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Analysis Of Mechanical, Electrical & Physical Behaviour of The Composite Tube (Epoxy/Glass) Made Up of Different Angle Through Filament Winding Technique & Design Optimization By Using FEA

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***Abstract—Filament Wound structures* are a kind of FRP composites that are being extensively used in many engineering fields because of their inherent advantages. This work involves the manufacturing technology viz. the filament winding technique to fabricate composite tubes. A step by step procedure of the fabrication process of tube is explained. The effectiveness of the FRP cylinders is evaluated by filling the E-Glass fibres in different orientation angle. The experimental results show that the cylinders having angle closer to the axial direction of the cylinder carrying more load capacity in comparison to normal FRP tubes. The Filament wound structures are able to effectively confine the fibres, thereby increasing their strength. To validate the results obtained from the experiments a 3-D finite element model of the filament wound tube was developed using NASTRAN in Unigraphics software. The nonlinear behaviour of the materials used in the experiments was incorporated into the FEA model by considering the appropriate stress-strain relationships. The behaviour of the confined composite cylinder was modelled using a Von-Mises stress criterion.are already defined on the style sheet, as illustrated by the portions given in this document.**

Keywords- Finite Element Model (FEA), Fibre Reinforced Plastic (FRP), Peak Exothermic Temperature (P.E.T)

I. INTRODUCTION

Composite materials can be defined as those that contain two or more constituent materials on a macro scale, each with different properties while still remaining distinct within the finished structure. This combination results in a new material which has several unique properties which cannot be achieved with either of the constituents acting alone.

One of the main advantages of the composite materials is their potential for high ratio of strength-to-weight and stiffness-to-weight. Other advantages include light weight, corrosion resistance, high specific strength, high specific stiffness, ease of fabrication, etc.

In a fibre reinforced composite material, fibres are the principal load-carry component. The type, length, volume fraction and orientation of the fibres in the matrix can contribute the effectiveness of the fibre reinforcement. Strength increases proportionally with the amount of fiber reinforcement. *E-Glass* has good strength properties at lower cost. It is used in circuit boards of computers to provide stiffness and electrical resistance. It is suited for different applications, where radio-signal transparency is desired as in aircraft radomes and in antenna, because of electrical resistance. It has a specific gravity 2.54 g/cc and a melting point 1555 °F (846 °C). Its refractive index is 1.547. The properties of E glass fibre as comparison to other fibres is shown in table.

TABLE I. FIBER PROPERTY

Material	Young's Modulus E (GPa)	Strength σ (GPa)	Density ρ (g/cc)	Strain of Failure ε (%)	Specific Strength σ/ρ (MJ/kg)	Specific Modulus E/ρ (MJ/kg)	Diameter (µm)	Upper Use Temp. (°C)
E-glass	69-72.4	1.7-3.5	2.6	3.0	0.95	27.6	25	350
S-glass	85.5	4.5	2.49	5.3	1.8	34.3	15	300
Kevlar	135	3.6	1.45	8.1	2.1	93	12	250
Carbon(HM)	517	1.86	1.96	0.38	0.95	264	8	600
Carbon(HS)	295	5.6	1.8	1.8	3-11	164	8	250
Steel	200	0.45	7.9	20	0.05	25	--	--
Aluminum	70	0.26	2.7	17	0.1	26	--	--

E-glass fibre use in the manufacturing of filament wound tubes is E-glass roving 1200 Tex epoxy compound. Its properties are:

		Unit	Limiting value
1.	Moisture content	%	0.3 Max.
2.	Loss of ignition	%	0.7 Max.
3.	Tex	mg/mt	1200 ± 10 %
4.	Appearance		Should be free from yellow fibres excess filamentation, black strand.

Resin matrix is a continuous phase in a composite material, and it plays a several important roles in the composite. It holds the reinforcement in place, act as a path for stress transfer between the fibres, and protects the reinforcement from an adverse environment, means the resin matrix serves to provide the corrosion resistance, protects the fibres from external damage. It also contributes to the overall composite toughness from surface impacts, cuts, abrasion, and rough handling.

Epoxy resins are a class of thermoset materials used extensively in structural and specialty composite applications because they offer a unique combination of properties that are unattainable with other thermoset resins.

Epoxies offer high strength, low shrinkage and excellent adhesion to various substrates. They are also effective in electrical insulation, chemical and solvent resistance, low cost and having lower toxicity. They are easily cured without evolution of volatiles or by-products by a broad range of chemical species. The different properties of thermoset resin are shown in table given below.

TABLE II. MATERIAL PROPERTY

Thermosets Material	**Young's Modulus E (GPa)**	**Strength σ (GPa)**	**Density ρ (g/cc)**	**Strain to Failure ε (%)**
Epoxy	2.6-3.8	60-85	1.10-1.20	1.5-8.0
Vinylester	3.1-3.3	70-81	1.12-1.13	3.0-8.0
Polyester	3.1-4.6	50-75	1.10-1.23	1.0-6.5
Phenolic	3.0-4.0	60-80	1.0-1.25	1.8
PUR	0.7	30-40	1.20	400-450
BMI	3.2-5.0	48-110	1.20-1.32	1.5-3.3
PI	3.1-4.9	100-110	1.43-1.89	1.5-3.0

Two important mechanical properties of any resin system are its tensile strength and stiffness. The following two figures show results for tests carried out on commercially available polyester, vinyl-ester and epoxy resin systems cured at 20°C and 80°C.

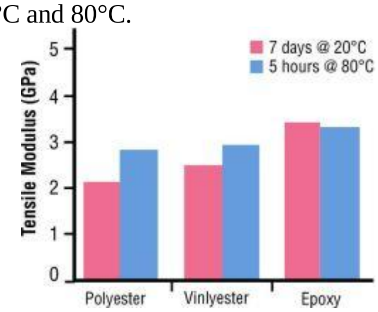

Figure 1. Tensile modulus of different resin.

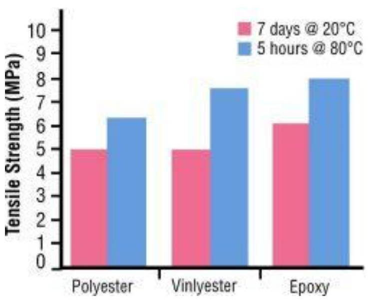

Figure 2. Tensile strength of different resin.

The first commercial epoxy resin in this class, the diglycidyl ether of bisphenol-A (DGEBA), remains the most widely used at present. The structure of pure DGEBA is shown in Figure:

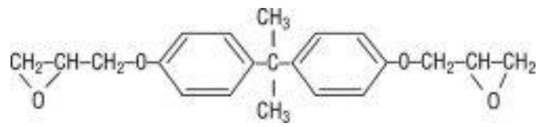

Figure 3. Chemical structure of diglycidyl ether of bisphenol-A

Various grades of material are available from multiple suppliers. The primary distinction between these grades is their viscosity, which can range from 5 to 14 Pa · s (5,000 to 14,000 cPs) at 25 °C (77 °F). The properties of epoxy (Lapox L 12) used in this project are:

	Lapox L 12	Unit	Limiting Value
1.	Appearance		Clear yellowish viscous liquid.
2.	Viscosity at 25 °C	cPs	7000 to 15000
3.	Gel time at 160 °C (Resin Mix.)	Sec.	60 to 120
4.	Epoxy content	Eq/Kg	5.0 to 5.6
5.	P.E.T	°C	185 to 210

The most commonly used chemical classes of hardeners are amines, amine derivatives, and anhydrides. Commonly used primary amines are diethylene triamine (DETA), triethylene tetramine (TETA), tetraethlylenepentamine (TEPA), and N-aminoethyl-piperazine (N-AEP). Other aliphatic amines sometimes used as epoxy hardeners are Diaminodiphenylmethane, meta-xylenediamine (MXDA) and the polymeric form of MXDA. The properties of hardener and catalyst used in the manufacture of filament wound tubes are:

Hardener (Lapox K 3)		Unit	Limiting Value
1.	Appearance		White fused solid.
2.	Melting point	°C	34 to 41
3.	Gel time at 160 °C (Resin Mix.)	Sec.	60 to 120

Catalyst (Lapox K 13)		Unit	Limiting Value
1.	Appearance		Clear, light yellowish liquid.
2.	Specific gravity at 25 °C	gm/cc	0.89 to 0.92
3.	Gel time at 160 °C (Resin Mix.)	Sec.	60 to 120

In this work, we have not taken any modifiers in the process.

II. FILAMENT WINDING TECHNIQUE

In a *filament winding* process, a band of continuous resin impregnated rovings or monofilaments is wrapped around a rotating mandrel and then cured either at room temperature or in an oven to produce the final tube. Mechanical strength of the filament wound parts not only depends on composition of component material but also on process parameters like winding angle, fibre tension, resin chemistry and curing cycle.

Once the rovings have been thoroughly impregnated and wiped, they are gathered together in a flat band and positioned on the mandrel. Band formulation can be achieved by using a straight bar, a ring or a comb. The band former is usually located on a carriage, which traverses back and forth parallel to the mandrel, like a tool stock in a lathe machine. The traversing speed of the carriage and the winding speed of the mandrel are controlled to create the desired winding angle patterns. Typical winding speeds range from 90 to 110 linear m/min, although for more precise winding, slower speeds are recommended. Relation to the mandrel rotating with a constant carriage feed of V, the wind angle is given by:

$$\theta = 2\pi Nr/v \quad (1)$$

Where r is the radius of the mandrel. Above equation shows that a constant wind angle can be maintained in a thick part only if the ratio N/V is adjusted from layer to layer.

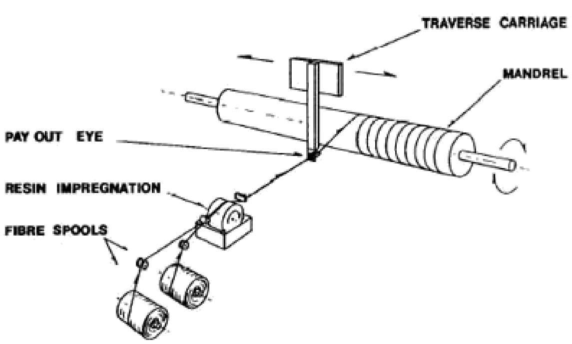

Figure 4. Schematic representation of the wet filament winding process.

In filament winding, one can vary winding tension, winding angle and/or resin content in each layer of reinforcement till desired thickness and strength of the composites are achieved. The properties of the finished composite can be varied by the type of selected winding pattern. Three basic filament winding patterns are:

In *Polar winding*, fibres are wrapped from pole to pole, as the mandrel arm rotates about the longitudinal axis as shown in figure. It is used to wind almost axial fibres on domed end type of pressure vessels. On vessels with parallel sides, a subsequent circumferential winding would be done.

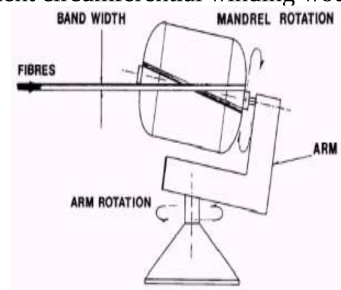

Figure 5. Polar Winding Technique

Hoop winding is a high angle helical winding that approaches an angle of 90 degrees. Each full rotation of the mandrel advances the band delivery by one full bandwidth as shown in below Figure.

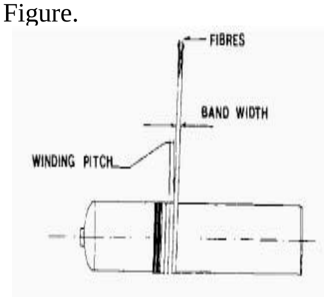

Figure 6. Hoop Winding Technique

In *Helical winding*, mandrel rotates at a constant speed while the fibre feed carriage traverses back and forth at a speed regulated to generate the desired helical angles as shown in below figure.

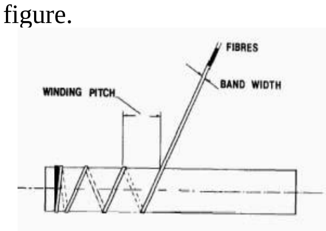

Figure 7. Helical Winding Technique

In the above three, helical winding has great versatility. Almost any combination of diameter and length may be wound by trading off wind angle and circuits to close the patterns. Usually, all composite tubes and pressure vessels are produced by means of helical winding.

III. FABRICATION PROCESS

In the fabrication process, the sample is made up of five filament wound tubes of different angle, which varies from 30˚ to 50˚ having dimension of 32 mm outer diameter, 26 mm inner diameter and length of 1000 mm.

For this formulation was suggested by the technical staff of Permali Wallace Pvt. Ltd. Bhopal for the manufacturing of filament wound tubes:

Part 1	**pbw**
Epoxy Resin (Lapox L 12)	100

Part 2	**pbw**
Hardener (Lapox K 3)	80
Catalyst (Lapox K 13)	2

Polymerization of composite tubes on a mandrel is generally performed by applying heat during and after winding. The temperature to cure the resin can range from 90 °C to 165 °C. The actual temperature is dependent on the resin used and on whether resin is modified with hardeners or accelerators. Once fully cured , remove the tube from the mandrel. After removal a cured filament wound tube has look like a figure given below:

Figure 8. Manufactured Tubes.

IV. EXAPERIMENTAL RESULTS

The mechanical properties, among all the properties of composite product are often the most important properties because virtually all service condition and the majority of end-use applications involve some degree of mechanical loading. The mechanical properties of composite can be classified as tension, compression, flexural, shear & hardness etc. The testing was conducted as per IS and ASTM standard. For achieving the theoretical Hoop stress, we have gone to the *Netting analysis*. Netting theory postulates that only the fibres transmit forces and that the fibres alone create the equilibrium with the force flows resulting from external loads.

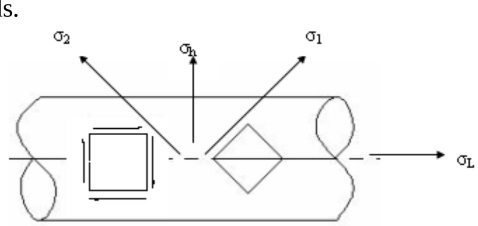

Figure 9. Netting analysis of filament wound tube.

Netting analysis using a constant helix angle can put all fibre stresses in tension. In this tube example the forces in the hoop and longitudinal direction of the fibre can be resolved into a single resultant force in the direction of the fibre. The cross-sectional area can be used to determine the actual fibre stress. Note that as shown in figure, shear forces have to be applied as well as direct force in order to maintain equilibrium of the element. Therefore a tube must contain equal numbers of +θ and –θ layers or it would tend to twist when external loads (for example internal pressure) are applied.

So, the Netting equation will be,

$$\frac{\sigma_h}{\sigma_l} = \tan^2\theta \qquad (2)$$

When considering a thin–walled cylinder with the hoop stress being twice the longitudinal stress, the theoretical optimum helical angle (θ) to produce the most efficient strength-to-weight units is 54.75 degrees.

$$\theta = \tan^{-1}(\sqrt{2}) = 54.75^\circ \qquad (3)$$

So, we analyze all the mechanical properties & theoretical hoop stress occurred in the tubes by utilizing the testing standard & the netting equation are.

TABLE III. MECHANICAL PROPERTY

F/W ANGLE	TENSILE STRENGTH (MPa)	HOOP STRENGTH (MPa)	COMPRESSIVE STRENGTH (MPa)	SHEAR STRENGTH (MPa)	Hardness (R)	FLEXURAL STRENGTH (MPa)
30°	217.978	72.659	160.304	74.439	104	426.311
35°	172.828	84.736	139.561	77.592	100	378.103
40°	156.647	110.296	135.531	75.588	101	368.269
45°	100.453	100.453	152.381	77.801	110	279.599
50°	75.999	107.939	146.154	73.302	113	205.773

The majority of applications involving composites are insulation-related. The key electrical parameters that must be studied to ascertain electrical insulation characteristics of plastic materials are dielectric strength, arc resistance and track resistance etc. The testing of electrical properties of tubes are conducted as per ASTM & IS. The following results are obtained after conducting test of different electrical property.

TABLE IV. ELECTRICAL PROPERTY

	DIELECTRIC STRENGTH		ARC RESISTANCE		COMPARATIVE TRACKING INDEX
ANGLE	Flatwise (KV/mm)	Egdewise (KV)	Inner surface (Sec.)	Outer surface (Sec.)	Sample (drops in 560 V)
30	16.33	>80	187	190	>50
35	19.34	56	172	197	>50
40	17.67	62	176	194	>50
45	19	>80	188	199	>50
50	18.7	>80	196	204	>50

The limiting value of Dielectric strength in Egdewise is 40 KV and generally the entire sample may resist more than 80KV, so the sample are passed. And the limiting value of Dielectric strength in Flatwise is ten times the thickness of the specimen i.e.: 30 KV or in KV/mm it is 10. Therefore the entire samples are passed, because they cross this value. The limiting value of Arc resistance is 120 Seconds and both the test of outer surface and inner surface of the tube shows more than this value. All the sample of different angle of the tube is resisting more than 50 droplets of NH_4CL in 560 V.
Physical properties test provide basic information that is necessary for characterizing and qualifying the material. These tests such as density, water absorption and specific gravity tests are used as a means of assuring product uniformity.

TABLE V. PHYSICAL PROPERTY

	SPECIFIC GRAVITY	WATER ABORSPTION	RESIN/GLASS CONTENT	
ANGLE		(mg)	% Weight of Resin	% Weight of Glass
30	1.92	4.18	33.99	66.01
35	1.93	3.9	28.49	71.51
40	1.93	4.59	30.86	69.14
45	2	3.67	26.14	73.86
50	1.86	4.18	28.47	71.53

V. DICUSSION

As we see the comparison chart, it is easily understood that tensile and flexural properties are decreases as the winding angle increases. It means that both the properties tend to their maximum value when the fibres are placed along the axial direction of the tube. And there is a little variation in compressive property, but in all of these angles 30 degree shows the maximum value but it has less hoop as well as shear strength. For optimum property 35 and 40 degree shows better results. Hardness of all the tubes is comfortably better. Results of electrical properties show excellent value. The dielectric strength of tubes is more than their limiting value. And the Arc resistance of tubes shows that its resistance will increases as the winding angle increases. Entire tubes have better track resistance property. All the tube has low water absorption and excellent physical property.

VI. FINITE ELEMENT MODELLING

Finite element method has become a popular technique for predicting the response of structures and materials. The finite element analysis (FEA) is a numerical procedure which is used to solve large scale of engineering problems involving stress analysis, heat transfer, electromagnetism and fluid flow etc. Finite element analysis software solves complex structure by breaking the structures into small elements. There are three basic steps used in any finite element analysis. Brief description of each of these steps is given below.

1. PREPROCESSING PHASE.
2. SOLUTION PHASE.
3. POSTPROCESSING PHASE.

Unigraphics is one of the world's most advanced and tightly integrated CAD/CAM/CAE product development solutions. The Unigraphics-NX Advanced Simulation applications suite, these tools are tightly linked with Unigraphics-NX 3D design geometry to accelerate simulation modeling, analysis and results evaluation, so that functional performance simulation results can directly influence design.
The full filament wound tube is modeled in 1000 mm length. To check the effect of non-symmetry due to the different angle, this tube has taken as 500 mm of using a 10 x10 element mesh for its better analysis of results. The meshed tubes are shown as:

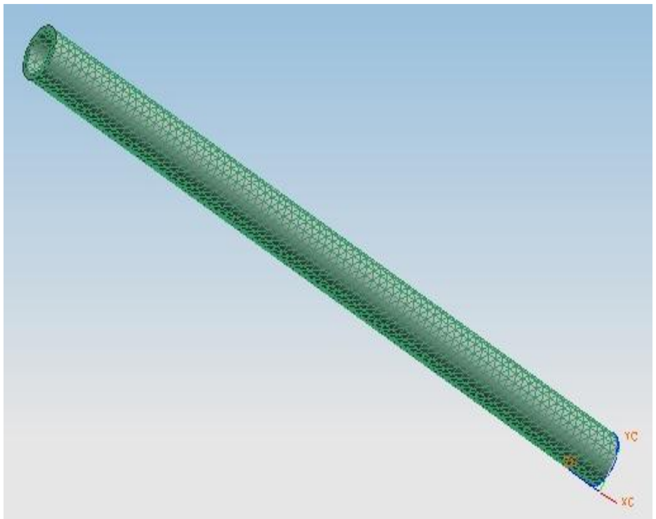

Figure 10. Modelled Mesh Tube

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A. Preprocessing Phase

During preprocessing phase all the inputs for the calculation are defined. For composite materials this phase requires more work and time than for metals. Since composite materials often are considered as orthotropic, it is important to define the material orientation in reference to the geometry. The filament wound tube is assumed to be cylindrically orthotropic, i.e., one of the material symmetry axes is parallel to the longitudinal axis of the cylinder. So the material properties of filament wound tube may be obtained from considering the Law of mixture. Therefore by using the theory of Law of mixture and experiment results the following properties are evaluated, that are given below in the following table:

TABLE VI. TUBE PROPERTY ANGLE WISE

Angle	E_1 (MPa)	E_2 (MPa)	G_{12} (MPa)	ν_{12}	ν_{21}	ρ (Kg/m^3)
30	5797.287	1200.266	160.325	0.27	0.06	1920
35	4215.317	940.919	272.502	0.41	0.09	1930
40	3269.311	704.593	248.727	0.42	0.09	1930
45	2088.419	486.811	273.177	0.49	0.11	2000
50	2190.173	488.878	224.234	0.46	0.10	1860

A nonlinear structural analysis was performed by taking into account the nonlinear material behavior of the filament wound composite tube. Unigraphics-NX performs the nonlinear analysis by employing "Newton-Raphson" criteria. Using this approach, the load is subdivided into a series of load increments and applied over several load steps.

B. Solution Phase

The solving phase is also the number crunching phase. In this phase we decide the solving, loading and boundary condition of the tube element. The filament wound tube was modeled in such a way that the axis of the tube coincides with positive z-axis and the bottom face lies in the x-y plane of the global coordinate system. The x-axis represents the radial direction and the y-axis represents the hoop direction of the tube.

The following boundary conditions were applied to the finite element model:

1) The bottom face of the tube was fixed, i.e. tube are fixed to arrest all the six degrees of freedom of that face were constrained. Some can be rotationally fixed and some can be constrained from translational movement.

2) Check the deformation of the tubes under following conditions:

a) Force may be applied as 1KN, 2KN, 3KN, 4KN, 5KN on longitudinal direction to predict the tensile property.

b) A torsion property may be predicted as applying the torque of 0.2, 0.4, 0.6, 0.8, 1.0 KN-m on the free end of the tube.

Numerous Design Criteria to predict behaviour of anisotropic and orthotropic materials have been proposed. The state of stress is described by the six Cauchy stresses (σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, τ_{zx}) which vary from point to point. The *Von-Mises* stress is a combination of these according to the following expression:

$$\sigma_{VM} = \sqrt{\frac{1}{2}\left[(\sigma_x - \sigma_y)^2 + (\sigma_x - \sigma_z)^2 + (\sigma_y - \sigma_z)^2 + 6(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)\right]} \quad (4)$$

For an obvious reason, this is also known as the effective stress. Note that by definition, the Von-Mises stress is always a positive number. For design purposes,

A factor of safety "N" is introduced leading to the condition.

$$\sigma_{vm} = \frac{\sigma_Y}{N} \quad (5)$$

Therefore, a safe design is considered to be one where

$$\sigma_{vm} < \frac{\sigma_Y}{N} \quad (6)$$

C. Post Processing Phase

In the post-processing phase the results will be examined and evaluated. It is therefore important to get the relevant results and to be able to visualize these in a reasonable way in Unigraphics software. We can easily interpret the results from the color coding. The orange-red color shows the maximum deformation zones and the blue area shows the minimum deformation zones. We can show the displacement, Von-Mises stress, Von-Mises strain energy and strain energy condition of filament wound tube at 30˚ angle.

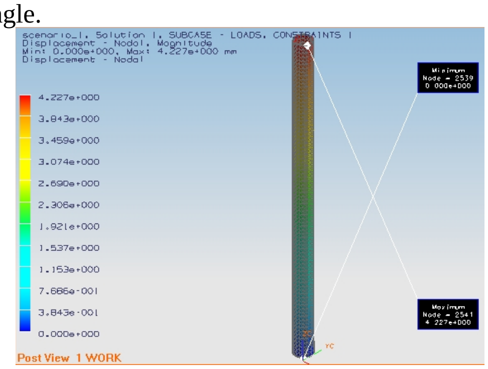

Figure 11. FEA Results

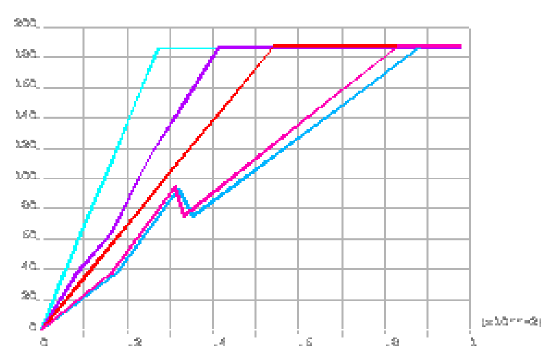

Figure 12. Stress-Strain of Different Angle Tube (MPa)

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D. *Fea Analysis*

Von-Mises stress-strain graph of different angles tube are obtained when we applied a force from 1 to 5 KN from the FEA analysis, we analyze that its behaviour are non-linear. Also the Strain energy behaves a non-linear variation with force applied upto a certain limit. So, we prefer and suggest that 30˚, 35˚, 40˚ are best to choose than 45˚and 50˚ angle tube. Here in the above figures the Turquoise line show 30˚ angle tube, similarly violet line 35˚, red line 40˚, Pink line 45˚ and dark blue line show 50˚ angle tube.

VII. Conclusion And Recommendation

The analysis of experimental results show that the filament wound composite tubes may be effective load carrying members that have high resistance to failure and deformation when compared to normal FRP tubes. The transverse support provided by the stiffeners in the hoop direction resists the global buckling of the structure. The composite action between the stiffeners and the skin helps in achieving the strength which is more than that of two individual components put together. A 3-D finite element model was developed using NASTRAN in Unigraphics to analyze the behavior of tubes. The model was basically used to validate the test results. The non-linear behavior of tubes was accounted for in the analysis by considering its stress-strain relationship. A Von-Mises criterion was used to make the model for the stress behavior of the tubes. Once the model was validated, it was used to perform a parametric analysis on some of the parameters involved in the composite tubes. The design-variables that were investigated in the analysis are different winding angles of the tubes. This parameter is assumed to have a significant effect on the strength properties of the cylinder. The load carrying capacity of the tubes increases with the decrease of winding angle and become closer to the axial direction. This increase is limited upto some critical point which reached after any further increase would not result a significant enhancement in the strength of the cylinder.

VIII. Future Work

Future research could be focused on improving the quality of the filament wound tubes by considering a new type of fabrication method. Tubes structures can be fabricated with different configurations. And the effect of each type configuration on the structural efficiency of the tubes can be analyzed. The finite element modal of the filament wound tubes can be made more accurate by considering other element type and practical boundary conditions. This finite element modal can then be utilized to conduct parametric analysis investigating design-variables such as orientation angle, grid configuration and different material properties.

References

[1] Astrom B.T., Manufacturing of Polymer Composites, Chapman & Hall, 1992.

[2] Gerstle F.P., "Composites," Encyclopedia of Polymer Science and Engineering, Wiley, NewYork, 1991.

[3] Lee H. and Neville K., Handbook of Epoxy Resins, McGraw-Hill, 1967.

[4] Goodman S.H., Handbook of Thermoset Plastics, Noyes, 1986.

[5] Brydson J.A., Plastics Materials, Iliffe Books Ltd. /D. Van Nostrand Co., 1966.

[6] Augustsson Engineer Curt, NM Epoxy Handbook, Nils Malmgren AB, Third Edition 2004.

[7] Loewenstein K.L., The Manufacturing Technology of Continuous Glass Fibers, 3rd revised ed., Elsevier, 1993.

[8] Miller D.M., Glass Fibers, Composites, Vol-1, Engineered Materials Handbook, ASM International, 1987.

[9] Gupta P.K., Glass Fibers for Composite Materials, Fibre Reinforcements for Composite Materials, A.R. Bunsell, Ed., Elsevier Publishers, 1988.

[10] Mallick P. K., Fiber Reinforced Composites (Material, Manufacturing & Design), ASM International, 2002.

[11] Rosato D. V. & Grove, Jr. C. S., Filament Winding, John Wiley & Sons, Inc.1964.

[12] Anderson Nick & Holman Jeff, Composite Tube Fabrication, Aerosleeves, LLC, 2004.

[13] Shah Vishu, Handbook of Plastics Testing Technology (IInd. Ed.), 1998.

[14] Mathur A. B., Testing and Evaluation of Plastics, Allied Publishers Pvt. Ltd.

[15] IS specification book, appendix-A.

[16] Agarwal, B. D., Broutman, L. J., "Analysis and Performance of Fiber Composites", 2nd ed., New York: Wiley, 1990.

[17] Jones, R., "Mechanics of Composite Materials", Taylor & Francis.

[18] Moaveni, Saeed, "Finite Element Analysis: theory and application", Prentice Hall, 2nd edition.

[19] Delli Parthiban & Leu Ming, Unigraphics-Nx3 for Engineering Design, University of Missouri – Rolla.

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