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A micro-meso bridge for the mesoscale modelling of woven composites

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Abstract. *The evolution of damage in a woven composite results from the interaction and competition among several elementary mechanisms which are greatly influenced by the microstructure. Thus, in order to develop a model as close as possible to the physics, it is necessary to observe, understand and describe each mechanism on the most appropriate scale. In this work, the construction of a woven composite micro model is presented as well as an homogenization procedure to study microcracking kinetics on the microscale and its impact on the mesoscale.*

Keywords: Woven composites; Damage; Homogenization.

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1 INTRODUCTION

In the past years high performance composite materials have taken an important place in aerospace applications. However the design methods are still based on experimental testing. The virtual testing whose objective is the exploitation of predictive models based on the physics of materials, represents a major challenge in composite structures design. This study focuses on the construction of a micro model of a woven composite Representative Volume Element (RVE). Such a model is used to perform static simulations aiming to investigate the cracking kinetics on the microscale. Starting from the knowledge of micro damage evolution, the construction of a bridge between the micro and the meso scales is developed. Useful to improve the existent meso models [1], such a strategy has already been developed for composite structures based on unidirectional plies [2][3][4]. In this strategy a first ply problem deals with the plane part of the meso strain, a second interface problem will take into account the out of plane part.

2 NUMERICAL MODELING

2.1 Micro model

The geometric complexity of woven composites implies the creation of a 3D finite element model of an elementary volume of the material, which enables to study the discrete damage mechanisms at the micro scale. Looking for a good final accuracy, such a numerical model should be built in order to represent the real material geometry and assuring a good mesh quality in the parts. These issues are not always dealt with in the literature.

To obtain information about the geometry, a first experimental analysis is carried out in order to identify the main parameters and characteristics of the material (Figure 1). The transverse and longitudinal yarn sections are measured and the variability of these parameters in the fibre direction is examined. Then the micro model of the woven elementary cell is developed in Abaqus using a geometry built with the real measured parameters.

The geometry that has been used (Figure 2) is characterised by compatible surfaces between the parts and it allows managing of the contact between the yarns and between the yarns and the matrix [5]. A hexaedral mesh is generated

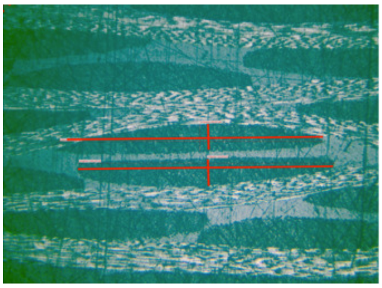

Figure 1: Micrographic picture of a woven epoxy matrix composite.

on the yarns. Moreover the mesh is compatible at the interfaces between yarns to handle contact and possible inter-yarn delamination [6]. The elementary cell is completed by the creation of homogeneous plies surrounding the woven ply and simulating the presence of external layers.

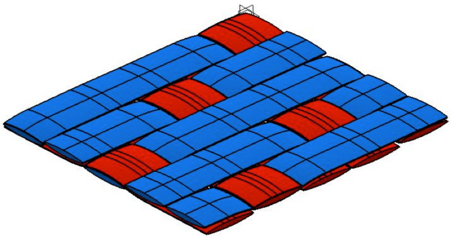

Figure 2: 5H Satin reinforcement RVE.

Firstly, simulations of the healthy cell are achieved to study the strain energy distribution in the yarns and to establish the most likely position of the cracks. In Figure 3 the strain energy densities evolution over a transverse yarn is shown for an applied strain of 1% along longitudinal yarns direction. It can be observed that the most important is the energy due to the stress in transverse direction opening possible microcracks. Moreover the evolution is almost constant over the yarn, the same behavior has been observed also for the other yarns. This means that when a crack appears it will span all over the yarn length.

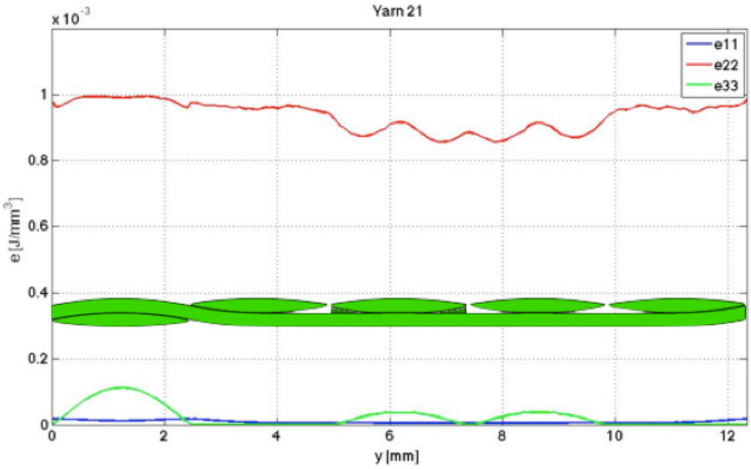

Figure 3: Strain energy density evolution over a transverse yarn, imposed deformation of 1%.

Other simulations are then performed introducing the discrete damage mechanisms, in order to understand the evolution of the microcracking phenomena through the analysis of the strain energy release rates. Microcracks are introduced in transverse yarns at different locations and the strain energy release rates are calculated. As it can be observed in Figure 4 the cracks show similar release rate values in the central part of the yarn section. The higher the strain energy release rate is, the higher is the probability for a crack to form. Therefore, for what concerns the single yarn, the microcracking process can be considered as a stochastic phenomenon. Finally multiple cracks are introduced sequentially in the cell and the strain energy release rate evolution with respect to microcracking density is found.

Strain energy release rate	Crack position
118 J/m^2	
112 J/m^2	
52 J/m^2	

Figure 4: Strain energy release rates for yarn microcracking, imposed deformation of 1%.

2.2 Homogenization procedure

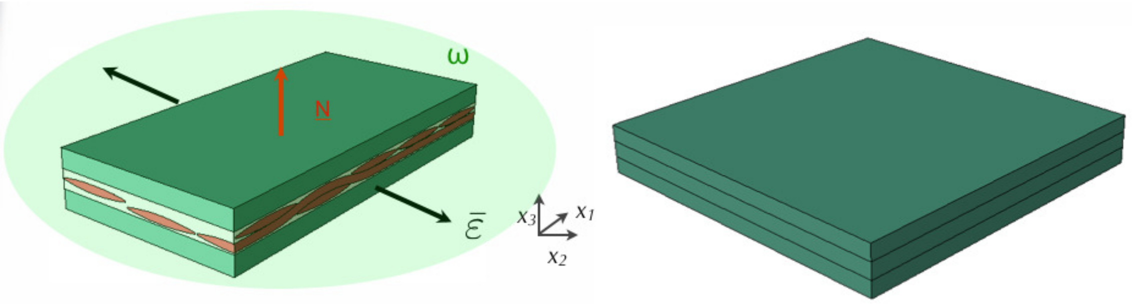

Figure 5: Problem RVE.

The first step of the homogenization procedure is to mathematically prove the existence of a link between the micro scale (where the woven microstructure is described) and the meso scale (where the ply is considered homogeneous). The problem RVE that will be called ω is represented by a periodic cell composed of a woven ply surrounded by two homogeneous plies. The central woven ply will be called ω_E.

Let's call K the Hooke's operator of the real material of the micro problem, and $\bar{K}$ the homogenized Hooke's operator. The hypothesis is to study the problem locally in the elastic domain. The stress field $\bar{\sigma}$ verifies the equilibrium and the displacement $\underline{\bar{u}}$ must be cinematically admissible. Therefore the problem is to find the displacement $\underline{\tilde{u}}$ that corrects the solution of the meso problem.

Find $\underline{\tilde{u}} \in U_p$

$$\int_{\omega} Tr\left[K\varepsilon\left(\underline{\tilde{u}}\right)\varepsilon\left(\underline{u}^*\right)\right]d\omega + \int_{\omega_E} Tr\left[\left(K-\bar{K}\right)\bar{\varepsilon}\varepsilon\left(\underline{u}^*\right)\right]d\omega = 0 \;\; \forall \underline{u}^* \in U_p \tag{1}$$

where $R = \left(K-\bar{K}\right)\bar{\varepsilon}$ is the residual stress which is zero if the material is homogeneous. In fact $\left(K-\bar{K}\right) = 0$ in the homogeneous plies. It has been demonstrated that the average micro strain over a surface cutting the woven ply is equal to the meso strain over the woven ply. Moreover the average micro stress along the normal N of a surface cutting the woven ply is equal to zero because the present study deals about the plane problem. Finally the link between the micro and meso scales is assured by the equivalence between the micro and meso strain energies.

$$E = \int_{\omega} Tr\left[K\left(\tilde{\varepsilon}+\bar{\varepsilon}\right)\left(\tilde{\varepsilon}+\bar{\varepsilon}\right)\right]d\omega = \int_{\omega_E} Tr\left[[\bar{K}]\bar{\varepsilon}\bar{\varepsilon}\right]d\omega_E \tag{2}$$

As an example in Table 1 the homogenization technique is applied to the healthy cell micro-model in order to compute the ply homogenized elastic properties. It can be noticed that the numerical results fit the experimental values, the only less accurate property is the shear modulus, which is much more affected by the incertitude on shear modulus of the fibers.

Table 1: Ply elastic homogenized properties.

	FEM	**Experimental**	**Units**
$E_{xx} = E_{yy}$	59.31	61 ± 1	GPa
E_{zz}	-	-	-
G_{xy}	3.5	4	GPa
ν_{xy}	0.05	0.06	-

3 CONCLUSIONS

A 3D numerical model for a woven microstructure has been built basing on a real material geometry. Using this model the intra-yarn microcracking scenario has been introduced to study the microcracking evolution in the ply. Moreover a proper homogenization procedure for healthy and cracked woven plies has been set up to link the micro and meso scales. The evolution of the strain energy release rate is computed with respect to the microcracks density in order to find the behavior of the microcrack density with respect to the applied strain. In the future the interface problem will be introduced in order to study the delamination scenario.

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