Optimum Design And Analysis Of Filament Wound Composite Tubes In Pure And Combined Loading

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Abstract

This is the investigation of the design and analysis processes of filament wound composite tubes under pure and combined loading. The problem is studied by using a computational tool based on the Finite Element Method (FEM). Filament wound tubes are modeled as single layered orthotropic tubes. Several analyses are performed on layered orthotropic tubes by using FEM. Results of the FEM are examined in order to investigate characteristics of filament wound tubes under different combined loading conditions. Winding angle, number of layers, level of orthotropy and various combined loading conditions were the main concerns of the study. The results of the FEM analysis are discussed for each loading condition. Both pure loading and combined loading analysis results were consistent with the ones mentioned in literature, such as optimum winding angles, optimum loading and optimum level of orthotropy. Finally, the required data is obtained for the design of filament wound composite tubes under combined loading.

Key words: Filament wound, Winding angle, FEM

1. Introduction

Composites are the materials that are composed of at least two components and form a new material with properties different from those of the components. Most composites are composed of a bulk material and a reinforcement material, generally fibers. The reinforcement materials usually have extremely high tensile and compressive strength. However, these theoretical values are not achieved in structural form. This is due to the surface flaws or material impurities, which results in crack formation and failure of the piece below its theoretical strength [1].

In order to overcome this problem, reinforcement is produced in fiber form, which prevents crack formation through the whole body. However, a matrix should be used to hold these fibers together, and improve material properties in the transverse direction of the fiber. The matrix also protects the fiber from damage, as well as spreading the load equally to each individual fiber.

The material properties of a composite are determined by the properties of matrix and fiber, volumetric ratio and orientation of the fibers. The volumetric ratio of fibers is mainly determined by the manufacturing method used. The higher the volumetric ratio, the closer will be the properties of composite and fiber. Orientations of the fibers are also important, since fibers have superior mechanical properties along their lengths. Composites have an increasing popularity in engineering materials, with their stiffness and strength combined with low weight and excellent corrosion resistance [1]. By studying the variable properties of composite materials, engineers use the advantage of anisotropy included within composite materials. By building a structure by properly selected resin, fiber, layer orientation and curing, optimization is successful in most cases

2. Modeling of composite tubes

Structural analysis is performed in order to investigate the behavior of layered orthotropic tubes with different materials in Table 1. Under pure and combine loading. The model is prepared with Shell 99 element with rigid region at other end with Mass 21 element in Ansys. As shown in Fig.1 this model is constraint with for all degrees of freedom at one end and load applied to the rigid region of the tube at other end as shown in Fig 2. The internal pressure is applied on the inner surface of the tube. Dimensions of the tube used in the study are given in Table 2.

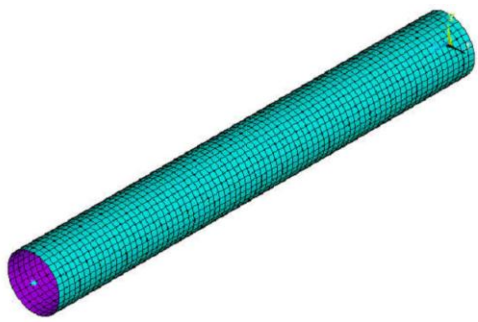

Fig 1. Finite element model of composite tube

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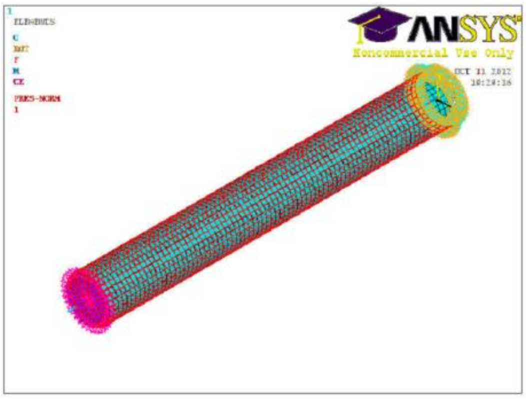

Fig.2 Boundary conditioned for composite tube.

3. Materials used for analysis

Table.1 Materials used for analysis

Mechanical Properties of Fiber Glass Epoxy Resins	Carbon / Epoxy (MPa)	E-Glass / Epoxy (MPa)	Aramid / Epoxy (MPa)
Elastic Constants			
Elasticity Exx	127700	45600	83000
Elasticity Eyy	7400	16200	7000
Elasticity Ezz	7400	16200	7000
Poisson ratio – xy	0.330	0.27	0.41
Poisson ratio – yz	0.188	0.27	0.4
Poisson ratio – zx	0.188	0.27	0.4
Shear modulus - Gxx	6900	8500	2100
Shear modulus - Gyy	4300	5500	1860
Shear modulus - Gzz	4300	5500	1860
Strength Constants			
Tensile stress – Sxx	1717	1243	1377
Tensile stress – Syy	30	40	18
Tensile stress – Szz	30	40	18
Compressive stress xx	1200	525	235
Compressive stress yy	216	145	53
Compressive stress zz	216	145	53
Shear Stress – Sxy	33	73	27
Shear Stress – Syz	33	73	34
Shear Stress – Szx	33	73	34

Table.2 Dimensions for composite tube

Length of the tube (mm)	400 mm
Fixing length at end	Rigid
Average radius (mm)	25 mm
Tube thickness (mm)	1 mm

4. Results and discussion

In this analysis, Carbon/Epoxy, E-Glass/Epoxy and Aramid/Epoxy tubes are subjected to loading action in pure and multi-axial loading with magnitudes axial, transverse as 1000 kN, torsional 1000 N.mm and internal pressure 10 bar and the analysis is repeated for varying degrees of winding angles from zero to 90^0. All deformation and stresses in corresponding directions are collected for pure and combined loading. Multi-axial deformations and stress levels are shown in Figures 3 - 10

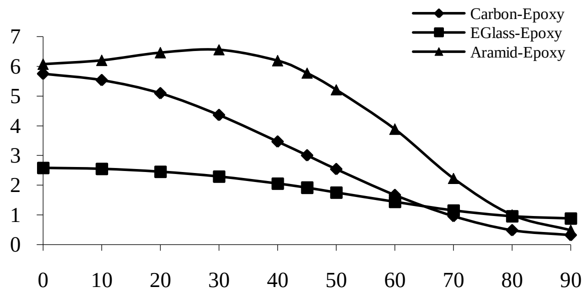

Fig 3. Axial deformation vs winding angle

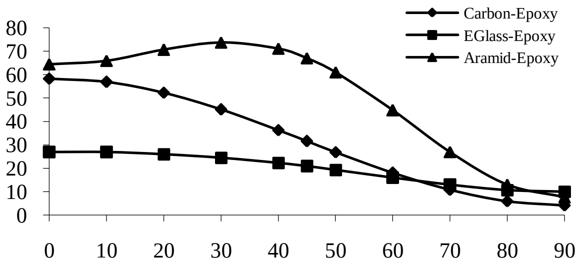

Fig 4. Lateral deformation vs winding angle

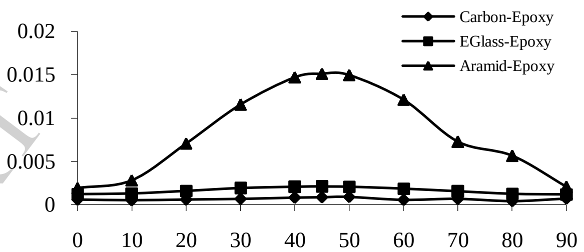

Fig 5. Angle of twist vs winding angle

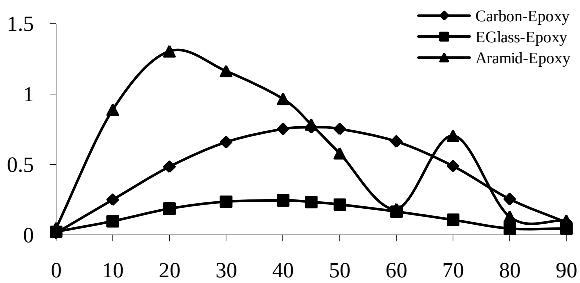

Fig 6. Radial deformation vs winding angle

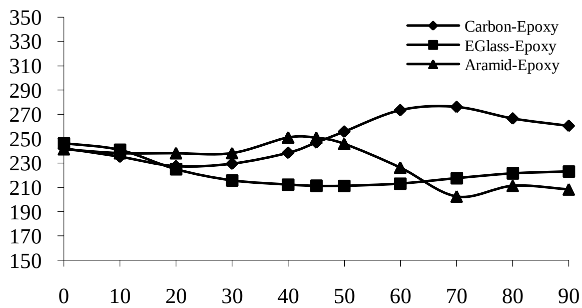

Fig 7. Normal stress vs winding angle

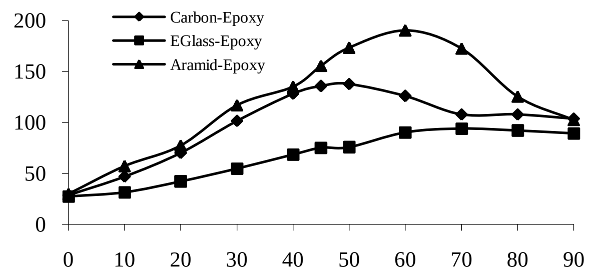

Fig 8. Bending stress vs winding angle

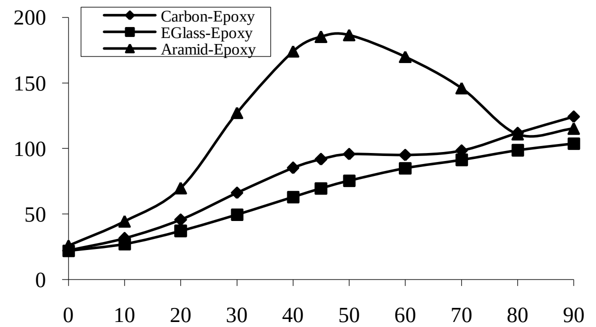

Fig 9. Shear stress vs winding angle

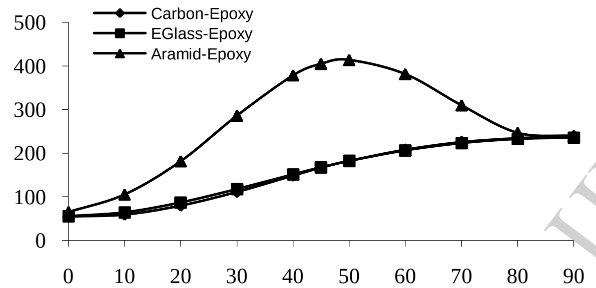

Fig 10. Hoop stress vs winding angle

5. Conclusions

In order to investigate the effect of winding angle on pure and combined loading. Analyses are performed separately for pure and combined loadings. In the case of pure loading, the results of the analyses were in agreement with the ones given in the literature. Optimum winding angle and material selected is displayed in Table 3-6.

Table.3 Optimum angles for Uni-axial loadings

Loading Type	Parameter	Carbon	EGlass	Aramid	Material Selected
Axial	Stiffness	90^0	90^0	90^0	Carbon
	Stress	90^0	90^0	90^0	
Transverse	Stiffness	90^0	90^0	90^0	Carbon
	Stress	0^0	0^0	0^0	
Torsional	Stiffness	0^0 / 90^0	45^0	45^0	E-Glass
	Stress	0^0	90^0	0^0	
Internal Pressure	Stiffness	0^0	0^0	0^0	Carbon
	Stress	0^0	0^0	0^0	

Table.4 Optimum angles for Bi-axial loadings

Loading Type	Parameter	Carbon	E Glass	Aramid	Material Selected
Axial Transverse	Stiffness	90^0	90^0	90^0	Carbon
	Stiffness	90^0	90^0	90^0	
	Stress	80^0	90^0	90^0	
	Stress	0^0	0^0	0^0	
Axial Torsional	Stiffness	90^0	90^0	90^0	Carbon
	Stiffness	90^0	90^0	90^0	
	Stress	90^0	90^0	90^0	
	Stress	0^0	0^0	0^0	
Axial Internal Pressure	Stiffness	90^0	90^0	90^0	Carbon
	stiffness	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
	Stress	10^0	45^0	0^0	
Transverse Torsional	Stiffness	90^0	90^0	90^0	Carbon
	Stiffness	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
Transverse Internal Pressure	Stiffness	90^0	90^0	90^0	Carbon
	Stiffness	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
Torsional Internal Pressure	Stiffness	0^0	80^0	50^0	E-Glass
	Stiffness	0^0	0^0	0^0	
	Stress	10^0	0^0	10^0	
	Stress	10^0	60^0	10^0	

Table.5 Optimum angles for Tri-axial loadings

Loading Type	Parameters	Carbon	EGlass	Aramid	Material Selected
Axial Transverse Torsional	Stiffness	90^0	90^0	90^0	Carbon
	Stiffness	90^0	90^0	90^0	
	Stiffness	80^0	90^0	0^0	
	Stress	80^0	90^0	90^0	
	Stress	0^0	10^0	0^0	
	stress	0^0	0^0	0^0	
Axial Transverse Internal Pressure	Stiffness	90^0	90^0	90^0	Carbon
	Stiffness	90^0	90^0	90^0	
	stiffness	0^0	0^0	0^0	
	Stress	20^0	45^0	70^0	
	Stress	0^0	0^0	0^0	
	stress	0^0	0^0	0^0	
Axial Torsional Internal Pressure	Stiffness	90^0	50^0 90^0	50^0 90^0	Carbon E.Glass
	Stiffness	40^0	50^0	40^0	
	stiffness	90^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
	stress	0^0	90^0	0^0	
	stress	10^0	45^0	10^0	
Transverse Torsional Internal Pressure	Stiffness	90^0	90^0	90^0	Carbon E.Glass
	Stiffness	40^0	0^0	0^0	
	stiffness	0^0	80^0	0^0	
	Stress	0^0	0^0	0^0	
	stress	0^0	0^0	0^0	
	stress	0^0	0^0	0^0	

Table.6 Optimum angles for Multi-axial loadings

Loading Type	Parameters	Carbon	EGlass	Aramid	Material Selected
Axial Transverse Torsional Internal Pressure	Stiffness	90^0	90^0	90^0	Carbon E.Glass
	Stiffness	90^0	90^0	90^0	
	Stiffness	80^0	90^0	0^0	
	Stiffness	0^0	0^0	0^0	
	Stress	20^0	45^0	70^0	
	Stress	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	
	Stress	0^0	0^0	0^0	

6. Recommendations to tube/pipe manufacturer

Pipe (or) Tubes manufacturing industries can look into this work for that there is lots of effect on the winding angle and level of orthotropy on deformation and level of stresses. The Schematic View of a Filament Winding Machineis shown in Fig11. Select by analysis of this type optimum winding angle and material, based on cost economy in mass production for actual loading condition on the pipe (or) tubes requirements. This presented winding angles and level of orthotropy are suitable for all lengths and loading magnitudes for them to be optimum for single layer. Fiber orientation for 45^0 and -45^0 are shown on the pipe in Fig 12

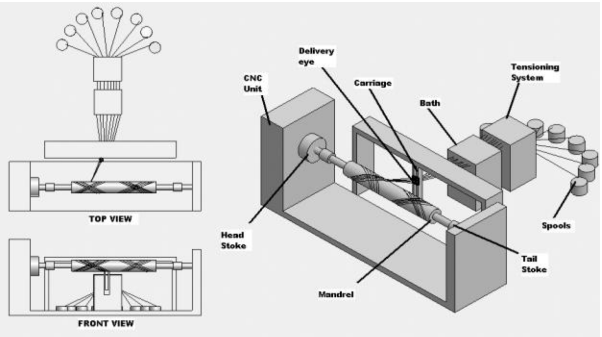

Figure 11 – Schematic View of a Filament Winding Machine

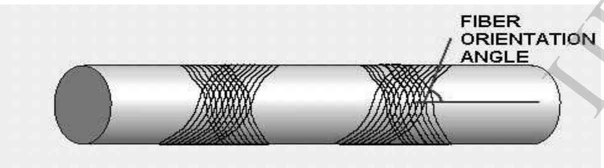

Figure 12 - Fiber orientation for 45^0 and -45^0

7. Scope of Further work

Above work is done only for single layer it can be extended for multi layer for better optimum winding angles and level of orthotropy.

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