BENDING TEST OF COMPOSITE REINFORCEMENTS

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January 11, 2008

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ABSTRACT: In shaping of composite reinforcements, tensile stresses are the major stresses, while in plane shear strains are the major strains. However the knowledge of the bending behaviour would give more precisely simulation of forming especially for stiffer and thicker textiles. Two standard tests are used to determine it. The cantilever test is limited because of its elastic linear model. The KES fabric bending test allows a more complicated model but its use is difficult for stiff and thick reinforcements. A new cantilever test using optical measurement has been developed to provide the searched flexibility. Tests have been performed on a carbon woven reinforcement and compared with KES measurements. The results allow to validate the experimentation.

KEYWORDS: Fabrics, Forming simulation, Bending behaviour, Experimental characterization.

1 INTRODUCTION

Modeling and simulation of composite reinforcement forming have now become important to predict first the feasability of the process and second the mechanical behaviour of the finished part. In textile shaping, tensile stresses are the major stresses, while in plane shear strains are the major strains [1]. However the knowledge of the bending behaviour would give more accurate simulation of forming especially for stiff and thick fabrics. Moreover Wang et al [2] demonstrated the relative importance of bending behaviour during composites forming by comparing bending and shear energies in case of viscous composites. The study of the reinforcement bending behaviour for the simulation comes to define the relationship between the moment M and the curvature κ of a bent beam, plate or shell depending on the complexity of the model. Two standard tests are usually used to characterize the bending behaviour. The first current cantilever test is based on an elastic linear model and its commercial equivalent is made up of a tilted plane making a fixed angle enabling to calculate the constant bending rigidity. The second, the KES-FB tester, enables to quantify bending properties for more complicated models but its use is inadequate if not impossible for stiff and thick reinforcements. A new cantilever test using optical measurements has been developed to test stiff and thick reinforcements. The sample can be a yarn, a monopoly or multiply reinforcement and it is placed uppon lathes which will successively retract during the test. The test can be stopped for a chosen overhang length and continued for new lengths. Thus, the complete test is a succession of quasi-static tests with different loading cases. A digital camera enables to take a picture at each stop length and the images are processed to extract the shapes of the bent sample. Two approaches can be considered to determine the bending behaviour from the shape of the specimen. The first, the direct method, is based on the computation of the moment and the curvature along the sample and the drawing of the moment-curvature curve. A model can then be determined from the curve by fitting. The second approach is based on an inverse method. The test is then simulated with finite element method and based on a postulated model. An optimization algorithm enables to determine the model parameters.

2 BENDING MODELS AND STANDARD TESTS

2.1 *Bending models*

The study of the bending behaviour of the reinforcement for the simulation comes to define the relationship between the moment M and the curvature κ of a bent beam, plate or shell depending on the complexity of the model. The bending behaviour of a reinforcement is a multiscale hierarchical problem. At microscopic scale, the yarn is constitued with fibers which interact with the others and the bending ridiity of the yarn is not the sum of the bending rigidity of the fibers. Relationship between fabric behaviour, structural configuration and mechanical behaviour of yarns and their constituent fibres is complex and a critical review has been wrote by Ghosh et al in [3]. At mesoscopic scale, the bibliography provides several analytical models for plain-woven fabrics taking into account the yarn section at crossover, the shape of the yarn, the contact condition at thread crossover, the set of yarn... More recently, Yu et al [4] considered that bending rigidity is dependent on the in-plane stiffness and proposed a non-orthogonal model based on asymmetric axial modulus defining bilinear behaviour over the range of tension to compression. At macroscopic scale, the most classical model is the linear elastic Peirce's model used with his bending test. The other classical model is the Grosberg's model used with the KES bending test. Past the non-linear region, the moment per unit length M is expressed by :

$$M = M_0 + B_f \kappa \quad if \kappa \geq M_0/B_f \tag{1}$$

where M_0 is the frictional restraint force (moment per unit width) and B_f is the flexural rigidity per unit width.

2.2 *Standard bending tests*

Peirce was the first to present a macroscopic measurement of the bending behaviour [5]. Assuming an elastic linear behaviour between the bending moment and the curvature of the strip, he proposed a cantilever test (fig. 1) to determine the bending stiffness. In this test the fabric is cantilevered under gravity.

In this model, bending moment M is a linear function of the curvature κ:

$$M = G \times b \times \kappa \tag{2}$$

where G is the flexural rigidity per unit width and b is the width of the strip. Peirce defined the ratio S of the flexural rigidity to the weigth w per unit length:

$$S = G/w \tag{3}$$

Assuming the fabric being an elastic with small strains but large deflections, he defined the relation between the ratio S, the angle θ of the chord with the horizontal axis and the length L of the bent part of the sample (fig. 1)

$$S = \frac{l^3}{8} \cdot \frac{\cos\theta/2}{\tan\theta} \tag{4}$$

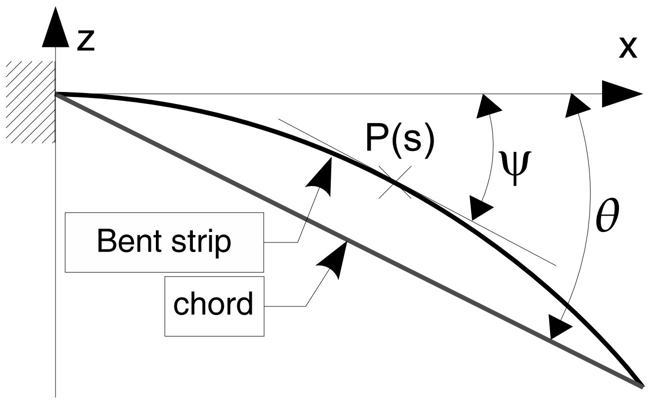

Figure 1: Peirce's test

Computing the cubic root of S gives a like a length parameter, the bending length, which allows to compare the fabrics. The commercial apparatus is made up of a tilted plane making an angle $\theta = 41.5\,°$. With this value, the formula becomes simpler :

$$S \approx l^3/8 \tag{5}$$

This configuration is described in standard tests [6, 7]. KES-FB tester is the test for quantifying bending property in pure bending deformation mode and enables then to record directly the evolution of the bending momentum per unit width with the curvature on a X-Y recorder unit during a load unload cycle. The bending rigidity and the bending hysteresis of Grosberb's model are also computed.

The dimension of the sample in the bending direction is equal to $1\,cm$ and its length is $20\,cm$ for flexible fabrics. It is clamped between a fixed and a moving clamps. The fixture setting of the sample in the clamps ensures pure bending deformation. During the test, the moving clamp rotates around the fixed ensuring a constant curvature through the sample length. The movement is made with a constant rate of curvature equal to $0.5\,cm^{-1}s^{-1}$ from $-2.5\,cm^{-1}$ to $2.5\,cm^{-1}$. The apparatus was developed for flexible textiles and testing stiff and thick reinforcements leads to reduce the length or can become impossible to perform.

3 NEW FLEXOMETER

3.1 General working

The new flexometer comprises two modulus: a mechanical modulus and an optical modulus. The mechanical modulus enables to place the sample in cantilever configuration under its own weigth and possibly with additional mass. The optical modulus enables to capture the shape of the bent sample. The sample can be a yarn, a monoply or multiply reinforcement. It has a length about 300 mm and a width to 150 mm. The thickness can reach several millimeters. At the begining of the test, the sample is placed uppon a special plane (fig. 2) comprising lathes. A translucent plate is fixed uppon the both to ensure the embedding condition. Thus the sample will not slid.

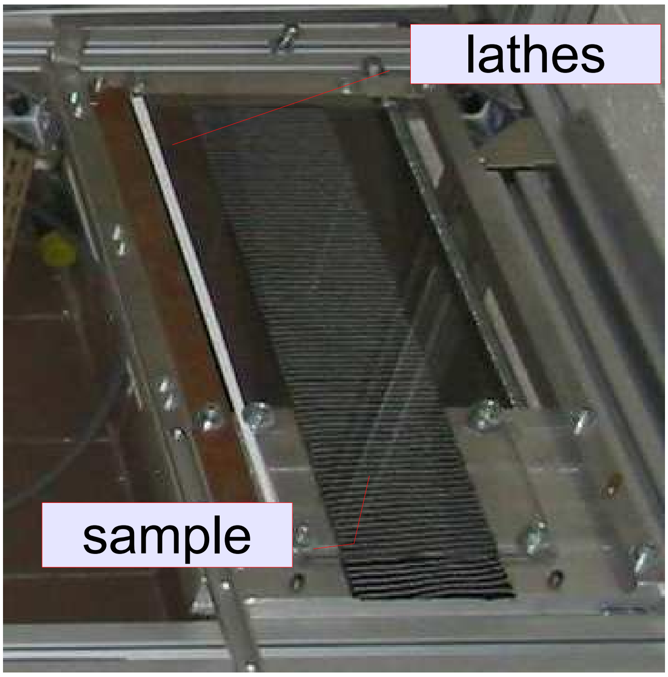

Figure 2: Flexometer

During the test, the lathes will successively retract and the length of overhang will increase. The test is stopped for a chosen overhang length and continued for new lengths. Thus, the complete test is a succession of quasi-static tests with different loading cases. While single cantilever test provides only one configuration, the new flexometer with its set of loading cases will enable to construct a non linear behaviour model because it provides different bent shapes with differents loading cases. A digital camera takes a picture at each stop length and the images are processed to extract the shapes of the bent sample. The following step is to extract the mean profil. Two approaches can be considered to determine the bending behaviour from the shape of the specimen. The first, the direct method, is based on the computation of the moment and the curvature along the sample and the drawing of the moment-curvature curve. A model can then be determined from the curve by fitting. The second approach is based on an inverse method. The test is then simulated with finite element method and based on a postulated model. An optimization algorithm enables to determine the model parameters.

3.2 Direct method

In this approach, the shape of the bent sample is defined by a set of XY data points and the bending moment and the curvature have to be computed along the sample. Because the shape is represented by a set of noisy data points it is not easy to compute directly the moment and the curvature and it is necessary to smooth the measured coordinates data using functions. A global polynom of exponential functions has been chosen to fit the set of points. A first order polynom is added to ensure the boundary conditions.

$$z(x) = \sum_{i=1}^{n} p_i e^{i*K*x} + k_1 x + k_0 \qquad (6)$$

With K an amplification factor to fit accuratly the points.

The degree n of the exponential polynom is defined to optimize the parameters with the least square criterium.

For a current point, P, (fig. 3) with (X_P, Z_P) coordinates, its curvilinear coordinate is given by :

$$s = \int_{x_0}^{x_P} \sqrt{1 + z'^2} du \qquad (7)$$

and the bending moment can be computed as :

$$M(P) = w \int_{s}^{L} (u - s) cos(\varphi) du \qquad (8)$$

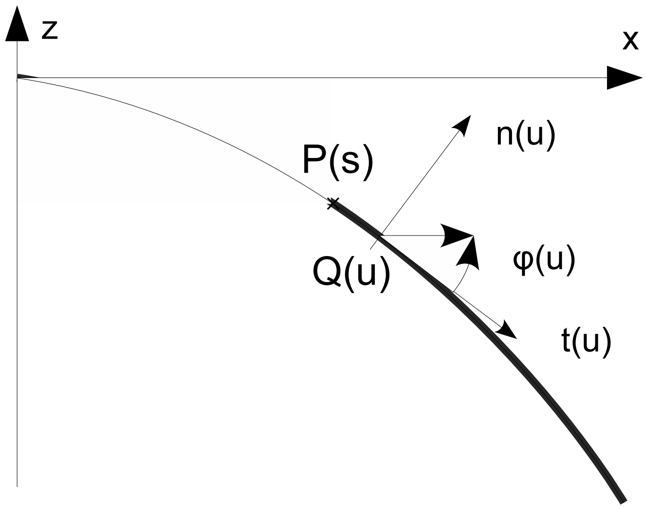

Figure 3: Moment computing

For each length of bending test, moment-curvature graph can be drawn. If the set of graphs are superposed, the behaviour is elastic and the moment-curvature graph for the greater length enables to define a bending model. If not, for each length of bending test, the moment and the curvature computed at embedding point enable to draw a point on the moment-curvature load graph.

3.3 Test and validation

Tests have been performed on a 2.5D carbon woven reinforcement and compared with KES results (fig. 4). The sample is 0.62 mm thick and its weigth is 630 g/m^2. For the flexometer it was 50 mm width and 300 mm long.

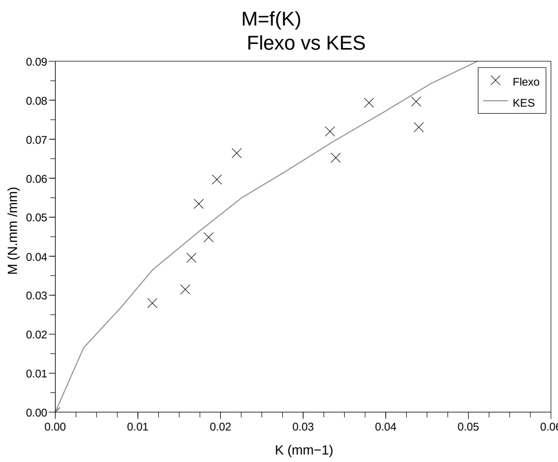

Figure 4: Flexometer results vs KES

For the KES-FB, it has been reduced to 30 mm width. KES tests have been performed at ENSISA of Mulhouse. One can notice a good correlation between both tests. This comparison allows to validate the flexometer.

4 CONCLUSIONS

The fabric bending behaviour is a complex multiscale mechanical problem and it is not possible to predict accuratly the bending behaviour from only the yarns properties with the present analytical models . At macroscopic scale bending behaviour is described by the constitutive moment curvature relationship which is not linear . Because standard bending tests for fabrics are not adequate, a new cantilever test has been disigned. Tests performed on a carbon woven reinforcement have allowed to validate this new test and the direct method. Therefore, the direct method doesn't able to define unload behaviour because of the difficulty to compute with good accurate the low curvatures. Thereby the second approach based on an inverse method will be investigated in the next step.

ACKNOWLEDGEMENT

All our thanks to Laurence Schacher of the Laboratoire de Physique et Mécanique Textiles de Mulhouse (ENSISA) to have allowed us to perform the KES bending tests.

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