Design of Composite Laminated Sandwich Pipe using Different Tools

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Abstract—*Filament Wound Sandwich Laminated pipe consisting of one or more layers of fiber impregnated with a resin system and cured, core layer is sandwich in between glass layers and makes a sandwich pattern. Mostly continuous advance mandrel process is used for Sandwich pipe manufacturing. A material property is different from Linear to skin and skin to core so individual material layer calculation and from that whole laminates calculation. In this paper three different Tools are used for calculation of Elastic Modulus of composite Laminate.*

Keywords: *Filament Winding, Continuous Advance Mandrel Process, Predication of Elastic Modulus*

INTRODUCTION

Filament winding is the process of impregnating glass fiber reinforcement with resin, then applying the wetted fibers onto a mandrel in a prescribed pattern. Fillers, if used, are added during the winding process. Chopped glass rovings may be used as supplemental reinforcement. Repeated application of wetted fibers, with or without filler, results in a multilayered structural wall construction of the required thickness. After curing, the pipe may undergo one or more auxiliary operations such as joint preparation. The inside diameter (ID) of the finished pipe is fixed by the mandrel outside diameter (OD). The OD of the finished pipe is variable and is determined by the pipe wall thickness[1].The concepts of the filament winding process are illustrated in Fig. 1.

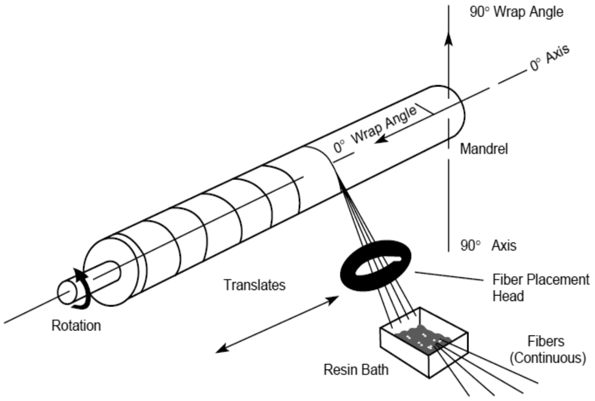


Fig. 1: Filament Winding Process

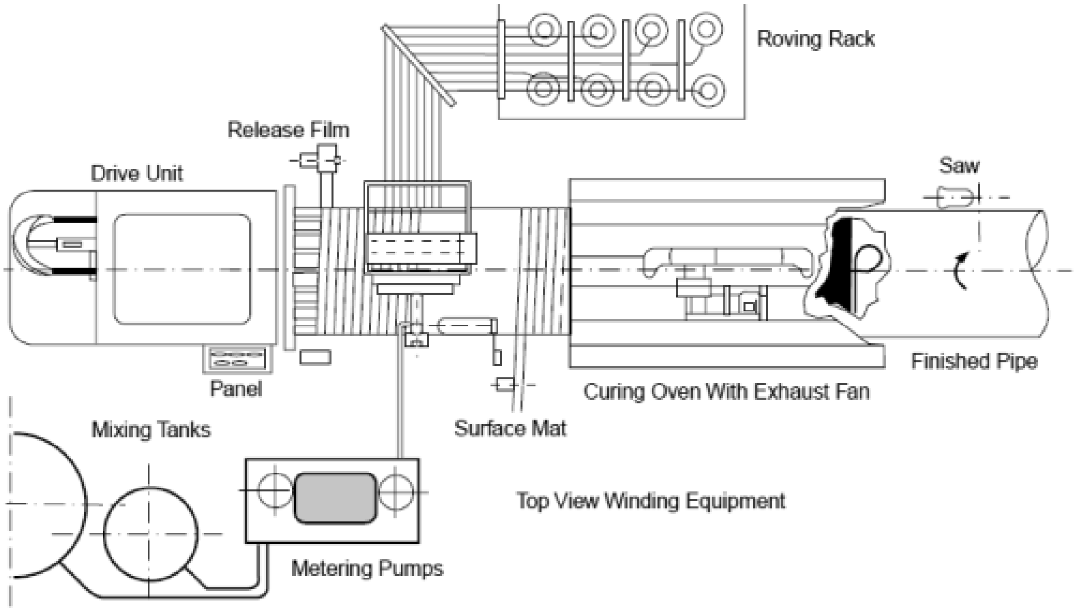


Fig. 2: Continuous Advancing Mandrel Method

Mostly continuous advancing mandrel method is used for sandwich pipe manufacturing, which is composed of a continuous steel band supported by beams, which forms a cylindrically shaped mandrel. The beams rotate, friction pulls the band around, and roller bearings allow the band to move longitudinally so that the entire mandrel continuously moves in a spiral path toward the end of the machine. Raw materials (continuous fibers, chopped fibers, resin, and aggregate fillers) are fed to the mandrel from overhead. Release films and surfacing materials are applied from rolls adjacent to the mandrel. After curing, a synchronized saw unit cuts the pipe to proper length. [1] This method is illustrated in Fig. 2. Finished pipe emerging from the curing oven is shown in Fig. 3.

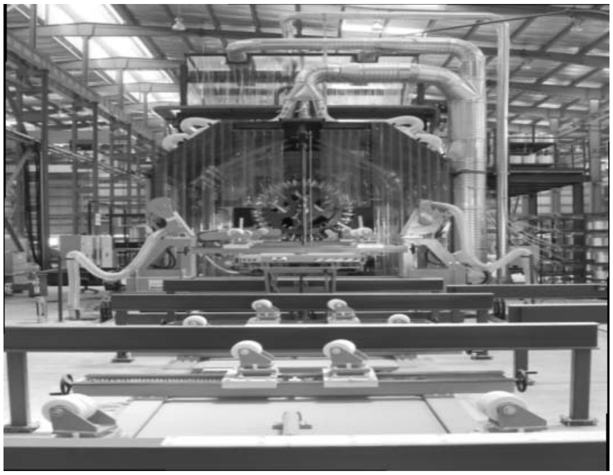


Fig. 3: Actual Setup of Continuous Advancing Mandrel Method

MECHANICAS OF COMPOSITE MATERIAL FOR LAMINATES CALCULATION

Mechanics of Composite Material Available material properties for fiber and resin are elastic modulus, Poisson ratio, and shear modulus from that using simple rule of mixture properties of lamina at material coordinate system can be calculated [2,3].

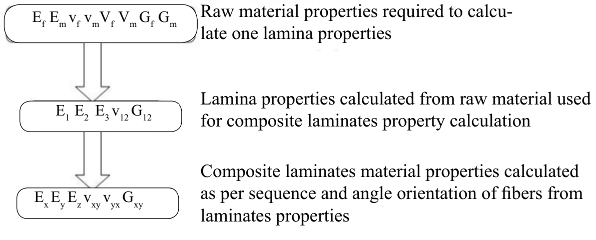


Fig. 4: Elastic Modulus Calculation using Mechanics of Composite Material

$$V^f + V^m = 1 \tag{1}$$

$$E_1 = E_1^f V^f + E^m V^m \tag{2}$$

$$\frac{1}{E_2} = \frac{V^f}{E_2^f} + \frac{V^m}{E^m} \tag{3}$$

$$v_{12} = v_{12}^f + v^m V^m \tag{4}$$

$$\frac{1}{G_{12}} = \frac{V^f}{G_{12}^f} + \frac{V^m}{G^m} \tag{5}$$

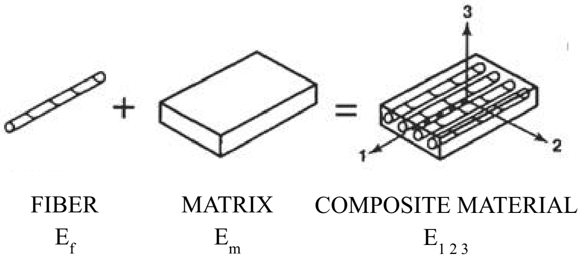


Fig. 5: Properties in Material Co-ordinate System for Orthotropic Material Behavior $E_2 = E_3$

Lamina contain glass in different manner like as unidirectional roving's, chopped strand Mat, woven roving's in that case value of multiplication factor β to elastic modulus of glass are 1, 0.5, 0.375, 0.2 respectively for unidirectional, woven roving's, glass fiber random in plane (CSM) and glass fiber random in space.

Form lamina level properties use calculated thickness of the lamina and transform material co ordinate properties to global co-ordinate system.

$$E_x = \frac{E_1}{m^4 + \left(\frac{E_1}{G_{12}} - 2v_{12}\right) n^2 m^2 + \frac{E_1}{E_2} n^4} \tag{6}$$

$$v_{xy} = \frac{v_{12}\left(n^4 + m^4\right) - \left(1 + \frac{E_1}{E_2} - \frac{E_1}{G_{12}}\right) n^2 m^2}{m^4 + \left(\frac{E_1}{G_{12}} - 2v_{12}\right) n^2 m^2 + \frac{E_1}{E_2} n^2} \tag{7}$$

$$E_y = \frac{E_2}{m^4 + \left(\frac{E_2}{G_{12}} - 2v_{21}\right) n^2 m^2 + \frac{E_2}{E_1} n^4} \tag{8}$$

$$v_{yx} = \frac{v_{21}\left(n^4 + m^4\right) - \left(1 + \frac{E_2}{E_1} - \frac{E_2}{G_{12}}\right) n^2 m^2}{m^4 + \left(\frac{E_2}{G_{12}} - 2v_{21}\right) n^2 m^2 + \frac{E_2}{E_1} n^2} \tag{9}$$

$$G_{xy} = \frac{G_{12}}{n^4 + m^4 + 2\left(\frac{2G_{12}}{E_1}\left(1 + 2{}_{12}\right) + \frac{2G_{12}}{E_2} - 1\right) n^2 m^2} \tag{10}$$

Where, m = cosθ and n = sinθ used for transformation of material properties.

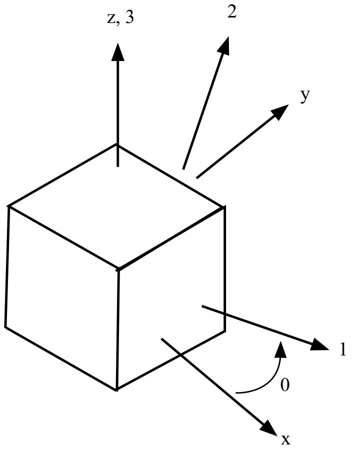


Fig. 6: Local and Global Co-ordinate System

Above equation will give material properties in global co ordinate system for one lamina only when more than one lamina combined to gather it will make laminates and for those it required to calculate effective material properties using ABDH matrix calculation.

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} \overline{Q}_{11} & \overline{Q}_{12} & \overline{Q}_{16} \\ \overline{Q}_{12} & \overline{Q}_{22} & \overline{Q}_{26} \\ \overline{Q}_{16} & \overline{Q}_{26} & \overline{Q}_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \tau_{xy} \end{Bmatrix} \tag{11}$$

$$A_{ij} = \sum_{k=1}^{N} \overline{Q}_{ijk} \left(z_k - z_{k-1} \right) \tag{12}$$

$$B_{ij} = \frac{1}{2} \sum_{k=1}^{N} \overline{Q}_{ijk} \left(z_k^2 - z_{k-1}^2 \right) \tag{13}$$

$$D_{ij} = \frac{1}{3} \sum_{k=1}^{N} \overline{Q}_{ijk} \left(z_k^3 - z_{k-1}^3 \right) \tag{14}$$

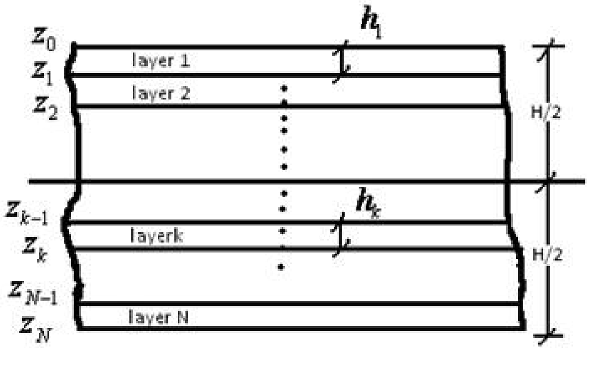


Fig. 7: Schematic Illustration Showing a Cross-section

$$\begin{bmatrix} a_{11} & a_{12} & a_{16} & b_{11} & b_{12} & b_{16} \\ a_{12} & a_{22} & a_{26} & b_{12} & b_{22} & b_{26} \\ a_{16} & a_{26} & a_{66} & b_{16} & b_{26} & b_{66} \\ b_{11} & b_{12} & b_{16} & d_{11} & d_{12} & d_{16} \\ b_{12} & b_{22} & b_{26} & d_{12} & d_{22} & d_{26} \\ b_{16} & b_{26} & b_{66} & d_{16} & d_{66} & d_{66} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{66} & D_{66} \end{bmatrix}^{-1} \tag{16}$$

$$\overline{E}_x = \frac{1}{a_{11} H}$$

$$\overline{E}_y = \frac{1}{a_{22} H} \tag{17}$$

$$\overline{G}_{xy} = \frac{1}{a_{66} H} \tag{18}$$

$$\overline{v}_{xy} = -\frac{a_{12}}{a_{11}}$$

$$\overline{v}_{yx} = -\frac{a_{12}}{a_{22}} \tag{19}$$

DESIGN OF COMPOSITE LAMINATED SANDWICH PIPE

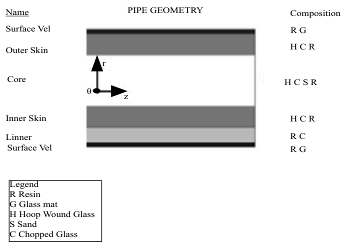


Fig. 8: Composition of Continuous Advance Mandrel Filament Wound Sandwich Pipe

Above figure shows the composition of sandwich pipe from which pipe wall thickness made.

Table 1 shows the Typical Design of 600 diameter sandwich pipe composition details for particular application and Table 2 shows the Mechanical properties of different laminates form which pipe wall thickness made.

Table 1: Detailing of Composite Laminated Structure

		SM Inner	Liner	Skin Inner	Core	Skin Outer	SM	Total
DN	OD	tism	tl	tis	tc	tos	tosm	tt
mm	mm	mm	mm	mm	mm	mm	mm	mm
600	618	0.2	1.1	1.0959	5.4757	1.0167	0.2	9.0883

Table 2: Detailing of Composite Laminated Material Properties

Properties	Ehf (MPa)	Eht (MPa)	Eat (MPa)	Poisson Ratio
SM	3300	3300	3300	0.3
Liner	10000	10000	8000	0.3
Skins	39000	39000	12500	0.29
Core	8500	4500	4800	0.18

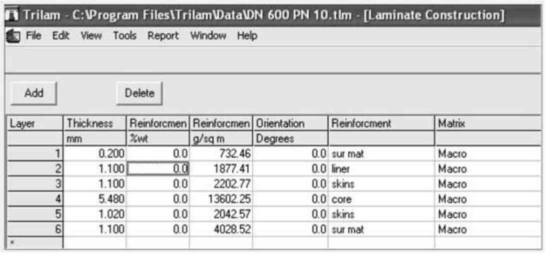
TOOLS USED FOR LAMINATES CALCULATION

TriLam

TriLam is primarily intended for the analysis and design of fiber reinforced thermo set plastic laminates. It is sufficiently general to handle all types of layered orthotropic and isotropic materials with or without core materials.

The prefix 'TRI' in TriLam implies that the program includes analysis in the three principle directions of a laminate, the third direction being through the thickness.

Operation of the program consists basically of the user defining each layer of the laminate in sequence. The program then calculates the properties of the laminate. Several loading options allow the user to apply combinations of loads to the laminate as a flat plate or as a cylinder. The program then calculates the stresses or strains as requested by the user and the strength ratios for each layer. The maximum number of layers that can be entered is limited only by available computer memory [4].



Layer	Thickness	Reinforcmen	Reinforcmen	Orientation	Reinforcment	Matrix
	mm	%wt	g/sq m	Degrees		
1	0.200	0.0	732.46	0.0	sur mat	Macro
2	1.100	0.0	1877.41	0.0	liner	Macro
3	1.100	0.0	2202.77	0.0	skins	Macro
4	5.480	0.0	13602.25	0.0	core	Macro
5	1.020	0.0	2042.57	0.0	skins	Macro
6	1.100	0.0	4028.52	0.0	sur mat	Macro
*						

Fig. 9: Laminates Preparation and Calculation using TriLam Software

COMPCYL Program

The MIL HDBK 17 equations are used for the unidirectional lamina material properties calculation and are the basis for calculating the random fiber properties. This program is developed by Rick Vane [5].

MATLAB [6]

44 MATLAB functions (M-files) specifically written for the analysis of fiber reinforced composite materials. It may be called the MATLAB Composite Materials Mechanics Toolbox [6].

Steps for Calculation of Elastic Modulus of Composite Laminates:

6 Layers, Thickness = 9.088mm

```
Q1 = ReducedStiffness(3300,3300,0.3,1.375)
Q2 = ReducedStiffness(8000,10000,0.3,3.33)
Q3 = ReducedStiffness(12500,39000,0.29,5.20)
Q4 = ReducedStiffness(4800,4500,0.18,2)
Q5 = ReducedStiffness(12500,39000,0.29,5.20)
Q6 = ReducedStiffness(3300,3300,0.3,1.375)
Qbar1 = Qbar(Q1,0)
Qbar2 = Qbar(Q2,0)
Qbar3 = Qbar(Q3,0)
Qbar4 = Qbar(Q4,0)
Qbar5 = Qbar(Q5,0)
Qbar6 = Qbar(Q6,0)
z1 = 0
z2 = 0.2
z3 =1.3
z4 = 2.39596
z5 = 7.87166
z6 = 8.88839
A= zeros(3,3)
A= Amatrix(A,Qbar1,z1,z2)
A= Amatrix(A,Qbar2,z2,z3)
A= Amatrix(A,Qbar3,z3,z4)
A= Amatrix(A,Qbar4,z4,z5)
A= Amatrix(A,Qbar5,z5,z6)
A= Amatrix(A,Qbar6,z6,z7)
H = 9.088393
```

COMPARISON

Table 3: Comparison of Elastic Modulus of Composite Laminates using Three different Tools Font Sizes for Papers

Properties	TRILAM Software	COMPCYL Excel Sheet	Mat Lab
Eat (GPa)	7.03	6.9402	6.9401
Eht (GPa)	14.79	14.1059	14.105
Eaf (GPa)	8.31	8.2774	8.27
Ehf (GPa)	19.68	19.3940	19.39
νah	0.29	0.2724	0.2724
νha	0.62	0.5535	0.5536

Above Table shows comparison between calculated material properties.

CONCLUSION

By using three different tools successfully calculated mechanical properties of Filament wound sandwich pipe, and also found that good results are matching with available tools like TRILAM and COMPCYL Program and formulated equations in MATLAB.

NOMENCLATURE

Ef, Em–Elastic Modulus of Fiber and Matrix respectively E1, E2, E3–Elastic Modulus in Material co ordinate 1, 2, 3 are the Longitudinal, Transverse and Normal direction respectively Ex, Ey, Ez–Elastic Modulus in Global Co ordinate system:

Eat–Axial Tensile Modulus

Eht–Hoop Tensile Modulus

Eaf–Axial Flexural Modulus

Ehf–Hoop Flexural Modulus

νha–axial to hoop Poisson Ratio

νah–hoop to axial Poisson Ratio

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