Journal of Engineering and Applied Sciences 12 (17): 4344-4348, 2017
ISSN: 1816-949X

Comparison of Horizontal and Vertical Cantilever Tests for the Characterization of Bending Behavior in Woven Fabric Prepregs

Hassan Alshahrani and Mehdi Hojjati
Department of Mechanical and Industrial Engineering, Concordia Center for Composites,
Concordia University, 1455 De Maisonneuve W, Montreal, Quebec, H3G1M8, Canada

Abstract: The success or failure of composite formation is determined by the properties of a material that predominate deformation during the process. Wrinkling is caused by out-of-plane deformation due to compressive loading in the plane of the material during the forming process. Consequently, capturing the out-of-plane properties using a suitable experimental method is required with the ultimate aim of predicting and optimizing forming processes. A comparison between two test methods to characterize the bending behavior of woven fabric prepreg was presented. Results show that the vertical cantilever test offers a good control of the deflection shape and reproducible results. On the contrary, the sample twisting was observed during the horizontal test as the sample is bent under its own weight.

Key words: Cantilever bending test, woven fabric prepreg, composite forming, out-of-plane deformation, own weight, comparison

INTRODUCTION

Conventional composite manufacturing techniques such as hand lay-up are labor intensive, time consuming and costly. Sheet forming through automated technologies can be used as an alternative process to conventional methods to reduce the manufacturing time and cost. The ability of the material systems to bend is one of the key deformation mechanisms that allow the forming process to produce complex shapes without flaws (such as wrinkles) (Alshahrani and Hojjati, 2016).

Thus, both the material characteristics of uncured composites and the parameters that influence bending stiffness must be better understood. Whereas continuous materials (such as sheet metals and composite plates with hardened matrix) show a relatively high bending stiffness, prepreg sheets are inherently much more flexible. This poses a problem during the characterization of bending behavior where no standard test for such materials is available. However, some test methods were proposed in the literature to determine out of plane bending properties of dry reinforcement and prepreg composites.

Most of setups that proposed for characterization of bending behavior are adapted from the cantilever test developed by Peirce (1930). In Peirce's setup, a rectangular strip of fabric on a horizontal platform being pushed slowly forward to project as a cantilever horizontally until the tip of the cantilever touches an inclined plane. Assuming an elastic linear behavior between the bending moment and the curvature of the strip, the bending stiffness can be calculated. Today, the standard cantilever test is defined with a specific value of an inclined angle equal to 41.5°.

This linear elastic assumption restricts such method to be applied to pre-impregnated composites. A modified of cantilever test that consists of a succession of quasi-static tests with different load cases was proposed by Bilbao *et al.* (2010). The test device is constituted by two parts: a mechanical part and an optical part. The mechanical part enables to place the sample in cantilever configuration under its own weight while the optical part takes pictures of the bent shapes by a digital camera.

Soteropoulos *et al.* (2011) designed a test in which samples are hung vertically and thus aligned with gravity. In their setup, the load was applied by attaching masses to a string tied to the tip of the sample. A digital camera was then used to capture the relative displacement of the sample under each load. Next, the digital image was graphically processed to generate data points along the sample length. To date this method has not been tested with thermoset prepreg materials.

Margossian *et al.* (2015) proposed a new approach that uses a Dynamic Mechanical Analysis (DMA) system to assess different test fixtures at a range of temperatures

Corresponding Author: Hassan Alshahrani, Department of Mechanical and Industrial Engineering, Concordia Center for Composites, Concordia University, 1455 De Maisonneuve W, Montreal, Quebec, H3G1M8, Canada

and speeds. However, due to a failure to record the deflections with the DMA system, the curvature was calculated using the Euler-Bernoulli theory. In addition, the researchers concluded that machine acceleration makes it difficult to apply a specific test speed. For a comprehensive review of bending tests towards prepreg composites, the reader is referred to Margossian *et al*. (2015), Alshahrani and Hojjati (2016).

The aim of this study is to evaluate the bending behavior of woven fabric prepregs under horizontal and vertical cantilever bending tests. A comparison between the test methods in terms of applied load and a potential for applying the processing conditions is discussed.

MATERIALS AND METHODS

The material tested in this study was the 5-Harness (5HS) satin carbon/epoxy woven-fiber prepreg, toughened with epoxy resin (Cycom 5320) designed for out-of-autoclave manufacturing applications. The fabric's areal weight is 380 g/m^2 and the resin content is 36% by weight. The measured thickness of uncured one-ply is approximately 0.52 mm. The sample dimensions used in both test methods are shown in Fig. 1. Using the Out-of-Autoclave prepregs (OOA) in the forming processes provide a great cost savings opportunity for the aerospace industry by allowing the use of low-cost tooling due to the lower cure temperatures.

Horizontal cantilever test: The sample was clamped by a metallic support and a table was used to hold the sample on a horizontal platform. Then, the table was moved slowly to let the sample to bend under its own weight as shown in Fig. 2. Images of the bent shape, captured by a digital camera were processed in ImageJ Software to extract the deflection profile and then calculate the curvature using Eq. 1:

$$K = \frac{y''}{\left(1+y'^2\right)^{3/2}} \qquad (1)$$

The moment was calculated based on principle of nonlinear beam deformation for flexible cantilever beam (Fertis, 2006) (Fig. 3):

$$M = W_0 \times x_0 \times \frac{x}{2} \qquad (2)$$

where, x_0 is the arc length of deformed segment and can be calculated by:

$$x_0 = \int_0^x \sqrt{1+y'^2}\, dx \qquad (3)$$

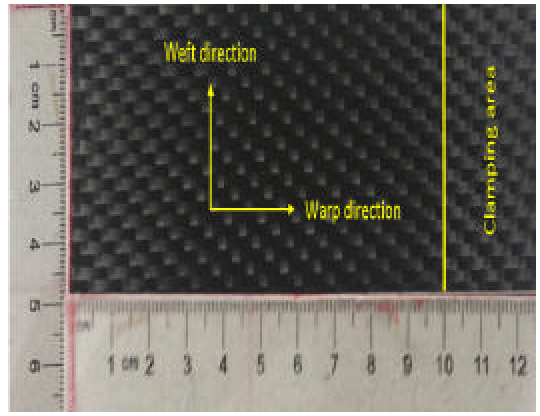

Fig. 1: Sample tested in horizontal and vertical cantilever tests

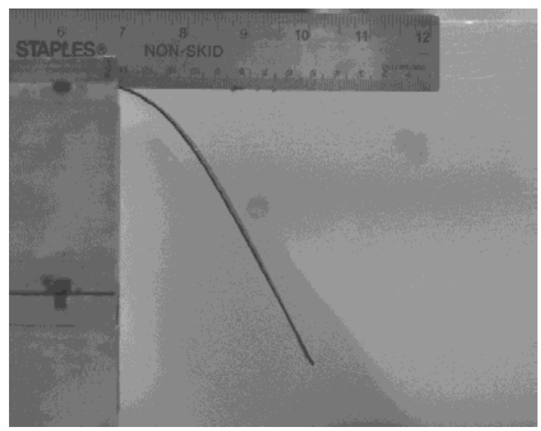

Fig. 2: Horizontal cantilever test setup

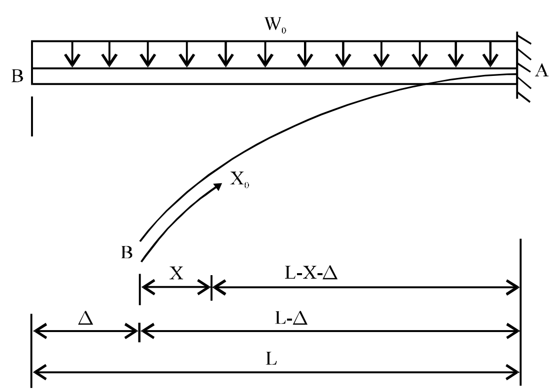

Fig. 3: Principle of flexible cantilever beam deformation (Fertis, 2006)

Simpson's rule which is one of the most commonly used numerical method was performed to approximate the above integration.

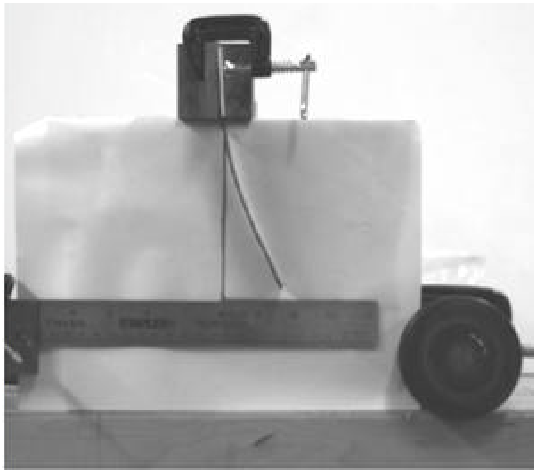

Fig. 4: Vertical cantilever test setup

Vertical cantilever test: In this setup, the sample was clamped vertically using custom grips and applying a horizontal force to achieve a certain tip displacement as shown in Fig. 4. The same procedure that used in horizontal test was applied herein to extract the bent shape and curvature calculation. However, the moment was calculated based on the cantilever beam with a concentrated load at the free end using Eq. 4:

$$M = P(L-y) \quad (4)$$

Where:

P = Applied load (mg)

L = The sample length

RESULTS AND DISCUSSION

Horizontal test results: The captured image was processed to generate data point along the sample length and extracting the bent profile as shown in Fig. 5. The polynomial fit was used in order to calculate the curvature according to equation. The bending moment was calculated based on equation and plotted against curvature in Fig. 6. The relationship between the moment and the curvature was nonlinear due to high order polynomial functions. Therefore, obtaining the bending stiffness might not be accurate. However, the analysis of bending behavior during composite forming requires high deflection to accurately simulate the process. In the horizontal test, the higher deflection can be obtained but cannot be controlled because the sample is bent under own weight. Thus, higher and controlled deflection is preferred during the analysis of bending behavior of such materials.

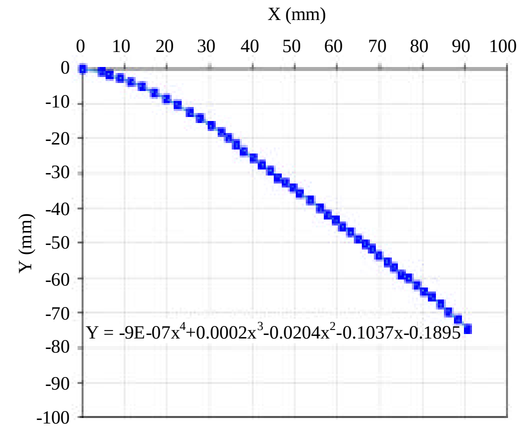

Fig. 5: Profile of the bent sample during horizontal test

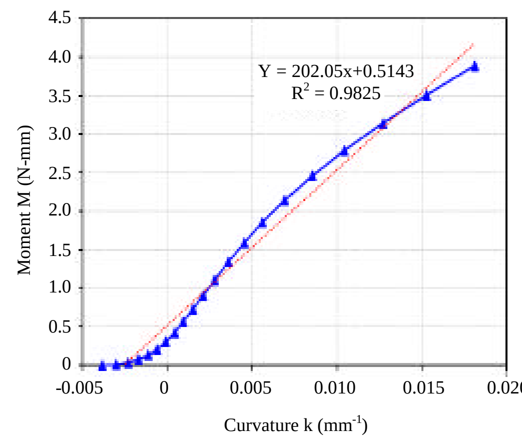

Fig. 6: The moment versus curvature with linear fit

Twisting in the sample during the test was frequently observed due to nonlinear loading effects (Fig. 7). This may create a problem for extracting the bending shape and obtaining acceptable results. It should be noted that the twisting strongly increases when the sample's length becomes large (ASTM, 2012).

In order to confirm the repeatability of the results, three tests were made as shown in Fig. 8. The results indicate that getting reproducible data during the horizontal test is more difficult. Moreover, obtaining a uniform temperature field in the sample before bending is more complicated.

Vertical test results: The bent shape of the sample up to a tip displacement of 40 mm was demonstrated in Fig. 9. The same procedure was followed to extract the data points along the sample length. The load required to achieve this displacement was recorded in order to calculate the bending moment using Eq. 4. In this test, the deflection shape can be controlled by selecting the

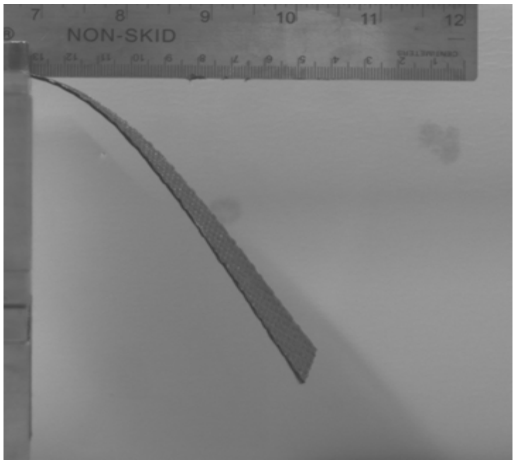

Fig. 7: Observed sample's twisting during horizontal test

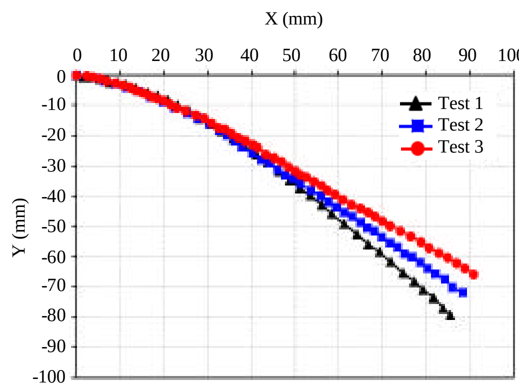

Fig. 8: Repeatability of the tests

desired tip displacement. Figure 10 shows a relatively linear trend between the bending moment and the curvature. Therefore, the value of bending stiffness (slope of this linear trend) is more reasonable compared to the horizontal test. Note that using a second derivative to calculate the curvature leads to increase the bending stiffness value. As long as the sample is under large deformation produced by bending, Eq. 4 must be used to calculate the curvature.

One issue with this test, the load applied to reach higher tip displacement creates an angle between the direction of applied load (string) and the horizontal line. However this angle is relatively small (3-4°) and assuming the load remains horizontal during the analysis is still valid. Incorporating this angle during the moment calculation is deferred to future work in order to obtain an accurate result.

Three different test trials was performed to see the repeatability of the recorded load to achieve the same tip

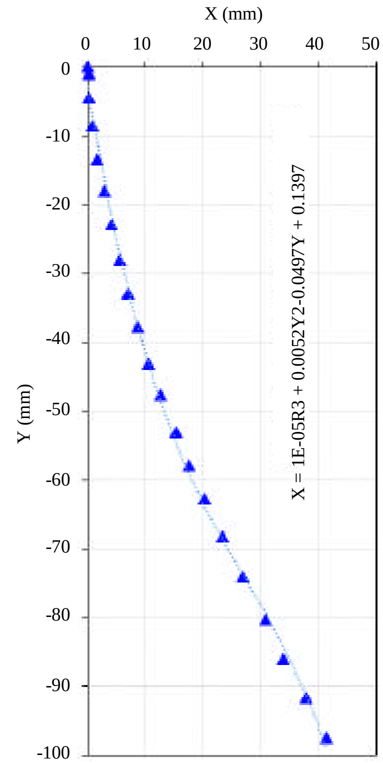

Fig. 9: Profile of the bent sample during vertical test

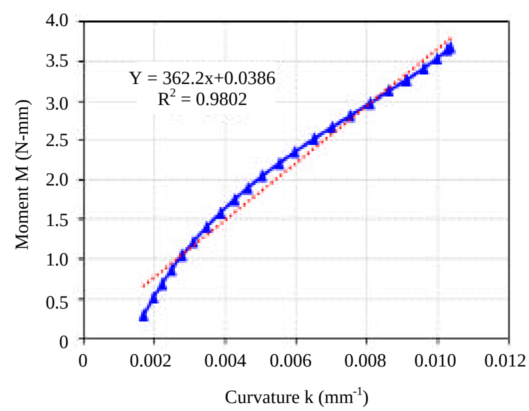

Fig. 10: The moment versus curvature with linear fit

displacement (40 mm) as illustrated in Fig. 11. A slight difference was seen between the three tests. However, the load used in moment calculation was the average of these three values. Also, the error percentage can be further deceased by replacing manual measurement with a more accurate load-measuring technique. From above analysis and results the vertical cantilever bending test is more reliable test for prepreg materials. In addition to that uniform temperature destitutions during the vertical test can be obtained due to that the sample is clamped vertically.

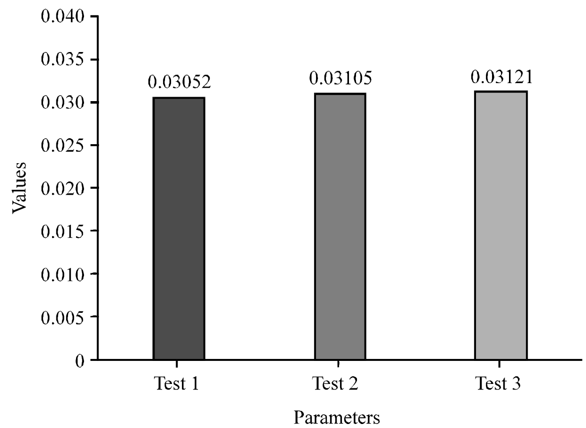

Fig. 11: Repeatability of the load required during vertical test

CONCLUSION

The study presents a comparison between the horizontal and vertical cantilever bending tests to characterize the bending behavior of prepreg composites. Twisting in the sample during the horizontal test was frequently observed due to nonlinear loading effects. This may create a problem for extracting the bending shape and obtaining acceptable results. The vertical bending test provides sufficient control of the deflection shape and repeatable test results. Moreover, uniform temperature distributions during the vertical test can be obtained. Therefore, the vertical bending test is a promising test method to characterize the bending behavior of prepreg composites and other soft materials.

ACKNOWLEDGEMENTS

Researchers of this study would like to acknowledge the financial support of NSERC (Natural Sciences and Engineering Research Council of Canada). Supporting provided by Najran University is also gratefully acknowledged.

REFERENCES

ASTM., 2012. D1388-08: Standard test method for stiffness of fabric. ASTM International, West Conshohocken, Pennsylvania, USA.

Alshahrani, H.A. and M.H. Hojjati, 2016. Out-of-Plane bending properties of out-of-autoclave thermosetting prepregs during forming processes. World Acad. Sci. Eng. Technol. Intl. J. Chem. Mol. Nucl. Mater. Metall. Eng., 10: 215-218.

Bilbao, E.D., D. Soulat, G. Hivet and A. Gasser, 2010. Experimental study of bending behaviour of reinforcements. Exp. Mech., 50: 333-351.

Fertis, D.G., 2006. Nonlinear Structural Engineering. Springer, Berlin, Germany, ISBN:978-3-540-32976-3,.

Margossian, A., S. Bel and R. Hinterhoelzl, 2015. Bending characterisation of a molten unidirectional carbon fibre reinforced thermoplastic composite using a dynamic mechanical analysis system. Compos. Part A. Appl. Sci. Manuf., 77: 154-163.

Pierce, F.T., 1930. Handle of cloth as a measurable quantity. J. Textile Inst., 21: T377-T416.

Soteropoulos, D., K. Fetfatsidis, J.A. Sherwood and J. Langworthy, 2011. Digital method of analyzing the bending stiffness of non-crimp fabrics. AIP. Conf. Proc., 1353: 913-917.