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Failure Analysis of Composite Fibre Metal Laminate Pipes with PVC Pipes subjected to shear load

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Abstract: *This work is carried out, to experimentally examine thefailure of FML and PVC pipes due to buckling. The pipe specimen is subjected to gradual circumferential stress with the help of nylon wires and the Load v/s Strain data was stored on the UTM controller. The peak load at which the specimen failed is noted down. Growth of any leak-susceptible crack is considered as a failure. It is observed that the buckling strength of FML pipe was 0.781 MPa as compared to 0.836 MPa of PVC pipe. These values are well above the standard atmospheric vacuum of 0.1 Mpa. This means that the FML pipes can be used for low to medium vacuum applications. Another observation made was, while performing this test the PVC pipe failed distinctly thus causing easy leakage whereas in the FML pipe, failure occurred at the outermost layers only, thus making it less susceptible to leakage*

Keywords: *Fibre Metal Laminates [FML], PVC, buckling failure, circumferential stress, load v/s strain*

I. Introduction

Hybrid material structures find innumerable applications in various arenas such as construction, aerospace, automotive, etc. There is no doubt that composites have earned their way in all fields of engineering. Clearly, a trend developed a few decades ago, to replace Galvanised Iron pipes with PVC pipes. The ease of manufacturing, light weight and anti-rust properties made PVC pipes very popular. However, these days, there is a need to find an alternate for PVC pipes owing to their non-degradable as well as hazardous properties. There are many such typical applications where composite pipes can compete with PVC pipes. Especially FML are gaining popularity due to distinct processing and cost advantages. FML manufacture employs aluminium moulds that do not need costly tooling. They also avoid add-ons such as mesh and electrical shielding. FML has huge innovation potential for functional integration of systems. Fibre-reinforced polymers require a minimum thickness to resist damage. This minimum skin thickness takes away the composites' weight advantage. It is seen that, PVC pipes are easily cracked due to their brittle nature, and cannot withstand high temperatures. Hence, it is necessary to know about such simple applications where it may be possible to replace PVC with FML.

II. Methodology

The composite FML pipe is fabricated by pultrusion method (hand layup). Initially two different methods were used for fabrication of Composite pipe. In the first method, the glass fibre mats and Aluminium sheets were cut, equal to the circumference of the cylindrical of mould length 347 mm and diameter 75mm along with allowance of 10mm. Then, de-moulant (mould releasing agent) is applied on the cylindrical mould. The application of the resin and the rolling up of the material (either aluminium sheet or glass fibre mat) on the mould was done simultaneously as shown in the Fig. 1

The aluminium sheet is rolled up and resin is applied on the outer surface. A glass fibre mat is then rolled up, over it and resin is applied so that the aluminium is embedded to the glass fibre mat. The seams of consecutive layers are kept perpendicular to each other to ensure a firm bonding at the seam. The layers were rolled up till the required thickness (2, 3 and 4 mm) were obtained. After the last layer is put, cellophane tape was rolled up tightly to ensure that voids are eliminated.

Fig.1: Fabrication of FML cylindrical structure using pultrusion technique

Fig. 2: Rolling up of sandwich FML composite on the cylindrical mould

In the second type, the glass fibre mat and aluminium sheet of length twice that of the circumference of the mould were cut to make a horizontal sandwich composite. De-moulant (mould releasing agent) is applied on a smooth flat surface and the glass fibre mat is placed on it. Then resin is applied. Later an aluminium sheet is placed on the glass fibre mat and resin is applied again. Voids are removed by uniform application of pressure after each layer is rolled up. After all the layers are stacked, the mould with de-moulant applied on it, is kept on the sandwiched horizontal FML composite. The stacked sandwich is then rolled on the mould as shown in the Fig. 2. Finally a layer of cellophane tape is applied to eliminate the voids. In both the methods, after the layup is done the mould is kept under the sunlight for 24 hours of curing and the FML composite is removed from the mould by part extraction.). The inner and outer surfaces of the FML composite vessel is rubbed with emery paper of grit size 320 to remove the excess resin and make the surface smooth for laminar flow. The edges are filed to remove the sharp edges.

III. Testing, Results And Discussion

The pipe specimen were subjected to gradual circumferential stress with the help of nylon wires and the Load v/s Strain data was stored on the UTM controller.A graph was plotted between these two values. The peak load at which the specimen failed was noted down. Appearance of any leak-susceptible crack is considered as a failure criteria. The following relation is used to convert the failure load to the buckling strength of the pipe.

$$\text{Buckling strength (MPa)} = \frac{Peak\ Load\ in\ N}{Rope\ contact\ \ area\ over\ the\ circumference\ \ \ in\ mm^2}$$

The buckling strength values obtained are as shown in the following Table 1.

Table 1: Buckling Strength of FML & PVC pipes

Specimen Number	Material	Buckling Load (N)	Buckling Strength(MPa)
Specimen 1	FML	4120.2	0.781
Specimen 2	PVC	4414.5	0.836

It is observed that the buckling strength of FML pipe was 0.781 MPa as compared to 0.836 MPa of PVC pipe. These values are well above the standard atmospheric vacuum of 0.1 MPa, which shows that the FML pipe can be used for low to medium vacuum applications. The following Fig 3 shows the FML and PVC pipe specimens post buckling failure.

Fig. 3: FML (top) & PVC (bottom) pipes after buckling failure

While performing the buckling test, the values of Load and Strain are continuously sampled and a graph is plotted between these two values. It is observed that at the buckling point, i.e. when the pipe specimen failed, there was a steep drop in the graph. With further increase in load, the graph again rose with a positive slope. Fig.4 shows the graph between Load and Strain for a FML pipe specimen.

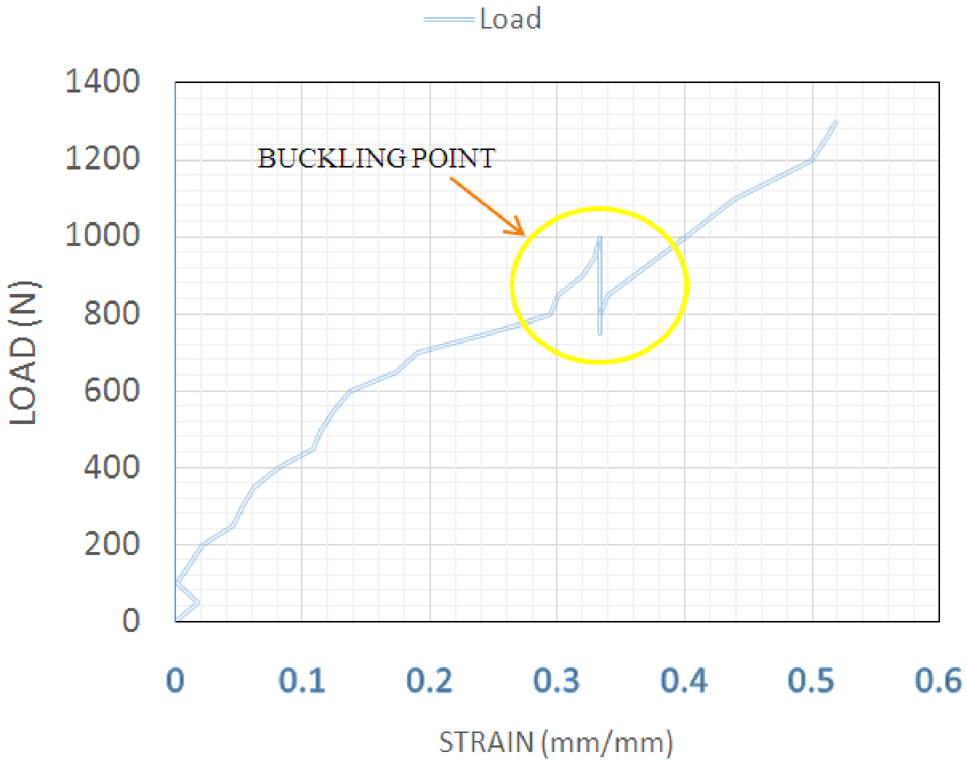

Fig. 4 Load v/s Strain graph for FML specimen

The steep drop in the graph at the buckling point can be attributed to the sudden displacement in the ropes caused by buckling failure of the pipe. On further application of load, this displacement ceases and hence the graph rises with a constant positive slope.

IV. Conclusions

1. Shear strength test was conducted on each of the specimen and it was found that the specimen with Roughness constant 24 um (Grit size- 60) has the maximum shear strength of 4.6 MPa. The other specimens of Roughness constants 20 (grit size- 120), 14 (grit size- 220), 9 (grit size- 320), 5 (grit size-600) have shear strengths of 4.1, 3.5, 3.2, 2.98 MPa respectively.
2. Four Different stacking orders are selected and the properties of each of them were compared. Aluminium sheet is used in the innermost layer as the smooth surface of Aluminium (Roughness constant- 0.05 um) inside will ensure streamline flow of the fluid flowing inside.Glass fibre is chosen as the outermost layer as the glass fibre surface outside will ensure minimum loss of heat (Thermal conductivity- 1.35 W/m K) and would be highly corrosion resistant to external factors.
3. The specimen with 1:2 ratio of Aluminium: glass fibre was found to be the lightest with a mass of 284 grams as compared to the specimens with ratios 1:4 (608 grams) and 1:8 (1024 grams).Buckling strength of FML composite pipe (1:2 ratio of Aluminium and glass fibre) is 0.781 Mpa and that of a PVC pipe of similar dimension is 0.836Mpa.

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