LAY-UP EVALUATION IN COMPOSITE MATERIAL TUBES

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Abstract. *This paper presents a finite element model used in ANSYS software. The model was used to design a new lay-up for an already existing tube, made in composite material. The configuration aims to improve tube's resistance, as subjected to in-service loads and to diminish production costs. The old and new lay-ups are compared using results from static and dynamic simulations and with an experimental evaluation with the new configuration.*

Keywords: *composite, pipes, lay-up*

1. Introduction

Composite materials are formed by the union of two or more distinctive materials with no chemical reaction between them. They consist of a matrix, responsible by structural stiffness and one or more reinforcement materials, responsible for overall resistance. The matrix also has the function of transmitting to the reinforcements the loads subjected by the assembly, Buarque (2004).

Reinforcements can be made of fibers or particles. If fibers, they can be long or chopped. Chopped fibers composites present physical and mechanical properties with small variation due material directions. Long fibers composites normally exhibit material anisotropy, with directions of lower and higher resistance to traction. These long fibers can be presented as fabrics or wires. This last option is adopted when to privilege a direction with a specified property is desired. Reinforcement fibers are actually made by innumerous filaments. This configuration is explained because some determined materials are more resistant in a filamentary form, Gibson (1994).

Despite the high values of traction strengths, fibers are not capable to stand alone compressive loads and their transverse mechanical properties are not as high as longitudinal ones. Thus, they are useless as structural materials, unless bonded together with a matrix. This matrix, besides having the needed stiffness, yet protects the fibers from environment hazardous conditions and external damages. The final structure, the composite material including the matrix, still presents transverse properties much inferior to those on fiber's direction. This can be avoided adding more fibers on other directions aimed to have better mechanical properties, forming the so-called laminated composite structures.

There are various applications of composite materials, in particular in cylindrical tubes. They have become an important class of engineering material, with application in many fields as chemical industry, aerospace and defense areas. Its use has increased due the high resistance allied to the low weight presented.

The Filament Winding process fabricates composite tubes in large scale. It consists in enrolling fibers, passed previously in a bath of resin, over a mandrill. A small moving car parallel to the mandrill axis conducts and delivers the fiber to be winded.

There are two groups of variables that affect mechanical properties in composite tubes production: Design and Process variables. Design variables are winding angles, stacking sequence, number of layers for each angle, total number of layers, thickness of each layer, total thickness of tube wall, and the presence of a liner to divide loads or to establish a barrier to chemical attack. Process Variables are winding velocity, winding pressure, regulation on the opening for exiting resin excess, resin's pot life and viscosity, time interval between each layer's winding and the use of prepregs.

2. Tests

Two simulation tests were performed using commercial ANSYS software (2003). The first, named "TEST 1", aims to represent traction assay performed on original tube, to lay-ups evaluation. The second, "TEST 2", aims to evaluate structure response to a dynamic load representative of tube's usage. For the two tests, a comparison of the results for two different lay-ups configurations was done. These are related to the original stacking sequence, and a new one, purposed to be analyzed. The lay-up sequences were called "ORIGINAL" and "NEW CONFIGURATION".

Due to operational limitations on the filament winding equipment, only angles of 0º (Tube's longitudinal direction) and 90º (Tube's radial direction) were possible.

For the two lay-ups, each layer has a 0,15mm thickness. Composite material was made of epoxy resin reinforced with E glass fibers, with 60% in volume. Its mechanical properties are presented in Table 1.

For TEST 1, a finite element mesh was created with an 8-node element, SHELL 99. 1640 elements were obtained totalizing 5000 nodes. The maximum tension failure criteria were chosen. Boundary conditions intended to represent fixation in one of tube's edges and a static distributed load in the opposite one. Force load was considered as 70,500N. This value was obtained in a traction test on original tube. Figure 1 presents the finite element mesh for the rear part of the tube according to the used in the tensile test. This figure shows fixation boundary conditions and, on the opposite side, a distributed load. Colored patterns show different number of layers on the test specimen. Detailed configuration of the lay-up is classified.

Table 1 – Material's Mechanical Properties

- Density	ρ = 1,94 g/cm^3
- Young Modulus along to fibers (?)	E_L = 45 GPa
- Young Modulus transverse to fibers (?)	E_T = 12 GPa
- Shear Modulus	G_{LT} = 4,4 GPa
- Poisson's Ratio	υ = 0,25
- Ultimate strength in longitudinal traction	σ_L^{tu} = 1.000 MPa
- Ultimate strength in transverse traction	σ_T^{tu} = 34 MPa
- Ultimate strength in longitudinal compression	σ_L^{cu} = 550 MPa
- Ultimate strength in transverse compression	σ_T^{cu} = 140 MPa
- Ultimate Shear Resistance	τ_{LT}^{su} = 40 MPa
- Maximum deformation in longitudinal traction	ε_L^{tu} = 0,0222
- Maximum deformation in transverse traction	ε_T^{tu} = 0,0028
- Maximum Shear	γ = 0,0091

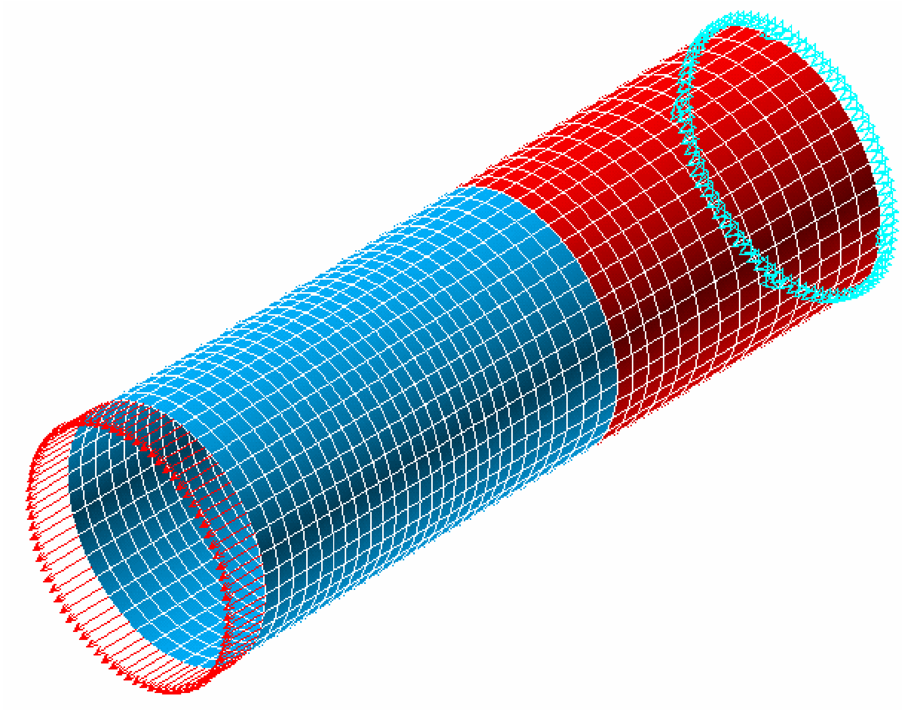

Figure 1 – Finite Element Mesh for TEST 1

For comparison in results, some layers were selected: 1, 4, 5, 11 and 24, all having same length and direction. Results as tube's longitudinal displacement and stresses in fiber's direction (S1) and transverse direction (S2) were analyzed. The values for the two considered lay-ups were accepted; however the NEW CONFIGURATION one presented better results, especially for S1 stresses in longitudinal fibers, and for S2 stresses for all fibers. Figure 2 shows longitudinal displacement results, for ORIGINAL and NEW CONFIGURATION tubes. Figures 3, 4, 5, 6 and 7 show S1 stresses for layers 1, 4, 5, 11 and 24.

ORIGINAL | NEW CONFIGURATION

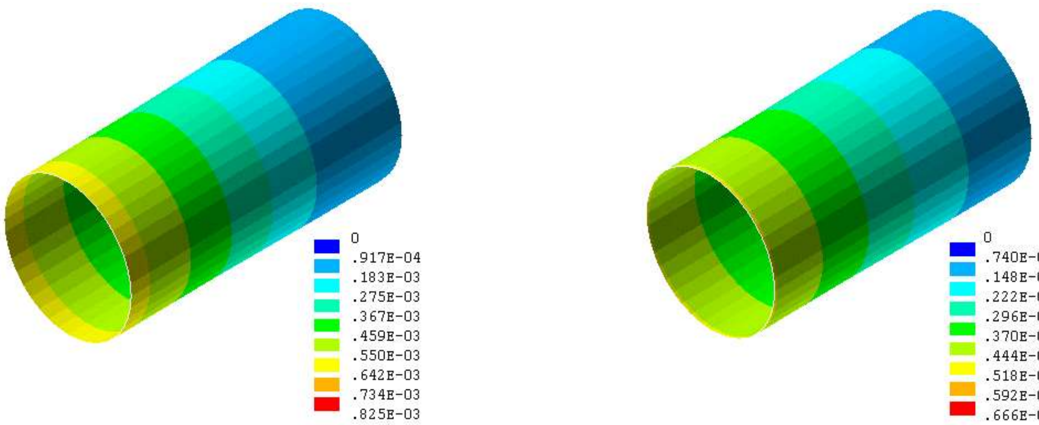

Figure 2 – Longitudinal Displacements

ORIGINAL | NEW CONFIGURATION

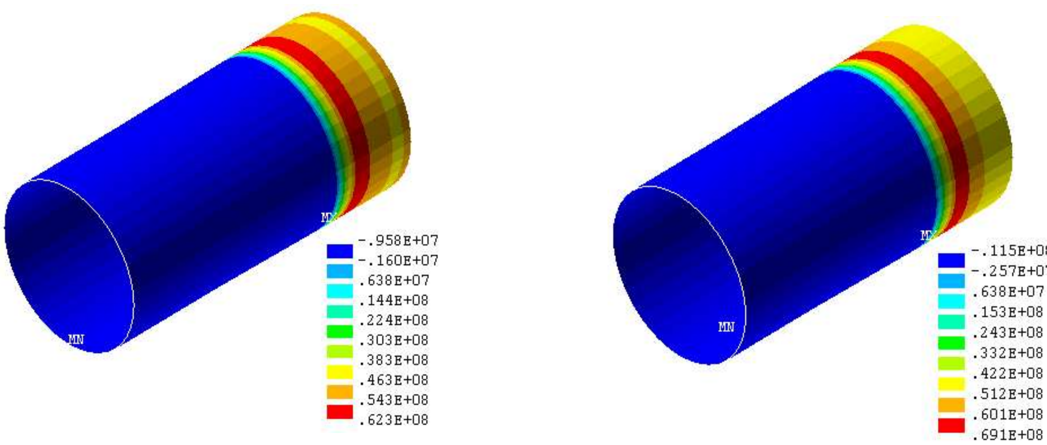

Figure 3 – S1 on Layer 1

ORIGINAL | NEW CONFIGURATION

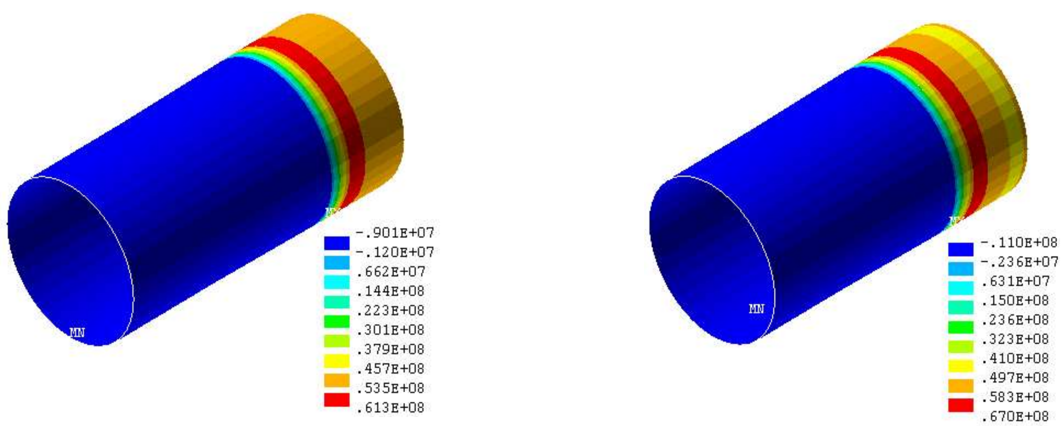

Figure 4 – S1 on Layer 4

ORIGINAL NEW CONFIGURATION

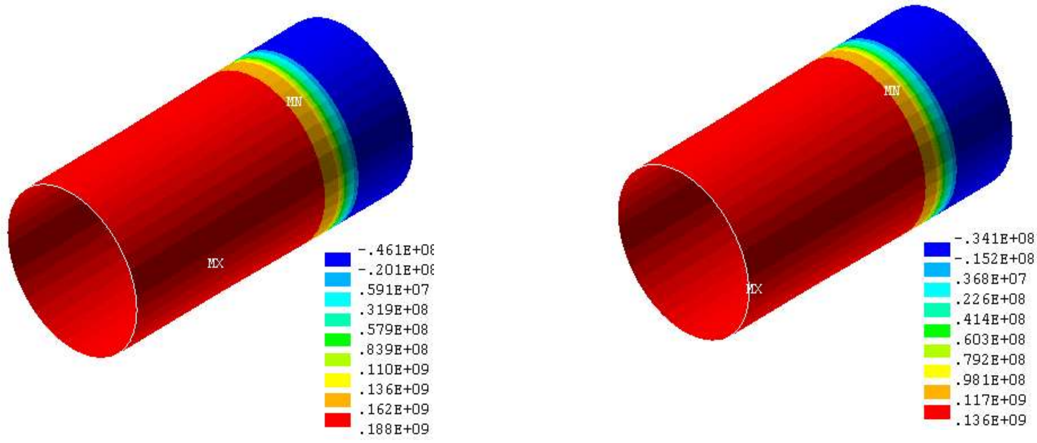

Figure 5 – S1 on Layer 5

ORIGINAL NEW CONFIGURATION

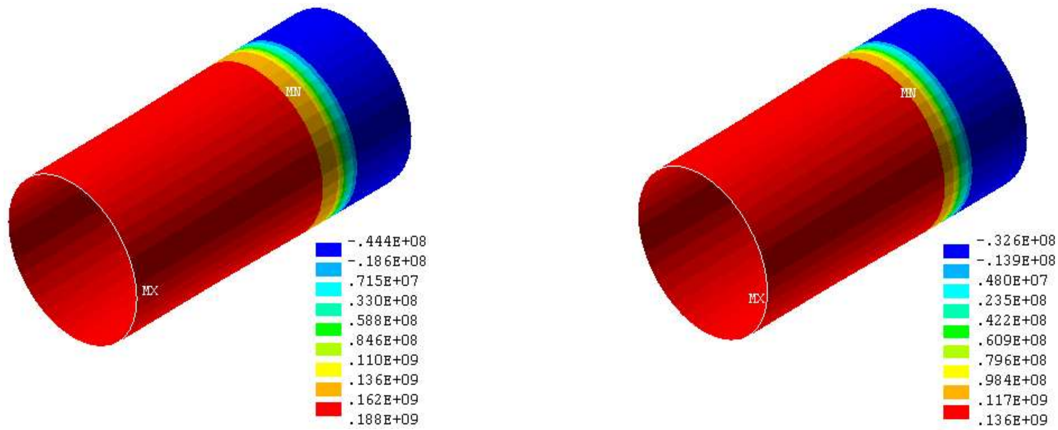

Figure 6 – S1 on Layer 11

ORIGINAL NEW CONFIGURATION

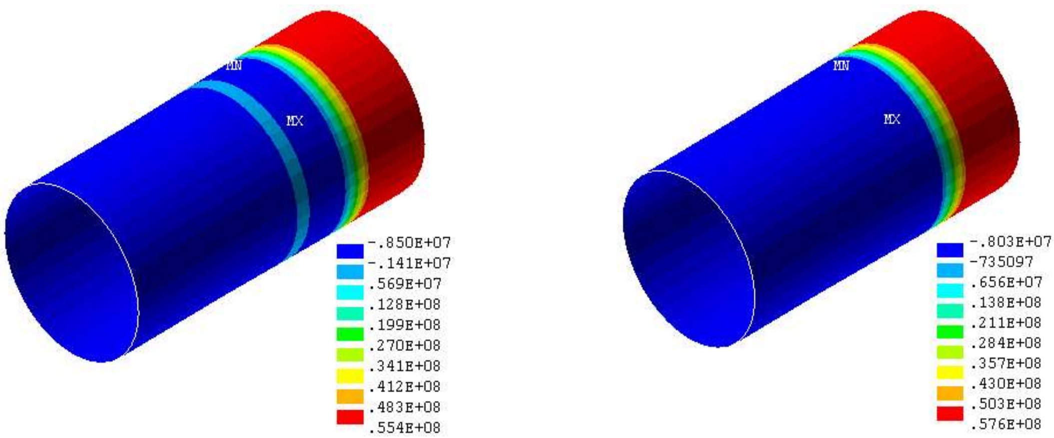

Figure 7 – S1 on Layer 24

TEST 2 was performed using maximum tension failure criteria and the boundary conditions tried to simulate the actual usage conditions in-service for the tube. This test was performed in the complete length of the tube and Figure 8 shows the finite element mesh used. Each color represent a different number of layers used. Note that Figure 1 is a part of Figure 8. The work presented in this paper had a hypothesis of not considering thermal effects in all analysis. Data used in load conditions are shown in table 2.

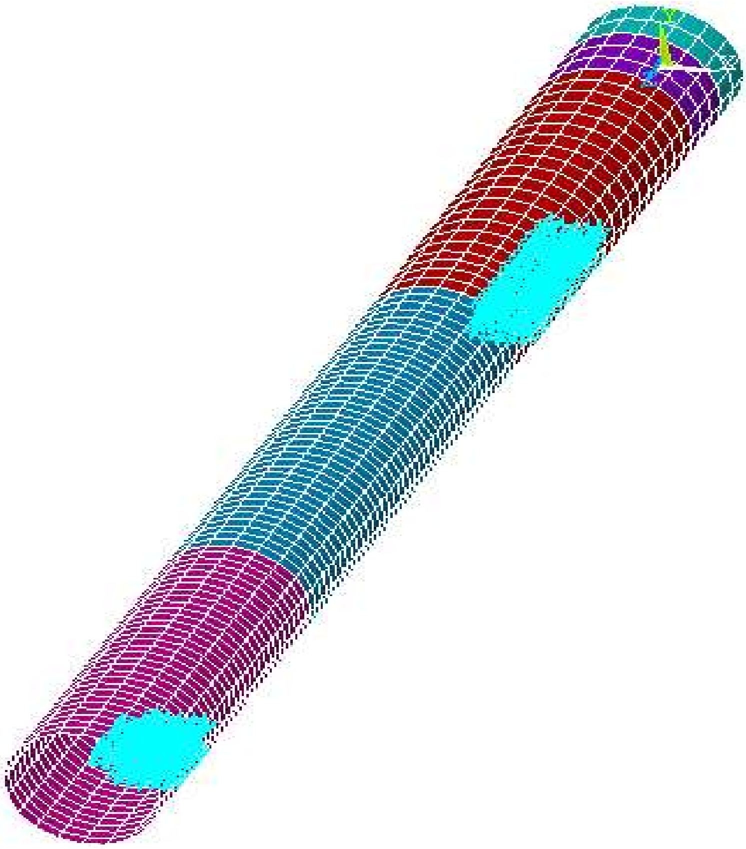

Figure 8 – Finite Element Mesh for TEST 2

Table 2 – Load Conditions for TEST 2

LOAD STEP	TIME (ms)	TIME INCREMENT (ms)	TUBE'S POSICTION (mm)	INTERNAL PRESSURE (MPa)	FRICTION FORCE (N)
1	1,00	0,100	311	60,340	2556,0
2	1,25	0,025	332	64,819	2767,6
3	1,45	0,020	355	65,931	3065,2
4	1,70	0,025	394	64,541	3646,8
5	1,95	0,025	436	61,531	4360,8
6	2,50	0,055	558	18,685	3773,2
7	3,00	0,050	679	8,548	3369,2
8	3,50	0,050	804	4,602	3122,4
9	3,90	0,040	925	2,881	2972,0

Results for this test were evaluated using LOAD STEPS vs. Stress Components (S1 or S2) graphics, containing ultimate strength limits to traction and compression, for the same layers selected on test 1. These are presented on figures 9 to 12. Legend symbols mean: S1UT (Ultimate S1 Stress component, in traction); S1UC (Ultimate S1 Stress component, in compression); S1GESP (S1 Stress component obtained for the original tube, in traction); S1GESPc (S1 Stress component obtained for the original tube, in compression); S1PROPt (S1 Stress component obtained for the new configuration, in traction); S1PROPc (S1 Stress component obtained for the new configuration, in compression).

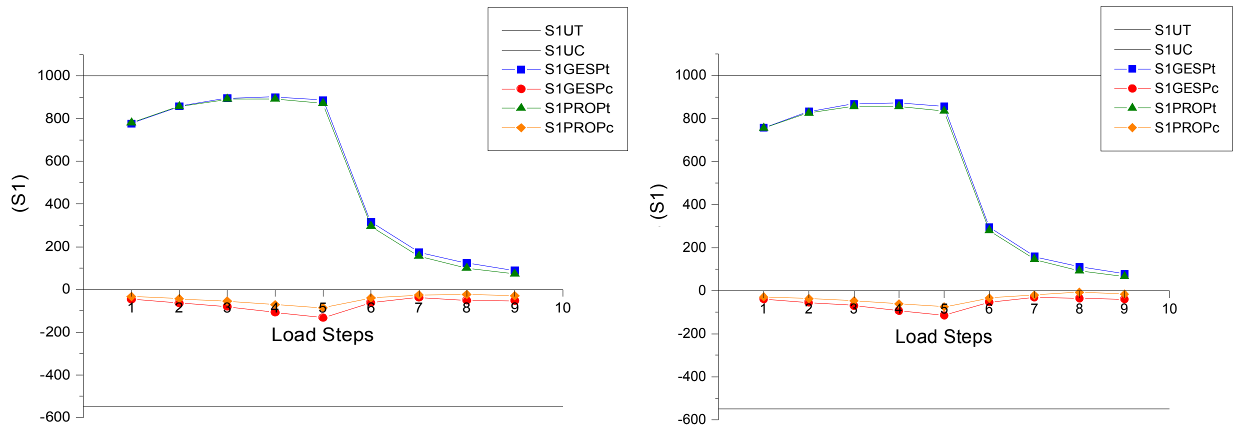

Figure 9 – Load Step vs. S1 Stress Component on Layers 1 and 4

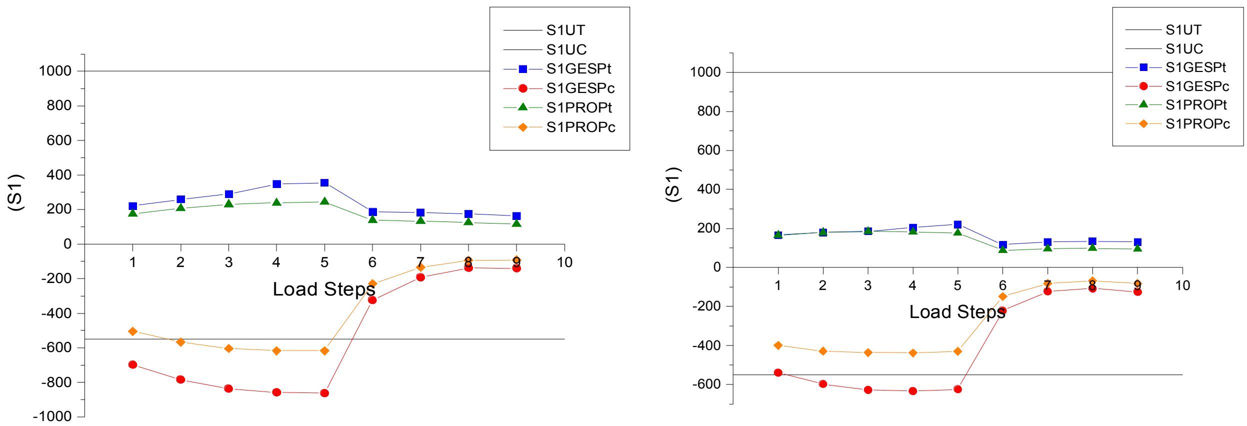

Figure 10 – Load Step vs. S1 Stress Component on Layers 5 and 11

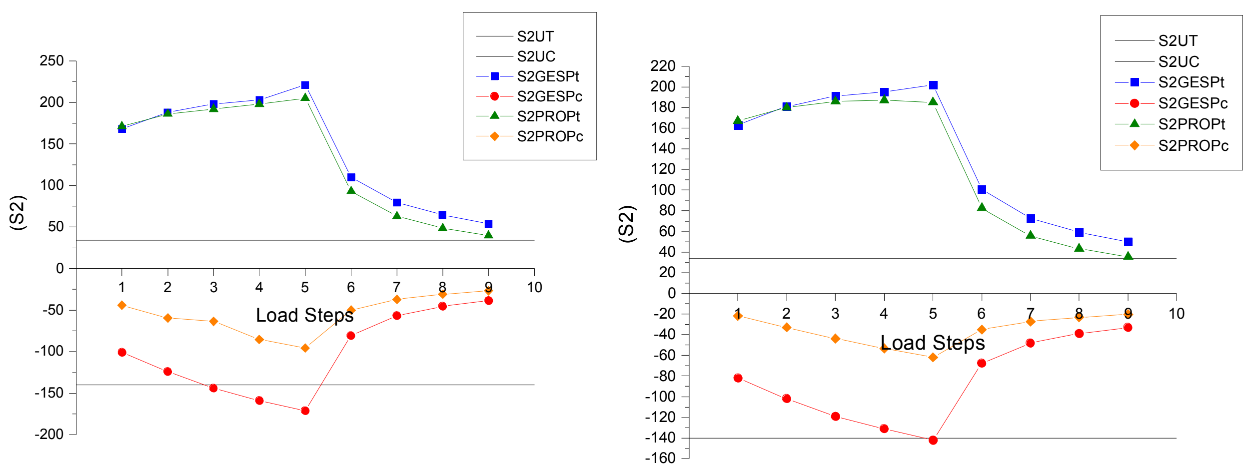

Figure 11 – Load Step vs. S2 Stress Component on Layers 1 and 4

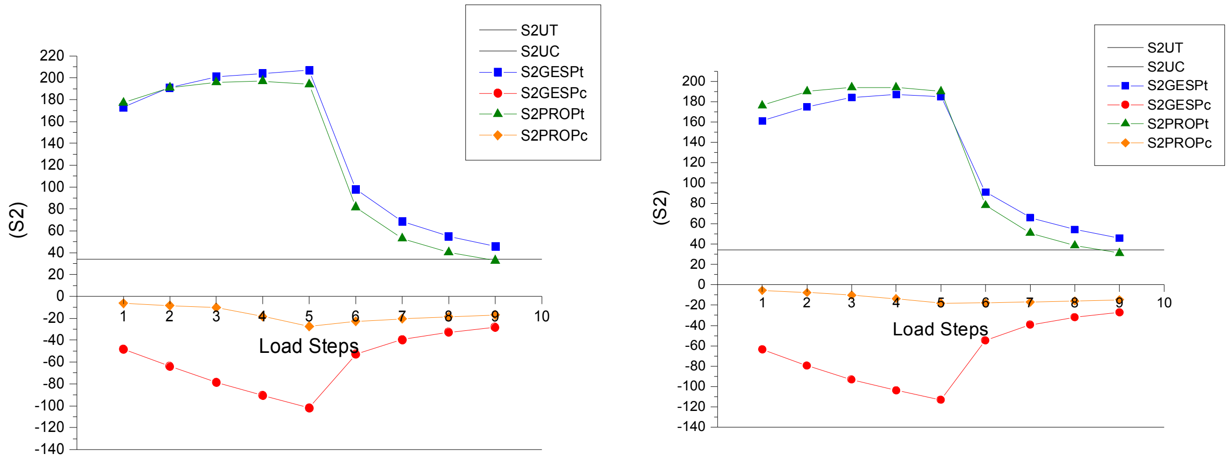

Figure 12 – Load Step vs. S2 Stress Component on Layers 5 and 11

It can be verified, on figures 9 to 12, that values on curves for NEW CONFIGURATION lay-up are always below than those for ORIGINAL lay-up, except for layer 1 at Load Step 1, presenting a small major difference. All other layers in this Load Step present slightly smaller (results not shown), except on layers in longitudinal direction (5, 6, 8, 9, 11, 12, 19 and 20), which S1 stress values showed a more accentuated difference, at least 20%, for NEW CONFIGURATION lay-up (It should be reminded that the major interested on this work is to increase longitudinal stiffness not losing circumferential one). For other Load Steps all layers in NEW CONFIGURATION lay-up showed lower values than ORIGINAL one. S2 Stress components in NEW CONFIGURATION showed lower results than ORIGINAL (Not shown values). This means a significant improvement on the structure response, mainly for compression stresses. It's worthy to mention that original tube's lay-up doesn't present problems, however it could have its configuration improved. A field test was done with the tube made with the new lay-up considered and had an excellent behavior to in-service load conditions. Besides the improvement in structure's response, the new configuration made possible a three hours reduction in fabrication process for each tube, providing a great reduction in financial costs.

3. Conclusions

Evaluating the presented results, it could be concluded that the NEW CONFIGURATION lay-up configuration provides a better behavior to the structure than the previous used. This original tube is not neglected, since the tests confirm its confidence, but the goal of improving tube's resistance in longitudinal direction could be achieved with the new design. Besides the structural advantages, as informed by the manufacturer, the tube with the new configuration lay-up diminished two hours in total time of production, compared to the original one.

4. References

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5. Responsibility notice

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