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Estimation of Optimum Fiber Angle of Composite Reinforced Tube using FEA

P.V. Lakshmi Prasanna
Student Scholar
Mechanical Engg. Dept.
Avanthi Institute of Engg & Tech
Vizianagaram, A.P., India

M. Lakshmi Sramika
Associate Professor
Mechanical Engg. Dept.,
Avanthi Institute of Engg & Tech
Vizianagaram, A.P., India

P. Seema Rani
Assistant Professor
Mechanical Engg. Dept.
JBIET
Hyderabad, T.S., India

Abstract: **Composite materials are combination of at least two components and structure a novel material with properties unlike from individual components. Most composites are poised of a reinforcement material, generally fibers. The reinforcement materials typically have exceptionally high tensile and compressive strength. The present work is aimed to determine the optimum fiber angle of pipe when fabricated with composite material like glass fiber and epoxy resin. FE analysis tool Ansys is used to determined to the fiber angle based on their deformation strains and stresses, maintaining the fiber volume fraction of 50%.. This optimum fiber angle is found on the comparing the results of Mild Steel and Composite Tube.**

Keywords: Ansys, MS (Mild Steel), Glass fiber, Epoxy resin, fiber angle.

I. INTRODUCTION

Filament wound composite pipes made of GRP have many potential advantages over pipes made of conventional materials, such as their resistance to corrosion; high strength, light weight and good thermal insulation properties. Continuous filaments are an economical and excellent form of fiber reinforcement and may be oriented to match the direction of stress loaded in a structure. Rousseau et al. [1] conducted parametric studies of the influence of winding patterns on the damage behavior of filament wound structures. Beakou et al. [2] used the classical laminated theory to analyze the effect of variable scattering on the optimum winding angle of cylindrical composites. Kabir [3] made the finite element analysis of composite pressure vessels having a load sharing metallic liner with a 3-D laminated shell element of the commercial FEM code, NISA-II. With developments in the manufacture of filament wound pipes, there is a growing interest in application of filament wound fiber-reinforced cylindrical composite structures. Plastic composites offer many cost advantages over metals due to their considerably higher strength-toweight ratios. Owing to their anisotropic nature, fiber reinforced composite material properties may be tailored by varying laminate fiber orientations. This is beneficial as the stiffness or strength of a structure can be maximized. Alternatively, the weight or cost can be minimized. Thin-walled filamentwound E-glass fiber-reinforced polyester tubes were tested under internal pressure to determine their burst strength. The finite element method, based on the Mindlin plate and the shell theory, is used in this application in conjunction with the initial failure criteria in order to obtain the failure load of layered composite tubes under internal pressure.

II. LITERATURES ON ANALYSIS OF FILAMENT WOUND TUBES

Design and analysis of composites is a wide are of research, which involves huge amount of academic studies in several disciplines. These studies involve both experimental and theoretical efforts. Main areas of these efforts are determination of material properties, examination of production parameters, investigations of geometries and loading conditions. These studies can be done within both a macro scale and a micro scale.

Experimental and theoretical investigations performed on filament wound composite tubes are one of the leading parts of these studies. In most of these studies the effects of winding angle on strength of filament wound composite tubes are investigated. These investigations are based on analytical or theoretical examinations.

P. D. Soden et al [4] investigated the influence of winding angle on the strength and deformation of E-glass fiber reinforced epoxy resin (Silenka 051L, 1200 tex, Ciba-Geigy MY750/HY917/DY063) filament wound tubes subjected to uniaxial and biaxial loads through various combinations of internal pressure and axial loads. The tubes were produced with a winding angle of ±45º, ±55º and ±75º. Thicknesses ranged from 1 to 3.6 mm with an internal diameter of 100 mm. Fiber volume fractions ranged from 0.4 to 0.53. A huge set of experimental data was produced, which is very valuable for design applications. Leakage and fracture strength envelopes, as well as elastic constants were presented for different combinations of structure and geometry.

P. D. Soden, R. Kitching and P. C. Tse [5] performed experiments in order to obtain experimental failure stresses for thin walled ±55º filament wound E glass (Silenka 051L, 1200 tex)-Epoxy (Ciba-Geigy MY750/HY917/DY063) tubes under axial loads. L. Parnas, N. Katırcı [6] investigated fiber reinforced pressure vessels under various loading conditions. Using classical laminated-plate theory, for a plane strain model of a thick-walled multi layered filament wound cylindrical shell, loading conditions such as internal pressure, axial force and body force due to rotation were considered. Environmental effects were also

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investigated. Optimization on winding angle for different axial forces, internal pressures, hygrothermal loading, and rotational speed loading are performed. The results of the analytical procedure, which based on Lethnitskii's approach, were compared with experimental results. Thin wall and thick wall assumptions were compared. It was shown that, up to an outer to inner diameter ratio of 1.1, two assumptions gave similar result. Beyond this value, thick wall assumption is better to use. By the numerical solution performed, optimum winding angle for internal pressure is found to be ranging between 52.1º and 54.2º depending on the geometry of the tube and the type of failure criteria used for the analysis. This result was very close to netting analysis solution of 54.74º for internal pressure. It was also stated that, thick wall assumption gives higher burst pressure values than a thin wall assumption, for winding angles between 48º and 64º. In the case of a loading, due to an angular speed, optimum winding angle is found to be between 81º and 83º. This value of the angle varies with the thickness of the tube. Note that, it is usually assumed that, if ratio of radius to thickness is higher than 10, thick wall assumption is used rather than thin wall assumption. M. Xia et al [7] investigated bending behavior of filament wound, fiber reinforced sandwich pipes. The analytical procedure developed was based on classical laminated plate theory, for multiple layered thick pipes under bending load. The effort also included analysis of sandwich pipes under bending load. The core of the sandwich pipe was assumed isotropic, where inner and outer layers were reinforced. The solution was performed using Lethnitskii's stress function approach. Performing the calculations, the effects of winding angle, maximum-minimum stress points, deformation and different materials were investigated.

In the studies made by C. Cazeneuve, P. Joguet, J. C. Maile and C. Oytana [8] the mechanical behavior of Kevlar (49)/epoxy (M10) and carbon (T300)/epoxy (M10) filament wound tubes were predicted. Fiber volumetric ratios were 50 and 55% for carbon and Kevlar, respectively. Usually, linear elastic laminated plate theory obtains the tube stiffness matrix by a homogenization process of each layer stiffness matrices according to thickness of the tube. It cannot predict the stress state of layer accurately (usually underestimates up to values of 10% [8]) but it predicts the layer in which damage is occurred. However, in the study performed by C. Cazeneuve et al, a nonlinear laminated plate theory was used with a gradual reduction in moduli of the tube layers. The gradual reduction in moduli is due to; force weightening caused by orientation of each layer with respected to load, woven characteristics of filament winded tube and plasticity. The affect of plasticity is easy to observe; reloading changes the moduli of the specimen. The value of reduction is strongly affected by the material properties, loading conditions and stress ratio. Three reduction constants were used in order to reduce the moduli, with different values for different portions of the stress-strain graph. Compression moduli were assumed to be equal to tension moduli.

M. F. S. Al-Khalil and P. D. Soden [9] performed an analytical procedure in order to obtain theoretical throughthickness elastic constants for filament wound tubes. The procedure is based on a linear elastic analysis, which obtains through thickness elastic constants from known unidirectional elastic constants. Performing necessary calculations, through thickness elastic modulus is found to be slightly higher than the transverse modulus. It was also observed that, through thickness elastic modulus is not highly affected by winding angle. On the other hand, through thickness poison ratio is highly affected by winding angle. It is practiced that, if an angle-ply laminate is preferred rather than a unidirectional off-axis laminate, through thickness poison ratio gets a higher value. Through thickness, poison ratios can be negative, generally in the case of a high in plane poison ratio. D. Hull et al [10] performed tests on terephthalic polyester filament wound tubes. Tubes were tested up to failure with an applied internal pressure. Failure types were investigated according to different stress levels and different elastic properties. It was found that, with a nonlinear behavior, decoupling between resin and the fiber seems to be occurred. Closed ended tubes experienced large-scale fiber fracture, whereas unrestrained mode tubes observed failure associated with shear effects. Olli Saarela [11] stated the fundamentals of computer programs for mechanical analysis and design of polymer matrix composites. He has observed micro mechanical and macro mechanical models, as well as analysis programs such as ABAQUS, ANSYS, NASTRAN and many special purpose programs. Fundamentals of these programs are given as well as comparison of special purpose composite analysis programs.

C. Wuthrich [12] determined the stresses on long thick-walled composite tubes under inner and outer pressure, axial forces and twisting moments. He has developed an analytical procedure, which also includes the thermal and hydrothermal effects into analysis. The results, which were presented in the report, were comparable with previous finite element results. D. W. Jensen and T. R. Pickenheim [13] wondered if fiber undulations of filament wound tubes have an important effect on compressive behavior of composite tubes. Undulations, which are created on crossings of a filament wound tube, is modeled by specimens containing certain undulations. Failure mechanisms, compressive strength and stiffness of the test specimens are observed. Flat panel coupons, which simulate crossings, are used for the tests. Material coupling, delamination, matrix splitting and fiber fracture were observed during the tests. It is also shown that, adjacent layers have great influence on undulated laminate, both in positive and negative sense. Behaviors of the specimens were linear up to failure, which were catastrophic in most cases. It is proved that undulation points were a source of fracture initiation.

L. Dong and J. Mistry [14] performed tests on composite cylinders under combined external pressure and axial compression. The test specimens were GRP cylinders

(Ciba-Geigy LY5052 epoxy and E0802 glass fiber) wound at an angle of 55°. Length to diameter ratio of tubes was 0.9 and diameter to thickness ratio was in the range of 48 to 54. Strain gages and acoustic emission is used for failure monitoring. Both, longitudinal cracks due to buckling and matrix cracks due to compression wereobserved.

III. FINITE ELEMENT ANALYSIS OF TUBE

A. Steps Followed in ansys

1. Selection of Material (Structural Steel).
2. Geometrical model of tube having dimension (500mmlong * 60mm diameter*2mm thickness).
3. Meshing of the model.
4. Boundary Conditions
    a. One end of the tube in fixed in all degrees of freedom.
    b. Pressure is allied inside of the tube (1MPa).
5. Results.

B. Finite Element analysis of Tube made of Mild Steel

FE analysis of tube made of mild steel having dimension 500mm long, 60mm diameter and 2mm thickness is analyzed by applying 1MPa pressure. The FE results are shown in fig 3 to 5 and consolidated results are shown in table 1.

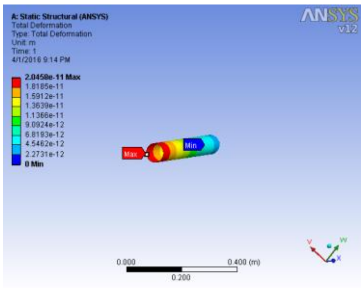

Figure 3: Deformation of MS Tube at 2MPa Pressure

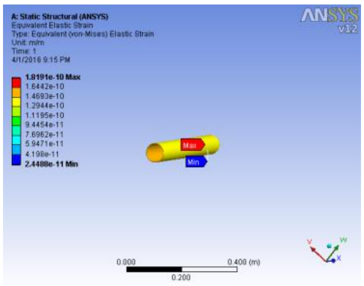

Figure 4: Von mises Strain of Mild Steel Tube

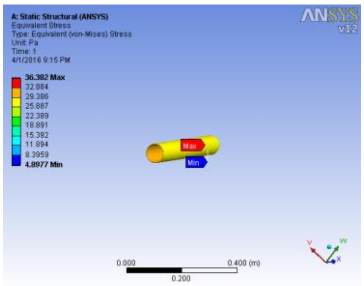

Figure 5: Von Mises Stress of Mild Steel Tube

Table 1: Consolidated results of Mild Steel

Material	Deformation (m)	Von Mises Strain	Von Mises Stress (Pa)
Mild Steel	2.045e-11	1.819e-10	36.382

C. Finite Element analysis of Tube made of Glass Epoxy:

FE analysis of tube made of Glass Epoxy having dimension 500mm long, 60mm diameter and 2mm thickness is analyzed by applying 1MPa pressure. The FE results are shown in fig 6 to 11.

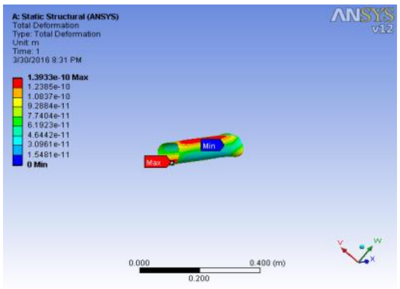

Figure 6: Deformation of 0 Deg Helix angle

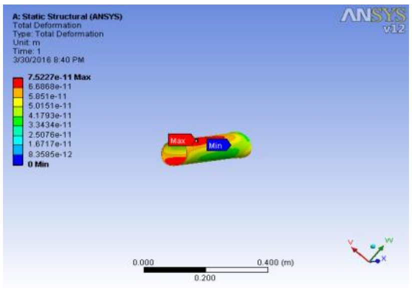

Figure 7: Deformation of 45 Deg Helix angle

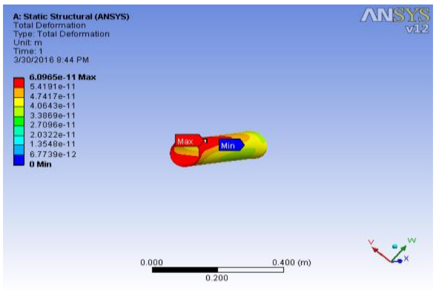

Figure 8: Deformation of 60 Deg Helix angle

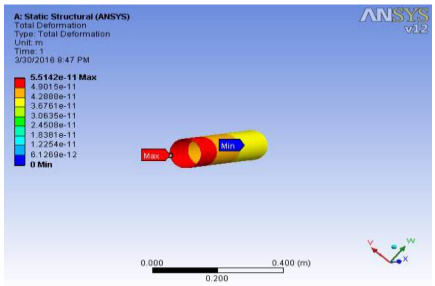

Figure 9: Deformation of 90 Deg Helix angle

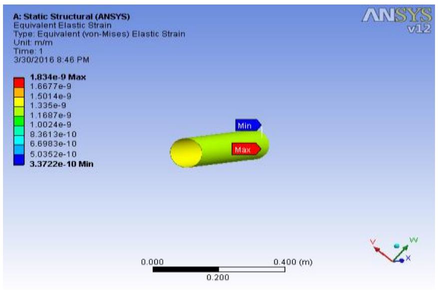

Figure 10: Von mises Strain of 90 Deg Helix angle

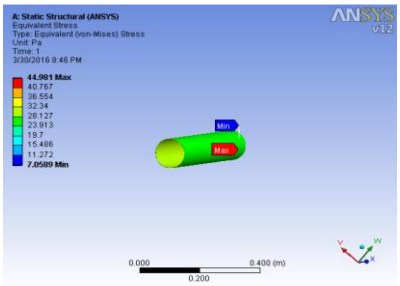

Figure 11: Von mises stress of 90 Deg Helix angle

4.0 RESULTS AND DISCUSSION

In the present work Ansys 12.0 work bench is used to analysis the composite tube having dimension 500mm long, 60mm in diameter and 2mm thick. An internal pressure of 1Mpa is applied in order to determine the optimum helix angle suitable for developing the composite tube. At first tube made of MS tube is analyzed and then composite tube is analyzed. Those results are compared. An optimum helix angle is found among the all the helix angles based on their deformation. Later optimum angle values are compared with MS material to determine the suitability for shifting from isotropic material to orthotropic material.

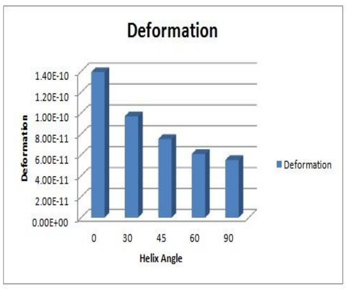

Figure 12: Graphs shows helix angle vs deformation

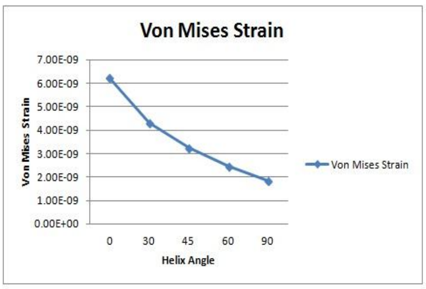

Figure 13: Graphs shows helix angle vs Von mises strain

In this graph the von mises strain at 90^o helix angle is minimum compare to other helix angle.

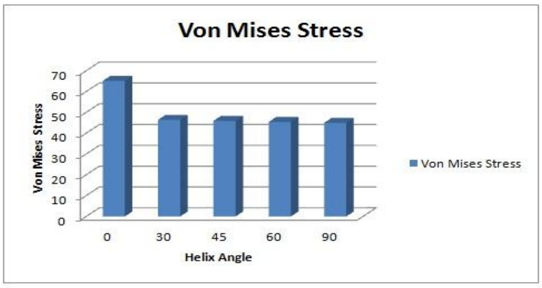

Figure 14: Graphs shows helix angle vs von mises stress

CONCLUSION

- From the results it is shown the 90^o is an optimum helix angle in built-up of composite tubes prepared of glass fiber and epoxy resin.
- The deformation of 90^o is 5.514e^{-11}m, less compared to other helix angles and very close to Mild Steel tube i.e. 2.045e^{-11}.
- The Von mises stress of composite tube at 90^o has value of 44.981Pa compare to steel which has value of 36.382 Pa.
- The results when compared composite material results shows much closer to conventional materials like mild steel in terms of stress and deformation.

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