NUMERICAL SIMULATION OF FLEXURAL BEHAVIOR OF GLASS FIBER REINFORCED POLYMER COMPOSITES

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ABSTRACT*: In this paper, the three-point bend flexural testing of composites reinforced with woven glass fibers and unidirectional glass fibers are presented. The experimental study was done according the ASTM standard. A finite element simulation was done in order to investigate the mechanical behavior of woven glass fibers and unidirectional glass fibers reinforced polymer composites. The finite element results were compared with experimental data, thus obtaining very close values. The composites plates were obtained through hand lay-up technology.*
KEYWORDS*: composite materials, flexural properties, fiber-reinforced composites, polyester matrix, finite element analysis*

1 INTRODUCTION

Composite materials represent arrangements of continuous or discontinuous fibers covered by a matrix. These materials have more and more applicability in all fields, due to performances / cost characteristics and excellent mechanical properties reported at weight [1-3].

This paper purpose is to determine the flexural properties of polymer matrix composite materials under three-point loading.

As reinforcement materials can be used both glass fibers, carbon fibers, Kevlar, and natural fibers.

Some researchers have identified different natural fibers used to substitute glass fiber. Rokbi et al. [4] has studied the flexural properties of polyester matrix composite reinforced with natural fibers after alkali treatment and Alhijazi et al. [5] done a natural fiber composites bending analysis.

García-Moreno et al. [6] and Kumar et al. [7] have carried out investigation on carbon/epoxy composites. Rajasekhar et al. [8] evaluated the flexural properties of glass fiber reinforced epoxy-based composites immersed in water and [9] for longitudinal basalt/woven-glass-fiber-reinforced unsaturated polyester-resin hybrid composites.

Thus, [10] have tested under flexural loading a polymer epoxy using different amount of glass fibers laminated faces as reinforcement and [11] a glass fibre reinforced polymer (GFRP) composites.

Christiansen et al. [12] have investigated the mechanical behavior in three-point bending of glass fibre-reinforced polyester resin composites and [13] presented the flexural strength of composites reinforced with woven glass fibre.

In order to provide the mechanical behavior of composite structures, numerous finite element analysis for various parameters were done in different programs.

Kumar et al. [14] have simulated the 3-point bend problem of isotropic and unidirectional FRP composite materials using three-dimensional finite element method in ANSYS 12 software. The finite element model is also developed in ANSYS for cross ply laminated woven Glass/Epoxy composite by [15].

Sadighi et al. [16] have studied the finite element simulation to investigate the mechanical behavior of three-dimensional woven glass-fiber sandwich composites and [17] analyzed the dynamic flexural behavior of sandwich beams, with composite face sheets and a foam core.

A finite element simulation for the 3D layer-to-layer angle-interlock woven composite undergoing three-point bending cyclic loading was presented by [18].

Cui et al. [19] have carried out a finite element stress analysis of three-point short-beam bending specimens of a unidirectional glass-fiber/epoxy composite.

It has also been simulated with the help of the Finite Element model the mechanical behavior for a glass fiber reinforced plastic composite bridge deck by Li et al. [20] and for a hybrid composites by [21].

The objective of this research was to evaluate the flexural mechanical properties of glass fiber reinforced polymer composites according to the ASTM standards and by means of a Finite Element

Analysis (FEA). These analyzes were done for two types of materials, uniaxial and biaxial glass fibers.

A three-point bend is suggested for prediction of flexural modulus of fiber reinforced composites. The flexural properties both for polymer matrix composites and for woven composites were determined experimentally using three-point tests according to ASTM D7264 [22]. This test method uses a standard 32:1 span-to-thickness ratio in comparison to other methods such as ASTM D790 [23], a three-point flexure for plastics which uses a standard 16:1 span-to-thickness ratio.

The objective of this research work was to evaluate the mechanical properties at three-point bend flexural testing of glass fiber reinforced polyester matrix composites. Finite element analysis was done to evaluate the properties of the composite materials and to compare the FEA results with experimental data.

2 MATERIALS AND METHOD

2.1 Materials

The used materials in this study are unidirectional (UD) glass fibers, woven glass fibers (WF) and polyester resin.

The type and the characteristics of the matrix are: Polyester resin type Lerpol TIX 3603/R (Italy) ortophtalic, tixotropized and ecological.

Technical characteristics of the resin are: Color: blue; Brookfield viscosity at 25°C: 400 cPs; Density at 16/15ºC: 1530 kg/m^3, Time for obtaining jelly with 2% peroxide of methyl-ethyl-ketone in 100g resin: 12 min; Exothermic peak: 185ºC; Exothermic peak time: 19’30” min; Solubility in water at 25ºC: 130 mg/l.

Methyl-ethyl-ketone peroxide has used as catalyst.

The used glass fabrics for samples are unidirectional fibers 225 g/m^2 (Germany): Warp: Roving 300 tex; Weft: Garn 22 tex, Figure 1 and woven fibers 450 g/m^2 from biaxial fabric, Figure 2.

Fig. 1 Unidirectional glass fiber 225 g/m^2

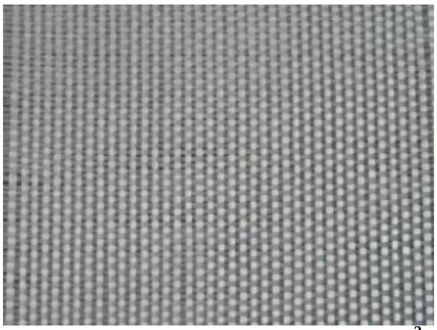

Fig. 2 Bidirectional glass fabric 450 g/m^2

2.2 Manufacturing methodology

The manufacturing technique of the composite plates was hand lay-up. This method is the most used for obtaining composite parts.

The manufacturing process was carried out at ambient temperature of 20°C. For obtaining a good impregnation it is useful to use a pressure in order to remove the resin excess, to homogenize the structure, and to increase the reinforcement degree.

From each composite plate five samples were cut, for determining the mechanical characteristics at flexure tests. These have 84 mm length x 13 mm width x 4 mm thickness dimensions according to manufacturing and testing standard ASTM D7264. This method is suitable for polymer matrix composite materials.

It was used the universal testing machine Instron 1196, and the speed for three-point bending tests was 1 mm/min.

For bending tests, no protection to the ends of the specimen shall be applied.

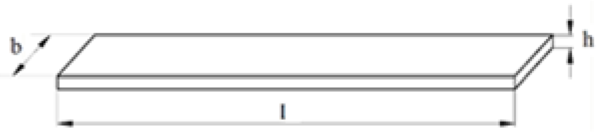

Fig. 3 Bending test specimen

The specimen is simply supported on both ends, and the punch of the test machine is placed in the middle of the distance between the support points, Figure 4.

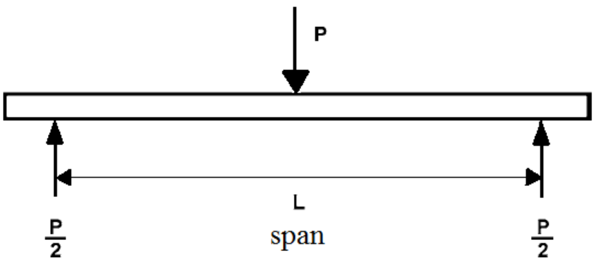

Fig. 4 Schematic representation of the flexural test (three-point bend test ASTM D7264)

The sample used for the flexural test is shown in Figure 5. The maximum flexural stress at the outer surface occurs at mid-span, and it was calculated using the equation 1.

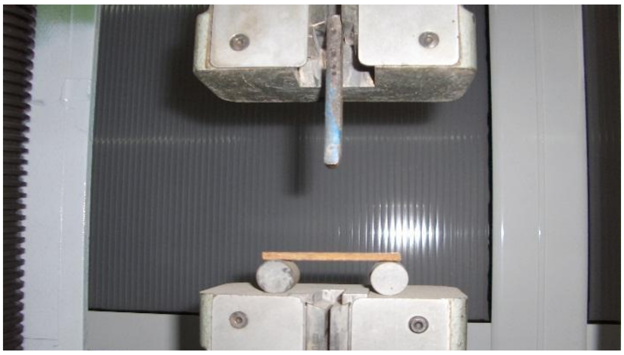

Fig. 5 Flexural tested sample

The flexural stress σ at the outer surface at mid-span is:

$$\sigma = \frac{3PL}{2bh^2} \text{ [MPa]} \quad (1)$$

where:
P - applied force, [N];
L - support span, [mm];
b - width of beam, [mm];
h - thickness of beam, [mm].

3 RESULTS AND DISCUSSION

The obtained experimental results for both unidirectional glass fiber and woven glass fibers reinforced polymer composites are presented in Table 1. In table only the flexural average strength values for each composite material are mentioned.

Table 1. Experimental results

Hand lay-up technique	Properties	Material	σ [MPa]
	Flexural average strength	UD 225 g/m^2	235.6
		WF 450 g/m^2	260.4

The flexural stress at break is directly influenced by the orientation of the reinforcement layers, because the fibers take the internal forces due to the mechanical stresses.

The maximum flexural strength of 235.6 MPa was obtained for UD composite with fibers orientation at 0^o.

The fibers in the bidirectional woven glass fibers have provided an increase of the composite strength with 10% compared to the UD composite at bending forces.

When compared the experimental results, it has noticed that the peak loads values are 466.71 N and 515.84 N, for unidirectional glass fiber and woven glass fiber respectively.

4 NUMERICAL SIMULATION

This paper analyses samples for three-point bend test using the SolidWorks Simulation Software. The analysis proposes to determine the stress state and the deformation of the samples. A mesh with 12187 nods and 7444 elements with 1.6 mm size element has been generated, Figure 5.

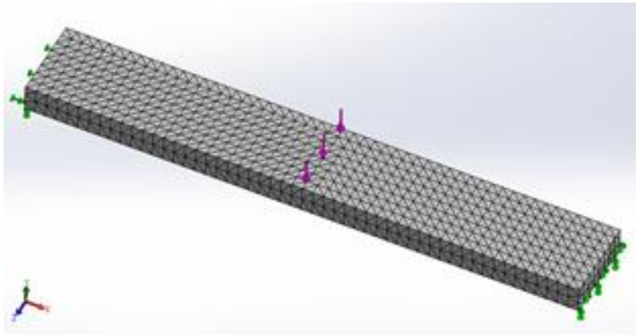

Fig. 6 Finite element network and restrictions

The UD glass fiber samples with fibers inclined at 0^o was analyzed according to the three-point bending test by FEM.

Figure 7 presents the distribution of von Mises equivalent stress. It is observed that the maximum value for unidirectional tissue is 234.911 MPa.

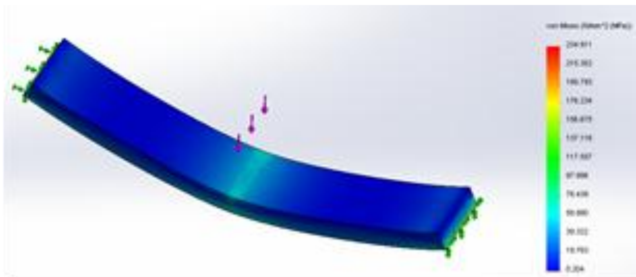

Fig. 7 Finite element flexural test analysis for von Mises stress of UD composite

In Figure 8 it is presented the displacement distribution for the UD composite. It is observed that we have a displacement of 10.40 mm.

Thus, Figure 9 shows the distribution of von Mises equivalent stress for woven glass fiber reinforced polyester resin composite. It is observed that the maximum value for this composite material is 253.312 MPa.

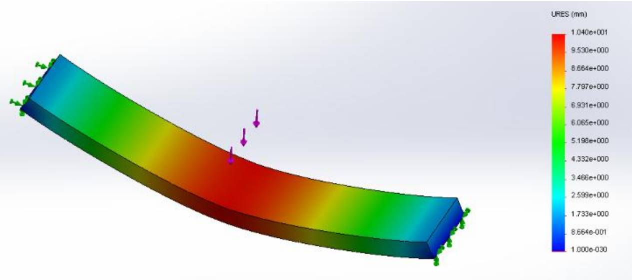

Fig. 8 Finite element flexural test analysis for displacement distribution of UD composite

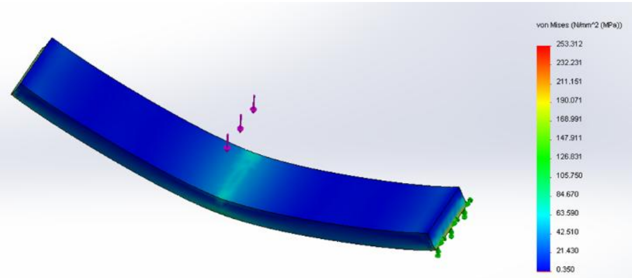

Fig. 9 Finite element flexural test analysis for von Mises stress of WF composite

In Figure 10 it is showed the displacement distribution for the WF composite. We can observe a displacement of 10.70 mm.

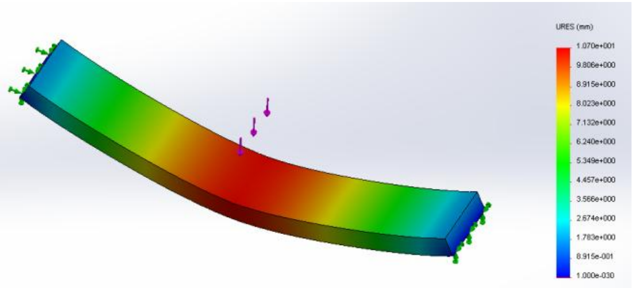

Fig. 10 Finite element flexural test analysis for displacement distribution of WF composite

We can conclude that, the UD glass composite with fibers inclined at 0º angle has lower mechanical characteristics then woven glass fiber reinforced polyester resin composite.

The numeric values are compared with the obtained experimental results

It is observed that the predicted values using the Finite Element model have very small difference with the measured values. For UD glass composite we have a difference of 0.29%, and for woven glass fiber composite of 2.72%.

In the case of UD glass composite the flexural loads are taken over only in the longitudinal direction of the fibers, and in the case of woven glass fiber composite the loads are taken in both longitudinal and transverse directions.

5 CONCLUSIONS

Flexural behavior of two different composite materials have been investigated in this research. The composites plates were obtained through hand lay-up technology using unidirectional glass fiber and woven glass fiber reinforced polyester matrix.

The mechanical properties of the both composite materials that are examined by a three-point bend test are carried out on Instron 1196.

The purpose of this study was to do a comparative assessment between experimental data at flexural stress and a Finite Element Analysis.

According to the three-point bending test, the mechanical properties of UD glass fibers and woven glass fiber reinforced polyester resin composites was analyzed. It was observed that the flexural properties increased in the case of woven glass fibers. The flexural strength was increased by 10% for woven glass fibers composites than UD composites.

Comparison between the finite element predictions and experimental data have showed a very small difference. The UD sample have a difference of 0.29%, and woven glass fiber composite of 2.72%. In flexural testing, woven glass fiber composite concludes an improved strength than UD composite, because of the fiber composition and the fiber orientation angles.

6 REFERENCES

[1] Barbero E.J. 2010 Introduction to composite materials design, second edition, CRC Press Taylor & Francis Group, USA, ISBN 978-1-4200-7915-9.

[2] Gay D. 1997 Matériaux composites, 4e édition, Hermes, Paris, ISBN 2-86601-586.

[3] Gdoutos E.E. 2005 Fracture mechanics, An introduction, Second Edition, Springer, USA, ISBN 1-4020-2863-6.

[4] Rokbi M., Osmani H., Imad A., Benseddiq N. 2011 Effect of chemical treatment on flexure properties of natural fiber-reinforced polyester composite, Procedia Engineering, Vol. 10, pp. 2092–2097.

[5] Alhijazi M., Zeeshan Q., Qin Z., Safaei B., Asmael M. 2020 Finite element analysis of natural fibers composites: A review, Nanotechnology Reviews, Vol. 9, pp. 853–875.

[6] García-Moreno I., Caminero M.A., Rodríguez G.P., López-Cela J.J. 2019 Effect of thermal ageing on the impact and flexural damage behaviour of carbon fibre-reinforced epoxy laminates, Polymers, Vol. 11(1), 80.

[7] Kumar C., Rawat P., Singh K.K., Behera R.P., Deep A. 2018 Combined effect of loading rate and percentage by weight of MWCNTs on inter laminar shear strength (ILSS) and flexural strength of CFRP, IOP Conf. Ser.: Mater. Sci. Eng. Vol. 377(1).

[8] Rajasekhar M.J., Vardhan M.D.H. 2017 Study of effect of water treatment on flexural properties of GFRP composites, International Research Journal of Engineering and Technology (IRJET), Vol. 4(9), pp. 1079-1081.

[9] Sapuan S.M., Aulia H.S., Ilyas R.A., Atiqah A., Dele-Afolabi T.T., Nurazzi M.N., Supian A.B.M., Atikah M.S.N. 2020 Mechanical properties of longitudinal basalt/woven-glass-fiber-reinforced unsaturated polyester-resin hybrid composites. Polymers, Vol. 12(10):2211.

[10] Monteiro Cheloni J.P., Silveira M.E., Silva L.J.D. 2018 Different methods of three-point bending analysis of polymer epoxy reinforced with fiberglass laminated faces, 4th Brazilian Conference on Composite Materials. Rio de Janeiro.

[11] Anbusagar N.R.R., Palanikumar K., Vigneswaran R., Rajmohan M., Sengottuvel P. 2015 Tensile and flexural properties of glass fibre reinforced nano polymer composite panels, Applied Mechanics and Materials, Vols. 766-767, pp. 372-376.

[12] Christiansen A.W., Lilley J., Shortall J.B. 1976 A three-point bend test for fibre-reinforced composites, Fibre Science and Technology, Vol. 7(1), pp. 1-13.

[13] Oberholzer T.G., du Preez I.C., Lombard R., Pitout E. 2007 Effect of woven glass fibre reinforcement on the flexural strength of composites, SADJ, Vol. 62(9):386, 388-9.

[14] Kumar M.P., Murthy V.B. 2012 Effect of specimen dimensions on flexural modulus in a 3-point bending test, International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 1(8), pp. 1-6.

[15] Sahoo S.S., Singh V.K., Panda S.K. 2015 Experimental and simulation study of flexural behaviour of woven Glass/Epoxy laminated composite plate, IOP Conf. Ser.: Mater. Sci. Eng., Vol. 75 (1).

[16] Sadighi M., Hosseini S.A. 2013 Finite element simulation and experimental study on mechanical behavior of 3D woven glass fiber composite sandwich panels, Composites Part B: Engineering, Vol. 55, pp. 158-166.

[17] Ivañez I., Santiuste C., Sanchez-Saez S. 2010 FEM analysis of dynamic flexural behaviour of composite sandwich beams with foam core, Comp. Struct., Vol. 92(9), pp. 2285-2291.

[18] Sun B., Yao Y., Jin L, Gu G. 2013 Finite element analyses of stress distributions of three-dimensional angle-interlock woven composite subjected to three-point bending cyclic loading, The Journal of The Textile Institute, Vol. 104(11), pp. 1186-1194.

[19] Cui W.C., Wisnom M.R. 1992 Contact finite element analysis of three- and four-point short-beam bending of unidirectional composites, Composites Science and Technology, Vol. 45(4), pp. 323-334.

[20] Li Y.F., Hsu T.H., Wu C.H., Badjie S. 2012 Three-point bending test and finite-element analysis on FRP bridge deck, 9th International Conference on Urban Earthquake Engineering / 4th Asia Conference on Earthquake Engineering, Tokyo Institute of Technology, Japan.

[21] Ashik K.P., Sharma R.S., Patil S. 2017 Evaluation of tensile, flexural and impact strength of natural and glass fiber reinforced hybrid composites. Renew Bioresour., Vol. 5(1).

[22] ASTM D7264/D7264M-07. 2007 Standard test method for flexural properties of polymer matrix composite materials.

[23] ASTM D790-02. 2002 Flexural properties of unreinforced and reinforced plastics and electrical insulating materials; ASTM: West Conshohocken, PA, USA.