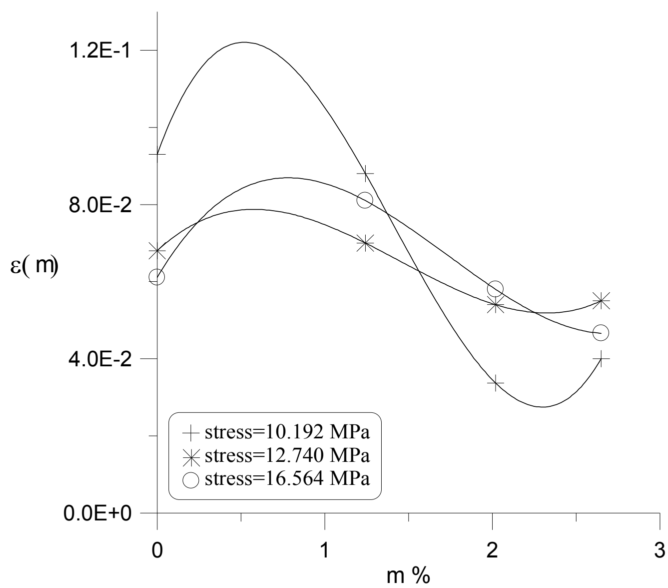


<u>Fig.(22)</u> ***ε(m)*****for unidirectional fiber-**
<u>Fig.(23)</u> ***ε(m)*****for unidirectional fiber-**
acidic water
Polish water



<u>Fig.(24)</u> ***ε(m)*****for unidirectional fiber-**
<u>Fig.(25)</u> ***ε(m)*****for bidirectional fiber-**
alkaline water
acidic water

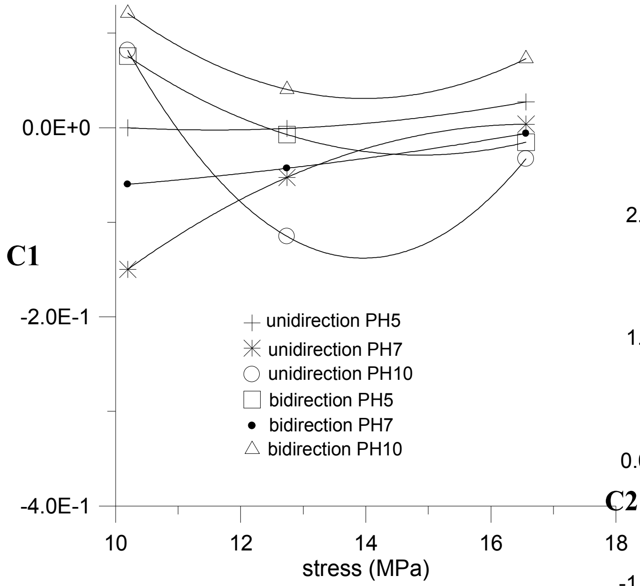




<u>Fig.(26)</u> ***ε(m)*****for bidirectional fiber-**
<u>Fig.(27)</u> ***ε(m)*****for bidirectional fiber- polish water**
alkaline water

Fig.(28) **Co-function**

Fig.(29) C1-function



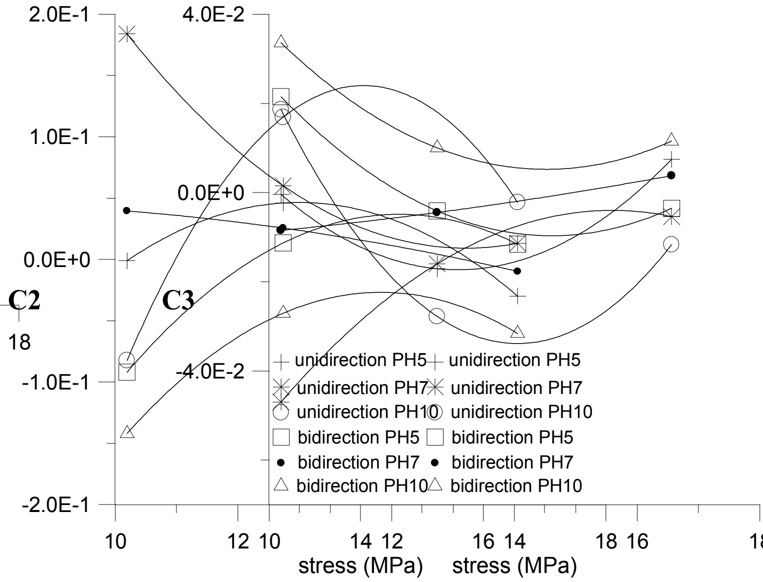
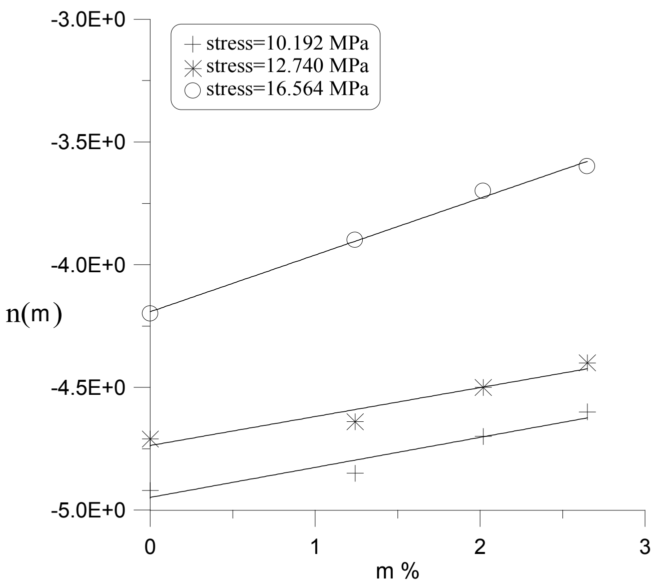


Fig.(30) **C2-function**

Fig.(31) C3-function



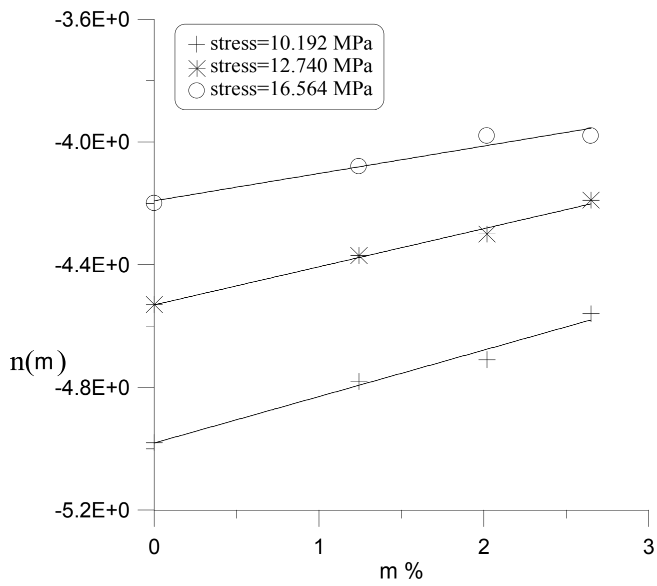
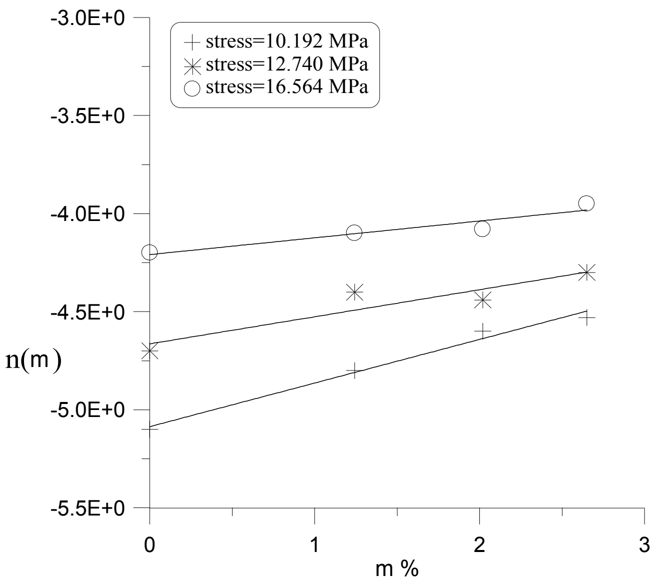
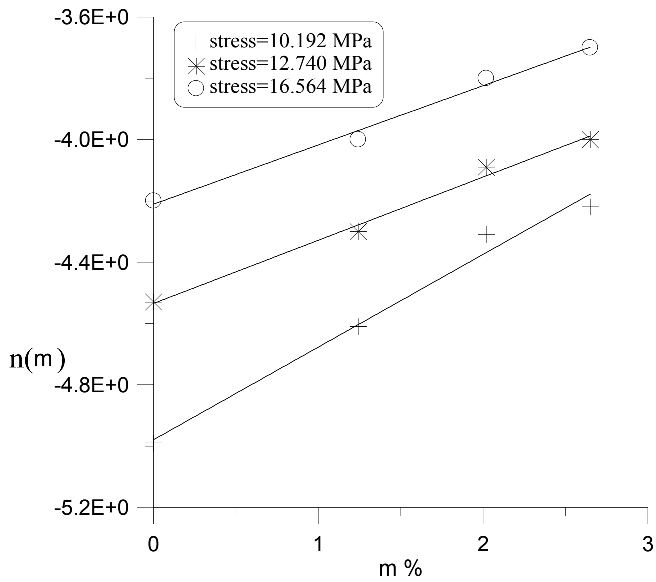


Fig.(32) ***n(m)*****for unidirectional fiber-acidic water**

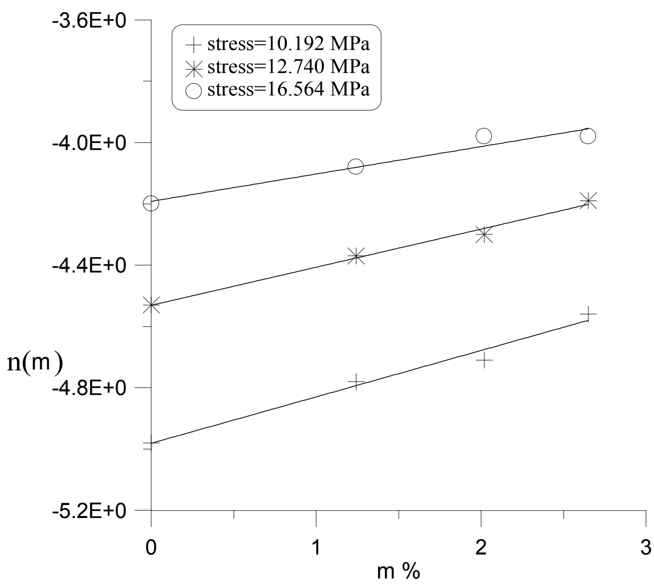
Fig.(33) ***n(m)*****for unidirectional fiber-Polish water**



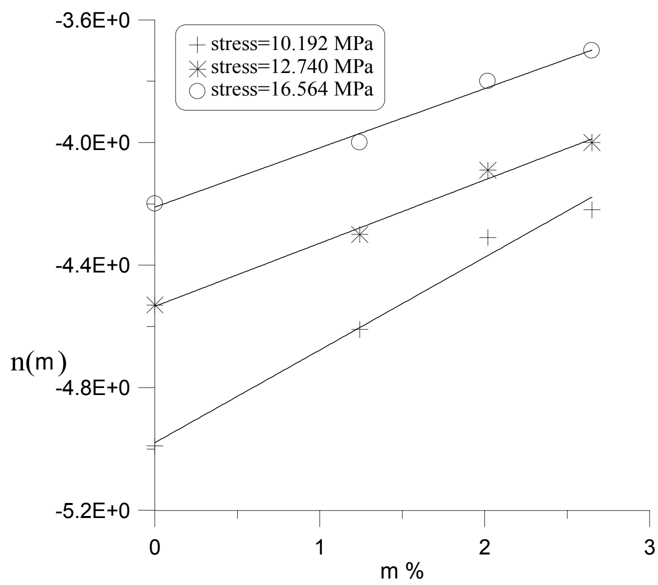
<u>Fig.(34)</u> n*(m)*for unidirectional fiber-alkaline water



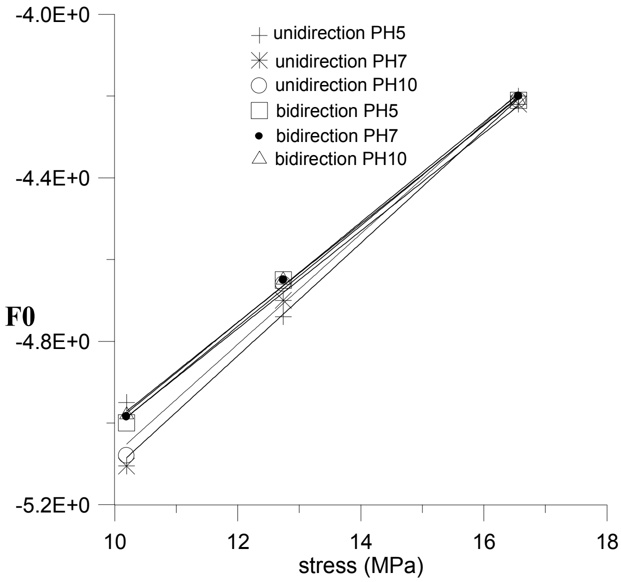
<u>Fig.(35)</u> n*(m)*for bidirectional fiber-acidic water



<u>Fig.(36)</u> n*(m)*for bidirectional fiber-polish water



<u>Fig.(37)</u> n*(m)*for bidirectional fiber-alkaline water



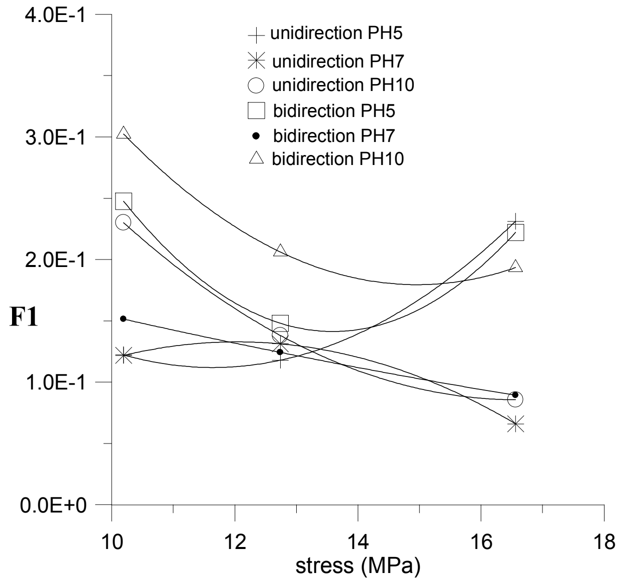


Fig.(38) Fo-function

Fig.(39) F1-function

Conclusions:

(1)The creep strain increase sharply with small time interval and then the creep strain rate approximately has a constant value for all experimental creep data.
(2) Increasing the moisture percentage results in increasing the creep strain values at the same time.
(3) Increasing the applied stress results in increasing the creep strain at any time for each case of sample.
(4) Increasing the value of (pH) results in decreasing the creep strain.
(5) The suggested theoretical creep strain equation (as a function of moisture percentage and the applied stress) is found and gives good criteria used to describe long time of creep strain.
(6) the moisture percentage value have a negligible effect on the strain rate.

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