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Influence of fiber orientation on the behavior of composite pipes subject to internal pressures

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Abstract:

In the field of engineering the matrices reinforced by synthetic fibers have become widely used in view of the high specific stiffness and resistance they offer. The main objective of this work is to simulate and analyze the mechanical behavior of a multilayer composite pipe for different fiber orientation angle. A finite element numerical model (MEF) under ANSYS has been developed to determine the displacement fields for a multilayer pipe under internal pressure. Subsequently, a parametric study was carried out to enhance the effect of the mechanical and geometrical characteristics of the materials constituting the multi-layer pipe. From the results obtained, it was found that the displacement fields are clearly influenced by the orientations of the composite layers.

Keywords : Multilayer composite pipe, MEF, internal pressure, constraint, layers.

Nomenclature

L	length, m	E	Young's modulus, Pa
D_{int}	Internal diameter, m	ν	Poison coefficient
e	Thickness, m	ρ	Volumetric mass, kg/m^3
G	Shear modulus, Pa	P	Internal pressure, Pa

1. Introduction

Composite materials are increasingly applied to the production of structural components in many fields. The design of piping systems made with composite tubes was mainly studied in the case of Nuclear Power Plants.
Composite pipes are used extensively in industry. Multi-layered, filament-wound composite structures have several advantages, including high stiffness and strength, corrosion resistance, and thermal resistance [1].

During the manufacture of composite pipes, and to guarantee their reliability, monotonous biaxial tests of filamentous tubes and other briction parameters are essential [2]. As a result, failure analyzes are performed to determine the service life of composite pipes [1, 3].

In this study, we used different materials that will compose our composite pipe subjected to internal pressure; a numerical model has been created in the ANSYS software for numerical analysis. Displacements U were determined for different angles of orientation of each layer and that while varying its thickness.

1.1. History of studies conducted previously

Lekhnitskii [4, 5] derived generic analytical formulations for the main loading cases applied to anisotropic media. In 1988, Durban [6] studied finite elastic-plastic deformations on pressure pipes. In 1995, Sayir and Motavalli [7] analyzed a composite laminated tube, describing the limitations of classical laminate theory for cylindrical geometries. They propose an alternative and more precise solution for this problem. In the same year, Salzar [8] published a study on the distribution of stresses in tubes with different fractions of volume reinforcement, aimed at obtaining lighter and more efficient structures. A theoretical model for tubes under several load cases such as torsion, flexion and pressurization was presented by Tarn and Wang [9]. This bibliographic overview is detailed in the article of Volnei Tita *et al.* [10] in their work the authors presented theoretical models (analytical formulations) to predict the mechanical behavior of thick composite tubes by the development of analytical formulations for a composite pressure tube with a single thick layer and a single rolling angle. For this case, the stress distribution and displacement fields are studied according to the different rolling angles and volume fractions of reinforcement.

On 2015 Sülü and Temiz [11] in their study they concluded that when layer numbers increased, the stresses decreased and these effects were seen on composite layers.

1.2. Basic notion

A composite material is an assembly of at least two immiscible components (but having a high penetration capacity) whose properties complement each other. The new material thus formed, heterogeneous, has properties that the components alone do not have.

This phenomenon, which makes it possible to improve the quality of the material in the face of a certain use (lightness, rigidity with an effort, etc.) explains the increasing use of composite materials in different industrial sectors. Nevertheless, the fine description of the composites remains complex from the mechanical point of view because of the non-homogeneity of the material.

A composite material is composed as follows: matrix + reinforcement + optionally: load and / or additive. Example: reinforced concrete = composite concrete + steel reinforcement.

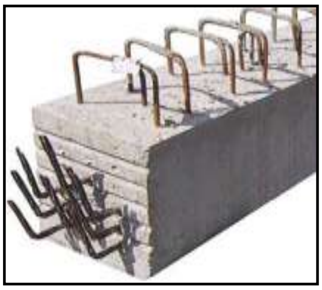

Figure 1: Reinforced concrete composite material

2. Problematic

In this work we have chosen to know the mechanical behavior of a pipe made of three materials and we have each time varied the orientation angle of the fiber of each material composing the pipe. Choosing the correct angle will reduce the displacement of the pipe due to internal pressure force which will make it resistant to internal forces.

3. Presentation of the model of pipe

In this work we have chosen to know the mechanical behavior of a pipe composed of three materials and we have varied each time the angle of orientation of the fiber of each material making up the pipe. The choice of the appropriate angle will reduce the displacement of the pipe due to internal pressure, which will make it resistant to internal stresses. This pipe has a length L = 1 m, an internal diameter D_{int} = 0.37 m and a thickness e = 30 mm, *i.e.* 5 mm for the epoxy layers and 10 for the composite layer.

The mechanical characteristics of our pipe have been grouped below (Table 1):

Table 1:
Mechanical characteristics of the pipe components

Materials	E (Gpa)	G (Gpa)	ρ(Kg/M^3)	ν
Glass	74	30	2600	0.25
Graphite	275.6	114.8	1900	0.2
Epoxy	2.76	1.036	1600	0.33

We subjected each layer of the pipe, represented by figure 2, to an internal pressure of 16 Bar to determine its U displacement.

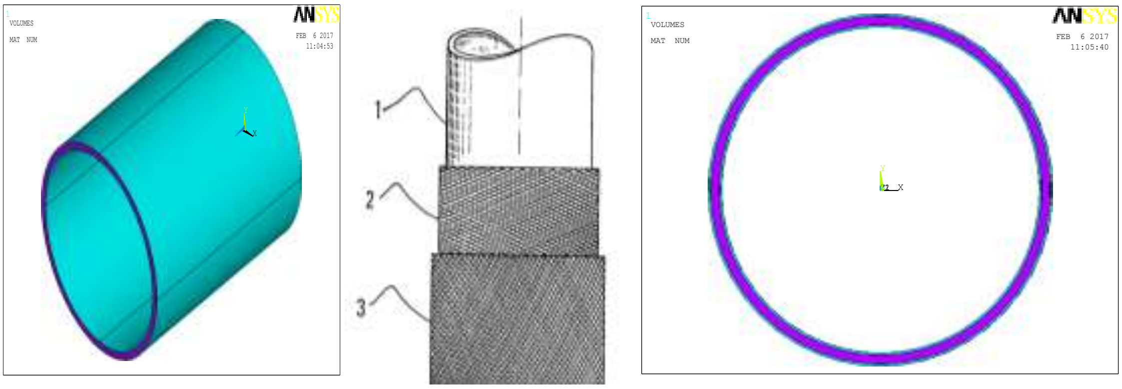

Figure 2: Geometry of the pipeline

"Solid" elements were used, for the mesh of our pipe. SOLID186 is a three-dimensional element containing 20 nodes. This element takes into consideration the quadratic displacement behavior. It has three degrees of freedom per node and allows for a stratification of 250 layers (Figure).

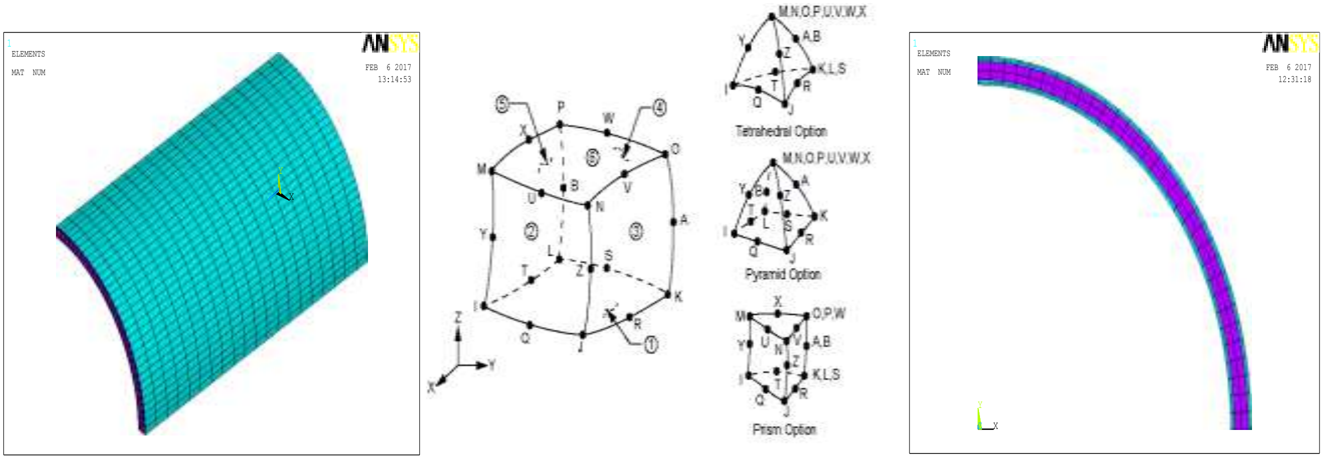

Figure 3: Geometry of the solid element 186.

The displacement U due to the effect of the internal pressure is represented in figure 4 below.

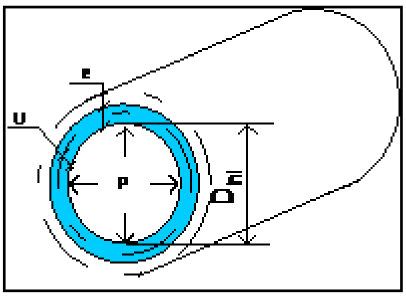

Figure 4: Displacement U due to internal pressure

4. Simulation and discussion of results

The results obtained are grouped in the figures 5 which represent the displacement as a function of the thickness of the pipe for each angle of orientation.

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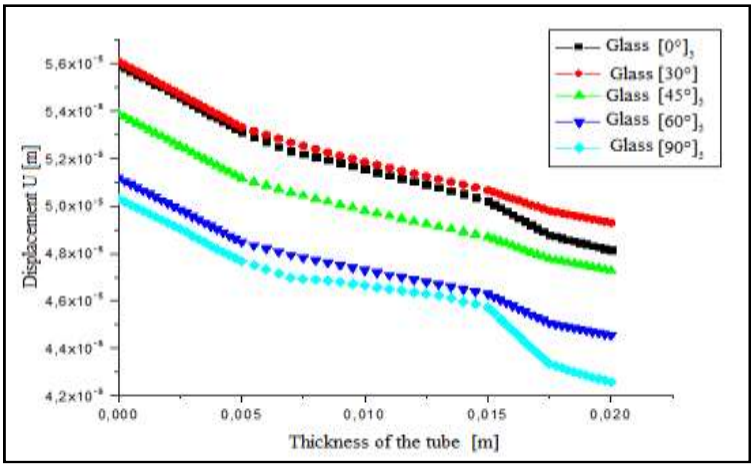
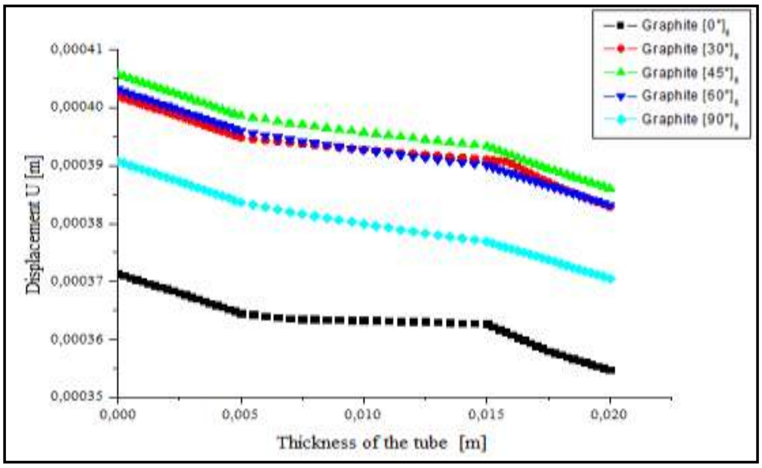
- The glass layer:



- The graphite layer:



- The Carbon layer :

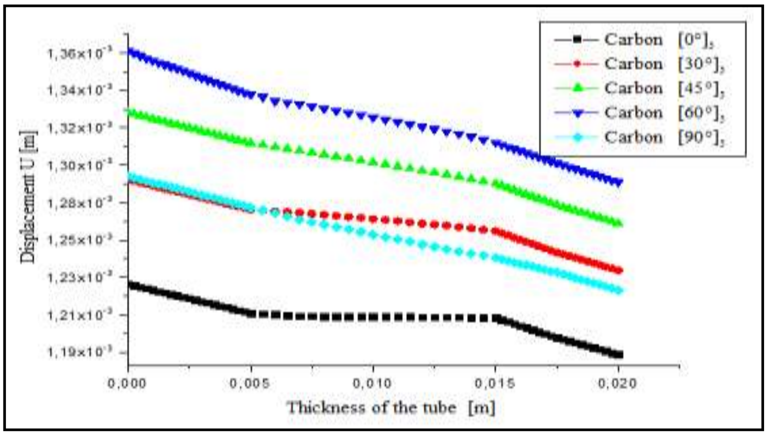
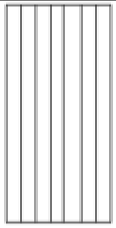
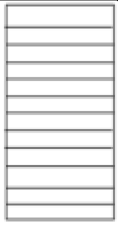
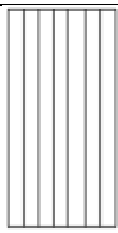


Figure 5: Fields of displacement as a function of the thickness of the fibers for different angles of orientation of the fibers.

The discussion of the results is grouped in the following table:

Table 2:
Discussion of the obtained results

The materials	Discussion	
	Results obtained	**Arrangement of fibers**
The graphite layer	As we can see according to the figure 3 We obtain a minimum displacement for the case where the fibers are oriented with a degree of 0 °	
The glass layer	As we can see according to the figure 3 We obtain a minimum displacement for the case where the fibers are oriented with a degree of 90°	
The carbon layer	As we can see according to the figure 3 We obtain a minimum displacement for the case where the fibers are oriented with a degree of 0 °	

According to the figure 5 indicating the results of the simulation by using the method of the finite elements FEM. we note that the layer in composite subjected to internal pressure, behaves in a different way and for each variation of the angle of orientation of the fiber we obtain a displacement U. this implies that the orientation angle of the fibers influences the mechanical behavior of the pipe.

The model of the multilayer tube that we propose will consist of the following layers:

• A layer of graphite whose fibers are oriented by [0 °].
• A glass layer whose fibers are oriented by [90 °].
• A carbon layer whose fibers are oriented by [0 °].

The good superposition of the layers composing the pipe will allow us to minimize the displacement U due to the internal pressures.

5. Conclusions

We have determined the displacement fields of a pipe subjected to an internal pressure of the order of 16 bars. The good arrangement of the layers composing the fibers and the correct orientation of its angle will influence the mechanical behavior of the latter by increasing this resistance to the displacement stress. This will give us a model of pipe very resistant to internal solicitations.

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