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LAYER EFFECTS OF MULTI-LAYERED FACE TO FACE ADHESIVELY BONDED COMPOSITE PIPES SUBJECTED TO INTERNAL PRESSURE

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The stress analysis of four, six and eight layered composite pipes with different orientation angles face to face adhesively bonded, under internal pressure, was carried out. The code of a numerical model was created in ANSYS software for numerical analyses. The problem was studied using a computational tool based on the Finite Element Method (FEM). Adhesive layers created using DP 410 and each layer of the composite pipes with different orientation angles was examined. Failure loads were numerically determined for each case. The radial, tangential, axial, shear and Von-Mises stresses were obtained numerically for adhesive layer and each layer of composite pipes in the radial direction. 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 were investigated in interface region between pipes and adhesive.

Keywords: Composite pipes, Adhesive, Stress analyses, Mechanical behavior, Finite Element Method (FEM).

Introduction

Multi-layered, filament-wound composite structures have several advantages [1]. Therefore, as manufacturing technology has developed, there has been growing interest in the application of fiber-reinforced composite pipes. Composite structures are mainly joined by adhesive bonding methods with high joint efficiency [1,2]. Thus, adhesive bonding methods are important for pipes connection.

Research is being conducted to determine the behaviors of pipe systems under different loadings. A few failure investigations have been reported in the literature, and they reported optimum failure loads, stresses, pipe radius, layer thickness, and winding angles [3-6]. Different bonding methods are used in the pipe systems. Huysmans et al. [7] developed newly type of coupler for glass-fibre reinforced plastic (GRP) pipes by using a three dimensional (3D) finite element analysis. The stress distribution within the coupler and stress concentrations located at the pipe and coupler edges were examined. Knox et al. [8]

carried out both experimental and numerical analyses about structural integrity of adhesively bonded glass reinforced epoxy (GRE) composite taper/taper pipe joints. In their studies, the numerical analyses were correlated with the experimental data for validation of the computer simulations and failure predictions and demonstrated the substantial defect tolerance of the bonded composite components. Parashar and Mertiny investigated [9] solutions and challenges associated with adhesively bonded fibre reinforced polymer (FRP) pipe sections.

In this study, we used *composite* pipes with different orientation angles and different adhesives. The code for a determined for different orientation numerical model was created in ANSYS software for numerical analysis. Failure loads were numerically angles. The radial, tangential, axial, shear and Von-Mises stresses also were determined for different orientation angles.

Materials and Method

The multi-layered composite pipes with different orientation angles adhesively bonded face to face shown in Fig. 1. Structural analyses were conducted in order to investigate the mechanical behavior of the layered composite pipes with different orientation angles adhesively bonded face to face 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. 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. 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. Failure analyses were performed for composite pipes with different orientation angles and the adhesives. The Tsai-wu failure criterion for composite pipes and the Von-mises failure criterion for adhesives were 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.

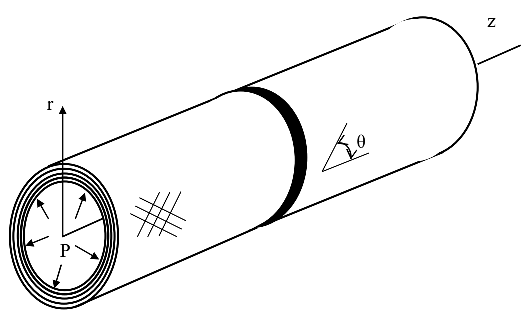

Figure 1. Multi-layered composite pipes adhesively bonded to face to face subject to internal pressure

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.

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

The adhesive was used DP 410, and its stress-strain was shown Fig. 2. The mechanical properties of the adhesive were studied experimentally using ISO 527-2 standard.

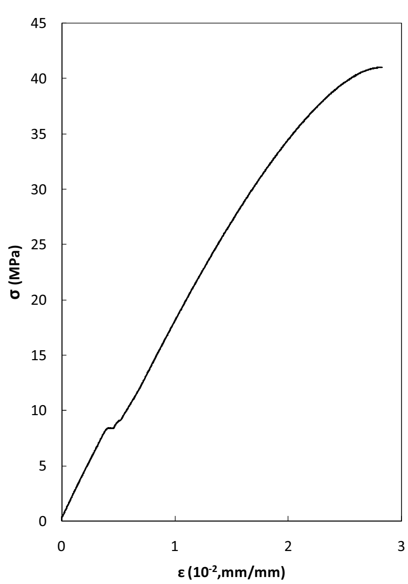

Figure 2. Tensile stress–strain curve of DP 410

Finite Element Model (FEM)

In the FEM studies, multi-layered composite pipes adhesively bonded face to face subject to internal pressure by using different orientation angles were simulated, as shown in Fig. 3. The stress analysis of multi-layered composite pipes adhesively bonded face to face under internal pressure was conducted. The Tsai-wu failure criterion for composite pipes and the Von-mises failure criterion for adhesives were used to calculate the failure stress distributions in all of the layers. In the analysis of multi-layered, composite pipes adhesively bonded face to face, 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.

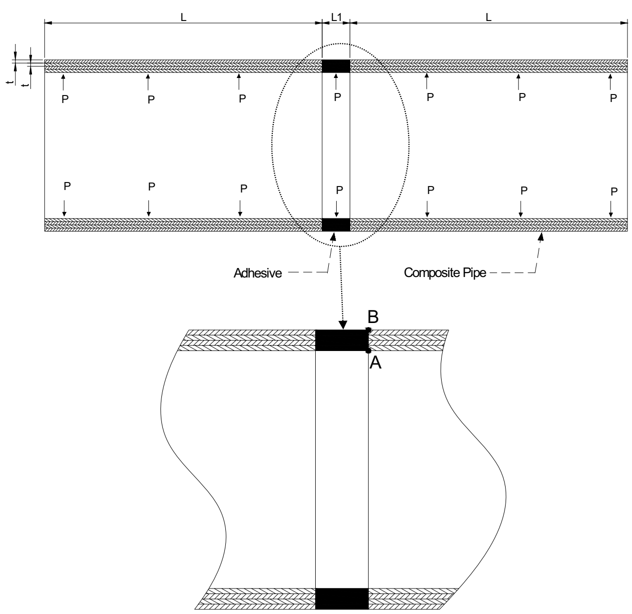

Figure 3. Finite element model

In the multi-layered composite pipes, the thicknesses of each layer were considered to be 0.375 mm (t), L=200 mm and L1=0.2 mm for E-glass fiber-reinforced composite pipes.

Results and Discussion

In the numerical analyses, models are created from the code generated in ANSYS software. Failure loads were obtained in Table 3. When the results were observed in all cases, the stresses on adhesive layer were observed for all layer number in Figs. 4-8. The stresses were examined in failure loads of each orientation angles of layer number (Table 3).

Table 3. Failure internal pressure of the multi-layered composite pipes with different orientation angles adhesively bonded face to face by using DP 410

Layer number	Orientation angles	Failure Internal Pressure (MPa)
4	$45^0/-45^0/45^0/-45^0$	7.5
	$55^0/-55^0/30^0/-30^0$	7.0
	$55^0/-55^0/55^0/-55^0$	8.0

6	$45^0/-45^0/45^0/-45^0/45^0/-45^0$	11.0
	$55^0/-55^0/55^0/-30^0/30^0/-30^0$	11.0
	$55^0/-55^0/55^0/-55^0/55^0/-55^0$	13.0
8	$45^0/-45^0/45^0/-45^0/45^0/-45^0/45^0/-45^0$	14.5
	$55^0/-55^0/55^0/-55^0/30^0/-30^0/30^0/-30^0$	14.5
	$55^0/-55^0/55^0/-55^0/55^0/-55^0/55^0/-55^0$	17.5

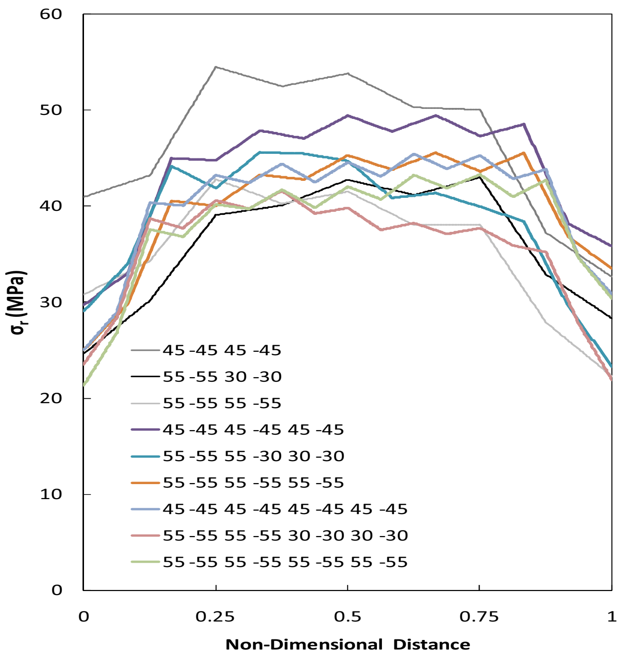

Figure 4. Radial stress distributions along A–B on the adhesive side for different orientation angles and layer numbers (Failure loads in Table 3)

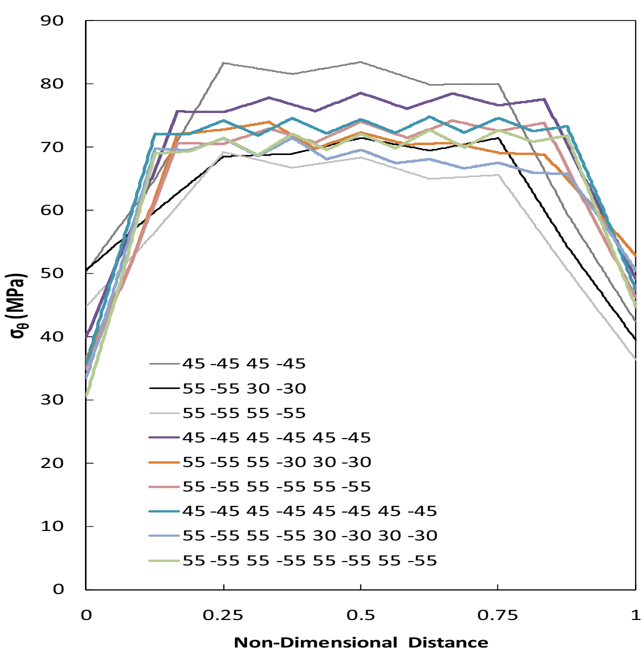

Figure 5. Tangentialstressdistributionsalong A–B on the adhesive side for different orientation angles and layer numbers (Failure loads in Table 3)

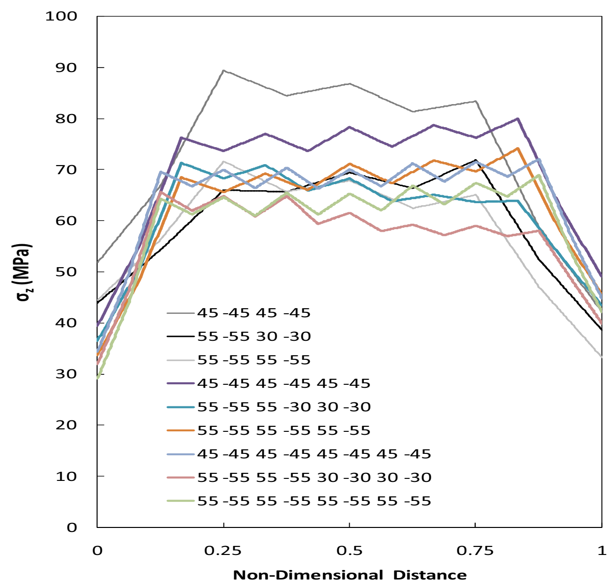

Figure 6. Axial stress distributions along A–B on the adhesive side for different orientation angles and layer numbers (Failure loads in Table 3)

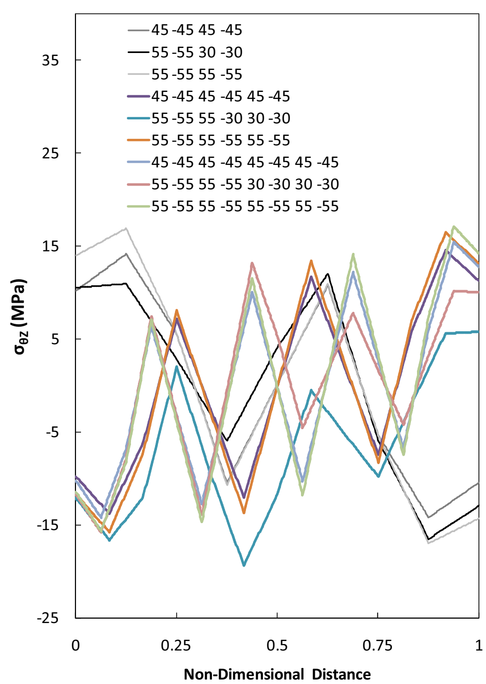

Figure 7. Shear stress distributions along A–B on the adhesive side for different orientation angles and layer numbers (Failure loads in Table 3)

In Fig. 4-6, when the figure is examined, it is seen that the effect of layer numbers and orientation angles on failure loads. All stresses were carried out in failure loads. If layers numbers of composite pipe increase, failure loads increase and the stresses decrease. Therefore, layer number can be said important for failure cases and the stresses.

As seen in Fig. 7, the layer number on adhesive affect stress distributions. Stress distributions of composite pipes with four layers are different from others. In inside surface and interfaces of layers, the stresses are different. Because layer number change strength. When effects of layer numbers are researched, shear stresses on adhesive and the stresses on composite pipes can be said that exhibit similar behavior.In Fig. 8, Von-Mises stresses distributions were showed. The stresses are the biggest in inner and outer surfaces. Von-Mises stresses on adhesive nearly demonstrate similar behavior. Because bonded strength of adhesive does not change.

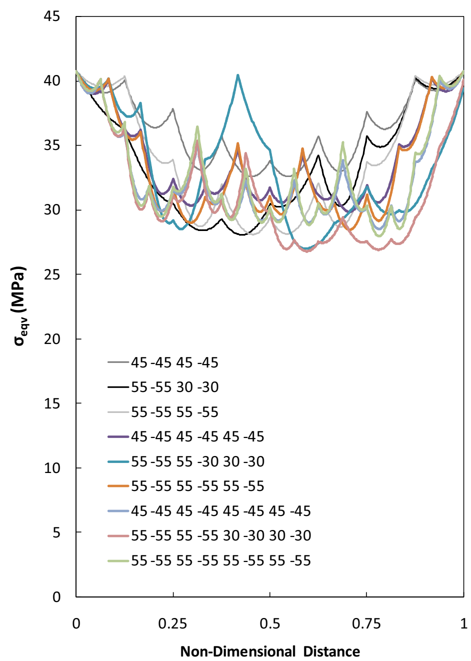

Figure 8. Von-Mises stress distributions along A–B on the adhesive side for different orientation angles and layer numbers (Failure loads in Table 3)

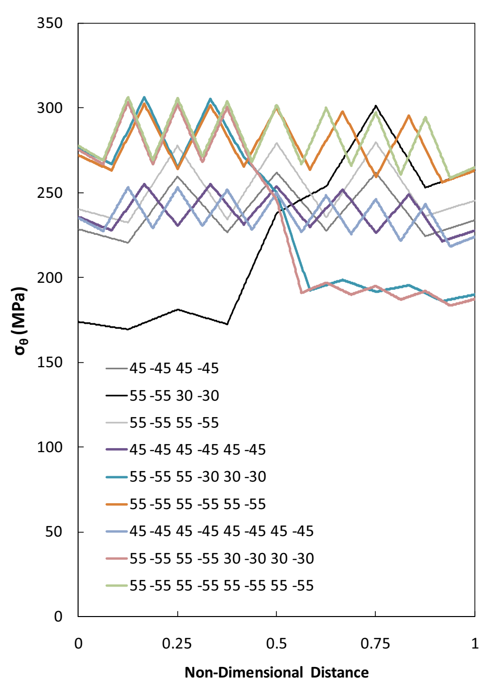

Figure 9. Tangential stress distributions along A–B on the composite pipe for different orientation angles and layer numbers (Failure loads in Table 3)

Tangential stress is the biggest and dangerous in composite pipes. As seen in Fig. 9, 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 stresses of adhesive layer are important for multi-layered composite pipes adhesively bonded face to face subject to internal pressure. Composite pipes are most strength than adhesives. Failures create in the weakest region.

Conclusion

This study presented the mechanical behavior of a 3D finite element model of multi-layered composite pipes adhesively bonded face to face subject to internal pressure. The composite pipes adhesively bonded face to face were analyzed at different orientation angles. The orientation angles were researched to determine their effects on radial, tangential, axial, shear and Von-Mises stresses for adhesive and tangential stresses for composite pipes. We can say that layer number affects stresses. When layer numbers increased, the stresses decreased and these effects were seen very much on adhesive layers. Because composite pipes has bigger strength than adhesive.

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