

## Three dimensional finite element model of a non-crimp fabric laminated using geometrically straight tows with crimped material properties

**L.M. Ferreira**

Departamento de Engenharia Mecânica. Escola Superior de Tecnologia de Abrantes do Instituto Politécnico de Tomar, Portugal

**E. Graciani, F. París**

Grupo de Elasticidad y Resistencia de Materiales. Escuela Técnica Superior de Ingenieros de la Universidad de Sevilla, España

### ABSTRACT

The compressive failure of a  $[0,90]_n$  non-crimp fabric laminate is studied using a 3D finite element model of the representative unit cell at mesoscopic scale. In previous analyses, tow elements coordinate systems were oriented in the actual direction of the fibres. Therefore, the same transversely isotropic mechanical behaviour was employed for every tow element (defined in the element coordinate system). A new approach is presented in this work, in which the geometrical crimp of the tows is neglected and straight tows are created. The actual crimp of the fibres is considered by introducing suitable anisotropic material properties in each zone of the tow. Anisotropic properties have been obtained by a rotation of the actual transversely isotropic mechanical behaviour, taking into account the actual orientation of the crimped fibres. This approach requires a larger amount of work to define the material properties but, on the contrary, the mesh can be easily created for any configuration. Results obtained with the new approach (i.e., the 'straight tows' model) have been successfully compared with those of the previous analyses (i.e., the 'crimped tows' model).

### 1. INTRODUCCIÓN

Non crimp fabric (NCF) composites have a complicated internal structure which affects the performance of the NCF composites, depending on the load scenario. It is then appropriate to develop a numerical model of a NCF composite prior to experimental characterization, in order to understand the influence of a significant number of parameters (for example, resin and fibre properties, internal geometry,...), in the elastic behaviour of the laminate and in the mechanisms of failure.

A full 3D finite element model, with a new approach in the definition of the crimp, has been developed to predict the failure mechanism under compressive loads.

### 2. MESOSCOPIC APPROACH OF THE NCF

The present study has been made at the mesoscopic level. Tows have been modelled as a homogenous material (without considering their microscopic constituents: resin and fibres). Different anisotropic properties (defined in the global coordinate system) have been employed in the different zones of the tows, obtained by a rotation of the transversely isotropic mechanical behaviour, taking into account the actual orientation of

the crimped fibres. Resin pockets have been modelled as a homogeneous isotropic material occupying the spaces between the tows.

The analysis has been made under the hypothesis of large displacements (using ANSYS software) and the load has been applied in a linear and progressive manner, until instability is reached. Linear elastic material behaviour has been considered.

### 2.1 Description of the 3D FEM

To present the model analyzed in this study it is necessary to define the concept of the representative volume element (RVE). It is a minimum repeatable cell which allows us to build any part of the non-crimp fabric composite by stacking multiple RVE. Due to the symmetry of the RVE, only one quarter RVE has been considered. The process to obtain the RVE, as well as the model analysed, is represented in Figure 1.

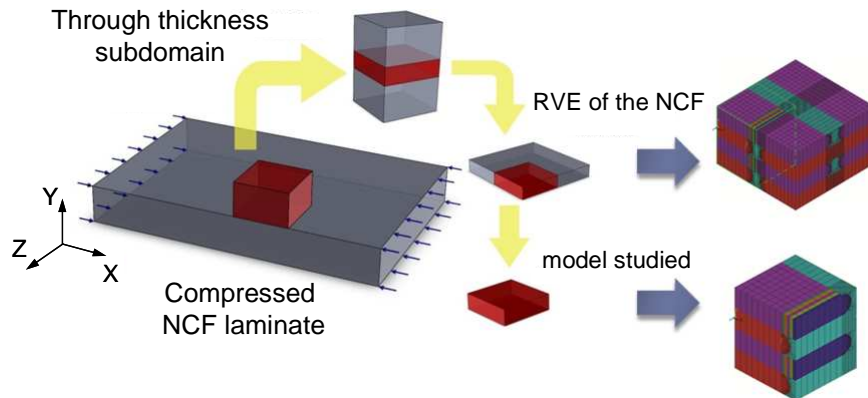


Fig. 1. Process to obtain the RVE and the analysed model.

### 2.2 Mechanical properties of the tows and resin

Structural solid element (SOLID185) with anisotropic behaviour in global coordinate system has been employed. The mechanical properties considered correspond to a T300/914 composite with a 55% volumetric fibre fraction, similar to the one used by Drapier and Wisnom (1999) and Graciani et al. (2005). The mechanical properties of resin and tows in a local coordinate system are presented in Tables 1 and 2. In the tows, direction 1 is the fibre direction, and directions 2 and 3 are the transverse directions.

Properties	Value
$E_{11}$	129 GPa
$E_{22} = E_{33}$	9.77 GPa
$\nu_{12} = \nu_{13}$	0.32
$\nu_{23}$	0.45
$G_{23}$	1.5 GPa

Table 1. Tow's material constants.

Properties	Value
$E_m$	4.5 GPa
$\nu_m$	0.4

Table 2. Resin's material constants.

A maximum crimp angle of  $3^\circ$  has been considered in the model. The properties of each tow element are defined taking into account the actual crimp in the fibres located at the position of the element. The crimped elements were identified and the corresponding

angle of crimp was calculated for each element. The angle of rotation used to simulate the crimp in the elements transforms the mechanical properties from transversely isotropic to anisotropic. The stiffness properties calculated for every element/angle, are defined as distinct anisotropic materials in the finite element model.

### 2.3 Boundary conditions

The boundary conditions applied to the faces of the model serve to impose the compressive stress state and guarantee the displacements compatibility in the limits of the model with the rest of the structure. Symmetry conditions have been assumed in the faces parallel to the XY plane and one of the faces parallel to YZ plane. The opposite face parallel to the YZ plane has a pure compressive load applied and displacements of its nodes are coupled to ensure that all nodes displace the same in the load direction. The boundary conditions in the top and bottom faces (parallel to the XZ plane) must guarantee the compatibility of the RVE under consideration with the adjacent RVEs. Thus, displacements of the nodes in both faces are coupled to ensure that the extension in the thickness direction is constant through the whole model.

## 3. RESULTS

Considering the boundary conditions and the load imposed, it is expectable that the  $0^\circ$  tows suffer instability phenomenon, known as mesobuckling.

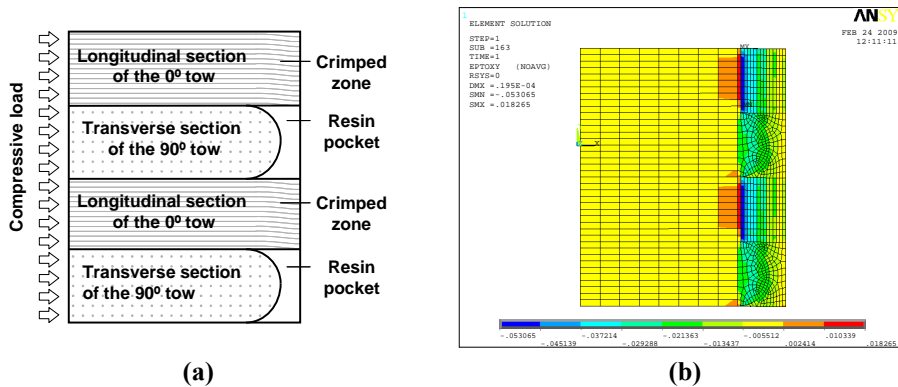
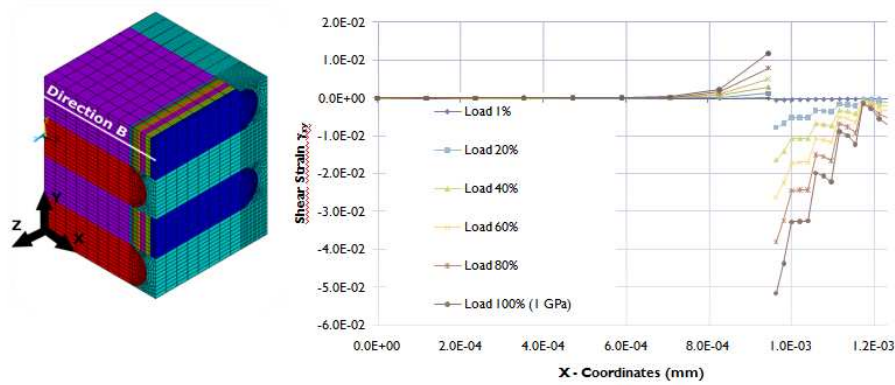


Fig. 2. Results in  $z = 0$  face. (a) Sketch of the model (b)  $\gamma_{xy}$  shear strains.

Figure 2(b) represents the  $\gamma_{xy}$  shear strain through the front face of the model (normal to Z axis). The model is sketched in Fig. 2(a) showing the different zones considered in the model. It is possible to appreciate the repetitive solution of strains within the tows having the same orientation. It can also be observed that the larger strain gradients arise in the zone where the  $0^\circ$  tows are affected by the crimp (i.e, where packages of resin appear between the  $90^\circ$  tows). Two consecutive vertical rows of elements appear in the  $0^\circ$  tows, one of them having the maximum positive value of  $\gamma_{xy}$ , and the other having the maximum negative value of  $\gamma_{xy}$ . The evolution of  $\gamma_{xy}$  strains along the ideal direction of the fibres in the  $0^\circ$  tows (called direction B) can be clearly appreciated in Figure 3.



**Fig. 3. Evolution of  $\gamma_{xy}$  shear strains along the represented direction.**

The results lead to think that the failure of the NCF under this type of load is controlled by the shear strains that appear in the  $0^\circ$  tow. The abrupt jumps in the shear strain take place in the zone where the  $0^\circ$  tow stops to be in contact with the adjacent  $90^\circ$  tow, and start to be in contact with the resin. The difference between the stiffness of the  $90^\circ$  tow and the stiffness of the resin is responsible for this jump in the shear strain and consequently it is in the root of the failure of the composite. This failure mechanism is in agreement with the results shown by Graciani et al. (2005), using a more complicated FEM model in which the tow elements were oriented following the actual crimp of the fibres.

#### 4. CONCLUSIONS

The behaviour of an antisymmetric  $[0,90]_n$  NCF composite under in-plane compressive load has been studied using a new 3D finite element model. In this model the fibre crimp is modelled by means of an appropriate definition of the material properties in the elements. The results obtained are similar to those shown in Graciani et al. (2005).

The advantages of this model in comparison with previous models are the rapid modelling and meshing and the possibility of introducing complex crimps without changing the geometry of the model (to simulate, for example, the effect of stitching in the NCF composite). However the geometrical simplification implies the use of certain algebraic calculations to determine the mechanical properties in the crimped zones. As an additional advantage, the use of a simpler geometry in the new FEM results in a higher quality mesh, which leads to better convergence of the non-linear analysis.

#### REFERENCES

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