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DETERMINATION OF YOUNG'S MODULUS FOR CFRP USING THE THREE – POINT BENDING TEST

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

[1)] Eng. PhD. Student, Machines and Manufacturing Systems Department, Politehnica University of Bucharest, Bucharest, Romania
[2)] Prof. PhD. Eng, Machines and Manufacturing Systems Department, Politehnica University of Bucharest, Bucharest, Romania
[3)] Prof. PhD. Eng, Machines and Manufacturing Systems Department, Politehnica University of Bucharest, Bucharest, Romania

Abstract: *Young's modulus has a very important role in unidirectional carbon fiber reinforced polymer. The aim of this work was to determine the value of Young's modulus for two panels of three specimens each, both were made in the laboratories of the University of Palermo, Italy. The panel 1, after lamination, the specimens was subjected to a treatment with ultraviolet radiation. The specimens used are laminated composite carbon fiber oriented unidirectional. The determination of Young's modulus was achieved with an Instron 3367 testing machine using the three-point bending test. The tangent modulus of elasticity was calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve.*

Key words: *Young's modulus, three-point bending test, carbon fiber, unidirectional composite.*

1. INTRODUCTION

The use of composite materials is becoming very popular in many industries. In particular, the aerospace and defense industries have been increasing their dependence on the application of composite materials. However, usage of these materials is currently limited, to a certain degree, by excessive costs that can be attributed to expensive raw materials and relatively complicated manufacturing and assembly procedures. Much effort has been made to reduce the associated costs in these areas. Many projects have been developed in manufacturing and assembly composite [1], which have been successful especially with results in introducing significant cost reductions.

Carbon fiber reinforced plastics (CFRP) are large scale used in aeronautic industry due to their advantaged [2]. In the same time CFRP can present degradations during their use, as delamination due to some impacts even with low energies, accompanied or not by fibers breaking, local overheating, water adsorption, the two last causes leading to the deterioration of the matrix.

Carbon fiber appeared in 1957 when, in order to improve cotton and silk that were only available for manufacturing nozzles and rocket, Barneby-Cheney and National Carbon produced a small amount of fiber. In 1961, A Shindo, from the Japanese Government Industrial Research Institute, Osaka has produced carbon fiber polyacrylonitrile (PAN). In 1967, Rolls Royce in England announced the project to use carbon fiber at components of jet engine.

Today, carbon fiber composite fiber is dominating the advanced industry. In the last two decades, carbon fibers properties have grown as a result of demand for materials; they are as strong and lighter as possible, especially in the aerospace industry. As reported strength/weight, carbon fiber is the best material that can be produced on an industrial scale at this time [18].

In a composite material, the matrix is designed to protect the dispersed phase in the environment action (corrosion and oxidation), transfer tensions 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 is lower than the reinforcement material it contains [19].

One of the most important mechanical properties in a material is the Young's modulus E. For the design process in engineering of the automotive or aeronautic industries, for instance it is of extremely importance to have reliable values of the E parameter. In fact, tabulated values are available in the literature, but the development of new materials such as composite polymer-based has motivated scientists to look for specific information [3].

Young's modulus is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's Law holds [16].

In solid mechanics, the slope of the stress-strain curve at any point is called the tangent modulus. The tangent modulus of the initial, linear portion of a stress-strain curve is called Young's modulus, also known as the tensile modulus. It can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material. In anisotropic materials, Young's modulus may have different values depending on the direction of the applied force with re-

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[*] Corresponding author: Institution address: 313 Spl. Independentei, Bucharest, Romania.
Tel.: +40 021.402.93.02;
E-mail addresses: *irina_petresscu@yahoo.com* (I. Petrescu), *cristinamohora@yahoo.com* (C. Mohora), *ispas@leo.optimum.pub.ro* (C. Ispas).

spect to the material's structure. These materials then become anisotropic, and Young's modulus will change depending on the direction from which the force is applied. Anisotropy can be seen in many composites as well. For example, carbon fiber has much higher Young's modulus (is much stiffer) when force is loaded parallel to the fibers (along the grain) [5].

When studying epoxy resin-based composites, the E modulus is a very important macroscopic parameter that needs to be determined either experimentally or theoretically or using both tools together [3].

In the past two decades, extensive research is recorded in prediction of mechanical properties of unidirectional fiber-reinforced composites. Several analytical models have been proposed for the accurate prediction of composite properties from those of the constituent fiber and matrix [6].

Grimberg R. et al. [7] proposes to use 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.

J.H. Lim et al [8] the phase-shift shadow moiré method (PSSM) enabled the measurement of the deflections of varies epoxy coated PET micro-cantilevers and hence to determine Young's modulus of the composite material. The non-contacting feature of the PSSM was essential in the deflection measurement of micro-cantilevers. The micro-cantilevers used in the experiment were fabricated using pure PET and coated with various types of epoxy coating. The results from the experiment showed that Young's modulus of the micro-cantilever can be altered using different coating materials. Without changing the major dimensions of the micro-cantilever, Young's modulus of the coating materials can be varied and therefore micro-cantilevers with different sensitivities can be produced.

Alfredo [9] developed closed form micromechanical equations to predict the transverse modulus *E*, and by combining the equations developed with other well known equations, thus resulting a set of layer stiffness constants required for 3D analysis.

Yixin in his paper report an experimental study on determination of flexural rigidity of the pultruded composite sheet pile panels with reduced or eliminated shear effect. Bank's approach was adopted in three-point and four-point bending tests with various spans. Bank [10] developed a method to simultaneously determine the section Young's modulus and the section shear modulus by using Timoshenko's deflection equation. The approach was modified in this paper to directly determine the *EI*, instead of *E* alone. Results from the three-point bending tests were compared with that from four-point bending tests to check the consistency, so were the results from single panel tests compared with connected double panel tests. The dependence of the flexural rigidity on the test conditions was also discussed [11].

Young's modulus of polymers is about two orders of magnitude smaller than that of metals and ceramics, whereas the yield strength is smaller by only about one order of magnitude. Therefore, polymers can exhibit much larger elastic strains without deforming plastically. When components made of polymers are designed, this large elastic deformation has to be taken into account. Both the elastic and the plastic behaviour of polymers are time-dependent even at room temperature [12].

Because the strength and elastic stiffness of the fibres used in polymer matrix composites is frequently more than a hundred times larger than that of the polymer matrix, the mechanical properties of polymer matrix composites are mainly determined by the fibre properties. For this reason, the highest possible fibre volume fractions are aimed at, with maximum values in aerospace industry of about 60%. Nevertheless, the mechanical behaviour of the matrix is also important because it determines load transfer to the fibres and it must not fail if the strength of the fibres is to be exploited fully [12].

According to ASTM C393, the displacement of the middle point of the specimen is given by:

$$\Delta = \frac{P \cdot L^3}{48 \cdot E \cdot I_y} + \frac{P \cdot L}{4 \cdot G \cdot A}, \qquad (1)$$

where *P* is the applied vertical load at midspan; *L* – the span or the distance between supports; A – the area section; I_y – the inertia moment of the section with respect to *y* axis; *E* – the flexural elastic modulus or Young longitudinal modulus for isotropic material; *G* – the shear modulus;

The apparent flexural rigidity is defined as the resistance of a beam to deflection due to only bending, neglecting shear deflections. The slopes of the load-deflection curves were used to determine the apparent flexural rigidity based on the first term of Timoshenko's equation [11].

2. STANDARD TEST METHODS FOR FLEXURAL PROPERTIES

Numerous investigations have been made in finding suitable methods for measuring test flexural properties. Standardization institutions such as the American Society

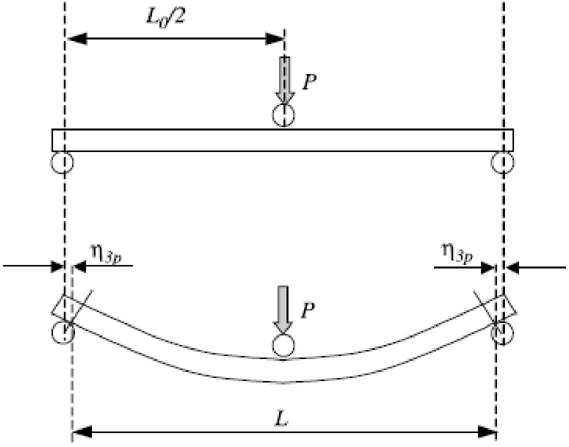

Fig. 1. Undeformed and deformed three-point bending test configuration.

for Testing and Materials (ASTM), European Structural Integrity Society (ESIS) and Japanese Industry Standards (JIS) have proposed some of the methods used in the current study.

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 [13]. A bar of rectangular cross section rests on two supports and is loaded by means of a loading nose midway between the supports (see Fig. 1). A support span-to-depth ratio of 16:1 shall be used unless there is reason to suspect that a larger span-to-depth ratio may be required, as may be the case for certain laminated materials polymers, the thickness of the oriented skin layer, which is dependent on moulding conditions and thickness, affects the flexural properties. Consequently, when the method specifies preferred dimensions for the test specimen. Tests which are carried out on specimensof different dimensions, or on specimens which are prepared under different conditions, may produce results which are not comparable. Other factors, such as the test speed and the conditioning of the specimens, can also influence the results. Especially for semi-crystalline comparable data are required, these factors must be carefully controlled and recorded.

The support span-to-depth ratio shall be chosen such that failures occur in the outer fibers of the specimens, due only to the bending moment. Therefore, a ratio larger than 16:1 may be necessary (32:1 or 40:1 are recommended). When laminated materials exhibit low compressive strength perpendicular to the laminations, they shall be loaded with a large radius loading nose (up to four times the specimen depth to prevent premature damage to the outer fibers.`

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 [14].

3. EXPERIMENTS ANS RESULTS

If a material is loaded with a force, the atoms within the material are displaced – the material responds with a deformation. This deformation determines the mechanical behaviour of the material. Different types of deformation exist which are not only caused by different physical mechanisms, but are also used in different engineering applications.

The use of bending tests to determine the mechanical properties of resins and laminated fibre composite materials is widespread throughout industry owing to the relative simplicity of the test method, instrumentation and equipment required.

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

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

The three point bending flexural test provides values for the modulus of elasticity in bending, flexural stress σf, flexural strain and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing.

However, this method has also some disadvantages: the results of the testing method are sensitive to specimen and loading geometry and strain rate [15].

The present experiment was conducted at the doctoral stage in University of Palermo, Faculty of Engineering Science, Department of Mechanics, Palermo, Italy.

A test machine Instron 3 367 (see Fig. 2) with electric drive was used to test the specimens. The machine used an Instron BlueHill software and has the following characteristics:

- Maximum load: 30 kN;
- Maximum speed: 500 mm/min;
- Maximum Stroke: 1 194 mm.

The experimental test was performed using a uniform rectangular bar supported horizontally on two knife-

Table 1

Dimensions of specimen

	Length[mm]	Width[mm]	Thickness[mm]
W11	150	20.03	4.50
W12	150	19.98	4.34
W13	150	20.19	4.44
W51	154	20.01	3.78
W53	154	20.14	3.59
W54	154	20.14	4.07

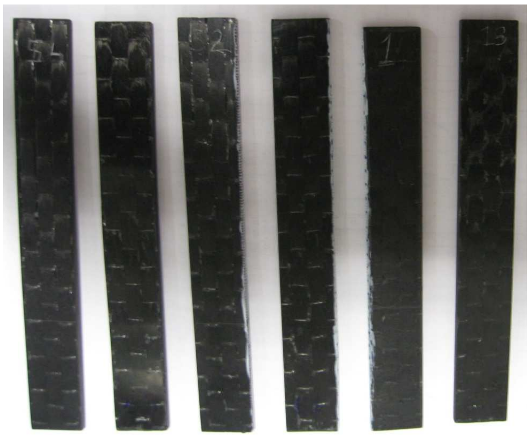

Fig. 4. The specimen position on the test machine.

edges. The specimens were subjected to a vertical force applied midway between the supports (see Fig. 3).

A series of observations is made with a constant load and a length of beam (distance between supports). From a logarithmic graph of the displacement versus the load, the mathematical relationship between deflection and load is ascertained. From the slope of a graph of load versus deflection, a value for Young’s modulus is obtained [4].

The experimental tests were made on two panels of laminates composite with unidirectional carbon fibers: Both panels were made in the laboratories of the University of Palermo, Italy. The panel 1, after lamination, the specimens was subjected to a treatmeat with ultraviolet radiation in a laboratory of the University in Warsaw, Poland. The two panels are made of carbon fiber and DGEBA resin, and has 16 number of passes.

Diglycidyl ether of bisphenol-A (DGEBA) is a typical commercial epoxy resin and is synthesised by reacting bisphenol-A with epichlorohydrin in presence of a basic catalyst.

The properties of the DGEBA resins depend on the value of *n*, which is the number of repeating units commonly known as degree of polymerisation [17].

The number of repeating units depend on the stoichiometry of synthesis reaction. Typically, *n* ranges from 0 to 25 in many commercial products.

All tests are performed in laboratory conditions at room temperature.

Carbon fibres are characterised by a high stiffness and strength. However, both parameters cannot be maximised simultaneously. In high-strength fibres, Young’s modulus does not exceed 400GPa, in high-stiffness fibres, the tensile strength is reduced [12].

The table above shows the dimensions of specimens for the two panels, W1 respectively W5. Also in Fig. 4 a picture with the six specimens used in the experimental test to determine the Young’s Modulus is presented.

The tangent modulus of elasticity, often called the “modulus of elasticity”, is the ratio, within the elastic limit, of stress to corresponding strain. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using Eq. (2).

$$E = \frac{L^3 \cdot m}{4 \cdot b \cdot h^3}, \qquad (2)$$

where:

E – modulus of elasticity in bending, [MPa],
L – support span, [mm],
b – width of beam tested, [mm],
d – depth of beam tested, [mm], and
m – slope of the tangent to the initial straight-line portion of the load-deflection curve, [N/mm] of deflection.

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 it was drawn the graphics above that highlights the relation of load and displacement related to each specimens. From the graphics above it can be seen the load displacement curves for each specimen.

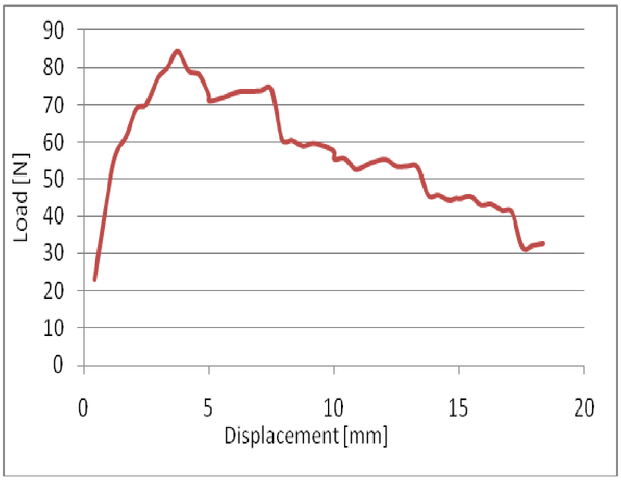

Fig. 5. The load- displacement curves for W11.

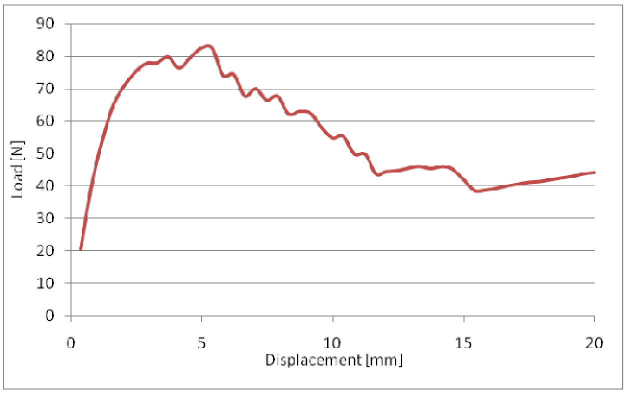

Fig. 6. The load-deflection curves for W12.

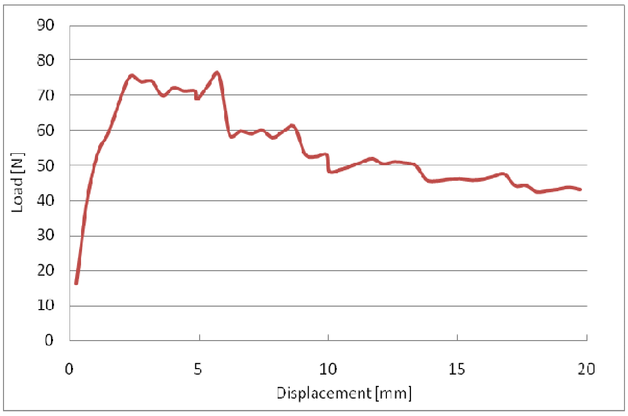

Fig. 7. The load-displacement curves for W13.

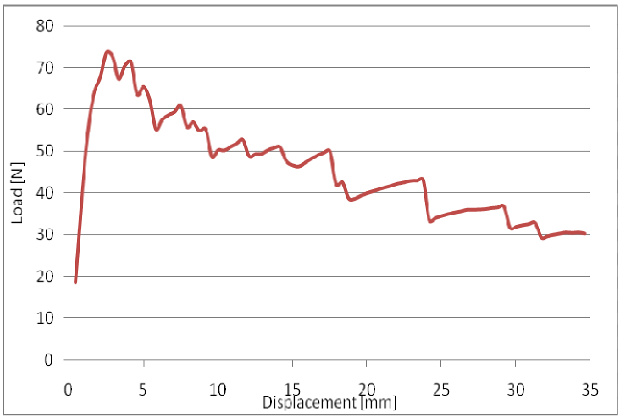

Fig. 8. The load- displacement curves for W51.

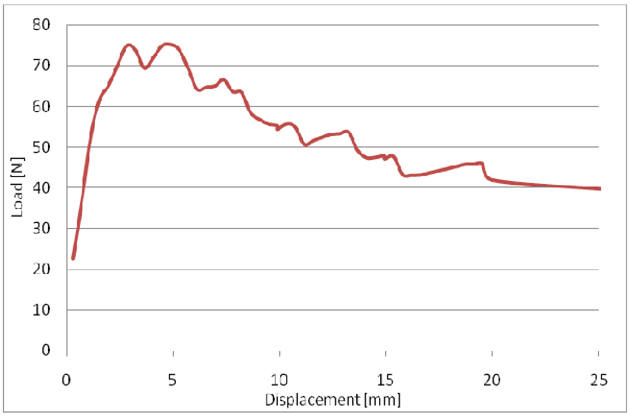

Fig. 2. The load- displacement curves for W53.

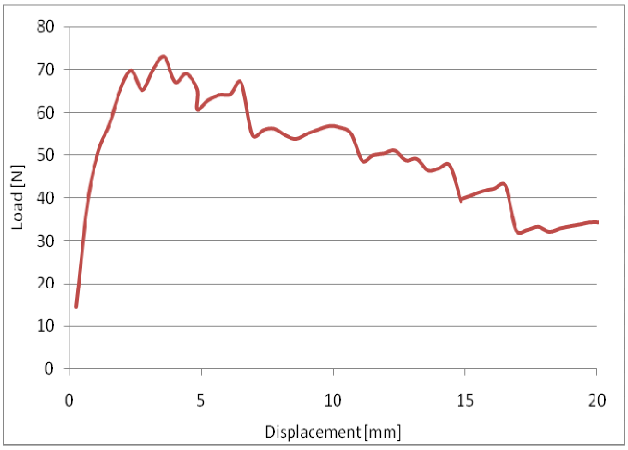

Fig. 9. The load- displacement curves for W54.

Table 2

Young's modulus values for the six specimens studied

Specimens	Young Modulus [MPa]
W11	125 850
W12	134 602
W13	138 416
W51	96 668
W53	89 411
W54	96 595

The portion of the loading curve which was linear on a plot of load was considered for the calculations of the modulus since only that portion could be assumed to constitute the region of elastic contact.

From the slope of a graph of load versus displacement, and using the Eq. (2) a value for Young's modulus is obtained. In the table 2 is shown the values of Young's modulus for each specimen. It can observe that the values from the panel 1 are higher with almost 40%, the reason is the fact that the panel 1 was subject to the ultraviolet radiation.

The results for flexural modulus are reasonably consistent, in the range 85–135 GPa, as long as the span-to-thickness ratio is greater than the 16:1 allowed under the ASTM and British Standards.

4. CONCLUSIONS

By using the polymer composite materials is reducing the production of raw materials, and the material loss is minimal. In many cases, the final product of polymer composite material no longer needed operations after processing, because the technical conditions imposed on the product are obtained even in the manufacturing phase. Also, using polymeric composite materials, the number of parts required for certain specific applications is low, reducing the number of connections, reducing the assembly time required and thus decreases the product price. Another advantage of using polymeric composite materials for manufacturing products is the ability to predict and to design composite material properties by choosing suitable weight constituents of nature and its direction in the matrix arrangement of reinforced, possible non-existent when using traditional materials. On these advantages, given to polymer composites compared with conventional materials, we add the following:

- High ratio strength/weight characteristic of these materials after beating the best steels [8];
- Resistance to corrosion under the action of environmental factors;
- Resistant to chemical agents;
- Vibration damping capacity;
- Resistance to fatigue;
- Low thermal expansion coefficient;
- Technology training simple parts;
- Easy processing at low temperatures (< 200 °C);
- Report performance ratio/high cost.

Polymer matrix composite materials have, however, some disadvantages:

- Low mechanical strength at high temperatures increase above a certain value of temperature can cause damage to the composite material;

- High thermal expansion coefficient;
- Low thermal conductivity;
- After the disposal presents problems for the environment.

The Young's modulus E is the one of the most important mechanical properties in a material. It is of extremely importance to have reliable values of the E parameter for the design process in engineering of the automotive or aeronautic industries. In the present, values are available in the literature, but the development of new materials such as composite polymer-based has motivated scientists to look for specific information. Generally, Young's modulus of polymers is about two orders of magnitude smaller than that of metals and ceramics, whereas the yield strength is smaller by only about one order of magnitude. Therefore, polymers can exhibit much larger elastic strains without deforming plastically. When components made of polymers are designed, this large elastic deformation has to be taken into account. Both the elastic and the plastic behaviour of polymers are time-dependent even at room temperature.

The aim of this work was to determine the value of Young's modulus for the two panels of three specimens each. The specimens used are laminated composite carbon fiber oriented unidirectional. 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 it was drawn graphics that highlights the relation of load and displacement related to each specimens. The portion of the loading curve which was linear on a plot of load was considered for the calculations of the modulus since only that portion could be assumed to constitute the region of elastic contact. The slopes of the load-deflection curves were used to determine the values of Young's modulus. From the results obtained, the values of Young's modulus for the specimens from the panel 1 are higher with almost 40%, the reason is the fact that the panel 1 was subject to the ultraviolet radiation.

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REFERENCES

[1] AA Baker et al., *An affordable methodology for replacing metallic aircraft panels with advanced composites*, Compos Part A Appl Sci Manuf 2002; 33(5), pp. 687–96.

[2] P. Morgan – *Carbon Fibers and their composites*, Taylor & Francis, Boca Raton, 2005.

[3] S. Tognanab, W. Salgueiroa, A. Somoza, A. Marzoccad, *Measurement of the Young's modulus in particulate epoxy composites using the impulse excitation technique*, Materials Science and Engineering A 527 (2010) 4619–4623.

[4] *Deflection of a Beam – Young's Modulus* `http://blog.cencophysics.com/2009/08/beam-deflection-youngs-modulus/`

[5] IUPAC, *Compendium of Chemical Terminology*, 2nd ed. (the "Gold Book"), 1997, Online corrected version: (2006) "modulus of elasticity (Young's modulus), E".

[6] K. Sivaji Babua1, K. Mohana Raob, V. Rama Chandra Rajuc, V. Bala Krishna Murthyd and M.S.R. Niranjan Kumare, *Prediction of Shear Moduli of Hybrid FRP Composite with Fiber-Matrix Interface Debond*, International Journal of Mechanics and Solids ISSN 0973-1881 Vol. 3, No. 2, 2008, pp. 147–156.

[7] 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.

[8] J.H. Lim, M.M. Ratnam, I.A. Azid, D. Mutharasu, *Determination of Young's modulus of epoxy coated polyethylene micro-cantilever using phase-shift shadow moiré method*, Optics and Lasers in Engineering, 49, 2011, pp. 1301–1308.

[9] A. Balaco' de Morais, *Transverse Moduli of continuous-fiber reinforced polymers*, Composites Science and Technology, 60, pp. 997-1002.

[10] L.C. Bank, *Flexural and Shear Moduli of Full-Section Fiber Reinforced Plastic* (FRP) Pultruded Beams", Journal of Testing and Evaluation, 17(1), 1989, pp. 40–45.

[11] S. Yixin, C. Giroux, Z. Bdeir, *Determination of* E_I *for pultruded GFRP sheet pile panels* `http://www.quakewrap.com/frp%20papers/Determination-Of-EI-For-Pultruded-GFRP-Sheet-Pile-Panels.pdf.`

[12] J. Rösler, H. Hardens, M. Bäker, *Mechanical Behaviour of Engineering Materials*, German edition published by the Teubner Verlag Wiesbaden, 2006.

[13] ASTM Standard, Designation: D 790 – 03 *Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials*

[14] BS EN ISO 178:2003, *Fibre-reinforced plastic composites — Determination of flexural properties.*

[15] `http://en.wikipedia.org/wiki/Three_point_flexural_test.`

[16] `http://en.wikipedia.org/wiki/Young's_modulus` *Young's modulus.*

[17] `http://sunilbhangale.tripod.com/epoxy.html` *Epoxy Resins*

[18] `http://www.compozite.net/materiale-compozite/materiale-compozite-istoric.html.`

[19] J.Rar, *Advanced Polymer Composite Materials*; ASM International, 1994.