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INTRAPLY FLOW BEHAVIOUR OF FABRIC REINFORCED THERMOPLASTICS

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Carbon and glass fibre fabric reinforced thermoplastics prepreg sheets are under development for the rapid stamping or thermoforming of aerospace and automotive components in order to speed up fabrication and reduce component costs. During thermoforming of fabric prepreg laminates both interply sliding and intraply deformations may occur, the latter being important for double-curvature geometries. The dominant intraply deformation mechanism in fabrics is the 'trellis effect' in shear where the fabric angle between the warp and weft directions changes. Thermoforming of fabrics is also dependent on the viscous matrix which influences processing conditions such as temperature, rate of loading, contact forces, interply friction and cooling effects. A rheological model for fabric reinforced thermoplastic sheets which combines fabric kinematics with a viscous fluid matrix and which could be used in process simulation software has been proposed by one of the authors [1]. This is a generalisation of previous rheology models for unidirectional fibre reinforced viscous fluids with inextensible fibres.

The aim of the present paper is to compare the fabric rheology model for the intraply behaviour with some experimental measurements on fabric reinforced thermoplastics. In [1] tests were proposed in which fabric prepreg specimens within a high temperature chamber in a tensile testing machine are pulled along an axis which bisects the fibre directions in the fabric. These tests were carried out on single plies and laminates of a commercial glass fabric/PA12 material (Vestopreg G101 from Hüls) at different loading rates from 1 mm/min - 2000 mm/min and temperatures in the range 180°C - 220°C. Fig. 1 shows a typical test specimen during test. In the centre of the specimen, marked as region 3, there is a uniform extensional flow with an almost constant tensile strain rate. In the test the fabric angle 2θ in the test region is found to reduce with time from its initial value of 90° due to trellis shear. Using a grid drawn on the fabric with photographs at intervals during the test, the fabric angle and axial strain were measured as functions of time. In the fabric rheology model the fabric angle is kinematically determined and independent of the polymer matrix properties. It is shown in [1] that in a constant rate extensional flow with extension ratio μ_1 at time t and constant strain rate λ, the fabric half-angle θ (t) is given by

$$\cos\theta = \mu_1 \cos\theta_o, \qquad \mu_1 = \exp \lambda t \qquad (1)$$

where θ_o is the fabric angle at t = 0. This equation is confirmed by the results in Fig. 2 which shows the predicted fabric angle θ from (1) plotted against true tensile strain $\varepsilon = \ln \mu_1$ and compared with measured angles from tests at different loading rates and temperatures. At tensile strains of about 0.23 it was observed that single plies began to fold and buckle out of plane,and laminates became delaminated. This corresponds to a fabric angle of about 50° with in-plane shear strain in the fabric of 0.7, and defines a locking angle in the fabric at which no further in-plane shear may take place. The test is an effective method of measuring the locking angle.

The general fabric rheology model requires three viscosity parameters for the orthotropic viscous sheet, corresponding to two through-thickness shear modes and one in-plane shear. The tensile test is not ideal for a precise determination of the viscosities, since although the sheet is pulled at a constant velocity, the flow and hence the stress state is unsteady due to the time dependence of the fibre orientation θ given in (1). Study of the fabric tensile test data showed that a simplified form of the model containing a single viscosity parameter η_1 was adequate for characterising the intraply fabric rheological properties. In this case it can be shown that the axial stress σ in the test region 3 in a specimen undergoing a constant tensile strain rate λ is given by

$$\sigma = \lambda\, \eta_1\, (4 - 3 \sin^2 2\theta) / \sin^4 \theta \qquad (2)$$

On substituting for θ here in terms of extension ratio μ_1 or true strain ε using (1), we obtain a stress-strain relation valid for the fabric tensile test, which contains the single viscosity parameter η_1. Measured stress-strain curves at different strain rates λ and temperatures can then be used to determine the fabric prepreg viscosity η_1. It was found that (2) fitted test data on glass fabric/PA12 and carbon fabric/PEI reasonably well. If this simplified rheological model is valid for these materials, it follows from (2) that a plot of normalised stress $\sigma / \lambda\, \eta_1$ should be independent of the test material and test conditions. Fig. 3 shows that this is the case to a reasonable approximation. Typical measured viscosities for glass fabric/PA12 were in the range 0.1-10 MPa s, depending on temperature and strain rate. If correct, these high viscosities for the composite fluid are puzzling since PA12 has a viscosity of about 200 Pa s. They were also very rate sensitive, which may suggest that friction effects between fibres and matrix are dominant deformation mechanisms, rather than matrix flow.

1. A. F. Johnson. Rheological model for the forming of fabric reinforced sheets, in Proceedings "Flow Processes in Composite Materials", Galway, Ireland, 1994.

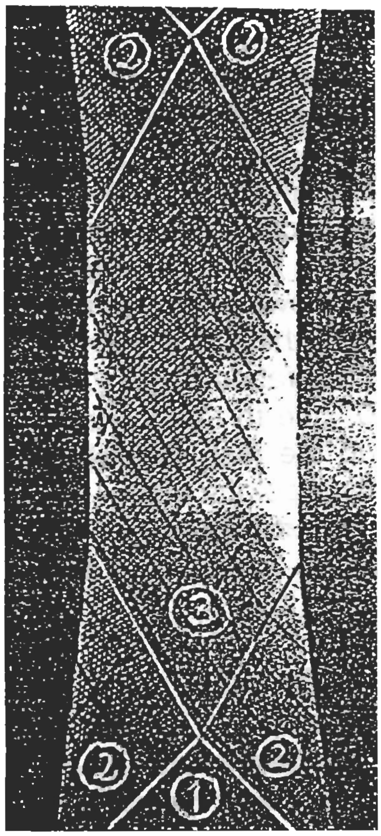

Fig. 1 Tension test of a fabric prepreg

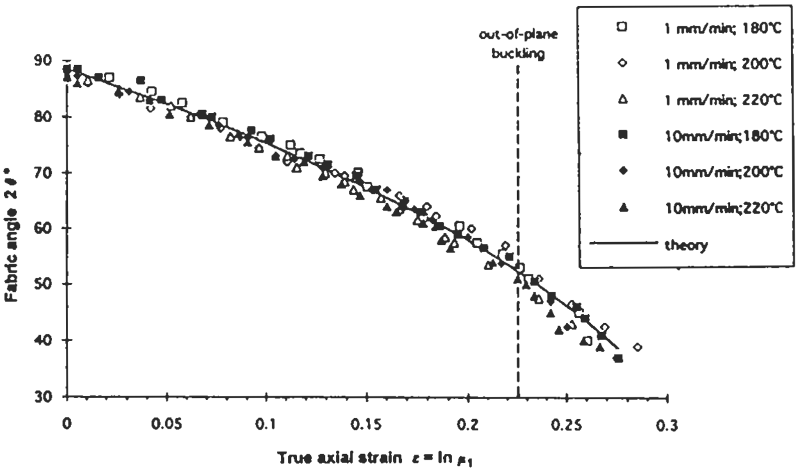

Fig. 2 Comparison of measured fabric angles with eqn. (1)

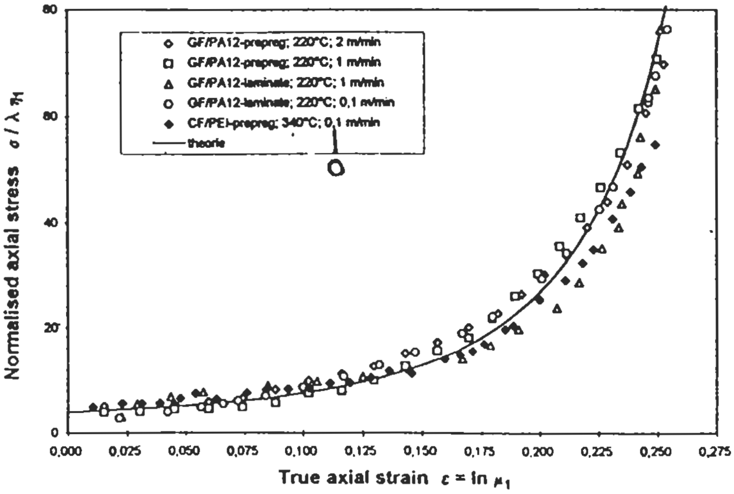

Fig. 3 Normalised stress-strain data compared with eqn. (2)

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