THE DETERMINATION OF YOUNG MODULUS FOR CFRP USING THREE POINT BENDING TESTS AT DIFFERENT SPAN LENGTHS

Irina PETRESCU[1], Cristina MOHORA[2], Constantin ISPAS[3]

În cadrul lucrării s-a determinat modulul lui Young pentru trei epruvete având lungimi de rezemare diferite în vederea creşterii preciziei valorii determinate. Materialele din care sunt realizate epruvetele utilizate sunt compozite laminate armate cu fibre din carbon orientate unidirecţional produse la Cytec Engineered Materials şi testate pe o maşină Instron 3367 cu ajutorul metodei de încovoiere în trei puncte. Pentru determinarea modulului de elasticitate tangential s-a utilizat porţiunea iniţială cu caracter liniar a curbei caracteristice a materialului.

The aim of this work was to determine the value of Young's modulus for three specimens at different span lengths in order to have a more accurate value. The specimens used are laminated composite carbon fiber oriented unidirectional made by the Cytec Engineered Materials and tested on an Instron 3367 using the three-point bending method. The tangent modulus of elasticity is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve.

Keywords: Young's Modulus, three-point bending test, carbon fiber, unidirectional composite.

1. Introduction

In the last three decades the composites based on unidirectional continuous fiber-reinforced laminates, together with the composites reinforced by short fibers or particulates, have been thoroughly studied and successfully applied in many fields of industry, including construction, transportation and manufacturing. [1] Prediction of the Young's modulus of composite materials has been the subject of extensive research over the last 40 years.

Carbon fiber reinforced plastics (CFRP) are used on a large scale in aeronautical industry due to their advantages [2]. In the same time, CFRP can present degradations during their use, as delamination due to some impacts even

[1] Eng. PhD. Student, Machines and Manufacturing Systems Department, University POLITEHNICA of Bucharest, Bucharest, Romania, e-mail: irina_petresscu@yahoo.com
[2] Prof., Machines and Manufacturing Systems Department, University POLITEHNICA of Bucharest, Bucharest, Romania, e-mail: cristinamohora@yahoo.com
[3] Prof., Machines and Manufacturing Systems Department, University POLITEHNICA of Bucharest, Bucharest, Romania, e-mail: ispas1002000@yahoo.fr

with low energies, accompanied or not by fibers breaking, local overheating, water adsorption, the last two causes leading to the deterioration of the matrix.

In a composite material, the matrix is designed to protect the dispersed phase in the environment action (corrosion and oxidation), transfer stresses and redistribute the efforts between fibers. For transfer load to be optimized and limited movements, the matrix must adhere sufficiently to the reinforcement element. In most cases, the matrix stiffness and mechanical strength are lower than the reinforcement material those of [3].

Young's modulus is one of the important characteristic specific to solid materials. For polymer composites, the factors affecting the Young's modulus are complicated, such as the nature of the matrix and filler, the compatibility between them, materials processing technology and conditions, the dispersion or distribution of the filler in the matrix, as well as the interfacial structure and morphology, and so on [4,5,6].

Prediction of the Young's modulus of composite materials has been the subject of extensive research over the last 40 years. For more detailed information about the available theories and approaches the reader is referred to review articles which treat the theme comprehensively, notably the review by Hashin, which contains a discussion of the most relevant approaches and theories [7].

Bending tests are used for determining mechanical properties of unidirectional composite materials. Due to the important influence of shear effects in the displacements, great span-to-depth ratios are used in order to eliminate these effects. Three-point and four-point test configurations are used in order to obtain flexural strength and flexural modulus [8].

Grimberg R. et al. [9] propose a nondestructive control method with ultrasound Lamb wave spectroscopy. The Lamb waves are generated using Hertzian contact which presents two important advantages: the coupling fluid between the transducer and the surface to be controlled is not required and the Hertzian contact behaves practically like a Lamb wave's punctual transducer, fact that assures a relatively simple modeling of the phenomena.

2. Experimental

Numerous investigations have been made in finding suitable methods for measuring test flexural properties. Standardization institutions such as the American Society for Testing and Materials (ASTM), European Structural Integrity Society (ESIS) and Japanese Industry Standards (JIS) have proposed the three point bending test as method used in the current study. The tests described in this article try to be consistent with the requirements of standards, in terms of sampling and test specimens, procedure and post-processing.

These test methods cover the determination of flexural properties of reinforced polymer, including high- modulus composites in the form of rectangular bars molded directly or cut from sheets, plates, or molded shapes. These test methods are generally applicable to both rigid and semi rigid materials. However, flexural strength cannot be determined for those materials that do not break or that do not fail in the outer surface of the test specimen within the 5.0 % strain limit of these test methods. These test methods utilize a three-point loading system applied to a simply supported beam [10].

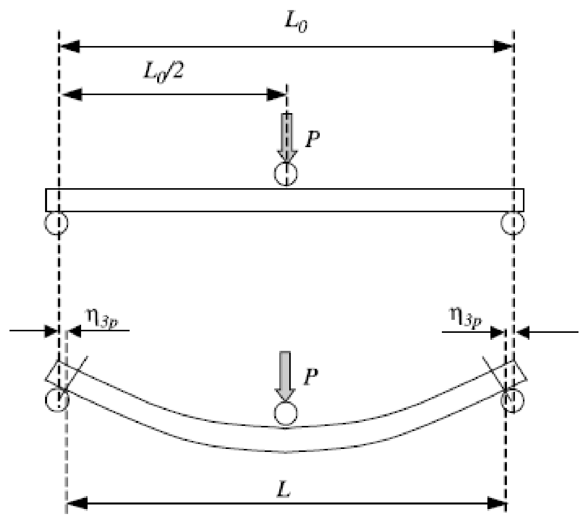

Fig. 1. Undeformed and deformed three-point bending test configuration.

Flexural properties can only be used for engineering design purposes for materials with linear stress/strain behaviour. For non-linear behaviour, the flexural properties are only nominal. The bending test should preferentially be used with brittle materials, for which tensile tests are difficult [11].

The present experiment was conducted at the doctoral stage in Universita degli Studi di Palermo, Facolta di Ingegneria, Viale delle Scienza, Edificio 8, Dipartamento di Meccanica, Palermo, Italy.

A test machine Instron 3367 (see Fig. 2) with electric drive was used to test the specimens. The machine has Instron BlueHill software.

The material is a CFRP composite made at the Cytec Engineered Materials having the product code with APC-2/IM7, a poly (ether ether) ketone, best known as the PEEK as the thermoplastic matrix.

Fig.2. Test bench used in the three-point bending tests.

The experimental test was performed using a uniform rectangular bar horizontally positioned on two supports. The specimens were subjected to a vertical force applied midway between the supports (see Fig. 3).

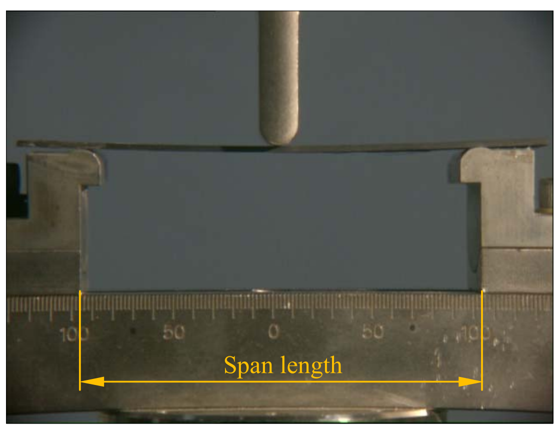

Fig.3. The specimen position on the test machine.

Table 1 shows the dimensions of three specimens named I1, I2 and I3. The samples width and thickness are approximately equal. For each of the three samples three measurements were performed in order to emphasize the repeatability of results. Since the results for each specimen are practically identical only one of them will be presented in this paper.

Table 1

Dimensions of specimen

	I1	I2	I3
Width [mm]	19,75	19,75	19,75
Thickness[mm]	1,52	1,54	1,54
Length [mm]	120	120	80

3. Results and discussion

The determination of Young's modulus was achieved with an Instron 3367 testing machine using the three-point bending test. With the data obtained from the experiments there were drawn the graphics below that highlight the relation between load and displacement related to each specimens. In the graphs, the load displacement curves for each specimen are presented.

The tests to determine the Young’s modulus were made considering different span lengths in order to have a more accurate value.

Considering a step of 10 mm, the span length value for I1 and I2 specimens were varied between the interval of 60 – 100 mm and in 20 – 60 mm in the case of I3.

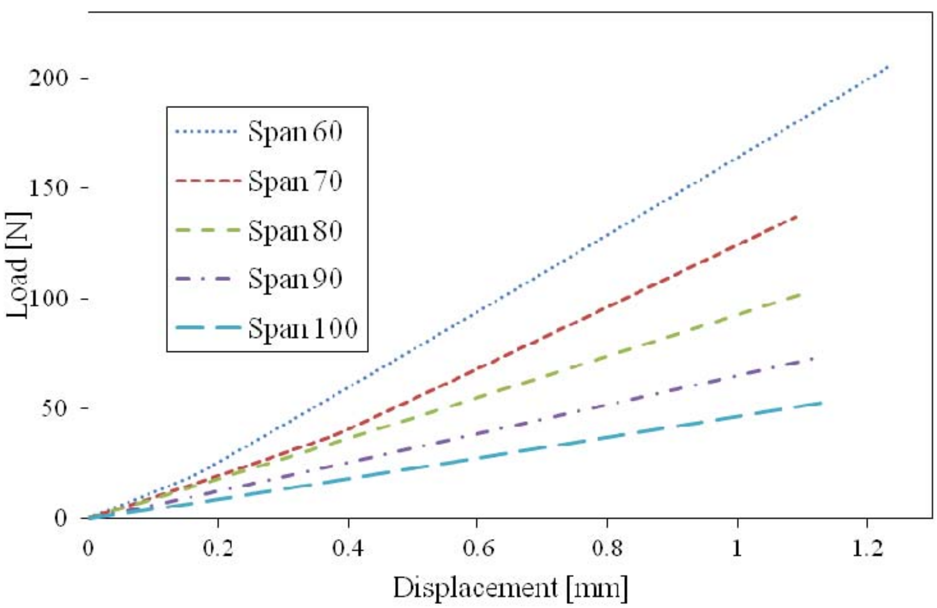

Fig.4 The sample I1

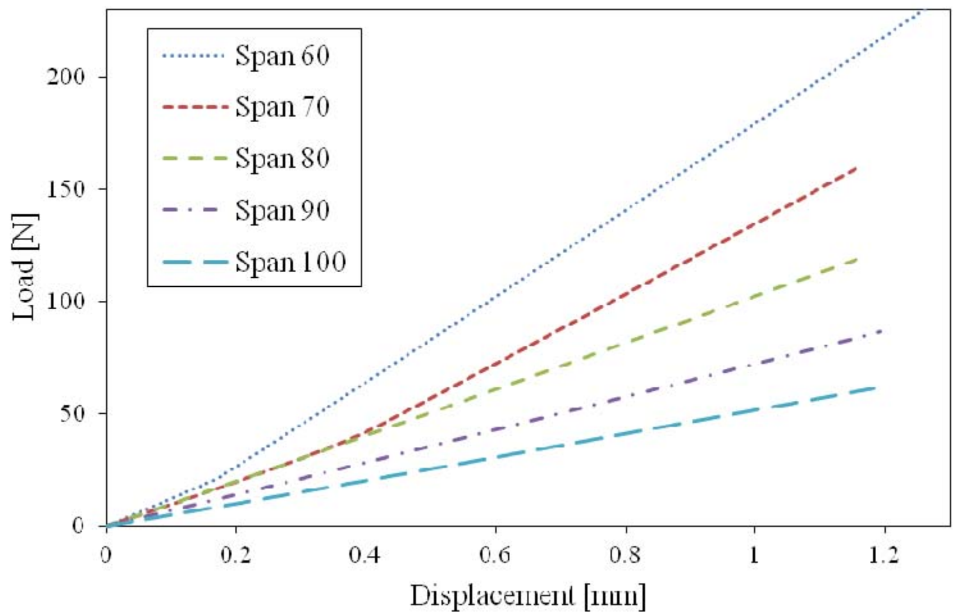

Fig.5 The sample I2

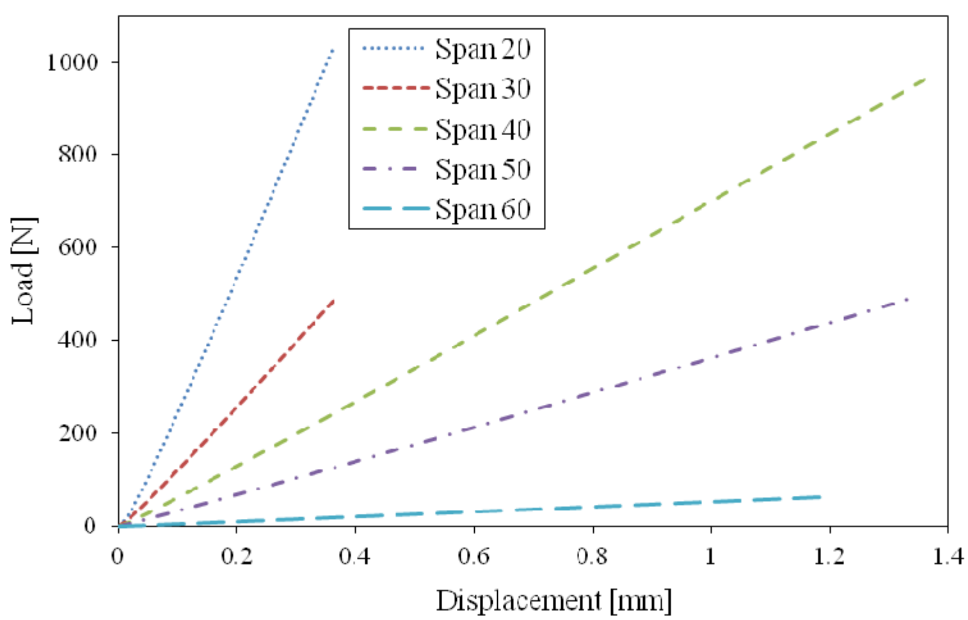

Fig.6 The sample I3

The proportionality between the load and the displacement is expressed by a stiffness term which is a function of the flexural stiffness Δ_f and the foam Young's modulus in compression.

From the slope of a graph of load versus displacement, and using the equation (4) a value for Young's modulus is obtained. In table 2 is shown the average of Young's modulus values for each specimen considering different span lenght.

A more complete three point bending midspan displacement equation can be written as:

$$\Delta_{tot} = \Delta_f + \Delta_s \tag{1}$$

where:

Δ_{tot} = Total deformation;

Δ_f = Flexural deformation;

Δ_s = Shear deformation.

$$\Delta_f = \frac{F \cdot L^3}{48 \cdot E \cdot I_y} \tag{2}$$

$$\Delta_{tot} = \frac{F \cdot L^3}{48 \cdot E \cdot I} + \frac{F \cdot L}{4 \cdot G \cdot A} \tag{3}$$

$$E = \left(\frac{F}{\Delta}\right) \cdot \frac{L^3}{48 \cdot I} \tag{4}$$

where:

F = the applied vertical load at mid-span;

L = the span or the distance between supports;

A = the cross-section area;

I = the inertia moment of the section with respect to the y axis;

E = the flexural elastic modulus or Young longitudinal modulus for isotropic material;

G = the shear modulus;

$\left(\frac{F}{\Delta}\right)$ = slope of the tangent to the initial straight-line portion of the load-deflection curve, [N/mm] of deflection.

Table 2

Young's modulus values for the three specimens studied

	I1	I2	I3
E[MPa]	212000	215000	203000

7. Conclusions

The aim of this work was to determine the value of Young's modulus for the three specimens. Unidirectional laminated composite carbon fiber specimens were used for these tests. The determination of Young's modulus was achieved with an Instron 3367 testing machine using the three-point bending test. With the data obtained from the experiments there were drawn plots that highlight the relation of load and displacement related to each specimens. The portion of the loading curve which was linear on a plot was considered for the calculations of the modulus since only that portion could be assumed to constitute the elastic region. The slopes of the load-deflection curves were used to determine the values of Young’s modulus. The Young’s modulus values obtained from experimental tests performed on the three samples are similar, especially for the first two samples, which have appropriate dimensional characteristics. For the sample I3 with the lower span length used, it results a smaller Young’s modulus value than for the specimens I1 and I2.

5. Acknowledgements

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labor, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/61178.

R E F E R E N C E S

[1] *X.L. Gao, K. Li, S. Mall,* A mechanics-of-materials model for predicting Young’s modulus of damaged woven fabric composites, involving three damage modes, International Journal of Solids and Structures 40 (2003) 981–999.
[2] P. Morgan – Carbon Fibers and their composites, Taylor & Francis, Boca Raton, 2005.
[3] *Jang Z*. Rar; Advanced Polymer Composite Materials; ASM Internațional, 1994;
[4] *J-Z. Liang*, Predictions of Young’s Modulus of Short Inorganic Fiber Reinforced Polymer Composites, Composites: Part B (2012), doi: 10.1016/j.compositesb.2012.01.010
[5] J-Z. Liang, Li Rky. Mechanical properties and morphology of glass bead filled polypropylene composites. Polym Compos; **vol. 19**, no.6, 1998, pp. 698-703.
[6] *J-Z. Liang, Li Rky, SC. Tjong,* Tensile properties and morphology of PP/EPDM/glass bead ternary composites. Polym Compos; **vol. 20**, no.3, 1999, pp. 413-422.
[7] *Z. Hashin,* J. Appl. Mech., **vol. 50** 1983 481.
[8] *F. Mujika,* On the difference between flexural moduli obtained by three-point and four-point bending tests, Polymer Testing **vol. 25** (2006) 214–220.
[9] *R. Grimberg et al*., Determination of Elastic Properties of CFRP Using Lamb Waves Resonant Spectroscopy, 2nd International Symposium on NDT in Aerospace 2010-We.5.B.1.
[10] Bank, L. C. (1989). “Flexural and Shear Moduli of Full-Section Fiber Reinforced Plastic (FRP) Pultruded Beams”. Journal of Testing and Evaluation, 17(1), pp. 40-45.
[11] BS EN ISO 178:2003 Fibre-reinforced plastic composites — Determination of flexural properties.