CREEP OF CARBON REINFORCED EPOXY LAMINATES

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Introduction

Creep of polymer matrix composites is dependent on the matrix and at temperatures in excess of the glass transition temperature relatively complex motions and interactions of long chain molecules take place. However, the orientation of the reinforcing fibers also plays a significant role. More fibers orientated in the direction of loading will result in a lower overall strain in the composite. Shear at the matrix-fiber interface is then mitigated by the presence of 45° fibers.

The present work was carried out room temperature on unidirectional off-axis $[45]_{20}$ carbon reinforced epoxy composites and a $[\pm 45]_{2S}$ angle-ply carbon reinforced epoxy laminates to determine the effect of lay-up on room temperature creep behavior.

Experimental

Materials

Plates of unidirectional carbon-epoxy (CFRP) were prepared from pre-impregnated HTA 58% V_f carbon fiber reinforced 6376 epoxy. The plates, consisting of either 20 unidirectional or 8 cross plies, were cured at 175°C under a pressure of 7 bar for 2h. Specimens, 180mm long, 16mm wide and 2.3mm (unidirectional plies) or 1mm (cross plies) thick were prepared with the fibers at 45° or ±45 respectively to the long axis. The mechanical properties are given below in Table 1.

Table 1. Properties of the Carbon-Epoxy Composites.

MECHANICAL PROPERTIES	UNIDIRECTIONAL $[45]_{20}$	CROSS-PLY $[\pm 45]_{2S}$
E-Modulus	15.6 GPa	20.4 GPa
Tensile Strength	145.0 MPa	188.4 MPa
Strain	1.54%	5.17%
Density	1.58 g/cm^3	1.58 g/cm^3

Apparatus and Procedures

Epoxy tabs, 40mm long, were bonded to each end of the specimen for protection while being clamped in the creep test rig. All the tests were carried out at room temperature. For the unidirectional off-axis $[45]_{20}$ specimens a 98 kN creep testing machine with a 10:1 lever ratio was used in accordance with ASTM D2990. Three constant stress levels of 100, 110 and 120 MPa were used. For the $[\pm 45]_{2S}$ angle-ply laminates, universal testing machines equipped with a 5 or 10 kN load cell were used to perform the creep tests according to ISO 899 at stresses varying from 50 to 142 MPa. The corresponding strain data were obtained from either adhesively attached 0/90 strain gauges or clip–on extensometers and recorded using a computer program.

Results and Discussion

Fig. 1 shows the creep curves for the $[45]_{20}$ composite at three different stress levels representing 69% (100 MPa), 76% (110 MPa) and 83% (120 MPa) of its tensile strength. Primary, secondary and tertiary creep was observed at each stress level.

Fig.1. Creep of unidirectional $[45]_{20}$ composite. Results – dashed lines. Predictions [Burger] – solid lines.

The creep behavior was expressed satisfactorily by a four element (Burger) model, containing a spring (E_1) and dashpot (η_1) connected in series to a parallel combination of a spring (E_2) and dashpot (η_2) given by

$$\varepsilon(\sigma t) = \sigma E_1^{-1} + \sigma E_2^{-1}(1-\exp\{-t \tau^{-1}\} + \sigma \eta_1^{-1} t \quad (1)$$

where σ is the applied stress, t is the time and τ is the relaxation time given by η_2/E_2. The values for E_1, E_2, τ and η_1 were determined by interpolation of the experimental data and given in Table2. This approach gave a good representation of the creep behavior, as shown in Fig. 1.

However, the creep behavior was better described by an empirical creep law [1] based on two power–law functions $g(\sigma)$ and $h(t)$ depending on stress and time, respectively, and a linear stress dependent term $\varepsilon_0(\sigma)$ given by

$$\varepsilon(\sigma t) = \varepsilon_0(\sigma) + K\sigma^m t^n \quad (2)$$

where K, m and n are constants, independent of σ. Applying Eq. (2) to the $[\pm 45]_{2S}$ cross–ply composite, Petermann and Schulte [2], showed that when $K = 1.8 \times 10^{-10}$, $m=4.5$ and $n=0.19$ and $\varepsilon_0(\sigma)\% = 0.009\sigma$ MPa - 0.093, correlation with the experimental data, was very good, as shown in Fig. 2.

Fig.2 Creep of $[45]_{20}$ unidirectional composite. Results –dashed lines. Predictions [2]–solid lines.

For creep testing the $[\pm45]_{2S}$ angle-ply laminate, nine stress levels ranging from 29% (50 MPa) to 83% (142 MPa) of the yield stress were chosen. The resulting creep curves are shown in Fig. 3, using a linear time scale. The threshold stress for creep was about 40% (69 MPa) of the yield stress. First and secondary creep stages were seen, although the tertiary stage was not evident. However, it was apparent that at a stress of 88 MPa (51% yield) a transition from linear to nonlinear instantaneous viscoelastic behaviour took place. Application of Eq. (2) described the results extremely well, using values of 1.5x10^{-10}, 4.5 and 0.21 for K, m and n respectively. For stresses below 88 MPa, ε_0 (%) $=0.0048\sigma$ MPa, whereas above 88 MPa, $\varepsilon_0(\%) = 0.0156\sigma$ MPa - 0.94.

Fig. 3 Creep of $[\pm45]_{2S}$ cross-ply composite. Results- dashed lines. Predictions-solid lines.

Conclusions

The creep behaviour of unidirectional $[45]_{20}$ and $[\pm45]_{2S}$ angle-ply laminates of carbon/epoxy was studied. An empirical creep law based on two power functions was adopted to predict the creep strain depending on the applied stress level and loading time. Very good agreement was found between the predicted and experimental results.

References

1. Nutting, P.G. A study of elastic viscous deformation, *Proc ASTM,* 21 (1921) 1162-1171.
2. Petermann, J. and Schulte, K. The effects of creep and fatigue stress ratio on the long term behavior of angle-ply CFRP, *Composite Structures,* 57 (2002) 205-210.