EVALUATION OF COMPOSITE MATERIALS EMPLOYED IN ROTARY WING AVIATION

Alexandre Galo Lopes, alopes@ime.eb.br
Arnaldo Ferreira, arnaldo@ime.eb.br
Instituto Militar de Engenharia

***Abstract**. The behavior of the stress distribution at the crack tip of a composite material, used in aviation components and known chemical composition, was analyzed by finite element method modeling. The aim was to investigate the influence of the presence of the fibers around a region composed exclusively of polymer matrix. The material under study consists of four layers of fibers. However, to reduce the computational effort, only the outer portion was studied, and others are considered symmetrical. We used shell element type SHELL 281appropriate for thinness of the material. The results show that the material behaves as a plane strain state and the presence of fibers did not cause significant changes in stress distribution in the Y direction adopted. Additional work is needed to better understand the mechanisms involved in crack propagation.*

***Keywords**: composite, computational, fracture, aviation, rotary, wing*

1. INTRODUCTION

The present work aims to computationally estimate the stress distribution at the crack tip of a hypothetical specimen. The main objective is to check the influence of the presence of the fibers around a region composed exclusively of polymer matrix, in order to understand the phenomenon of propagation of a fatigue crack in future studies.

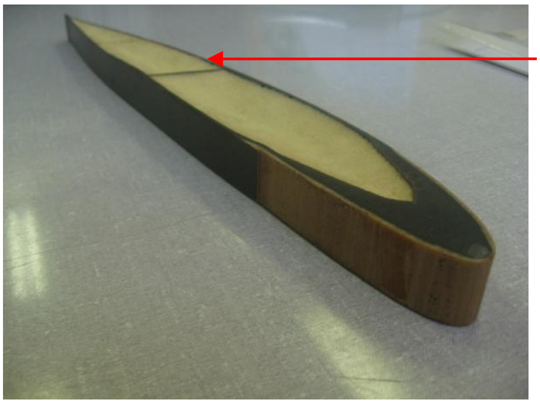
A premature failure was found in certain aircrafts in which its blades have presented a fatigue crack supposedly aggravated by mechanical overload static, by polymer degradation due to environmental factors, or a combination of all these factors. Figure 1 illustrates the flaw in the discussion.

Figure 1. Region of recurrence of crack propagation

In order to analyze the mechanical behavior of a material, a model was made with the specific tool of 3D CAD, as discussed in later sections of this article. Some technical data on the material was proposed based on visual inspection and reports of experts in the field of maintenance, and consulting specialized literature.

2. CAD MODELING

The software used was Solidworks© version 2009. The dimensions of the specimen are justified by the small thickness of the shell to be analyzed, as can be seen in Figure 2.



Surface of material composite to be analyzed

Figure 2. Cross section of the blade analysed

The elements of interest, such as the size of the region consists exclusively of the matrix phase, as the dimensions of such reinforcement phase (fiber) were arbitrary based on the thickness of a layer of composite laminate real. Figure 3 shows a micrograph of the region of interest, where are observed clues of four layers of fiber reinforced polymer material.

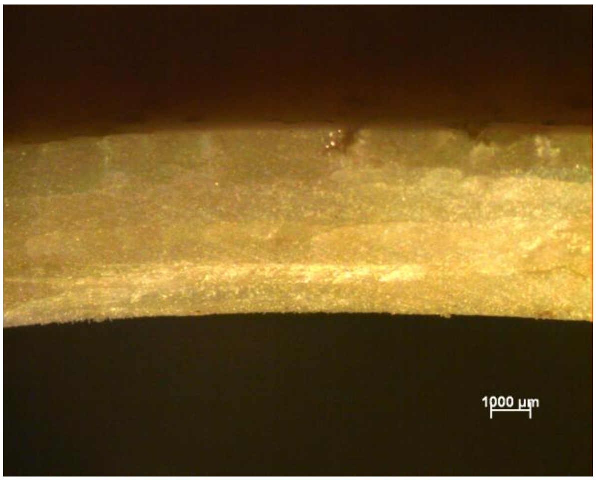


Figure 3. Cutaway view of a real composite sample

It is assumed that the hypothetical configuration as a grid format assign to the composite a structural rigidity associated with a tear resistance (*ripstop*). Figure 4 illustrates the mesh in question.

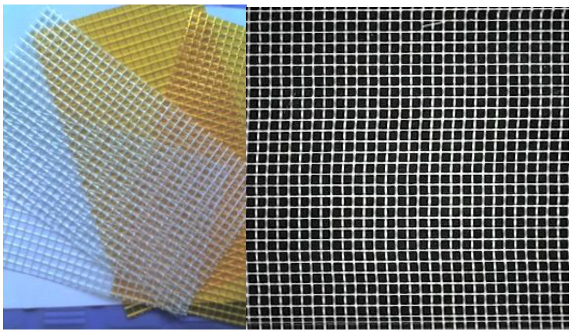


Figure 4. Hypothetical fiberglass mesh

The proposed specimen was divided into three regions of interest, illustrated in Figure 5: the specimen, the bundle of fibers surrounding the region of the matrix phase and matrix phase, as will be discussed in the following sections.

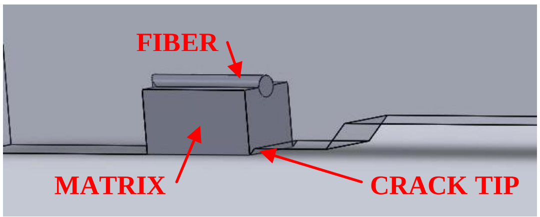


Figure 5. Detail of the crack tip in specimen

2.1. Specimen

The specimen has dimensions as Figure 6, with dimensions in mm.

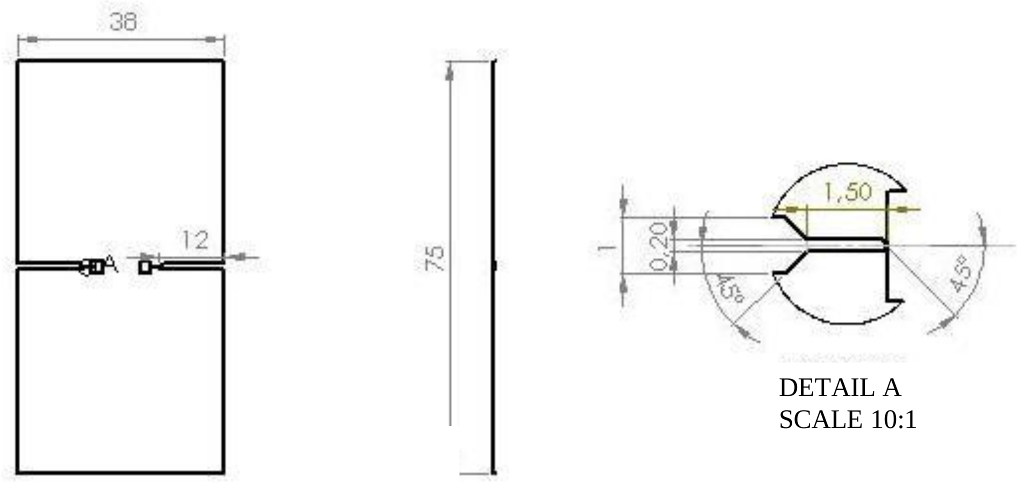


Figure 6. Specimen's dimensions

It was considered that the pre-crack has been developed by the penetration of a blade with 0.2 mm thick and edged with two symmetrical chamfers to 45° of horizontal centerline. For modeling purposes, it was assumed that the thickness of the CP containing one composite layer has a unitary value.

2.2. Fiber

The fiber orientation was determined by visual inspection. It was found that the fibers are aligned with the preferred direction of crack propagation.

It was considered that the bundles of fibers are grouped into a cylindrical structure, perpendicular each other, with nodes distributed equally spaced and without strain in regions where the bundle intersect.

2.3. Matrix

The matrix phase consists of a block, wrapped by fiber and with an exposed face of the pre-crack tip, as illustrated in Figure 5. This block has a fundamental importance, since that is the main object of interest analysis, as will be discussed in the sections relating to the mechanical behavior.

3. MATERIAL PROPERTIES

For the model can provide results close to reality, were sought in the literature values for the epoxy composite material, reinforced by fiberglasses. Despite of hypothesis of a component to be manufactured with this material, and the absence of data on the manufacturing method - which could change the mechanical properties of composite – its possible override these initial values to a more realistic computational analysis, after the chemical characterization of the polymer and of the fiber used in the real case.

In all cases, was considered a value of Poisson's ratio ν=0,3.

The values used were taken from Canevarolo (2004) and are presented in Table 1.

Table 1. Characteristic values of the composite's* epoxy fiberglass reinforced components

	Modulus of Elasticity (GPa)	Tensile Strength (GPa)	Specific Mass (g/cm^3)
Fiberglass type E	72.4	2.4	2.54
Epoxi composite	45	1.1	2.10

* Composite with 33.3% fiber unidirectional

However, the literature reference of Table 1 does not provide data about the polymer matrix, alone.

3.1. Epoxy's modulus of elasticity

According to Rezende et al (2011), the Hercules 3501-6 epoxy has the following properties:

Table 2. Characteristic values of the Hercules 3501-6 epoxy

Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Elongation (%)	Fracture toughness (kJ/m^2)
3.8	46	1	0.08

4. COMPUTATIONAL ANALYSIS

For computational analysis, it was used the software Ansys 12.1, given the simplifying assumptions described below.

4.1. Hypothesis

- The phenomenon is studied locally at the crack tip, with contour defined by the closer fibers;
- There is no delamination at the level of tension applied, sufficient for the formation of surfaces beyond those produced by the provoked discontinuity;
- The fibers are aligned parallel and perpendicular to the direction of crack propagation;
- Fibers parallel to the preferred direction of crack propagation behavior do not interfere with fracture;
- The flexibility of the fibers due to its thinness does not interfere in the mechanical behavior. The crack opening imposes to the perpendicular fibers on its direction of propagation, and to them alone, a tractive effort up to its rupture;
- Every specimen has mechanical behavior associated with the composite values. Locally at the crack tip, their values are related to the matrix material and fiber, individually;
- For purposes of geometric modeling, it was not considered the volume fraction (or the relationship between fiber dimensions, their number and specimen's thickness);
- The specimen under study is composed by four layers, which will be considered only the outer layer;
- The mechanical behavior of the composite in tension is linear in stage I and stage II, as illustrated by the diagram at Figure 7;

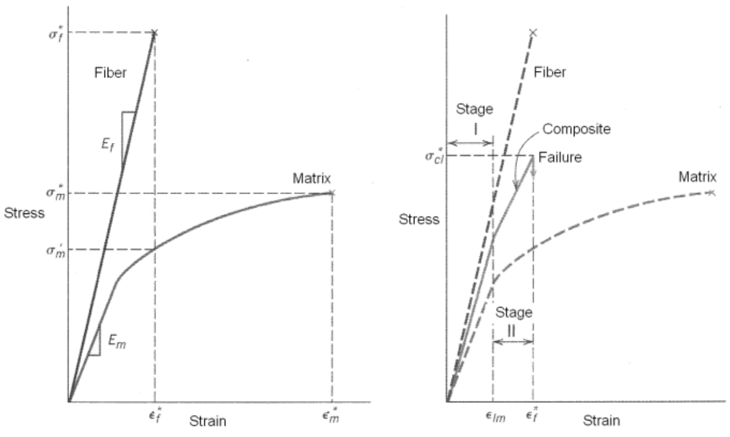


Figure 7. Schematic stress-strain curves for materials with brittle fiber and ductile matrix (Callister, 2008)

- The composite of epoxy reinforced with fiberglass presents fragile global behavior when subjected to tensile test, due to dominant mechanical characteristics of the reinforcement to be subjected to maximum stress, as shown in Figure 8. The focus of the study is the crack tip, where there is only the polymer matrix, that is, we want to analyze the local behavior of the specimen loading levels much lower than necessary for its total collapse. In the region of the crack tip, the material behaves exclusively as the epoxy, whose mechanical behavior is illustrated in Figure 9. It will be checked how this affects the stress distribution around fiber region with the crack.

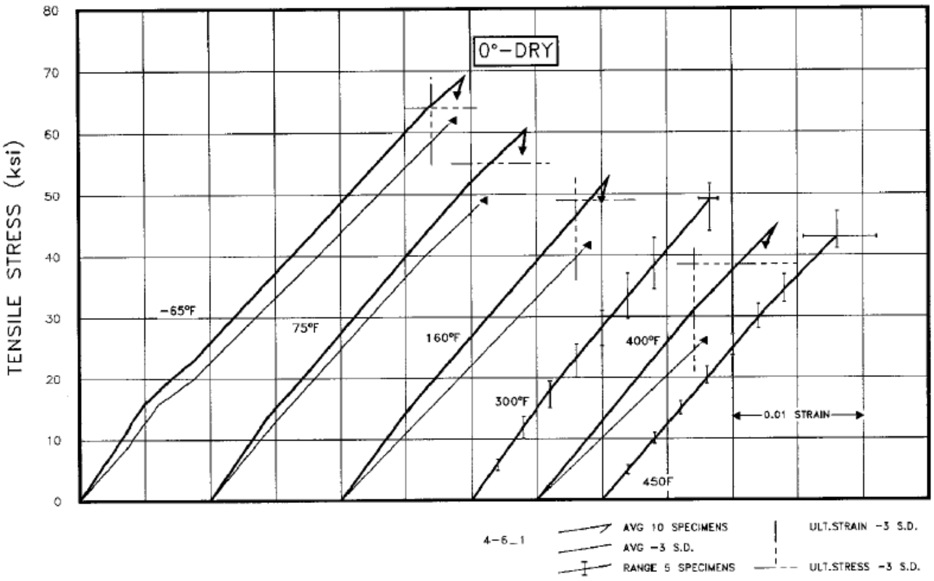


Figure 8 – Tensile stress-strain for E-720E/7781 fiberglass epoxy (dry) loaded in the 0° direction (Department of Defense, 2002)

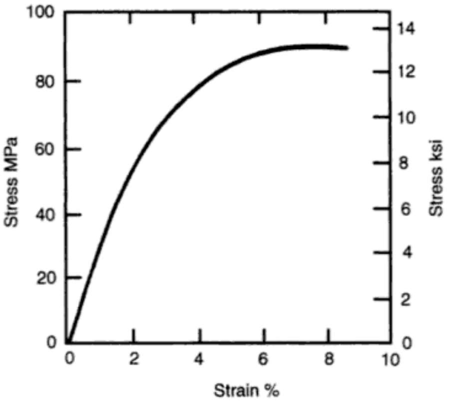


Figure 9 – Mechanical behavior of epoxy DGEBA (Penn and Wang, In: Lubin and Peters, 1998)

- The matrix phase provides perfectly plastic behavior, for purposes of study of stress at the crack tip, as shown by the diagram Figure 10.

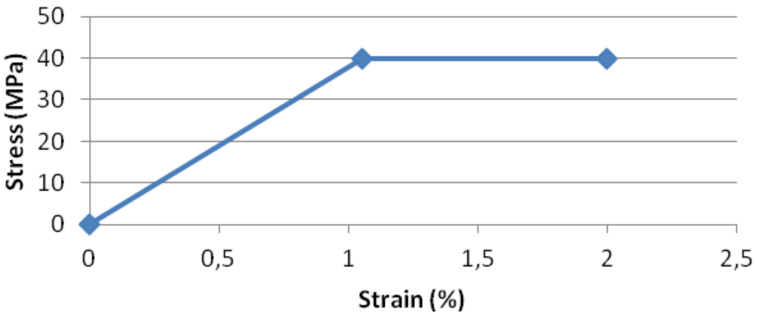


Figure 10. Stress-strain diagram of epoxy designed for the crack tip analysis

4.2. Discussion about procedures and results

In order to simplify the analysis and reduce the computational effort, the specimen was reduced to its lower symmetrical portion.

The analysis of a three-dimensional model, although considered various aspects of mesh refinement of finite element, of analysis parameters and of constraints between the elements involved, showed unsatisfactory results.

Sought, then, an even more simplified analysis of the reduced geometric configuration by APDL tool, according to a structure modeled as shell.

All data were entered through manually code lines, with most appropriate parameter settings available in the software's database.

The elements were modeled as SHELL281, as illustrated in Figure 11, applicable to the study of laminated and sandwich structures, with the effect of membrane stiffness only. Using this type of element is justified by the small thickness and the possibility of including structural reinforcements, as will be discussed below.

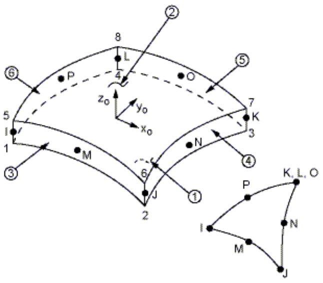


Figure 11. SHELL281 element type

One of the models available for the components analysis with structural reinforcement is the 3D-smeared reinforcing (REINF265), illustrated in Figure 12, with the representation of a fiber near the contact between the finite elements reinforced and not reinforced, in a position on 99% of the width of the reinforced element, with the cross-sectional area of the fiber in the same dimensions planned for the three-dimensional model.

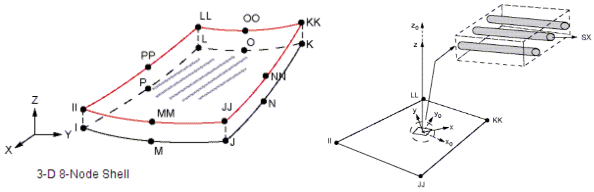


Figure 12. Element cross section scheme

Figure 13 illustrates the fibers positioning in the matrix surrounding.

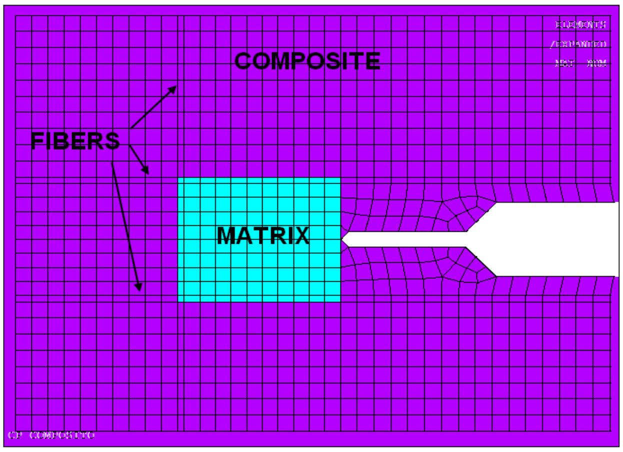
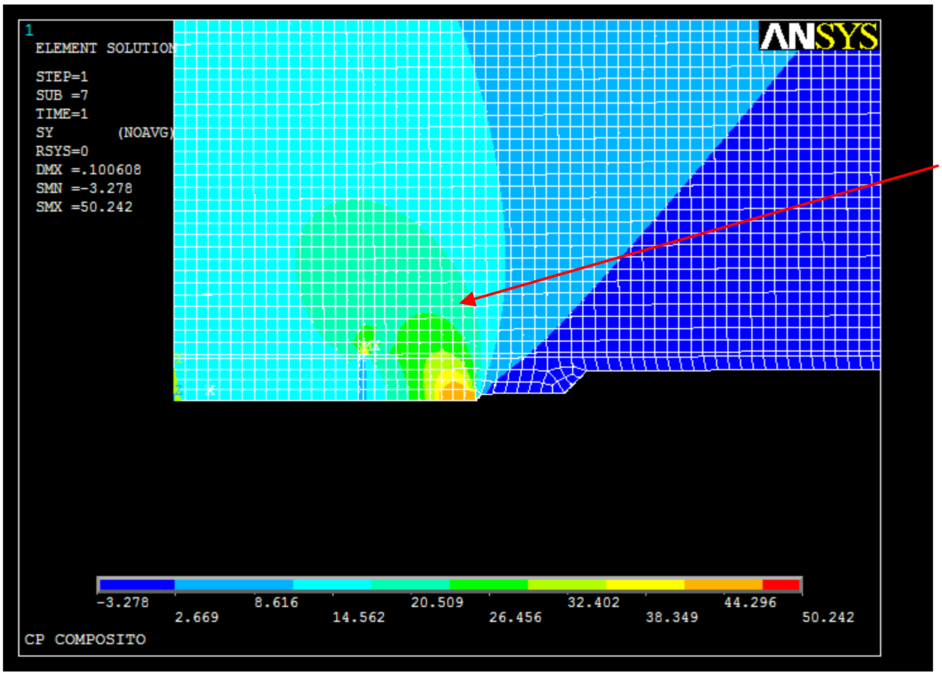


Figure 13. Display of materials, especially using fiber reinforcements

It was used the charge to a displacement of 0.1 mm, and the tangent modulus in that region is refereed as 1 MPa. From these data it was possible to determine the values for the stress distribution, as shown in Figure 14. It was used the BISO (bilinear isotropic hardening) tool for this purpose.



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1
ELEMENT SOLUTION

STEP=1
SUB =7
TIME=1
SY       (NOAVG)
RSYS=0
DMX =.100608
SMN =-3.278
SMX =50.242
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Stress distribution according to the classical model of Irwin

Figure 14. Stress (nodal) distribution in Y direction, in MPa

Irwin presented a concept of plasticity at the crack tip in materials with ductile failure mode, in which the stress distribution assumes a peculiar shape. Figure 15 illustrates schematically the stress distribution for materials submitted to plane-strain and plane-stress state.

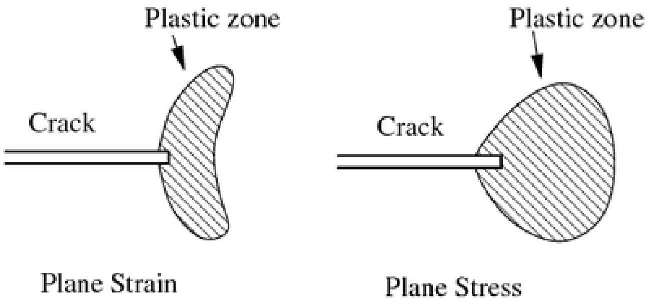

Figure 15 – Plastic zone in ductile materials, according to Irwin

It is observed in Figure 14 a format of stress distribution in MPa, similar to that presented by the classical model of Irwin in plane-strain state.

In Figure 16, there are strains intensities distributed similarly. Note that strain values above 1%, which is the breaking of the material, were only observed in the region close to the singularity.

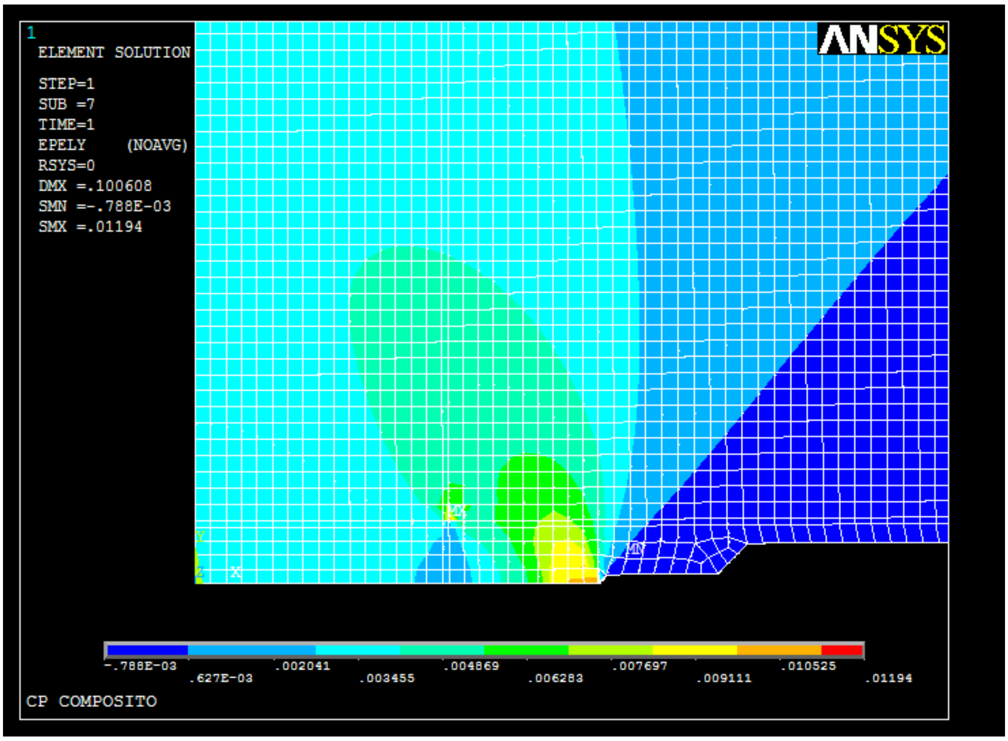

Figure 16. Strain (nodal) distribution in Y direction

Figure 17 illustrates a small region of plastic deformation occurred at the crack tip.

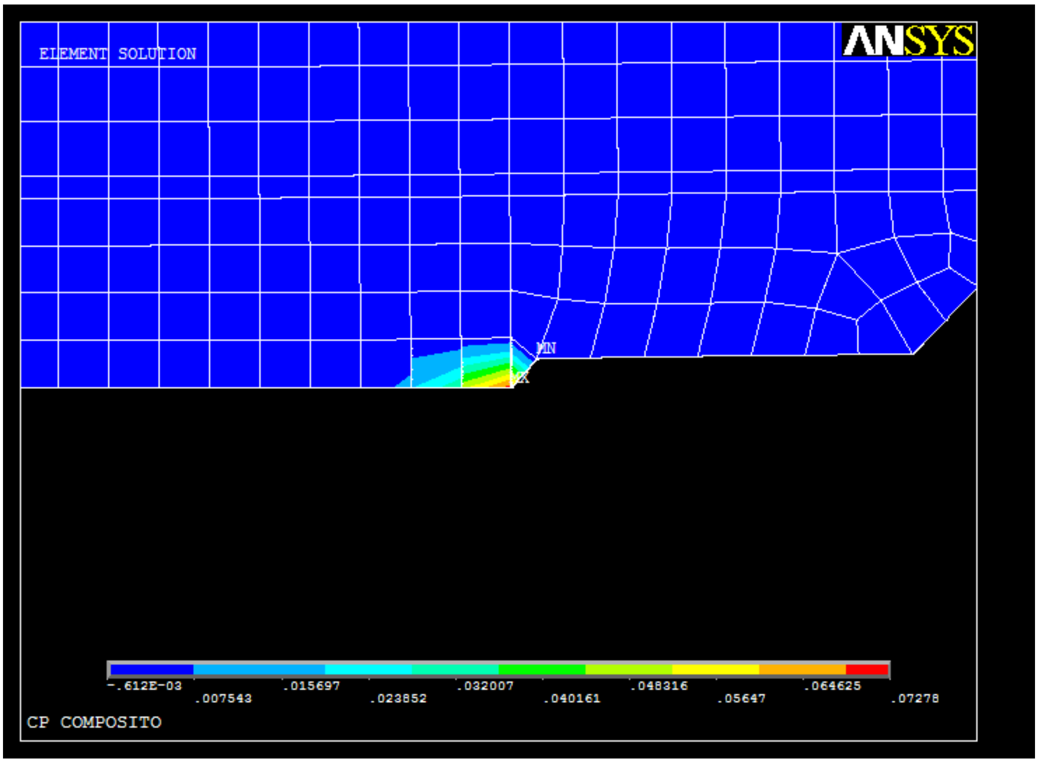

Figure 17. Plastic strain (nodal) distribution in Y direction

5. CONCLUSION

This paper aims to present the mechanical behavior of the crack tip when the specimen is subjected to tensile testing, in order to map out strategies of mechanical tests seeking the smallest possible loss of specimens, given the high cost of raw materials.

The choice of a two dimensional analysis, over a three-dimensional, proved very efficient for the goals. The economy of computational effort generated by defining all possible symmetries also brought advantages in this regard.

The modeling with specific types of finite elements, in this case the SHELL281, was essential to use appropriate tools to study the composite. The shell model could have been evaluated by other elements, but each has strengths and limitations that, at the final analysis, would be more or less advantageous to simulate the real behavior.

It emphasizes the use of reinforcement to simulate the contour of fibers. It was found that the presence of fibers in the proposed model would not cause any great change in the global distribution of stresses in the Y direction, which is apparently a positive factor for future mechanical.

Although the thickness of the specimen was small compared with the other dimensions, there was the shape of the distribution of stresses that the material behaved like plane-strain state, according to Irwin's approach.

Stress peaks in the region where the fiber changes its direction should be disregarded because they are considered in modeling regions that do not correspond perfectly to a real mesh.

For the presented material properties, results were evaluated only for very low load (displacement).

The investigation continues and additional work is still needed for better modeling and to understand the mechanisms involved in the process of crack propagation.

6. ACKNOWLEDGEMENTS

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