EPJ Web of Conferences **6**, 31010 (2010)
DOI:10.1051/epjconf/20100631010

Mesoscopic Strains Maps in Woven Composite Laminas During Off-axis Tension

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Abstract

The mechanics of woven carbon-fiber reinforced plastic (CFRP) composites is influenced by the complex architecture of the reinforcement phase. Computational (i.e. finite element based) approaches have been used increasingly to model not only the global laminate stiffness, but also damage evolution and laminate strength. The modeling combines the identification of the architectural unit cell (UC), the selection of suitable constitutive models of the different phases, the creation of a fine discretization of the UC in finite elements, the application of an incremental solution procedure that solves iteratively for the stresses and strains in the UC, [1].

The experimental validation of computational models is carried out mainly at the macroscopical level, i.e. simulation of the macroscopic stress-strain curve. Damage, however, is a localized, strain-dependent phenomenon and therefore only accurate strain distribution within the UC (at the mesolevel) can identify critical conditions in terms of damage location, extension and evolution.

The validation of computational damage procedures is a key task and full-field optical strain analysis methods appear the ideal instrument. However, only limited examples of direct finte element method (FEM) vs experimental strain correlation are found because of the limited sensitivity and spatial resolution of some techniques and the complexity and applicative difficulty of others.

The aim of the present paper is to present the application of the digital image correlation (DIC) technique, [2], to the full-field strain analysis at the mesoscopic level (i.e. within the UC) of a woven CFRP lamina when the direction of loading forms an angle to the material direction.

The material under consideration is a woven carbon fiber reinforced epoxy composite. Orthogonal yarns, each made of of several thousand fibers, are woven according the twill-weave architecture is shown in Fig. 1a. Single-ply laminas were manufactured and tested to eliminate the random 3D influence of multiple-ply laminates and to favor computational model validation.

Specimens with different loading directions with respect to the material principal directions were prepared and tested in a servo-hydraulic testing machine. Specimen surface preparation consisted in a speckle pattern generation to allow the application of the DIC tecnique. During the tensile experiment, the speckle pattern is recorded (frame rate of 0.1 picture/second) using a CCD camera equipped with a microscopic lens and adjustable light sources. In-house DIC software was used for in-plane displacement and strain determination and mapping.

For brevity only the case of loading in the tow yarn direction is considered here. Fig. 1b shows a tipical strain map obtained with the DIC technique at an applied macroscopic strain of 0.9%. The strains are small but the DIC dechnique is sensitive enough and suitable filtering reduce the noise

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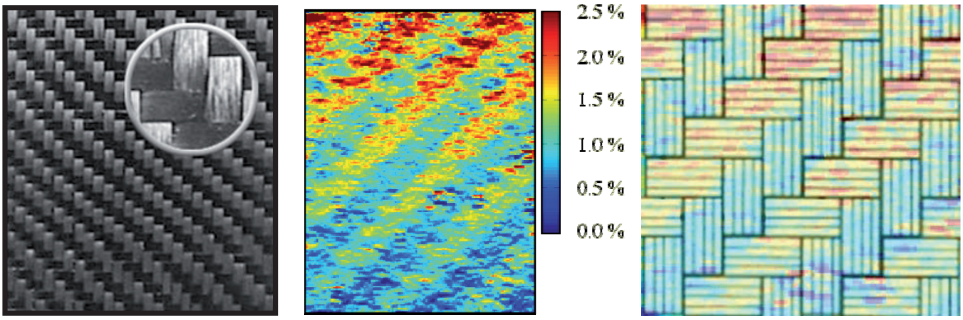
level of the strain maps. Strong local strain gradients are determined and referred to the yarn architecture in Fig. 1c.

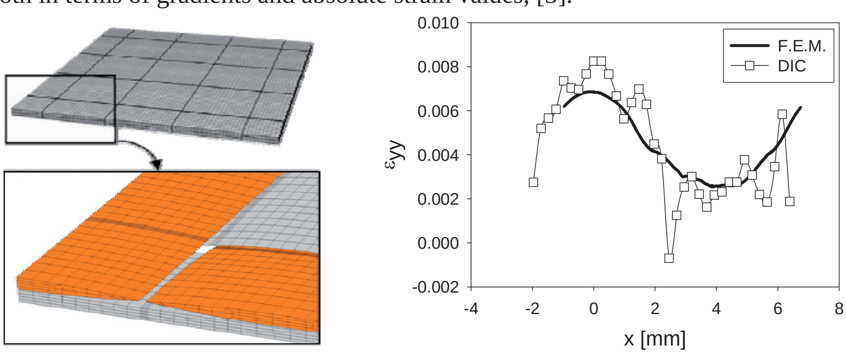


a) b) c)

Fig. 1. a) Weave architecture; b) longitudinal strain map; c). strain-to-yarn localization

The DIC measurements were validated by averaging the strain over the field of view and comparing it with the macroscopic strain given by a high-sensitivity MTS extensometer.

The mesoscopic srain data obtained with DIC are used to assess and validate parallel material model development by direct FEM vs experimental strain correlation. Fig. 2a shows the FEM model of the unit cell for the twill-weave architecture with a detail of the yarn geometry and finite element discretization. Suitable boundary conditions are applied to the UC model contours before the analysis, [1]. Fig. 2b shows and example of the comparison of the local longitudinal FEM/DIC strain distribution along a transverse line of Fig. 1c. The comparison shows the excellent correlation achieved both in terms of gradients and absolute strain values, [3].



a) b)

Fig. 2. a) FE model of unit cell; b) DIC vs. FEM strain correlation.

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