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Creep and Stress Relaxation Behaviour of Rice Husk Reinforced Low Density Polyethylene Composites

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ABSTRACT

The creep and stress relaxation behavior of rice husk reinforced low density polyethylene composite was analyzed in this study. The exponential and power model were used to study the creep while the stress relaxation assessed the time required for the composites to maintain a certain strain level. The creep strain increased with increase in time, at various temperatures, with its highest creep at 70°C while the lowest is at 30°C, the power model provided an excellent fit than other models with a coefficient of determination of 0.9977 at 30°C, the neat low density polyethylene had a good stress relaxation behavior with 4.95 seconds for it to decay and subsequently decreased with increase in filler concentration.

Keywords: creep, stress relaxation, rice husk, composites

INTRODUCTION

Deformation of materials over time when acted upon by constant stress is termed creep, the resultant stress continually increased with increase in time, its counterpart, stress relaxation occurs when stress decreases under constant strain over time. Both occur in materials such as metals and polymers, hence temperature-dependent, though polymers are more susceptible to creep deformation due to its viscoelastic property (Callister, 2007).

Factors such as time and temperature have a significant effect on the viscoelastic properties of the polymeric matrix which determines the mechanical behavior of composites (Rowel et al., 2001; Nwosu-Obieogu et al., 2016). Creep analysis of composites is very essential in the study of its deformation rate prior to application, it determines the ability of the composite to withstand highest possible operating load at elevated temperature, resistance to high temperature corrosion and avoidance of material failure, these findings have ensured the reliability and durability of composites in buildings and bridge construction (Mirzaei et al., 2011; Monticelli et al., 2019; Qi et al., 2018; Sreekala et al., 2001).

Various researchers have reported on creep and stress relaxation behavior of composites. Lorandi et al (2018) analyzed the creep behavior of carbon/epoxy non-crimp fabric composites and the result showed that the deformation was dependent on stress and temperature. Qi et al. (2018) studied the stress relaxation behavior of magnetorheological elastomers to improve its anti-stress relaxation property, results showed that the anti-stress relaxation property of magnetorheological elastomer is highly dependent on magnetic field and temperature. Monticeli et al (2019) carried out creep/recovery and stress-relaxation tests in a standardized carbon fiber/epoxy composites, and the result confirmed that temperature is a determinant factor to creep and stress relaxation properties. Riara et al. (2013) analyzed the creep and stress relaxation behavior of cellulose reinforced low-density polyethylene composites at different cellulose loading and temperature, the creep performance decreased with increase in temperature and improved with cellulose loading while creep modulus decreased with increase in time and temperature. Lechat et al. (2011) studied the tensile and creep properties of polyethylene terephthalate and naphthalate fibers and there was a similarity in the creep rate value for both fibers.

Several researchers have used the linear, power law, and other empirical models to establish the relationship between independent factors (time and temperature) and dependent factors (creep strain and stress relaxation) of fiber-reinforced composite (Lin et al., 2004). Information on creep and stress relaxation analysis of materials may be fuzzy and insufficient most times, hence the need to adopt modeling in this research to develop better assumption and satisfactory description of creep theories, analysis and application.

Obaid et al. (2017) studied the stress relaxation behavior of polymers reinforced with short elastic fibers, a simplified analytical model that informs on the influence of polymer viscoelasticity on shear stress transfer to the fibers was proposed, and the model explained the effect of fiber addition on the relaxation behavior. Ihueze (2007) modeled creep behavior in raffia plant fiber-reinforced plastics using the power-law model and multiple linear regression model and both models gave a good fit, but the multiple linear regression model had a better fit than the power law. Andrea Sorzia (2016) modeled the creep and stress relaxation test of a polypropylene microfiber using a fraction-exponential kernel method and it is fitted well in a viscoelastic operator.

Premalal et al. (2002) investigated on the physical properties of rice husk, the cellulose (25-25%), hemicellulose (18-21%), lignin (26-31%), silica (15-17%), solubles (2-5%), moisture content (5-10%), surface area (0.92 m^2/g) and density (1.00g/cm^3) indicated that rice husk is a good constituent/component for composite reinforcements. Zhang et al., 2020 developed biochar reinforced high-density polyethylene composites investigating the properties of the composites. It was discovered that these properties improved by the addition of biochar. Hence, this paper models creep behavior of rice husk low-density polyethylene composites using power and exponential models and also analyses its stress relaxation decay.

Theoretical Analysis

Several creep model equations are used to represent the high-temperature time-dependent deformation behavior of engineering materials, many of which comprise components (Holdsworth, 2010)

$$Power: \varepsilon f = a.t^b \tag{1}$$

$$Exponential: \varepsilon f = a.(1 - exp\,(-b.t)) \tag{2}$$

Where ε_f= creep strain, t = time and a,b are the fitting constants.

MATERIALS AND METHOD

Materials and Equipment

Rice husk fiber, low-density polyethylene (LDPE) , electrical grinding machine was used to reduce the particle size of the rice husk, an oven was used to dry the moisture in the rice husk , injection moulding machine(MA2800-1350, USA) was used to prepare the composite and Hounsfield (Monsanto) Tensometer (model no. S/N 8889, India) was used to analyse the creep and stress relaxation decay of the composites.

Preparation of Rice Husk

50g of the pulverized rice husk was first soaked in deionized water for two hours, filtered and oven-dried at 50^{0}C overnight, grounded and sieved to a particle size of 150µm.

Preparation of the Composite

Rice husk reinforced with low-density polyethylene composites were produced using an injection moulding machine and the filler loading was varied from 2g, 4g, 6g, 8g, and 10g on the low-density polyethylene. The creep and stress relaxation decay analysis were carried out with Monsanto Tensometer.

Creep Analysis

The composites were stressed using a load of 1.5KN. The exact time of loading of the weight at various temperatures was recorded. The material continued to deform indefinitely under constant stress (load). The samples were allowed to deform (under constant load) for a period of 2 days varying the temperature from 30^{o}C to 70^{o}C. The deformation was recorded at an interval of 2 hours.

Stress Relaxation Decay Analysis

The stress relaxation (decay) was evaluated by taking a constant strain section through the creep curves to obtain the corresponding time (log time). The graph was then re-plotted as stress versus time.

RESULTS AND DISCUSSION

From **Figure 1**, It can be deduced that strain rate continued to increase when the load is subjected to various temperatures over time, the higher the temperature, the closer it is to the glass transition temperature, the higher the strain, the faster the creep rate increases, this occurred due to the increase of the thermal kinetic energy and free volume in the creep of the matrix, the load stress level promotes a significant deformation and temperature demonstrates a high influence on strain results on the composites, the findings are in line with (Lechat et al., 2011; Lorandi et al., 2018; Riara et al., 2013; Zhang et al., 2017).

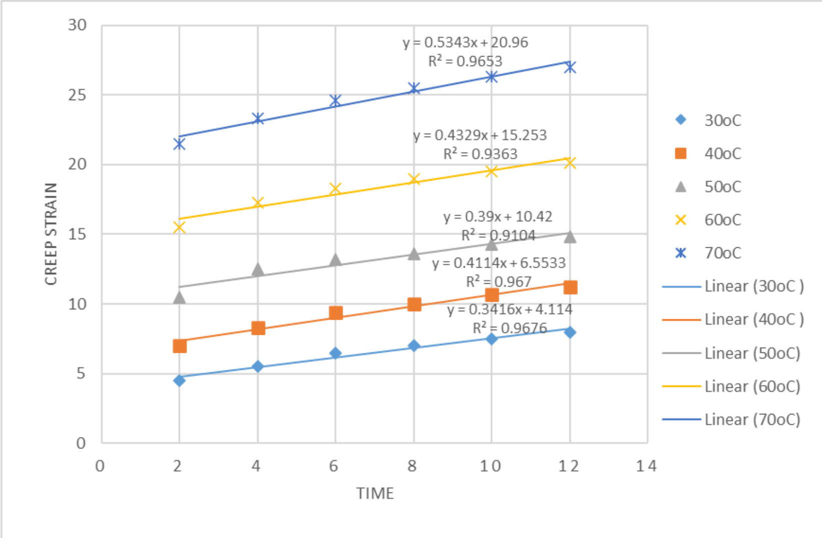

Figure 1. Linear graph of creep against time

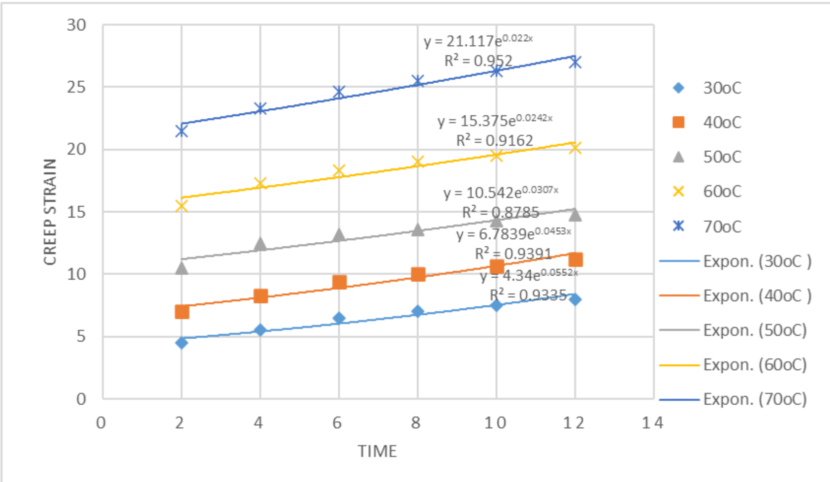

Figure 2. An exponential plot of creep strain against time

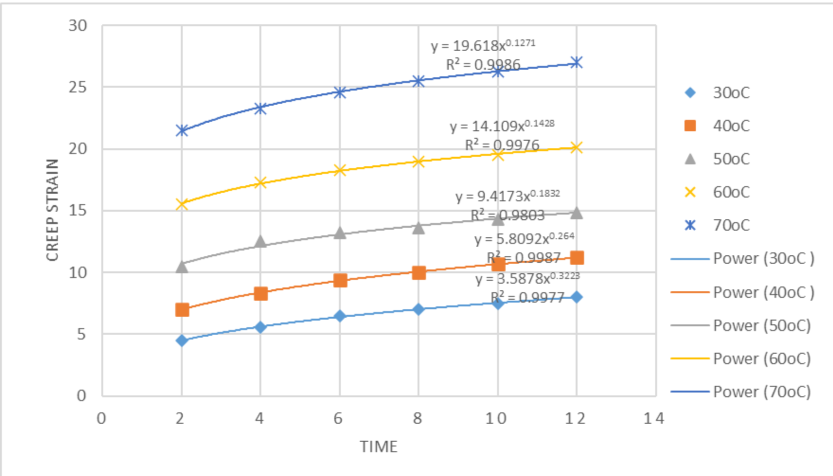

Figure 3. Power plot of creep strain against time

From **Figure 2** and **3**, the power and exponential models satisfactorily established a relationship between the independent factor (time) and dependent factor (creep strain), the power model gave a better fit with a coefficient of determination of 0.9977 at 30°C than the exponential model, generally, both models had a good coefficient of determination at various temperatures, this argument is consistent with (Ihueze, 2007; Sorzia, 2016).

The stress relaxation revealed that the amount of load (stress) to maintain a certain strain level in the composite decreases with time, It can also be postulated that decay increased with increased filler content and occurred at a reduced time interval, this indicates that the molecules chains need to stretch and slide more quickly at large strain level (Qi et al., 2018; Zhang et al., 2017).

The (LDPE) reinforced with 10g filler required the maximum stress (load) of 50.05 N/mm^2 to maintain a certain stress level. The stress decreases slowly and occurred at a reduced time of 1.30 seconds. The decrease in stress continued as the filler content decreases in the order 10g-8g-6g-4g-2g and also the time increases subsequently with reducing filler concentration. The Virgin low-density polyethylene took the highest time of 4.95 seconds to decay signifying that a decrease in stress was observed in response to the strain generated than LDPE reinforced with rice husk.

CONCLUSION

The creep continuously increased with an increase at various temperatures, hence within the limits of the parameters involved in this study, an immediate elastic recovery equal to the elastic deformation followed by a period of the slow recovery is observed. The power model has a better analysis of the creep behavior and the neat low-density polyethylene had a good stress decay than other composites. This can serve as a useful information for the processing of composites involving rice husk to avoid material failure.

NOMENCLATURE

^{o}C - centigrade
g - grams
m - metres
% - percentage
ε f - creep strain
t - time
kN - kilonewton

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