11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

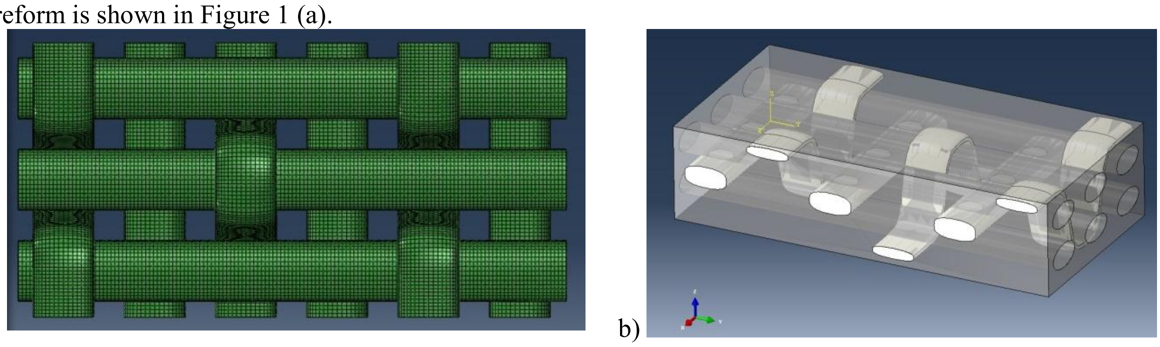
FINITE ELEMENT MODELLING OF A NON-CRIMP 3-D ORTHOGONAL WOVEN COMPOSITE

Serra Topal (*)[1, 2-a], Stephen Ogin[3-a], Andrew Crocombe[4-a], Prasad Potluri[5]

[1] Dr., Gazi University, Dept Mechanical Engineering, 06570 Ankara, Turkey, http://w3.gazi.edu.tr/~serra
[2] Visiting Researcher, s.topal@surrey.ac.uk, http://www.surrey.ac.uk/mes/people/visiting_staff/serra_topal.htm
[a] University of Surrey, Dept Mechanical Engineering Sciences, GU2 7XH Guildford, United Kingdom
[3] Professor, s.ogin@surrey.ac.uk, http://www.surrey.ac.uk/mes/people/stephen_ogin/index.htm
[4] Professor, a.crocombe@surrey.ac.uk, http://www.surrey.ac.uk/mes/people/andrew_crocombe/index.htm
[5] Dr., The University of Manchester, School of Materials, M13 9PL United Kingdom, prasad.potluri@manchester.ac.uk, http://www.manchester.ac.uk/research/prasad.potluri/

Key Words: *non-crimp 3-D orthogonal woven composites, finite element modelling.*

Laminated composite materials based on plies having fibre reinforcement in two dimensions have found ready applications in complex engineering structures. However, with only the polymer holding adjacent plies together, delamination is a common cause of failure. 3D reinforcement has the advantage that the through-thickness (z-direction) reinforcing yarns impart an extraordinary resistance to delamination unmatched by any other fibre-reinforced composite material. Advances in understanding the behaviour of non-crimp 3D orthogonal woven composites have been accomplished as reviewed by Bogdanovich [1], but the complexity of the structure, especially when different types of damage is introduced requires a finite element approach [e.g. 2-4]. In the present study, a preliminary finite element analysis of a 3-D orthogonal non-crimp woven composite has been conducted which explicitly, and for the first time, incorporates the through thickness z-yarns. In order to fully model the microstructural arrangement of yarns, a typical volume of the composite has been modelled. For our case, the volume includes three longitudinal (warp) yarns, six widthwise (weft, or fill) yarns and three z- (binder) yarns that penetrate two layers of weft yarns. A plan view of the finite element model of the fibre architecture preform is shown in Figure 1 (a).



a) b)

Fig. 1. The fibre architecture and the completed finite element model, including the matrix

As a first step in the analysis, the tow geometric parameters, such as cross-sectional shape, path and position within the structure have been specified. Cross-sections of the fibre yarns have been created as lenticular, with a narrower section for the z-yarns. Regarding the material properties, which can be seen in Table 1, the isotropic matrix material properties have been used (epoxy resin) with representative values for orthotropic E-glass fibre tows (the fibre volume fraction in the tows is about 0.6).

Table 1. Material properties of the finite element model of the present study

Matrix material	Fibre material				
$E = 2$ GPa	$E_1 = 45$ GPa	$\nu_{12} = 0.22$	$G_{12} = 5$ GPa	$\alpha_1 = 5.4\ 10^{-6}\ K^{-1}$
$\nu = 0.4$	$E_2 = 10$ GPa	$\nu_{13} = 0.23$	$G_{13} = 5$ GPa	$\alpha_2 = 1\ 10^{-6}\ K^{-1}$
$\alpha = 55\ 10^{-6}\ K^{-1}$	$E_3 = 10$ GPa	$\nu_{23} = 0.21$	$G_{32} = 5$ GPa	$\alpha_3 = 1\ 10^{-6}\ K^{-1}$

After the addition of the matrix to the model with a simple Boolean operation, the finite element model is geometrically complete (Fig 1 (b)). Following the specification of the material orientations that are continuously changing for the z-yarns, eight-noded hexahedral elements were utilized for the successful meshing of the model. A strain of 1% was applied in +x direction (parallel with the z-yarns) and the results for stress and displacements are depicted in Figure 2 (a)-(f).

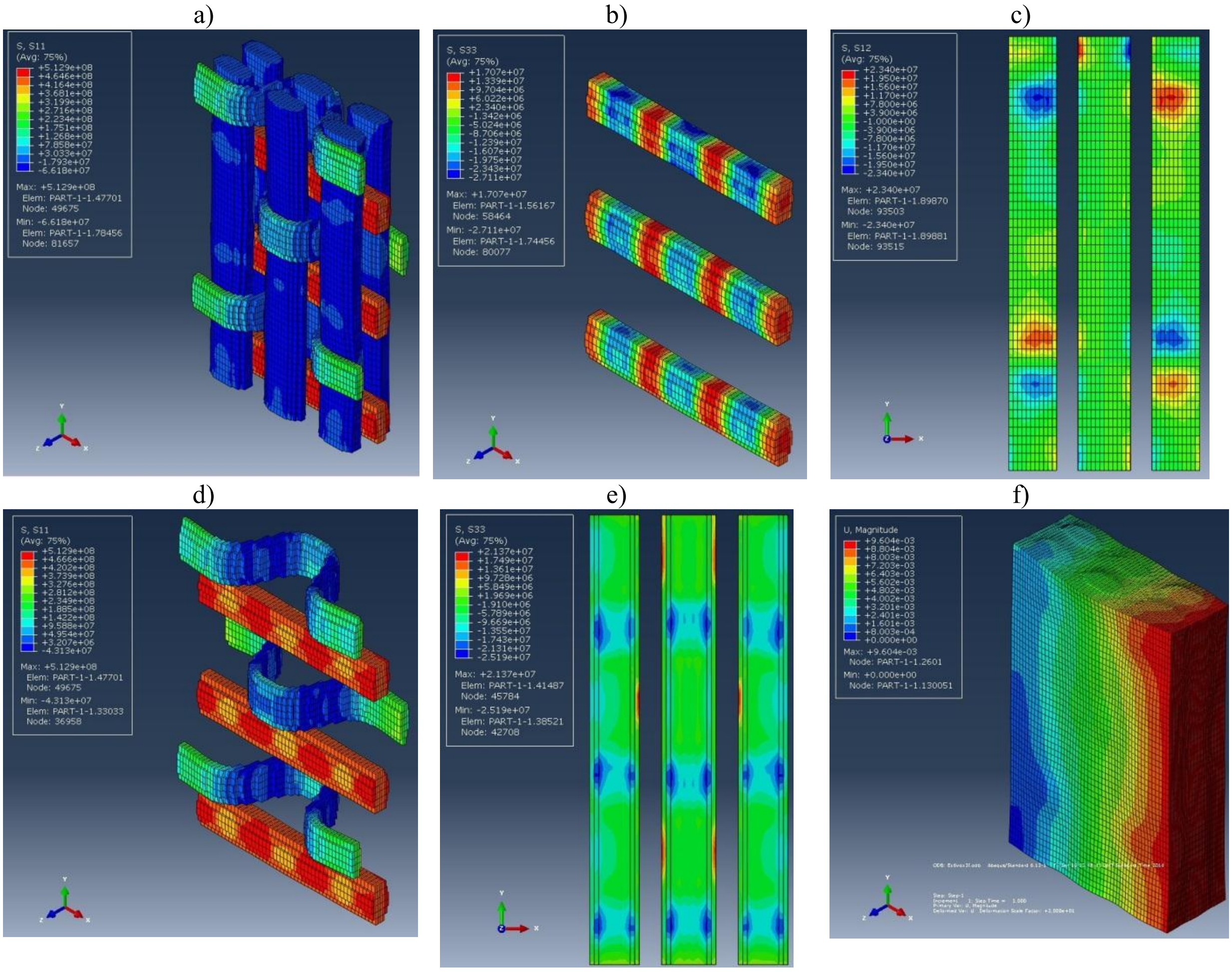


Fig. 2. Stress distribution (a-e) for the fibre preform and individual yarn sets and total displacement (f)

RESULTS

As expected, the x-direction stresses in the weft yarns are much lower than for the warp yarns while the z-yarns sustain an intermediate level of stress (Fig 2a). Deformation of the z-yarns as a consequence of loading caused compressive z-stresses for both the warp (Fig 2b) and weft yarns (Fig 2e). The regions that are shown in dark blue and red in (Figs 2b, 2c, 2d and 2e) are severely affected, having high stresses. Also the z-yarn material either side of the z-crown experiences compressive x-direction stresses due to contact with the weft yarns (Fig 2d). The Young modulus in the direction of the loading for this low volume fraction model has been evaluated to be 6.7 GPa, which is in agreement with an approximation of the modulus based on the simplistic Voigt and Reuss models. The conference paper will further describe the results and set them within the context of attempts to understand the experimental behaviour of these 3D composites.

REFERENCES

[1] A.E. Bogdanovich, Multi-scale modelling, stress and failure analyses of 3-D woven composites. *J. Mater. Sci.*, Vol. **41**, pp. 6547–6590, 2006.

[2] B.H. Le Page, F.J. Guild, S.L. Ogin, and P.A. Smith, Finite element simulation of woven fabric composites. *Composites: Part A,* Vol. **35**, pp. 861-872, 2004.

[3] Z. Lu, Y. Zhou, Z. Yang and Q. Liu, Multi-scale finite element analysis of 2.5D woven fabric composites under on-axis and off-axis tension. *Comp. Mater. Sci.*, Vol. **79**, pp. 485-494, 2013.

[4] A. Shigang, Z. Xiaolei, M. Yiqi, P. Yongmao, and F. Daining, Finite element modelling of 3D orthogonal woven C/C composite based on micro-computed tomography experiment. *Appl. Compos. Mater.,* Vol. **20**, October 2013.