MESO-MACRO MODELLING THE IN-PLANE SHEAR DEFORMATION BEHAVIOUR OF NCF CARBON/EPOXY PREPREGS IN AUTOMOTIVE APPLICATIONS

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ABSTRACT:

Non-Crimp Fabric (NCF) thermoset prepregs are being used extensively to achieve lightweight structural parts of passenger cars. Modelling the precise draping behaviour of such fabrics, mainly linked to their in-plane shear deformation, plays an important role in making good quality complex car body parts. Two approaches have been used in this particular works to simulate the deformation of NCF prepregs using hypoelastic computational model. The meso-scale approach models the individual components of fibres, matrix and stitching materials. The stitching represented by beam elements share the common nodes with fibre and matrix continuum elements. The shear behaviour is simulated in parallel and cross to the stitching direction using picture frame and bias extension tests. The second approach considers the macroscopic deformation behaviour of NCF prepreg using continuum shell elements. The nonlinear shear behaviour of the material, highly dependent upon the stitching direction, is introduced in the form of shear rigidity as a function of shear angle. The simulation results from the two methods have also been compared with experiments.

KEYWORDS: NCF, Theromset Prepreg, Meso-macro modelling, Shear behaviour, automotive parts

1. INTRODUCTION:

The lightweight automotive structures are being developed in order to improve the energy efficiency, reduce the vehicle emissions and meet the requirements of environmental regulations. Composite materials are being considered a primary choice for such applications. However, this is not very straightforward step to exploit such advanced composite materials. The material cost, snap cure resins, fabric formability, efficient processing etc are among the most important factors that constrain the widespread use of such materials.

Thermoset prepregs having non-crimp fabric (NCF) reinforcements are being considered a priority candidate material for automotive structural parts [1-2]. However, the draping of NCF prepregs is quite complex and needs to be carefully characterised. The in-plane shear behaviour of NCF prepregs, mainly linked to their drapeability, is one to major deformation modes that greatly influence to achieve complex structural geometries. The picture frame and bias extension tests are being used, from the last few decades, to characterise the in-plane shear of fabrics and prepregs. Eventually,

Excerpt from ISBN 978-3-00-053387-7

this helps to do preforming simulation of such materials in order to predict any forming defects and thereby optimise the processing parameters. The NCFs, unlike woven fabrics, are considered not to deform in shear according to fixed pin-jointed nodes assumption at cross-over points [3-7]. This leads to develop meso-scale modelling of the NCF materials where a detailed modelling approach based on interaction of individual components is achieved. Although this approach has not been proven to be very efficient based on the defining a large number elements and their contact interactions, yet this approach is fair enough to adopt it based on the observed deformation mechanism of fibre slippage or sliding during shear deformation. However, it has also been observed during in-plane shear deformation and 3d preforming of thermoset prepregs that the fabric sliding is negligibly small due to the resin interaction with the fabric. This eventually facilitates to adopt the pin-jointed deformation behaviour for the prepreg material.

In this particular work, two modelling approaches are proposed to analyse numerically the shear deformation behaviour of NCF prepregs. One of the proposed approaches is a macro-scale modelling of the prepreg material based on global shear deformation behaviour of pillar stitched NCF prepreg. Since the shear behaviour is dependent upon the stitching orientation, therefore, the two separate set of shear rigidities as a function of shear angle of the material are considered. The second approach is presented with a detailed modelling strategy of NCF prepreg components of fibres, resin and stitches. The resin and fibres are indeed modelled with the use of continuous approach represented by shell elements. The stitching material is represented by beam elements. These elements are assigned with individual material properties and there is not sliding or contact interaction between these elements due to the common nodes.

2. Inplane shear characterisation of the analysed material:

The material investigated is carbon/epoxy prepreg with biaxial pillar stitched non-crimped fabric (NCF) having an aerial weight of 400gsm of fabric. The material has been developed for compression moulding process with a snap cure resin system to meet the high volume production-rate requirements of automotive industries [2].

The material in-plane shear behaviour is determined from Picture Frame (PF) tests along and across the direction of the stitches shown in Figure-1. The prepreg is heated to 45˚C before testing. The shear behaviour is represented in the form of normalised force (N/mm) versus shear angle in radians. The stitching tensile (ST) direction shear behaviour is treated as positive shear angle whereas stitching compression (SC) is represented as a function of negative shear angle from the point of view of macro-level modelling of the NCF prepregs.

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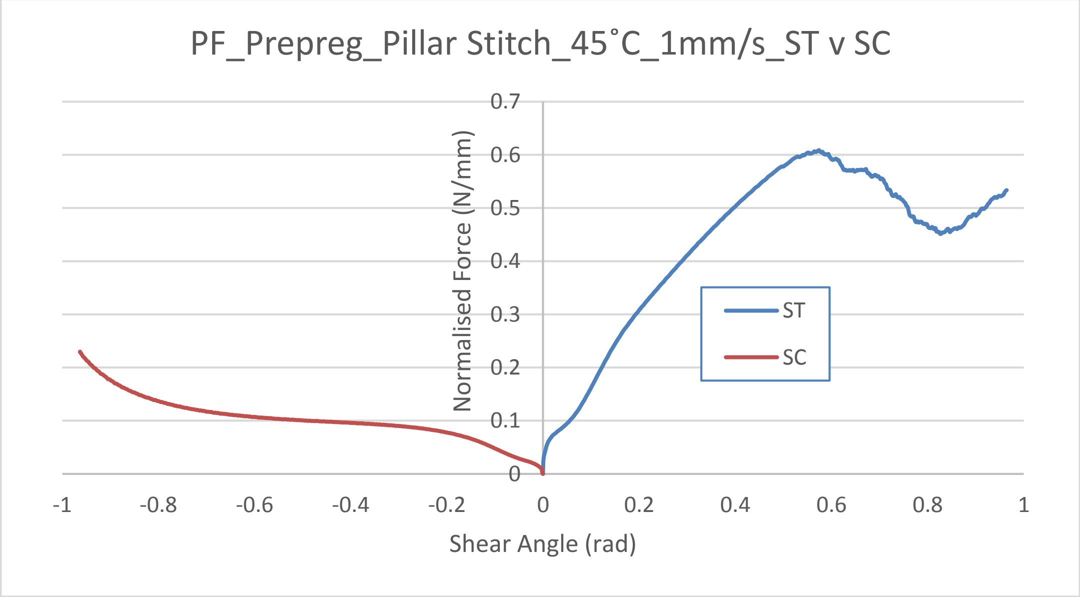

Figure 1: The shear behaviour of pillar stitched NCF prepreg measured at 45˚C of preheating with stitching tensile (ST) and stitching compression (SC) orientations.

3. NCF PREPREG MODELLING STRATEGIES

It has been observed during in-plane shear tests of bias extension and 3d forming of NCF prepregs using hemispherical geometry that there is negligibly small sliding of the fibres. Therefore, it has been concluded that the NCF prepreg deformation behaviour can be modelled that pin-jointed assumption. However, the complex in-plane shear behaviour due to the NCF reinforcement geometry has to be considered during modelling. The modelling is carried out in Abaqus/Explicit using user material subroutine based on the hypelastic computational model [8]. The two approaches in this respect has been adopted as described below.

3.1. MESO-SCALE NCF PREPREG MODELLING

The meso-scale model consists of two superimposed quadrilateral shell elements (S4R) having common nodes and the bar elements (2-node linear B31) along the diagonal of the quadrilateral elements as shown in Figure 2. One of the shell element is assigned with biaxial fabric material behaviour and the second element takes the resin properties. The bar elements are representing the stitches and are allocated with non-linear elastic behaviour as the stitches behave during deformation of the NCF prepreg.

3.2. MACRO-SCALE NCF PREPREG MODELLING

The macro-scale deformation of the NCF prepreg is modelled with only shell/ membrane elements and the in-plane shear behaviour of material is assigned in the form of shear rigidity as a function of shear angle (radians). The shear behaviour of NCF material can be assigned both in the form of polynomial equation as described

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by Samir et al. [9] or it can also be split into different stages based on the shear force response of the material as a function of shear angle [2].

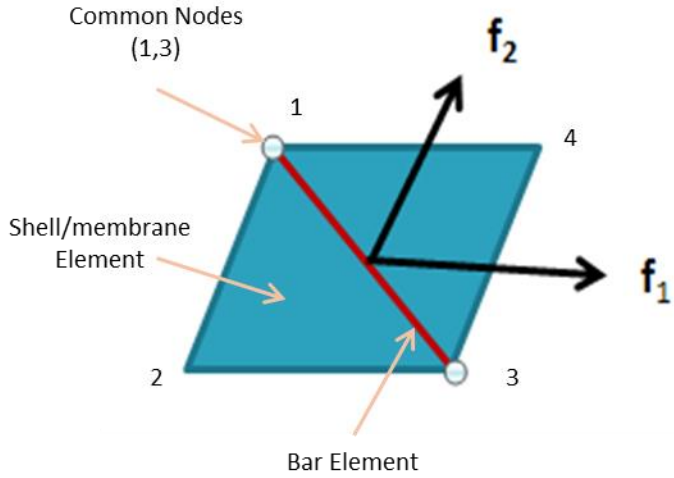
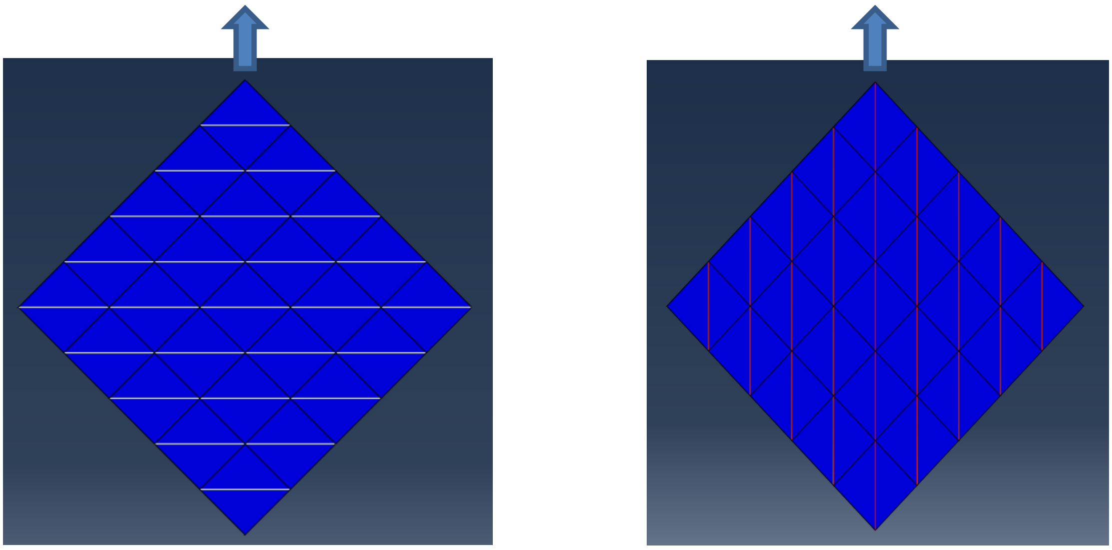


Figure 2: The schematic representation of NCF modelling in Abaqus using shell and bar elements.



a) Stitching perpendicular to the loading

b) Stitching along the loading

Figure 3: The NCF Picture frame test modelling in Abaqus using shell and bar elements for the two loading cases of across and along the stitches.

4. 3D FORMING OF NCF PREPREG

The NCF prepreg forming results of simulations are compared with experiments based on the macro-scale modelling approach described above and shown in Figure 4. It can be observed that the shear behaviour of NCF prepreg modelled as a function of shear angle can generate similar deformation an shear angle as observed in experiments.

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However, the results are limited to pillar stitched NCF prepreg using hemispherocal dome tools.

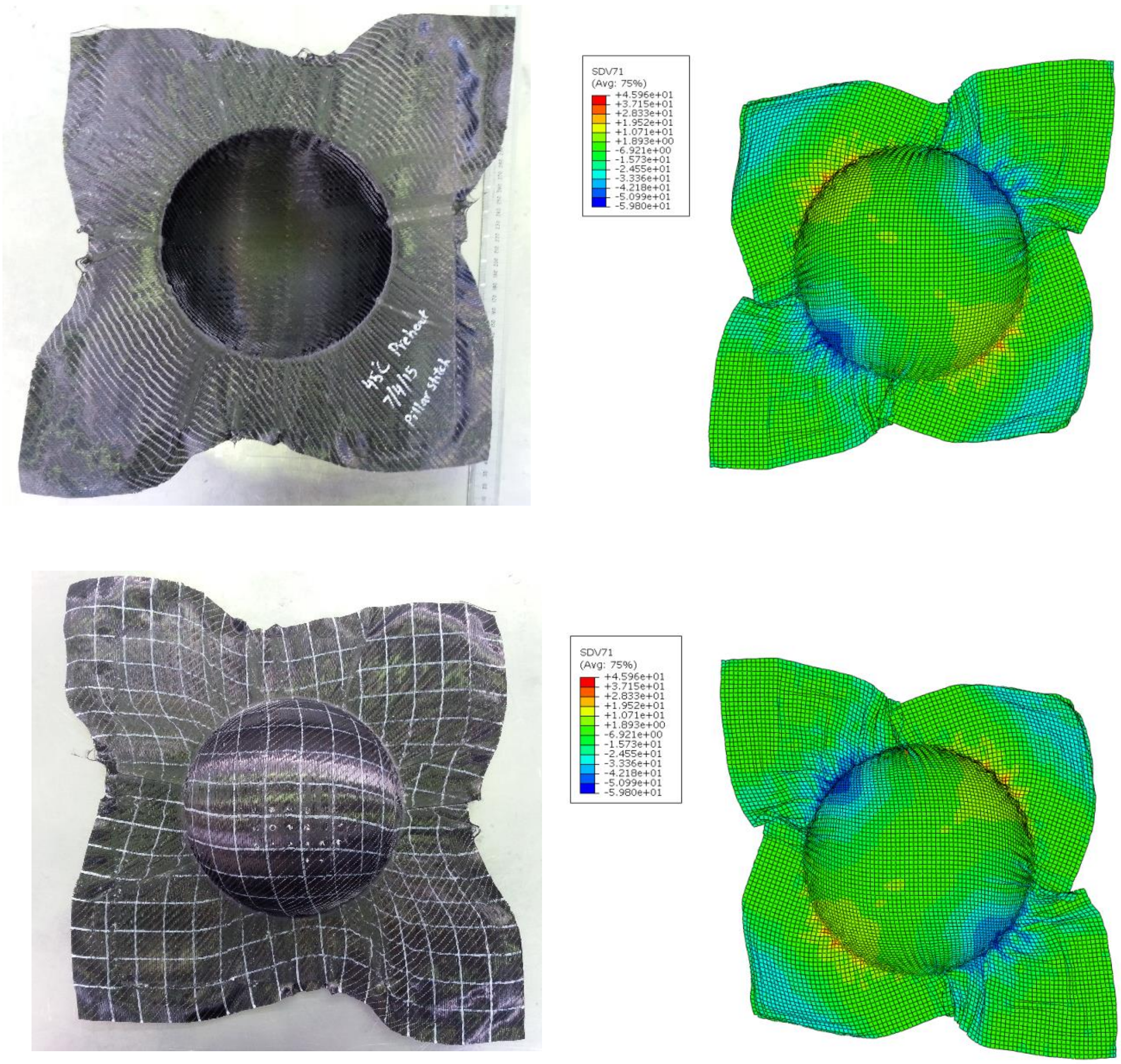

Figure 4: The comparison of deformation behaviour of NCF prepreg with macro-scale modelling approach simulations and experiments using hemispherical dome tools. SDV71 is the shear angle in degrees.

5. CONCLUSIONS

The present work is aimed at modelling the shear behaviour of NCF prepregs using meso- and macro-scale approaches of modelling. It has been observed with in-plane shear tests of Bias Extension and 3D forming of NCF prepregs that there is a negligibly small amount of fibre sliding that evolves during deformation. This helps to simplify the modelling approach for the NCF prepregs. The pin-jointed rotation of fibres can be assumed during shear deformation. The results shown in the case of 3D forming of NCF prepreg using hemispherical dome corroborate the approach used to simulate

Excerpt from ISBN 978-3-00-053387-7

the prepreg material. Further investigations on in-plane shear tests in simulations using the proposed approaches are in process.

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Excerpt from ISBN 978-3-00-053387-7