The Effect of Stress and Temperature Variation on the Creep Behavior of Epoxy Adhesive Bounding

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***Abstract*—Two types of polymer composites are bounded with different adhesives. The composites are Carbon and Glass Fiber Reinforced Polymer (CFRP and GFRP). The adhesives are epoxy and epoxy- multiwall carbon nanotubes. The creep test is achieved with a wide range of applied stresses and temperatures. Increasing the stress and temperature result in increased the creep strain. Before bounding, the CFRP exhibit a higher resistance to creep behavior as comparing with GRFP. The lowest creep strain values are found with the bounded specimens by epoxy- multiwall carbon nanotubes type. The volume fraction of carbon nanotube of adhesive composite has an effect on the creep behavior.**

Keywords—Creep, CFRP, GFRP, epoxy, CNTs.

1- INTRODUCTION:

The creep behavior of carbon fiber- epoxy is studied. It observed that at room temperature, no creep tensile rupture failure is occurred. At elevated temperatures, the flexural creep compliance is taken at isothermal [1]. Different conditions of stress (20-60 MPa) and temperature (25-90 ^{o}C) are used to study the creep models of random fiber glass. A nonlinear creep behavior is found for all ranges of stress and temperature. The predicted creep model gave a good agreement with the experimental data [2]. The creep of basalt fiber reinforced epoxy (BFRE) and glass fiber reinforced epoxy (GFRE) are studied at high temperature. The result indicated that the creep resistance of (BFRE) is higher than those of (GFRE). The creep behavior is generally nonlinear for all range of temperature and stress [3]. The addition of (0.5 wt.%) carbon nanotubes results in increase the modulus of epoxy and increase the threshold strain energy release rate from 24-73 J/m2 [4]. Two type of epoxy is tested at different level of the applied stress. It observed from the experimental data that when the carbon fiber is used in the epoxy resin, the creep strain is reduced at a percentage (38-58%) as comparing with epoxy resin [5].

2- EXPERIMENTAL WORK:

A. Materials

The polymer materials which bounded with epoxy are carbon glass fiber reinforced polymer (CFRP and GFRP). The first material consist of (6-layers sheet) made from composite CFRP. A plane woven type carbon fiber represents the upper and lower layer. The other four intermediate layers are put with a unidirectional ($0^{o}/90^{o}/0^{o}/90^{o}$). Sheet thickness is (1mm), volume fractions are; (60% carbon fiber and 40 % epoxy). GFRP, consist of (6-layers sheet) woven fiber glass with (1mm) thickness. The volume fractions are; 54% carbon fiber and 46 % epoxy.

The mechanical properties for each composite material are listed in table (1)

Two types of adhesives are used for bounding. The first one is quick mast 105 (DCP), table (2).

In order to increase the bounding strength, a multiwall carbon nanotube (MWCNTs) is added to epoxy to form the second resin, table (3).

TABLE (1) MECHANICAL PROPERTIES OF COMPOSITE MATERIAL

Material	Tensile strength (MPa)	Modulus of elasticity (GPa)	Elongation (%)
GFRP	240	6	1
CFRP	950	18	1.5

TABLE (2) NOMINAL EPOXY SPECIFICATION

Compressive strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)	Pot life (min.)	Density (g/cm3)	Viscosity (poise)
70	25	45	50-70	1.1+0.05	3-5

TABLE (3) NOMINAL MWCNTS SPECIFICATION

Purity	Wall numbers	Outer diameter (mm)	Length (□m)	Density (g/cm3)	Electrical conductivity
99%	3-15	13-18	1-12	0.15-0.35	100

B. Mixing method:

The mechanical stirrer method is used to blend the MWCNTs with epoxy resin. A homogenizer mechanical stirrer device is used, Fig. 1. Epoxy resin is mixed with MWCNTs at 10000 RPM for 15 minutes and left ten minutes for cooling. At those conditions, a homogenous dispersion of MWCNTs into the epoxy resin is a chivied.

Fig. 1 Mechanical stirrer device

The composite material of adhesive bonding is prepared by adding the MWCNTs to the epoxy resin with three values of volume fractions 0.25, 0.3 and 0.4%.

C. Tensile test:

Tensile test specimens of composite polymers (carbon and galas fiber) are machining according to (ASTM – D638-03). The standard and manufactured specimens are shown in Figs. 2 and 3 respectively.

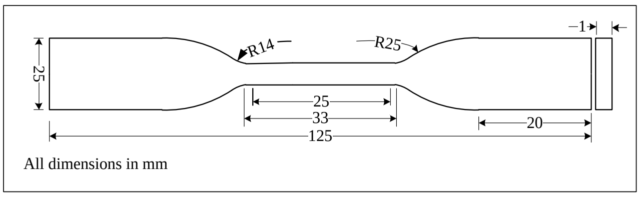

Fig. 2 Standard tensile test specimen

A. 2-4 Creep test:

A standard creep test specimens is used according to (ASTM2990), Fig. 5. The creep specimens for are manufactured with thickness of 1mm, Fig.5.

In order to test the creep behavior of the adhesive joint, the specimens are manufactured from two symmetrical half specimens with (10mm lap length) such that the final glued specimens have the same standard creep specimen dimensions, Figs. 6 and 7.

The tensile test machine setup is shown in Fig. 4

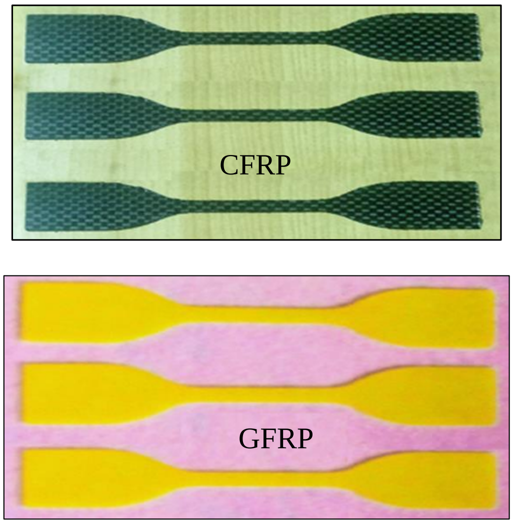

Fig. 3 Tensile test specimens of composite polymers

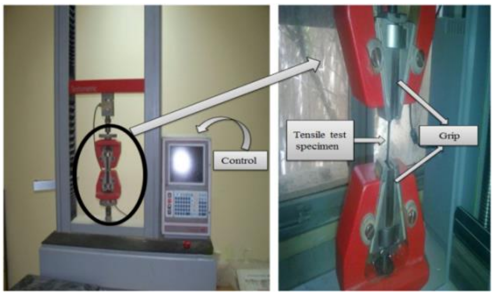

Fig. 4 Tensile test machine

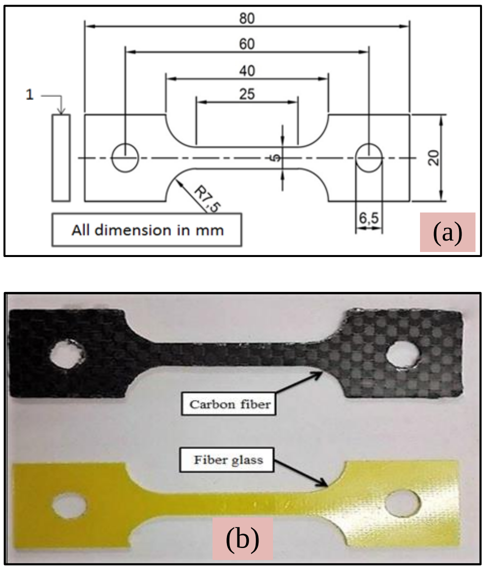

Fig. 5 Creep test specimens (a) schematic (b) manufactured

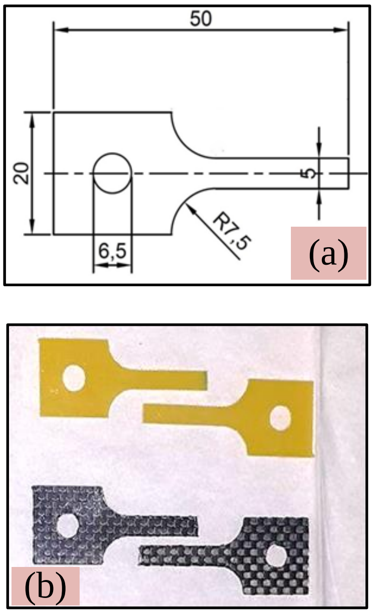

Fig. 6 Half creep specimens (a) schematic (b) manufactured

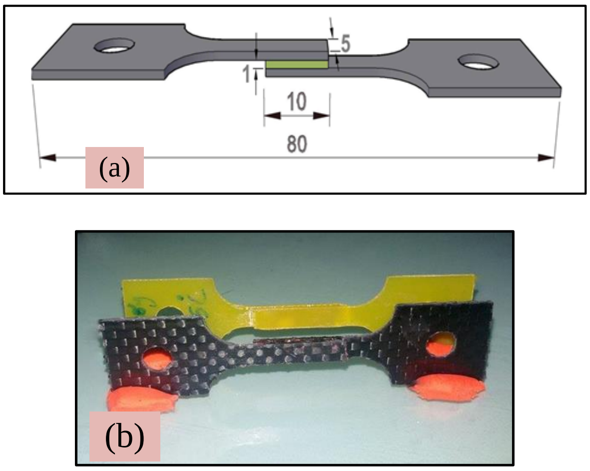

Fig. 7 The glued creep specimens (a) schematic (b) manufactured

The creep test machine has a controlled temperature heater. The creep test has done with three values of the applied stress (4, 5.4 and 7 MPa). For each value of the applied stress, five values of the applied temperature were used (25, 50, 60, 70 and 80 ^{o} C).

The creep test includes the reading of deformation (δ) during time (t). The creep strain is calculated at each interval time according to the following equation:

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

Where:

ε (t): instantaneous strain (mm/mm).

δ (t): instantaneous deformation (mm).

L: gauge length (mm).

III. RESULTS AND DISCUSSION:

The tensile strength for (CFRP and GFRP) is obtained from tensile test results, Fig. 8. Those values are recorded as 950 and 220 MPa for carbon and glass fiber reinforce polymer respectively.

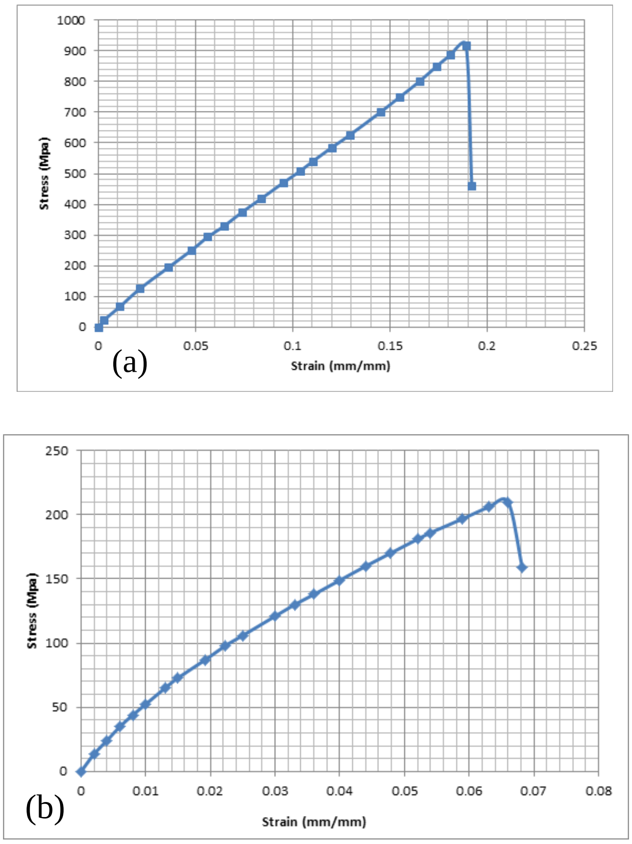

Fig. 8 Stress- strain curve for (a) CFRP (b) GFRP

A. Creep behavior for CFRP and GFRP

The experimental results of creep test at room temperature for the two polymers are shown in Fig.9, the creep test time is 2000 minute. Normally, increasing the stress results in increase the creep strain values. Approximately, the homogenous increasing in the stress interval results in a homogenous increase in the creep strain values. A higher resistance to the creep behavior is observed in the CFRP as comparing with GFRP for each values of the applied stress. This can be consoled to the fact that the CFRP have a higher tensile strength as comparing with GFRP.

In order to study the temperature effect on the creep behavior, the test has been done at a constant applied stress (σ = 4 MPa) with different temperature values, Fig. 10. Increasing the applied temperature gave an increase in the creep strain values. A higher difference is observed between the room temperature and (T= 50, 60, 70 ^{o} C). This difference is increased more at the final temperature (T=70 ^{o}C). Approximately, the same creep strain values are observed for temperatures (T= 60 and 70 ^{o}C).

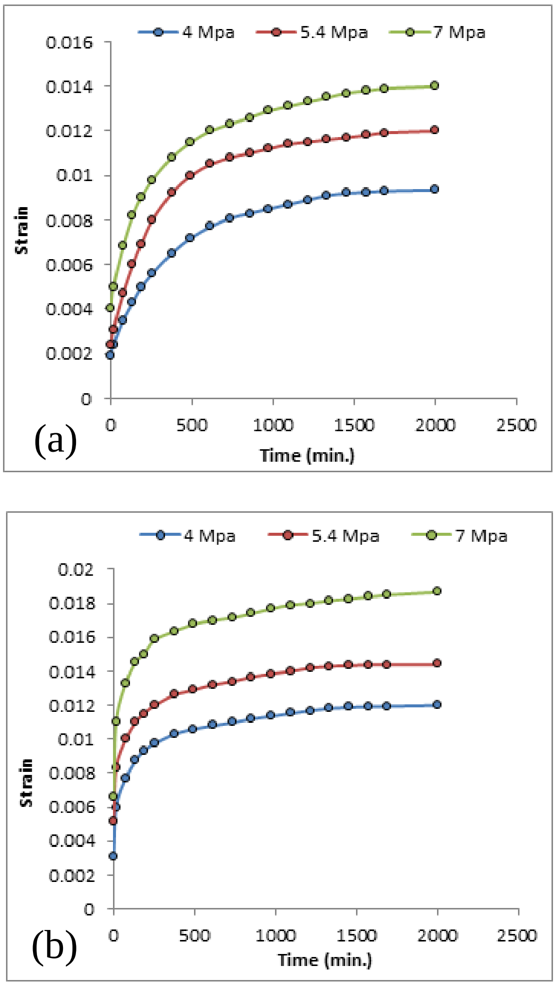

Fig. 9 Creep behavior at (T= 25 oC) for (a) CFRP (b) GFRP

The creep behavior for both polymer at each value of the applied stress and temperature are shown in Figs. 11 to 13. For all temperature values and at each applied stress, CFRP gave a higher resistance to creep behavior as comparing with the GFRP. This can be related to the fact that the (CFRP) have a higher strength values than the (GFRP). Lower strain values are observed at the lower temperature and stress for (CFRP), Fig.13-a, while the higher strain values are observed at the higher temperature and stress for (GFRP), Fig.18.

A. 3-2 Creep behavior for adhesive bounding-epoxy:

The creep test has been achieved for the epoxy-adhesive bounded specimens with the same conditions (temperature and stress) as in CFRP and GFRP, Figs.14 and 15. In general, the creep strain values for epoxy-adhesive bound are smaller than those of CFRP and GFRP. Approximately, the same creep strain values are observed for temperatures (T= 25 and 50 ^{o}C). The strain values are increase with increasing the temperature values (T= 60, 70 and 80 ^{o}C). A marked difference is observed in the creep strain values between the temperature values (T= 50 and 60 ^{o} C) for all ranges of time. Approximately, the initial strain values are the same for temperature ranges (T< 80 ^{o} C).

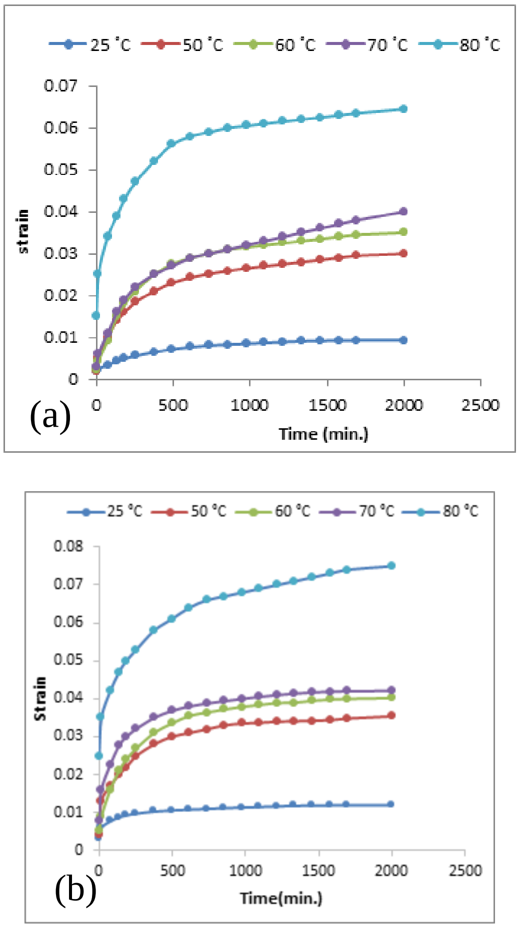

Fig. 10 Creep behavior at (σ = 4 MPa) for (a) CFRP (b) GFRP

B. Creep behavior for bounded specimen with CNTs:

The creep behavior of CNTs is studied for both polymers (CFRP and GFRP) with three volume fraction values (0.25, 0.3 and 0.4 %). Fig.18 represents the creep behavior of this bounding at stress (σ = 4, 5.4 and 7 MPa). As it has been observed, increasing the applied stress results in increase in the creep strain values. For each polymer, the adhesive bounding of epoxy with CNTs (0.3%) gave the higher resistance to creep behavior. The weakness strength is observed in the volume fraction percentage 0.25%. Approximately, for all volumes fraction, the initial creep strain has the same values.

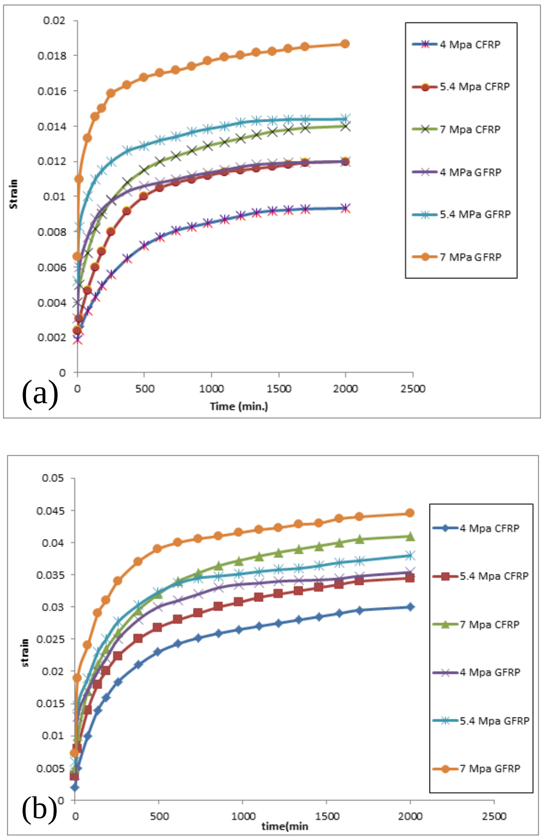

Fig. 11 Creep behavior for CFRP and GFRP (a) T= 25 ^{o}C (b) T= 50^{o} C

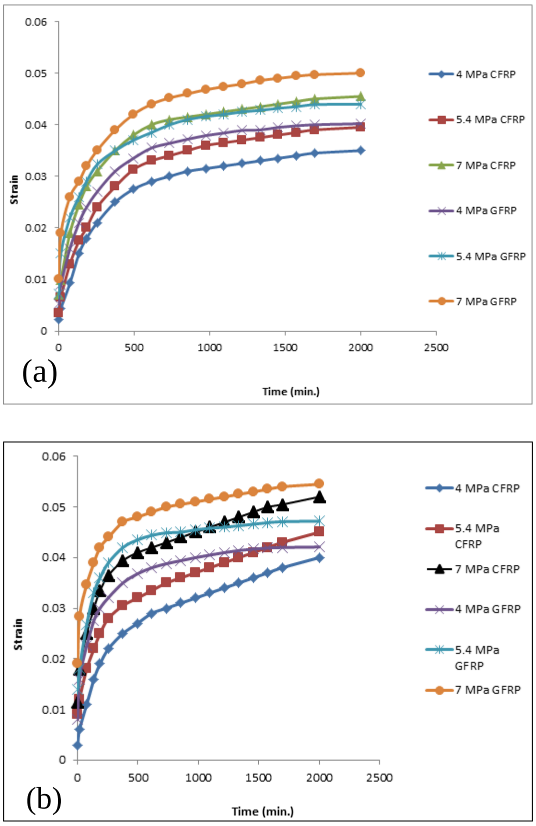

Fig. 12 Creep behavior for CFRP and GFRP (a) T= 60 oC (b) T= 70^{o} C

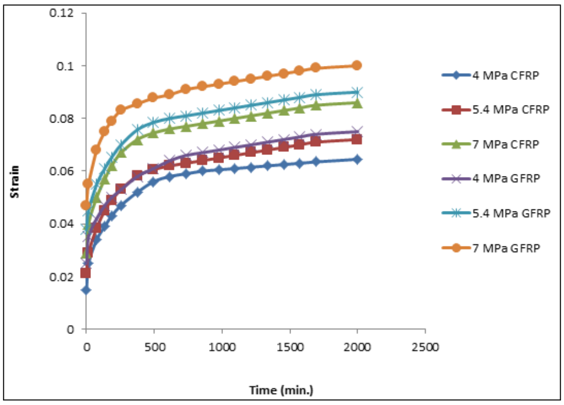

Fig. 13 creep behavior for CFRP and GFRP T= 80 ^{o}C

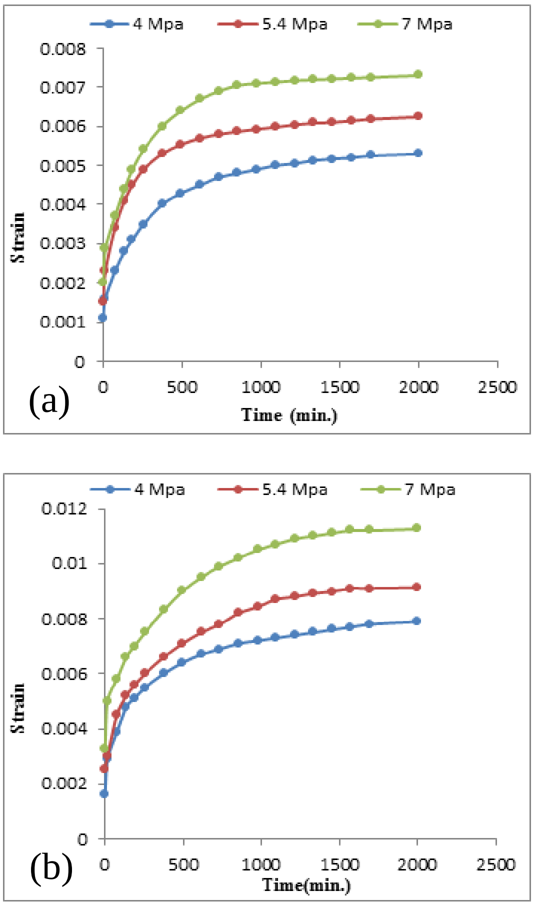

Fig. 14 Creep behavior at (T= 25 oC) for epoxy bounded, (a) CFRP (b) GFRP

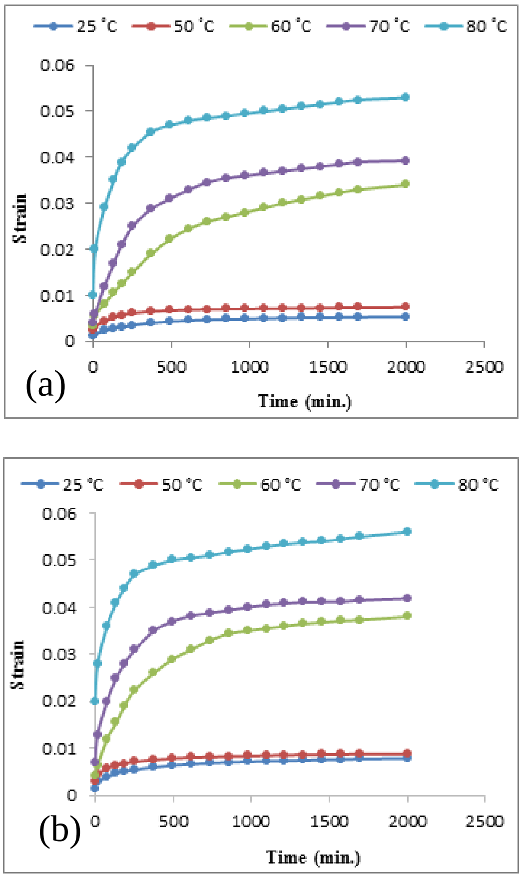

Fig. 15 Creep behavior at (σ = 4 MPa) for epoxy bounded, (a) CFRP (b) GFRP

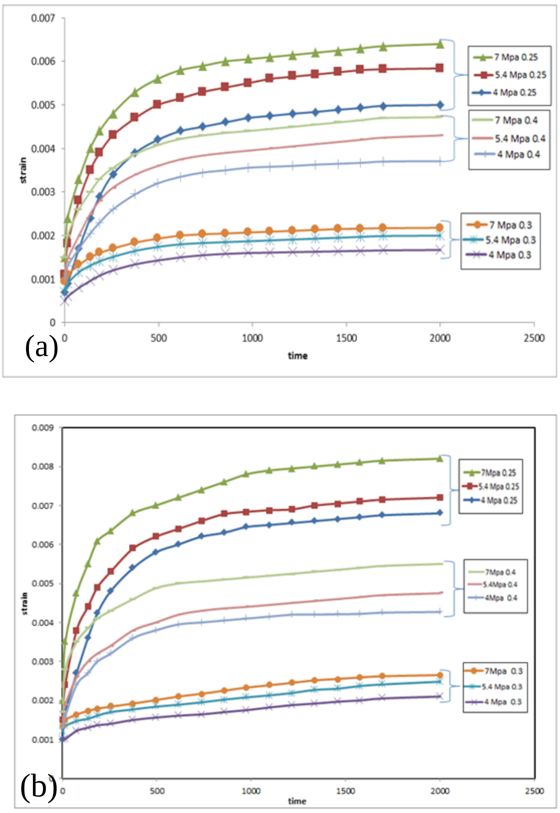

Fig. 16 Creep behavior at (T= 25 ° C) for CNTs bounded, (a) CFRP (b) GFRP

IV. Conclusions:

1) The stress and temperature have an effect on the creep behavior of polymer.
2) The CFRP resist the creep behavior more than the GRFP.
3) The Lowest strain values are observed at lower temperature and stress for (CFRP).
4) The highest strain values are observed at higher temperature and stress for (GFRP).
5) The epoxy-adhesive bounded specimen resists the creep behavior more than those of (CFRP and GFRP).
6) At (T< 80 ° C), the initial strain values are the same in the epoxy-bounded specimens.
7) The bounded specimens by CNTs exhibit a higher creep resistance as comparing with those of epoxy.
8) The highest creep strength is observed in the bounded specimens by CNTs (0.3%).

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