MECHANICAL BEHAVIOR OF A 2.5D C/C COMPOSITE

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Introduction

Unlike the Carbone/Carbone composites (C/C) manufactured by liquid impregnation of the matrix [1-5], the mechanical behavior of Chemical Vapor Infiltration-C/C composites has not been a subject of extensive studies. The 2.5D C/C composite investigated in the present paper was produced by CVI. The fiber preform consists of stitched multiple layers of satin (8-Harness) woven fiber tows (Fig.1). The nonlinear stress-strain behavior under tensile and shear loading is associated to damages and failures mechanisms through an experimental study combining mechanical tests and microscope inspection of the test specimens under load. A macroscopic model of the nonlinear behavior of the 2.5 D C/C composite is proposed. It relies on the theory of anisotropic damage developed by Ladeveze [6] and it is guided by experimental data on the matrix damage modes identified by optical microscopy.

Experimental

The front face of eleven on-axis tensile testspecimen (parallel to the plies, as opposed to the lateral face perpendicular to the plies) was polished for microscope examination. Stuffer (direction 1) and filler (direction 2) direction-oriented samples were prepared. For examination of the specimens under load, a high magnification microscope (up to 416) built on a stage with three displacement axes and coupled with a CCD camera, a video recorder and a control monitor was used. The same region of the gauge area was inspected at increasing applied loads according to a grid of fifty to seventy views, covering roughly a fifth of the total gauge area [7]. An alternative method needed be used for examination of damage in the interior of the samples. For this purpose, a mold was mounted on the specimens. When a load close to the ultimate failure load was reached, an epoxy resin was injected into the inside of the specimen to fill in the open cracks. The load was kept constant during resin polymerization. The four Iosipescu test specimens were cut out the same part as the tensile specimens. Intralaminar Iosipescu shear tests were performed [7,8]. The front face had been previously polished for microscopic examination of the area located between the V noches [7]. The previously described observation techniques used under tensile loads were applied for damage identification under shear loads. Ten off-axis tensile tests (15°, 22.5°, 45°, 67.5°, and 75° with respect to direction 1) were performed to identify or validate the model either proposed for the mechanical behavior.

Results and conclusions

The same families of microcracks and cracks have been detected during the on-axis and the shear tests (Fig.2) :
(i) <u>a-cracks</u> : intra yarn matrix cracks, parallel or perpendicular to the loading direction,
(ii) : <u>b-cracks</u> : inter yarn matrix cracks located between perpendicular tows,
(iii) : <u>c-cracks</u> : inter and intra-tow matrix cracks extending across longitudinal tows (with fiber bridging).
All the matrix cracks were oriented parallel to both tow directions. Additional damage modes were not observed. However, it is worth mentioning that microcracks located at fiber-matrix interfaces were observed under all loads. The influence of matrix cracking on the stiffness has been analyzed [7,9]. Residual deformations result from non-closure of the matrix cracks created under load [7,9].

The proposed model lies within the classical framework of the thermodynamic of irreversible processes [6,10]. Due to simplifications in the model based on the results of microscope observation of the damage modes, it involves only three scalar damage parameters : two tensile parameters, based on the stiffness loss, and one shear parameter combining the tensile ones. Anelasticity induced by damage is described by a threshold function of "plasticity" (isotropic criterion). The introduction of parameters taking into account the coupling of tensile and shear components in the damage and anelasticity evolution laws has been guided by the experimental data on damage. The identification of damage parameters requires only one 45° off-axis (plane of the plies), and two on-axis (parallel to fibers direction in the plane of the plies) uniaxial tensile tests (Fig.3) [7,11]. The model is validated on the tensile stress-strain curves measured from various off-axis tensile tests. A good agreement is obtained between the predictions and the measured stress-strain curves (Fig.4).

On-axis and off-axis compression, tension-compression tests, and biaxial tension-shear tests would permit extension of the model. Firstly, the pertinence of an isotropic criterion for anelasticity could be investigated. Secondly, the possible coupling of the tensile and compressive damage parameters could be taken into account. Finally, the pertinence of the model could be validated by biaxial proportional and non-proportional tension-shear tests.

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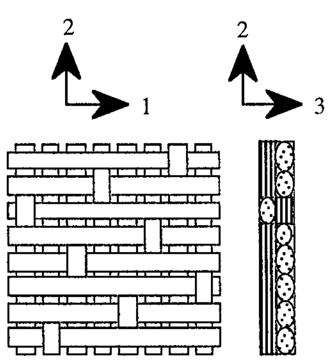

Figure 1 : 8-Harness satin weave pattern and tow directions

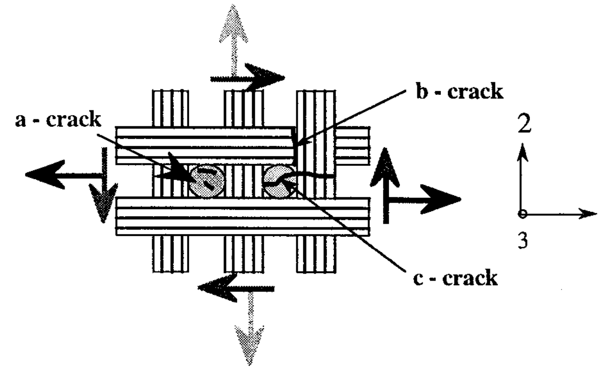

Figure 2 : Schematic diagram summarizing the three families of cracks detected during the tensile and the shear tests

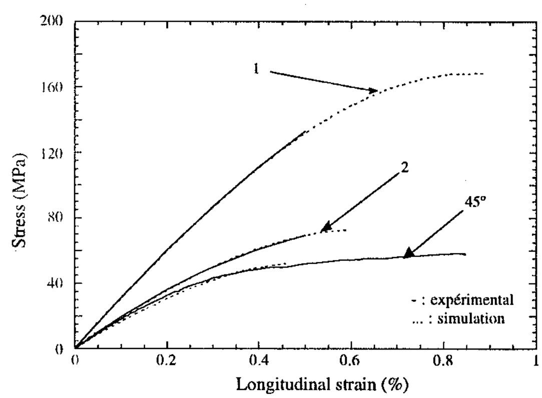

Figure 3 : Comparison of computations with the experimental stress-strain curves for damage parameters identification : on-axis (directions 1 and 2) and off-axis (45° in the plane of the plies) tensile tests

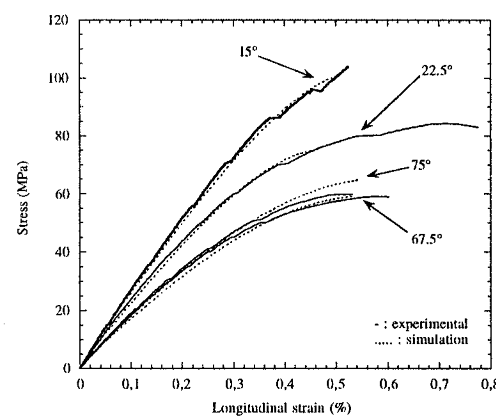

Figure 4 : Comparison of predicted and experimental stress-strain curves for various off-axis tensile loading conditions (15°, 22.5°, 67.5°, and 75° with respect to direction 1)