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ANALYSIS OF MECHANICAL BEHAVIOR OF THE COMPOSITE PPS/C IN THE BENDING TEST BY THREE POINTS AND TENSILE TEST USING THE FINITE ELEMENT METHOD

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Abstract. *Some technological advances achieved in recent years in sectors such as aerospace, automotive and petrochemical, only became possible after the development of structural composite materials. These materials belong to a very broad class, being of polymers reinforced with fibers, hybrid materials metal/composite, structural concrete, and other materials that have metallic or ceramic matrix. In the present study was designed a computer simulation model of the bending test by three points and tensile test using the finite element method, with the commercial software ANSYS. This simulation has the objective to analyze the structural behavior of the specimen tested. The material used in the simulation and for testing is a composite laminate consisting of a polymer matrix of PPS (poly phenylene sulfide) reinforced with carbon fibers, which has the general characteristic of combining the high mechanical strength of the fibers with the low density of the polymer matrix. We also conducted tests to validate the simulation model. We used the failure criterion of Tsai-Wu. The Tsai-Wu theory is considered one of the most complete failure criteria, since it imposes "symmetry" in relation to tensions in the directions 1 and 2 (x and y for example).*

Keywords: *Composite, Simulation, Finite Element Method*

1. INTRODUCTION

The use of composites comes increasing strongly in the last decades. These materials belong to a very wide class, being from polymeric reinforced with fibers, hybrid materials metal/composite and others that possess metallic or ceramic matrix. Among the main advantages of the composites, when comparing the metals, are the high mechanical resistance associated to a low weight, combined with a good fatigue resistance, corrosion and durability

The composite materials are usually orthotropic, making more difficult the prediction of its mechanical behavior. According to Mendonça (2005) the problem of prediction of failure in orthotropic lamina is similar that observed in the isotropic lamina.

The proposed study consists of analyzing the mechanical behavior of the composite thermoplastic material: the PPS - poly phenylene sulphide, reinforced by carbon fibers, in the bending test by three points and tensile, using the of finite elements method. This analysis is done using the Tsai-Wu failure criteria.

Thermoplastics materials are deformable at high temperatures and pressure, because the bonds are weak (Kaw, 1997).

2. FAILURES MECHANISMS IN COMPOSITES REINFORCED WITH FIBERS

The problem of failure calculated in the orthotropic laminate is identical, even certain point, to the observed in the isotropic laminate (Mendonça, 2005).

Several types of failures can appear in a polymeric composite laminate. They can happen in the fiber, in the matrix or in the interface among them. With relationship to the rupture way in the fibers, depends of same factors, such as: material, diameter, length of the fibers, fiber volume ratio, orientation of the fibers, and loads.

Tensile loads can cause the rupture of the fibers, depending sensibly on the interlaminar strength between the fiber and polymeric matrix. The tensile failure in the longitudinal direction by rupture of the fibers is usually catastrophic.

Compression loads can induce the failure of the fiber through microbuckling or shear. The calculation of the compression load failure by the microbuckling of the fiber is based on the buckling of these in an elastic component (matrix). This resistance is dominated by the elastic properties of fiber and matrix. The Fig. 1 shows the microbuckling failure.

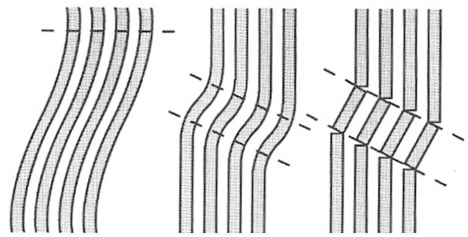

Figure 1 – Microbuckling failure (Daniel, 1994).

2.1 Tsai-Wu Criterion

The generalized failure criteria assume that the composites laminas are homogeneous, anisotropic, and combine the different types of failure in a polynomial approximation. The more popular generalized failure is the Tsai-Wu quadratic failure criterion (1971). In this criterion was proposed increase terms in the equation of failure Hill (1948), with the objective of approaching the experimental data obtained for the several materials (Mendonça, 2005). The Hill theory in which is based the Tsai-Wu criterion, considers that the von Mises criterion, proposed for the initiation of isotropic yield metals, could be modified to include the anisotropic effects of orthotropic materials ideally plastics.

With the coordinates system of the material and plan of tensions in the sheet, can be considered that the equation of the criterion is the Eq. (1).

$$f_1 \; {}_1 + f_2 \; {}_2 + f_{11} \; {}_1^2 + f_{22} \; {}_2^2 + f_{66} \; {}_{12}^2 - \sqrt{f_{11} f_{22}} \; {}_1 \; {}_2 \quad (1)$$

Where:

$$f_1 = \frac{1}{X_T} + \frac{1}{X_C};\; f_1 = \frac{1}{Y_T} + \frac{1}{Y_C};\; f_{11} = -\frac{1}{X_T X_C};\; f_{22} = -\frac{1}{Y_T Y_C};\; f_{66} = \left(\frac{1}{{}_{12}}\right)^2 \quad (2)$$

σ_1: Stress in the axis 1;
σ_2: Stress in the axis 2;
τ_{12}: Shear stress in the plane 1-2;
X_T: Tensile ultimate strength in the axis x;
X_C: Compressive ultimate strength in the axis x;
Y_T: Tensile ultimate strength in the axis y;
Y_C: Compressive ultimate strength in the axis y.

3. MATERIALS AND METHODS

3.1 Material

We used a structural thermoplastic polymeric composite PPS (Poly phenylene sulphide) reinforced with carbon fibers constituting five layers of 0,31 mm from the manufacturer TenCate Cetex, being the kind of harness satin of T300 fiber 3k 5HS.

The mechanical properties and resistance data of the material have as references to the manufacturer TenCate, these values are presented in Tab. 1.

Table 1 – Mechanical proprieties and strength data of material PPS/C.

Young's modulus 0º - MPa	57.000
Young's modulus 90º - MPa	53.000
Shear modulus 0º - MPa	2.651
Shear modulus 90º - MPa	2.651
Poisson's Ratio	0.21
Tensile ultimate strength 0º - MPa	730
Tensile ultimate strength 90º - MPa	646
Compressive ultimate strength 0º - MPa	-558
Compressive ultimate strength 90º - MPa	-526

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Table 1 – Mechanical proprieties and strength data of material PPS/C. Cont.

Bending ultimate strength 0° - MPa	955
Bending ultimate strength 90° - MPa	794
Bending modulus 0º - MPa	58.000
Bending modulus 90º - MPa	45.000
Shear strength in plane 1-2 - MPa	108

3.2 Bending Tests By Three Points

To perform the bending tests by three points was used in a test machine, model Shimadzu AG-X from the Department of Materials and Technology, FEG-UNESP. This equipment is coupled to a microcomputer that has a program to realize data acquisition. With this program you can obtain directly the graph of force versus displacement, which will be compared with the graphs constructed with values obtained with ANSYS. The machine has a load cell with maximum capacity of 10 kN. Fig. 2 shows this machine.

Figure 2 – Testing machine used.

The realized of the bending tests by three points occurred saps the following sequence:

1 - Cut the specimens using a water-cooled machine and Norton BNA 12 cutting disc, as 140 x 25,4 mm, width and length respectively;

2 - Removal of excess material from cutting step, resulting in specimens presented in Fig. 3;

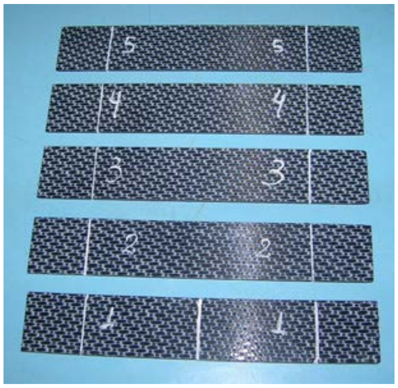

Figure 3 – Specimens used in the bending tests by three points.

3 - Positioning of the specimen in machine testing and calibration of the machine, as shown in Fig. 4;

Figure 4 – Positioning of the specimen in testing machine.

4 - Descent of the punch and application of the load on the specimen up to rupture, the speed used in the tests was 15 mm/min, the tested material is shown in Fig. 5;

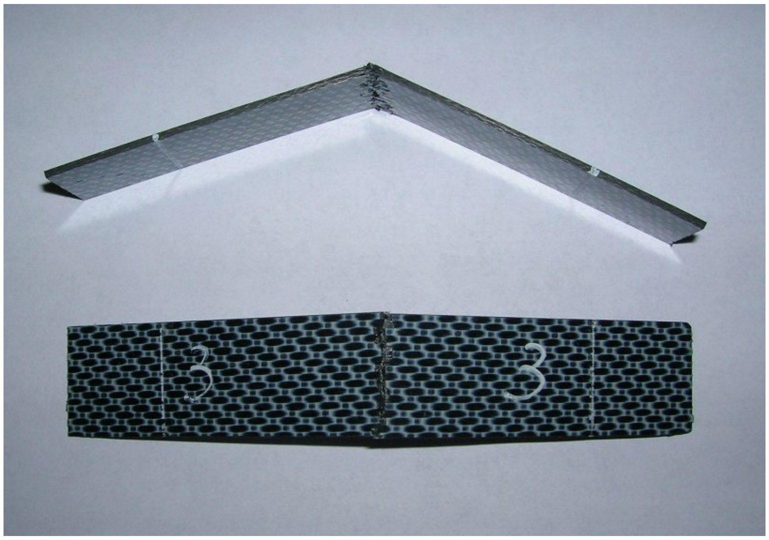

Figure 5 – Specimen after test.

5 - Return the punch;
6 - Saving the test data: the data acquisition program provides the force versus deformation diagram and highlights the maximum force, in Fig. 6 shows the output screen of the program of testing machine;

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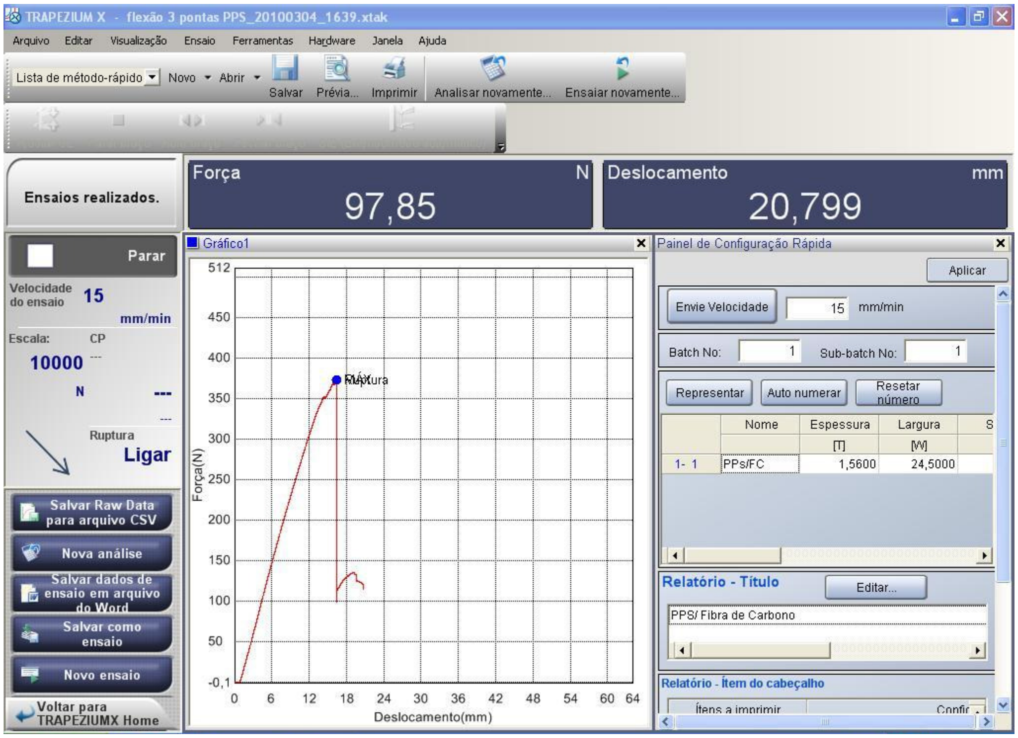

Figure 6 – Screen output from the program of testing machine.

3.3 Tensile Test

The tensile tests were performed in the testing machine INSTRON, model 8801 from the Department of Materials and Technology, FEG-UNESP. The machine has a load cell of 100 kN, Fig. 7 illustrates the testing machine used.

Figure 7 – Testing machine INSTRON 8801.

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Procedure of the tensile tests:

1 - Cut the specimens using a water-cooled machine and Norton BNA 12 cutting disc, as 160 x 25,4 mm, width and length respectively;

2 - Removal of excess material from cutting step, resulting in specimens showed in Fig. 8;

Figure 8 – Specimens used in the tensile tests.

3 - Positioning of the specimen in machine testing and calibration the machine;

4 - Application load on the specimens;

5 - Acquisition and save of test data.

4. SIMULATION

For the bending tests by three points and tensile tests was used the 3D solid model, making the modeling each lamina of the material tested. The layers were joined together by contact of the "Bonded", this contact determines that the laminas are linked to one another. Two materials were created, one for the mechanical properties at 0 and another at 90 degrees.

To the bending tests by three points, the force applied by the punch (in the middle of the specimen) was varied from 0 to 370 N was constructed so that the virtual graph of force versus displacement and this compared with the graph obtained from the tests. The ends were used restrictions of movement on the y axis. The modeling of this test is shown in Fig. 9, Fig. 10 shows an approximation model highlighting the layers of the laminate and the mesh generated for this model illustrated in Fig. 11.

The modeling of the tensile test is shown in Fig. 12. In this simulation the force was applied on one side of the specimen and on the other side was used a fixed support, that restricting their movements. The generated mesh for this model is shown in Fig. 13.

For the construction of the both models were used the following elements:

SURF154 element can be used for several applications containing loads or boundary conditions on the surface. It can be used on the surface of an area of any 3-D element. The element is applicable to structural analysis in 3-D. Allows exist simultaneously several loads and boundary conditions. It may consist of four to eight nodes.

The SOLID186 is a solid 3-D element of higher order. The element is defined by 20 nodes with three degrees of freedom per node: translation in the nodal directions x, y, z

The CONTA174 is used to represent the contact between sliding surfaces or geometry in 3-D and has a deformable surface, the element is using with the element "target" TARGE170. The element is applicable to 3-D geometries for structural analysis of contacts and engagements. This element is located on surface 3-D elements, such as the SOLID186.

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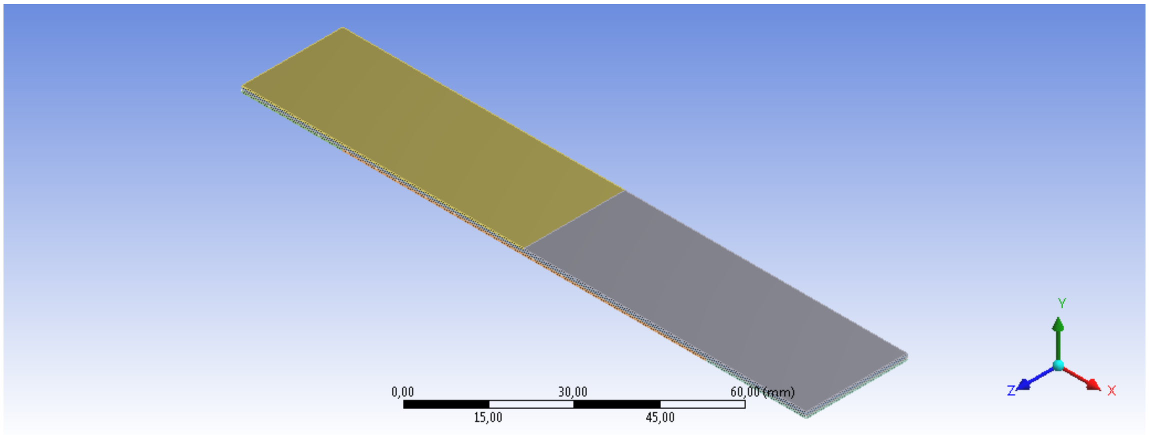

Figure 9 – Model of bending tests by three points.

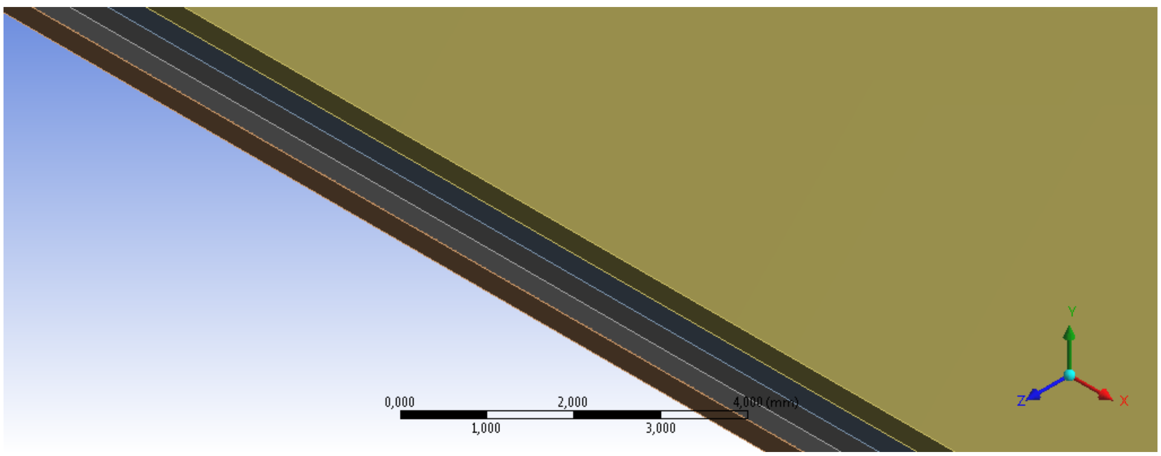

Figure 10 – Details of the laminas of the model of bending tests by three points.

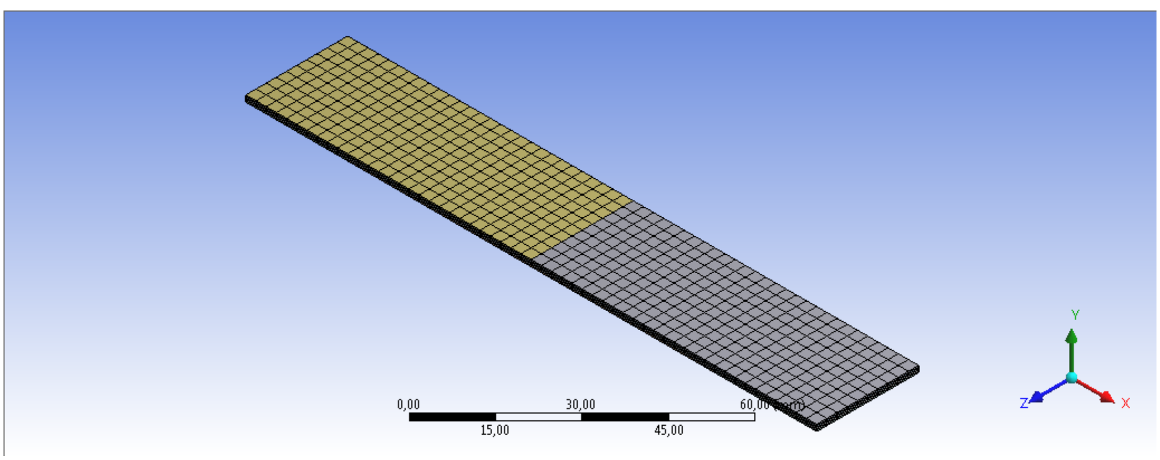

Figure 11 – Mesh of the model of bending tests by three points.

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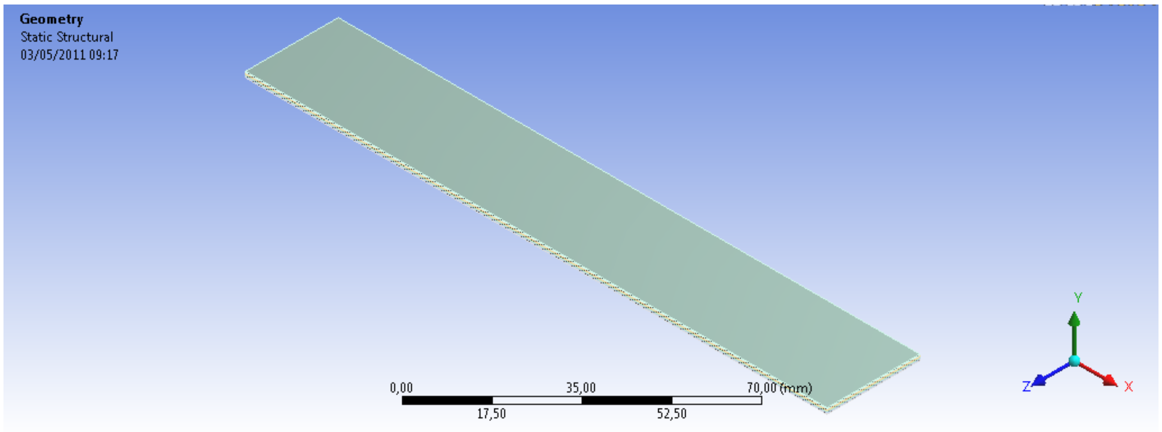

Figure 12 – Model of the tensile test.

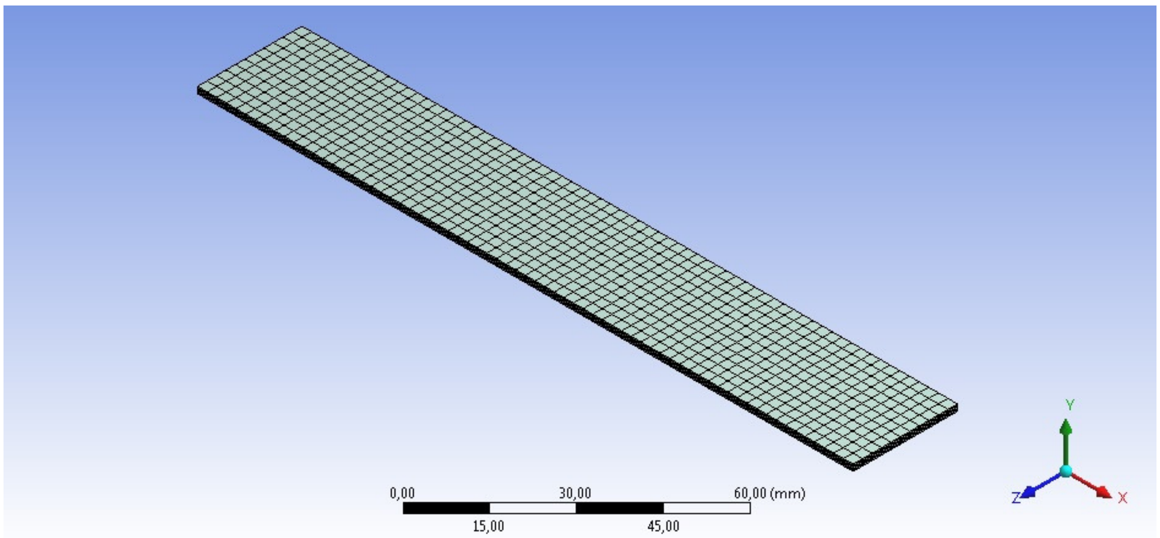

Figure 13 – Mesh of the tensile test.

5. RESULTS

In the simulation of bending tests by three points was varied the force applied to the specimen with 0 to 370 N resulting in a graph of force versus displacement, this graph was compared with the virtual graphs obtained in the tests, these data are shown in Fig. 14. The greatest bend occurred with the maximum force of 370 N, is shown in Figure 15, and has maximum value of 13,469 mm.

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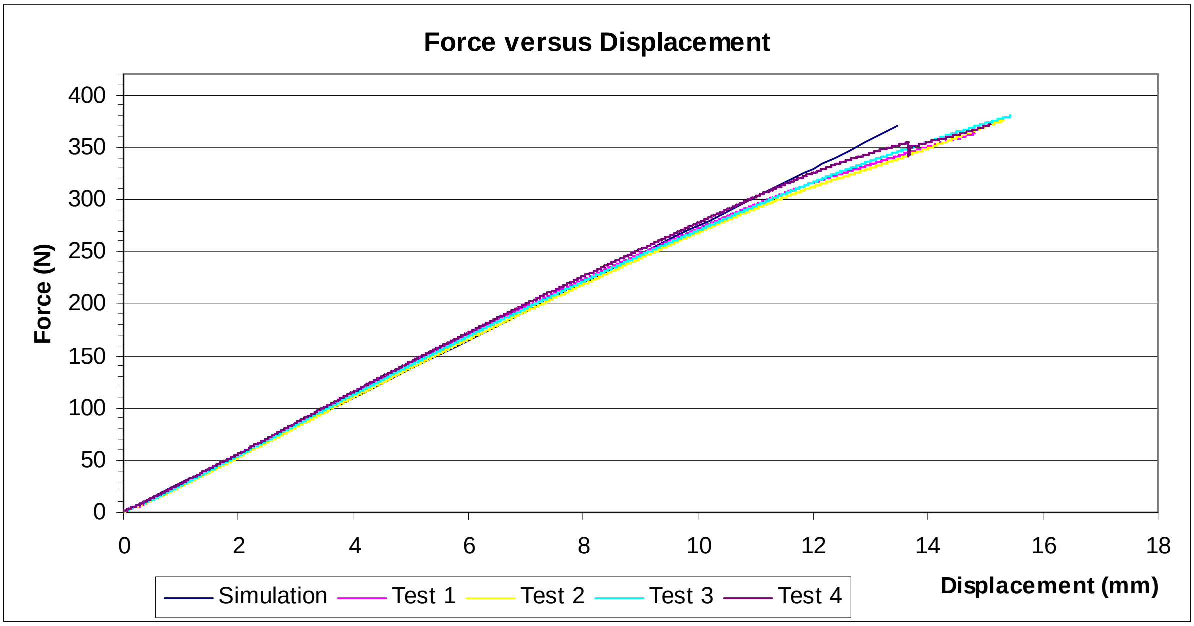

Figure 14 – Graph of force versus displacement.

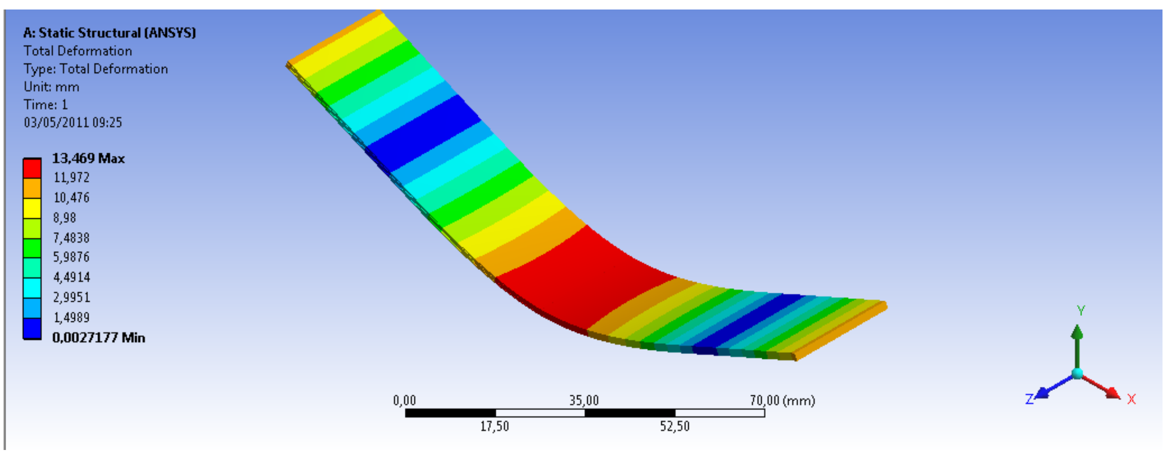

Figure 15 – Greatest bend.

To calculate the failure criterion of Tsai-Wu used the values of normal stress acting on the axes and the shear stress in the plan. Figure 16 illustrates the normal stress acting on the "x" axis of the specimen.

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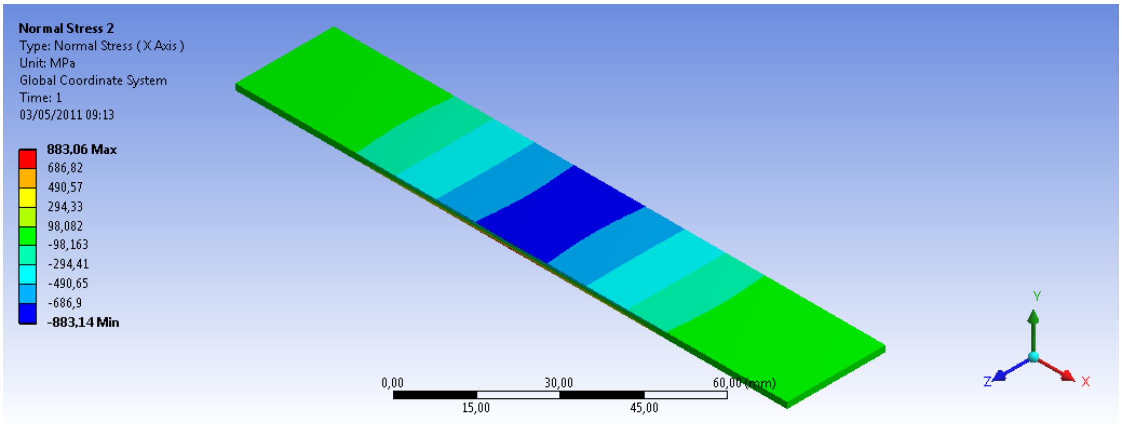

Figure 16 – Stress acting on the "x" axis in the bending tests by three points.

With the values the normal stress in the axes and shear stress in the plane is possible to calculate the failure criterion of Tsai-Wu shown in Eq. 1, the highest value for this criterion was 1.06, in the node located in the center of the specimen and in the first lamina, as the value is above 1.00 indicates that the failure process has already begun.

In the simulation of the tensile test was used an average value of force found in tests, which is 23,25 kN.

Similarly the bending tests by three points, in the tensile test data were collected from normal and shear stresses acting on the specimen, in order to calculate the failure criterion of Tsai-Wu. Figure 17 presents the stresses acting on the "x" axis of the specimen. The maximum value found of the failure criterion is 1.02, which shows that the specimen is about to fail.

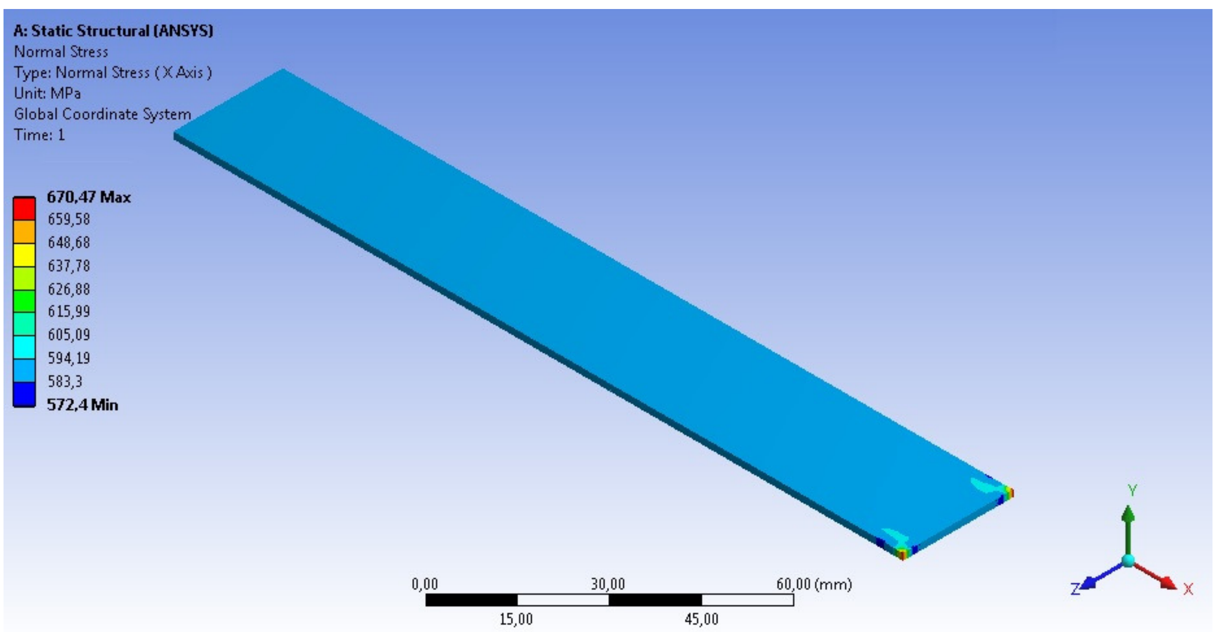

Figure 17 – Stress acting on the "x" axis in the tensile test.

6. CONCLUSIONS

The simulation models presented in this study reproduces satisfactorily the tests, as can be seen by comparing the virtual with the experimental results, thus confirming the reliability of the models.

To use this type of material in projects is must know very well the conditions of loading, since the mechanical properties of composite varies considerably depending on the coordinate axes.

In both the simulation models, the ultimate stress values (when Tsai Wu criterion is greater than 1.0) are conform to the values of the mechanical properties shown in Table 1.

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