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CREEP BEHAVIOUR OF THIN WALLED COMPOSITE TUBES

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INTRODUCTION

Fiber reinforced composites are more and more employed in high performance structure for nuclear power plant, mainly as water piping tubes. The increase of the use of composites is due to the advantages that they give : high stiffness, large ultimate strength, corrosion resistance. This last advantage is sought for the pieces in contact with water, and it's one of the reason why the composite can be preferred to metal. However the mechanical behaviour of composite is actually poorly know [1]. The high anisotropy is the main difficulty to obtain a realistic model of behaviour. This problem implies that the safety factor used in the design of structure is often too large. In this article a general overview of the mechanical behaviour of tube made in glass epoxy material is proposed. We discuss especially the creep behaviour under biaxial loadings.

MATERIALS

The tubes are made filament winding. The thermosetting matrix is an epoxy DGEBA from CIBA-GEIGY, the fibers are glass E. With the filament winding process several meso-structures can be obtained, for example crossed structure made by helicoïdal winding or laminate structures. This work will be focused on the laminate structures.

Finaly the material is a $(+55 / -55)_3$. The angle 55° is chosen to optimize the stiffness of composite to a biaxial load due to an internal pressure ($\sigma_{\theta\theta} = 2\ \sigma_{zz}$).

EXPERIMENTAL METHOD

Two kinds of test were performed on thin walled tubes specimen. On the one hand creep tests with a tensile stress σ_{zz} ($\sigma_{\theta\theta} = 0$) or a hoop stress $\sigma_{\theta\theta}$ ($\sigma_{zz} = 0$) or both with $\sigma_{\theta\theta} = 2\ \sigma_{zz}$.

On the other hand cyclic loading tests with an increasing force (CLI) with different rates of loading (0.1 MPa/s, 1 MPa/s; 10 MPa/s). Some results of these last tests are reported in the figures 1 to 4. They show that the behaviour of the composite can be divided into basic phenomena. The first one is an elasto-plastic straining which allows obtaining an hysterisis curve independant on time for high bading rates of loading. The second is a viscoelastic one taking into account a rate dependance of the total strain. The third phenomena is a damage occurence observed for large loading, $\sigma_{zz} > 50$ MPa (rupture is observed for σ_{zz} # 70 MPa).

The creep test shows that the viscoelastic behaviour is nonlinear for uniaxial loading.For biaxial loading ($\sigma_{\theta\theta} = 2\ \sigma_{zz}$) the amplitude of viscoelastic strain is low (<<0.05 %). The biaxial loading is quasi purely elastic. The results of this test are proposed in figures 5 to 7.

PROPOSED MODEL

In this paragraph the analysis is focused on the undamaged behaviour. In fact as observed in the experimental results short creep tests and/or low loadings imply no damage and consequently can be separated from the whole behaviour in this particulary test. However the use of a damage variable must be considered for other loadings [2].

The background of the present model is based on the linear viscoelastic behaviour observed on an isolated laminae loaded with a stress parallel to the fiber [3]. We assume that for laminate, if the stress is in the direction of the fibers, the behaviour is also viscoelastic and linear. And so that the elastoplastic behaviour and the nonlinear viscoelastic behaviour are governed by a part of the overall stress σ note extrastress Σ [4]. We also assume that behaviour is not affected by a stress σ_{rr}. This assumption is not classical, an independance to the hydrostatic pressure is prefered, but for composite this hypothesis leads to an elastoplastic strain ε_{rr} # $\varepsilon_{\theta\theta}$ which is not experimentaly verified. Taking into account all these hypothesis Σ can be written as :

$$\begin{cases} \Sigma_{zz} = \dfrac{2\left[\sigma_{zz}(1-\cos 2\theta) - \sigma_{\theta\theta}(1+\cos\theta)\right]\sin^2\theta}{3+\cos 4\theta} \\ \Sigma_{\theta\theta} = \dfrac{2\left[\sigma_{zz}(1-\cos 2\theta) - \sigma_{\theta\theta}(1+\cos\theta)\right]\cos^2\theta}{3+\cos 4\theta} \\ \Sigma_{z\theta} = 0 \\ \Sigma_{rr} = 0 \\ \Sigma_{rz} = \sigma_{rz} \\ \Sigma_{\theta r} = \sigma_{\theta r} \end{cases}$$

Then, the yield criteria $f(\sigma)$ is a function of the invariants of Σ. For plane stresses due to tensile or internal pressure loading the criteria can be proposed as :

$$f(\sigma) = \left| \sigma_{zz} - \frac{\sigma_{\theta\theta}}{tg^2\theta} \right| - \sigma_{zz}c = 0$$

where σ_{zz^c} is the yield point in tensile test (from CLI test σ_{zz^c} = 20 MPa).

$\bar{\sigma} = \sigma_{zz} - \dfrac{\sigma_{\theta\theta}}{tg^2\theta}$ is the equivalent stress. A first overview of the model can be proposed here as :

$$\left|\bar{\sigma}\right| \leq \sigma_{zz^c} \qquad \underline{\varepsilon} = \underline{\varepsilon_e} + \underline{\varepsilon_{ve}}$$

$$\left|\bar{\sigma}\right| > \sigma_{zz^c} \qquad \underline{\varepsilon} = \underline{\varepsilon_e} + \underline{\varepsilon_{ve}} + \underline{\varepsilon_p} + \underline{\varepsilon_{vp}}$$

where $\underline{\varepsilon}$ is the overall strain, $\underline{\varepsilon_e}$ is the elastic strain, $\underline{\varepsilon_{ve}}$ a viscoelastic deformation which can be characterised by a relaxation spectrum [5] and an asymptotic limit such as :

$$\underline{\dot{\varepsilon}_{ve}} = \Sigma \, \underline{\dot{\xi}_i} \qquad \underline{\dot{\xi}} = \frac{1}{\tau}\left[\mu(\tau)\underline{A}\bar{\sigma} - \underline{\xi}\right]$$

where ξ_i discribe an elementary relaxation phenomenon, with a relaxation time τ and $\mu(\tau)$ a relaxation spectrum function. The tensor $\underline{A}$ is equal to the difference between the relaxed and the instantaneous values of the stiffness, $\underline{A}$ derived from the laminate theory. The definition of ε_p or ε_{vp} is more complex and requires that a choice to discribe the flow rule. The classical assumption of a dissipation potential leads to the normality rules :

$$\dot{\varepsilon}_{p_{ij}} = \dot{\lambda} \frac{\partial(f)}{\partial(\sigma_{ij})}$$

$$\dot{p} = -\dot{\lambda} \frac{\partial(f)}{\partial(R)} \qquad \text{and} \qquad \dot{\alpha} = -\dot{\lambda} \frac{\partial(f)}{\partial(X)}$$

where p is the cumulative plastic strain and α is the hardening variable, R and X being respectively the isotopic and the kinematic hardenings.

Taking into account the form of the criteria, it is shown that in plane stress

$$\underline{\dot{\varepsilon}_p} = \dot{\lambda} \begin{bmatrix} k & 0 & 0 \\ 0 & -\dfrac{k}{tg^2\theta} & 0 \\ 0 & 0 & 0 \end{bmatrix} \qquad k = \text{sign}\left[\sigma_{zz} - \frac{\sigma_{\theta\theta}}{tg^2\theta}\right]$$

Then, the kinematic equations (not developped here) leads though a consistency equation to :

$$\dot{\lambda} = \frac{\gamma \frac{\partial(f)}{\partial(\sigma)} : X\,dp - \frac{\partial(f)}{\partial(\sigma)} : d\sigma - Cr(Q - bR)p^m dp}{Ct \frac{\partial(f)}{\partial(\sigma)} : \frac{\partial(f)}{\partial(\sigma)}}$$

which provides $\dot{\varepsilon}_p$ (where γ, Cr, b, Q, m, Ct are constant).

On an other hand $\dot{\varepsilon}_{vp}$ is postulated such as $\dot{\varepsilon}_{vp} = \sum_{i=1}^{N(\bar{\sigma})} \dot{\xi}_i^{vp}$

with $\dot{\underline{\xi}}_i^{vp} = \frac{1}{\tau}\left[\mu'(\tau)\,\bar{\sigma} \begin{bmatrix} k & 0 & 0 \\ 0 & -\frac{k}{tg^2\theta} & 0 \\ 0 & 0 & 0 \end{bmatrix} - \underline{\xi}_i^{vp} \right]$ where $N(\bar{\sigma})$ is a "discrete" function of $(\bar{\sigma})$.

CONCLUSION

The form of the proposed model presently allows predicting a nonlinearity of the behaviour and provides a good correlation with the experimental data of several tests not described in this paper. It accounts for the change of the Poisson ratio during creep and cyclic tests. However the complet identification requires long time testings and consequently the model must be corrected to take into account the damage which occurs in these cases.

It can also be shown that the forms of the $\dot{\varepsilon}_p$ and $\dot{\varepsilon}_{vp}$ governing equations can be analyzed as partly due to fibers reorientation [5].

REFERENCES

[1] Z. Hashin, *"Analysis of composite materials - a survey"*, Journal of Applied Mechanics, Vol. 50, September 1983, 481 - 505.

[2] D. Perreux, C. Oytana, *"Continuum damage mechanics for micro - cracked composites"*, Composites Engineering, Vol. 3, N°2, 1993, 115 - 122.

[3] P. Le Moal, D. Perreux, D. Varchon, *"Viscoelastic behaviour of composite : comparison between a self - consistent model and experimental data"*, ICCM - 9, 12-16 July 1993, Madrid Spain, to be published.

[4] A.J.M. Spencer, *"Deformations of fibre-reinforced materials"*, Oxford University Press, 1972.

[5] Maire J.F., *"Etudes théorique et expérimentale du comportement de matériaux composites en contraintes planes"*, Thèse de l'Université de Franche - Comté, Laboratoire de Mécanique Appliquée R. Chaléat, septembre 1992.

CYCLIC LOADING TESTS WITH AN INCREASING FORCE

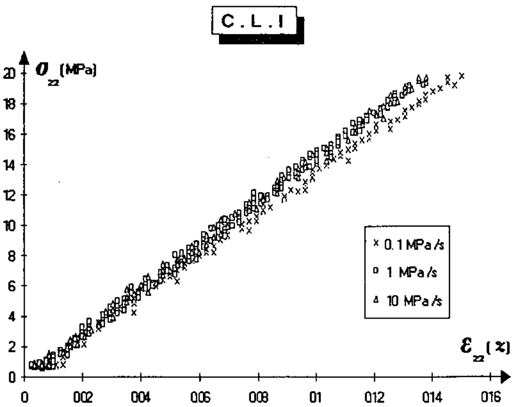

Figure 1

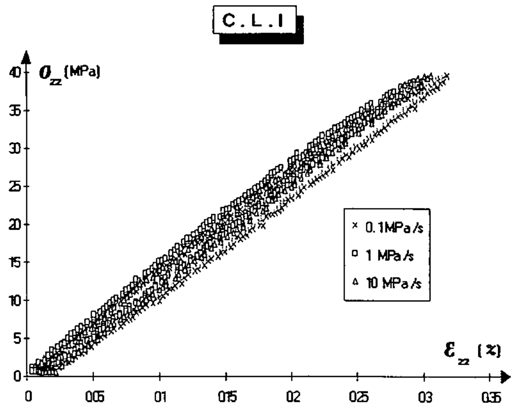

Figure 2

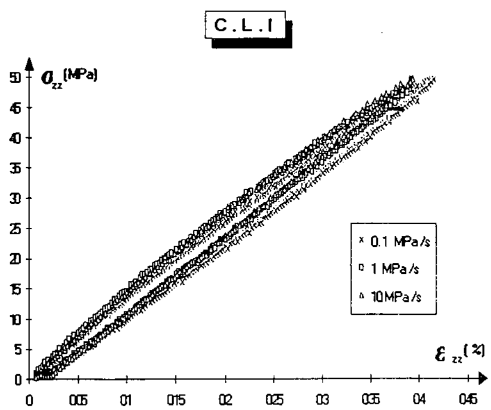

Figure 3

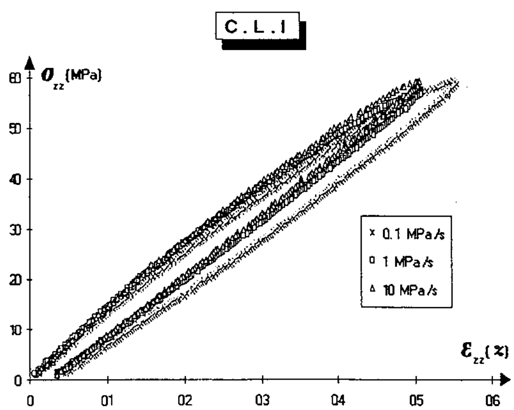

Figure 4

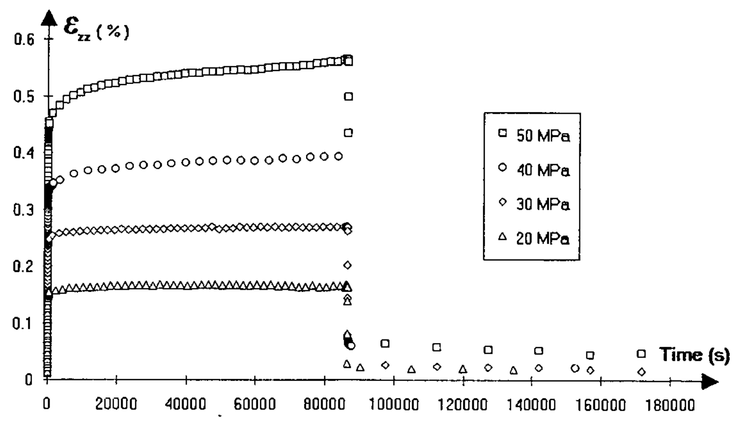

Figure 5 : Tensile Creep Tests

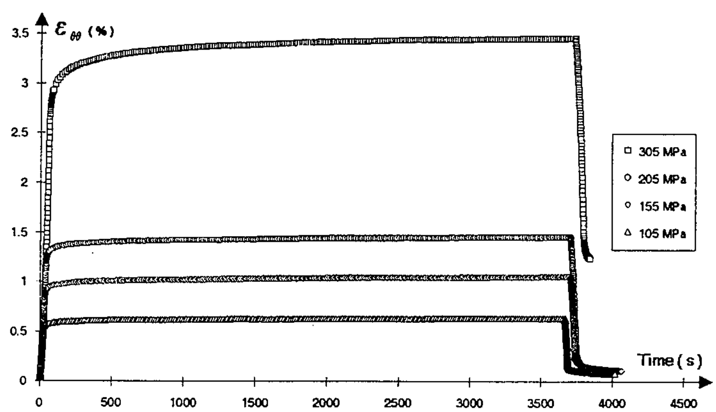

Figure 6 : "Opened Ended" Internal Pressure Creep Tests

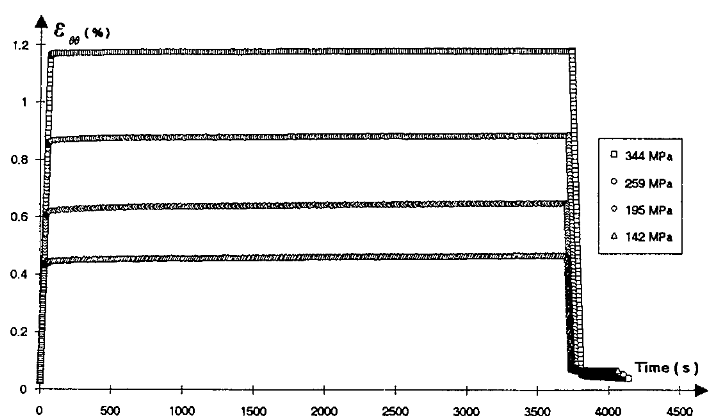

Figure 7 : "Closed Ended" Internal Pressure Creep Tests