Experimental and Theoretical Studies on Mechanical Characteristics of an Important Composite Material

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Polymeric composites are widely used materials in very complex parts, because of their special characteristics. There are theoretical relationships which can be used in predicting a composite material characteristic values (stress, elasticity modulus, elongation etc) but, reality proved that these relations are not so accurate. So, determining real values of polymeric composite material important mechanical characteristics is essential for parts exploitation resistance and reliability calculi. This paper presents experimental and theoretical studies for determining a random reinforced glass fiber polymeric composite material mechanical characteristics, pointing out the importance of knowing real values of these characteristics in parts designing. The obtained results are, also, confirmed by statistical data processing while, importance of the involved studies is evidenced by a case study finite element ANSYS simulation.

Keywords: polymeric matrix, reinforcing element, glass fibers, composite, mechanical characteristics

Nowadays market challenges, based on economy and efficiency of the manufacturing process, as well as various customers needs, resulted in the development of new and high quality materials, such as composites. Scientists have defined composite materials in many ways [5], [10], but, the common idea of all these definitions is that composites represent artificial materials, made of two basic, not-mixable, components represented by the *matrix* and the *reinforcing elements*.

There are many polymeric composite types, widely used in various fields as, automotive, navy and aircraft industry; customer goods manufacturing (skies, skates, surf boards); medical equipment production, etc.

When the matrix is made of polymeric materials and the reinforcing element is glass -fibers or flakes type, then the composite is called glass reinforced polymeric composite material. The percentage of these composites type, considering all composites manufactured, is estimated to be exceeding the value of 90% [10]. For commonly manufactured glass fibers reinforced polymeric composites, the glass fibers content does not exceed percentage value of 40% – if discontinuous fibers are used but, can reach 60 % – if long fibers are used [6, 8].

Some important characteristics obtained by glass fibers reinforcing of polymeric materials can be stated as: increased values of elasticity modulus; higher tensile, bending and torque resistance; lower flow resistance; reduced thermal elongation coefficient; better resistance to chemical agents, when compared to ordinary metallic materials.

Properties of polymeric matrix composite materials do vary to a high extent, for the same material type, from a batch to another, or, even from one point, to the other, of the same batch / product. There are a lot of factors that do influence composite characteristics, some of the most important being: component type; component volume or, mass, ratio; shape and dimensions of the reinforcing element; orientation and position of the reinforcing element into the matrix; bounder conditions of reinforcing element and matrix; real manufacturing conditions when components, as well as the resulting composite material, are obtained [7].

Other mechanical characteristics influencing factors can be also the speed of ageing process and the environmental humidity. Usually, glass fibers reinforced polymeric matrix composites are the most sensitive to medium humidity because of the fact that both component materials (matrix and reinforcing element) are water sensitive.

Schematic representation of the factors that do influence polymeric composite characteristics is shown in figure 1.

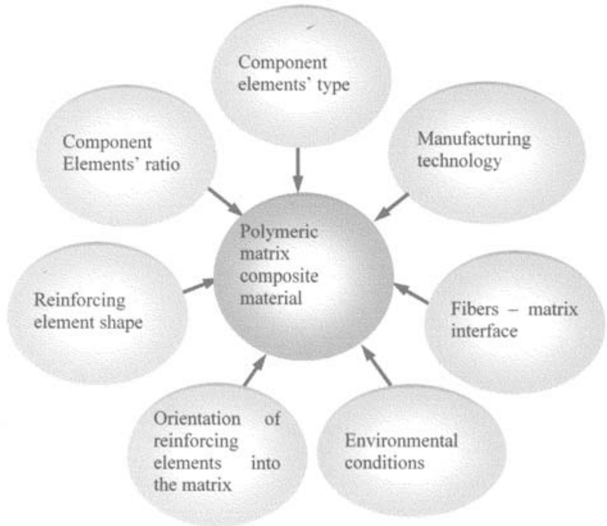

Fig. 1. Influencing factors of polymeric composite characteristics

A thorough study of specific literature has resulted in very poor data on polymeric composite material properties, especially when considering its special particularities, as: reinforcing element disposal, percentage of fibers content, composite manufacturing technology, etc. The composite characteristic values,

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determined by theoretical models are significantly different from the real ones, noticed while experimenting [1,10].

Considering the above presented facts and, specially, the high influence that polymeric composite's mechanical characteristics have on composite products exploitation behaviour [3], a study on some mechanical characteristics of a random reinforced glass fibers composite material has been carried out. By comparing the obtained results with the ones determined through theoretical mathematical relationships (presented by the specific literature) there has been noticed that there is not a good concordance i.e. there is a high discrepancy between theoretical values compared to real ones. Statistical processing of experimentally obtained results enhanced the importance of the study. Also, a case study done with finite element analysis, meaning simulation with ANSYS software, points out, once more, the importance of knowing real mechanical characteristic values specific to each part composite material.

Experimental part

The studied polymeric composite is a multiphase material, that requires complete description, with reference to the composition and geometry variables, and to the manufacturing technology [1]. It's worth to be mentioned that this material is an important one, due to its important characteristics which enabled to be used in various complex and special parts (navy, aircraft and/ or automotive components, high pressure resistance elements, etc.)

So, for a complete "definition" of the composite material used in experimental tests, there must be stated the aspects that follows:

- components type: reinforcing element is glass fibers EC12-2400-P1800(65) while the matrix is polyester resin Aropol S 599;
- volume ratio: 30% glass fibers and 70% polyester resin;
- shape and dimensions of the reinforcing element: short glass fibers with beam diameter, d = 12 [μm] and length density of 2400 [tex];
- orientation and position of the reinforcing element, into the matrix: short fibers random orientation;
- composite material manufacturing technology: spraying.

Determining tensile characteristics of random glass fibers reinforced polymeric materials is performed in accordance with SR EN ISO 527:2000 standard specifications. The method involves tensile loading along the main axis of a sample, at constant speed, until it fails or, till the moment when the loading / strain gets to the pre-established value. In testing, the sample is fixed into the testing machine clamping elements so that its main axis to be identically with the one of the testing unit. The traction speed is the same as the speed of the clamping elements and, it is about 1 mm/min.

In order to determine the required characteristics values, there were used five samples, whose shape is identically to standard specification (SR EN ISO 527-4:2000) (fig. 2), while prescribed and real dimensions are the ones mentioned in table 1 and, respectively, table 2.

Avoiding sample cracking or, sample slippery out of the fixing clamps or, even worse, the possibility of having the sample fixed into only one of the fixing clamps, the sample dimensions used in experiments were set to their upper values.

Real samples were obtained by milling procedure, out of the corresponding rough material, as specified by SR EN ISO 293:2003 standard. Each of the experiments samples, got a code number, for an easier analysis and study of their tensile behaviour (fig. 3).

As for the testing unit, there has been used a special testing machine, LFV 25 HH WALTER-BAI. Image taken while experimenting is presented in figure 4.

Table 1

TENSILE STRENGTH SAMPLE DIMENSIONS - ACCORDING TO SR EN ISO 527 - 4:2000

Dimension	Symbol	Value [mm]
Total lngth	l_3	150
Extreme part width	b_2	20±0,2
Thickness	h	4 ... 10
Narrow part length	l_1	60±0,5
Narrow part width	b_1	10±0,2
Reference length	L_0	50±0,5
Distance between fixing clamps	L	115±1

Table 2

REAL DIMENSIONS OF EXPERIMENTAL SAMPLES

Sample No.	l_3 [mm]	b_1 [mm]	h [mm]	b_2 [mm]
T1	150.01	10	9.93	19.99
T2	150.30	9.92	10.03	20.18
T3	150.17	9.84	10.15	19.88
T4	150.16	9.86	9.66	20.20
T5	150.09	9.91	9.99	19.93

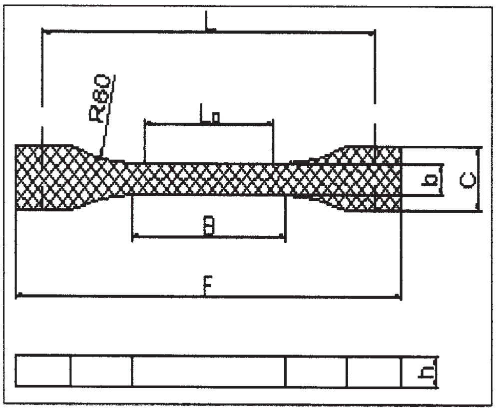

Fig. 2. Sample geometric characteristics, according to SR EN ISO 527-4:2000

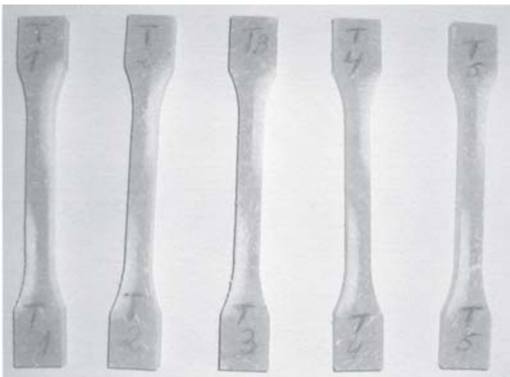

Fig. 3. Samples before experimenting

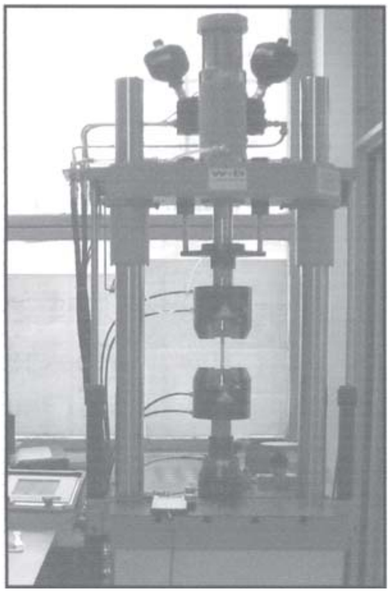

Fig. 4. Stand for tensile strength experiments

Results and discussions

Broken samples, after tensile experiments were carried on, are shown in figure 5. A thorough study of the samples' failure surface would point out that the fibers were completely broken and plugged out of the matrix.

When observing the experimental values of the tensile strength and elasticity modulus obtained, there can be noticed some variability of the experimentally obtained data. That can be because of material unhomogenity, or internal faults of these materials (inclusions, voids, etc.), or of real manufacturing conditions. The experimentally obtained average values for mechanical characetsristics studied were: tensile stress, 92.44 MPa; elasticity modulus, 5.9 GPa and elongation, 0.88%

Fig. 5. Samples after experimenting

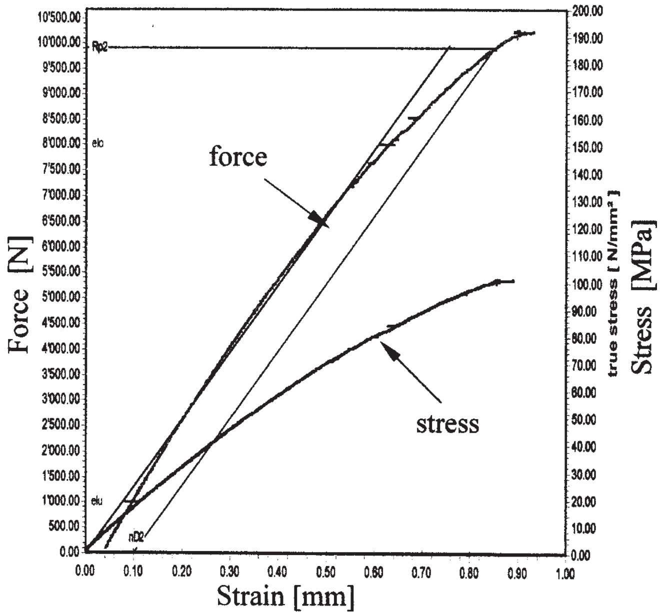

Fig. 6. Curve variation of studied parameters - for T2 sample

The force / stress and strain graphs, obtained for two of the studied samples (polymeric matrix composite material, reinforced with 30% glass fibers elements – T2 and T5) are presented in figure 6 and, respectively, figure 7.

An experimental result is complete if it contains, both the measured value and the measurement error. Statistical processing of experimental data has been carried out, in order to prove and to enhance the reliability and importance of the obtained results.

The measuring target is defined by the characteristic to be measured and, for the involved experiments, the measuring target is represented by the tensile strength value.The measurement error (uncertainty) characterizes the variance of measuring result values, influenced by random errors [13].

So, measurement error can be calculated by the mathematical relation:

$$u_c = \sqrt{u_A^2 + u_B^2} \tag{1}$$

where:

u_A is the A type uncertainty determined by experimental data, of n successive measurements for the same measuring point;

u_B – the B type uncertainty determined from the components:

u_1 – calibrating error, specified into the measuring device certificate;

u_2 – measurement error, due to the temperature real values.

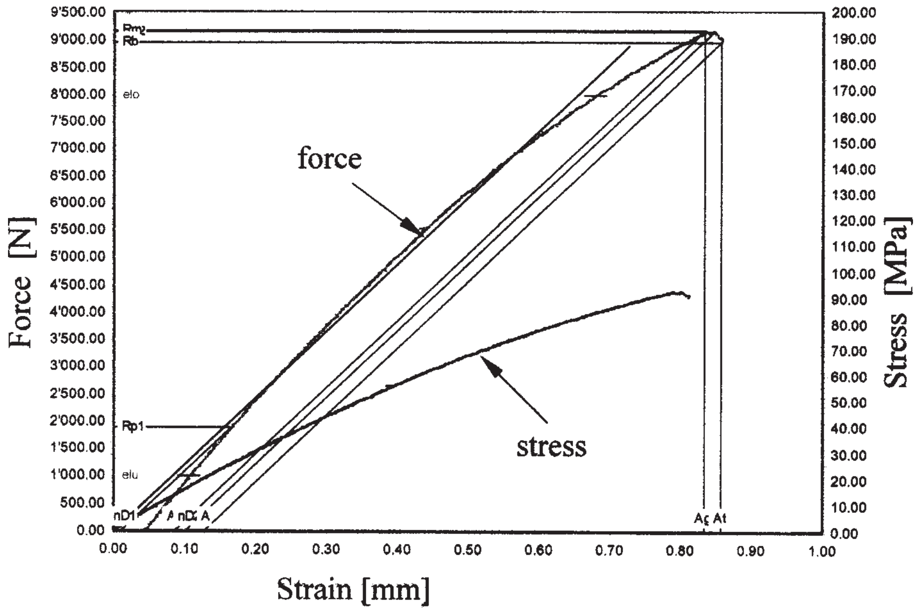

Fig. 7. Curve variation of studied parameters - for T5 sample

Standard error, for the studied sample, is considered to be: $u_A = s(\bar{y})$ so, the next values have been obtained:

$$\bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} = 92{,}44[MPa] \qquad s_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{(n-1)}} = 5{,}21606[MPa] \quad (2)$$

$$s(\bar{y}) = \frac{s(y)}{\sqrt{n}} = 2{,}33269[MPa] \quad \Rightarrow \quad u_A = s(\bar{y}) = 2{,}33269[MPa] \quad (3)$$

where:

$s(\bar{y})$ is the mean standard error;

s_y – experimental standard error ;

$\bar{y}$ - average mean of the validated results (tensile stress values), y_i.

Calibrating error of the measuring device is:

$$u_1 = \frac{U}{k} = \frac{0{,}003}{2} = 0{,}00150\ [MPa] \quad (4)$$

where :

U = 0.003 is the error specified by the calibrating certificate, for a 95% significance level.

Measurement error due to temperature influence is calculated by relation:

$$u_2 = u(\delta t) = \frac{Y \times \alpha \times \delta t}{\sqrt{3}} \quad (5)$$

knowing that:

Y – is the nominal value, to be measured;

α - thermal expansion coefficient of the measuring equipment ($\alpha = 11.5 \cdot 10^{-6}\ K^{-1}$)

Δt - estimated temperature variation, while measuring.

So, $$u_2 = \frac{92{,}44 \times 11{,}5 \times 10^{-6} \times 2}{\sqrt{3}} = 0{,}001227\ \text{[MPa]} \quad (6)$$

As result, total error is determined by:

$$u_c = \sqrt{u_A^2 + (u_1 + u_2)^2} = 2{,}332691\ [MPa] \quad (7)$$

and the extended measuring uncertainty is calculated:

$$U_{95\%} = k \times u_c = 4{,}66538\ [MPa]; \quad (k=2) \quad (8)$$

The measurement final results, are established considering the u_2 component neglected (as there was, an approximately constant temperature of 20[0]C) and thus:

$$X = \bar{y} \pm u_c = 92{,}44 \pm 2{,}332691\ [MPa] \quad (9)$$

The above data statistical processing proved and enhanced the experimental results obtained, pointing out the same average values for tensile stress and a dispersion of results, within the statistical predicted interval (9).

Estimating tensile strength and elasticity modulus values for random reinforced glass fibers polymeric composite materials can be done by specific equations of compound law, as follows [6]:

$$\Rightarrow \sigma_{MC} = \sigma_{MF} \cdot V_F + \sigma_{MM} \cdot V_M =$$
$$= 3450 \cdot 0.3 + 55 \cdot 0.7 = 1073.5\ [MPa] \quad (10)$$

where:

σ_{MC} – tensile stress of composite material ;

V_F –fibre volume ratio, $V_F = 0.3$;

V_M – matrix' volume ratio, VM = 0.7;

σ_{MF} -fiber tensile stress value,

$\sigma_{MF} = 3450$ [MPa]

σ_{MM} - matrix tensile stress value,

$\sigma_{MM} = 55$ [MPa];

and,

$$\Rightarrow E_C = E_F \cdot V_F + E_M \cdot V_M = 72400 \cdot 0.3 + 3700 \cdot 0.7 = 24.310\ [GPa] \quad (10)$$

where:

E_C – tensile elasticity modulus of the composite;

E_F – fiber's tensile elasticity modulus,

$E_F = 72400$ [MPa];

E_M – matrix tensile elasticity modulus,

$E_M = 3700$ [MPa];

as well as,

$$\Rightarrow A_C = A_F \cdot V_F + A_M \cdot V_M = 3{,}2 \cdot 0.3 + 1.5 \cdot 0.7 = 2.01\ [\%] \quad (11)$$

where:

A_C - elongation of composite material;

A_F – fiber elongation, $A_F = 3{,}2$ [%] ;

A_M –matrix elongation, $A_M = 1{,}5$ [%]

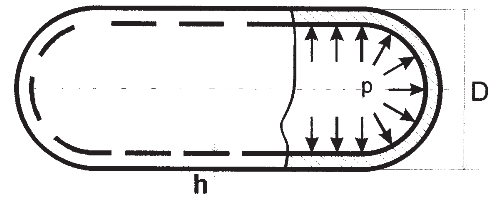

Fig.8. Geometrical characteristics of the studied model

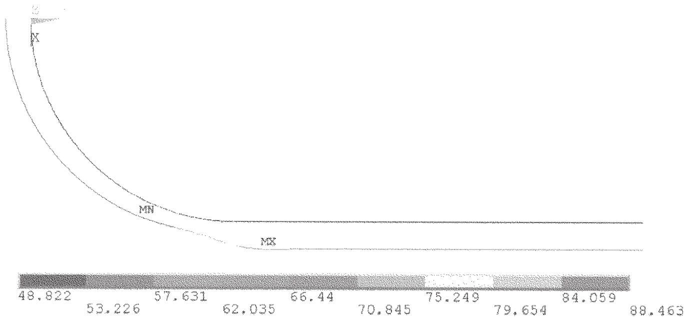

Fig. 9. Equivalent von Misses stresses for 1/8 of the pressure vessel model

For the studied glass fibers random reinforced composite material, it has been considered a case study – based on one of this material application. So, the part was supposed to be a cylindrical pressure vessel with hemispherical ends (fig. 8), subjected to internal pressures. The dimensions were: D = 100 mm, t = 10 mm and an applied constant pressure of 2 MPa was considered, all the above values being appropriate for common gas tanks. In fact, the pressure vessel length does not influence on the stress state induced by internal pressure but, in order to define the model, a 2 meters length has been considered for the cylindrical part of the pressure vessel.

The finite element analysis, with ANSYS software, has been done, considering the axial-symmetrical geometrical shape and loading thus, a 1/8 model was studied. The structure was meshed using the axial-symmetric shell 209 element, resulting a model with 178 elements. Once analyze performed, a maximum von Misses stress, about 89 MPa, resulted (9).

It can be noticed that this maximum value is within the range of 87.68 – 101.27 MPa, representing real tensile stress values for the studied random glass fibers reinforced polymeric composite material. So, if no real values of material mechanical charateristics are known, a waste of time, effort, material, money would be, as the part's design would be wrong.

Conclusions

Polymeric composites represent widely used materials, which have known a great extend, lately. The most important components of a polymeric material, meaning the matrix and the reinforcing element, as well as the composite manufacturing technology do significantly influence the real material characteristics.

Determining the real values of polymeric composite characteristics, such as tensile strain and stress, elasticty modulus or elongation, is necessary, knowing that these real characteristics involve good or, contrary, bad products' exploitation bahaviour .

For an important material, such as 30% glass fibers random reinforced polymeric matrix composite, specific references indicate tensile stress values about 103-206 [MPa] [4], [8]. The experimenatlly obtained values, of 87.68 – 101.27 [MPa] are, relatively close to the recommended ones but, much smaller than the theoretically and mathematically determined ones. That, can be due to the fact that compounds law does not „consider" all the real composite manufacturing conditions and assumes a series of simplifying hypothesis.

Statistical processing of the experimental data (for elasticity modulus values) enhanced the accuracy of obtained results.

A case study, by finite element analysis and ANSYS simulation pointed out the importance of knowing real mechanical characteristic of a composite material in the designing stage of the part to be used in exploitation.

Further research should be developed so as to determine other polymeric composites real mechanical characteristics, such as compressive strength, bending strength , etc. and, if possible, some dependence relations (regression models) of these real values characteristics on the influencing factors (reinforcing element ratio, glass fibres diameter, glass fibres length, matrix material type, etc.).

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