Creep Behavior in Fiber-Reinforced Epoxy (DGEBA) Composites

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ABSTRACT

The composite material was prepared by reinforcing the epoxy with E-glass fiber. The creep and flextural test were measured in this work for one and two layer of E-glass fiber with volume fraction rate of (10%, 20%, 30%, and 40%) in orientation of (0-90°) immersed in epoxy (DGEBA) resin with total thickness of 4mm. The tests were done at different temperature levels from (25 to 55)C^o for creep test. The results had revaluated showing that the creeping properties of this composite materials will be improved with increasing the volume fraction layer of fiber at different temperature levels with constant stress. Creeping increases when the temperature increases and decreases with increasing of the number of layers and volume fraction of fiber. The creep constant increases with increasing the temperature up to 45C^o then the creep constant down. The creeping energy of epoxy E-glass (epoxy composite) increases with increasing the volume fraction rate of E-glass fiber.

خاصية الزحف في الألياف المدعم بمتركبات الايبوكسي

الخلاصة

إن المواد المتراكبة تحضر بتقوية مادة الايبوكسي بالألياف الزجاجية نوع (E) . تجربة الزحف و الانحناء تم قياسها في هذا البحث لطبقة وطبقتين من الألياف الزجاجية نوع (E) وبنسبة حجميه (١٠%، ٢٠%، ٣٠%، ٤٠%) وباتجاه (٠°-٩٠°)مغمورة في الايبوكسي (DGEBA) وبسمك إجمالي قدره (٤ ملم).

تم أجراء اختبارات الزحف في درجات حرارة مختلفة تراوحت مابين (٢٥-٥٥) م° . أظهرت النتائج بعد إن تم تقييمها من إن خواص الزحف لمثل هذه المواد المتراكبة قد تحسنت بزيادة النسبة الحجمية لطبقة الألياف الزجاجية عند مختلف درجات الحرارة وتحت إجهاد ثابت.

أظهرت النتائج إن الزحف يزداد عندما تزداد درجة الحرارة ،وكذلك فان الزحف يقل بزيادة عدد طبقات الألياف وكمياتها . إن ثابت الزحف يزداد بزيادة درجة الحرارة ولحد (٤٥ م ْ) وبعدها يقل ثابت الزحف ،حيث إن طاقـة الزحـف للايبوكسـي المقـوى بالأليـاف الزجاجيـة عنـدها يـزداد بزيـادة النسـبة الحجمية للألياف الزجاجية.

INTRODUCTION

In materials science, **creep** is the tendency of a solid material to slowly move or deform permanently under the influence of stresses. It occurs as a result of long term exposure to high levels of stress that are below the yield strength of the material. Creep is more severe in materials that are subjected to heat for long periods, and near melting point. Creep always increases with temperature [1]. The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied structural load. Depending on the magnitude of the applied stress and its duration, the deformation may become so large that a component can no longer perform its function — for example creep of a turbine blade will cause the blade to contact the casing, resulting in the failure of the blade. Creep is usually of concern to engineers and metallurgists when evaluating components that operate under high stresses or high temperatures. Creep is a deformation mechanism that may or may not constitute a failure mode. Moderate creep in concrete is sometimes welcomed because it relieves tensile stresses that might otherwise lead to cracking. Unlike brittle fracture, creep deformation does not occur suddenly upon the application of stress. Instead, strain accumulates as a result of long-term stress. Creep is a "time-dependent" deformation. The temperature range in which creep deformation may occur differs in various materials. For example, tungsten requires a temperature in the thousands of degrees before creep deformation can occur while ice will creep near 0 °C (32 °F).[2] As a rule of thumb, the effects of creep deformation generally become noticeable at approximately 30% of the melting point for metals and 40–50% of melting point for ceramics. Glacier flow is an example of creep processes in ice. The mechanism of creep depends on temperature and stress. The various methods are:

General Creep Equation

$$\frac{d\varepsilon}{dt} = \frac{C\sigma^m}{d^b}e^{\frac{-Q}{kT}} \qquad ....(1)$$

where ε is the creep strain, C is a constant dependent on the material and the particular creep mechanism, m and b are exponents dependent on the creep mechanism, Q is the activation energy of the creep mechanism, σ is the applied stress, d is the grain size of the material, k is Boltzmann's constant, and T is the absolute

temperature. At high stresses (relative to the shear modulus), creep is controlled by the movement of dislocations. [3]For dislocation creep, *Q = Q (self diffusion), m* = 4-6, and *b* = 0. Therefore, dislocation creep has a strong dependence on the applied stress and no grain size dependence. Some alloys exhibit a very large stress exponent (*n* > 10), and this has typically been explained by introducing a "threshold stress," σ_{th}, below which creep can't be measured. The modified power law equation then becomes:[3]

$$\frac{d\epsilon}{dt} = A\,(\sigma - \sigma_{th})^n\,e^{\frac{-Q}{RT}} \quad \ldots(2)$$

Where *A, Q* and *n* can all be explained by conventional mechanisms (so $3 \leq n \leq 10$). When subjected to a step constant stress, viscoelastic materials experience a time-dependent increase in strain. This phenomenon is known as viscoelastic creep. The effect of increasing molecular weight tends to promote secondary bonding between polymer chains and thus make the polymer more creep resistant. Similarly, aromatic polymers are even more creep resistant due to the added stiffness from the rings. Both molecular weight and aromatic rings add to polymers' thermal stability, increasing the creep resistance of a polymer.[5] Both polymers and metals can creep. Polymers experience significant creep at temperatures above ca. –200°C; however, there are three main differences between polymeric and metallic creep.[2] Polymers show creep basically in two different ways. At typical workloads (5 up to 50%) ultra high molecular weight polyethylene (Spectra, Dyneema) will show time-linear creep, whereas polyester or aramids (Twaron, Kevlar) will show a time-logarithmic creep.

A review of deformation in oriented thermoplastics has shown that anisotropy is known to influence their creep behavior [7]. For example, the 100 s isochronous modulus in LDPE fell fivefold for a 45/ orientation to the draw axis compared to that aligned with this axis [8]. The subject of creep in oriented, reinforced composites has received less attention compared to that of polymers. The few publications on the subject, as reviewed in [9], show that strain magnitudes can be many orders lower as might be expected when strong, brittle fibers are arranged to support the load. In a polyester laminate, for example, the instantaneous elastic strain was 0.75% and the creep strain accumulated to just 0.2% in 1000 hr at 20/C in air under a stress of half its tensile strength [10]. In fact, the reinforcement was introduced to polymers in order to eliminate their troublesome dimensional instability under moderately low loading. Ceramic fibers: glass, boron and carbon fibers are strong, elastic and brittle and apart from their elastic strain, are otherwise inextensible. Consequently, individual fibers themselves display a negligible plastic or a viscous (time-dependent) strain [11]. Thus creep may be almost entirely eliminated when continuous fibers are aligned with the stress direction [12]. The role of mixture always predicts the density of fiber-reinforced composites [13]

$$\rho_c = V_f \rho_f + V_m \rho_m \qquad \qquad \text{...(3)}$$

$$V_f = \frac{1}{1 + \dfrac{(1 - W_f)\rho_f}{W_f \rho_m}} \qquad \qquad \text{...(4)}$$

where
ρ_c : density of the composite
ρ_m: density of the matrix
ρ_f : density of the fibers
V_m: volume fraction of the matrix
V_f: volume fraction of the fiber
W_f: weight fraction of the fiber

Theoretical Part
Several equations were used in this search for calculation the theoretical composite materials properties.

$$\epsilon = \frac{\Delta L}{L_\circ} \qquad \qquad \text{...(5)}$$

$$k = slop\, \frac{log\,\epsilon}{log\,t} \qquad \qquad \text{...(6)}$$

Where
ϵ is the strain
Q   is the creeping energy.
t   is the time in the creeping test.
T   is the temperature for the creeping test.
K   is the creeping constant.

EXPERIMENTAL WORK
1-Diglycidyl ether of bisphenol-A (DGEBA) is a typical commercial epoxy resin and is synthesised by reacting bisphenol-A with epichlorohydrin in presence of a basic catalyst.
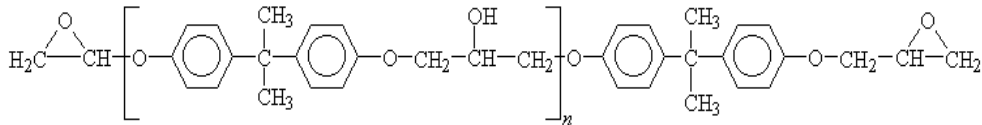
The properties of the DGEBA resins depend on the value of *n*, which is the number of repeating units commonly known as degree of polymerisation the number of repeating units depend on the stoichiometry of synthesis reaction. Typically, *n* ranges from 1 to 25 in many commercial products. Epoxy resin Diglycidyl ether of bisphenol-A (DGEBA) was used with its hardener in ratio (3:1).
2- Fiber glass type (E-glass) Figure (12).
3-Hand lay-up technique was used to prepare sheets of epoxy composites reinforced with E- glass fibers (one and two layer). The sheets were left to solidify at room temperature. Epoxy composites with standard dimensions (ANSI / ASTM D 638) Figure (13).
4- The volumes fraction of E-glass was (10, 20, 30, and 40).
5-The creep test was carried out with different temperature (25, 35, 45, and 55).
6-Creep test specimens Figure (13) were used standard dimensional suitable for the creeping machine (ASTM-BS1178) Figure (14).

RESULTS AND DISCUSSION
The results of strain experimental are shown in figures (1) to (4). These figures show the effect the time on the strain of the epoxy, from these figures can be see that the strain increase with increasing the time at constant temperature for one layer because of the epoxy are viscoelastic at all temperature with time so that in considering the strain induced in service it is always required to take into account not only the stress, but the time for which it is applied. The viscoelastic properties are also highly temperature dependent so that the maximum temperature must be clearly specified, and taken into consideration. Also, we can see that the strain decrease with increasing the volume percent of the fiber because the additive the fiber to the matrix or epoxy lead to composite materials (epoxy and fiber) is stiffer and stronger than the polymer matrix and the stiffer increase with increasing the percent of the fiber. The cause of the stiffer of the composite that the density of the fiber great than the matrix or epoxy. The figures (1) to (4) also, show that the strain increase with increasing the temperature because the viscoelastic of the epoxy increase with increasing the temperature.

The result in figure 5 to 8 shown the reinforcing the Diglycidyl ether of bisphenol-A (DGEBA) with fiber lead to increase the strain with increasing the volume fraction of the time of the creeping for two layer. Also, we can see that the strain in one layer composite materials great than the strain in two layer composite materials, this attributed to the fact that the reinforcement imparted by the fibers allowed stress transfer from the matrix to the fibers. At low layer the matrix is not restrained by enough fibers and in the high layer, the stress was more distributed and the composite stiffness increased, this is due to strong interface region between the matrix and the fibers.

Figure (9-10) show the creep constant at different temperature. The creep constant increased with increasing the temperature up to $45^{o}C$ then the creep constant down

because the materials are brittle and stiff at the primary and then the material become plastic with increasing the temperature where the average strain increases by linearly this lead to plastic castrate.

Figure (11) show that the creeping energy of the epoxy reinforcement of the glass fibers, where the energy increase with increasing the volume fraction of the glass fiber.

CONCLUSIONS

From the results of the creep at different temperature and volume fraction of glass fiber, the following conclusions can be list:

1- The creep rate decreased with increasing the volume fraction of glass fibers.
2- The creep rate decreased with increasing the layer of glass fibers.
3- The creep rate increase with increasing the temperature.
4- The creep rate in on layer high than the creep in two layer at different temperature.
5- The creep constant increased with increasing the temperature.
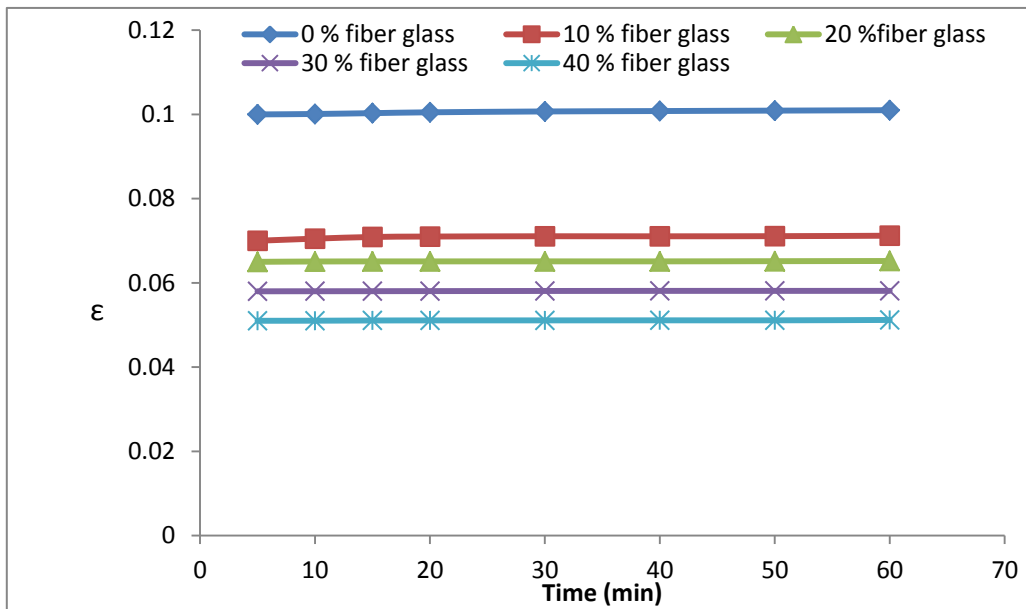
Figure (1): change of strain with time for % fraction of fiber glass of one layer at room temperature.
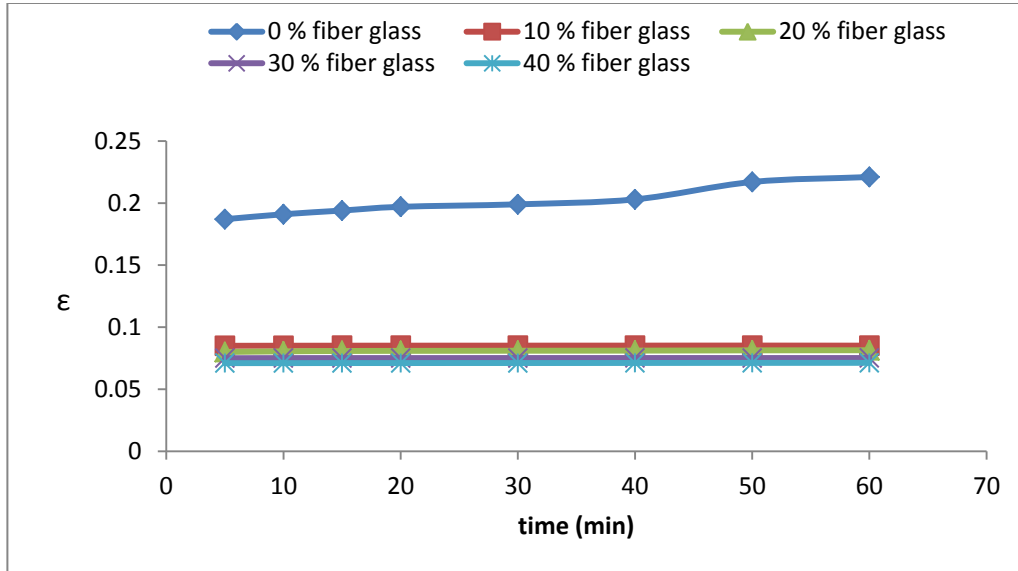
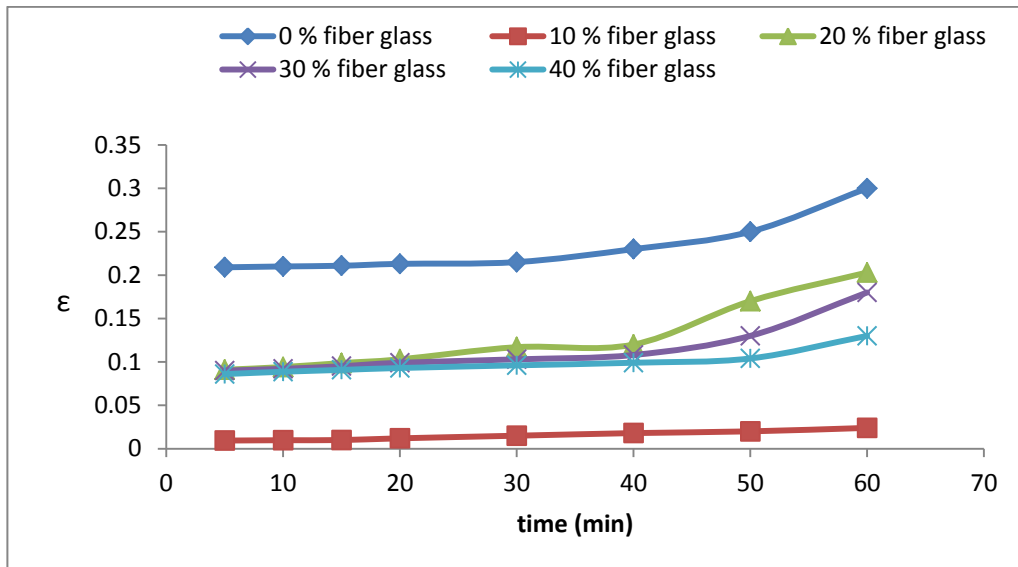**Figure (2): change of strain with time for % fraction of fiber glass of one layer at T=35 C.**

Figure (3): change of strain with time for % fraction of fiber glass of one layer at T=45 C.
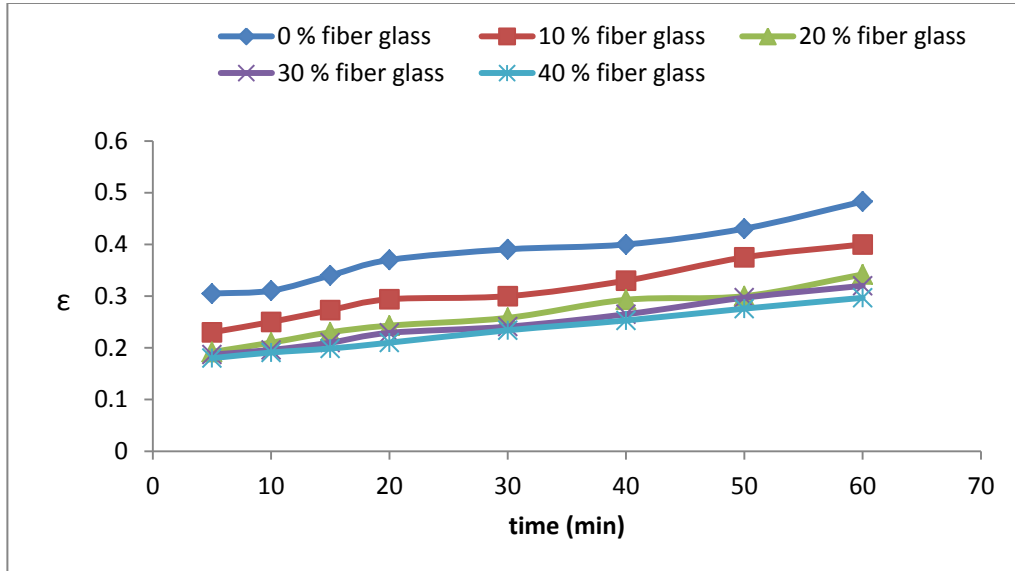
Figure (4): change of strain with time for % fraction of fiber glass of one layer at T=55 C.
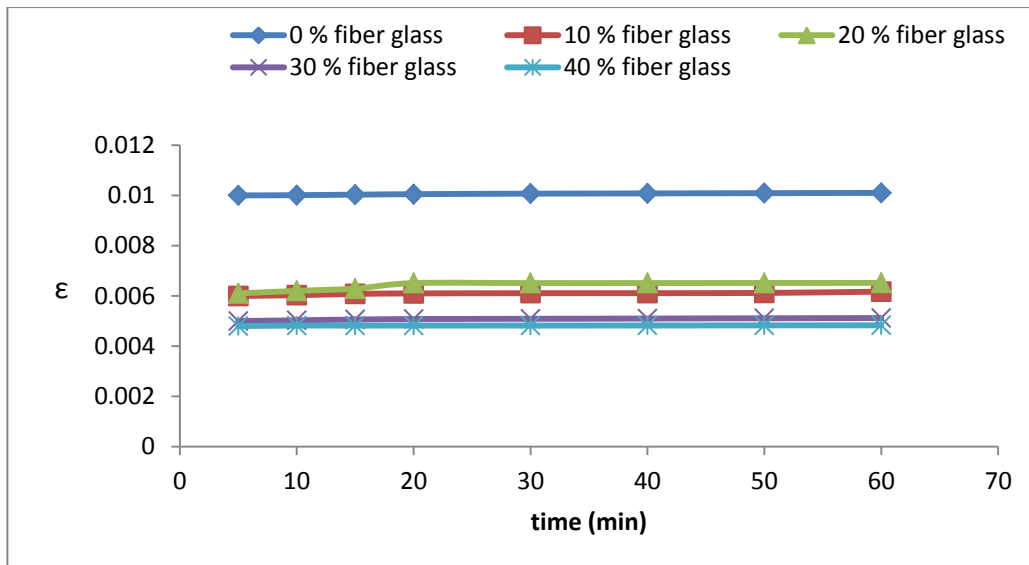

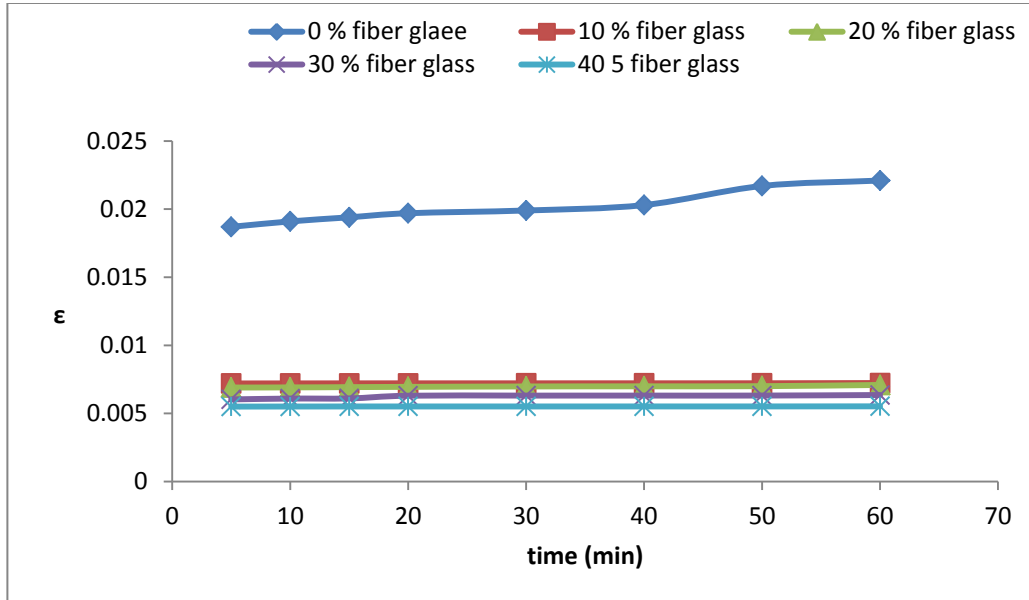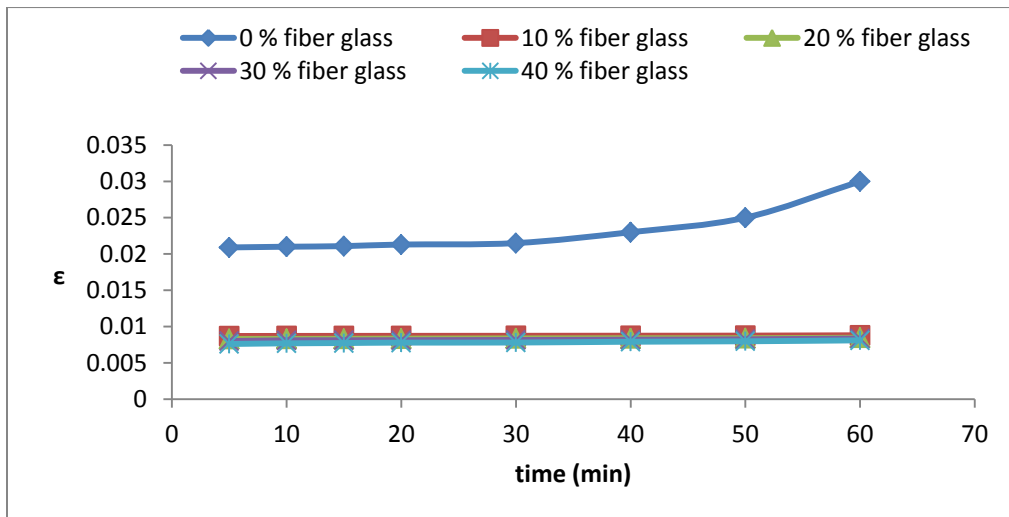**Figure (5): change of strain with time for % fraction of fiber glass of two layers at 25 C.**

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Figure (6): change of strain with time for % fraction of fiber glass of two layers at 35 C.

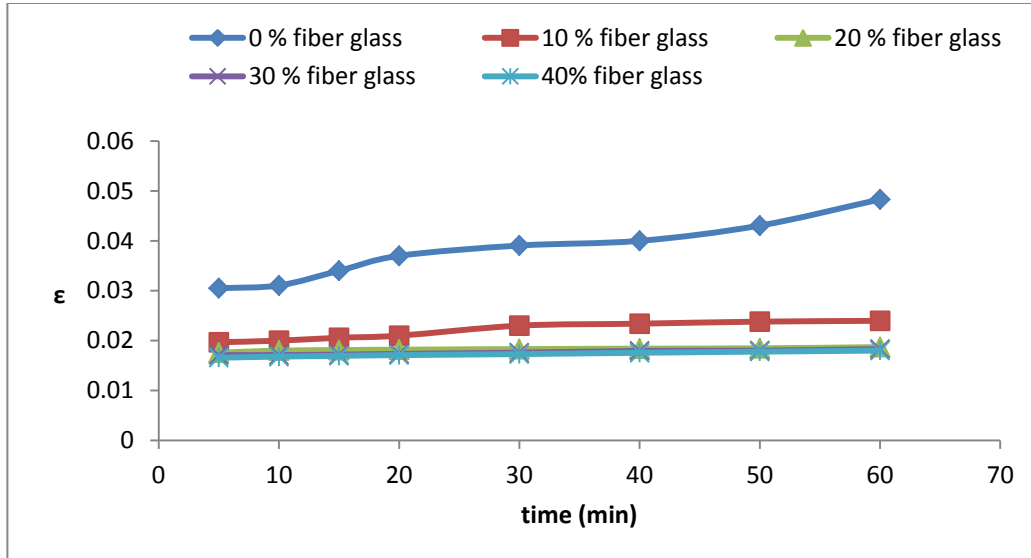**Figure (7): change of strain with time for % fraction of fiber glass of two layers at T = 45 C.**

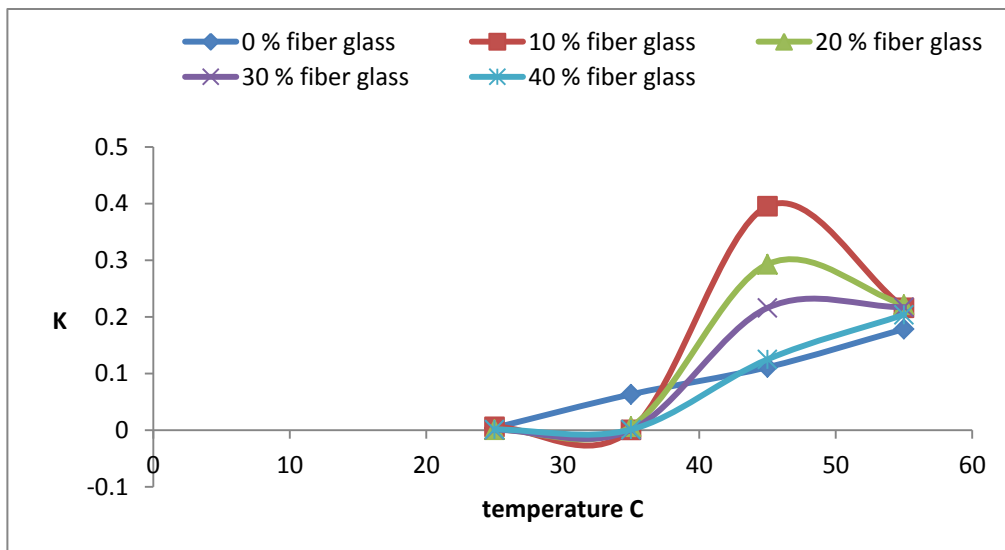**Figure (8): change of strain with time for % fraction of fiber glass of two layers at T=55 C.**

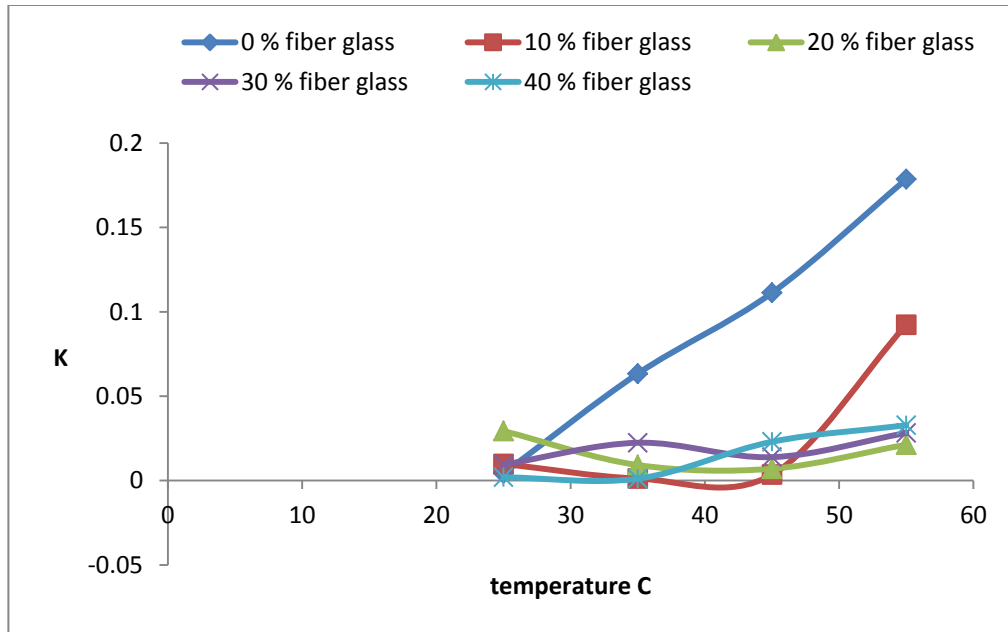**Figure (9): creep constant (K) with different temperature of one layer.**

Figure (10): creep constant (K) with different temperature of two layers.
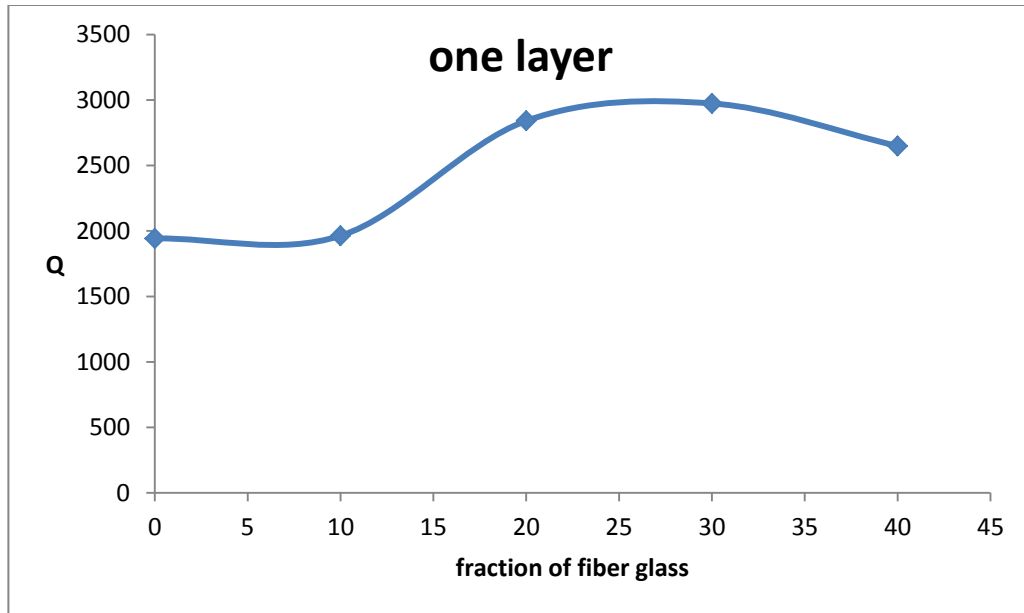
Figure (11): change of heat with fraction of fiber glass.

Figure (12): - Fiber glass type (E-glass) woven rove with angle of (0-90) continuous direction with surface density (0.5 Kg/m^2).
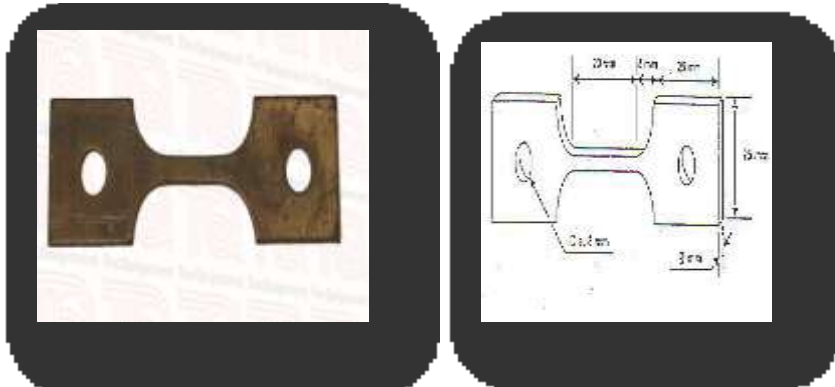
Figure (13) : CREEP-SPECIMEN

Figure (14): creeping machine

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