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EXPERIMENTAL, THEORETICAL AND NUMERICAL INVESTIGATION OF CREEP CHARACTERISTICS OF FISH SCALE POWDER-CHICKEN FEATHER FILLED POLYESTER COMPOSITES

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Natural fibres would play a significant part in the production of composite materials since these fibres are entirely renewable, environmentally friendly, have a high specific strength, inexpensive, and biodegradable. The objective of this research is to investigate the potential of fish scale powder and chicken feather as reinforcing agents in polyester composites, as well as the composites' creep behaviour. Hand lay-up procedures were used to prepare weight fractions (0.2, 0.5, 0.8, and 1.1%) of chicken feather along with 5% fish scale powder. It is observed that the composite with 0.8% chicken feather and 5% fish scale powder showed encouraging results as it enhanced the creep strain by 74.29% and diminished the stress by 40.71% compared with neat polyester. The experimental, theoretical, and numerical results were compared. Good accuracy has been observed, with a relative error of no more than 3.2%. These findings indicate that natural fibres have enhanced creep properties and might be a feasible alternative to industrial applications.

Keywords: polyester composite, Fish scale powder, chicken feather, Burgers model, Prony Series, creepbehaviour

1 INTRODUCTION

Apart from energy, one of the most pressing issues confronting the present generation is environmental preservation. Novel solutions are needed today more than ever to either safeguard the environment or create environmentally friendly products. Natural fibers have gotten a lot of attention as a possible alternative to synthetic fibers as reinforcement of various resins for advanced applications because of their properties like low density, high specific strength, and the fact that they are renewable, sustainable, and environmentally friendly. [1]

Growing environmental consciousness demonstrates the significance of creating biodegradable, recyclable, and eco-friendly composite materials. Due to their appealing assortment of properties, natural fibers including kenaf, ramie, jute, palm, leaf spring, sisal, flax, and hemp have the potential to replace glass fibers, carbon fibers, and other common reinforcements in composite materials. These fibers possess important qualities including stiffness, flexibility, toughness, and strength. Additionally, they are sustainable, renewable, and have a high availability. [2]. Several studies have been published on the use of chicken feathers, fish scales, and other waste residues as reinforcing and biodegradable agents for thermoplastic composites, including horse hair, sheep wool, rice husk, jute fiber, and Sisal fiber [3]. For example, C.N. Aiza Jaafar et.al [4] explore the effects of using fish scales as a reinforced filler on the mechanical properties of high density polyethylene composites. The findings indicated that Young's modulus and impact strength parameters increased with filler concentration. Antaryami Mishra [5] worked on epoxy composites reinforced with wood dust and chicken feather using hand lay-up technique to prepare Composites of teak wood dust composites of (10, 15, and 20%) weight, as well as 5% chopped chicken feather combined with epoxy, to evaluate the mechanical behavior of the composites. Anup Kumar [6] Create mechanically characterized epoxy-based composites that are strengthened with different weight percentages (wt.%) of chicken feather fiber and residual powder removed from Rohu fish scales to improve the mechanical and physical characteristics of the resulting composite. Throughout the whole examination into the characterization of hybrid composites, the 3 wt.% of particle produced the most optimal findings. Ayyappa Atmakuri et al. [7] investigate the effect of matrix material on the mechanical characteristics of composite materials by contrasting epoxy resin natural fiber composites with bio-resin. Compression molding and hand lay-up were both used to create the composite samples. By adjusting the weight percentage of the fiber material, a total of five distinct composites were created. The findings demonstrated that hybrid composites outperformed individual fiber composites in terms of characteristics. B.H. ABED et al. [8] Examine the creep behavior of an epoxy composite material reinforced with Y_2O_3 powder at weight ratios of 2%, 7%, 13%, 17%, and 22%. At a constant temperature of 16 2°C, each volume ratio was exposed to five loads ranging from 1N to 5N. Experimental and computational studies were used to investigate creep behavior, stress, and elasticity modulus. B.H. ABED and Ali A. Battawi. [9] Studied the creep behavior of polystyrene composites reinforced with natural fiber in varying weight fractions, constant load, and different temperatures. The fabrication setup for composite materials was created using the hand layup process. Using curve-fitting methods, the Maxwell techniques was used to extract the stress and modulus of elasticity from the strain–time curve. Numerous studies have found that, the fabrication of bio-composites can employ chicken feather and fish scale powder as biodegradable reinforcing materials because they have little to no economic value. Yet, little studies had been done on how the creep feature affects polyester composites reinforced with the aforementioned fillers.

The animal fibers employed in this study (fish flakes powder and chicken feather) are frequently referred to as waste by-products that contribute to environmental contamination owing to disposal issues. Burning and burying are the two most common ways of disposal, both of which have significant environmental consequences.

2 THE ADAPTABILITY OF THE VISCOELASTIC MODEL

The major goal of this study is to see how creep strain affects composite material and how this prosthetic material deforms when natural fiber (fish scale powder (FSP) and chicken feather (CF)) increased at constant temperature with time.

The Burgers model is a Maxwell model in series with a Kelvin model that displays linear viscoelastic behavior. As demonstrated in Fig. 1, a material's strain response during a creep test is a mix of elastic, delayed elastic, and viscous strain responses, as represented by the Burgers model. It's a good term for the first two stages of creep, namely decelerated and equivelocity creep. Visco-elastic materials, like the polyester composites, may be studied using the Burgers model in order to identify their stress or strain relations as well as their time dependencies [10].

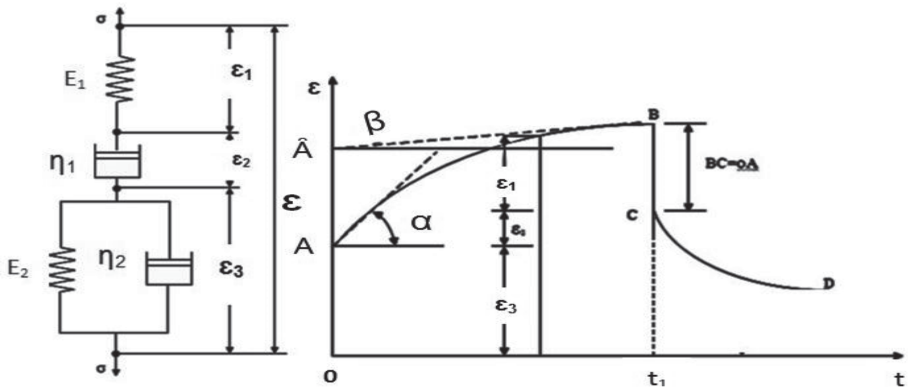


Fig. 1 Burger model with creeping behavior [11]

The total strain in the Burger model can be written as follows [11]:

$$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \tag{1}$$

Whereas:

ε= total strain in Burgers (four-element) model's.

ε_1= the spring strain for Maxwell model's.

ε_2= strain in dash-pot for Maxwell model's.

ε_3= strain in Kelvin model's.

that is:

$$\varepsilon_1 = \frac{\sigma}{E_1} \tag{2}$$

$$\dot{\varepsilon}_2 = \frac{\sigma}{\eta_1} \tag{3}$$

$$\dot{\varepsilon}_3 + \frac{E_2}{\eta_2}\varepsilon_3 = \frac{\sigma}{\eta_2} \tag{4}$$

From equation 1 and equation 2, the following second order differential equation between (stress and strain) may be expressed using equation 5 [11]:

$$\sigma + \left(\frac{\eta_1}{E_1} + \frac{\eta_1}{E_2} + \frac{\eta_2}{E_2}\right)\dot{\sigma} + \frac{\eta_1\eta_2}{E_1 E_2}\ddot{\sigma} = \eta_1\dot{\varepsilon} + \frac{\eta_1\eta_2}{E_2}\ddot{\varepsilon} \quad (5)$$

Equation.5 is solved using the Laplace transformation method, as shown below:

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

Experimental data for creep tests in linear viscoelasticity behavior may be used to establish the material constant (E1 , E2, η1, η2) [11].

$$\sigma(t) = \frac{\varepsilon_0}{A}\left[(q_1 - q_2 r_1)e^{-r_1 t} - (q_1 - q_2 r_2)e^{-r_2 t}\right] \quad (7)$$

Where: $$r_1 = \frac{P_1 - A}{2P_2}, r_2 = \frac{P_1 + A}{2P_2}, A = \sqrt{P_1^2 + 4P_2} \quad (8)$$

Where: $$P_1 = \frac{\eta'_m G_m + \eta'_m G_k + \eta'_k G_m}{G_m G_k}, P_2 = \frac{\eta'_m \eta'_k}{G_m G_k}$$

The stress relaxation equation can be expressed as:

$$E(t) = \frac{\sigma(t)}{\varepsilon_0} = \frac{1}{A}\left[(q_1 - q_2 r_1)e^{-r_1 t} - (q_1 - q_2 r_2)e^{-r_2 t}\right] \quad (9)$$

Table (1) lists the constant values of the materials for different weight fraction.

σ_0 Is the initial stress, $\varepsilon(t)$ is the creep strain at time t; and (E1, E2, η1, η2) are the Burger model parameters, this might be estimated by regression on the experimental creep data, and ($\dot{\sigma}$, $\dot{\varepsilon}$, $\ddot{\sigma}$, $\ddot{\varepsilon}$) are the first and second derivatives, respectively, of stress and strain with respect to time t.

Table 1. Burgers material constant values for different weight fraction

w.f.% constant	0%	5%FSP+0%	0.2%CF+5%FSP	0.5%CF+5%FSP	0.8%CF+5%FSP
P1 (Mpa.)	106.663	134.1925	85.852	169.693	80.6176
P2 (Min2)	86.3725	280.684	50.181	73.819	58.2499
q1 (MPa. Min.)	651.0416	2574.0025	1111.111	816.3265	806.4516
q2 (MPa.Min2)	2987.798	12155.055	9056.289	443.625	2116.907
A (Min2)	105.030	129.941	84.674	168.82	79.158
r1	0.012	0.00757	0.0117	0.00591	0.0125
r2	3.463	0.4705	1.6991	2.292	1.37148

3 EXPERIMENTAL ANALYSIS

Carp fish scales were gathered from a local market. To eliminate impurities, the fish scales were washed in water. To remove fat and other contaminants, the scales were immersed in an ethanol solution for 10 minutes, then rinsed with distilled water and dried in the sun for two days. A grinding machine was used to crush fish scales into powder, an electronic weighing balance was used to weigh the fiber composites. 5% weight fraction of fish scales powder (FSP) was used as a reinforcement to polyester for all specimen see figure (2). On the other hand, chicken feathers (CF) are cleaned in distilled water with detergent and sun dried for a week to eliminate any contaminants such as oil, blood, and colors. After that, they were sliced into 2 mm long pieces as shown in Fig. 3 with a weight fraction (0.2, 0.5, 0.8, and 1.1 %). The fabrication setup for composite materials was created using hand lay-up technique. Polystyrene granules are dissolved in chloroform and combined with magnetic stirring. Liquid polyester was added after it had been prepared separately and agitated for 3 hours. The ratio of polyester to polystyrene is (92:8) [9]. Add the FSP at a constant rate of 5% for all specimens and mix for 3 hours in the mixer. After that, add the hardener (K-6) to the mixture in a 10:1 ratio and stir for 15 minutes. To make the composites specimens, clean the mold well to remove dust, CF are added to it in different weight fractions for each sample separately, then (polyester/ polystyrene) mixture is poured slowly and leave the specimens to dry for two days, after that, dry it entirely in the oven at 50°C for five hrs. Fig.4 demonstrate creep samples according to ASTM (D2990), the specimen measurements for creep testing were 80 × 20 × 2 mm. The creep test was performed using a creep testing equipment (WP600) Fig. 5. Tests are conducted at a constant temperature of 18°C, which was maintained with the help of a temperature control system, and at a static load of 1N. The computer creates the relevant data and graphics when the specimen is stretched.

Fig. 2 Powder of fish scales

Fig. 3 Chicken feathers were removed from thequillcut into 2mm lengths

Fig. 4 Creep samples in differentWeight fraction

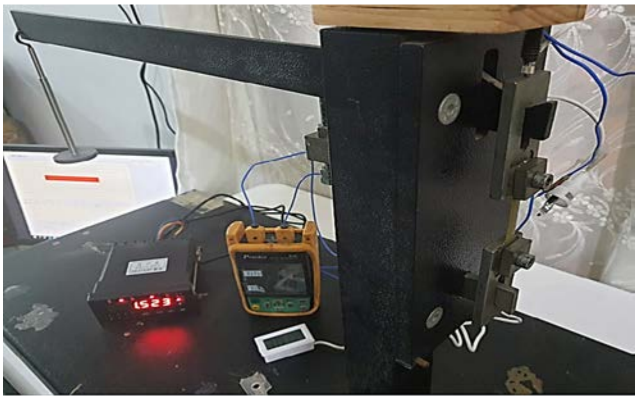


Fig. 5 Creep testing equipment

4 IMPLEMENTATION OF FINITE ELEMENTS

The FEA package selected for this study is ANSYS 15.0 program. Hence; the creep model for a linear viscoelastic solid are not represented in Equation (6), but instead the Prony series are implemented in this FEA based software, because the Prony series utilize a sequence of decaying exponentials to achieve amazing processing efficiency and a clear physical basis. Using the experimental data constants, where the Prony Series has been tweaked to act like the Burger's model. Since the Burgers model parameters are related to the Prony coefficients in some way, these four parameters may be translated into Prony representation coefficients $(g_1, g_2, \tau_1, \tau_2)$ using the approach described in the literature [12]. As a result, the material constants that must be utilized in ANSYS are as follows:

$$g_1 = \frac{1}{(\alpha-\beta)}\left(\frac{G_k}{\eta_k}-\beta\right), g_2 = \frac{1}{(\alpha-\beta)}\left(\alpha-\frac{G_k}{\eta_k}\right) \quad (10)$$

$$\tau_1 = \frac{1}{\beta} \, and \, \tau_2 = \frac{1}{\alpha}$$

Where $\alpha, \beta = \frac{P_1 \pm \sqrt{P_1^2 + 2P_2}}{2P_2}$

The material properties shown above could be utilized to represent the burger material model in ANSYS. Table 2 lists the parameters of Burgers model and coefficients of Prony series used in ANSYS for various weight fractions.

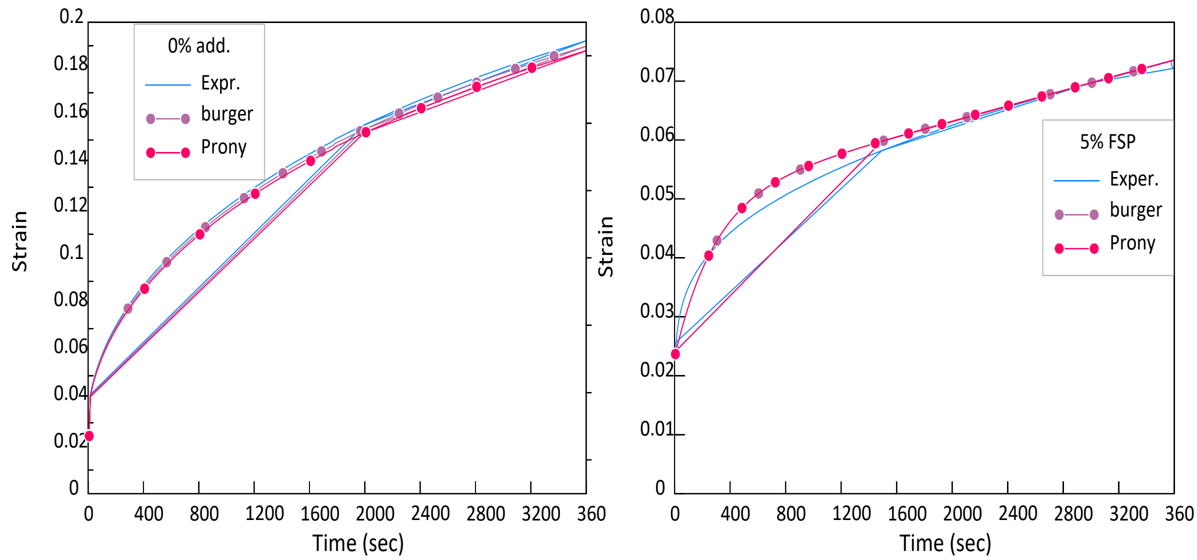
Table 2. Prony coefficients and Burgers parameters for various weight fractions

Weight fraction%	Burger parameter				Prony coefficients			
	E1(MPa)	E2(MPa)	η_1 (MPa. min.)	η_2 (MPa. min)	g_1	g_2	τ_1 sec.	τ_2 sec.
0%	39.976	14.6	869.504	15.9109	0.2623	0.737	82.159	0.2886
5%FSP+0%	43.305	36.755	2574.0025	173.5659	0.44108	0.5588	132.0555	2.1253
0.2%CF+5%FSP	180.47	15.5303	1111.111	126.5822	0.06577	0.89819	85.1969	0.5885
0.5%CF+5%FSP	60.196	21.805	816.3265	118.6943	0.0777	0.9218	169.1156	0.43613
0.8%CF+5%FSP	36.342	14.452	806.4516	37.9362	0.27113	0.7287	79.849	0.7291
1.1%CF+5%FSP	71.544	18.248	1052.631	131.9087	0.1737	0.8263	78.2597	1.3588

The equivalent modulus strain was calculated using FEM software to analyze creep models. The creep sample was created using the Auto CAD 2022 software, which was then exported to the ANSYS program. The deformation was calculated using the ANSYS APDL 15 program, which was utilized as a numerical tool to show the influence of stress relaxation modulus in a structural element, element plane 181. The meshing procedure began with the selection of the volume, followed by the tetrahedron as the element form (Auto. meshing).

5 RESULTS AND DISCUSSION

The creep compliance–time curves derived from theoretical, numerical simulation and the creep test, during constant loading time of 3600 sec. are given in Fig. 6 for polyester composite reinforced with different weight fraction of (FSP and CF) fibers. the comparative results of experimental data with theoretical data represented in Burgers model and results obtained from Proney series which can be used in commercially finite element software ANSYS 15.0 show a high level of accuracy and strong match between them, with a relative error less than 3.2%.



(a) (b)

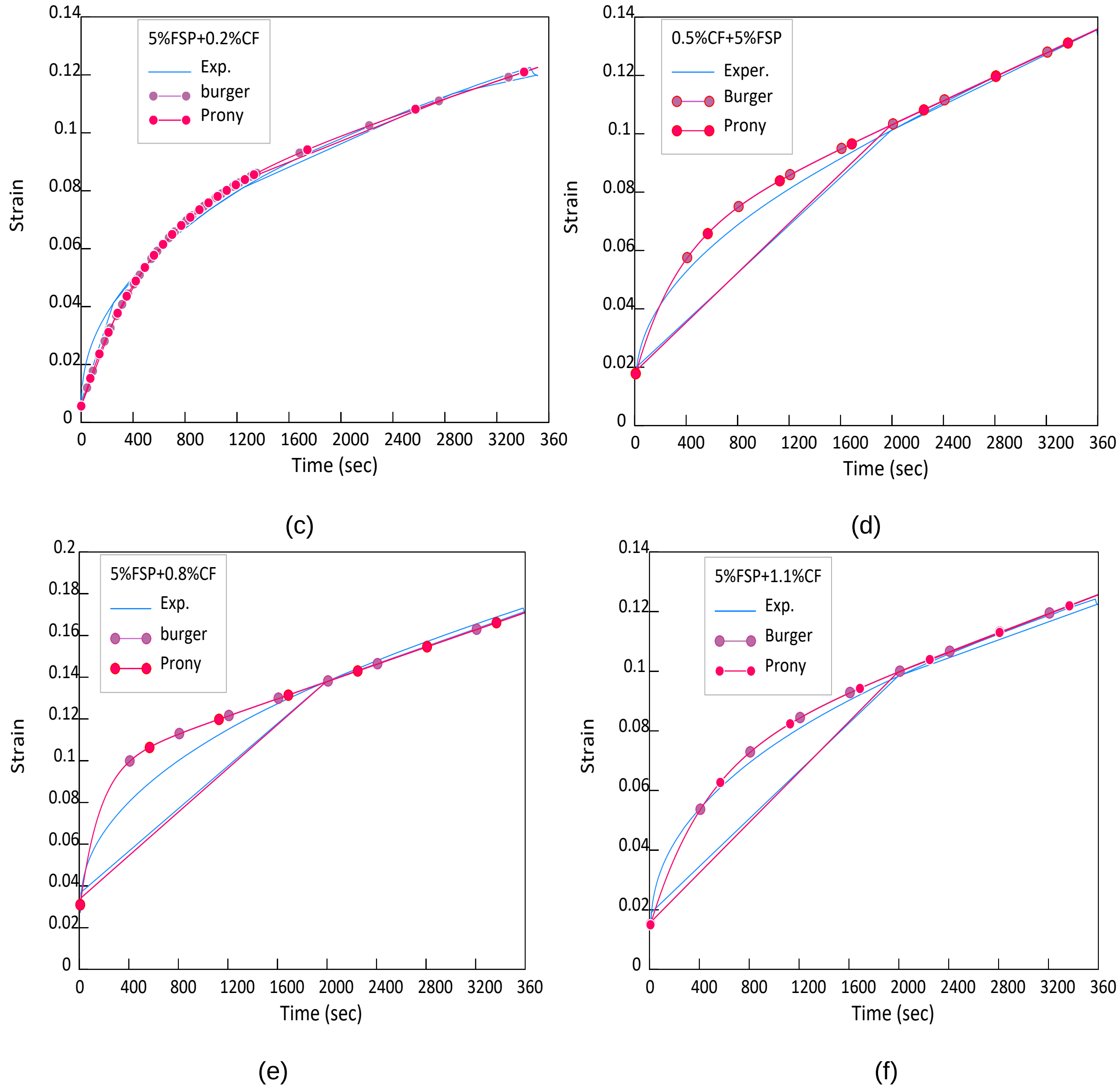
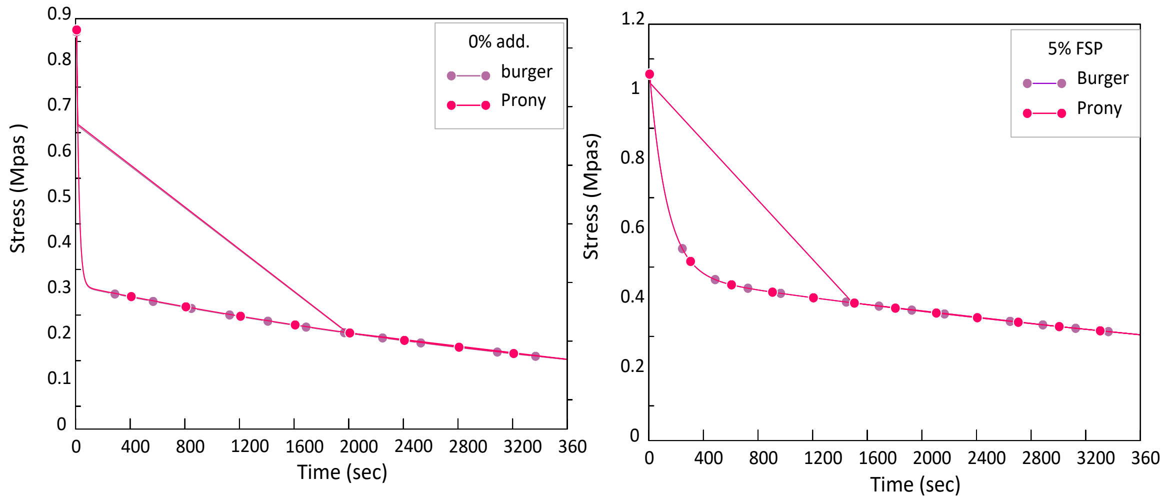
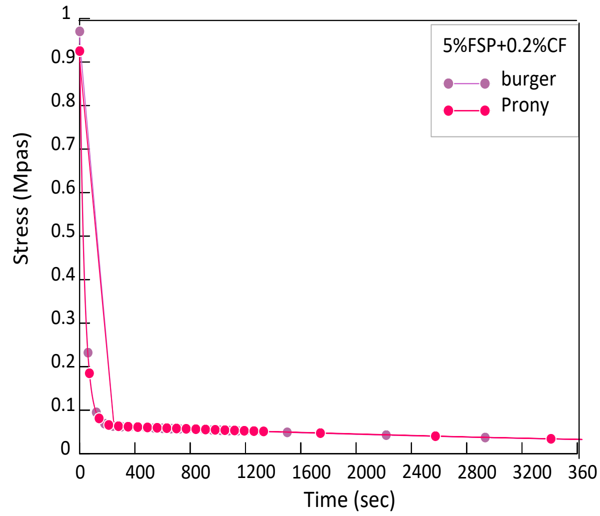


Fig. 6 illustrate creep strain–time curves in theoretical, numerical and experimental results for polyester composite reinforced with different weight fraction of (FSP and CF) fibers [(a) pure polyester, (b) 5% FSP, (c) 0.2%CF+5%FSP, (d) 0.5CF+5%FSP, (e) 0.8CF+5%FSP, (f) 1.1CF+5%FSP]

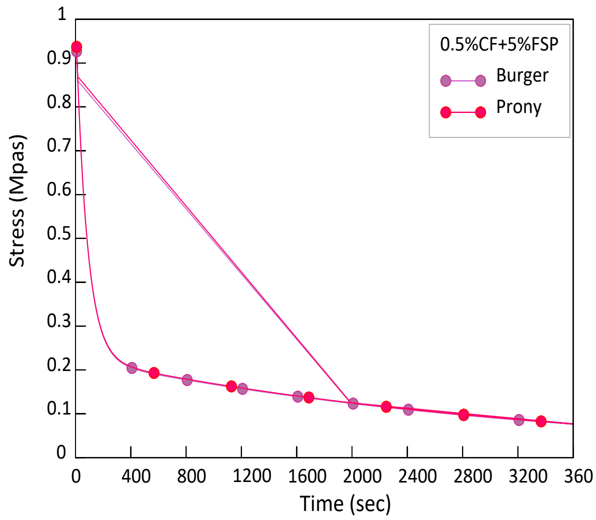
In general, the results demonstrate that the percentage strain of a reinforced polyester composite is lower than that of a neat polyester, implying that it can bear more strain before failure. It may be observed that the creep strain of the polyester reinforced fiber composites was enhanced by increasing the weight fraction of (FSP and CF) fibers. The (0.8% CF+5% FSP) weight ratio exhibited the best creep strain among the rest ratios with 74.29% enhancement compare with neat polyester.



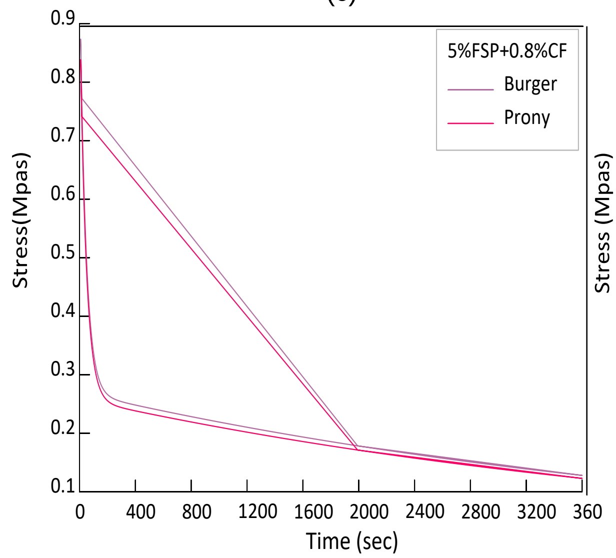
(a) (b)



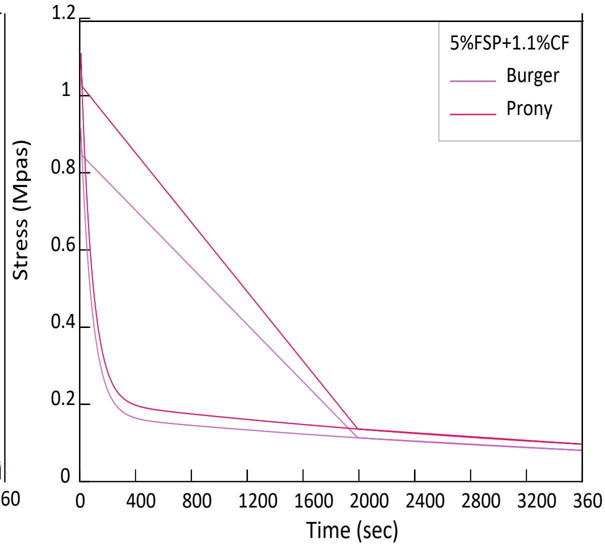
(c)



(d)



(e)



(f)

Fig. 7. show creep stress –time curves in theoretical, numerical and experimental results for polyester composite reinforced with different weight fraction of (FSP and CF) fibers [(a) pure polyester, (b) 5% FSP, (c) 0.2%CF+5%FSP, (d) 0.5%CF+5%FSP, (e) 0.8%CF+5%FSP, (f) 1.1%CF+5%FSP]

Similarly, the stress characteristics of polyester composites are studied Fig. 7 above, and it is found that the stress keeps dropped gradually with increasing weight fraction of animal fibers. However, the (0.8% CF+0.5% FSP) weight fraction gave the best value between all the other composites with 40.71 % decreasing rate in comparison with neat polyester. From which it was concluded that the stress is transferred from the matrix to the fibers, which is indicated by the fact that fiber has the ability to carry the load.

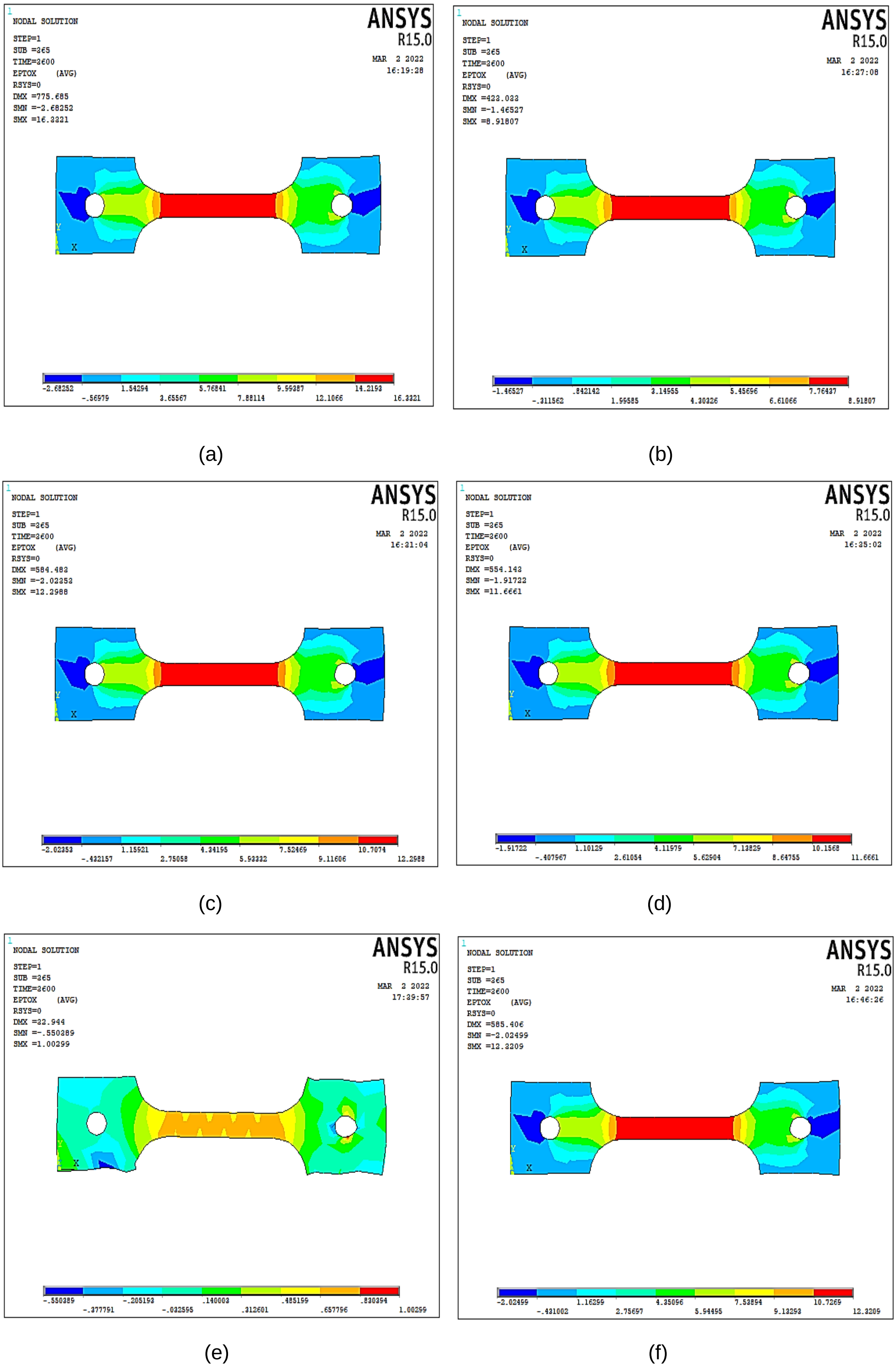


Fig. 8 show Numerical results of creep behavior for polyester composite reinforced with different weight fraction of (FSP and CF) fibers [(a) pure polyester, (b) 5% FSP, (c) 0.2%CF+5%FSP, (d) 0.5%CF+5%FSP, (e) 0.8%CF+5%FSP, (f) 1.1%CF+5%FSP]

A Prony series used to represent Burgers model in ANSYS software using the Laplace transform and other equations, as listed in Table (2), As a result; ANSYS program 15.0 software was carried out to determine the distribution of creep strain at the specimen subjected to 1 MPa for 3600 sec. at 18◦C. Where the maximum and minimum creep stress are recorded for the specimens as shown in the Fig. 8. It demonstrates that material influence by creep stress increases with time, since polyester material had a viscoelastic characteristic.

6 CONCLUSION

The creep strain of FSP/ CF composites was found to have enhanced as the weight fraction increased. It was observed that the 0.8% CF+0.5% FSP composite exhibited the best creep strain among all fiber composites with 74.29% enhancement compare with neat polyester. Stress, on the other hand, was observed to diminish when the animal fiber reinforcement ratio increased, 0.8% CF+0.5% FSP weight fraction was found to had the best value between all the other reinforced composites with 40.71 % decreasing rate in comparison with neat polyester. The results demonstrate that such improvements may lead to enhanced filler matrix interaction and, as a result, better composite characteristics. Hence, the creep behavior of neat polyester and reinforced composite polyester varies. In addition, High degree of accuracy has been achieved for experimental, theoretical and numerical simulation for polyester composite, thus the relative error no more than 3.2% was observed.

7 NOMENCLATURES

Ps − Polystyrene
Up − Liquid polyester
FSP – fish scale powder
CF – chicken feather
ε= total strain in Burgers (four-element) model's.
ε1= the spring strain for Maxwell model's.
ε2= strain in dash-pot for Maxwell model's.
ε3= strain in Kelvin model's.
Ϭ0 - initial stress.
wt. % − weight ratios of chicken feather fillers.
Ϭ (t) − stress relaxation.
ε1 = Maxwell element.
η1 − Dashpot constant.
E (t) − creep modulus at any time.
ε (t) − strain at any time.
P1, P2, q1, q2, A, R1, R2: material constant.
E1=Em – Maxwell spring stiffness.
E2=Ek – Kelvin – Voigt spring stiffness.
η1=ηm – Maxwell dashpot damping coefficient.
η2= ηk– Kelvin – Voigt dashpot damping coefficient.
g_1, g_2, τ_1, τ_2 - material constant (to represent Burger material model).

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