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STRAIN MEASUREMENT IN TESTS ON FIBRE FABRIC BY IMAGE CORRELATION METHOD

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ABSTRACT

Strain measurements are investigated by an image correlation method, for tensile tests, in order to analyse the non-linearities due to crimp. The interest of the method is the possibility to study the phenomena at different scales and so to contribute to a better understanding of the yarn interactions and of their influence on the fabric mechanical behaviour

1. INTRODUCTION

Fabrics are made of yarns that are intertwined in regular patterns (plain, twill, satin...) and give a flexible surface. Their stiffness is only significant in tension, in the yarn directions. They are very efficient reinforcements for thin composite structures, especially in case of double curved parts for which the unidirectional reinforcements cannot normally be used [1-2]. The knowledge of the mechanical properties of the fabrics is necessary both for stretched structure analyses and, when manufacturing composites, for the simulation of forming stages before resin injection (first stage of the R.T.M. process) [3]. Those mechanical properties are very specific because of the possible motions between the yarns and the fibres within the yarns [4-3]. In this paper, tensile tests on woven reinforcement are undertaken for fabrics used in R.T.M. composite manufacturing process. The mechanical tensile properties of the fabrics are analysed by a biaxial tensile test, in order to measure the non-linear behaviour due to the change of shape of the undulations (given by weaving) when the fabric is in tension. The strain measurement that are necessary in these tests are delicate. The classical efficient local measurements (extensometers, strain gauges) cannot be used. A local sensor easily perturbs the very weak stiffness, due to the fibrous constitution of the fabric. Some optical techniques

using digital photographs have been used for fabric biaxial tensile tests [5]. The difficulty of the procedure leads to use of a CCD camera associated to an image correlation method in the present paper. The optical measurement gives the mean value of the tensile strain over the specimen and a field of strains. It permits a check on the homogeneity of the strain field in the active part of the specimen and also analysis of local variation of the strains near the yarns.

2. EXPERIMENTAL ANALYSIS OF FIBRE FABRIC MECHANICAL BEHAVIOUR

2.1. Mechanical behaviour of fibre fabrics

Fabrics are made of woven yarns themselves composed of juxtaposed fibres. The diameter of these fibres is very small (generally 5 to 7 μm for carbon fibres and 5 to 25 μm for glass fibres). Consequently these fibres can only be submitted to a tensile stress in the fibre direction. Because they can slide relatively in case of yarn curvature, the yarn can only be submitted to a tension. The mechanical behaviour of the fabric is thus defined only by the two tensions in warp and weft direction, which depend on the two corresponding deformations. Different approaches can be used to determine the tension-strain curves. A biaxial tensile test is described in the next section. 3D numerical simulations of the elementary pattern can also be used to define these curves [6].

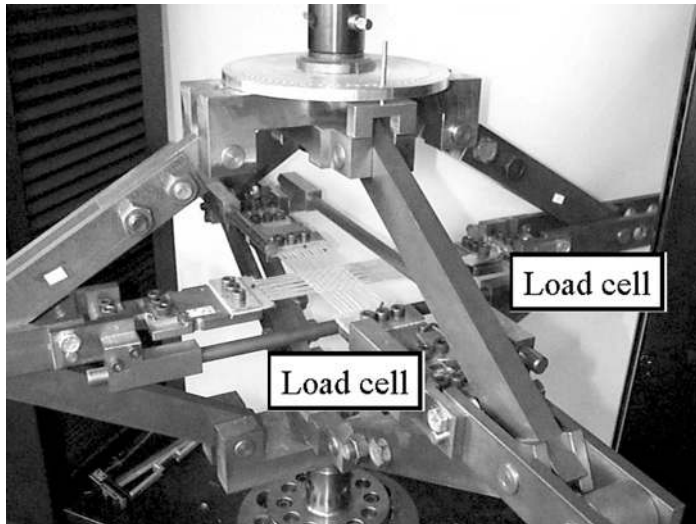


Fig. 1a.: Biaxial tensile device

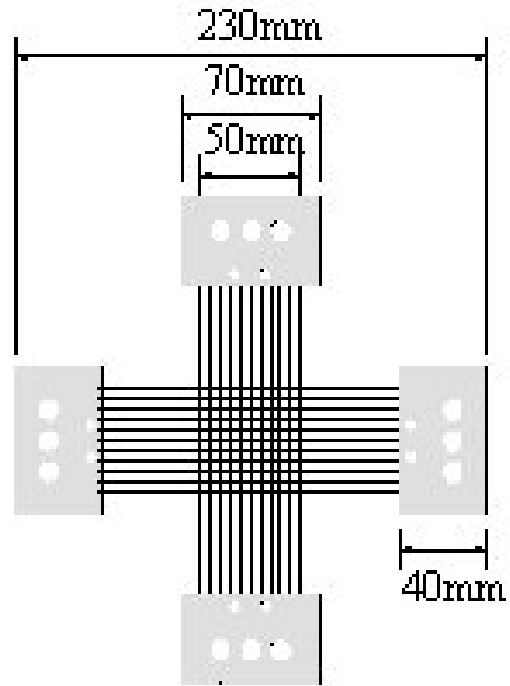


Fig. 1b : Scheme of the sample

2.2. Biaxial tensile tests

The device shown Fig. 1a is directly set on a classical traction/compression machine [8]. It works via strain ratio in warp and weft directions. This ratio can be fixed at six different values. The crosshead speed is 10 mm/mn.

For a non-deformed fabric, the yarn nets are perpendicular to each other, for traditional 2D fabrics. Nevertheless, when a fabric is deformed, the angular variations can be important especially when the fabric is formed on a double curved surface. The biaxial tensile device allows setting the angle between weft and warp yarn directions to a value different from 90°, but this variable option is not used here.

The cross shape of the sample is shown Fig. 1b. The studied part is the woven central square. The ends are not woven. The cross shape is particularly well adapted to biaxial tests on woven materials because they have no in-plane shear stiffness so the stress/strain field can be considered as homogenous at the macroscopic level in the active part of the cross shape specimen. Defining the initial state is a delicate problem. A load criterion to determine the

precise start time of the test is not adopted in this analysis because of the very low loads at the beginning of the test. A kinematical criterion is used. It rigorously marks out the beginning of the test with the instant where every yarn of each direction comes simultaneously into the mean plane of the device (before the test begins the fabric is bending under its own weight and has a bowl shape). This moment is characteristic and can be easily identified.

In order to avoid the perturbations due to friction in the mechanical device, load cells are directly set behind the specimen and give total load on the fabric specimen in each direction.

2.3. Strain measurements with mechanical extensometers

The definition of tensile curves requires the measurement of the two axial strains in warp and weft directions respectively. The lack (or the very low value) of some stiffness render very difficult or impossible the use of sensors directly placed on the fabric. Mechanical extensometers cannot be clamped directly on the fabric specimen otherwise they modify the local properties. Nevertheless, measures have been performed, by clamping the two

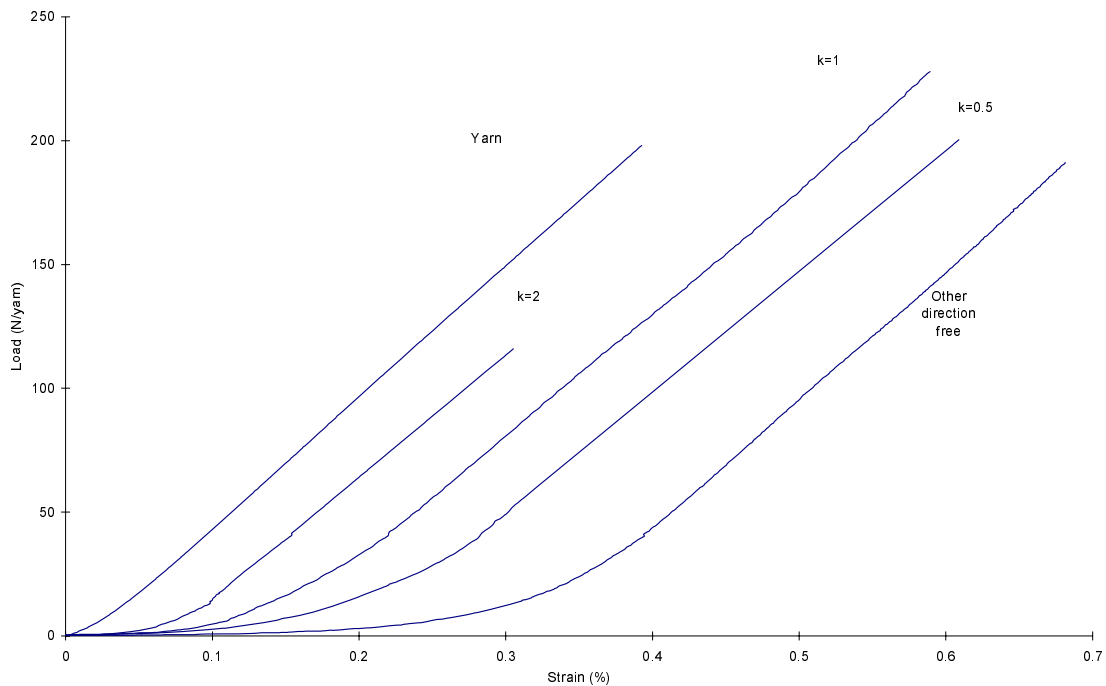


Fig. 2. Tension load versus strain for different ratio k , for 2*2 twill carbon

extensometers on the rigid extremities of the cross-shaped specimen. In order to obtain the strains in the woven part of the specimen, the stretching in the non-woven part must be subtracted. These values are obtained with a tensile test on a yarn sample. In this manner, the tensions can be obtained as function of the strains for different ratios k ($k = \text{warp strain} / \text{weft strain}$). For example, the results are given in Fig. 2 for a carbon weave. It is a 2*2 twill carbon with 0.35 untwisted yarn/mm. It can be seen that the non-linearities due to the change of shape of the yarns are important. Other biaxial tensile curves of different woven reinforcements used in R.T.M. process can be found in [9].

Even where, measurements made using extensometers are possible, they have major drawbacks:

- a) The measurements have to be post-treated, which renders the analysis more complicated. Knowledge of the non-woven part tensile stiffness is necessary and must be determined very precisely.
- b) Only a mean strain value is obtained in each direction. This does not permit either a check on the homogeneity of the strains

or determination of local strain measurements.

The optical measurements described below aim to avoid these drawbacks, and also to measure directly the strain field.

3. IMAGE CORRELATION IN TENSILE FABRIC TESTS

3.1. Strain measurement obtained with digital image correlation method

This method is based on numerical treatment of grey scale digital images representing the sample at different deformation states. Each image, obtained with a CCD camera BASSLER A113 P, has a size of 1030*1300 pixels. The first image, representing the undeformed specimen is divided into equal squares whose size can be of 4*4 to 40*40 pixels (Fig. 3). The four corners of each square are then localised on each image of the deformed sample by using a correlation method [10]. This position can be obtained with an accuracy better than 1/20 pixel. That gives the displacement field from which the Green-Lagrange strain tensor can be deduced.

No contact with the observed surface is needed.

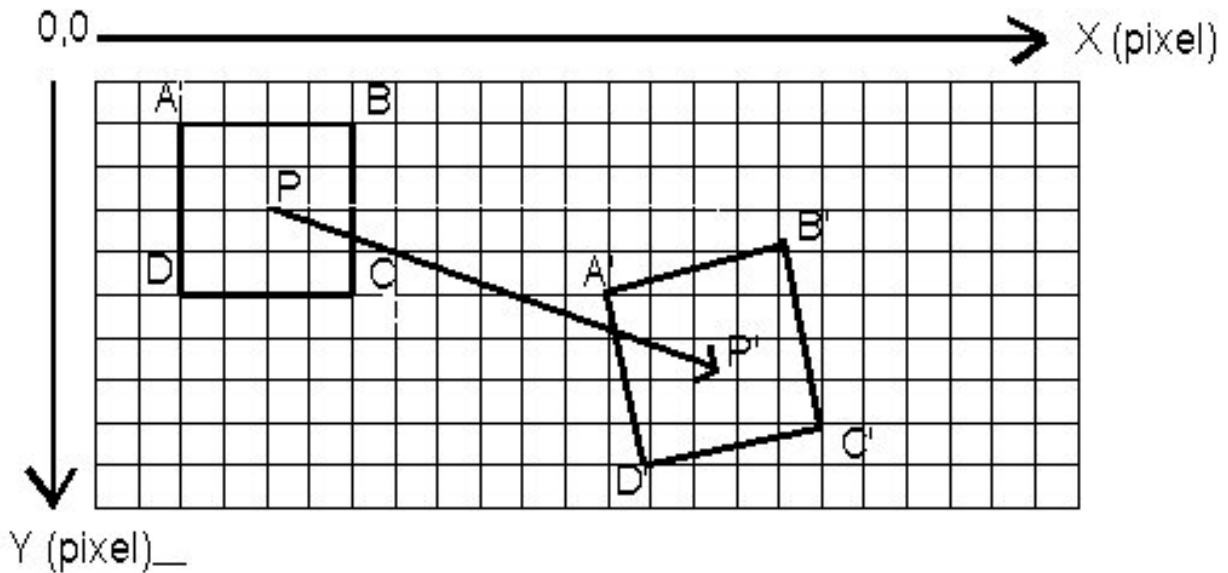


Fig. 3: Identification of the position of deformed square

The measurable strain is between 0.01% and more than 100% and thus is favourable for biaxial tests on fibre fabric.

3.2. Biaxial tensile test on fibre fabric at macroscopic level.

A biaxial tensile sample of an unbalanced glass plain weave is used for this experiment. The yarns have an approximate diameter of 1 mm (1.75 yarn/mm in the warp direction and 1.2 yarn/mm in the weft direction). The central part of the sample is a square of 50*50 mm². Paint pulverisation, with commercial products of three different colours, gives a randomised image of this square with distinct points of 0.05 to 0.1 mm diameter and a large grey scale.

The upper part of the biaxial tensile device is modified to include the camera. The lens is chosen to observe all the sample central part. The observed yarn width is then about 10 pixels. Some holes of 7*3 pixels size appear between yarns where they cross together. Their colours on the images are uniform and do not disturb the calculation.

Squares of 10*10 to 40*40 pixels can be used to calculate the displacement field. The displacement vectors on the central part of the sample are represented on Fig. 4a. Such figure gives an information on the quality of the global biaxial effect for $k=1$.

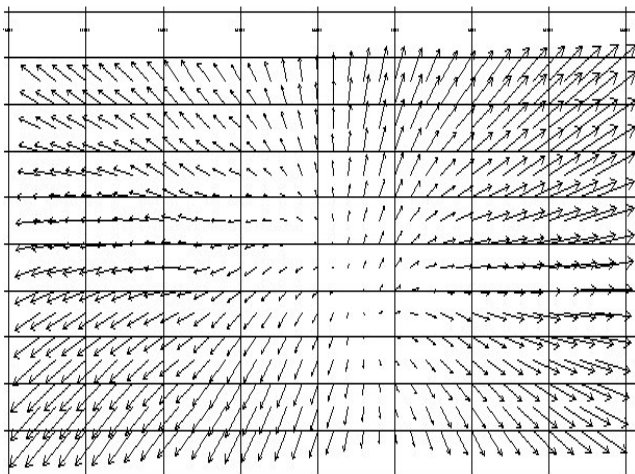


Fig. 4a: Displacement vectors

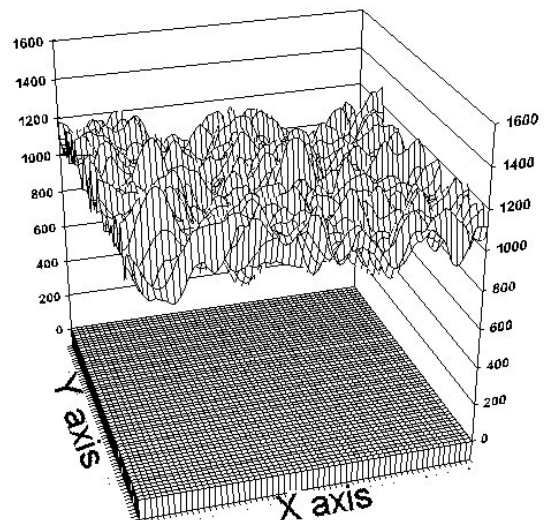


Fig. 4b: Strain surface for $\epsilon_{yy} * 10000$

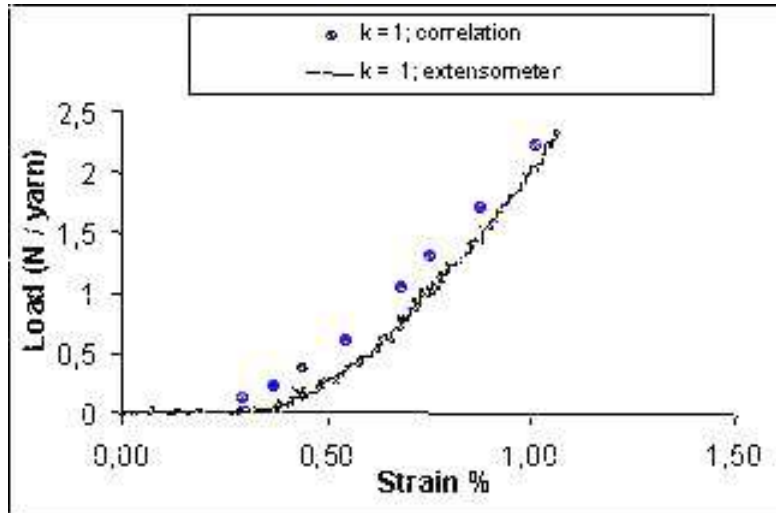


Fig. 5: Load/strain curve in the warp direction for $k=1$, obtained with the two methods.

Each strain tensor component can be plotted on a three dimensional diagram (Fig. 4b). Undulations appear in relation with the square pattern size. They are smoothed when this size increases. They relate the fabric surface topology.

From these surfaces, obtained for different loads, a mean strain value is deduced and used to draw the load/strain curves. One of these curves, presented on Fig. 5, compares the results obtained in warp direction to those coming from the extensometer measurement. The curves obtained on the same sample, but not at the same time, have a slight gap along the strain axis. The small difference comes from the post-treatment of the results when the extensometers are used.

For this application, image correlation method gives some improvements. Yarn rigidity measurement and subtraction of the strain of the non-woven part are not necessary; the accuracy can thus be increased. The image correlation results are superior to those from extensometer; they give displacement and deformation full fields, rather than a mean value of one component. That allows checking of the homogeneity of the strains in the active part of the specimen. The measurement process can also be automated to give a sufficient number of points for each load/strain curve.

3.3. Strain measurement at the yarn size

With suitable lenses, the digital image can be focused on a specific part of the sample to visualise the strain field at different levels [11]. For fibre fabric, the interaction area between weft and warp yarn has an important part to explain mechanical behaviour. On Fig. 6b, yarn size is about 150 pixels. This is sufficient to measure displacement field at the cross-over of two yarns. The case shown on this figure is a uniaxial tensile test ($k=0$) in the weft direction. Correlation calculations concern only the extracted area shown on Fig. 6b.

The Fig. 6a represents the strain component ε_{yy} on this area (y is the tensile and the weft directions), with small values in warp yarn and higher values in tensile (or weft) direction.

These examples illustrate the ability of the image correlation method to contribute to the knowledge of the fibre fabric behaviour at different levels. It can easily replace extensometers to obtain load/strain curves, and associated with a 3D finite elements simulation of mechanical tests [6] could contribute to enhance the behaviour model of woven fibre fabrics.

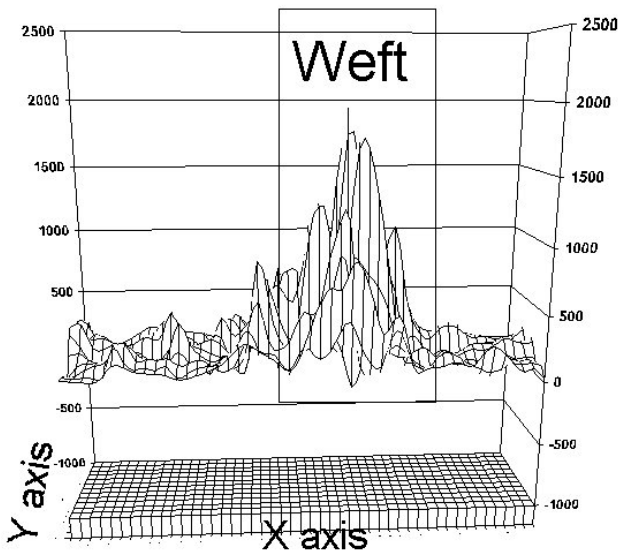


Fig. 6a: Strain component ($\epsilon_{yy} * 10000$)

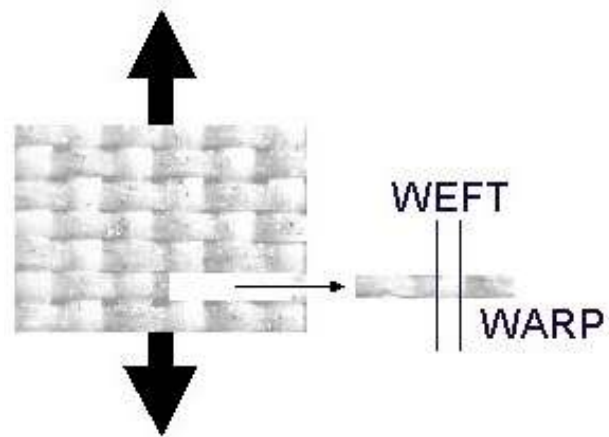


Fig. 6b: Analysed area on the tensile glass specimen

5. CONCLUSIONS

Image correlation method gives some benefits relative to extensometers, to study the behaviour of fibre fabric. It can be adapted to the classical mechanical tests.

- a) Samples are rapidly and easily prepared.
- b) It needs no contact with the sample.
- c) Results give a full field of displacement and strains.
- d) Results can be obtained at multilevel.

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