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Determination and analysis of mechanical properties of composite material used in national manufactured wind turbine Blades

Determinación y análisis de propiedades mecánicas de materiales compuestos utilizados en álabes de turbinas eólicas de manufactura nacional

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Abstract

This article presents the analysis and determination of the mechanical properties under tension, for a composite material reinforced with uniaxial fiberglass and polymeric matrix, under the considerations set out in the ISO 527 standards, through mechanical tests. The mechanical properties obtained and analyzed were the Modulus of Elasticity, the maximum stress, the strains and the Poisson's ratio. The expected theoretical results are determined in advance and these data were used in the finite element program to estimate the actual failure and observe the deformations against the applied loads. In the end, both results were compared, and it was observed that better results were obtained in the experimental tests than those estimated, obtaining the uncertainty parameter in the same way. Giving input to future investigations for the determination of the other mechanical components of said composite material and to be able to estimate the failure in the blades of national manufacture, through the finite element program.

Fiber-matrix composite, Mechanical properties, Volume fraction

Resumen

Este articulo presenta el análisis y la determinación de las propiedades mecánicas a tensión, para un material compuesto reforzado con fibra de vidrio uniaxial y una matriz polimérica, bajo las consideraciones marcadas en las normas ISO 527, a través de ensayos mecánicos. Las propiedades mecánicas obtenidas y analizadas fueron los Módulos de elasticidad, los esfuerzos máximos, las deformaciones unitarias y el coeficiente de Poisson. Se determinan de antemano los resultados teóricos esperados y se utilizaron dichos datos en el programa computacional de elemento finito para estimar la falla real y observar las deformaciones contra las cargas aplicadas. Al final se compararon ambos resultados y se observó que se obtuvieron mejores resultados en las pruebas experimentales que las estimadas, obteniendo de igual manera el parámetro de incertidumbre. Dando entrada a futuras investigaciones para la determinación de las otras componentes mecánicas de dicho material compuesto y poder estimar la falla en los álabes de manufactura nacional, a través del programa computacional de elemento finito.

Compuesto de fibra con matriz, Propiedades mecánicas, Fracción volumétrica

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Introduction

Currently, the demand for electricity is increasing, being the case of Mexico, the majority acquisition of this resource is through the burning of fossil fuels or coal burning causing great pollution. One of the alternatives that have arisen for a long time are clean or alternative energies, which are considered non-polluting during the operating process, but in the same way they pollute in the manufacturing process as the waste of the material that remains at the end of its operation. useful life. In the case of wind turbines, there are mainly two groups, the so-called HAWTs for its acronym in English, horizontal axis wind turbines, which predominate by the amount of energy power they can provide and the so-called VAWTs, for its acronym in English. Vertical axis wind turbines, which are mainly characterized by the low energy power they supply, however they have certain characteristics such as operation at low speeds other than horizontal ones. [one]

The design of the blades is mainly oriented to the various issues and equations of aerodynamics [1, 2], however, the materials used primarily composite materials, have to be able to resist the stresses and structural loads produced by wind currents. As of the same structure of the turbine, for this the IEC 61400-1 standard is used as a follow-up principle, but due to this, the safety factors are very high to guarantee the useful life of the turbine itself.

Therefore it is sought to determine the mechanical properties of the composite material reinforced with fiberglass, for the case of investigation, since it is the main material used for the manufacture of national blades. Where later the finite element computer program will be used, since it is desired to reduce the failure factor in the blade and thus be able to reduce the safety factor of the IEC 61400-1 standard, hoping that this will reduce the number of layers necessary in the manufacture of the blades, reducing costs, times, weight and even post-life waste.

Methodology

Composite material is called a combination of two or more different or equal base materials, in order to obtain a new material with better properties. [3]

The composite material to be used in this research is fiberglass combined with a polymeric matrix, called epoxy resin. Fiberglass is used as reinforcement in various branches such as wind power; fiberglass can be found as filaments and usually together forming sheets where the same fibers can be found oriented at 0 °, ± 45 °, ± 90 ° with respect to an axis of symmetry. These arrangements are known as uniaxial, biaxial and in the case of having a combination of three orientations, triaxial. Obtaining individual sheets or combinations of various arrangements. [4]

The resins or matrices are used in the compound to be able to transmit the loads to the individual fibers, distributing the loads between them and protecting them from environmental effects. [4]

Composite materials behave mainly as orthotropic materials, where the orientation of the load influences such as the orientation in which the fibers are found, generating a large number of variables. The study of macromechanics is referred to the behavior of the composite material where the material is assumed homogeneous and the detected properties are considered as an average. However, in the study of micromechanics, it is referred to the behavior of the composite material where the material is examined individually. [5] Giving input to the theoretical estimation of the mechanical properties of the composite material either as a whole or separately, assuming that there are certain initial variables such as the Modulus of elasticity of each material among others.

Micromechanical behavior

The properties of a sheet of composite material can be obtained through experimentation or can be estimated mathematically through the materials constituted. [5] For this, the modulus of elasticity of the fiber is determined and in the same way the modulus of elasticity corresponding to the matrix, through the theorem of "Volumetric fraction".[5]

$$V_f = \frac{\frac{M_f}{\rho_f}}{\frac{M_f}{\rho_f}+\frac{M_m}{\rho_m}} \tag{1}$$

Where:

V_f = It is the ratio between the volume of the fibers and the total volume of the composite material.

ρ_f, ρ_m = It is the density of the fiber and the matrix.

M_f, M_m = It is the mass fraction of the fiber and the matrix, these being equal to the ratio between the mass of the fibers and the mass of the compound and in the same way for the matrix.

Taking into consideration that the mass fraction of the compound will be equal to 1, equivalent to the sum of the mass fraction of the fiber and the matrix. [5]

$$M_f + M_m = 1 \quad (2)$$

Therefore, the volumetric fraction of the compound is equal to 1, this being the sum of the volumetric fraction of the fiber and the matrix. [5]

$$V_f + V_m = 1 \quad (3)$$

The modulus of elasticity referred to the main direction of the composite material is determined as: [5]

$$E_1 = E_f V_f + E_m V_m \quad (4)$$

Where:

E_f, E_m = They are the modulus of elasticity of the fiber and the matrix, respectively.

The stress in the main direction is then obtained from: [5]

$$\sigma_1 = E_1 \varepsilon_1 \quad (5)$$

Either an estimate of the expected displacement or the total deformation of the composite is available. For the case of determining the modulus of elasticity perpendicular to the main axis, we have: [5]

$$E_2 = \frac{E_f E_m}{V_m E_f + V_f E_m} \quad (6)$$

Knowing the estimated displacement or deformation for the secondary axis or having the estimated force, the missing variable will be determined: [5]

$$\sigma_2 = E_2 \varepsilon_2 = E_2 \left[V_f \frac{\sigma_2}{E_f} + V_m \frac{\sigma_2}{E_m} \right] \quad (7)$$

The Poisson's ratio v_12, is obtained by the following equation, where the deformations are referred to the maximum stress: [5]

$$v_{12} = -\frac{\varepsilon_2}{\varepsilon_1} \quad (8)$$

To determine v_21, it must be determined experimentally or considering the composite material as orthotropic, but elastic for this situation, being:

$$\frac{v_{21}}{E_2} = \frac{v_{12}}{E_1} \quad (9)$$

The maximum strain theorem is used to determine the estimated fracture point of the composite material, being:

$$\varepsilon_1 = \frac{1}{E_1}[\sigma_1 - v_{12}\sigma_2] \quad (10)$$

$$\varepsilon_2 = \frac{1}{E_2}[\sigma_2 - v_{21}\sigma_1] \quad (11)$$

Mechanical tests

The mechanical tests are necessary to be able to have the experimental data and to be able to have a more true reference point when comparing the theoretical data or to be able to make estimates of maximum stresses or failure points in more complex structures that have the material to be analyzed. For this, the ISO 527-1 standard will be used as a reference, in which it marks that the test consists of elongating a specimen to its maximum length values, along its longitudinal axis, at a constant speed until reaching the fracture of the specimen or until predetermined values of load stress or longitudinal deformation are reached. This standard establishes the operating conditions for obtaining the data, as well as the general equations for measuring the slope of the modulus of elasticity, the maximum stresses in the direction of the load or on the longitudinal axis, and the stress with respect to the axis. perpendicular to the load or secondary. [6]

In ISO 527.-5, the test conditions are specified to determine tensile properties emphasizing the test method is suitable for all polymeric matrix systems reinforced with unidirectional fibers. [7] The modulus of elasticity or Young's is determined by the developed principle of Hooke's law, where the slope between two points that indicates the norm is considered, being:

$$E_t = \frac{\sigma'' - \sigma'}{\varepsilon'' - \varepsilon'} \tag{12}$$

Where:

E_t = Slope modulus of elasticity (GPa)

σ'' = It is the stress in the direction of the load, at the deformation instant ε ^ ", (MPa)

σ' = It is the stress in the direction of the load, at the deformation instant ε ^ ', (MPa)

Conditions for test speed, minimum sampling quantity and other operational considerations are found in ISO 527-1.

Experimental development

For the manufacture of the specimens, the UE glass fibers were used with a ratio of weight per area of 1182 g / m^2 with a fiber density of 2.6 g / cm3 and the epoxy resin135 with a density of 1.13 g / cm^3 was used as matrix. cm3, obtained from technical and commercial data sheets, being Saertex for fibers.

Two types of test pieces were manufactured, the dimensions of which are established in the ISO 527-5 standard, for which 6 test pieces of each type were obtained, having a fiber arrangement of 0 ° and 90 ° depending on the case. To comply with the test conditions established by the standard, a plate was manufactured with 2 layers of uniaxial glass fibers, where the mold was prepared to be able to perform the infusion and continuous monitoring was carried out throughout the infusion process until reaching the curing point of the resin. Controlling the temperature through a prefabricated oven for said activity and an equivalent temperature was supplied to be able to obtain a temperature on the surface of the plate between 70 ° C - 80 ° C, maintaining it until the final curing process, this being among the 10hr - 12hr.

The final thickness that was obtained due to the two layers was 1.8mm, which caused that the cuts in the plate to be able to obtain the dimensions of the specimens, would have to be by water jet, both to avoid deformations and delamination by the heat produced by the cutting disc. So-called "end taps" or flange reinforcements were added to the test tubes. These eyelash reinforcements were manufactured with biaxial fiberglass, as a substitute for some other material, following the conditions of the standard, the adhesive used was an epoxy adhesive, which supported the load conditions set by the standard. In Figure 1 the specimens are observed after cutting.

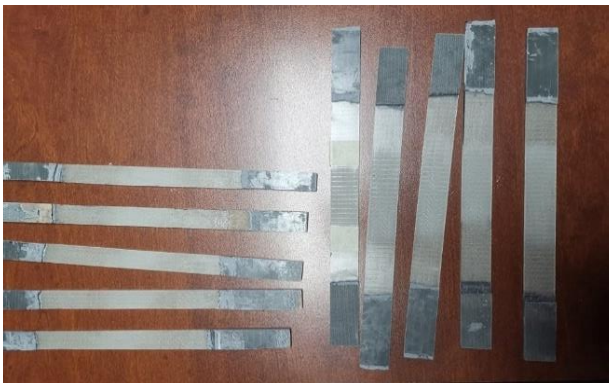


Figure 1 Specimens for stress testing

Theoretical calculations

The calculation of the volumetric fraction was solved using equation (1), however, the technical data sheet of the composite material already provided this data and only the remaining variables were obtained for the matrix with equation (2) and equation (3) . With these results and the densities of the materials, the moduli of elasticity were theoretically obtained, the maximum expected stresses were obtained through equation (5) and equation (7) taking as reference the deformations obtained by experimental tests of colleagues from the CIATEQ research center [8], in the same way the expected failure strain is added, using equation (10) and equation (11). The theoretical results are shown in Table 1.

Material	Et [GPa]	ε	σ [MPa]	ε (failure)
Uniaxial 0 °	42.44	0.018	750	0.017
Uniaxial 90 °	6.28	0.009	56	-

Table 1 Theoretical results

Tension tests

The tests carried out were carried out for two types of specimens, type A and type B, as indicated by the ISO 527-5 standard in order to obtain the maximum efforts in the directions of the loads, such as displacements and modulus of elasticity. In Figure 2 the positioning of the type A specimen is shown, before carrying out the test, as in Figure 3 the detachment of the fibers is observed at the end of the test.

Figure 2 Start of stress test

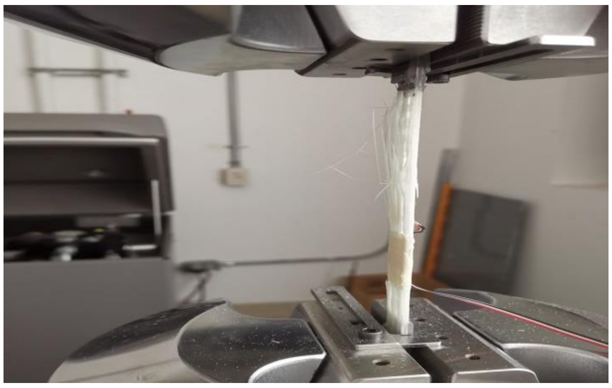
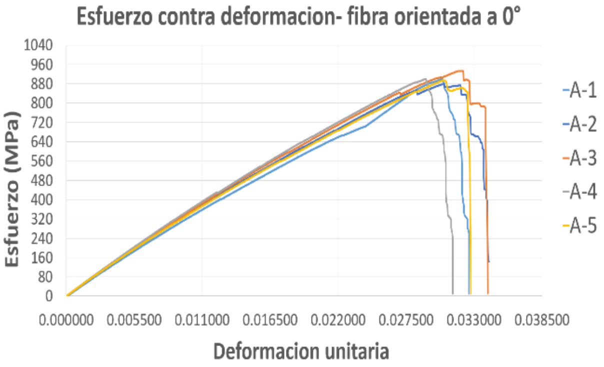


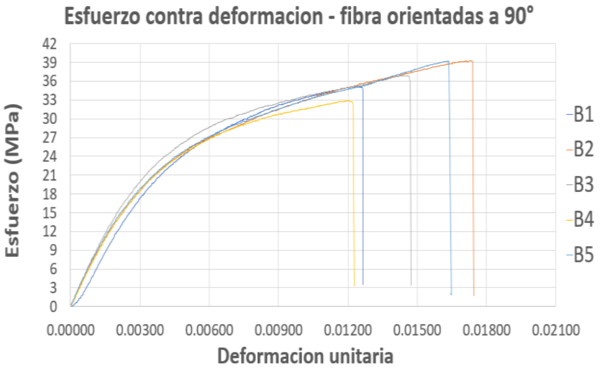
Figure 3 Specimen fracture

In Graph 1 you can see the different curves obtained from the 5 tests carried out for type A specimens for uniaxial fiberglass with the fibers oriented at 0 ° with respect to the load axis, this being the stress versus deformation graph.



Graphic 1 Stress versus strain curves, type A specimens

In Graphic 2 you can see the different curves obtained from the 5 tests carried out for the type B specimens for uniaxial fiberglass with the fibers oriented at 90 ° with respect to the load axis, this being the stress versus deformation graph.



Graphic 2 Stress versus deformation curves, type B specimens

Results

During the mechanical tests, a monitoring of the temperature was carried out, as well as the humidity in the test tubes to avoid that these variables were affected in the tests. Table 2 shows the results of the graphs, analyzed using the mean of the results, equivalent to the standard uncertainty. [9] However, since it did not evaluate the coefficient of variation, it was decided to use the uncertainty parameter Rk for tensile properties. [14]

This parameter is specified in the GL2010 standard, where it is defined to:

$$R_k = \bar{x}\left[1 - \nu\left[1.645 + \frac{1.645}{\sqrt{n}}\right]\right] \quad (13)$$

Where:

$\bar{x}$ = It is the mean of the variable.

ν = Variation coefficient of the variables with respect to the number of tests.

n = Number of tests.

Evidence	Et [GPa]	ε ($due\ to\ equation\ 5$)	σ [MPa]	ε (real fault)
Uniaxial 0 °	36.548	0.024	900.96	0.031
Uniaxial 90 °	6.29	0.0058	36.65	0.0147

Table 2 Experimental results analyzed with the standard uncertainty factor, equivalent to the mean

The results obtained through the uncertainty parameter Rk, for the fibers oriented at 0 ° and at 90 ° with respect to the load, being for the tests type A and type B, respectively, are shown in Table 3.

Specimens type A						
n	$\bar{\sigma}$	D.	ν	R_k, σ	R_k, E	R_k, ε
#	MPa	MPa	%	MPa	GPa	%
5	900.9	20.4	2.2	852.4	34.06	2.84
Specimen type B						
n	$\bar{\sigma}$	D.	ν	R_k, σ	R_k, E	R_k, ε
#	MPa	MPa	%	MPa	GPa	%
5	36.6	2.74	7.5	30.1	5.8	0.93

Table 3 Data analysis with the uncertainty parameter Rk

Analysis of the results

The volumetric fraction values were acquired through the fiberglass technical sheet, in Saertex [10]. However, as a matter of study interest, small coupons of the composite material were manufactured to experimentally determine the percentage of resin that remained in the fiber plate, where the results obtained through the weight of the material and the percentage of the volume, using the equation (1), coincided with the data in the technical sheet, for which the same reference data was continued. Being for the volumetric fraction of the fiber equal to 51.1% and 70.6% for the mass fraction of the fiber.

The deformations used as reference [8] are of a fiber with a density 17% lower than the density of the fiber in the analysis of this investigation.

For the case of the modulus of elasticity, it is observed that in the main direction 1 for the results of the fibers oriented at 0 °, there is a negative difference of 13.9% of the experimental results with respect to the theoretical ones. However, the unit deformation in elastic conditions or the slope of the Modulus of elasticity Et, is 25% better in the real results than in the theoretical ones, without considering that the real results give the estimate of the deformation in the fracture and for In this case, the real results indicate a 45.2% improvement, which suggests that this is due to the fact that there is a greater quantity of fiberglass filaments and it could be estimated that they are finer due to the density differential that exists between the reference and experimental data. Also observing that there is a 17.6% positive difference in the experimental results referred to the maximum stress in tension.

For the case of the modulus of elasticity in the secondary direction 2 for the results of the fibers oriented at 90 °, there is a positive difference of 0.2% in the experimental results. For the deformation results, it is observed that there is a negative 35.6% difference with respect to the experimental results.

The data for both types of tests were obtained at the same constant speed, under the same environmental conditions, by using an MTS universal machine, with a maximum load capacity equal to 100 KN.

By analyzing the results using the uncertainty parameter Rk, reference values are obtained for future research regarding the stress tests of this fiberglass. [14]

For the case of the tensile stress in the principal direction 1, we have σ¯= 900.9 MPa, but applying the uncertainty parameter Rk, we obtain that σ_1 = 852.4 MPa, obtaining a difference of 5.3%. For the case of the Modulus of elasticity Et = 36.54 GPa, applying the uncertainty parameter Et-1 = 34.06 GPa, being a difference of 6.8%. In the case of the unit deformation of the failure, we have ε = 0.031, applying the uncertainty parameter ε1 = 0.0284, having a difference of 8.3%.

For the case of the tensile stress in the principal direction 2, we have σ¯= 36.6 MPa, applying the uncertainty parameter σ_2 = 30.1 MPa, having a difference of 17.7%. For the Modulus of elasticity Et = 6.29 GPa, applying the uncertainty parameter we have Et-2 = 5.8 GPa, having a difference of 7.8%. Analyzing the unit deformation, we have ε = 0.0147, applying the uncertainty parameter we have ε_2 = 0.0093, having a difference of 36.7%.

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Conclusions

The mechanical tests were carried out in a controlled environment where it was monitored that there were no considerable changes with respect to the temperature and humidity of the place, so that these factors were not interpreted in the tests. The main difference observed in the curves for the two types of test is estimated to be due to the manufacturing process, since despite having control throughout the testing process and the same manufacturing process, there are factors that They cannot be controlled, because the manufacturing process of the test tubes is influenced by human handling, as well as there is no means to determine that the flow of the resin behaves in the same way during the infusion process since the Specimens were manufactured by two layers of fibers, this can cause there to be a deviation, no matter how small, and cannot be detected during its manufacture. The difference between the theoretical and experimental results for the type A test or with the fibers oriented at 0 ° from the load axis, analyzing them with the uncertainty parameter Rk, a positive difference of 12% was obtained for the stress σ_1, a negative difference of 19.7% for the Modulus of elasticity E1 and a positive difference of 40.1% for the strain at fault ε_1. For type B tests or with the fibers oriented 90 ° from the load axis, analyzing them with the uncertainty parameter Rk, there is a negative difference of 46.25% for the stress σ_2, a negative difference of 7.6% for the Modulus of elasticity E2 and a positive difference of 3.2% for the strain at fault ε_2.

These results being considerable enough to be able to make use only of the theoretical ones and with them to be able to use the data in the finite element program, however, they give an estimate of the properties. In order to make use of the finite element computer program and simulate structural stresses, more experimental tests must be carried out and the missing efforts, deformations and moduli of elasticity must be obtained, in order to reduce the error and thus be able to simulate in larger pieces.

Another observation data is that the data acquisition was through the extensometer of the same machine and respecting the conditions of the ISO 527-1 and ISO 527-5 standards, however, a detail of interest is that, for type tests B, the fracture was partially horizontal, but for future research it would be good to use biaxial strain gauges in type A specimens and to compare the results obtained for direction 2 with those obtained in type B tests.

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