Experimental Investigations on Cylindrical GFRP Composite Pipes under Compression Loading

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***Abstract*:** In a wide variety of aerospace applications have the mechanical properties of a thin cylindrical shell are important. Thin cylindrical shell structures are used to store a small and large quantity of fluids and solids. Glass Fabric reinforced epoxy composite is used to prepare the thin cylindrical pipes with different diameters and varying thickness of the composite pipes. The additives as glass flakes are added with 5%, 10% and 15% of the resin content in the matrix. The rolled composites specimens are prepared with the stainless steel (SS) mould. Experiments are test on Universal Testing Machine under lateral compression test to study the breaking load and compressive strength of the specimens. The failure modes are also observed.

Keywords: *Glass Fabric, additives, lateral compression test, breaking load, crack, crushing load*

1. Introduction

Composite material is a combination of two different materials which has strength to weight ratio and possess high strength and lighter in weight. Composite materials are used in industries like aerospace, automobile, marine applications etc. Mechanical properties are exhibiting more in composite materials. Cylindrical shell structures are used to store a large quantity of fluids and solids. Cylindrical thin shells are subjected to loading in three types of forces: axial compression, circumferential (lateral) compression and shear. In this paper we are discussing the different diameter of thin composite cylindrical shells with varying thickness and also additives are added. The failure behaviour of the GFRP specimen pipes of different diameters and thickness are subjected to lateral compression loading with and without additives is discussed.

Y. Pratap reddy et al [1] investigated the numerical buckling analysis of the composite cylindrical shell under compressive loading with and without holes on the lateral surface of the cylinder. They predicted the buckling factor, deformation and interlaminar shear stresses of the specimens. L. Gangadhar and T. Sunil Kumar [2] has done numerical analysis of buckling of GFRP composite cylindrical shell with and without cutouts under compression loading. They determined the compressive stress, buckling load and lateral strain of the specimens with and without cutouts using ANSYS.

Tafreshi, A [3] has studied on delaminated GFRP composite cylindrical shells under combined axial compression and bending. They observed the instability analysis of the delaminated layer of the composite cylindrical specimen. R S Priyadarsini et al [4] investigated the numerical and experimental study of buckling of composite cylinders under axial compression. They evaluated the buckling behaviour of the thin cylindrical shell and compared with numerical analysis. Eyvazian Arameh et al [5] has studied experimentally the corrugated metal composite tubes under axial compression loading. They observed the crushing behaviour of the metal composite tube. Kiyoshi Kemmochi [6] has exact solutions for stress and deformation analysis of the composite cylindrical pipe subjected to lateral compression loading. M Xia et al [7] analysed the composite laminated cylindrical pipes under lateral compression loading. They evaluated the stresses and deformations in the multi layer composite cylindrical pipe experimentally and compared with theoretical results.

2. Experimental work

2.1 Mould Preparation

In this paper the mould is prepared with stainless steel (SS) material and fabricated the stainless steel (SS) pipes as shown in figure 1.

Fig 1:. SS Pipes of Different Diameters for fabrication of shells

These SS pipes are used for rolling of composite material. Different dimensions of stainless steel pipes are selected for different diameters of shells. Based on outer diameter of stainless steel pipes the inner diameter of shells is determined. Extraction fixtures are required to extract the shells rolled over the stainless steel pipes. As the rolled composite material over stainless steel pipes was kept cured for 24hrs to get harden and requires fixtures are used to extract the shells. The extraction fixtures are as shown in figure 2. The diameters of the SS steel pipe which is used as a mould are 2 inch, 3 inch and 4 inch.

Fig 2: Extraction Fixtures for Different Diameters of shells

2.1.1 Calculation for required fabric

The calculations for the Glass fabric required are

Perimeter of pipe= $2\pi r$ (1)

From the perimeter of the pipe we can calculate the fabric required for the different diameter of pipe per roll. Based on the number of rolls we can calculate the total fabric required for different diameters.

Total fabric required = perimeter x number of rolls (2)

For different diameters of 2 inch, 3 inch and 4 inch, the total fabric required for 8 rolls to prepare the composite pipe will be 1.27 m, 1.91 m and 2.57 m.

2.1.2 Calculation for matrix required

To calculate the resin in grams required for different diameters of pipe are given as

Resin required = $\frac{outer\ radius\ of\ the\ pipe\ x\ GSM\ of\ fabric}{8}$ (3)

From the above equation the resin quantity required will be for the different composite pipe diameters are 150 gm, 220 gm and 298 gm respectively. Hardener is added in ratio of 1:10 of resin(i.e,1gms of hardener for 10 gms of resin) and pigment is added in ratio of 1:5 of matrix (i.e,0.5 gms of pigment for 10 gms of matrix). We should add the percentage of glass flakes with respect to resin content with the following equation are

Percentage of glass flakes = Resin quantity in gms x percentage (4)

For 2 inch diameter pipe, the percentages of glass flakes for 5%, 10% and 15% are 7.5 gms, 15 gms and 22.5 gms respectively. For 3 inch diameter pipe, the percentages of glass flakes for 5%, 10% and 15% are 11 gms, 22 gms and 33 gms respectively. For 4 inch diameter pipe, the percentages of glass flakes for 5%, 10% and 15% are 15 gms, 30 gms and 45 gms respectively.

2.2 Specimen fabrication

Bidirectional (BD) Glass fabric with 13 Mill fibre was used a reinforcement as shown in figure 3. This fabric is weaved with 4H Satin construction of 48 threads per inch in warp and 36 threads per inch in weft directions of the fabric. The thickness of the fabric is of 0.36 mm. The fabric is of 457 GSM was supplied by Allied agencies, Hyderabad [8, 9]. Laminate composite structures can be built with continuous fibres orientated in different directions to improve strength in other directions. These composite structures are used for tanks for storing.

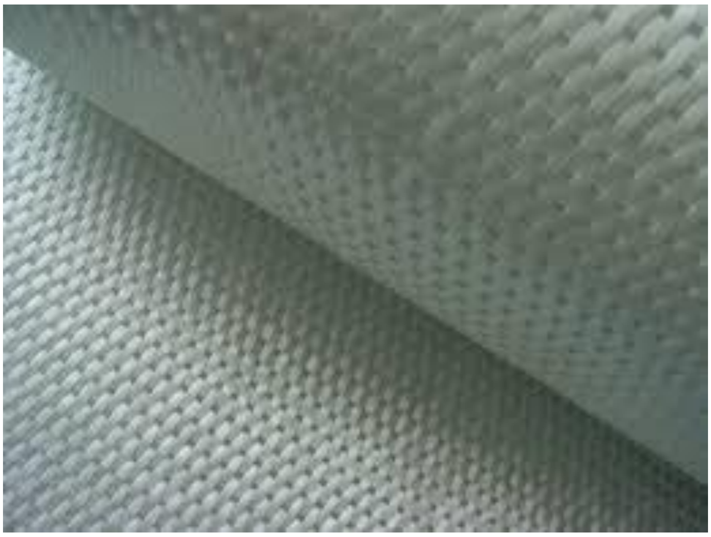

Fig 3: BD Glass Fabric

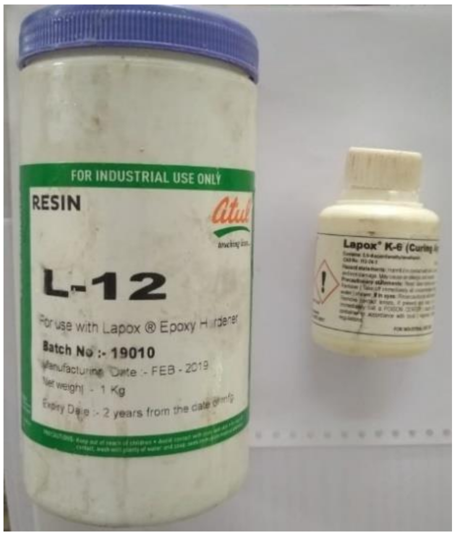

Fig 4: Matrix materials

The matrix material is a combination of Lapox L12 (epoxy) and Lapox K6 (hardener) with a ratio of 10:1 [10, 11] by weight as shown in figure 4. Lapox L-12 is a liquid, unmodified epoxy resin of medium viscosity which can be used with various hardeners for making glassfibre reinforced composites. The choice of hardener depends on the processing method to be used and on the properties required of the cured composite. Hardener K6 is a low viscosity room temperature curing liquid hardener. It is commonly employed for hand layup applications. Being rather reactive, it gives a short pot life and rapid cure at normal ambient temperatures.

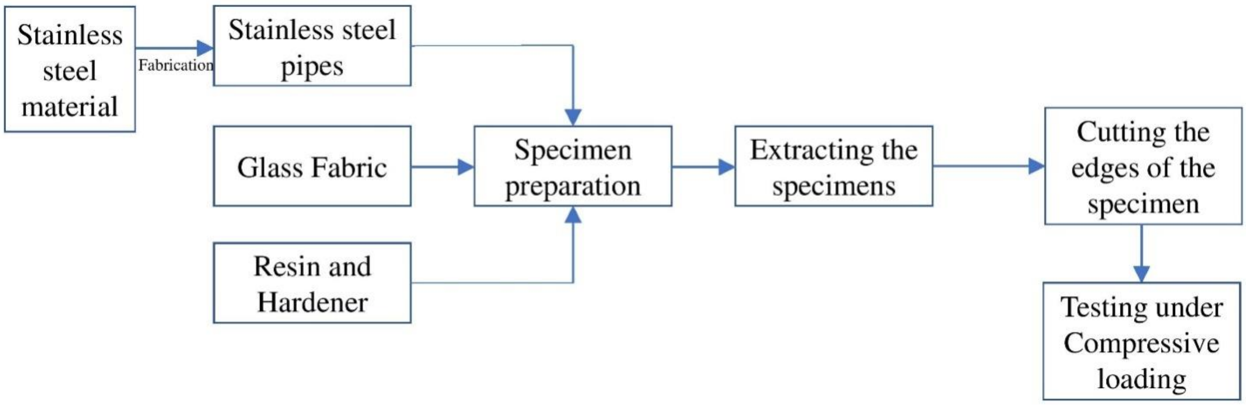

Fig 5: Methodology of fabrication of GFRP specimens to testing

2.3 Manufacturing of GFRP composite pipes

Manufacturing of GFRP composite pipes include following procedures:

- Cleaning and applying the wax polish to the mould (SS pipes)
- Marking the dimensions on the fabric
- Matrix mixing and applying on the fabric
- Sprinkling of glass flakes
- Rolling over stainless steel pipes
- Curing the rolled GFRP composite pipe for 24 hours at room temperature
- Extraction of shells and cutting the edges of GFRP composite pipe
- Edge sealing of shells
- Post curing of shells in furnace at 100℃

In manufacturing of GFRP composite pipe, first clean the mould (SS pipes) and applying the wax polish to the mould and used as release agent. Mark the dimensions on the fabric and mix the resin, hardener and pigment as per ratio. Matrix mixture is stirred for 5 min so that the mixture is diluted so that it is eventually spread on the fiber when it is applied. Using brush it is eventually spread all over the fabric as shown in figure 6. For changing the strength of the shells the additives i.e., glass flakes are sprinkled over the fabric applied with matrix. The glass flakes are as shown in figure 7. Different percentages of glass flakes as per the calculations are sprinkled. The sprinkled glass flakes are as shown in figure 8.

After sprinkling of glass flakes the matrix spread over fabric comes to a semi solid state and now we roll the composite material over the stainless steel pipes which is previously applied a coating of waxpol with applying equal load along the width of the pipe. After rolling the composite pipes are left at room temperature for 24 hours [10]. Due to reactivity between resin and hardener the composite pipes become harder. As the curing completes the composite pipe has to be extracted over the SS pipe using extraction fixtures and hammer to apply force to extract. After curing composite pipe becomes harder this cannot be extracted easily. By applying gradual force on extraction fixture all around the fixture diameter.

Fig 6: Applying of matrix

Fig 7: Glass Flakes

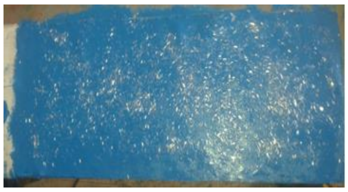

Fig 8: Sprinkling of Glass Flakes

Fig 9: Edge Sealed GFRP composite pipes

After edge cutting of composite pipe the property of composite pipe may vary at the edges as they are exposed to the atmospheric conditions, the compressive strength may change for unsealed edges. In order to prevent the changes edges are sealed using matrix and allowed to curing for one day. The edge sealed composite pipes are as shown in figure 9. Finally, the edge sealed specimens are post cured by placing them in furnace at 100 degree centigrade for few hours. By post curing the strength of the shells will be increased as the matrix and fabric gets harden.

2.4 Experimental test setup

2.4.1 Compression test in Lateral direction

We applied the compression load in lateral direction progressively and with a crosshead speed of 2 mm/min. The GFRP composite specimens are loaded laterally is as shown in figure 10. The breaking load of the specimens have noted with respect of categories of specimens. The observation resulted as higher breaking load for small diameter specimens with respect of high diameter specimens.

Fig 10: Lateral Compression of the GFRP Specimen

It has been observed that for varying height of member, keeping cross-sectional and the load applied constant, there is an increased tendency towards bending of a member. Member under compression usually bends along minor axis, i.e., along least lateral dimension. In compression test the slenderness ratio plays an important role [12]. According to column theory slenderness ratio has more functional value. At the time of testing, the tester should check that specimen is exactly at centre of compression pads so that load is applied perpendicular to the specimens.

3. Results and Discussions

3.1 Lateral Compression Test

The compressive loads of different diameters having variable thickness of GFRP composite pipe without and with percentages of additives are given in Table 1 and Table 2.

By comparing the compressive loads of 4 mm thick shells, it is observed that

- The compressive load was decreased by 48 % by adding the additives (15% glass flakes) when compared without additives for 2″ diameter and 4 mm thick shells.
- The decrease in compressive load may be because of the crack initiation [8] due to less bonding strength between laminae and uneven distribution of flakes.
- The remaining 3″ and 4″ diameter 4 mm thick shells of compressive load are compared with and without additives are same and greater than the without additives.
- The percentage increase in compressive load for 4″ diameter 4 mm thick shells with additives (15 % glass flakes) has increased by 35 % is compared without additives.
- The compressive load was decreased by 16.6 % by adding the additives (15% glass flakes) when compared without additives for 2″ diameter and 2 mm thick shells.
- The remaining 3″ and 4″ diameter 2 mm thick shells of compressive load are compared with and without additives are more than the without additives.
- The percentage increase in compressive load for 3″ diameter 2 mm thick shells with additives (15 % glass flakes) has increased by 12 % is compared without additives.
- The percentage increase in compressive load for 4″ diameter 2 mm thick shells with additives (15 % glass flakes) has increased by 29.6 % is compared without additives.

Table 1: Compressive strength of different diameters with 4 mm thickness composite pipe without and with percentage of additives

S No	Diameter (inch)	Thickness (mm)	Additives	Compressive load (kN)
1	2	4	Without (Pure)	40
2	3	4	Without (Pure)	70.4
3	4	4	Without (Pure)	100
4	2	4	Glass flakes-15%	20.8
5	3	4	Glass flakes-15%	70.4
6	4	4	Glass flakes-15%	135

Table 2: Compressive strength of different diameters with 2 mm thickness composite pipe without and with percentage of additives

S No	Diameter (inch)	Thickness (mm)	Additives	Compressive load (kN)
1	2	2	Without (Pure)	7.2
2	3	2	Without (Pure)	8.8
3	4	2	Without (Pure)	10.8
4	2	2	Glass flakes-15%	6
5	3	2	Glass flakes-15%	10
6	4	2	Glass flakes-15%	14

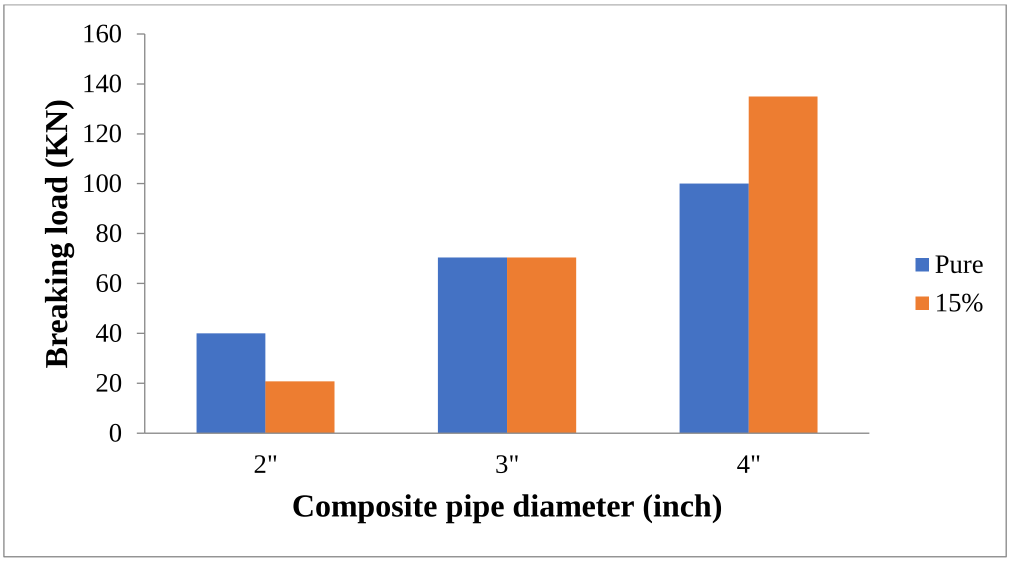

Fig 11: Comparison of different diameters with 4 mm thickness composite pipe without and with percentage of additives

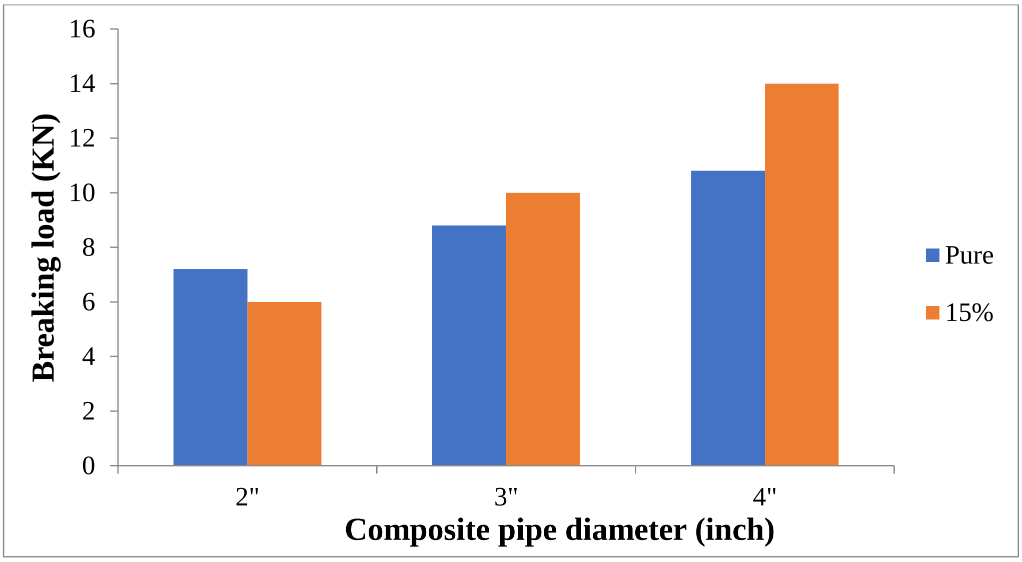

Fig 12: Comparison of different diameters with 2 mm thickness composite pipe without and with percentage of additives

4. Conclusions

The cylindrical shells were fabricated for compression test of specimens is carried out in UTM machine. Lateral compression test was conducted. To find the compressive strength on GFRP shells with varying constituents or additives (i.e. glass flakes are added) under lateral compression loading conditions are carried out. The compressive load with respect to composite pipe diameter is plotted with varying thickness of with and without additives. The percentage increase in compressive load for 4″ diameter 4 mm and 2 mm thick shells with additives (15 % glass flakes) has increased by 35 % and 29.6 % is compared without additives. With addition of flakes (15 % glass flakes) improves the compressive load for 2 mm and 4 mm thick shells of diameter 4″.

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