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STRESS ANALYSES OF MULTI-LAYERED COMPOSITE PIPES SUBJECTED TO INTERNAL PRESSURE

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The stress analyses of four, six and eight layered composite pipes with different orientation angles, under internal pressure, were investigated. The code of a numerical model was created in ANSYS software for numerical analyses Each layer of composite pipes was modeled with the same characteristics. The problems were studied using a computational tool based on the Finite Element Method (FEM). Each layer of the composite pipes was examined with different orientation angles. Failure loads of four, six and eight layered composite pipes were obtained from the numerical results. Radial, tangential axial and shear stresses were determined in the radial direction of the composite pipes. The shear extension coupling was considered because the lay-up angles with + θ and – θ layers were in the different radii. Effects of orientation angles and layer numbers were investigated.

Keywords: Composites, Stress analyses, Finite Element Analysis (FEA), Failure analyses, Pipelines.

Introduction

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]. Therefore, as manufacturing technology has developed, there has been growing interest in the application of fiber-reinforced composite pipes.

Research is being conducted to determine the behaviors of various composite pipes under different loadings. One of the important mechanical properties of a composite pipe is its service life. This makes it imperative to determine a piping system's leakage integrity and reliability. This depends on the strong lay-up in the principal pipe directions, which is determined with monotonic biaxial testing of filament-wound pipe [2] and testing other parameters during manufacturing. Therefore, failure analyses are conducted to determine the service life of the composite pipes. A few failure investigations have been reported in the literature, and they reported optimum failure loads, stresses, pipe radius, layer thickness, and winding angles [3-9]. The stress analysis of a multi-layered composite cylinder with local delamination was examined. In the work, they proposed a realistic analytical model and developed a system of differential difference equations with constant coefficients by introducing a transformation of super-subscripts. Also, this study was indicated that all stresses in the composite layers were lower than the stresses in the internal metal cylinder. In addition, there are several studies related to pipes in the literature [10]. Arjomandi and Taheri [11] determined that the behaviors of sandwich pipes are subject to pure bending, which is one of the governing loading conditions for offshore pipelines.

In this study, we used different orientation angle composite pipes. The code for a numerical model was created in ANSYS software for numerical analysis. Failure loads were determined for different orientation angles and different layer numbers. The radial, tangential, axial and shear stresses also were determined for different layer numbers and different orientation angles. We also investigated the stress distributions of filament-wound composite pipes with different layers.

Materials and Method

The multi-layered, filament-wound composite pipes shown in Fig. 1 have four plies [1]. Structural analyses were conducted in order to investigate the mechanical behavior of the layered composite pipes under internal pressure loading, and the orientation angles were important for the analyses. Therefore, they were used in Table 1 in which the orientation angles are shown. The composite pipes were manufactured using epoxy and glass fibers.. EPR 828 EL epoxy resin was mixed with EPH 875 hardener for use as the matrix material. In the manufacturing process, a length of 1 m was used in winding. E-glass fiber-reinforced composite pipes were produced with an inner radius of 51 mm and a thickness of each layer of 0.375 mm. The glass fabric used was unbalanced; the tow counts in the principal material directions were different from each other. The mechanical properties of this material were studied experimentally using ASTM standards, i.e., ASTM D3039-76 for the tensile test, ASTM D3410 for the pressure test, and ASTM D7078 for the shear test. Table 2 shows material constants obtained from our experimental study. In the study, we used the finite element method (FEM), and the numerical model was prepared in ANSYS 14.5 software based on FEM. The model code was created with the SOLID186 element in ANSYS software. First, a numerical model was created in ANSYS 14.5 software. Some numerical analysis results by using the orientation angles shown in Table 1 were obtained by using the numerical model. The Tsai-wu failure criterion for composite pipes was considered for failure analyses. When the failure load was determined for the E-glass fiber-compositepipes, it was considered as the maximum internal pressure (P), and the stresses were examined at the maximum pressure values.

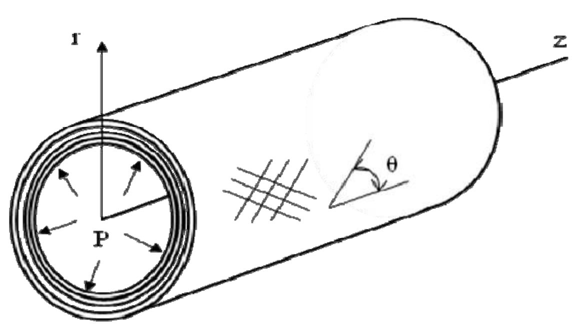

Figure 1. Multi-layered composite pipe

Table 1. Orientation angles used in the studies

Layer number	Orientation angles
4	$45^0/-45^0/45^0/-45^0$
	$55^0/-55^0/30^0/-30^0$
	$55^0/-55^0/55^0/-55^0$
6	$45^0/-45^0/45^0/-45^0/45^0/-45^0$

	$55^0/-55^0/55^0/-30^0/30^0/-30^0$
	$55^0/-55^0/55^0/-55^0/55^0/-55^0$
8	$45^0/-45^0/45^0/-45^0/45^0/-45^0/45^0/-45^0$
	$55^0/-55^0/55^0/-55^0/30^0/-30^0/30^0/-30^0$
	$55^0/-55^0/55^0/-55^0/55^0/-55^0/55^0/-55^0$

Table 2. Material constants for E-Glass

Properties	Four layers	Six Layers	Eight Layers
E_x (MPa)	25760	24115	23130
E_y (MPa)	8824	9687	9383
G_{xy}(MPa)	4965	4965	4965
G_{yz}(MPa)	3472	3472	3472
G_{xz} (MPa)	4965	4965	4965
ν_{xy}	0.14	0.14	0.14
ν_{yz}	0.22	0.22	0.22
ν_{xz}	0.14	0.14	0.14
X_T (MPa)	699.98	770.57	859.80
Y_T (MPa)	78.29	78.10	87.00
Z_T (MPa)	78.29	78.10	87.00
X_C (MPa)	382.63	446.85	653.47
Y_C (MPa)	119.91	186.91	177.65
Z_C (MPa)	119.91	186.91	177.65
S (MPa)	85.92	81.73	84.27

Finite Element Model (FEM)

The stress analysis of multi-layered composite pipes under internal pressure was conducted (Fig. 2) and the Tsai-wu failure criterion was used to calculate the failure stress distributions in all of the layers. In the analysis of multi-layered, filament-wound composite pipes, 3D non-linear FEM was conducted. The ANSYS code version 14.5 and the 20-node iso-parametric quadrilateral solid element, SOLID186, were used for the composite pipes. The 20-node element was defined with twenty nodes with three degrees of freedom at each node, i.e., translation in the nodal x, y and z directions. In the multi-layered composite pipes, the thicknesses (t) of each layer were considered to be 0.375 mm for E-glass fiber-reinforced composite pipes.

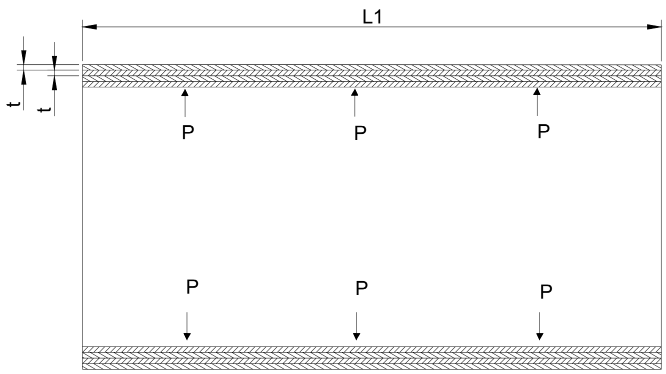

Figure 2. Finite element model

In the composite pipes, the thicknesses of each layer were considered to be 0.375 mm (t), L1=200 mm for E-glass fiber-reinforced composite pipes.

Results and Discussion

Models are created from the code generated for the numerical analyses in ANSYS software. Failure loads were shown in Table 3. When the results were observed in all cases, the stress distributions on composite pipes were shown for all layer number in Figs. 4-7. The stresses were examined in failure loads of each orientation angles of layer number (Table 3).

Table 3. Failure internal pressure of the different orientation angles multi-layered composite pipes

Layer number	Orientation angles	Failure Internal Pressure (MPa)
4	$45^0/-45^0/45^0/-45^0$	7.8
	$55^0/-55^0/30^0/-30^0$	7.7
	$55^0/-55^0/55^0/-55^0$	9.5
6	$45^0/-45^0/45^0/-45^0/45^0/-45^0$	11.5
	$55^0/-55^0/55^0/-30^0/30^0/-30^0$	11.5
	$55^0/-55^0/55^0/-55^0/55^0/-55^0$	14.0
8	$45^0/-45^0/45^0/-45^0/45^0/-45^0/45^0/-45^0$	15.0
	$55^0/-55^0/55^0/-55^0/30^0/-30^0/30^0/-30^0$	15.0
	$55^0/-55^0/55^0/-55^0/55^0/-55^0/55^0/-55^0$	17.5

All stresses were carried out in failure loads. When the figure is examined in Fig. 4-7, it is seen that the effect of layer numbers and orientation angles on failure loads. If layers numbers of composite pipe increase, the values of failure load increase. Therefore, layer number can be said important for failure cases and the stresses.

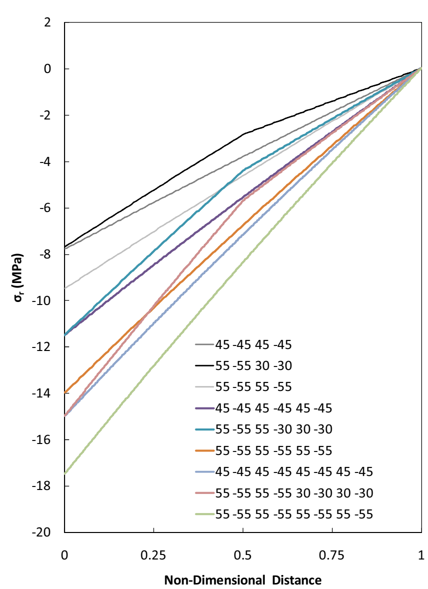

Figure 4. Radial stress distributions for different orientation angles and layer numbers (Failure loads in Table 3)

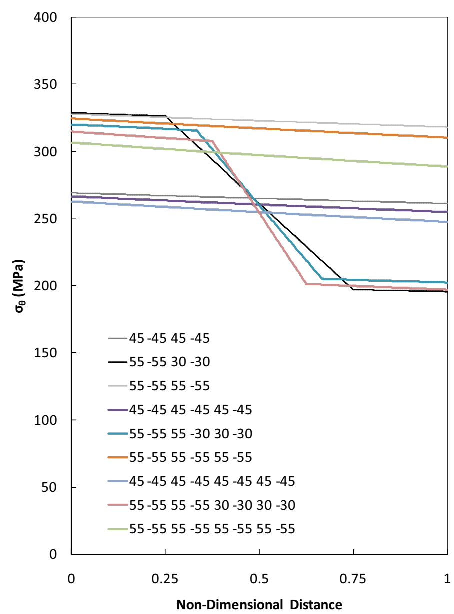

Figure 5. Tangential stress distributions for different orientation angles and layer numbers (Failureloads in Table 3)

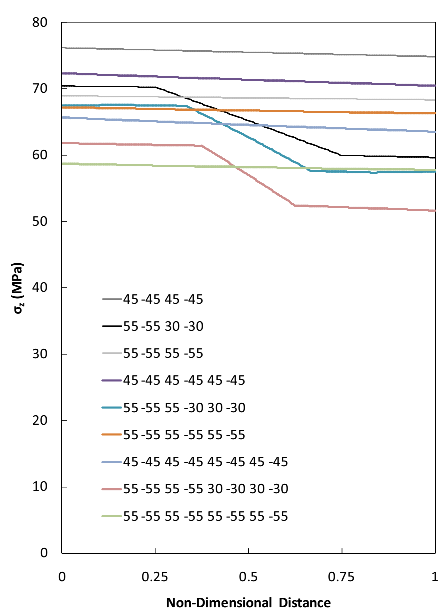

Figure 6. Axial stress distributions for different orientation angles and layer numbers (Failure loads in Table 3)

As seen in Fig. 4-7, stress distributions of four layers composite pipes are different from others. To outside from inside surface, the stress distributions are different. Because layer number change strength and failure internal pressures. When effects of layer numbers are researched, shear stresses on composite pipes can be said nearly that exhibit similar behavior. But, different shear stress behaviour can see at middle part of composite pipes. Because layer number change stress distributions. The tangential and axial stresses are the biggest in inner. On the other hand, the radial and shear stresses are the biggest in outer surfaces.

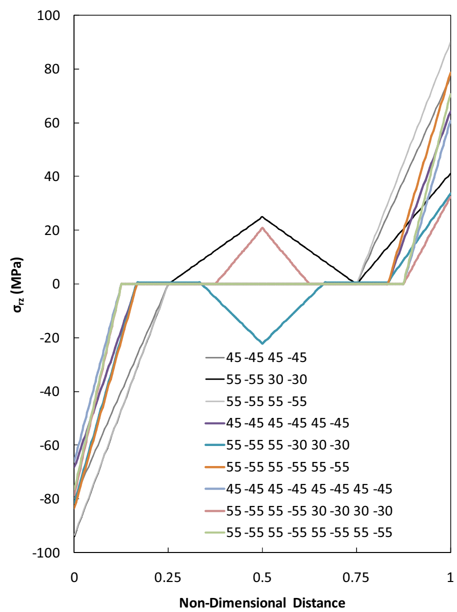

Figure 7. Shear stress distributions for different orientation angles and layer numbers (Failure loads in Table 3)

Tangential stress is the biggest and dangerous in composite pipes. As seen in Fig. 5, the stress distributions of the layers with same orientation angles are very close each other. Layer stress is important in composite pipes. Composite layers with ± 55^0 winding angles are most durable layers.

We can say that the layer number are important for multi-layered composite pipes subject to internal pressure. Composite pipes are most strength. When layer number of composite pipes increase, their strength increases. Failures create in the weakest region.

Conclusion

This study presented the stress distributions of a 3D finite element model of multi-layered composite pipes subject to internal pressure. The composite pipes were analyzed at different orientation angles and layer numbers. The orientation angles were researched to determine their effects on radial, tangential, axial and shear stresses for composite pipes. We can say that layer number affects stresses and failure internal pressures. When layer numbers increased, the stresses decreased and these effects were seen on composite layers.

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