Compression behaviour study for glass fiberglass-reinforced plastics used in the construction of wind turbine blades

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Abstract. Classical materials of whose manufacturing requires high energy consumption have begun to be replaced by composite materials, as a better alternative to energy and environmental problems caused by the production of the classic ones. The design of blades with a high efficiency that are resistant and having deformations within the allowable limits and as a mass as small as possible is not a simple problem. Currently, the use of composite materials in the construction of blades is a perfect solution but determining the structure with optimal strength requires finding a compromise between the strength limits of materials and costs. In the assembly of a wind turbine, the critical component is the blade and thus the material for the construction of wind turbine blade (WTB) must have high rigidity, fatigue strength, low weight, and good wear resistance. This paper presents the results obtained at compression on the glass fibre reinforced plastics (GFRP) composite, used in the construction of turbine blades. To increase service life and to investigate defects during operation, compression tests have been performed to determine the mechanical properties of [0°/90°] and [±45°] reinforced specimens in accordance with ASTM D3410.

1. Introduction
Due to the increase in global energy consumption, new strategies to increase the efficiency of renewable energy are developed. These resources, as well as production technologies with lower negative influence as possible on the environment, are a priority for the future. In recent years, wind turbine blade manufacturers have been looking for new design solutions to ensure long blade to increase the production of the green energy. Another constructive solution is for the blade to be rigid enough not to deform under the action of loads, but at the same time to be light, meaning to rotate at a minimum wind speed of 4.5-5 m/s. In the structure of a wind turbine, the turbine blade is the most important component, and the design process involves the knowledge of several factors: resistance to variable stresses, external loads from wind and gravity, the basic material used [1].

The materials used in the construction of wind turbine blades must have low density, be rigid to prevent large deformation of the blades, have a high resistance to fatigue and degradation [2,3]. Large parts of the blades are made of composite that are materials consisting of several constituents, incorporated in a continuous phase called matrix material. The blade cover that defines the aerodynamic profile is typically constructed of composites with polymer matrix (PMC) [4]. The most widely used composite material in the wind turbine industry is fiberglass reinforced plastics (GFRP). This type of material meets the following characteristics: good mechanical properties, good corrosion resistance, favourable production cost compared to carbon fibre reinforced composites (CFRP) [5].
most cases, glass-reinforced composites are made of E-glass, because they have good mechanical and electrical properties, and high heat resistance [6]. An analysis of the evolution of degradations in wind turbine blades shows that the most common degradations are exfoliation of the protective layer, delamination in the composite material, failure of individual layers, delamination and cracks in the protective layer, delamination between fabric and matrix, but also joints with improper adhesive, Figure 1. It was found that areas with a high presence of damage appear at a distance of 1/3 of the length from the tip of the blade to the fixing area in the rotor [7].

![Figure 1. Different types of blade damage [9].](image)

Wind turbine blades work in hard conditions, such as: the impact by hitting of birds, variable stress (fatigue), vibration, ice deposition, variations in humidity and temperature, the action of UV rays. Due to defects that may occur during operation, new methods of self-repairing of the polymeric material have been searched [8]. The paper aims to evaluate the possibility of self-repair of wind turbine blades by inserting spherical microcapsules in the polymer matrix. During crack propagation, the microcapsules initially filled with an adhesive will break and stop cracking.

Two-way compression tests of the GFRP material from which the wind turbine blades are made are performed. In addition to the compressive stress, the stress variation curves were also obtained. The latter was obtained by mounting strain gauge in the section to be broken. The stress-strain variation was obtained as long as the strain gauge allowed this. As a result, the importance of these determinations is the tracing of the characteristics \( \sigma - \epsilon \), for the two studied cases, even if not until the fracture, at least for a field of interest, beyond the elastic limit.

2. **Studied samples**
Samples cropped from reinforced composite plates at \([0^\circ / 90^\circ]\) and \([\pm 45^\circ]\) with Epikote MGS LR 385 fiber glass, manufactured by SC Compozite S.R.L. Brasov were taken into consideration. The specimens comply with the provisions of the ASTM D3410 standard [10]. The cross-sectional dimensions of the specimens with fiber orientation at \([0^\circ / 90^\circ]\) are 7.92mm × 7.74mm, and for specimens with fiber orientation at \([\pm 45^\circ]\) the dimensions are 7.26mm × 7.26mm, Figure 2. The method consists in subjecting the composite specimen to compression, on which strain gauge are glued, on the central calibration portion, having a length of 12.7 mm (Figure 3). To eliminate the buckling of the device, the ends of each test piece were embedded in aluminium fixtures, glued with a two-component epoxy adhesive.
3. Experimental set-up and results

Compression tests were performed on reinforced specimens with orientation at [0° / 90°] type 1 and with orientation at [± 45°] type 2. In order to establish the longitudinal modulus of elasticity of the material, a resistive electrical transducer (TER) was glued on one side of the specimen in the direction of the test force. The strain gauge used was type EA-13-249LZ-120, manufactured by VISHAY, and has the following characteristics: electrical resistance $R = 120\Omega \pm 0.35\%$, factor gauge $k_G = 2.095 \pm 0.5\%$, transverse sensitivity factor $K_T = 0.2\%$. The adhesive used for gluing TER was Z70 (HBM). For TER application, the surface of the specimen was polished with P100 sandpaper (Bosch) and cleaned with isopropyl alcohol (STF 85/2000). After maintaining the pressure applied on the TER glued for 24 hours (to complete the polymerization and attenuate the residual stresses developed during this time), a polyurethane M-coat insulating varnish was applied and the connection cables to the P3 Vishay bridge were tinned (Figure 4).

![Figure 2. Raw plates at [0°/90°] and [±45°].](image)

![Figure 3. Specimen of compression test (IITRI method) [11].](image)

![Figure 4. Reinforced test piece [0° / 90°] [± 45°], ready for compression testing.](image)

![Figure 5. INSTRON 8801 testing machine.](image)
Compression tests were performed on an INSTRON 8801 test machine (Figure 5), which developed a maximum force of 100kN. The test regime was established by the deformation growth rate of 0.5 mm/min. Normal tension and modulus of elasticity or calculated with the following relations:

\[ \sigma = \frac{N}{A} ; \quad E_{11} = \frac{\sigma_{11}}{\varepsilon_{11}} \]  

(1)

where \( N \) = axial force; \( A \) = cross section area; \( \sigma_{11} \) = normal stress; \( \varepsilon_{11} \) = specific deformation.

Following the compression test for the type 1 test specimen, an average compressive strength of \( \sigma_{c90} = 1769 \) MPa and a longitudinal modulus of elasticity of \( E_{c90} = 18051 \) MPa were determined. In Figure 6 shows the characteristic compression curve for the test piece with reinforcement at \([0^\circ / 90^\circ]\). The modulus is determined as the slope of the graph approximation line represented in the normal stress /specific longitudinal strain coordinates, \( \sigma-\varepsilon \) by the points determined from the force value records by the Instron 8801 and the specific longitudinal deformations recorded from TER. To determine the slope of the curve approximation line, the feature of MS Excel to display the approximation line equation (trendline) has been used, finding: \( y = 18051x - 6.183 \) (Figure 7).

\[ y = 18051x - 6.183 \]

Figure 6. Characteristic curve to compression for type 1 specimens (reinforcement at 0°/ 90°).

Following the compression test for the type 2 specimen, an average compressive strength of \( \sigma_{c45} = 106 \) MPa and a longitudinal modulus of elasticity of \( E_{c90} = 7661 \) MPa were determined. Figure 8 shows the characteristic compression curve for the test piece with reinforcement at \([+45^\circ / -45^\circ]\). And in this case the module is determined as the slope of the graph approximation line represented in the normal voltage /specific longitudinal deformation coordinates, \( \sigma-\varepsilon \) by the points determined from the
recordings of force values by the Instron 8801 and specific longitudinal deformations recorded from TER. The slope of the approximation line of the curve was determined as above, finding $y = 18051x - 6,183$ (Figure 9).

![Figure 8](characteristic_curve_to_compression_for_type_2_specimens_reinforcement_at_plus_45_to_minus_45.png)

**Figure 8** Characteristic curve to compression for type 2 specimens (reinforcement at +45°/-45°).

![Figure 9](determination_of_elastic_modulus_E_c_45_equals_7661_MPa.png)

**Figure 9** Determination of elastic modulus $E_{c45} = 7661$ MPa.

4. Conclusions
It is found that for the specimens of type 1 (reinforcement at 0°/90°) values of the longitudinal modulus of elasticity and of the tensile strength were obtained higher than the values recorded in the tests on the specimens of type 2 (reinforcement at +45°/-45°). This is due to the larger cross section for specimen type 1. The cut specimens of type 2 enter the area of plastic deformations at a lower value than the cut specimens of type 1. It follows that the specimens with fiber orientation at 0°/90° are more advantageous for the compression stress. In this case, it is recommended to lay the fibers at 0°/90° for wind turbine blades, as they have a high compressive strength. The obtained results demonstrate that this material used in the construction of wind turbine blades, can be used with confidence, meeting the design requirements.

5. References

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