Abstract

This dissertation focuses on the thermo-mechanical properties of triaxial weave fabric (TWF) composites. The fabric is made up of continuous, interlaced strips of composite material with longitudinal fibres (tows) in three directions, at 0 degrees and ± 60 degrees. TWF composites are of interest for future lightweight structures, both rigid and deployable. A particular attraction of this material is that it is mechanically quasi-isotropic, on a macroscopic scale, and hence can be used to construct single-ply structural elements of very low areal mass. Potential applications include reflectors, antennae, and communication satellites.

In detail, the behaviour of TWF is more subtle than standard laminated composites, as in single-ply woven fabrics many of the local, three-dimensional degrees of freedom remain unconstrained. This results in some important differences between the behaviour of single-ply TWF composites and standard composites. Previous work on woven fabrics has concentrated on micromechanical analysis, which assumes that there is a repeating unit cell throughout the whole volume of the composites. However, most of these models focused on plied, thicker materials for which a continuum model is more representative. This dissertation aims to provide computational and experimental solutions for the thermo-mechanical behaviour of TWF.

The particular type of TWF that is investigated is the fabric SK-802, manufactured by Sakase Adtech Co. Ltd., Japan. This fabric consists of 1000 filaments of T300 carbon fibre, produced by Toray Industries Inc., Japan, woven in the "basic weave" pattern. For the matrix, the resin Hexcel 8552, from Hexcel Composites, UK, is used. This fabric has a dry mass of 75 g/m^2 and a thickness of about 0.15 mm. The manufacturing of TWF composites, using vacuum bagging in an autoclave is investigated.

A micromechanical investigation is conducted, starting from the fibre volume fraction determination. Two geometrical parameters are needed to establish the material properties of a tow: the cross-sectional area and the thickness. They can be determined either from micrographs of cross-sections taken through the cured composite or from direct calculation. Transversely isotropic material properties are assumed for the tow.

The profile of the axis of the tow is found to be important for modelling TWF.

A triangular waveform is found to be the best compromise between accuracy and simplicity. It is found that the aspect ratio of test specimens affects the measurement of some material properties namely the axial modulus, bending modulus, and Poisson's ratio. The stiffness measured in direction at 90° to a set of tows is sensitive to the width of the specimens, but the stiffness along the tows is fairly insensitive. Hence, it is concluded that the material properties are best measured in 0°-direction specimens.

Neglecting edge effects, the elastic behaviour of TWF is best described by the ABD matrix of a homogenized plate. This matrix is derived based on the unit cell approach. Homogenized material properties are obtained from the analysis of a unit cell consisting of "wavy 3-dimensional beams" using periodic boundary conditions. This analysis is a simplified version, in terms of geometrical modelling and boundary condition set up, of recently proposed solid element models found in the literature. The constitutive relationship of this unit cell is related to suitably defined in-plane and out-of-plane mid-plane strains and curvatures to corresponding force and moment stress resultants per unit length.

The thermally-induced deformation of TWF is best analyzed with solid element models as such models are able to take into account the out-of-plane behaviour at the tow cross-over regions and the three dimensional deformation. It is shown that beam grillage models do not capture the full extent of this deformation. It is found that the Gaussian curvature at the tow cross-over regions is negative everywhere implying a saddle shape out-of-plane deformation due to the anisotropic thermal expansion of a pair of crossing tows. A solid element model has allowed a better understanding of the nature of the deformation caused by the temperature variation in the through thickness direction. As a result, two dominant deformation modes are found: bending and twisting due to a temperature gradient through the thickness and a uniform temperature increase, respectively. It is concluded that the thermal deformation of single-ply TWF composites is described by two parameters, the linear coefficient of thermal expansion (CTE) and the coefficient of thermal twist (CTT).

The predictions of the thermo-mechanical behaviour of TWF are verified and assessed by a series of carefully designed tests. American Society for Testing and Materials (ASTM) guidelines are used as a basis for most of the test set ups. Due to the extreme thinness of TWF and the presence of hexagonal holes, these test procedures are modified. It is shown that the variation in measurement from all investigated tests ranges from 2% to 20%. In comparison, the homogenized model predictions capture the measured extensional stiffness and Poisson's ratio with good accuracy; a difference of only 3% is observed. These predictions appear to be a slight underestimate of the measured values in in-plane shear and bending. The most likely reason for these underestimates is the stiffening of the tow overlap regions which is not fully captured by a beam model. The solid element model over-predicts by two times the measured CTE of TWF. The predicted and measured CTT differ by 1% and 10% in the 0°- and 90°-direction narrow strip, respectively.

Keywords : composite materials, deployable structures, triaxial weave fabric, thermo-mechanical properties, periodic boundary condition, unit cell, size effects, transversely isotropic material.