Mechanical Characterization of Glass Fibers–Reinforced Composites for Wind Turbine Blades Applications

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Abstract. Blades in wind turbine present a vital role. They are airfoil shaped blades. they harness wind energy and drive the rotor of a wind turbine. Composite materials are the mostly used for the fabrication of blades. They exhibit many high mechanical properties such as high tensile and bending stiffness and weight. These properties give the blades structures more efficiency than using other material. This article presents the results of many experimental analyses performed on a E-glass fiber reinforced composite with polyester resin matrix. E-glass fibers are used as main reinforcement in the composites dedicated to wind turbine blades applications. The composite specimens were produced using a manual lay-up method. Quasi-static tensile and three point bending analyses were conducted to determine the tensile and bending behavior of the composite materials. Different fiber volume fraction was tested in order to determine their effect on the mechanical properties. It was found that the young's modulus, ultimate strength and strain to failure increase with the fiber volume fraction. Also, the results show that the increase of the fiber volume fraction has a substantial influence on the bending performances (modulus and strength). The results obtained show that the composite material made with E-glass fiber (mat type) give high mechanical characteristics under tensile and bending tests.

Keywords: Glass fibers · Composite · Tensile test · Bending test · Wind turbine blades

1 Introduction

The structure of wind turbine is affected, nowadays, with the advancements in material technology. Composite material has become widely used in wind structures due to their high mechanical properties, weight and high corrosion resistance. The blades present the very important component in the efficiency of wind structures. In this case, composite material has been used by all turbine manufacturers (Eker et al. 2006)

L. Walha et al. (Eds.): CMSM 2021, LNME, pp. 901–908, 2023.
https://doi.org/10.1007/978-3-031-14615-2_101

Glass fiber reinforced polymer composite is used in different industrial applications. The mechanical properties of the composite material depend on the fiber and matrix strength and fiber orientation. They are used in marine and piping industries as well as in the wind turbine blade applications. The static behavior of unidirectional glass fiber reinforced composites with epoxy resin as matrix is studied (Torabizadeh 2013). The results show that the young's modulus and the tensile strength increase when the temperature decreases. The shear stress-strain curves show a nonlinear behavior at all temperatures. Sandwich structure with E-glass fiber reinforced composite and foam core is studied under impact test (Srivastava 2012; Adekomaya and Adama 2017). This type of material is used in a various industrial application due to their high bending property and their high resistance to corrosion. The failure mode of the sandwich specimens is the delamination between skin/core, the shear damage at the core and the tensile failure in the skins.

Sathishkumar et al. (2014) studied the static and dynamic characteristics of glass fiber reinforced composites. The highest bending and tensile strength are obtained for the composite with 25% volume fraction. Also, the results show that the young's modulus increase with the glass fiber volume fraction. The damage characterization of glass fiber reinforced composite is determined during tensile test (Harizi et al. 2014). They defined the different damage status of the material. This is useful to monitor the damage evolution during static loading. Finite element methods are also utilized to study the mechanical properties of composite material (Pandav and Sawant 2017). In addition, the fiber orientation and the thickness of glass fiber reinforced composite is reviewed (Sikarwar et al. 2014). The experimental results show that the glass/epoxy composites present good agreement with impact loading when the young's modulus at higher strain rate are considered. Also, the damage area decreases when the speed of the projectile increases. The effect of the stress concentration on the fatigue life of the glass fiber reinforced composite is also tested (Ferdous et al. 2020; Movahedi-Rad et al. 2018).

This paper presents the mechanical behavior of E-glass reinforced composite with a polyester resin as matrix. The quasi-static tensile and bending tests are conducted on the composite with different fiber volume fraction. The material is manufactured with a manual lay-up method. The young's modulus, tensile and bending strength are determined and compared.

2 Material and Manufacturing

The glass-fiber reinforced composite considered in this paper is made from commercial dry rolls of glass fibers used as non-woven E-glass mat version obtained from cut fibers arranged without preferential orientation. The glass fibers have a mass density of 300 g/m^2 and young's modulus of 72 GPa. The tensile strength of the glass fibers used in the composite material is 3.45 GPa. Three different reinforcement volume fractions were used; 18%, 22% and 26%. The fiber volume fraction of 18% is the one that gives a structure with a single layer of reinforcement. The maximum fiber volume fraction that can be used to manufacture the composite with a homogeneous distribution of the reinforcement over the thickness is 26%. The fiber volume fraction of 22% is the value in the middle. The matrix type was an unsaturated polyester orthophthalic resin mixed with 2% hardener and 0.5% catalyst. It is a very common thermosetting resin in the composites industry. It presents good mechanical properties such as good impact resistance, a very good ability to impregnate glass fibers and low price. The tensile strength of the orthophthalic polyester is 50 to 75 MPa and the Young's modulus is 3.2 to 4.5 GPa (Krawczak and Pabiot 1991). Glass-fiber plies were first cut from the roll. The mold used is a frame wood with 400 mm and 300 mm of length and width. The thickness is of 2 mm. The wax is used as a release agent for the mold and the fibers were cut to the size and type needed. A manual lay-up method is used to fabricate the composite plates, as shown of Fig. 1. They were cured at room temperature for 24 h. After demolding, the composite plates were kept at room temperature for one or two weeks in order to obtain complete polymerization of the resin. Then, the specimens were cut up using a numerically controlled machine tool. To avoid edges effect on the response of the material, 10 mm length were cut up with each specimen.

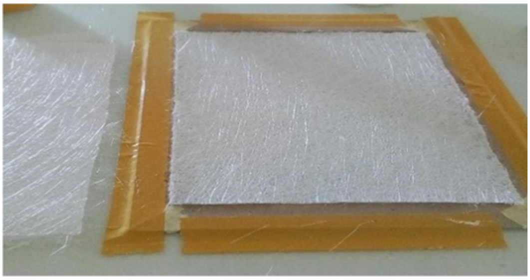

Fig. 1. Manufacturing process of composite material

3 Experimental Set-Up

The properties of the glass fibers–reinforced composites are determined under tensile test. The composite materials were catted according to the ASTM standard D638. The tensile test is conducted using a universal machine MTS with a load cell of 200 kN and rate of 5 mm/min, as shown in Fig. 2. The composite materials are tested in order to determine their mechanical properties. The displacement of the traverse of the machine is used to calculate the strain. The specimens having a constant rectangular cross section with a clamping length of 10 mm. For the tensile test, the tested beams have an effective length of 50 mm, a width of 10 mm and a thickness of 2 mm.

Three-point bending tests were conducted using the universal machine MTS, as shown in Fig. 3. The quasi-static load was performed at a displacement rate of 10 mm/min with 200 kN load sensor. For the bending test, the tested beams have a length of 100 mm, a width of 15 mm and a thickness of 2 mm. The span length is 80 mm. Tests were performed to evaluate the bending stiffness (Eq. 1) and bending modulus (Eq. 2):

$$\sigma = \frac{3FL}{2bh^2} \tag{1}$$

Fig. 2. Tensile test set-up

$$E = \frac{FL^3}{2wbh^3} \quad (2)$$

with: F is the load, L is the span length, h is the thickness, b is the width, w is the displacement. The test is repeated three times in order to take into account the variability of the results due to the experimental conditions.

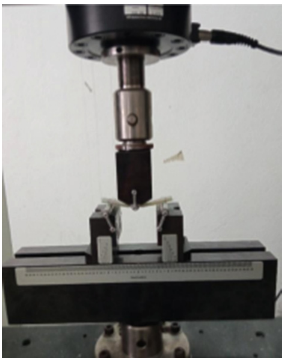

Fig. 3. Three-point bending test set-up

4 Results

The experimental tensile tests were performed on specimens of glass-fibers reinforced composite with different glass fiber volume fraction. The stress-strain curves derived from recorded data is presented in Fig. 4. Different mechanical properties can be calculated from the presented results such as young's modulus, ultimate strength and strain to failure. The result shows that the increase of the glass fiber volume fraction increase the performance of the composite material. The young's modulus is 2.7 GPa, 2.8 GPa and 2.9 GPa for the composite with glass fiber volume fraction of 18%, 22% and 26%, respectively. Also, the Ultimate strength is of 133 MPa for the composite with 18% fiber volume fraction, 149 MPa for the composite with 22% fiber volume fraction and 175 MPa for the composite with 26% fiber volume fraction. Finally, the strain to failure is increased with 20% when the volume fraction of the glass fibers is increased from 18% to 26%.

The tensile properties of the studied material (polyester/glass fibers) can be compared with the composite made with polypropylene/glass fibers dedicated to wind turbine blades (Elhenawy et al. 2021). Polyester/glass fibers presents remarkable improvement in the tensile strength compared to composite with polypropylene/glass fibers. In addition, natural fibers are used as composite reinforcement for wind turbine blades. Natural fibers are ecological and present high strength (Holmes et al. 2009). However, they present low thermal stability (Kalagi et al. 2016).

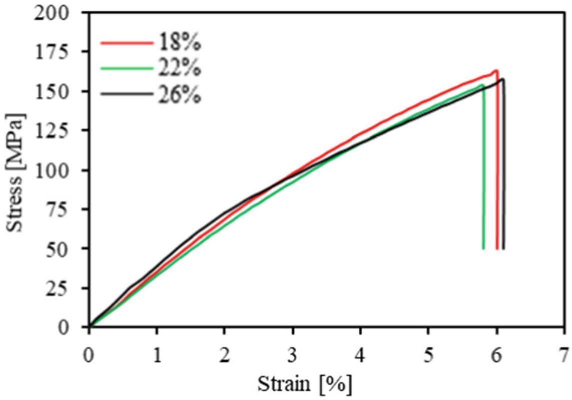

Fig. 4. Stress-strain curves under tensile test

The glass fiber reinforced composite with different fiber volume fraction were tested under three-point bending test. The span length is of 80 mm. Figure 5 presents the stress-strain curves obtained for the different configurations. Firstly, a linear elastic domain extends up to a strain of about 1.5% for the different configurations studied. Then, the beams exhibit a shorter nonlinear behavior until the break. Results show that the fiber volume fraction has a significant effect on the mechanical properties of the composite under bending test. The composite with a fiber volume fraction of 26% presents the higher bending modulus and bending strength. The bending modulus of the composite with 26% fiber reinforcement is 12.7 GPa and it is equal to 6.3 GPa for the composite with 18% fiber reinforcement. Also, bending strength is increased with 25% when the fiber volume fraction increase with 8%.

The mechanical properties of the tested composite materials under tensile and three-point bending test are summarized in Table 1.

One can conclude that this material would be suitable for wind turbine blades applications. The tensile and three-point bending characterization were studied, revealing interesting mechanical properties for this composite material. For more mechanical stability while reducing the mass, sandwich composite with auxetic core could probably

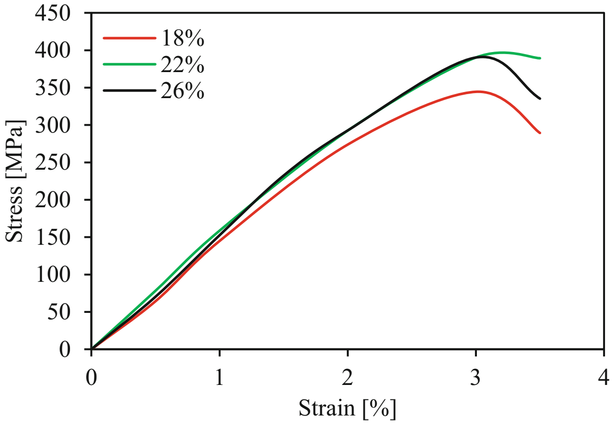

Fig. 5. Stress-strain curves under three-point bending test

Table 1. Mechanical properties of the composite materials.

Fiber volume fraction		18%	22%	26%
Tensile test	Modulus [MPa]	2777 ± 21	2879 ± 6	2919 ± 3
	Ultimate strength [MPa]	133 ± 4	149 ± 2	175 ± 3
	Strain to failure [%]	4.8 ± 0.21	5.1 ± 0.24	6 ± 0.26
Three-point bending test	Modulus [MPa]	6342 ± 56	6556 ± 89	6739 ± 128
	Strength [MPa]	289 ± 16	335 ± 19	389 ± 44

help to enhance the static properties of the wind blades. Experimental tests, involving dynamic study of the composites (Essassi et al. 2019; 2021) can be made. In addition, fatigue behavior and compression properties of the composite must be determined (Essassi et al. 2021(1); 2022).

5 Conclusion

This work presents an experimental analysis of the quasi-static tensile and bending properties of E-glass reinforced composite with a polyester resin as matrix. This structure is produced by a manual lay-up method. Different fiber volume fraction was tested: 18%, 22% and 26%. The results taken from tensile tests show that the young's modulus, ultimate strength and strain to failure increase with the fiber volume fraction. Also, the bending performance (modulus and strength) increase when the fiber volume fraction increase.

Acknowledgements. The South African and Tunisian authors acknowledge the South African and Tunisia Research Cooperation Program 2019 (SATN 180718350459) for partially supporting this research. The authors gratefully acknowledge the assistance and support of KIMIBURG to elaborate this work. The authors also thank the CEO, Dr. Dhafer Ben Salah, for providing the materials for the elaboration of the composites.

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