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Computational Materials Science 39 (2007) 142–148
COMPUTATIONAL MATERIALS SCIENCE
www.elsevier.com/locate/commatsci

Micromechanical modelling of shear deformation of a 90°-ply in Glare® at elevated temperatures

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Received 12 October 2005; received in revised form 19 December 2005; accepted 18 January 2006

Abstract

This work focuses on modelling the interlaminar shear deformation of a 90°-composite glass fibre epoxy ply, using finite-element analysis (FEA). The investigated transverse layer is part of a typical Glare® lay-up. This approach uses a unit cell of a single, resin embedded fibre, assuming hexagonal fibre alignment. This representative volume element (RVE) is provided with periodic boundary conditions (PBCs). Matrix yielding and micro mechanical damage due to debonding at the fibre–matrix interface are the main consequences after interlaminar shear load is applied on the RVE. Temperature dependent material properties, thermal residual stresses of the 90°-layer and the Glare® composite, as well as the adhesive strength at the fibre–matrix interface are taken into account. Comparing the computational and experimental results shows that plastic matrix deformation and further occurring damage can be assigned to defined global shear loads at given temperatures. It is shown that the parameters concerning the interfacial strength have a large influence on the global shear behaviour of the RVE. Thus, the basis for further investigations is explored to give design criteria for given thermal and mechanical loads in structural applications.

Keywords: GFRP; RVE; Periodic boundary conditions; Interlaminar shear load; Interface debonding

1. Introduction

In this work a micromechanical model of an interlaminar shear loaded unidirectional reinforced ply is proposed, loaded transverse to the fibre direction. It is partly based on the work of Fiedler and Hobbiebrunken [1,2], which focuses on localisation of initial transverse cracking under tensile loads considering thermal residual stresses in microscopic scale (between fibre and matrix). Whereas these approaches are based on a multi scale approach to consider the locally different stress states on the mesoscopic scale (composite layer scale), the approach proposed here in is based on the superposition of a simplified global stress field on the micro scale, and focuses on damage initiation and propagation at the fibre matrix interface.

Experimental investigations of interlaminar shear properties of Glare® laminates [3] showed that fibre matrix debonding is the dominant damage mode in the 90°-plies, with pronounced development of multiple debonding especially at elevated temperatures.

This modelling approach uses a two-dimensional periodic unit cell of a single fibre embedded in resin matrix, to get a first sight into the micro structure of the investigated transverse laminate layer under higher interlaminar shear deformation. The model gives information about the mechanisms of changing the load distribution due to fibre matrix debonding, and its influence on the micro- and mesoscopic material behaviour, considering different temperature conditions.

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doi:10.1016/j.commatsci.2006.01.034

2. Material

Glare® is a glass fibre-reinforced metal laminate (FML). It is chosen for the fuselage of ultra high capacity aircraft due to its excellent fatigue properties, weight saving, as well as damage tolerance and safety aspects. It consists of thin aluminium 2024-T3 sheets bonded together with interspersed composite plies made out of high-strength unidirectional orientated S2-glass fibres embedded in a modified epoxy matrix and autoclave cured at 120 °C. The special Glare® grade 4B-6/5-0.3, investigated in this work, consists of 6 aluminium plies and 5 fibre-reinforced polymer layers, each laid-up of three unidirectional fibre plies oriented in [90,0,90] direction.

This approach focuses on the damage behaviour of interlaminar shear loaded 90°-plies. Thus, from the multiple material data of the Glare® composite only the overall stiffness and the coefficient of thermal expansion (CTE) are used, as well as the assumed isotropic properties of the constituents of the glass–epoxy prepreg, all given in Table 1.

Adhesive shear values taken from the data sheet [4] were used to calculate the longitudinal material properties of the epoxy matrix. Using the given data points, a linear interpolation leads to a multi-linear plasticity description. The glass fibres were modelled isotropic and linear elastic. For the matrix and the fibre material a constant CTE is used over the applied temperature range.

Table 1
Modelling material constants of constituents and Glare® laminate

	Young's modulus (MPa)	Yield stress (MPa)	Yield strain	CTE (μm/m °C)	Poisson's ratio
S2-glass	88,000	–	–	1.6	0.33
FM94 epoxy					
@ 218 K	2900	34.800	0.012	60	0.39
@ 297 K	2280	27.132	0.0119	60	0.39
@ 355 K	922	10.142	0.011	60	0.39
Glare®4B-6/5-0.3	48,500			21.1	

3. Modelling

Following the definition given by Fish and Shek [5] this approach can be classified as superposition based. A given homogenous load of mesoscopic scale is applied on a heterogeneous and representative volume element (RVE) in the micro scale. For using the RVE some conditions have to be satisfied: the spatial stress state has to be uniform over the represented element volume and a periodicity of the heterogeneous pattern has to be found in the micro structure, which can be applied for our 90°-ply, at least away from the machined notches of the specimen (see also scheme in Fig. 2). To account for these properties a two-dimensional RVE with hexagonal fibre alignment is used (Fig. 1). The dimensions of the RVE are result of the hexagonal arrangement of the fibres in the matrix with a fibre diameter of 8 μm and the given fibre volume fraction of $V_f = 0.6$.

The loads applied on the RVE can be divided in local and global loads. The local loads or rather the local displacements inside the RVE are a result of the periodic conditions and represent the response of the RVE due to the applied global load. The global displacements represent the homogeneous strain field of the mesostructure due to mechanical or thermo-mechanical loads.

To investigate the interlaminar shear properties, double notch shear (DNS) tests according to ASTM D 3846 were performed, schematically shown in Fig. 2. By applying longitudinal compression interlaminar shear stresses are trans-

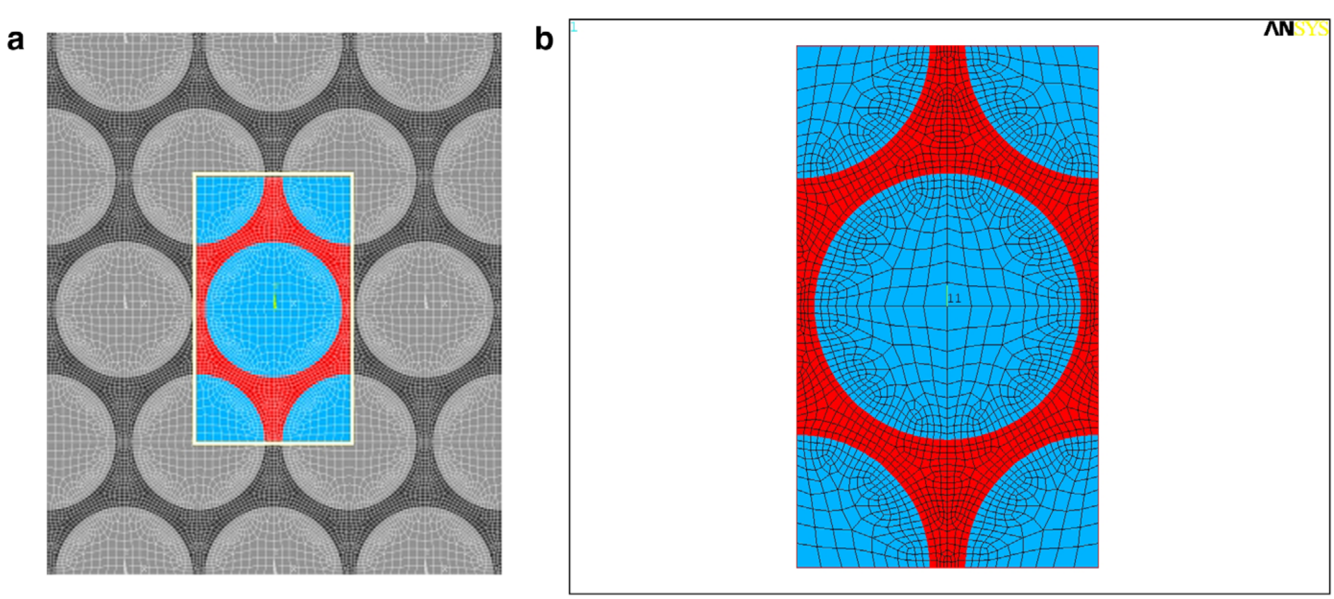

Fig. 1. Periodicity of hexagonal unit cell and its meshing.