EXPERIMENTAL AND NUMERICAL ANALYSIS OF GFRP PIPE MADE BY FILAMENT WINDING

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Abstract - -- *In the present study, mechanical and thermal characterization of filament wound glass fibre reinforced polymer (GFRP) composite pipe is carried out experimentally. The tested pipe is composed of E-glass with angle wedding. The mechanical behaviour under axial monotonic loading is studied. The Compression test was carried out according to the instruction of ASTM D2015-01 standard. Some mechanisms like debonding, whitening, matrix/transfer cracking, delamination and splitting of fiber were detected in the failed component during compressive testing. Further finite element model is carried out to understand the mechanical and thermal characteristics of GFRP pipe using commercial ANSYS software. Both experimental and numerical results for the GFRP pie were reported and discussed.*

Keywords: GFRP Pipe, Compressive strength, thermal analysis

1. INTRODUCTION

The advantage of composite material over conventional engineering materials stem largely from their high specific strength, stiffness and fatigue characteristics. Composite materials over the years have emerged as a strong contender for replacing steel in piping and other applications. Glass fibre plastic pipes is the fore runner in this area due to principle features like optimized strength, mass production and the overall economics of the product

Filament winding process is a widely adopted method for producing axis symmetric composite structures. The most common way of doing this is by wet winding, where a band of pre-impregnated glass fibres are applied onto a rotating mandrel and then the material is cured with or without the application of an external heat source. Although composite materials have greater scope than their counterparts, they pose some critical engineering challenges due to their inherent properties of anisotropy and non-homogeneity. Hence proper designing of the material is absolutely necessary to canvas their advantages. In our case the filament winding process has number of parameters which to a greater extent affect the mechanical properties of the pipe. Certain key parameters like winding angle provide information that is generally useful to explain the mechanical behaviour of the pipe. However less satisfactory predictions have been made so far regarding other process parameters. Hence an experimental & theoretical investigation were undertaken to study their effects.

2. FABRICATION OF GFRP PIPE

It is a fabrication process mainly used for manufacturing open (cylinders) or closed end structures (pressure vessels or tanks). This process involves winding filaments under tension over a rotating mandrel. spindle (Axis 1 or X: Spindle) while a delivery eye on a carriage (Axis 2 or Y: Horizontal) traverses horizontally in line with the axis of the rotating mandrel laying down with the fibres in the designed pattern or angle. The most common filaments are glass or carbon and are impregnated in a bath with resin as they are wound on into the mandrel. Once the mandrel is completely covered to the desired thickness, the resin is cured. Depending on the resin system and its cure characteristics, often the rotating mandrel is placed in an oven or placed under radiant heaters until the part is cured. Once the resin has cured, the mandrel is removed or extracted, leaving the hollow final product. For some products such as gas bottles, the mandrel is a permanent part of the finished product forming a liner to prevent gas leakage or as a barrier to protect the composite from the fluid to be stored.

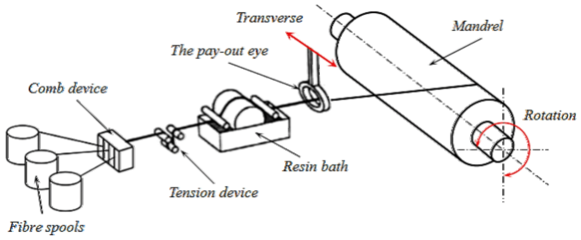


Fig 1 Fabrication of glass fibre pipe by filament winding method

Filament winding is well suited to automation, and there are many applications, such as pipe and small pressure vessel that are wound and cured without any human intervention. The controlled variables for winding are fiber type, resin content, wind angle, tow or bandwidth and thickness of the fiber bundle. The angle of the fiber has an effect on the properties of the final product. A high angle hoop will provide circumferential strength while lower angle patterns (either polar or helical) will provide greater longitudinal/axial tensile strength.

Products currently being produced using this technique ranges from pipes, golf clubs, Reverse Osmosis Membrane Housings, Oars, bicycle forks, bicycle rims, power and transmission poles, pressure vessels to missile casings, aircraft fuselages and lamp posts and yacht masts

3. EVALUATION OF MECHANICAL PROPERTIES

The evaluation of the engineering properties of the FRP composite materials are complex due to their anisotropy and inhomogeneity nature. ASTM is known as American Society for Testing and Materials is an international standards organization that develops a standard for testing of wide range of system services and materials. The specimens are cut into standard ASTM size. In this study, mechanical testings such as compression test conducted as per the ASTM standards.

3.1 Compression test

Compression test is conducted on a specimen using a universal testing machine (UTM) to determine the ultimate compressive strength of a material. When the material is subjected to compressive loading, the relationship between stress strain is similar to obtain for tensile loading. Up to a certain value of stress the material behaves elastically i,e stress is proportional to strain beyond this value, plastic flow starts, i,e more strain starts that happening in elastic limit for increment value of loading. It is seems that a compression test is more difficult to conduct than tensile test due to specimen must have large cross sectional area to resist any buckling due to bending. Specimen undergoing strain hardening as deformation proceeds, and Cross section specimen increases with deformation, thereby requiring substantial increase in the require load. The lateral instability due to buckling action can be avoided by keeping the ratio of height (h) to diameter (d) of the specimen less than 2. The compressive strength essentially depend open 'h'to'd' ratio hence higher is h/d ratio, lower the compressive strength

Standard data

(a) Material of the specimen = E-glass fibre

(b) Size of the cylindrical specimen = 76mm

(c) Thickness of the specimen= 3mm

Fig 2 GFRP pipe under Compression test

Sl.No	Load (kN)	Defor mation (mm)	Sl.No	Load (kN)	Defor mation (mm)	Sl.No	Load (kN)	Defor mation (mm)
1	0	0	26	25	1.87	51	50	2.84
2	1	0.14	27	26	1.93	52	51	2.87
3	2	0.29	28	27	1.95	53	52	2.94
4	3	0.44	29	28	2	54	53	2.95
5	4	0.53	30	29	2.04	55	54	2.99
6	5	0.72	31	30	2.07	56	55	3.02
7	6	0.75	32	31	2.12	57	56	3.07
8	7	0.8	33	32	2.16	58	57	3.1
9	8	0.87	34	33	2.19	59	58	3.13
10	9	0.95	35	34	2.24	60	59	3.18
11	10	1.02	36	35	2.28	61	60	3.22
12	11	1.1	37	36	2.3	62	61	3.28
13	12	1.15	38	37	2.36	63	62	3.3
14	13	1.23	39	38	2.39	64	63	3.35
15	14	1.29	40	39	2.42	65	64	3.4
16	15	1.35	41	40	2.47	66	65	3.45
17	16	1.45	42	41	2.51	67	66	3.47
18	17	1.49	43	42	2.53	68	67	3.54
19	18	1.54	44	43	2.59	69	68	3.57
20	19	1.59	45	44	2.62	70	69	3.61
21	20	1.63	46	45	2.71	71	70	3.68
22	21	1.69	47	46	2.73	72	71	3.7
23	22	1.73	48	47	2.75	73	72	3.74

Fig 3 Load-Deflection plot of Compression test

Numerical Analysis

Finite element method (FEM) is a widely used method for numerically solving differential equations arising in engineering and mathematical modeling. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.

The FEM is a general numerical method for solving partial differential equations in two or three space variables (i.e., some boundary value problems). To solve a problem, the FEM subdivides a large system into smaller, simpler parts that are called finite elements.

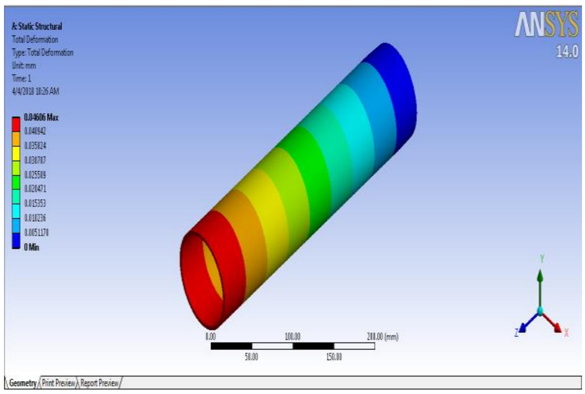
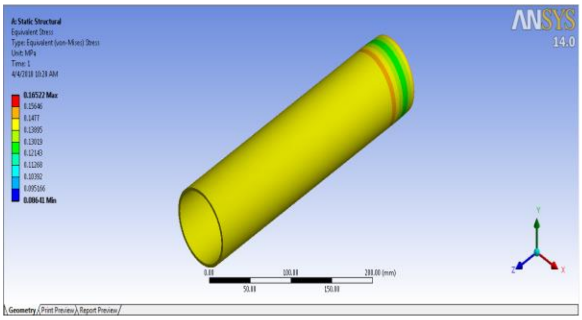


Fig 4 Stress analysis of GFRP pipe using ANSYS

The above images show the stress analysis of glass filament wound pipes. The result in the ANSYS to withstand 100 kN

S.NO	LOAD	DEFORMATION
1.	10	0
2.	20	0.05117
3.	30	0.010236
4.	40	0.015353
5.	50	0.020471
6.	60	0.025589
7.	70	0.030707
8.	80	0.035824
9.	90	0.040942
10.	100	0.04606

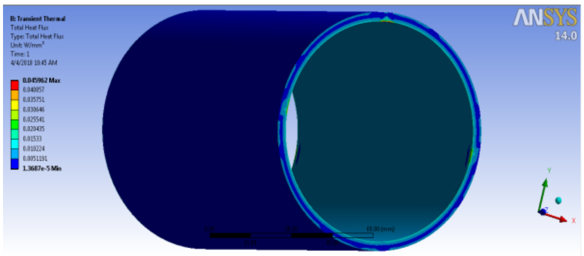


3.3 *Pressure test*

The internal pressure is applied by a micro-processor controlled 2000 Bar hydraulic testing machine at the test facilities of Omega laboratory, Guindy, Chennai. The system records the change in internal pressure with time during the test, until the specimen fails, and so the bursting pressure. The system is accredited by METU Mechanical Engineering Department. The GFRP pipe is subjected to 15 bar pressure for 5 minutes. There is no pressure drop is found during the test period.

3.4 *Thermal analysis*

The filament wound pipe has to withstand temperature effect. The thermal properties of glass fibre are high strength and melting point at 740ºC and thermal conductivity at 1.2 W/mm²/ºC. But resin used via winding is low melting temperature. But at high temperature of liquid or any matters that pass through pipe the resin will melt at certain temperature. So assume to be the temperature of liquid pass through pipes is 60ºC. At this boundary condition we have to assume room temperature 22ºC. At the maximum temperature and heat flux is listed below



Sl. No.	Load (kN)	Deformation (mm)
1.	0	$1.3687e^{-5}$
2.	10	0.0051191
3.	20	0.010224
4.	30	0.01533
5.	40	0.020435
6.	50	0.025541
7.	60	0.030646
8.	70	0.035751
9.	80	0.040857
10.	90	0.045962

3.5 *Strain gauge test*

In the present work, UFRA-5-350-23 rosette type electrical resistance strain gauges are employed for recording the strain data. The main test materials for the strain gauge are metals, ceramics and composites. Operating temperature range of the gauge is -20 to +150°C and the strain limit is 3% (30000×10^{-6}). Strains in axial and hoop directions can be measured simultaneously by the mentioned system. Figure shows the UFRA-5-350-23 strain gauges.

For the installation of strain gauges, grease, rust, etc. at the bonding surface are removed. The bonding surface is lightly polished with an abrasive paper to obtain a smoother surface. Having a perfectly smooth surface is vital in strain gauge installations because the quality of the bonding of the strain gauge to the test surface is directly related with the smoothness of the surface. The strain gauges are fixed on the tubes by their special CN adhesive. The lead wires originated from the strain gauges are soldered to the connecting terminals of the strain gauge data acquisition system.

Testing procedure

The internal pressure tests are performed according to the standard ASTM D1599-Plastic Pipe, Tubing, and Fittings". The method covers the determination of the resistance of either thermoplastic or reinforced thermosetting resin pipe, tubing, or fittings to hydraulic pressure in a short time period, and consists of loading the tube to failure in a short time interval by means of a hydraulic pressure.

The tubes that are fabricated by wet filament winding method and cut into desired length are fixed to the end closures by means of an adhesive. The adhesive employed is CIBA – GEIGY Araldite AV 138–Hardener HV 998 epoxy adhesive. Once the adhesive is applied, the tube and the end closure system are placed in the furnace at 80°C for one hour to allow the adhesive to cure. The internal liner is placed in the tube. The strain gauge is fixed in the middle portion of the tube by using its CN adhesive. It is filled completely with water. The tube is attached to the hydraulic pressure system assuring no air is entrapped. The cables originated from the connecting terminals of the data acquisition system are connected to the strain gauges by soldering. Pressure is applied and increased uniformly and continuously, until the tube fails. Meanwhile, the pressure increase and changes in the strain are monitored and recorded.
Using the necessary formulations, the strain and pressure data are evaluated to obtain the mechanical characteristics.

The internal pressure system records a single pressure value each second, until the tube fails. These pressure values are recorded in bars. The computer program returns the pressure data in the form of a text document

The strain gauge data acquisition system records three data for each three measurement units per second and it returns the strain data in the form of a text document. For the evaluation of data, in order to have a consistency with the pressure values, the corresponding data recorded per second is considered for all measurement units. From the experimental and numerical test results it is found that there is nomuch variation in the results.

5. CONCLUSION

- The mechanical, thermal properties of GFRP composite pipe have been discussed. The important application of these composites has highlighted
- The various preparation technologies were used for preparing the GRP composites with various environmental conditions. .
- Ultimate tensile strength of fiber glass increased with increase in the fiber glass
- The Young's modulus of elasticity of the composite increased with the fiber glass
- For improving the composites properties, the fibers were treated with various chemicals and matrix blend with suitable chemical for making the GRP composites. This may improve the mechanical, thermal, properties of the GRP composites.

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