NON-LINEAR VISCOELASTIC BEHAVIOR OF HIBISCUS-ESCULENTUS FIBER REINFORCED POLYMER COMPOSITES

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Abstract

The paper highlights the sources of linear/nonlinear viscoelastic and visco plastic behavior in hibiscus Esculentus fiber reinforced polymer composites materials. The significance of the study is directly related to the very nature of this material composite which tends to indicate a time dependent behavior. The behavior could either be a linear or nonlinear one and this is normally considered in the study of fiber reinforced composites since it is directly related to strain rate effects, micro damage induced to the structure of the composite and or irreversible plastic strain. The micro damage is due to the application of high stresses or strain and such high stress levels result in an irreversible phenomenon such as viscoelasticity and viscoplasticity and viscoplastic responses and the process parameters involved were identified. The results show that the viscoplastic strain increases exponentially fig 1 and 2 and attains asymptotic limit of 0.18% for 65MPa (fig 1a) and 0.26% for 70 MPa (fig 1b)

Keywords: Composite Micro-architecture, Fibre/matrix Interface, Viscoelastic and Viscoplastic Behavior, Transverse Cracking, Elastic modulus, Power Law Model.

1.0 Introduction

In the recent times attention has been drawn to the polymer reinforced composites and this is due to their superior properties which they exhibit. Higher specific strength and durability are the main advantages over the respective classical materials (Hassan, 1995). Moreover their cost has significantly decreased over the years due to the improvement in manufacturing and industrial design. The increased use of polymer composites stem primarily from the fact that after use they can easily be recycled and biodegradable (Lov, 1971).

Thus they are environmentally friendly and cheap or durable for engineering and industrial applications. However polymer composites have certain drawbacks as well. They tend to exhibit time dependent behavior which are related to the stress-strain behavior of the materials as function of time (Marklond, 2008). This time dependent attribute is known as viscoelastic behavior and it could be a linear or nonlinear function of time. This lime dependent linear behavior is expected to be observed at low tensile loads. Also some natural fibre composites indicate nonlinear behavior even al low tensile loads and this accompanied by irreversible deformation also known as viscoplastic strains (Nordin, 2006). The development or onset of viscoplastic strains can be attributed to micro damage induced to the material due to application of high stress or strain.

2.0 Composite micro-architecture

Polymer composite materials consist of usually two or more materials, namely the matrix and the reinforcement. The reinforcement can either be in form of particle or fibres (short or continuous long fibres) and mainly their role is to improve the mechanical properties (Tensile, flexural and creep strength of the composites) (Schapery, 1977). That is usually due to the superior mechanical properties of the reinforcement. Natural fibres are brittle and indicate a linear mechanical behavior but the final polymer reinforced composite is not linear since the matrix resins by their very nature indicate a non-linear behavior (Spathes, 2001). Often times the macroscopic properties of a Composite material depend on two main factors; first from the actual material properties of the constituents, matrix and reinforcement and secondly, from the bonding between them also known as interface. This interface is usually responsible for the poor macroscopic properties of the composite. Well-formed interface imply extensive contact area between the constituents which leads to a more effective load transfer from the matrix to the fibre and macroscopically to higher mechanical properties of the composite. The low properties of the composite are attributed to the weak interface between the epoxy matrix and the hibiscus esculentus fibre.

3.0 Development of the Viscoplasticity model

Polymer composite materials are associated with time dependent effects. One of these is the existence of microscopic irreversible deformation on the materials also known as viscoplasticity. In this paper a unified model was developed in order to predict the non-linear viscoelastic and viscoplastic behavior. There the initial stages of deformation are due to the thermally activated and plastic deformations which follow a path according to strain distribution around specific regions with high free volumes. These free volumes stored elastic energy and once the energy exceeds a critical value then neighbouring areas present non-recoverable states. The rate of viscoplastic deformation is due to the thermally activated rearrangement within the composite material structure as shown within the composite material structure. It has been shown (Nordin, 2006) and (Marklond, 2008) that for polymer composite the development of viscoplastic strains may be represented by a functional, the integral representation is

$$E_{vp}(\sigma,t) = C_{vp}\left\{\int_0^t \sigma(t)^m dt\right\}^m \qquad \ldots 1$$

C_{vp} and M, m are constants to be evaluated, σ is the creep rate and E_{vp} is the viscoplastic strains

$$Hence\ E_{vp}(t) = C_{vp}\alpha_0 Mm\left[\frac{t_1}{t^*}\right] \qquad \ldots 2$$

For creep test at fixed stress σ (t) = $\sigma_0$for t∈ [o,t]
t* is the characteristic time constant
t_1 is the initial time (seconds)
for longer creep test

$$E_{vp}(t_1+t_2) = C_{vp}\alpha_0 Mm\left[\frac{t_1+t_2}{t^*}\right]^m \qquad \ldots 3$$

The power law model assumes the VP-Strains in creep test grow exponentially

$$E_{vp} = A\left[\frac{t}{t^*}\right]^m \qquad \ldots .4$$

Where A is stress dependent and should follow the relationship

$A = C_{vp}\sigma_0^{Mm}$ … 5

The expression is shown in fig 1.0 and fig 2,0 for the power law fitting of the visco plasticity data and the power law fitting of the A parameter.

Viscoelasticity model development

Viscoelasticity property concerns polymer composite materials that exhibit strain rate effects **in** response to applied stresses. Polymers consist of polymeric-chains. In polymers, visco plasticity is related to the diffusion of molecules. When a polymer is loaded, the polymer chains tend to rearrange their position and the energy spent for this rearrangement is recorded as a hysteresis loop in the stress.

4.0 Strain curve

The viscoelastic analysis is based on the non linear viscoelastic material model developed by (Schapery, 1977) and generalized using thermodynamic treatment by (Lov, 1971) for a given stress history σ(t), t∈ [o.t], the strain ε(t) is given by

$$\varepsilon = d(\sigma_{max}).(\varepsilon_o + g_1\int_0^t \Delta\sigma(\varphi - \varphi')\frac{d(g_2\sigma)}{dt}dt = Evp(r,t) \qquad \dots 6$$

$$where\ \Psi = \int_0^t \frac{dt'}{a_0}\ and\ \varphi' = \int_0^t \frac{dt'}{a_0} \qquad \dots 7$$

ε_0 is the elastic strain

$$and\ \Delta S(\Psi) = \sum_t^n C_i\left(1 - exp\left(\frac{-\varphi}{t_1}\right)\right) \qquad \dots 8$$

Where ΔS (Ψ) is the linear viscoelastic creep compliance and equation (8) is the pony series a_0 is the shift factor, g_1 and g_2 are stress invariant dependent material properties and for a linear time response.

$g_1 = g_2 = a_0 = 1$ …9

Materials and method

The material constituents of the polymer composites is the Hibisuc-esculentus fiber which served as the reinforcement and the epoxy resin which acted as the matrix. The visco plasticity data shown in fig 1 and 2 were determined using the monsanto instron 3364 Hounsfield tensometer at the indicated pressures and dimensionless time periods.

5.0 Results and Discussion

The visco plasticity strain versus time curves is shown in Fig 1 and Fig. 2 is the curve for the power law fitting of stress level parameters. A. The curves show that the viscoplastic strain effects increases non linearly with time hence a non linear functional. The power law parameter A which indicates threshold stress level also increases nonlinearly with stress hence also a nonlinear characteristic profile. The log-log plots show a linearized behavior which is hypothetical for functional analysis and satisfactory treatment of experimental data for hibiscus esculentus fibre-reinforced polymer composite.

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REFERENCES

Hasan O.A.. Boyce M.C. (1995). "A constitutive model for the non linear viscoelastic viscoplastic behavior of glassy polymer", polymer engineering science 35, pp 331-344.

Lov Y.C. Sehapery R.A. (1971). "Viscoelastic characterization of a Nonlinear Fiber reinforced plastic", Journal of composites materials, 5, pp 208-234

Marklond E., Eitzenberger J., and Varna J. (2008). "'Nonlinear Viscoelastic viscoplastic material model including stiffness degradation for hemp/lignin composites". Composites science and technology. 7, vol. 68, no. 9. Pp 2156-2 162. ISSN 02660-3538.

Nordin. L and Varna, J. (2006). "Nonlinear Viscoplastic and Nonlinear Viscoelastic material model for paper fiber composites in compression". Composites part A: Applied Science and manufacturing, 2, vol. 37 No. 2, pp 344-355. ISSN 1359-835x

Schapery R.A. (1977). "Nonlinear viscoelastic and viscoplastic constitutive equations based on thermodynamics", mechanics of time-dependent materials, I, pp. 209-240.

Spathes G., Kontov K. (2001). "Nonlinear viscoelastic and viscoplastic response of glassy polymers", polymer Engineering and science. vol. 41, No.8

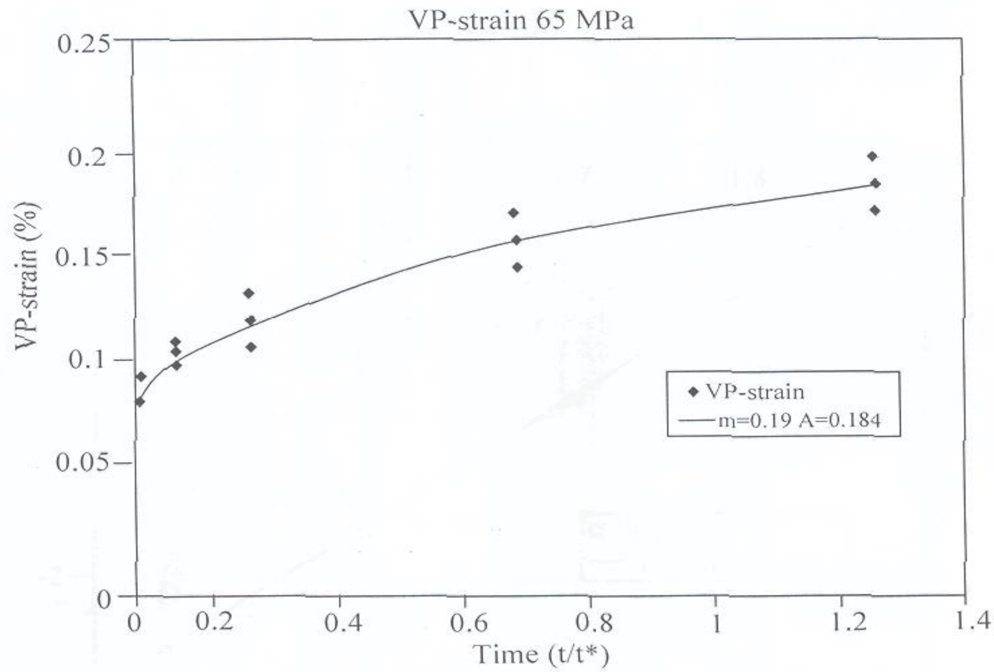

Figure 1a: Power law fitting of the viscoplasticity data

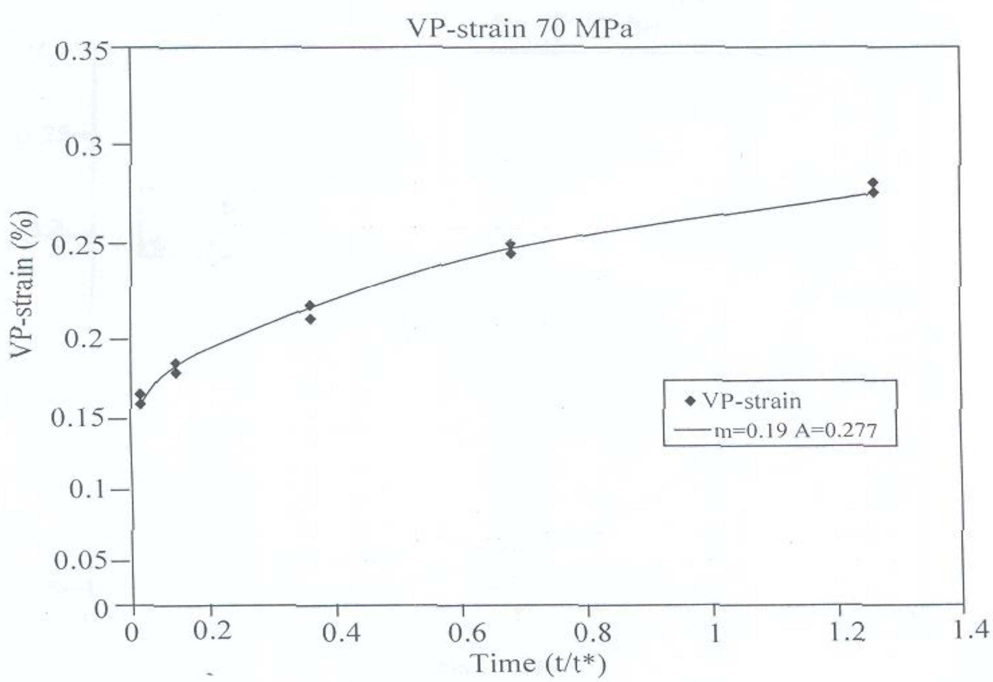

Figure 1b: Power law fitting of the viscoplasticity data

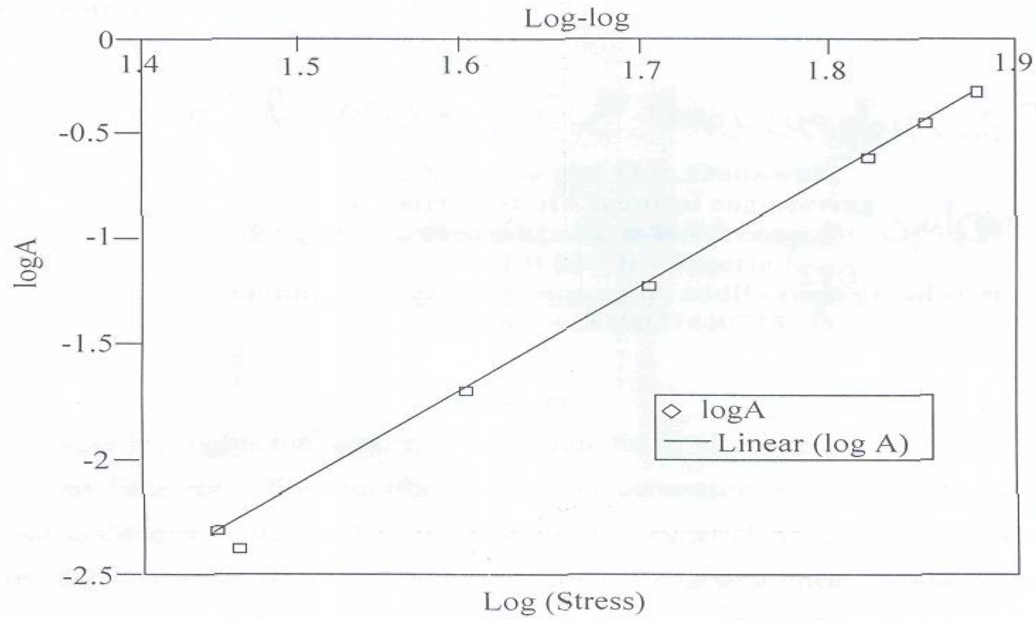

Figure 2a: Power law fitting of the A parameter

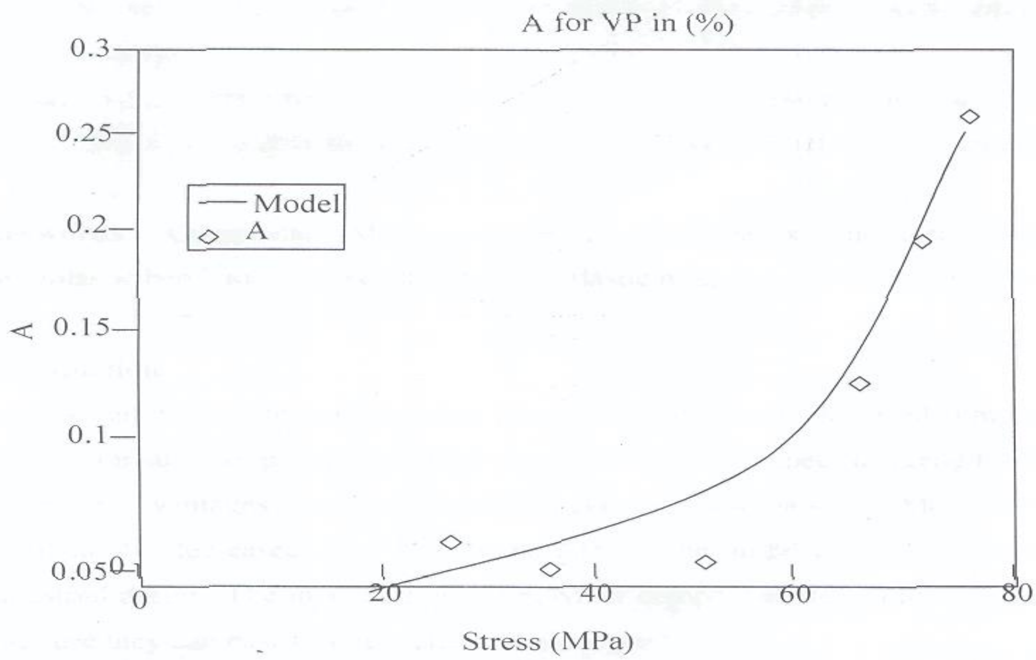

Figure 2b: Power law fitting of the A parameter