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TENSILE RELAXATION BEHAVIOR FOR MULTI LAYERS FIBERGLASS FABRIC/EPOXY COMPOSITE

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ABSTRACT: *In this paper, a tensile relaxation behavior of fiberglass fabric/epoxy composites were evaluated. The effect of stress relaxation temperature compared with room temperature were investigated. Fiberglass fabric layers at different volume fraction were studied. The Maxwell model was used to predict a material's response under different loading conditions. Relaxation time constant was determined at different volume fraction and at different relaxation temperature. It was found that, the relaxation time is highly increased with increasing the fiberglass volume fraction. In addition, the number of relaxation cycles (load/reload) is increased with increased the fiberglass volume fraction. The relaxation time decreased dramatically by increasing the relaxation temperature from room temperature to 60 °C. The material relaxation time constant is strongly affected by both the relaxation temperature and the volume fraction of the fiberglass.*

KEYWORDS: Relaxation, Relaxation modulus, Viscoelasticity models, Stress relaxation

INTRODUCTION

Plastics have become an inseparable and integral part of our life. Therefore, determination the mechanical properties of plastic and its composites such as its relaxation behavior is very important for engineering applications purpose [1]. Several studies were performed to clarify the effect of different parameters on the mechanical and thermal properties of polymer composites. However, very few investigations have been dedicated to the stress relaxation properties of polymer composites. Viscoelastic materials subjected to a constant strain will relax and as a result, the stress decreases gradually. Understanding the relaxation behavior of polymer-fiber reinforced composites under transient loadings is important to understanding the broad range of viscoelasticity. Polymers are viscoelastic materials and exhibit time-dependent relaxations when subjected to stress or strain. While creep is a measure of increase in strain with time under a constant stress, stress relaxation is the reduction of stress with time under a constant strain [2, 3]. Particularly engineering components often subject to a constant strain as opposed to constant stress such as threaded joints. The automotive industry has also started to specify stress relaxation tests for critical sealing products in the cars. Nutting and Struik relationships for creep and Maxwell and Kohlrausch-Williams-Watts (KWW) functions for stress relaxation were used to establish which of them can be a better model to fit the stress relaxation data [4, 5]. A number of theoretical and experimental studies have mainly dealt with the investigation of the relaxation phenomena of polymer and its composites and in some cases with the relationships between the results of different tests in order to estimate or predict the short and long-term behavior of polymers under different conditions [6-20]. Findley et al. [11], used power law model to model short and long-tern stress relaxation behavior. They results were found to be in good agreement with experimental data. George et al. [12, 13], investigated the stress relaxation behavior of short pineapple-fiber reinforced polyethylene composites. They concluded that, the addition of natural fiber had a decreased stress relaxation and fiber-matrix interface bonding has a great effect on the overall behavior. Gutman et al. [14], studied the effect of environmental and chemical factors on stress relaxation in polyester-fiberglass composite; certain chemical environments deteriorate the polymer composite structure and an increase in relaxation was observed when the specimens were exposed to acidic and basic environments. Nagy and Vas [15], proposed a new method for the estimation of the real tensile load response by using the viscoelastic response given to the real relaxation stimulus. Razavi-Nouri [16], investigated the creep and stress relaxation of a polypropylene based copolymer, Struik and Nutting relationships were used for fitting the data obtained from the creep experiments. The results indicated that while the Maxwell model was good enough to predict the stress relaxation time.

This work presents an experimental study of modal testing of laminated fiberglass fabric/epoxy composite materials to contribute for a better understanding of the relaxation behavior of components made from fiberglass fabric /epoxy composite materials. Mechanical relaxation test machine designed and manufactured to measure the relaxation of polymeric materials. The required specimens from fiberglass fabric /epoxy composite material was manufactured laboratory by using vacuum bagging technique. The effects of fiberglass layers and temperature on the relaxation behavior of fiberglass fabric /epoxy composite are studied. Relaxation time constant was determined at different volume fraction and at different relaxation temperature.

Mechanical Model and Theoretical Formulation

In this section, we describe the theoretical model and derive the governing equation. Most viscoelastic materials are highly influenced by the nonlinear elastic and viscous damping terms so that, their rheological properties are nonlinear time dependent. The Maxwell model was used to predict a fiberglass fabric/epoxy composite response under different loading conditions. The Maxwell model can be represented by a purely viscous damper and a purely elastic spring connected in series. In this configuration, under an applied axial stress σ , the stress on each element is the same and equal to the imposed stress, while the total strain is the sum of the strain in each element, therefore, the total strain being composed of the two components can be expressed as following [21]:

$$\varepsilon_t = \varepsilon_e + \varepsilon_v \qquad (1)$$

Where, ε_e is the elastic strain in the spring and ε_v is the viscus strain in the damper.

In elastic zone, the following stress-strain relation is expressed ,

$$\sigma = E\varepsilon_e \qquad (2)$$

While in plastic zone, the relation between stress and strain for the plastic materials is obtained by:

$$\sigma = \eta\, d\varepsilon_v/dt \qquad (3)$$

Where E is the elastic modulus and η is the material coefficient of viscosity.

Differentiating Eq. (1) with respect to time, we obtain the strain rate for a uniaxial stress is as follows:

$$\frac{d\varepsilon_t}{dt} = \frac{d\varepsilon_e}{dt} + \frac{\sigma\varepsilon_v}{dt} \tag{4}$$

Substituting from Eqs. (2) and (3) into Eq. (4), thus

$$\frac{d\varepsilon_t}{dt} = \frac{d\sigma}{Edt} + \frac{\sigma}{\eta} \tag{5}$$

In the relaxation test, the strain ε in held constant, so

$$\frac{d\varepsilon_t}{dt} = 0 \quad and\ \ therefore, \qquad \frac{1}{E}\frac{d\sigma}{dt} = -\frac{\sigma}{\eta}$$

Then,

$$\frac{d\sigma}{\sigma} = -\ \frac{E}{\eta}dt \tag{6}$$

Integrating the eq. (6), we obtain,

$$\ln\sigma = -\frac{Et}{\eta} + C \tag{7}$$

At the start of the stress-relaxation experiment, t = 0, and $\sigma = \sigma_o$ is the initial stress.

Thus, Eq. (7) becomes

$$\ln\sigma - \ln\sigma_o = -\frac{E}{\eta}\ t \tag{8}$$

From the Eq. (8), the stress versus time equation becomes:

$$\sigma(t) = \sigma_o e^{-(\frac{Et}{\eta})} \tag{9}$$

Thus;

$$\sigma(t) = \sigma_o e^{-(t/\lambda)} \tag{10}$$

Where $\lambda = \frac{\eta}{E}$ is the relaxation time constant.

Equation 10, provide a reasonable qualitative display of relaxation, which can be used to predict approximately the relaxation behavior under different conditions.

MATERIALS AND EXPERIMENTAL

Fiberglass fabric /epoxy composites produced by vacuum bagging technique. This technique was used to manufacture composite laminates with 30 cm length and 10 cm width. The thickness of these sheets is almost 2 mm. The specimens with dimensions 12 mm width and 120 mm length was cutting from the sheets. Tables 1 and 2, shows the mechanical properties of epoxy and fiberglass fabric /epoxy composite.

Table 1. Mechanical and physical properties of used epoxy resin.

Density (kg/m^3)	Tensile strength (MPa)	Tensile modulus (GPa)	Failure strain (%)
1200	60	1.3	1.8

Table 2: Maximum tensile strength of fiberglass fabric /epoxy composites

v_f %	30%	45%
σ_u (MPa)	74	81

Experimental procedure

Referring to Fig.1 uniaxial tensile stress relaxation tests were performed on a relaxation tensile testing machine, which manufactured for the purpose. Relaxation tensile testing machine was provided by controllable temperature chamber. The tensile force was measured directly through the digital load cell. Every test was performed on a new specimen. In each test, the specimen was loaded to maximum stress (10% from fracture stress) and let it to relax to minimum stress (8% from fracture stress). The variation on stress was recorded with time until the minimum stress was reached then the specimen was loaded to maximum stress again. The cycle was repeated until the fracture of the specimen.

RESULTS AND DISCUSSION

Fig. 2, shows the relationship between the relaxation time and the relaxation stress for v_f = 30 % fiberglass fabric/epoxy composite. It can be seen that the total relaxation time reaches to 46 hours. Referring to Fig. 3, It can be noticed that the total number of load/ reload cycle is 9 cycles. The relaxation time of first cycle is higher than other cycles. This is can be explained that the fiberglass fabric play a main role to resist the relaxation of epoxy lamella. In addition, the relaxation time is decreased in the next cycles until the fracture.

Fig. 1. Relaxation test machine with oven

Figure 4, illustrates, the effect of reinforcing epoxy by v_f = 45 % of fiberglass fabric on the relaxation time. It can be seen that the relaxation time increased significantly and reached to 53 hours. As shown in Fig.5, the total number of load/reload relaxation cycle is 12 cycles. The first relaxation cycle has the longest relaxation time compared with next cycles. The relaxation time decreased gradually with next relaxation cycles up to fracture. This behavior is consistent compared with the results of v_f = 30 % fiberglass fabric specimen. Fig. 6 shows comparison between the relaxation time of epoxy composite having different number of fiberglass fabric layers in the first relaxation cycle. It can be seen that the relaxation time of specimen having v_f = 45% is slightly higher (13:59 hours) than the specimen having v_f = 30% (13:29 hours).

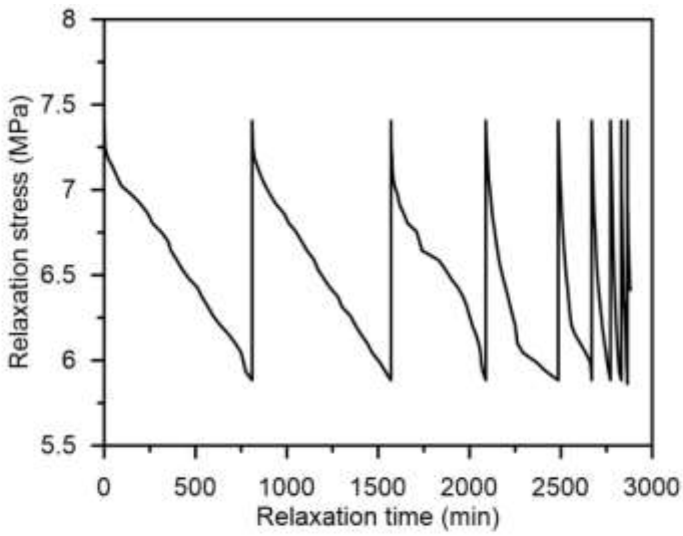

Fig. 2. Relaxation stress for fiberglass fabric/epoxy composite with v_f =30% at room temperature.

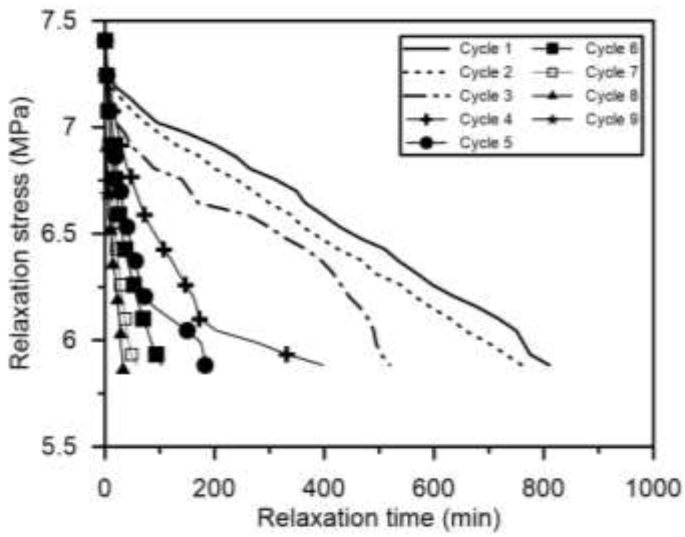

Fig. 3. Relaxation cycles for fiberglass fabric/epoxy composite with v_f =30% at room temperature.

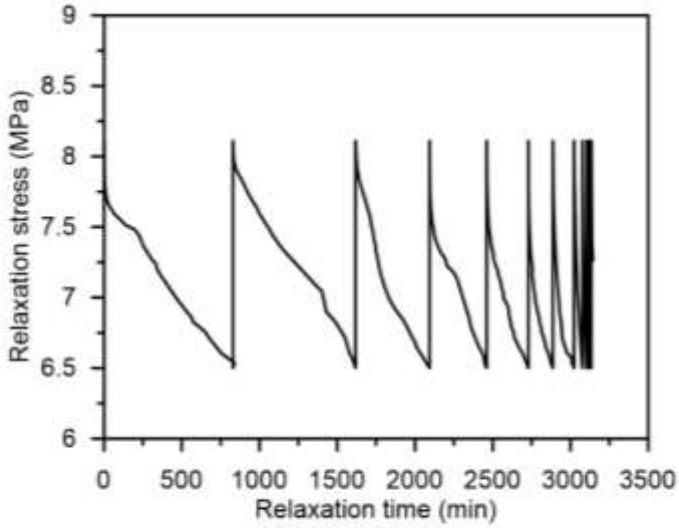

Fig. 4. Relaxation stress for fiberglass fabric/epoxy composite with v_f =45% at room temperature.

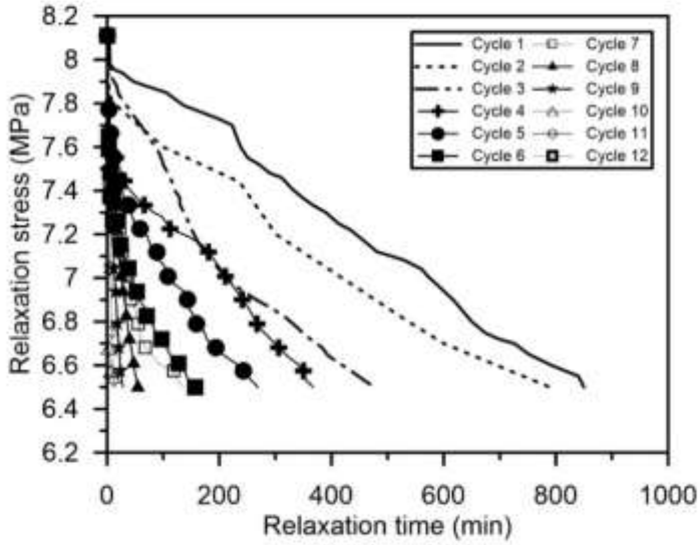

Fig. 5. Relaxation cycles for fiberglass fabric/epoxy composite with v_f =45% at room temperature.

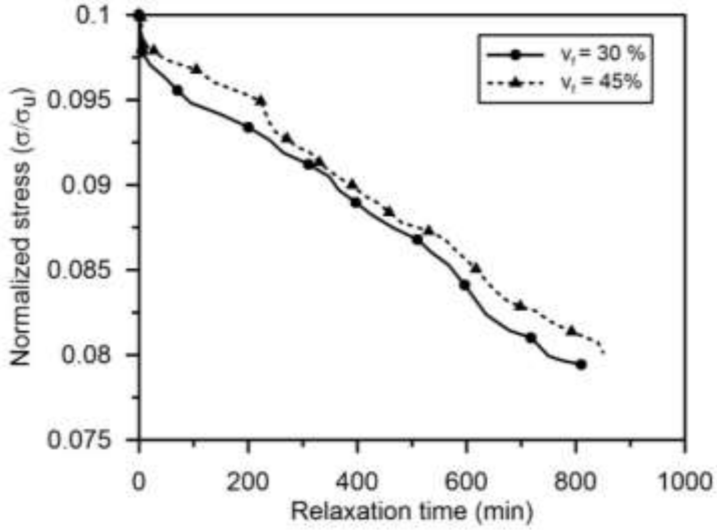

Fig. 6. Comparison between first relaxation cycle for v_f =30%, and v_f =45%, at room temperature.

This means that the number of fiberglass fabric layers play a dominant role for increasing the total relaxation time of fiberglass fabric /epoxy composite. This effect of fiberglass fabric layers is clearly noticed in the next relaxation cycle.

Referring to Fig. 7, the relaxation behavior of epoxy composite (v_f = 30%) at 60 °C is presented. it can be seen that the total relaxation time reaches to about 6 hours. Fig. 8, shows the rime of each relaxation cycle (load /reload cycles) of fiberglass fabric /epoxy composite at T=60 °C. It can be noticed that the total number of load/reload cycles is about 7 cycles, the relaxation time of first cycle is higher than others. This can be explained that the fiberglass fabric play a main role to resist the relaxation of epoxy lamella. This behavior is consistent with the relaxation behavior of fiberglass fabric /epoxy composite at room temperature. In addition, it can be noticed that the relaxation time of fiberglass fabric layer reinforcing the epoxy resisting the relaxation load are decreased in the next cycles until the fracture.

Fig. 9, illustrates the effect of reinforcing epoxy by v_f = 45% of fiberglass fabric on the relaxation time at T = 60°C. It can be seen that the relaxation time increased significantly and reached to 14:3 hours. Fig. 10, shows the relaxation time (load/reload cycles) in each relaxation cycle of fiberglass fabric /epoxy composite at T=60°C. it can be noticed that the total number of load/reload relaxation cycle is about 9 cycles. The first relaxation cycle has the longest relaxation time compared with next cycles. The relaxation time decreased with next relaxation cycles up to fracture. This behavior is also consistent with the relaxation behavior of fiberglass fabric /epoxy composite at room temperature.

Fig. 11 shows the comparison between the relaxation time of epoxy composite having different number of fiberglass fabric layers at relaxation temperature of 60 °C at first load /reload cycle. It can be seen that the relaxation time of specimen having v_f = 45% from fiberglass fabric reaches to 3:40 hours compared with 2:00 hours of specimen having v_f =30% of fiberglass fabric. This mean that the number of fiberglass fabric layers play a dominant role for increasing the resisting of relaxation of epoxy composite at T=60 °C.

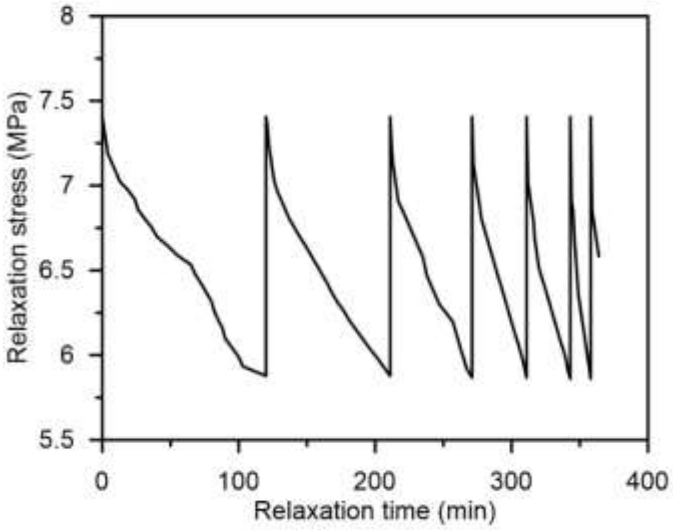

Fig. 7. Relaxation stress for v_f =30% composite at 60°C

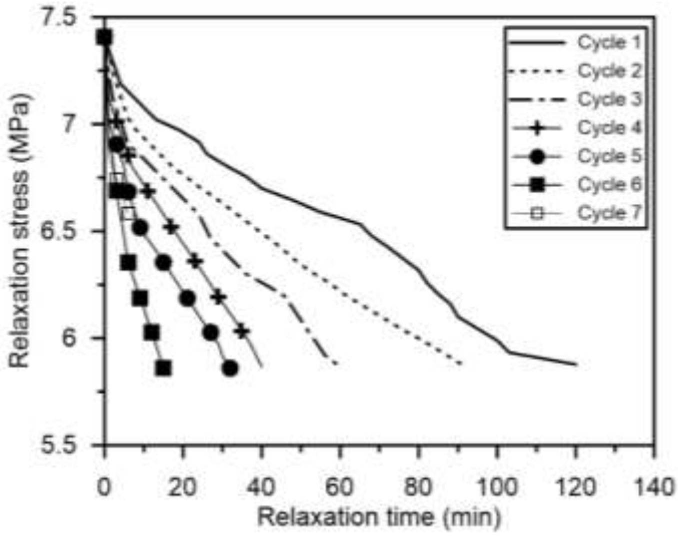

Fig. 8. Relaxation cycles for v_f =30 composite at 60°C.

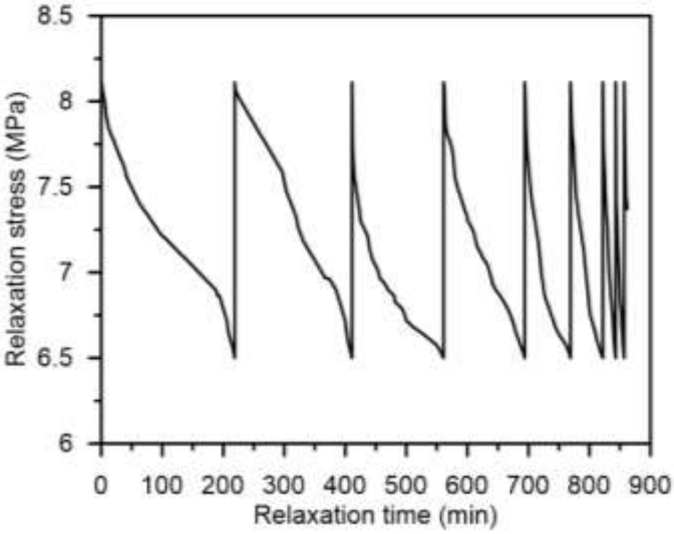

Fig. 9. Relaxation stress for v_f =45 composite at 60ºC.

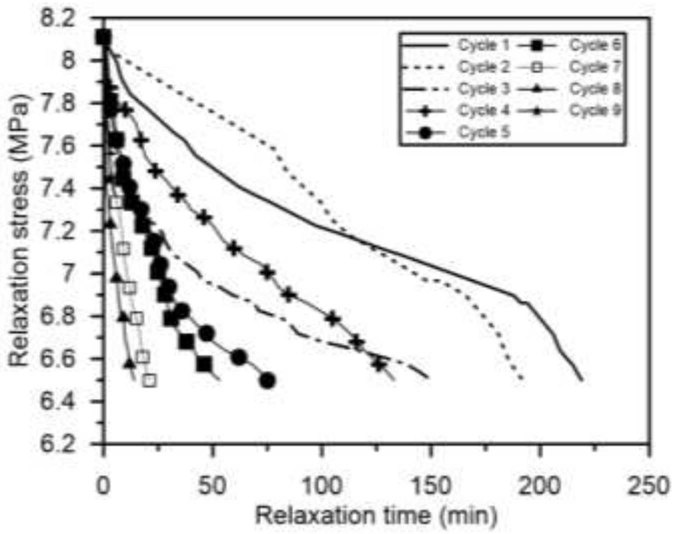

Fig. 10. Relaxation cycles for v_f =45% fiberglass fabric/epoxy composite at 60ºC

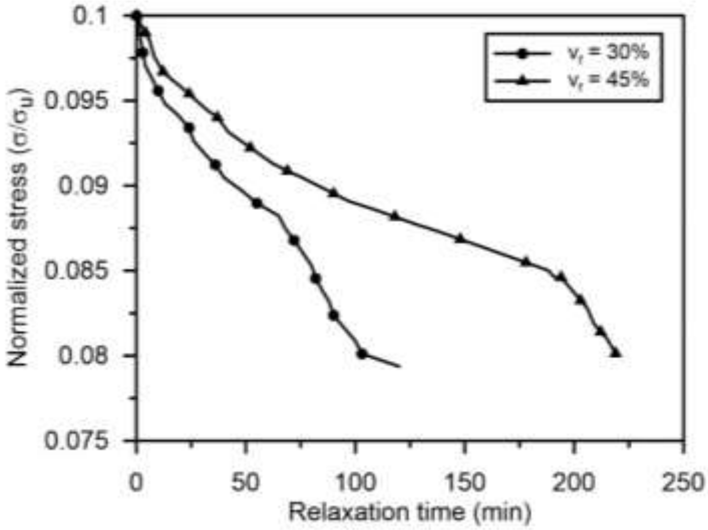

Fig. 11. Comparison between first relaxation cycle for v_f =30% and v_f =45% at 60°C.

The relaxation behavior of fiberglass fabric /epoxy composites is affected by relaxation temperature significally, where the relaxation time is decreased dramatically by relaxation temperature compared with the relaxation time at room temperature. In addition, as the number of fiberglass fabric increased the relaxation time increased at both room temperature and at T=60°C. This behavior of relaxation time at T=60°C can be explained by the relatively deboning of fiberglass fabric and epoxy matrix.

The fiberglass fabric/epoxy composite relaxation time constant λ in Eq. 10 can be obtained using curve fitting of experimental results as shown in Figs. 12 and 13. Table 3 shows the value of relaxation time constant for fiberglass fabric/epoxy composite at different conditions. It can be seen that the relaxation time constant is highly affected by the volume fraction of the fiberglass and it is strongly dependent on temperature. Here the significance of relaxation time constant is evident; it is physically the time needed for the stress to fall to 1/e of its initial value.

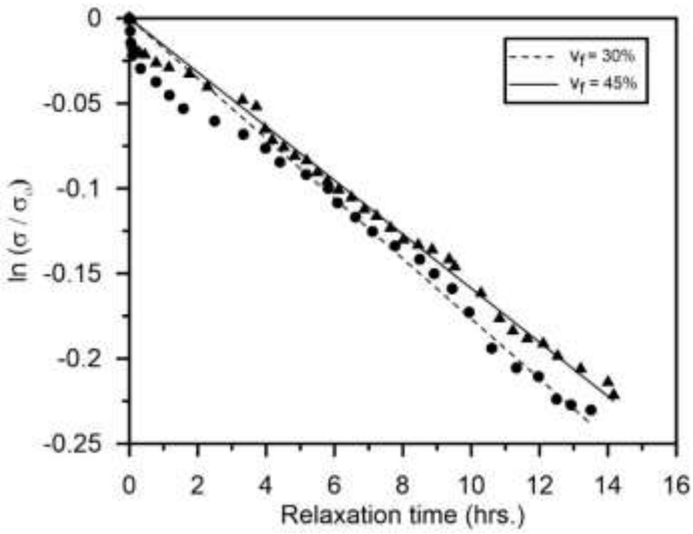

Fig. 12. The relaxation time constant for fiberglass fabric/epoxy composite at room temperature.

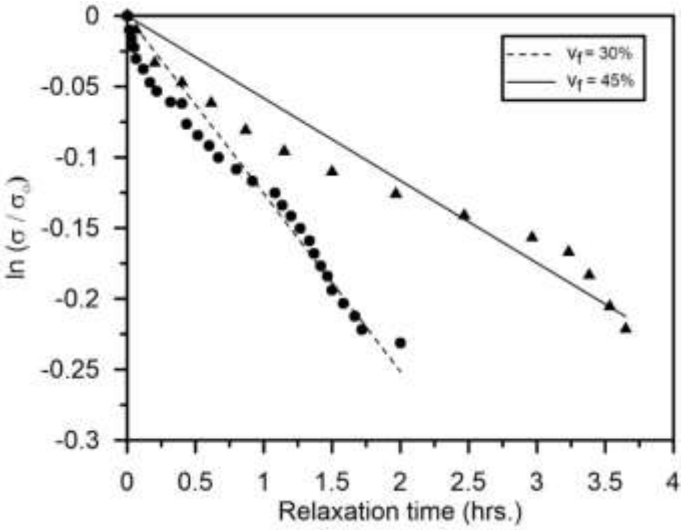

Fig. 13. The relaxation time constant for fiberglass fabric/epoxy composite at 60º C

Table 3. Constant K for fiberglass fabric/ epoxy composite

	Room Temperature.		60 º C	
v_f	30%	45%	30%	45%
λ	56	63	8	17

CONCLUSIONS

From study the relaxation behavior of fiberglass fabric /epoxy composites, the following conclusions can be drawn. The total relaxation time of epoxy specimen having v_f = 45% of fiberglass fabric is relatively long (53 hrs.) compared with the specimen having v_f =30% (46 hrs.). In both v_f =30% and v_f = 45% fiberglass fabric reinforced epoxy, the first relaxation cycle (load/reload) have the longest time compared with the next relaxation cycles. At 60 °C, the relaxation time of specimen having v_f = 45% of fiberglass fabric (14.3 hrs.) relatively long compared with the specimen having v_f =30% of fiberglass fabric (6 hrs.). The total relaxation time is highly affected by increasing the test temperature from room temperature to 60 °C, the relaxation time decreased (14.3 hrs.) at 60 °C compared with (53 hrs.) at room temperature for the specimen reinforced with v_f = 45% of fiberglass fabric. The relaxation time constant is highly affected by the volume fraction of the fiberglass and it is strongly dependent on temperature.

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