Some aspects regarding the influence of humidity on the tensile characteristics of GFRP composite material

C Morăraş, P D Barsanescu and C A Tugui

1Mechanical Engineering, Mechatronics and Robotics Department, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania
2Materials Processing Technologies and Equipment Department, “Gheorghe Asachi” Technical University of Iasi, Iasi, Romania
e-mail: moraras.ciprian@yahoo.com

Abstract. Composite materials have experienced great development in recent years, replacing traditional materials. Designed as metastructures, their properties recommend them in different fields, from sports materials to those in aeronautic and energy industries. In combinations of metallic layers or composites based on carbon/glass fibers, the properties of these materials allowed both the miniaturization of devices and the construction of large lightweight components. The paper aims to present the results of the tensile evaluation of the glass fiber reinforced plastics (GFRP), used in the construction of wind turbine blades. The blades are the most critical components of the wind turbines, being exposed to the damage and the defects that appear during operation can lead to the loss of the integrity of the blade structure. In order to increase the lifetime and to study the defects during operation, tensile tests were performed to determine the mechanical properties on a dry specimen, reinforced at [0 ° / 90 °], and the results obtained were compared with two specimens subjected to immersion in water for 14 and 21 days, two other specimens were immersed in seawater (Black Sea) for 14 and 21 days and one specimen was immersed in liquid nitrogen for 4 days.

1. Introduction

Wind energy is the energy resource with the fastest development. Wind energy is widely used today and has an important role in global energy development. Due to the increase in energy consumption, the major trend of wind energy is the design and construction of larger wind turbines, but this process involves many aspects: manufacturing, material use, stresses during operation (compound stresses, environmental factors, shocks).

In most cases, the wind turbine blades (WTB) are made from composite materials. These materials present a good ratio between strength and weight, are resistant to fatigue, having low density. A type of composite material used in the construction of wind turbines is glass fiber reinforced plastics (GFRP). It is recommended due to corrosion and impact resistance, lower production cost than carbon fibers reinforced plastics (CFRP). Studies have been carried out in [1] and [2] on the mechanical and elastic characteristics for different orientations of glass fibers reinforcement promoting them to use in the construction of WTB.

Experimentally, the water absorption after 4800 h, and the degradation of the mechanical properties on the transversal direction to the fibers, for composite materials with polymeric matrix were studied, resulting in the decreasing of the longitudinal modulus of elasticity E between 55% and 65% [3]. It has
been shown that moisture plays a significant role in the long-term durability of GFRP, influencing the mechanical properties of composite materials [4]. The results of experimental researches [5] have been demonstrated the degradation of mechanical characteristics due to moisture absorption in the case of unidirectional or bidirectional reinforced composite materials.

Manfredi L.B. and others [6] studied the effect of water absorption in epoxy matrix composite material and found that water absorption affects both the matrix and the fiber-matrix interface, causing micromechanical damage, which visibly leads to a decrease in the mechanical properties of the studied material.

Imielinska K. et al. [7] studied the behaviour of fiberglass-reinforced epoxy composite material and obtained results that demonstrate that water absorption has a negative effect on the studied material. Thus, the water content affected the microstructural integrity of the material, causing internal defects. Exposure of the polymeric matrix composite material to the aggressive environment caused severe degradation in the matrix fiber interface, as well as excessive fiber detachment [8].

2. Studied samples
In this work, tensile tests were performed on specimen made of GFRP material, immersed in tap water and in sea water containing certain salts. The immersion was performed for several days, respectively: 14 days and 21 days. In addition, an immersion in liquid nitrogen was performed for 4 days at the initial temperature of -70°C. The results obtained from the tensile test, in terms of specific stresses and strain, were compared with each other and those of the initial dry sample. Immersions in tap water, salt water and liquid nitrogen of the GFRP samples were made to see the influence of humidity, existing salts or low temperature.

The aspects taken into consideration to determine the influences of humidity and low temperature are: the shape of the stress-strain characteristic curve, the value of the ultimate tensile strength, the value of the maximum strains, the energy below the force-displacement curve representing the energy that can be taken by the sample. All samples were made of the same plates of GFRP, in the direction of 0° longitudinal fibres (Figure 1).

Figure 1. Raw plates at [0°/90°] and [±45°].

Figure 2. Dimensions of the specimens, according to ASTM D639.

The studied specimens were cropped according to ASTM D639 (Figure 2). The preparation of the tests was carried out in the Materials Strength workshop of the Faculty of Mechanical Engineering.

Cl⁻ ions present in water is determined by volumetric methods based on precipitation reactions. Cl⁻ ions reacts with AgNO₃ in neutral environment to form insoluble silver chloride.

\[ \text{Cl}^- + \text{AgNO}_3 \rightarrow \text{AgCl}↓ + \text{NO}_3^- \]

The ions SO₄²⁻ present in the water is determined by precipitation with a solution of BaCl₂. The reaction that occurs is:

\[ \text{SO}_4^{2-} + \text{BaCl}_2 \rightarrow \text{BaSO}_4↓ + 2\text{Cl}^- \]
Table 1. Determination of Cl⁻ and $SO_4^{2-}$ anions in seawater and tap water.

| The determined size | Seawater  | Tap water (Prut source) |
|---------------------|-----------|-------------------------|
| pH                  | 8         | 6.5                     |
| Cl⁻ (mg/l)          | 884       | 359                     |
| $SO_4^{2-}$ (mg/l)  | 659       | 495                     |

Sea water has slightly basic pH, and low acid pH tap water. The concentration of Cl⁻ ions in seawater is 2.46 times higher than the concentration of Cl⁻ ions in tap water. In the case of, $SO_4^{2-}$ ions seawater has a much higher content than tap water. The presence of Cl⁻ and $SO_4^{2-}$ anions and in high quantity in sea water causes more severe oxidizing properties of sea water than tap water.

3. Experimental set-up and results
Each of the immersed samples was loaded for tension test on an INSTRON 8801 machine, at a maximum force of 100kN, Figure 5. The test regime was established by the deformation growth rate of 0.5 mm / min.
Figure 7 shows the characteristic stress-strain curves for all immersion cases, including the nitrogen-immersed sample. The analysis of these curves shows the following:
- reported to the dry sample, all other samples have lower ultimate tensile strength;
- reported to the dry sample, the strains are higher.
In these conditions, it can be shown that with immersion, in tap water, in salt water or in liquid nitrogen, there are significant changes in tension characteristics: ultimate strength tensile, maximum strains and even Young's modules.

Based on the characteristic curves, the following diagrams were plotted, respectively:
- Figure 8 – variation of ultimate strength tensile for each sample immersed in function of the number of immersion days;
- Figure 9 - the variation of maximum strains for each sample immersed in function of the number of immersion days;
- Figure 10 – The deformation energy of the samples calculated as the area under the strain– stress curves depending on the number of immersion days for immersion in normal water, salt water and nitrogen;
- Figure 11 – The deformation energy of the samples taken separately for 14 days of immersion and for 21 days of immersion.

**Figure 7.** Characteristic curve stress-strain for all samples.

**Figure 8.** Ultimate tensile stress variation versus to the number of immersion days.
Figure 8 shows the following:
- The highest ultimate tensile strength is for the dry, un-immersed sample;
- As the samples have been immersed for longer, the ultimate tensile strength decreases;
- The decrease is slightly higher in samples immersed in salt water, the greater the decrease the greater the number of immersion days;
- As mentioned above, the liquid nitrogen sample was in contact with nitrogen throughout the surface for four days. It is found that we also have a decrease in ultimate tensile strength. This decrease is not as large as in samples immersed in water and taken out after 14 and 21 days respectively.

Regarding the change of the maximum strain in relation to the immersion time and the type of water used, Figure 9, we observe the following:
- In relation to the non-immersed sample, maximum strains are higher for any of the cases studied, including the liquid nitrogen sample;
- With the increase in immersion time, regardless of the type of water used, the maximum strain increases;
- After 14 days of immersion, the maximum strain is higher in the case of seawater use;
- After 21 days of immersion, the maximum strain is higher in the case of normal water use;
- As it can be seen in Figure 7, the highest value of the maximum strain is recorded for the sample immersed in liquid nitrogen.

![Maximum strain variation](image)

**Figure 9.** Maximum strain variation versus to the number of immersion days.

On the basis of the records of the change in the loading force F [N] reported to the elongation, Δl [m] of the sample, the area below the corresponding curves are calculated. Given the shape of the curves in Figure 6, it can be said that the area determined by the variation F-Δl represents the deformation energy, for the most part, elastic. Elastic deformation energy is an indicator of the ability of wind turbine blades to absorb, through elastic deformation, the wind energy representing external demand. The calculated energy was in J [N•m]. From the observation of variations in Figure 10, the following can be concluded from:
- The energy accumulated by deformation (elastic) is lower in the case of all samples immersed in relation to the non-immersed (dry) sample;
- The deformation energy decreases with the increase in immersion time for all samples;
- 14 days after immersion, there is no significant difference between the deformation energy that can be accumulated in the saltwater sample compared to the normal water sample;
- 21 days after immersion, the deformation energy that can be accumulated in the saltwater sample is significantly lower than the energy that can be accumulated by the submerged sample in normal water.
- For the sample immersed in liquid nitrogen, the decrease is less pronounced than for all samples immersed in water.

Figure 10. Energy under the curve strain-stress versus to the number of immersion days

Figure 11 shows the values of the deformation energies, on time levels. As previously observed, it is observed that 14 days after immersion, there are no significant differences between the deformation energies, in the case of immersion in normal water compared to immersion in water. The difference is significant after 21 days of immersion, to the detriment of immersion salt water.

Figure 11. Energy under the curve strain-stress for each immersed sample.

4. Conclusions
In this paper, a study was performed on the influence of immersion in normal water, seawater, and liquid nitrogen of GFRP samples. Previously, specimen from GFRP were prepared for tensile test. It has been found that some of the characteristics studied based on the tensile test have experienced significant variations in immersion cases.

In all cases, the ultimate tensile strength has a lower value in the case of immersion. For this reason, it is considered that the surface of a wind turbine blade which has damaged coating, water can
infiltrate, and ultimate tensile strength can decrease sharply. There is also a decrease in the deformation energy (elastic) in all cases of immersion. This leads to a lower possibility of converting wind energy into elastic deformation energy, given that water enters the volume of the material.

Both the ultimate tensile strength and the deformation energy are lower in the case of immersion in salt water. And immersion in nitrogen leads to a decrease in both ultimate tensile strength and deformation energy. These decreases are not as great as in the case of immersion in water (normal and salty) maybe also because the immersion time was much shorter. The only parameter that has higher values after immersion is strain, for all cases.

5. References
[1] Goanta V, Hadar A and Bogdan Leitoiu 2010 Experimental Procedure Designed to Determine the Elastic Characteristics of Fiber-Reinforced Polymeric Composite Materials Materiale Plastice 47(4) pp 450-456
[2] Steigmann R, Savin A, Goanta V and Barsanescu P D 2016 Determination of mechanical properties of some glass fiber reinforced plastics suitable to Wind Turbine Blade construction IOP Conf. Series: Materials Science and Engineering 147 012140 doi:10.1088/1757-899X/147/1/012140
[3] Pomies F, Carlson L A and Gillespie J.W 1995 Marine environmental effects on polymer matrix composites Composite Materials: Fatigue and Fracture 5 ASTM STP 1230 Martin R H, Ed., American Society for Testing and Materials, Philadelphia pp 283-286
[4] Cerbu C 2007 Aspecte privind degradarea caracteristicilor elastice si mecanice de încovoiere ale materialelor compozite sticlã / polimer din cauza absorbției de umiditate, revista MATERIALE PLASTICE 44(2)
[5] Corum J.M, Battiste R.L., Ruggles M.B and Ren W 2001 Durability – based design criteria for a chopped-glass-fiber automotive structural composite Composite Science and Technology 61 pp 1083-1085
[6] Manfredi L B, De Santis and Vázquez A 2008 Influence of the addition of montmorillonite to the matrix of unidirectional glass fibre/epoxy composites on their mechanical and water absorption properties Composites: Part A 39 pp1726-1731
[7] Imielinska K and Guillaumat L 2004 The effect of water immersion ageing on low-velocity impact behaviour of woven aramid-glass fibre/epoxy composites Composite Science and Technology 64 pp 2271-2278
[8] Ramirez F.A, Carlsson L.A, and Acha, B.A. 2008 Evaluation of environmental effects on polymer matrix composites by micromechanical and macromechanical tests 13th European Conference on Composites Materials (13-ECCM), Stockholm, Sweden, June 2-5