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Technical note

EXPERIMENTAL AND NUMERICAL STUDY ON THE EFFECT OF CREEP BEHAVIOR ON EPOXY COMPOSITES REINFORCED WITH YTTRIUM OXIDE POWDER

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The creep test is one of the important approaches to determining some mechanical properties of composite materials. This study was carried out to investigate the creep behaviour of an epoxy composite material that was reinforced with Y_2O_3 powder at weight ratios of *2*%, *7*%, *12*%, *17*% and *22*%. Each volume ratio was subjected to five loads over the range of *1N* to*5N* at a constant temperature of *16 ± 2°C*. In this work, creep behaviour, stress and elasticity modulus were studied through experimental and numerical analyses. Results showed that increasing the weight ratio of Y_2O_3 powder enhanced creep characteristics.

Key words: epoxy composite, yttrium oxide, creep, ANSYS/APDL, weight ratios.

1. Introduction

Composites may be defined as any multicomponent material that presents a certain property of any of its constituents in accordance with the percentage of the constituent and wherein a combination of two or more components can provide improved properties to the end product. Epoxy-reinforced composites are important because they provide stiffness and high strength-to-weight ratios. The knowledge of creep behaviour is required to design parts for long-term use [1].

Creep behaviour is an important design property of polymers because it is responsible for important strength reductions and time-dependent changes in the dimensions of a product. These changes may affect the product's capability to resist design load. Polymers are susceptible to creep even at room temperature. Many researchers have studied this problem. Al-Hassani and Areef investigated the creep behaviour of an epoxy composite material that was reinforced with three

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volume fractions of glass fibres at room temperature. Their results showed that creep behaviour increases when the volume fraction is increased [1].

Glaskova and Aniskevich estimated the creep behaviour of an epoxy/clay nanocomposite under the effect of moisture. They reported that the elastic modulus increases by *25*% with the increase in filler content and decreases by *40*% with the increase in moisture content[2]. Subramanian et al. studied the influence of fibre length on the creep performance of a fibre-reinforced polypropylene composite at different stress levels and room temperature. The creep strain of all tested materials increases with respect to time. Moreover, sensitivity changes in accordance with stress level [3]. Papanicolaou *et al.* compared the experimental and theoretical results for the creep behaviour of an epoxy material reinforced with fibreglass [4]. Bakonyi and Vas subjected nonreinforced polypropylene and fibreglass-reinforced polypropylene to creep and tensile tests at different loads for *10h* is to determine the average ratios of failure force [5]. Lorandi *et al.* applied different stress and temperature conditions to evaluate the creep behaviour of a carbon/epoxy composite over test time [6]. Zhai *et al.* conducted a series of creep tests to predict the behaviour of E-glass-reinforced composites experimentally and constitutively [7].

Fu *et al.* studied the influence of loading rate on the creep response of an epoxy resin under indentation to establish the scope of deformation under constant loads [8].

2. Experimental work

2.1. Materials used

The epoxy resin used in this work was Nitofill EPLV (Jordan Industry). Its hardener was K-6. The resin and hardener were mixed at the ratio of 1:2. Y_2O_3 powder with an average grain size of *30* μ*m* was used as the reinforcement at *2*%, *7*%, *12*%, *17*% and *22*% weight ratios.

2.2. Composite preparation

The epoxy composite was mixed with Y_2O_3 powder in accordance with the predefined weight ratios by first using the hand lay-up technique and then by using a magnetic stirrer for *15 min*. Then, the hardener was added at the amount specified by the suppliers. Subsequently, the mixture was placed in a vacuum chamber to remove bubbles and then carefully poured into a rubber mould with the required dimensions of the samples. The mixture was finally left for *72h* to dry and then removed and cured for 5 days. Five specimens were prepared for each volume ratio.

2.3. Tensile test

The tensile test was carried out by using a Zwick/Roell Z100 universal testing machine to obtain the mechanical properties that were required as the input in the finite element model (ANSYS) program. Specimen dimensions were selected in accordance with the ASTM D638 standard[9].

2.4. Creep test

The creep test was performed by using a WP600 creep testing machine as shown in Fig.1. The specimens were moulded initially to meet the ASTM D2990 standard requirements [10] as indicated in Fig.2. Each volume ratio was subjected to loads ranging from*1N* to *5N* at constant temperature (*16 ± 2 °C*).Strain as a function of time was recorded every *8s* for *1h*. Then, the load was removed, but the readings were continued to be taken for another hour because the rate of change in the first hour was high and additional points had to be collected to obtain a curve with increased accuracy. The creep specimens are shown in Fig.3. Figure 4 depicts the rubber mould used in this study.

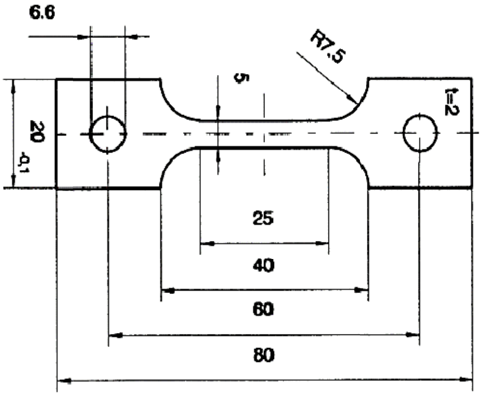

Fig.1.Standard creep specimen.

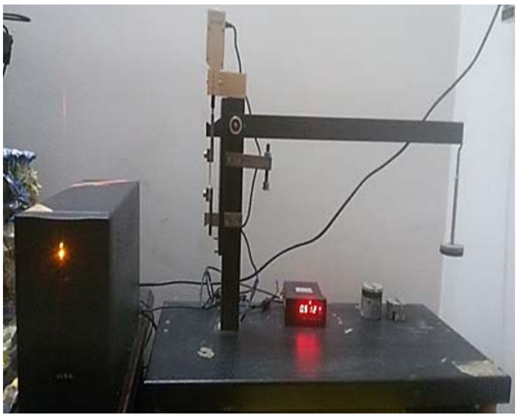

Fig.2.Creep test device

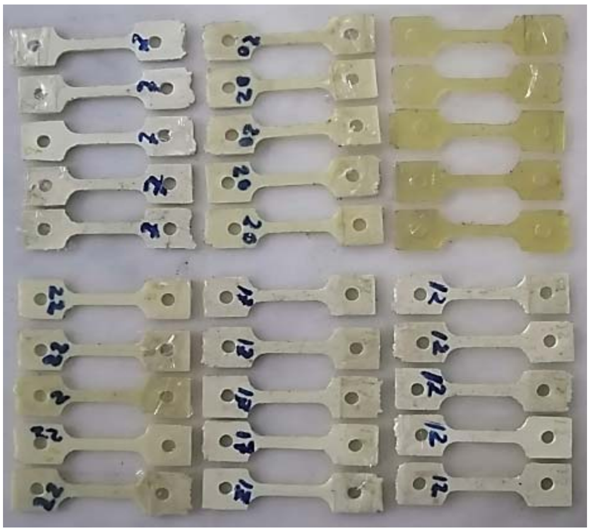

Fig.3. Creep specimens with different weight ratio.

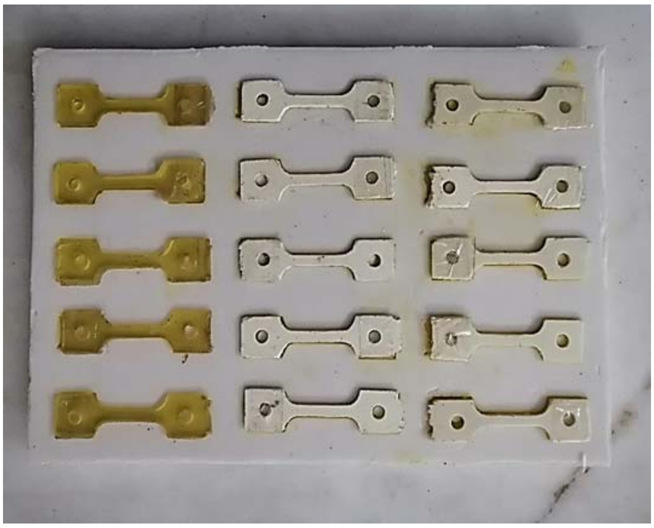

Fig.4.Creepspecimens rubber mold.

3. Theoretical analysis

Maxwell and Kelvin–Voight models were utilised to represent the creep model in the finite element model for finite element analysis (FEA) [11]. Material constants (C1, C2 and C3), stress and Young's modulus must be determined. The Maxwell model was represented by the general creep equation as follows

$$\text{Creep strain} = C_1 \sigma^{C2}\ t^{C3} \exp(-Q/RT) \quad (3.1)$$

whereσ is the applied stress, t is the time of the creep test, Q is the activation energy and (R) is Boltzmann's constant. T represents the absolute temperature. In this study, the temperature was constant for all creep tests, and $-Q/RT$ was taken to be equal to zero. Hence, the general creep equation took the form of

$$\text{Creep strain} = \varepsilon_{creep} = C_1 \sigma^{C2}\ t^{C3}. \quad (3.2)$$

The applied stress σ can be found by using the equation below

$$\sigma(t) = \sigma_o e \frac{-\delta t}{\eta} \quad (3.3)$$

where $\delta = \dfrac{\sigma_o}{\varepsilon_I}$

σ_o : initial stress (1, 2, 3, 4, 5)Mpa.
ε_I: initial strain
t: time in sec.
$\eta = \dfrac{\sigma o}{\acute{\varepsilon}}$, where $\acute{\varepsilon} = slope = \dfrac{\Delta\varepsilon}{\Delta t}$,which can be inferred from experimental readings.

Equation constants (C1, C2 and C3) must be calculated as input for the FEA model (ANSYS). Log strain was plotted versus log time for several loads as shown in Fig.5. The slope, which represents C3, was calculated. Figure 6 shows the relationship of stress versus strain (in log–log scale) that was needed to find C2 on the basis of the slope.

C1 was determined by inputting the value of C2 and C3 into the general creep Eq.(3.2). The creep constants for each weight ratio of composite materials are summarised in Tab.1.

Young’s modulus was calculated by applying the following equation

$$E(t) = \frac{\sigma(t)}{\varepsilon(t)} = \frac{\delta\eta}{\eta+\delta(t)}. \tag{3.4}$$

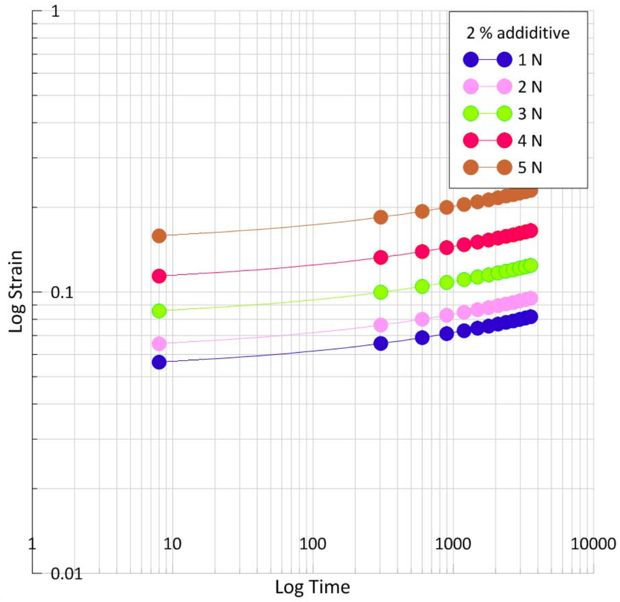

Fig.5. Log strain versus log time for *2*% additive at different loads.

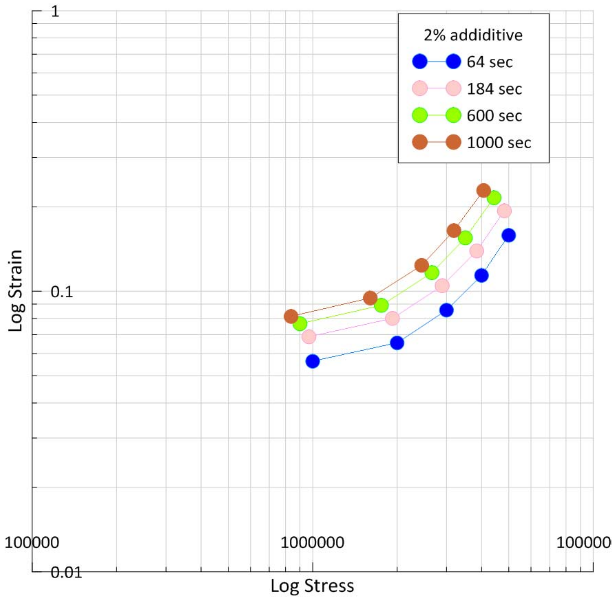

Fig.6. Log strain versus log stress for *2*% additive at different loads.

Table 1. Creep constants for each weight ratio used in FEM.

Y_2O_3 %	C1	C2	C3
0% (Epoxy)	*1.9035980453*	*0.5949980809*	*-0.9220200842*
2%	*1.6032895882*	*0.6232712681*	*-0.92201292*
7%	*1.402752392*	*0.5966758675*	*-0.92201292*
12%	*1.0021744219*	*0.6206395851*	*-0.92201292*
17%	*0.801802437*	*0.6036495364*	*-0.92201292*
22%	*0.7013568137*	*0.4274674809*	*-0.92201292*

5. Finite element modelling for creep analysis

The aim of creep modelling is to simulate time-dependent behaviour in engineering design up to the critical state of creep. A 3D model of the specimens was constructed and analysed through the nonlinear FE method. Several parameters are necessary as inputs in the FEA of creep issues. These material parameters were obtained from experimental data. The FE model was loaded with stable load at the lower part of the specimen, and creep strain values were taken and compared with the experimental results. The analysis in this work was performed by using ANSYS/APDL Ver.15.0. PLANE182 elements were sufficient for predicting creep behaviour. Boundary conditions were selected to represent a case that was similar to the specimen. The applied loads were the same as those used in the experimental tests. The holes made in the samples to enable handling were also modelled. Figure 7 depicts the numerical solution of the creep test by using ANSYS software.

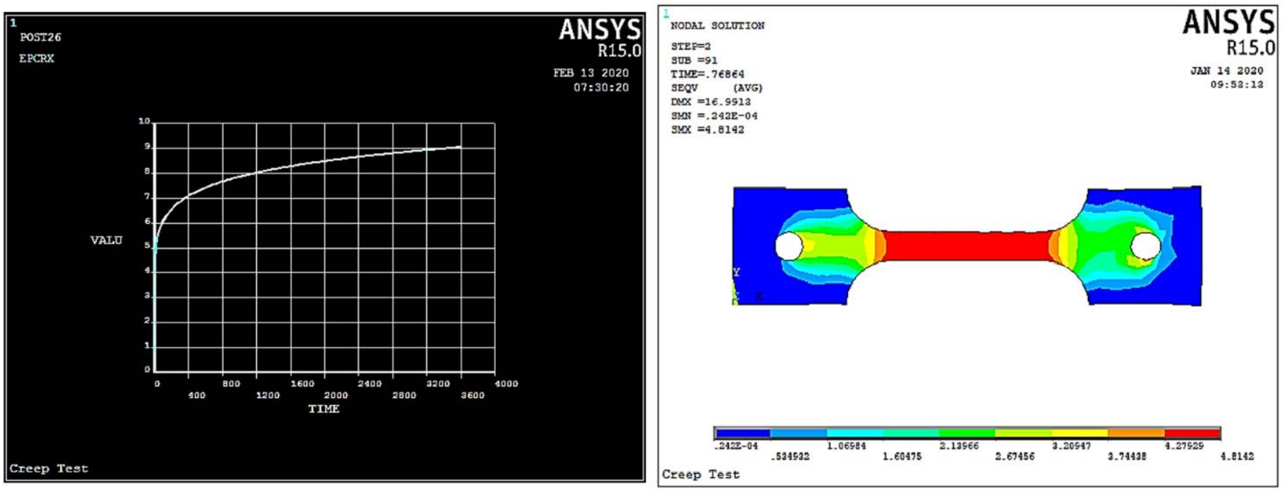

Fig.7. Creep test using ANSYS/ APDL software.

6. Results and discussion

The experimental and numerical results are shown in Figs 8 to 12. Each figure represents the effect of time on strain (creep behaviour). Five different weight ratios of Y_2O_3 (*2*%, *7*%, *12*%, *17*% and *22*%) were subjected to each load at a constant temperature (*16 ± 2 °C*) for a total of five loads. Thirty specimens were examined to investigate the stages of deformation that occurred given that cross-sectional area decreased with the continuous increase in the length of the specimen due to stress build-up. Notably, no creep fractures were detected. As observed from the figures, strain decreased gradually with the increase in the weight ratio of Y_2O_3. The epoxy with the reinforcement was stronger and stiffer than the pure epoxy. Hence, creep features gradually improved as the weight ratio of Y_2O_3 powder was increased to *22*% as mentioned above. Consequently, the secondary stage, which is the most important part of the creep curve, improved because of the appearance of viscoelasticity. This characteristic, which is based on the properties of the specimen, determines the predestined lifetime of components[12]. The Maxwell and Kelvin model [11] may be the simplest viscoelastic model used to predict creep strain over time. The model under *1N* load is shown in Fig.13. Figure 14 represents a comparison of creep strain under the addition of Y_2O_3 at different weight ratios. The experimental and numerical data showed good correlation as indicated by the difference of *0*%–*12*% between the experimental and numerical data. These differences were due to several reasons, including the environment. For example, humidity plays an important role in the experiment and changed continually. However, in the numerical simulation, this variation was ignored. Instead, humidity was taken as a factor that remained constant during the experiment. Another factor was the method used to fix the specimen. In the experiment, the specimen slipped negligibly. This problem did not occur at all in the numerical simulation. As shown by the results in Fig.15, adding Y_2O_3 powder as a reinforcement to epoxy increased Young's modulus of the material gradually. A high Young's modulus is indicative of high stiffness. This relationship provided clear and certain indications of the capability of this type of reinforcement to reduce gap and void formation in the matrix during moulding.

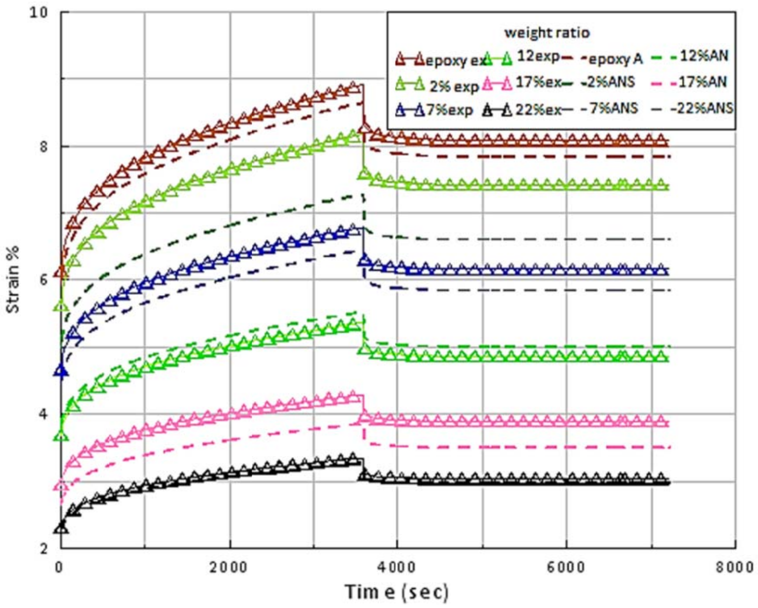

Fig.8. A comparison of ANSYS and experimental study of strain versus time for different weight ratios at *1N* load.

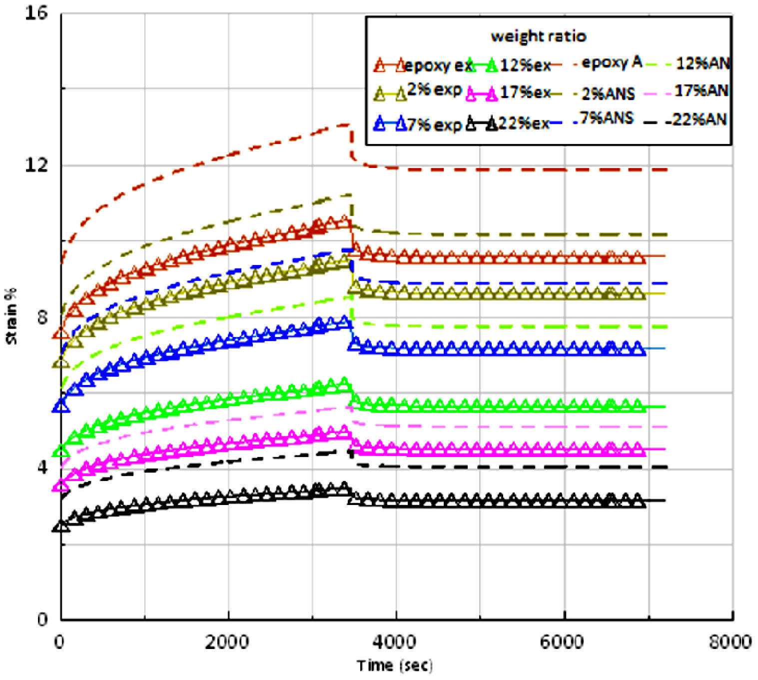

Fig.9. A comparison of ANSYS and experimental study of strain versus time for different weight ratios at *2N* load.

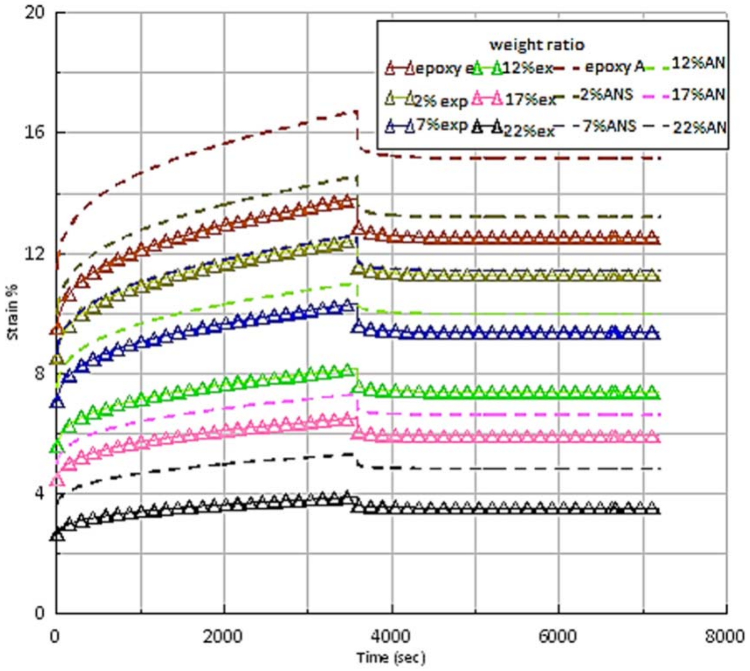

Fig.10. A comparison of ANSYS and experimental study of strain versus time for different weight ratios at *3N* load.

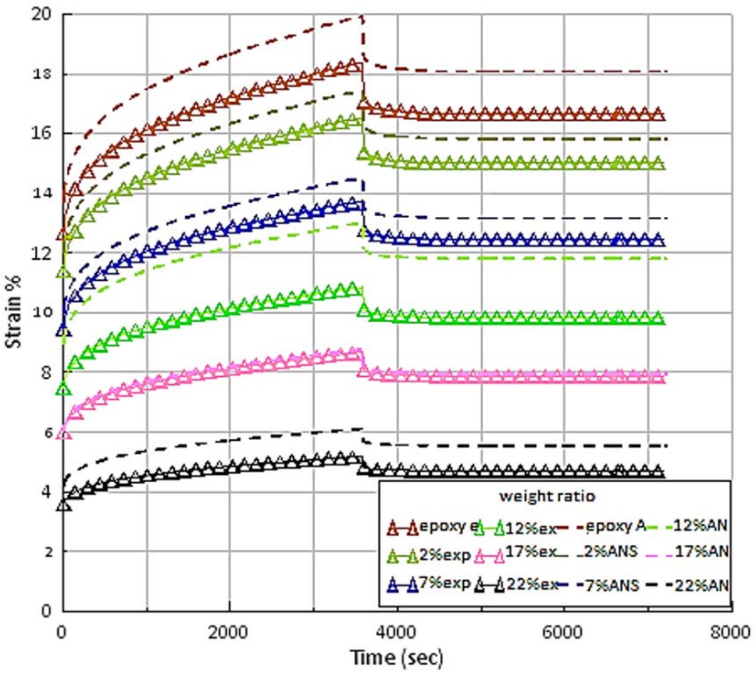

Fig.11. A comparison of ANSYS and experimental study of strain versus time for different weight ratios at *4N* load.

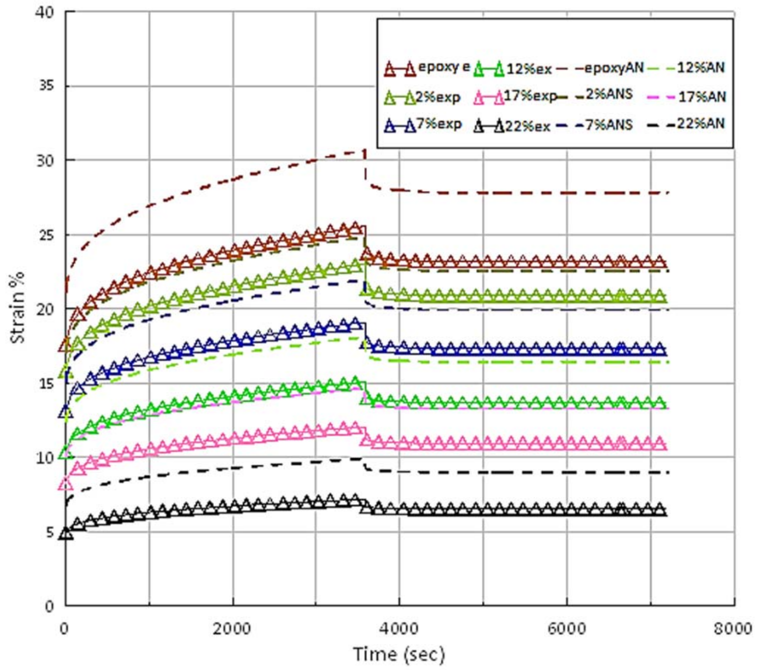

Fig.12. A comparison of ANSYS and experimental study of strain versus time for different weight ratios at *5N* load.

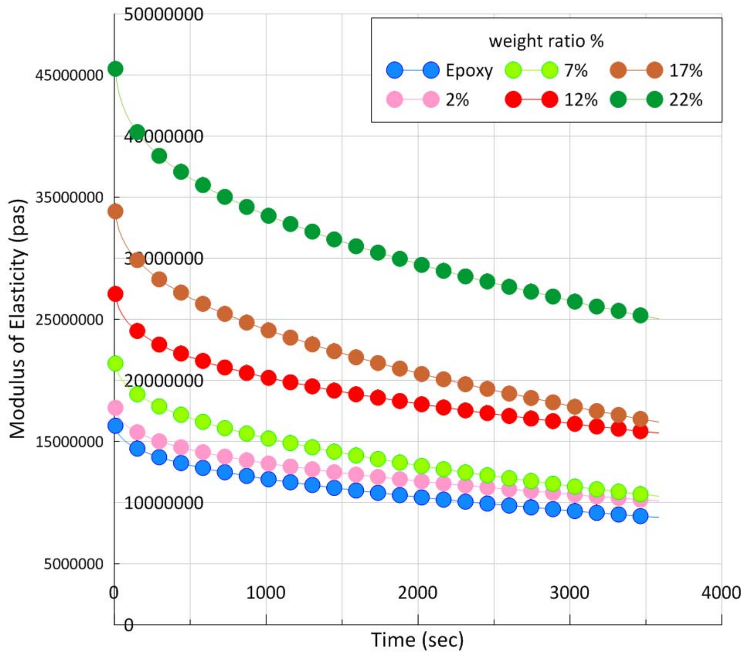

Fig.13. Modulus of elasticity for different weight ratios at *1N* load.

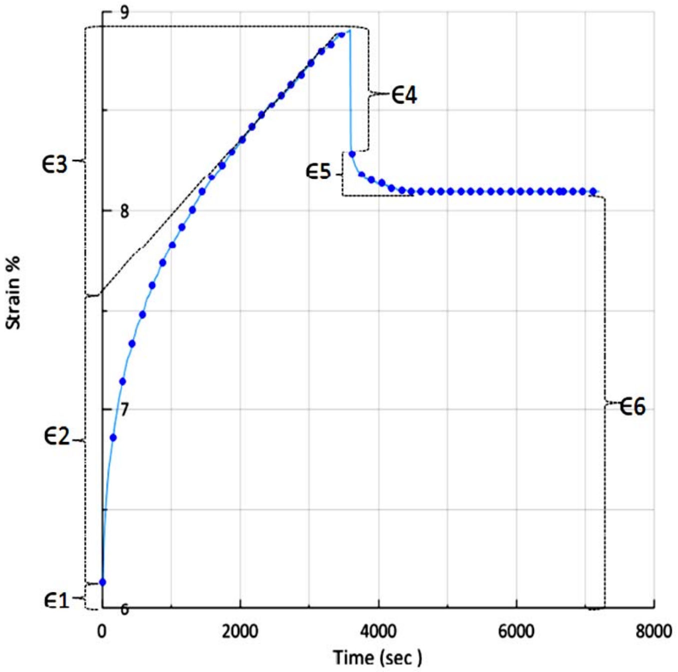

Fig.14. Creep behavior of epoxy at *1N* load.

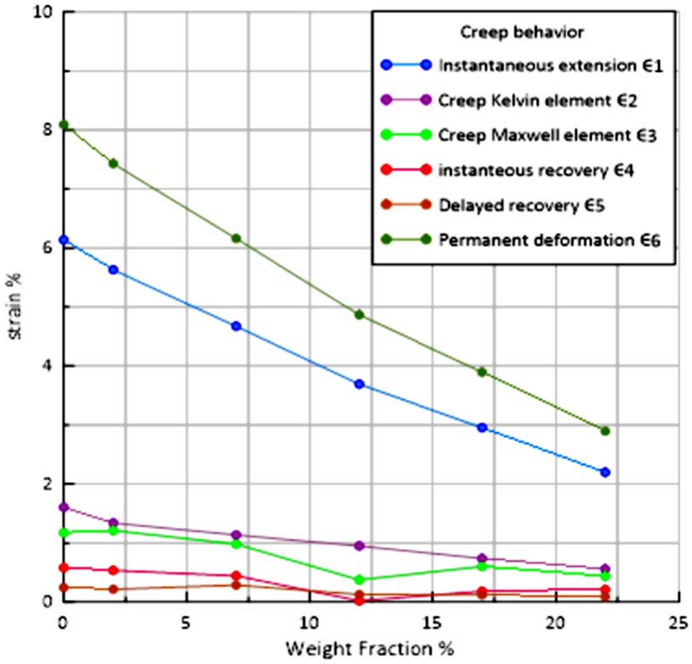

Fig.15. Effect of weight ratio on creep behavior at 1N load.

Stresses tend to decrease with the increase in the weight ratio of Y_2O_3 as illustrated in Fig.16. Plain epoxy had a high stress value that indicated the existence of highly localised strain in the matrix. Therefore, the stress value decreased significantly as the weight ratio of Y_2O_3 was increased to *22*% due to strong bonding between the reinforcement and the epoxy, resulting in an improved stress distribution.

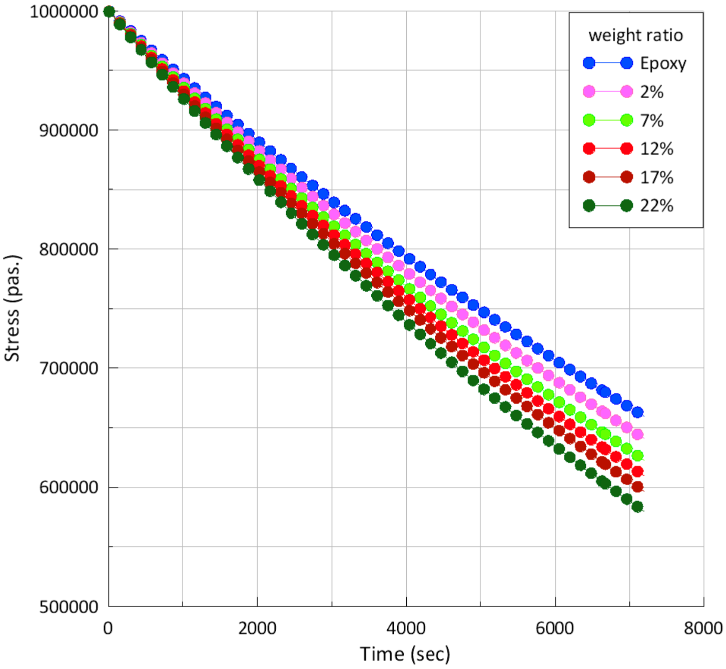

Fig.16. Stress versus time for different weight ratio at *1N* load.

7. Conclusion

In this study, the creep behaviour, stress and Young's modulus of epoxy composites that were reinforced with Y_2O_3 powder at five different weight ratios were investigated under five loads at constant temperature. The conclusions could be summarised as follows:

1. Creep characteristics could be enhanced by increasing the weight ratio of Y_2O_3 powder. This result indicated that reinforcement plays an important role in improving the mechanical properties of materials.
2. The addition of reinforcement to the epoxy composites extended the secondary stage of the creep curve, thus prolonging the time to breakage.
3. Young's modulus increased with the increase in the reinforcement ratio, thus yielding materials with increased stiffness.
4. Stress distribution was improved by adding reinforcement to the mixture. Stress noticeably decreased with the increase in the weight ratio of the reinforcement.
5. The weight ratio of *22%* provided the best creep properties. Superior properties might be obtained by increasing the weight ratio beyond this value.
6. A comparison revealed good correlation between the experimental and numerical results.

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