SIMULATION SOFTWARE DEVELOPMENT FOR ANALYSIS OF THE MECHANICAL BEHAVIOUR OF THE COMPOSITE MATERIALS

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ABSTRACT:
IN THE RECENT YEARS, THE COMPOSITE MATERIALS WERE USED FOR THE CONSTRUCTION OF THE STRUCTURES FROM THE MOST ENGINEERING AREAS. CARBON FIBER REINFORCED POLYMER IS A COMPOSITE MATERIAL THAT IS OFTEN USED IN AEROSPACE INDUSTRY. TO DEVELOP LIGHTWEIGHT ADVANCED MATERIALS IT IS IMPORTANT TO KNOW VERY WELL THE MECHANICAL BEHAVIOUR OF THESE MATERIALS UNDER DIFFERENT LOADING CONDITIONS. THIS PAPER PRESENTS THE WAY TO DEVELOP COMPUTING SOFTWARE OF THE TENSILE STRENGTH OF THE COMPOSITE MATERIALS USING THE GRAPHICAL PROGRAMMING. BASED ON SOME REAL VALUES OF THE TENSILE FORCES AND DISPLACEMENTS OBTAINED FROM THE TENSILE TEST OF CARBON FIBER SPECIMEN, ONE COMPUTES, BY THIS METHOD, THE TENSILE STRENGTH AND THE SPECIFIC ELONGATION OF THE MATERIAL.

KEY WORDS: *TENSILE STRENGTH, CARBON FIBER, LABVIEW, COMPUTING SOFTWARE, SPECIFIC ELONGATION.*

INTRODUCTION

The widespread use of the composite materials for all the mechanical structures means that it is a major interest in the development, analysis, designing of structural components realized by composite materials.

The composite materials are defined, in [1], [2], as being the solid and deformable bodies, which are obtained through the assembly, with the specific technological methods [1], of two or more distinct materials, from chemical point of view.

These composite materials are characterized [2], of the high resistance and stiffness, the inhomogeneous structure, the low weight, the insulator properties etc.

According to [3], the modern applications starts with the glass fibers followed by the more recent fibers as, carbon, aramid, boron, silicon carbide, etc. A typical example is the carbon fibers that are widespread used in the aerospace industry and for the sports equipment. These materials are of 5 – 10 times more resistant than the Aluminum alloys and these have only 60% from the alloys weight.

Due to the fact that these materials are used in the aerospace area, it is very important for a designer engineer to know its mechanical behavior under different loading conditions.

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This paper presents easy computing software that can be applied for the calculations from the strength of materials area, especially for the determination of the tensile and compressive strength. For the software development, a graphical programming environment was used, LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench). LabVIEW [6] is a system developed by NI (National Instruments) that allows the user to design software using a graphical language.

For the software testing, the real values of the initial data were used. These were extracted by the experimental testing of the carbon fiber specimen under tensile loading. A set of numerical were obtained and one draws the p – σ and p - Δℓ curves..

THEORETICAL BACKGROUND OF THE TENSILE STRENGTH COMPUTING

A more accurate knowledge of mechanical properties of the materials used in aerospace industry represents a very important condition for their more efficient use. The mechanical properties of materials are defined by established characteristics, representing their behavior working conditions and these are expressed by some parameters. The physical and mechanical properties of the materials determine the behavior of the structures from aerospace industry under different working conditions.

The determination of the mechanical characteristics is realized by the specimen testing using special testing machines, adequate for its task. During the testing it is followed the material behavior till the specimens fracture by acquiring the specific parameters and analyzing the values of these parameters and the fracture aspect.

In the real working conditions, the loading applied under the structures are eccentric; in these cases, it can appear besides the axial tensile force, *p*, some bending moments, M_{iy} and M_{iz}. According to [4], in the case of the eccentric traction, the total normal tensile stress is given by the relation:

$$\sigma = \frac{N}{A} + \frac{M_z y}{I_z} + \frac{M_y z}{I_y} = \frac{P}{A}\left(1 + \frac{y_P y}{t_z^2} + \frac{z_P z}{t_y^2}\right),$$

(1)

where i_z and i_y are the main inertial central radii of the cross section.

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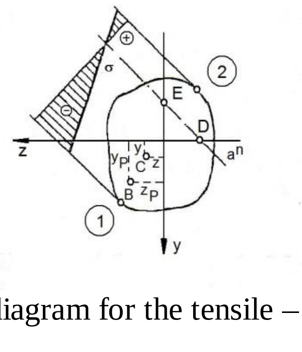


Fig. 1 The axial efforts diagram for the tensile – compressive loading [4]

For σ = 0, the neutral axis equation (a^n) results (Fig. 1):

$$1 + \frac{y_P y}{t_z^2} + \frac{z_P z}{t_y^2} = 0\,.$$

(2)

The neutral axis is a straight line that intersects the axis of the reference system in D and E points of coordinates:

$$\left.\begin{aligned} y_D = 0 \quad and \quad z_D = -\frac{i_y^2}{z_P}; \\ z_E = 0 \ \ and \ \ y_E = -\frac{i_z^2}{y_P} \end{aligned}\right\}.$$

(3)

The neutral axis divides the cross section in two parts, a bigger one where the tensile normal stresses are developed and a smaller one, with the compressive normal stresses. As in the case of the oblique bending, the value of the normal stress σ is proportional with the distance of the considered point to the neutral axis. If the neutral axis doesn't intersect the section surface, then in the section the tensile stresses are developed. The maximum normal stresses appear in the distant points of the neutral axis, (1) and (2):

$$\sigma_{1,2} = \frac{P}{A}\left(1 + \frac{y_P y_{1,2}}{i_z^2} + \frac{z_P z_{1,2}}{i_y^2}\right).$$

(4)

From the previous relations, some observations could be highlighted [5]:

- The neutral axis cross by the opposite frame to the one that contain the tensile force;
- If the specimen weight is neglected, then the position of the neutral axis depends only of the place where the tensile force is applied;
- From (3) results that the neutral axis is move away of the weight centre of the section when the tensile force is near; if the tensile force is move away then the neutral axis is near.

Based on the strength of materials considerations, software for the tensile strength determination was developed. It is considered, from [4] that the tensile strength can be determined with the relation:

$$\sigma_t = \left(\frac{p}{A} + \frac{M_{iy}}{W_y} + \frac{M_{iz}}{W_z}\right).$$

(5)

where: A is the cross sectional area of the specimen in [mm^2], p is the tensile force in [N], M_{iy}, M_{iz} represents the bending moments on Oz, respectively Oy axis in [Nmm], W_y, W_z are the axial strength modulus, on Oy, respectively Oz axis in [mm^3] and σ_t is the tensile strength of the material in [MPa].

According to [4], [5], W_y and W_z can be obtained using the following relations:

$$W_z = \frac{b \times h^2}{6} \ [mm^3];$$

(6)

$$W_y = \frac{h \times b^2}{6} \ [mm^3],$$

(7)

where: h is the thickness of the specimen in [mm] and b represents the width of the specimen in [mm].

For the determination of Mi_y and Mi_z, the following equations can be used [4]:

$$M_{iy} = p \cdot z \ \ and \ \ M_{iz} = p \cdot y,$$

(8)

where y is the distance from the tensile point to the Oz axis in [mm] and z represents the distance from the tensile point to the Oy axis in [mm].
The specific elongations were noted with $\Delta\ell$ and calculated using the relation (9):

$$\Delta\ell = \frac{\ell - \ell_0}{\ell_0} \cdot 100\,[\%],$$

(9)

where: ℓ is the displacement value, red on the p -ℓ curve, ℓ_0 is the initial length of the specimen and $\Delta\ell$ represents the specific elongation in [%].

MATERIALS AND METHODS

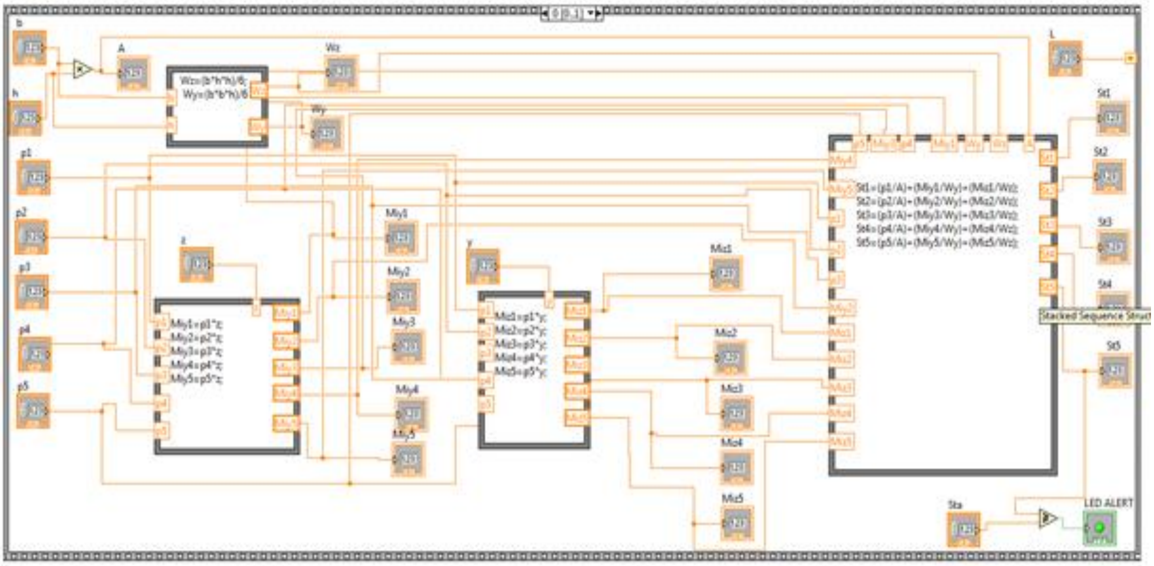
The tensile properties indicate how the material will react to forces being applied in tension. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, reduction in area, tensile strength, yield point, yield strength and other tensile properties.

The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up to fracture.

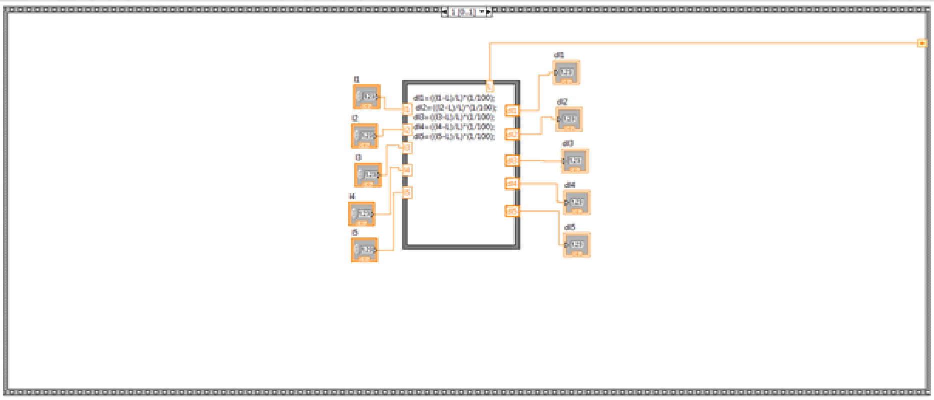
Using the mathematical relations from previous chapter, computing software for the determination of the tensile strength and the specific elongation was developed.

The LabVIEW software application is divided in two main parts: the diagram, or the code, where are created the links between the inputs and outputs and the panel, where the user introduces the inputs and obtain the outputs (results) that can be numerical or graphical.

For the developing of the mathematical algorithm, in the diagram a Stacked Sequence structure with two frames was used. The LabVIEW code (Fig. 2, a) and b)) contains mathematical elements and C++ based programming components as, Node Formula. One used this element to introduce the more difficult relations. In the first frame (Fig. 2, a) the determination of the tensile strength was performed and the second frame (Fig. 2, b) presents the way to obtain the specific elongations. In this case, a Node formula element was used, too.



a)



b)

Fig. 2. The LabVIEW code of the application of the simulation of the mechanical behaviour of the composite material: (a) first frame – tensile strength computing, (b) second frame – specific elongation computing

The panel of the software (Fig. 3) contains the controls (inputs) and the indicators (outputs). The inputs are placed in the left side of the panel (represents with green color) and the outputs that are marked with red color are placed in the right side. A LED was put on the panel to alert when the obtained tensile strength value exceeds the admissible value of the tensile strength that was set related to the used composite materials.

The specimen dimensions as length, width and the thickness, the tensile forces and the displacements were considered as being inputs and the outputs were the tensile strengths and the specific elongations. The values from the tensile forces and the displacements were been taken from the experimental data.

As the work procedure, after the introduction of the initial data, the developed software will compute the final values and will specify if the maximum value of the tensile strength is higher than the admissible value.

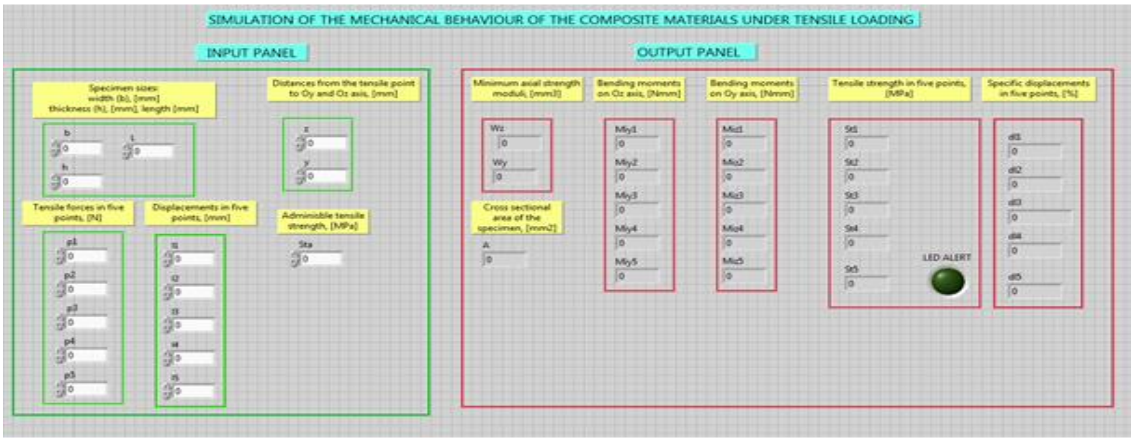


Fig. 3. The panel of the application of the simulation of the mechanical behaviour of the composite material

RESULTS

In order to test the functionality of the proposed LabVIEW algorithm, one used the real data extracted from the experimental results in the tensile loading conditions of a carbon fiber specimen. The geometrical dimensions of the specimen were considered 250 x 10 x 3 mm and the values of the tensile forces were red on the p - ℓ diagram from Fig. 4.

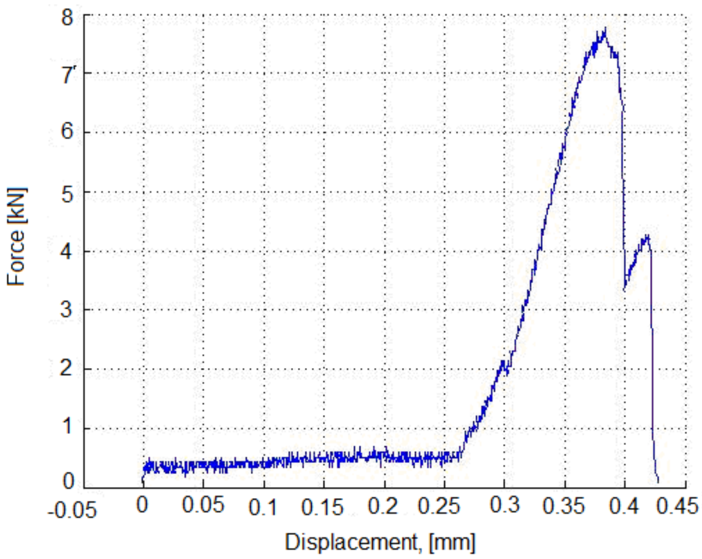


Fig. 4. The characteristic curve force – displacement for the case of tensile loading of the carbon fiber specimen

The admissible value of the tensile strength of the carbon fiber material used in aerospace industry was considered as being of 800 MPa. The values of the tensile forces and the displacements were centralized in the Table 1.

Table 1 Tensile forces and the displacements values.

Point	Tensile force (*N*)	Displacement (*mm*)
1	1450	0.05
2	2950	0.13
3	4450	0.24
4	5950	0.31
5	7450	0.38

Applying these values and considering the values for "z" and "y" as being 3 mm, respectively 1 mm, one computes by the software developed the tensile strengths corresponding to the five points, σ_t (in the LabVIEW panel σ_t is equal with *St*) and the specific elongations $\Delta\ell$ (that is *dl* in LabVIEW application). The numerical results obtained after the computations can be observed in Fig. 5.

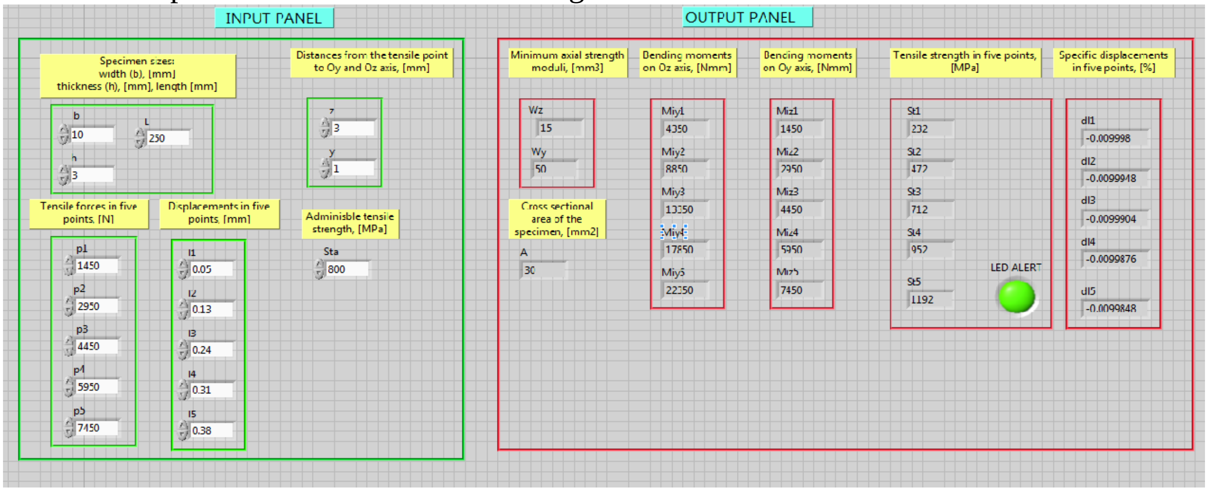


Fig. 5. The numerical results of strength of materials calculation using the graphical programming software

The numerical results were registered in Table 2.

Table 2 Tensile strengths and the specific elongations values.

Point	Tensile strength *(MPa)*	Specific elongation (%)
1	232	-0.009998
2	472	-0.009948
3	712	-0.0099904
4	952	-0.0099876
5	1192	-0.0099848

In order to comment the numerical results, the characteristic curves tensile force – tensile strength and tensile force – specific elongations for the carbon fiber material were plotted. So, Fig. 6 and 7 present the distribution of the tensile strength values, and respective the specific elongation versus tensile force.

From the Table 2 it can be observed that the values for tensile strength σ_t are positive that is absolutely normal because the tensile force is oriented upward. It observes that the graphic dependence between tensile force and tensile strength and tensile force – specific elongations are of linear distribution.

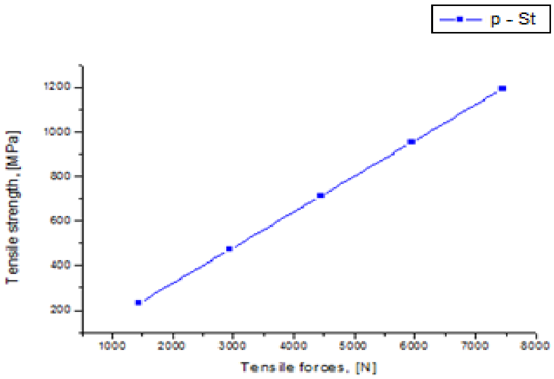


Fig. 6. Characteristic curve tensile force – tensile strength for carbon fiber

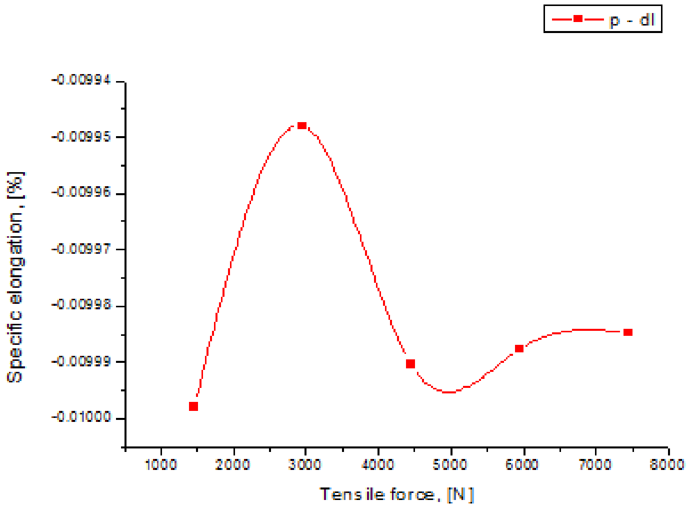


Fig. 7. Characteristic curve tensile force – specific displacement for carbon fiber

CONCLUSION

Taking into account that the mathematical relations from strength of materials area can be sometimes a little difficult and basing on saving time criteria, nowadays, the engineers tends to use more and more different computing software.

The main purpose of this paper is to show and describe an easy way to compute many formulas in the same algorithm. This software graphical programming code is not general, it can be used only for tensile and compressive loading, but it can be considered a point to start for other complex software algorithms.

Using a graphical programming environment, it is showed the way to combine two different programming languages: graphical (G) and C++. Certainly this software could be developed using only mathematical graphical elements, but the introducing the C++ code in the Formula Node component consists a way to simplify the algorithm and to make it more understandable for the beginner users.

The using of the Stacked Sequence structure in the diagram was preferred because the code is complex and in this way, one could presents two distinct results: ones for the tensile strengths and others for the specific elongations.

As a final conclusion it can asserts that is a strong connection between the programming and the engineering area of any type. Certainly, the engineering is in the front but it is well known that all the computing engineering software is based on a programming type. Thus, this paper wants to present a way to link two distinct researches areas in one domain.

As a future research topic one proposes to develop software to monitor, locate and evaluate the damage (micro crack) inside a structure.

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