International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 34, No. 5, October, 2024, pp. 593-602
Journal homepage: http://iieta.org/journals/rcma

Enhancements of Creep Compliance of Kevlar and Carbon Fibers Reinforced Sika Epoxy Composites

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https://doi.org/10.18280/rcma.340507

Received: 26 June 2024
Revised: 10 August 2024
Accepted: 8 October 2024
Available online: 31 October 2024

Keywords:
composite material, creep compliance, burger model, Prony series, mechanical properties

ABSTRACT

Kevlar, Carbon and fiber glass are widely used in various kind of industries because of their superior properties like; great stiffness, high strength, wear resistance and low density those benefits contributed to increase their usage in different fields like electronics, automobile, aerospace and civil engineer. This study is carried out to improve the creep behavior of epoxy composite materials by incorporating two type of fiber for reinforcement using Hand-layup techniques. Sika epoxy resin is mixed once with Kevlar fibers, and once with Carbon fiber to produce a composite material. Experimental and numerical simulation are carried out to provide an extensive knowledge of the creep behavior of epoxy composite materials at various weight ratio. Visco-elastic materials creep strain and stress relaxation are analyzed utilizing Prony and Burger models. Based on the results, the addition of Carbon and Kevlar fibers to Sika epoxy composite increase its mechanical characteristics compare to pure epoxy. Carbon fiber possesses lowest creep strain and low stress level than Kevlar fibers. Sika epoxy composite containing 5% weight fraction of Carbon fiber has the highest resistance to creep, up to 80% more, compared with Sika-epoxy; followed by Kevlar fiber which is up to 75% more, compared with Sika-epoxy. The use of carbon/Sika epoxy composite results in higher creep compliance and modulus of elasticity compared with Kevlar/Sika epoxy composite.

1. INTRODUCTION

Composites are becoming increasingly common due to growing demand for lightweight, effective components these materials have earned recognition for their excellent stiffness, strength, and corrosion resistance [1]. Also, it's essential in mechanical and industrial engineering since they offer customized characteristics to satisfy certain requirements of performance in different application [2, 3]. Composite materials are adaptable combinations designed for specific uses, blending a flexible base with strong reinforcing fiber like carbon, glass, or Kevlar. These materials are known for having excellent mechanical characteristics when contrasted to the materials they are composed of. Since they provide durability, exceptional rigidity, and light-weight characteristics make them perfect in industries where reducing weight is essential, like in aircraft contraction [4]. The main objective of this research is to investigate mechanical characteristic of epoxy composite material reinforced by two type of fibers Kevlar and Carbon fibers under creep condition. Epoxy resin is a class of polymer thermo-set that exhibits remarkable adhesive abilities and mechanical toughness for a wide range of applications in industry. Their ability to be compatible with numerous reinforcement materials allows for substantial design flexibility. This makes it beneficial in advanced epoxy-based composite materials used in industries such as aerospace, automotive, structural engineering, and electronics. Therefore, these composites provide superior performance and exceptional durability. thus, becoming an essential component in modern production [5, 6].

Fiber-reinforced polymer composites are superior to traditional composites in terms of efficiency since fiber reinforcement gives the final product dimensional stability. These composites provide plenty of benefits, including flexibility, ease of installation, and an ex-tended life of service. There are numerous forms and types of fibers reachable, aramid fiber (Kevlar) is particularly remarkable due to its effect on strength, stiffness, and other essential characteristics [7-9].

Kevlar fibers are synthesized and produced in a mass scale since they require advanced technology, they getting recognition for its excellent mechanical properties, compared with glass and Carbon fiber it enhances impact resistance, and Kevlar exhibits a superior ability to withstand fracture and reduce impact load [10]. Carbon fiber is widely used in various industries due to its exceptional properties, used in mechanical drilling for precise shape. Yet, the difficulties resulting from damages induced by cutting through machining have an enormous effect on the performance and acceptability [11]. Several researchers have examined fiber characteristics under creep behavior scenarios. Vasudevan et al. [12] investigate the influence of stacking sequences on the mechanical characteristics of Kevlar/glass fiber and carbon/glass fiber composite. Through their observation, they found that enforcement of this synthetic fiber into the fiber composites resulted in a 7.5% enhancement in absorption energy. Sahu et al. [13] illustrated the effects of hybridization on the mechanical characteristics of Kevlar, glass, and Carbon fibers hybrid composites via both experimental and numerical simulation. The finding shows a good correlation be-tween the experiment and numerical results. Behera et al. [14] fabricated the effect of moisture on the mechanical characteristic of Kevlar fiber-reinforced epoxy composite. Using hand lay-up technique, by immersion in three different types of solutions. They revealed that compo-site-absorbed moisture decreases tensile and breaking strength significantly. Almeida Jr et al. [15] studied the creep characteristics of Carbon fibers reinforced epoxy composite with different fiber orientations. By employing both [Findley's and Burger's models] to predict the creep behavior of Carbon fibers reinforced epoxy composite, experimental data is then utilized to validate analytical results. Battawi and Abed [16] examined the creep behavior of natural fibers (fish scales and chicken feathers) as a suitable reinforcement in polyester composite, with different weight fractions of natural fiber employing the hand lay-up method. In comparison with pure polyester, results reveal encouraging characteristics, as it increases creep strain to 74.2% and reduces creep stress to 40.71%. experimental, numerical and theoretical results were compared with average deviation and was found to be no more 3.2%. Battawi and Abed [17] explored the effects of adding two types of natural fiber sheep wool and horse hair as a reinforcement agent of polyester composite to improve mechanical properties in terms of creep behavior. ANSYS Mechanical APDL was implemented to verify experimental and theoretical results. Abed and Battawi [18] studied the creep characteristics of polyester/polystyrene composites reinforced with a weight ratio of fish scales at constant load and temperature. The Maxwell technique was used to determine stress and modulus of elasticity from the (strain/time) curve, by employing curve fitting techniques. Creep characteristics, stress, and modulus of elasticity are studied experimentally. Abed et al. [19] evaluated how immersion media affect the creep behavior of polyester compo-site material reinforced with fillers derived from chicken feathers. Creep samples were made by varying weight ratios and immersed in three separate mediums. The results show that composite samples show enhancing creep characteristics due to the immersions. Abed et al. [20] investigated the creep behavior of epoxy composite with several weight ratios of Yttrium powder. The composite creep samples were subjected to five distinct loads at constant temperatures. Both numerical and experimental evaluations were conducted to assess creep behavior, Young's modulus, and stress of the composites. Yang et al. [21] researched the creep behavior of epoxy composite tubes in flexural loading using an experimental analysis, creep test was conducted at various stress values from (45%-75%) of the flexural ultimate strength at constant temperature and time. The mechanical efficiency, deformation, and reliability of the tubes were evaluated using superposition techniques. Rahmani et al. [22] examined the corrosion and creep characteristics of an epoxy-based composite material reinforced with Kevlar, carbon, and glass fibers. Results revealed that Carbon fiber had the highest creep resistance in comparison with Kevlar and glass fibers, in contrast, Kevlar fiber exhibits the lowest corrosion risk among the three types of fibers. Bharadwaj et al. [23] proposed a mathematical model to convert the Burger model into the Prony series by using the ANSYS program. Therefore, the model can depict the entire time-dependent creep behavior. A significant similarity between the data gathered experimentally and the data obtained via ANSYS software. The creep phenomenon in Visco-elastic material can be divided into three categories: primary, secondary, and tertiary. Creep refers to the material elongation with time, usually occur-ring at high temperatures, while some materials exhibit creep at low temperatures or room temperature. In the primary stage, the material exposed high deformation which slowed down eventually. The creep curve is affected by the material, time, and load. While in the second stage, the material deformation is relatively constant. Finally, in the tertiary stage, a high rate of deformation will occur rapidly leading to material failure. Most engineering practices focus on the primary and secondary stages, hence in practical applications high deformation seen in the tertiary stage was rarely experienced [24]. Figure 1 shows the three stages of creep behavior.

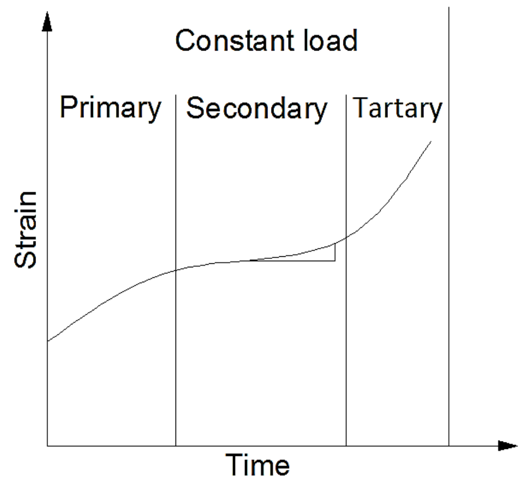


Figure 1. Stages of creep behavior [20]

Previous studies have mainly focused on Kevlar or Carbon fiber-reinforced epoxy composites applying various mechanical properties. This work especially examines creep performance. We seek to explore how Kevlar and Carbon fibers in different weight ratios can exhibit beneficial effects that could improve the composite material's resistance to creep. This approach not only increases our current understanding but also provides insightful guidance to produce advanced composite material that satisfies specific performance criteria .

In summary, this research paper thoroughly investigated the creep characteristic of epoxy composite reinforced by mixing two types of fibers, Carbon and Kevlar. Using a hand lay-up technique. Experimental, theoretical model, and numerical simulations are conducted. By doing this we hope to increase our knowledge of how material composite deforms with time and enhance their ability to carry out load-bearing and structural tasks.

2. MATERIALS AND METHODS

2.1 Material

Aramid/Kevlar fiber used in this research (Figure 2) has exceptional mechanical characteristics, such as high strength, high degree of stiffness, and resistance to heat, its weight is approximately 1/5 of steel wire weight, its modulus is 2-3 times of glass fiber or steel wire, also its strength (5-6) times compared to the latter. Additionally, it has impressive toughness twice that of steel wire. Notable, even at a temperature reach 560℃ Kevlar fiber sustains its structure integrity, without melting or decomposing. Further, it features strong insulation and aging abilities and a long life.

Unidirectional woven Carbon fiber, as shown in Figure 3, imported from Poland, comes in a roll with a length of 50m, width of 100mm, and thickness of 0.167 mm. exhibit specific mechanical properties, including 4000N/mm^2 tensile strength, 230,000 N/mm^2 modulus of elasticity, 1.7% elongation to break and 1.82g/cm^3 density. The epoxy resin used is Sikadur -31CF type manufactured in the Kingdom of Bahrain has the following characteristics: easy mix and use, very good adhesion, high resistance to chemicals, good wear resistance, and strong adhesive. Was used as a composite material to bind multiple layers of carbon and Kevlar fibers.

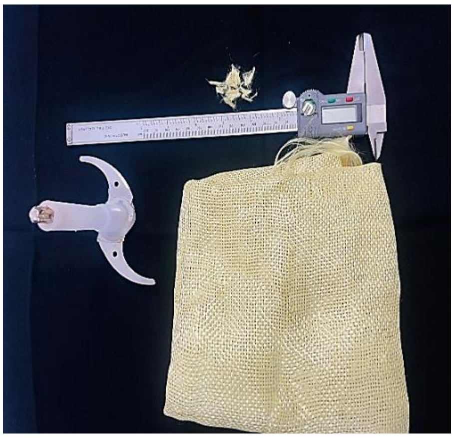


Figure 2. Fiber of Kevlar used in weight ratio

Figure 3. Fiber of carbon used in weight ratio

2.2 Preparation of composite

Resin Sika epoxy is processed as a matrix and mixed with a curing agent named hardener with suitable proportions (3:2%). Samples were prepared as four different reinforcements of Kevlar and Carbon fiber contents of 0, 1, 3 and 5 wt.% as well as pure Sika epoxy samples using a conventional (hand layup) technique.

To create tensile and creep test samples, the reinforced Kevlar and Carbon fiber were cut using a Stanly knife 5mm long and inserted in a longitudinal pattern by the specified weight ratios after the molds were entirely cleaned. next, epoxy resin was gradually poured over the fibers, to ensure sufficient hardening samples were left to cure for 48 hours. Afterwards, it was placed in an oven set at 50 Celsius temperatures for further hardening. Finally left for 7 days before the testing began. The blend must have a decent homogeneity to protect the particle from separating or settling, which could bring an uneven mixture and induce agglomeration following hardening.

2.3 Mechanical testing

2.3.1 Tensile test

Tensile strength test specimens were conducted in compliance with ASTM standard (D638), as shown in Figure 4, and tensile properties of the samples were assessed using a universal testing apparatus (Zwick/RoellZ100), which has a maximum load of up to 300KN (Figure 5), by applying 5mm/min. of cross-head speed and occurred at room conditions. Three different samples were examined in a tensile test, and their average values were considered and used as the final result. Mechanical property resulting from the test was used as an input data in numerical simulation. See Figure 4 for tensile properties and Figure 5 for the testing apparatus.

Figure 4. Tensile test machine

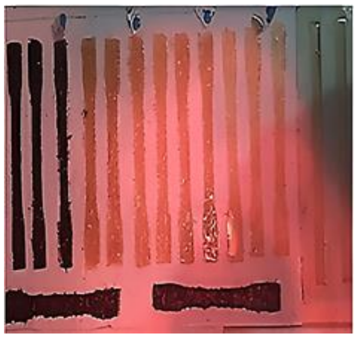
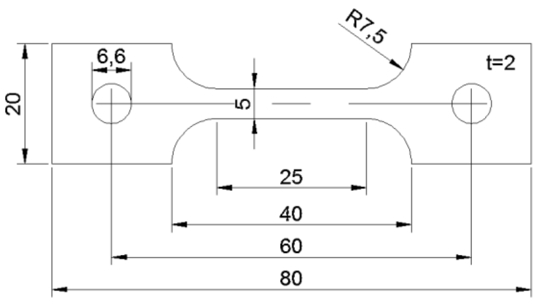


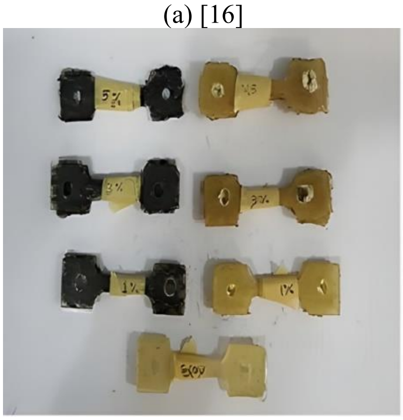
Figure 5. Tensile samples with different fiber weight ratio of Kevlar and Carbon fiber

2.3.2 Creep test

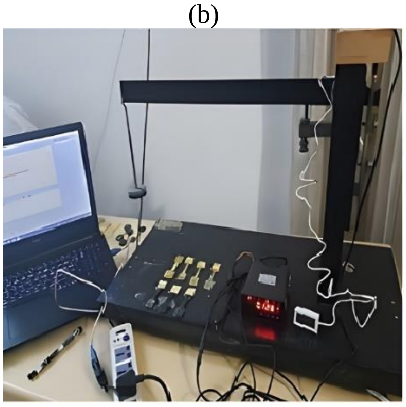
Creep testing was performed following (ASTM2990) standard [20] at a constant temperature of 27℃ with applying a static load of 2N. The specimen is subjected to a load for one hour, removed, and readings are obtained for an additional hour, strain rate of the samples was measured using a digital strain meter. The data collected from the strain/force versus time were digitally stored, analyzed, and recorded on a personal computer. the specimen's dimensions are: 80mm in length, 20mm in width, and 2 mm in thickness as shown in Figure 6 (a and b), despite all specimens reinforced with different fillers, they share the same dimensions. The creep test was conducted utilizing creep test equipment (wp600) as depicted in Figure 6 (c).



(a) [16]



(b)



(c)

Figure 6. (a) Creep samples standard; (b) Creep samples of Kevlar/Carbon fiber; (c) Creep test equipment (wp600)

3. CONSTITUTIVE CREEP EQUATIONS

In essence, Visco-elastic models can used to describe the elastic and viscos nature of polymetric material. Hence the term (Visco-elastic) demonstrates both elastic and viscos models. In the present study employed These models as a useful estimation for under-standing the time-dependent behavior of polymers. Nearly every material has Visco-elastic characteristics. Over time loading rate and the applied load both affected polymer deformation.

Materials that possess both elasticity and viscous features are studied in viscoelasticity. Elastic materials undergo instantly deformation when a force is applied but revert to their original shape when the force disappears. In contrast, viscous substances don't display these features, rather they demonstrate behaviors that vary over time. A viscous material frequently deforms under stress and once the stress is released, it doesn't return to its initial state. Visco-elastic materials are stated by illustrating a strain response that relies on time over constant stress (Creep) and a stress response that depends on time under constant strain (Relaxation) [25].

In visco-elastic materials, the relationship between stress, strain, and time has been investigated using mechanical models that take into account stress and strain in place of force and deformations. A linear visco-elastic dash-pot and a linear spring made up a linear viscoelasticity model. The Maxwell model is a visco-elastic model that exhibits behavior similar to a spring (E_1) sequentially with a dash-pot (η_1). Burgers model integrates the Maxwell and Kelvin models (E_2), in parallel with viscos dash-pot (η_2) as shown in Figure 7. In sequence to provide the most accurate predictions of stress relaxation and creep behavior [25, 26]. The overall strain can be expressed as follow:

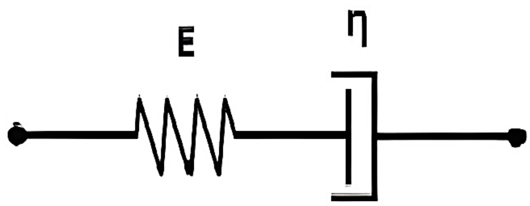
$$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$$

where, ε: the total strain in Burgers model, ε_1: strain in the spring according to Maxwell model, ε_2: strain in dash-pot for Maxwell mode, ε_3: strain in Kelvin model.

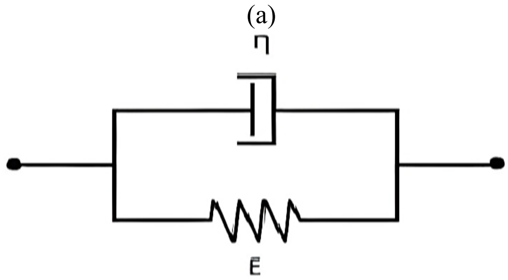
$$\varepsilon = \frac{\sigma}{E} \quad (1)$$

$$\acute{\varepsilon} = \frac{\sigma}{\eta} \quad (2)$$

hence, σ: applied stress, ε: strain, ε': strain rate, E: modulus of elasticity and η: Viscosity.



(a)



(b)

Figure 7. (a) Maxwell model; (b) Kelvin-Viogt model [21]

These constants represent the required Burgers model. It intends to model the behavior of creep with constant initial stress (σ_0), by combining these two models, by considering initial, primary, and secondary creep strain with acceptable accuracy. Figure 8 shows the schematic representation of the Burger's model. Generally, the fundamental equation of Visco-elastic material is presented in the differential equation form below:

$$\sigma+\left(\frac{\eta_1}{E_1}+\frac{\eta_2}{E_2}+\frac{\eta_2}{E_2}\right)\dot{\sigma}+\frac{\eta_1\eta_2}{E_1E_2}\ddot{\sigma}=\eta_1\dot{\varepsilon}+\eta_1\eta_2/E_2\ddot{\varepsilon} \qquad (3)$$

To determine material constants (E_1, E_2, η_1, η_2) experimental data may use in the linear viscoelasticity:

$$\sigma(t)=\varepsilon_o/A\left[\left(q_1-q_2r_1\right)e^{-r_1t}-\left(q_1-q_2r_2\right)e^{-r_2t}\right] \qquad (4)$$

where, $r_1=(P_1-A)/2P_2$, $r_2=(P_1+A)/2P_2$, $A=\sqrt{(P_1+4P_2)}$, $P_1=(\eta_1/E_1+\eta 1/E_2+\eta_2/E_2)$, $P_2=\eta_1\eta_2/E_1E_2$, $q_1=\eta_1$, $q_2=\eta_1\eta_2/E_2$, stress relaxation equation can be presented as:

$$\mathrm{E(t)}=\sigma(\mathrm{t})/\varepsilon_o=1/\mathrm{A}\left[\left(q_1-q_2r_1\right)e^{-r_1\mathrm{t}}-\left(q_1-q_2r_2\right)e^{-r_2\mathrm{t}}\right] \qquad (5)$$

where, r_1, r_2, P_1, P_2, A, q_1, q_2 are material constants, this fundamental equation of linear stress (4), strain (5), derivate with time $\dot{\sigma}$, $\ddot{\sigma}$, $\dot{\varepsilon}$, $\ddot{\varepsilon}$.

Maxwell and Kelvin-Viogt models are appropriate for theoretical and qualitative assessment, but they frequently struggled to depict accurately the physical behavior of actual material, to improve the realism of these materials, additional springs and dash-pots need to be combined to raise the number of elements involved.

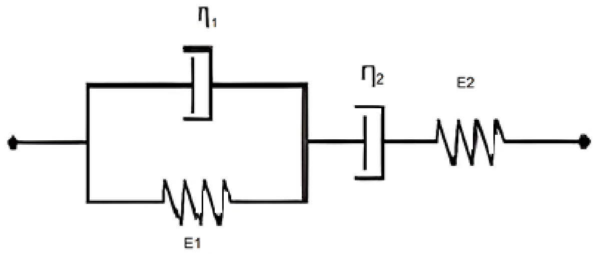


Figure 8. Burger model [21]

The Burger model, as shown in Figure 8, is the simplest linear model that accurately describes the behavior of time-dependent Visco-elastic materials. This model combined Maxwell and Kelvin-Viogt models in series. The fundamental equation could be derived by investigating the strain responses under applied load, which represented in Eq. (6). The constants used in these equations are detailed in Table 1.

$$\varepsilon(t)=\frac{\sigma_0}{E_1}+\frac{\sigma_0}{\eta_1 t}+\frac{\sigma_0}{E_2}\left(1-e\eta_2^{E_2t}\right) \qquad (6)$$

Table 1. Constant values of Burgers model

		Additives%			
		0	1	3	5
	P_1 min	330.30	803.01	354.03	203.75
	P_2 min^2	271.45	1016.51	598.54	258.57
	q_1 Mpa. min	36630.03	105263.1	79051.38	104112.4
Constant s of Burgers model / Kevlar	q_2 Mpa.min^2	36683.10	206609.18	184735.90	184696.58
	A min^2	328.65	800.47	350.63	201.19
	r_1	0.0030	0.0012	0.0028	0.0049
	r_2	1.2137	0.7887	0.5886	0.7830
	P_1 min	330.30	625.4	1898.4	921.3
	P_2 min^2	271.45	422.2	1192.8	1029.7
	q_1 Mpa. min	36630.03	7502.9	58993.5	45997.1
Constant s of Burgers model / Carbon	q_2 Mpa. min^2	36683.10	6246.4	38480.5	64356.5
	A min^2	328.65	420.2	1190.8	1027.7
	r_1	0.0030	0.2429	0.2965	0.0516
	r_2	1.2137	1.2382	1.2949	0.9464

4. FINITE ELEMENT MODELING

Since the introduction of the intricacy of a mathematical model, few Visco-elasticity problems have a proven analytical solution. Nevertheless, the implementation of numerical simulation and digital technology has had an important effect on this field of study. Finite element analysis is one of the numerical techniques created to face the difficulties of structure analysis consisting of both linear and non-linear Visco-elastic material. Such methods are carried out through specialist application programs made for this purpose such as AN-SYS software [25, 26].

Eq. (6) was not included in the model of creep for linear Visco-elastic solid. Instead, FEM utilizes the Prony series, which uses a series of (decaying exponentials) for efficient analysis and a solid physical basis. By utilizing the data from experiments. Burger model behavior can be mimicked in the Prony series. Given the connection between the parameters of the Burgers model and the Prony series, it can be possible to transform these parameters ($\mho_1$, $\mho_2$, g_1, g_2) through Prony coefficients by the procedure mentioned in the literature [23].

$$\mho 1=\frac{1}{\beta},\mho 2=\frac{1}{\alpha},\mathrm{g}1=\frac{1}{\alpha-\beta}\left\{\frac{\mathrm{Gk}}{\eta\mathrm{k}}-\beta\right\},\mathrm{g}2=\frac{1}{\alpha-\beta}\{\alpha-\mathrm{Gk}/\eta\mathrm{k}\} \qquad (7)$$

where, $\alpha,\beta=\frac{\mathrm{P_1}\pm\sqrt{\mathrm{P_1}^2-2\mathrm{P_2}}}{2\mathrm{P_2}}$. Burger model parameters and Prony series coefficients used in the ANSYS program for different weight ratios of Kevlar and Carbon fiber are presented in Table 2.

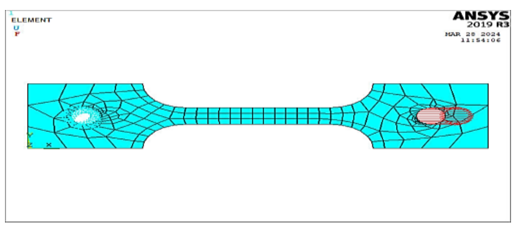


Figure 9. Finite elements design of creep test sample

Table 2. Constant values of Prony series

		Additives%			
		0	1	3	5
Constant s of Prony series / Kevlar	B 1/sec	5.10E-05	2.07E-05	4.73E-05	8.23E-05
	p_1 sec^2	19617.12	48193.64	21242.19	12225.12
	Ţ$_1$ sec	19570.01	48117.53	21140.26	12148.50
	g_1 N/mm	1.801	2.710	4.115	9.523
	α 1/sec	0.0212	0.0131	0.0098	0.0130
	p_2 sec^2	921922.44	3662182.76	2154759.6	930870.81
	Ţ$_2$ sec	47.1089	76.1091	101.926	76.6243
	g_2 N/mm	8.888	4.952	11.028	24.691
Constant s of Prony series / Carbon	β 1/sec	5.10E-05	1.7494E-05	3.1619E-06	1.8059E-05
	p_1 sec^2	19617.12	57248.7134	316324.895	55439.2245
	Ţ$_1$ sec	19570.01	57160.9726	316256.9103	55371.803
	g_1 N/mm	1.801	1.975	4.301	8.333
	α 1/sec	0.0212	0.0113	0.0147	0.0148
	p_2 sec^2	921922.44	5015351.55	21500570.71	3733197.73
	Ţ$_2$ sec	47.1089	87.7408	67.9845	67.4205
	g_2 N/mm	8.888	8.1300	16.606	33.167

In this study, the commercial finite element software ANSYS 15.0 was used to model a numerical solution. Plane 182 2D solid structure element with four nodes and two degrees of freedom commonly used in the ANSYS program, was performed to model a finite element analysis of the creep test sample utilized in this simulation. The force is applied along the X-axis, while the constraint is along the Y-axis, with 218 elements and 275 nodes. AutoCAD software was used to create a two-dimensional creep sample, then exported to ANSYS to simulate the behavior of creep for an epoxy composite sample reinforced with two types of filler in different weight ratios. Figure 9 depicts a two-dimension finite elements design of a creep test sample.

5. RESULTS AND DISCUSSION

Sika epoxy composite conducted to mechanical test prior to and after adding fiber reinforcement to assess the effects addition of fibers on the mechanical characteristics of the materials.

5.1 Creep strain

Figures 10 and 11 present the behavior of creep strain as a function of time for both Sika epoxy-reinforced Kevlar fiber and Sika epoxy-reinforced Carbon fiber in three different weight fractions compared with pure Sika epoxy between experimental, theoretical, and numerical studies. the pure Sika epoxy composite exhibits high creep strain values in compared with the one reinforced with the fiber. With increasing the percentage of Kev-lar and Carbon fiber creep strain tends to decrease gradually. the lowest creep strain value obtained with Kevlar fiber at 3% weight fraction, the rate of creep strain was reduced by half compared with pure Sika epoxy, while for Carbon fiber creep strain was reduced to 44% at 1% weight fraction.

The experimental results indicate that pure Sika epoxy has a creep strain (0.0148) but when Kevlar fiber was added at weight fractions (1%, 3%, and 5%) this value dropped gradually to (0.00984, 0.00648, and 0.0028). and adding Carbon fiber to Sika epoxy creep strain was reduced to (0.01352, 0.0062, and 0.0032) compared with pure Sika epoxy.

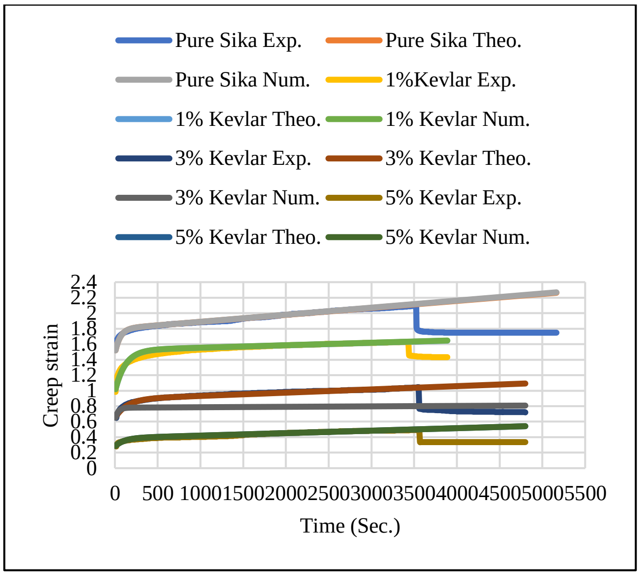


Figure 10. A comparative of creep strain between exp. theo. and num. result for Kevlar fiber

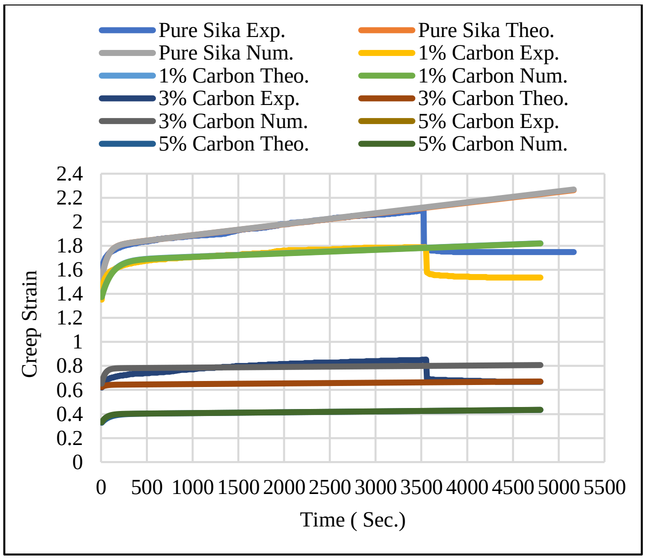


Figure 11. A comparative of creep strain between exp. theo. and num. result for Carbon fiber

5.2 Creep stress

Figures 12 and 13 show the discrepancy of creep compliance, defined by the pro-portion between stress and versus time by applying a static load of 2N at constant temperature (27 degree Celsius). the stresses steadily decrease with an increase in the weight fraction of Kevlar and Carbon fibers. Yet, the Sika epoxy composite containing a 3% weight fraction of Kevlar fiber has the highest percentage compared with Carbon fiber and pure epoxy. Hence, Kevlar can withstand more stress, up to 15% more, compared with pure Sika epoxy, while Carbon fiber can handle only 8%.

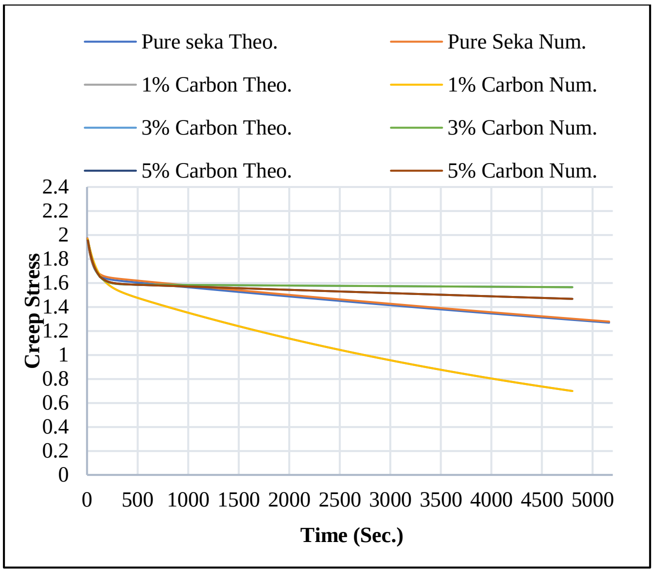


Figure 12. A comparative of creep stress between exp. theo. and num. result for Kevlar fiber

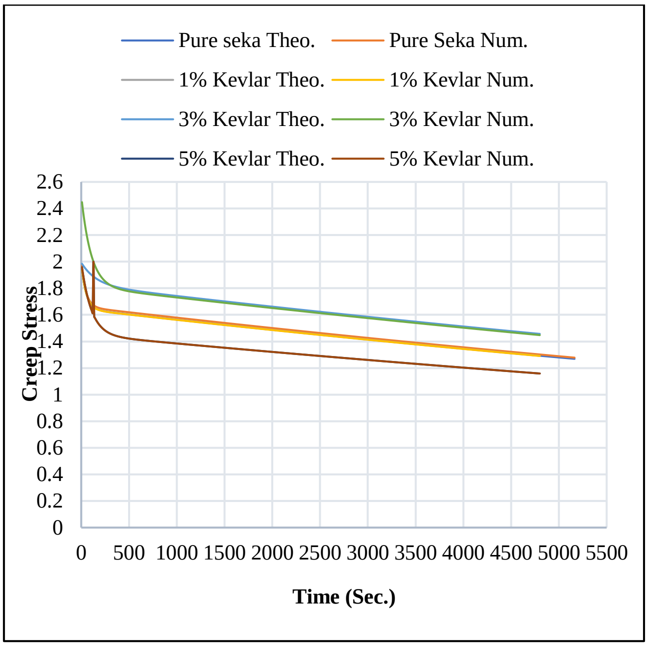


Figure 13. A comparative of creep stress between exp. theo. and num. result for Carbon fiber

Three compliant master curves that were nearly coincidental depicted convergence of experimental, theoretical, and numerical results and showed a relatively small percentage of error. Figure 14 represents the initial strain at time (0 sec.) and maximum strain at time (3600 sec.) for carbon and Kevlar fiber at various weight ratio, while Figure 15 shows stress at time (3600 sec.) for carbon and Kevlar fiber at various weight ratio.

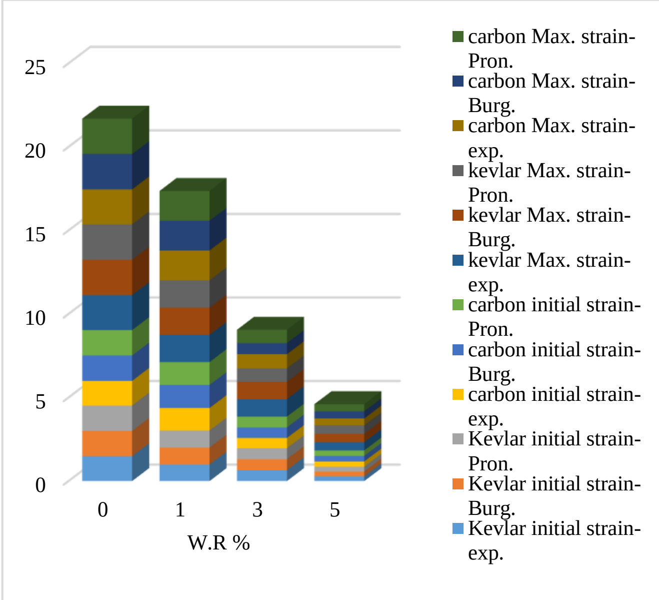


Figure 14. Initial and maximum strain for Kevlar and Carbon fiber in exp., Burger and Prony at various weight ratio

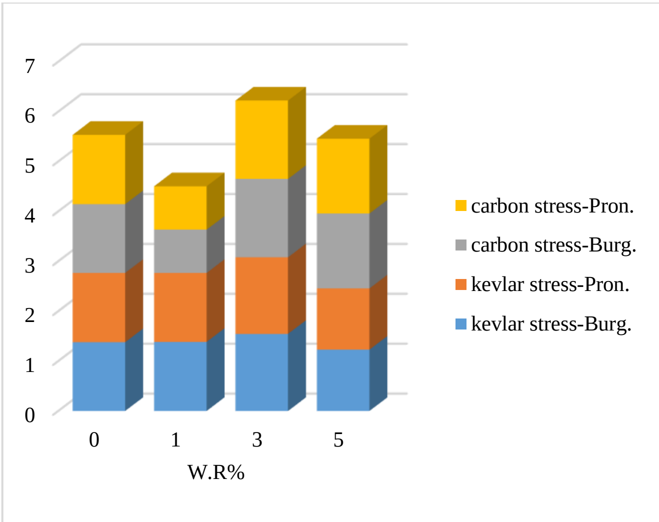
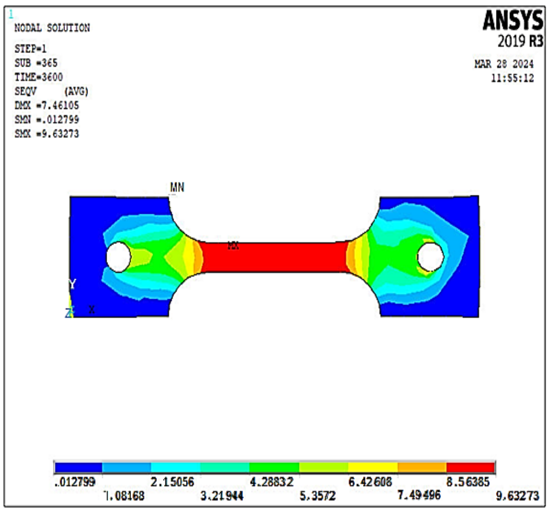
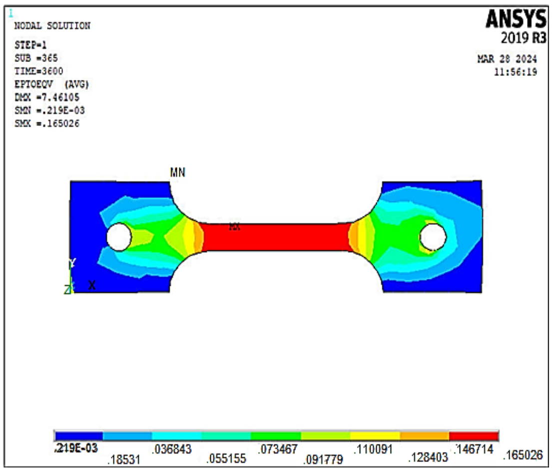


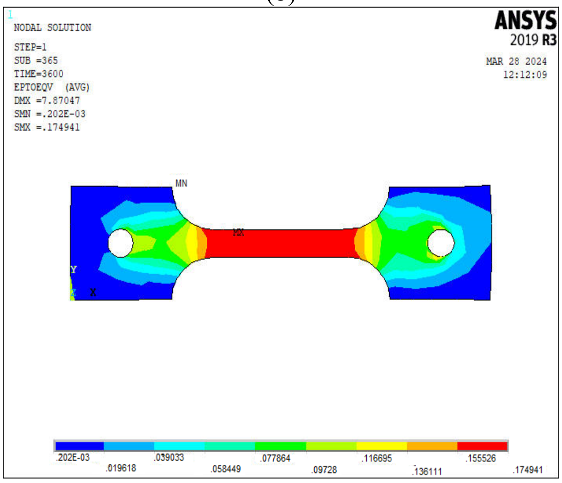
Figure 15. Stress at 3600 sec. for Kevlar and Carbon fiber in Burger and Prony at various weight ratio



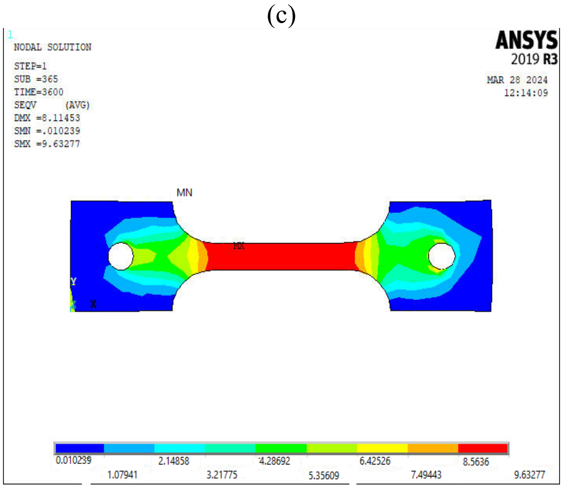
(a)



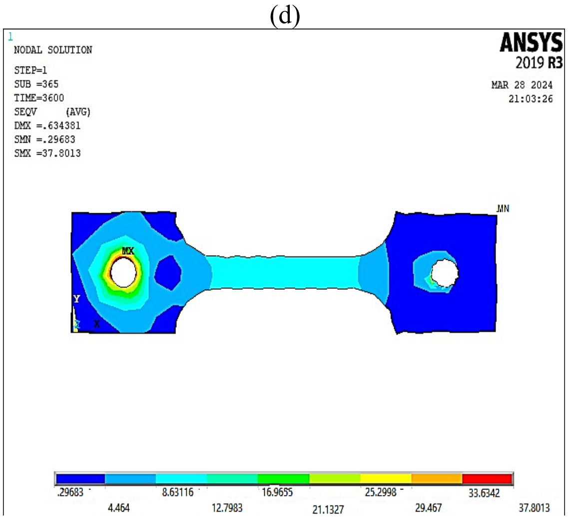
(b)



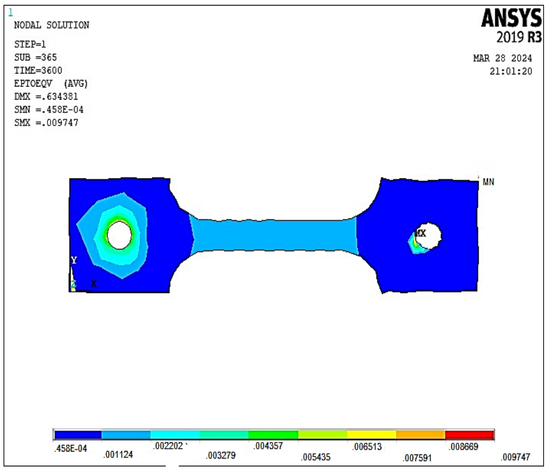
(c)



(d)



(e)



(f)

Figure16. Numerical simulation results of creep strain and stress for epoxy reinforced with Kevlar and Carbon fiber (a) creep strain for pure epoxy, (b) creep stress for pure epoxy, (c) creep strain for 3%Kev lar fiber, (d) creep strain for 1% Carbon fiber, (e) creep stress for 3% Kevlar fiber and (f) creep stress for 3% Carbon fiber

The finite element result (ANSYS 15.0) utilized Prony series equations to illustrate the Burger model. Creep strain and creep stress for a specimen with 2N load and 27-degree Celsius temperature were analyzed. Figure 14 shows creep behavior for maximum and minimum values. Also, it was observed that numerical simulation results of creep strain satisfy experimental data as shown in Figure 16.

6. CONCLUSIONS

In this study, the creep behavior of Sika epoxy composite reinforced with Carbon fiber and Kevlar fiber was investigated. The result of the creep test revealed that improved creep compliance correlated with high weight fraction, this suggests that weight percentage is essential for determining the mechanical characteristics of the materials. Fiber type is cruel, Carbon fiber possesses the lowest creep strain and low-stress level than Kevlar fibers. Hence carbon fibers are stronger and have greater resistance to creep. Consequently, it's strongly recommended. The results proved that the theoretical results obtained using the Burger method fit closely with the Prony series utilized in numerical simulation ANSYS 15.0 program results both had potential for accurate prediction of experimental findings.

Compared with pure Sika epoxy, it was found that Kevlar fiber reduced creep strain by 15% at 1%, 50% at 3%, and 75% at 5%, while Carbon fiber reduced it by 9% at 1%, 44% at 3%, and 80% at 5%. Carbon fiber have considerably higher resistance to creep compare with Kevlar fiber. In term of resistance to creep and strength, Carbon fiber is recommended. Whereas Kevlar fiber seems more cost-effective than Carbon fiber for the same quantity. For creep stress the Sika epoxy composite containing a 3% weight fraction of Kevlar fiber has the highest percentage compared with Carbon fiber and pure epoxy. Hence, Kevlar can withstand more stress, up to 15% more, compared with pure Sika epoxy, while Carbon fiber can tolerate only 8%.

According to our evaluation, we suggest the practical application of composite materials. Carbon fibers can be employed for circumstances that require high resistance to creep and strength. For applications with adequate effectiveness of cost and sufficient mechanical properties, Carbon fibers are chosen. For future studies, we are investigating the effects of fiber orientation on mechanical behavior to determine the most efficient configuration for a particular application.

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NOMENCLATURE

wt.%	Weight ratio percentage.
E_1	elastic spring.
E_2	elastic model
E	modulus of elasticity
P_1, P_2, q_1, q_2, A, r_1, r_2	material constant

Greek symbols

η_1	Maxwell dashpot damping coefficient
η_2	Kelvin Voigt dashpot damping coefficient.
σ	Applied stress
ε	strain
ε'	Strain rate
η	Viscosity
$\dot{\sigma}$, $\ddot{\sigma}$	Stress derivative with time
$\dot{\varepsilon}$, $\ddot{\varepsilon}$	Strain derivative with time
Ƭ$_1$, Ƭ$_2$, g_1, g_2	material constant (to represent Burger material model)

Subscripts

p	nanoparticle
f	fluid (pure water)
nf	nanofluid