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Experimental Investigation of Buckling of Laminated Composite Cylindrical Shells with &Without Cutouts Subjected To Axial Compression

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Abstract: *GFRP (Glass Fiber Reinforced plastic) composite materials are find many applications in engineering fields like mechanical and civil engineering applications. It is because of the properties of these materials like light weight when compared to other materials, durability, rust proof and many more. The composite cylindrical shells are being used very widely in underground pipelines, Aerospace industries, submarines and so on. In present study, the buckling of thin walled glass reinforced polymer cylindrical shells with and without cutouts has been investigated by applying axial load on the shells. The results which were obtained in this experiment will show how the imperfections like cutouts will affect the buckling behavior of the shells.*

Key words: *Composite, cylindrical shell, cut outs, buckling.*

I. Introduction

Thin walled cylindrical shells find wider applications as primary structural members in various fields of engineering such as civil, mechanical, aerospace and nuclear engineering fields. Stiffened and unstiffened shells made up of metallic and laminated composite materials (large diameter to thickness ratio) are extensively used in underwater, surface, air and space vehicles as well as in construction of pressure vessels, storage vessels, storage bins and liquid storage tanks. The contribution of geometric imperfections due to manufacturing processes takes dominant role in decreasing the buckling load of cylindrical shells. Buckling is often viewed as the controlling failure mode of these structures due to its relatively small thickness of these structural members. It is therefore essential that the buckling strength of the thin shells along with knowledge of its post buckling behavior has been the subject of many researchers in both analytical and experimental investigations.

The problem of cylindrical shell buckling subjected to axial compressive loads has been investigated by various researchers using approximate analytical methods as well as finite element methods. Theoretically evaluated classical buckling load is generally much higher than the actual buckling load of the cylindrical shell and a knock-down factor is introduced to evaluate a better approximation based on an extensive experimental investigation. Now a day the usage of composite cylindrical shells are gradually increased in many engineering fields like mechanical and civil engineering applications. This is due to the properties of those materials like light weight when compared to other materials, durable, rust proof, high strength and so on. The composite cylindrical shells are extensively used in many applications like automobiles, underground pipelines, submarine and in aerospace industries. For these shells there are many factors will leads to failure of shells. One of them is modification of the shells according to requirement like in some cases it is required to make cutouts to the shells.

In the past many researchers have investigated the buckling of the cylindrical shells by using different materials and parameters. Vartdal et al has studied the effect of rectangular type cutouts on deformation of the steel tubes under axial loading. The cutouts are made in different positions of the shells. El Naschie has investigated the buckling of cracked cylindrical shell for the first time. Jullien has studied the buckling analysis of cylindrical shells with cutouts under axial loading. The cutouts are of different types like circular, square, rectangle. .Shariati and Rokhi has performed the simulation and analysis of steel cylindrical shells of different diameter and length with elliptical cutout under axial loading and also investigated the effect of cutout size and the cutout angle. Shariati and Mahdizadeh has used the abaqus software for numerical study to investigate the cylindrical shell response with elliptical cutout and the shells having with various diameters and lengths. They also shown several parametric relationships based on the numerical and experimental results using the Lagrangian polynomial method. Toda has studied the effect of circular cutouts on buckling of cylindrical shells then after he analysed by fixing the ring type stiffeners at cutouts. Yeh et al has performed the analysis and experimental procedure for studying the bending and buckling of moderately thick walled cylindrical shells with cutouts. Almorth et al has done the non linear analysis of cylindrical shells of having cutouts of opposite side under axial loading. Rahimi and Poursaeidi has performed the plastic analysis of cylindrical shells with circular cutouts. Tennyson has presented the how the unreinforced cutouts will affect the buckling of cylindrical shells. Brogan has investigated the cutouts effect on buckling.Mark W. Hilburger has illustrated the effects of laminate orthotropy on the buckling and failure response of compression-loaded composite cylindrical shells which has a cutout by numerical and experimental results.

In present work experimental investigation of buckling analysis of laminated composite cylindrical shells with cutouts and without cutouts carried out for r/t = 100. The cutouts are of circular type. In this it's also shown that the how the cutouts will affect the buckling of the shells.

The testing was carried out in this experiment by using an hydraulically operated type Universal Testing Machine (UTM). The capacity of the machine is up to 50KN. It's a table mounted type machine. It has a fixed bottom head and moving top head. It has wide variety of advantages like Easy settings, Accurate measurement and Maintenance inspections. This machine uses Trapezium X software which is compatible to the Windows. The advantage of this software is no need to insert the testing parameters like speed, load and other each time. The machine can be operated by connecting any pc. If the pc is not available the parameters can be inserted to the machine by using portable hard drive which has the data created at other location. It has high speed sampling rate (0.2 msec). The test force ranges from 1/1000 to 1/1 of load cell capacity. It has stream line maintenance function which means each time the machine switched on it'll diagnosis itself for problems and reminds the operator the for periodic maintenance by displaying messages on the screen. The safety function prevents the damages of jigs and accidents by stopping the test if there are sudden changes in the feed rate.

II. Experimental Procedure

A detailed experimental study was undertaken to investigate the buckling behavior of composite GFRP cylindrical panels subjected to in plane compressive load. To meet the wide range of needs which may be required in fabricating composites, the industry has evolved over a dozen separate manufacturing processes as well as a number of hybrid processes. Each of these processes offers advantages and specific benefits which may apply to the fabricating of composites. Hand lay-up and filament winding are two basic processes for fabricating cylindrical shells. The hand lay-up process is the oldest, simplest, and most labor intense fabrication method. In hand lay-up method liquid resin is placed along with reinforcement (woven glass fiber) against finished surface of a mandrel. The resin serves as the matrix for the reinforcing glass fibers. The specimens were manufactured using a purpose built mandrel and traditional hand layup process. Then the cylindrical shell is cut in to the required size of the cylindrical panels. A plastic sheet was covered the outside diameter of the mandrel by applying polyvinyl alcohol inside the sheet as releasing agent. Lay up starts with the application of a resin (epoxy and hardener) on the mandrel by brush, whose main purpose was to protect the fibers from exposure to the environment and to get smooth surface. The laminates used were of type Rovimat 1200 consisting of E-glass woven roving and epoxy resin matrix. Ply was cut from roll of woven roving. Layers of reinforcement were placed on the mandrel and resin coat was applied again by brush. Using serrated steel rollers any air which may be entrapped was removed. The process of hand lay-up was the continuation of the above process before the resin coat had fully hardened. The mandrel with shell was kept rotating for a minimum of 48 hours before being extracted and cut to exact cylindrical panels shape for testing. The fabricated shells will undergo the compression test. For this a Universal Testing Machine has been used.

III. Fabrication Process

The fabrication of the composite materials involved in different operations. They may vary depending upon technology, facilities and skills of the person. The manufacturing process is also vary because of the wide variety of the composite materials and their applications. Each process has various characteristics that define the type of product to be produced. This allows the manufacturer to provide the best solution for the customer.

To manufacture the specimen we used the filament winding machine which is available commercially. It has a mandrel of 300mm dia. Before winding the fiber around the mandrel the surface has to be cleaned with acetone so that the impurities which are present on the surface of the mandrel like dist, dirt, rust and etc., can be removed. It can help to obtain got surface finish. A release film is coated on the surface of the mandrel so that it's very easy to separate specimen from the mandrel. A reference line of 0^0 is marked in axial direction of the mandrel. The untwisted continuous filament roving's of Boron free E-glass and isophthalic polyester matrix were used to prepare the specimen. The fiber roving's are passed through the resin bath and wounded on mandrel. After completion of the winding process the mandrel kept ideally for 48hrs. so that winding gets cured properly. After separating the specimen can cut into no. of pieces of required size.

IV. Specimen Preparation

The purpose build mandrel of 300mm diameter was used to make the cylindrical shell of 1500mm length with 1.25mm thickness. The cured cylindrical shell was extracted from the mandrel using specially designed hydraulic fixture. Four numbers of specimens with each 300mm length cylindrical shell were prepared for testing. Among those four specimens, for two specimens has the cutout of diameter 50mm. The +45°/-45° ply orientation (winding angle in filament winding machine) was maintained with 1200tex direct roving's and isophthalic polyester matrix to get the 1.25mm thickness cylindrical shell specimens.

Removal of shell from mandrel

The end parts were significantly thicker than the middle part as shown in figure, to ensure zero radial displacements along the edges and to minimize the risk of local splitting or delaminating at the boundaries. The specimens were accurately sized to 300mm length on lathe machine and thickness was measured using specially designed vernier micrometer. The measured thickness was shown in table 1. For the given mechanical properties of the manufactures of fiber and resin the laminate properties, were calculated. The theoretically calculated mechanical properties of the laminate for evaluating buckling loads using finite element program are shown in Table 3. The edges of the cylindrical shell are fitted into circular, 5mm deep grooves within the circular steel plates thus leaving a free unsupported length 290mm between the inner faces of the fixing plates. The grooves were filled with a mixture of resin and quartz powder. Measurement of cylinder thickness was carried out using vernier micrometer mounted on specially designed bracket.

Fabricated sized cylindrical shells without holes

Fabricated sized cylindrical shells with holes

V. Inspection

The inspection is done with the help of height gauge to measure the height of the cylinder (Uniform). The inside and outside micro meters are used for the measuring of inner as well as outer diameter of the cylinder to find out the thickness of the cylinder at several cross sections marked.

Shell after inspection

The geometry of the composite cylindrical shell subjected to axial compressive load is outlined as follows:

Radius of the cylindrical shell	=	150 mm
Thickness of the cylindrical shell	=	1.25 mm
Length of the cylindrical shell	=	300 mm
Size of the circular cutout	=	50mm

VI. Buckling Test

In this experiment the shells has to be compressed by applying the load axially. The deformation has to be take place in axial direction. For this make sure that the applied load should be equal in all directions.

The experimental setup is as shown in the above figure. In this the shells has to be compress by applying the load axially. This experiment has carried out by sing an Universal Testing Machine (UTM). The capacity of the machine is 50KN. This machine is an hydraulically operated machine. It has a fixed bottom head and moving top head. The shell which has to be tested has to be placed in between the two heads. Make sure that the shells placed right at the centre and the ends of the shells are fixed in groove of the fixing plates.

Final set up for buckling test

When the load is applied on the shell as it reaches to a certain level the shell will buckle with loud noise. The buckled mode shapes of the specimen as shown in the figure.

Buckling modes of the shell

VII. Results & Discussions

Table.1 and Table.2 shows the mechanical properties of the glass fiber and polyester resin respectively. The properties of the fibers and matrix were supplied by the manufacturers. Table 3 shows the theoretically calculated material properties of the composite materials based on the glass fiber and polyester resin.

Table-1. Mechanical properties of composite fibers.

Type of fiber	E_f (GPa)	v_f	G_f (GPa)
E-Glass	72.4	0.28	30

Table-2 Mechanical properties of composite resin.

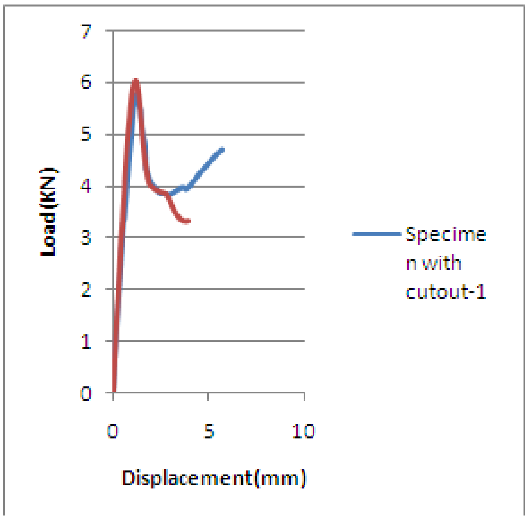
Type of resin	E_m(GPa	v_m	G_m (GPa)
Polyester	9	0.3	3.26

Table-3. Mechanical properties of composite laminate

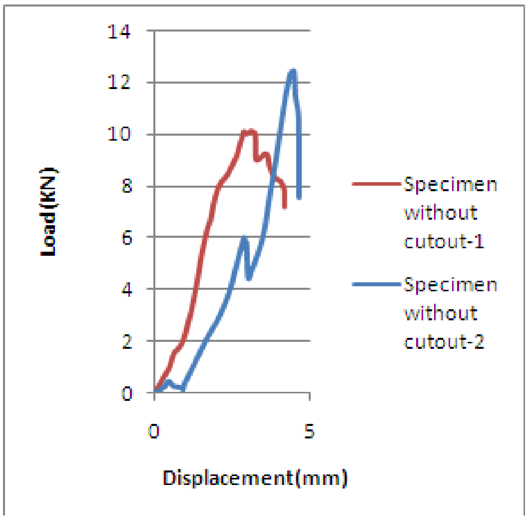
S.No.	Composite material properties (E-glass/polyester)		
	Property	Direction	Value
1	Longitudinal modulus (GPa)	E_{11}	50.21
2	Transverse modulus(GPa)	E_{22}	20.8913
3	Shear modulus (GPa)	G_{12}	7.7518
4	Poisson's ratio	v_{12}	0.263

VIII. Graphs

The results which were obtained during the experiment has shown below in the form of graph. These graphs will show the response of the specimens to the applied load at various stages. In these it is considered that the displacement on X-axis and the load on Y-axis.



Specimens with cutout



Specimens without cutout

Table-4. Buckling loads of shells

Specimen	Buckling load value(KN)
Specimen with cutout-1	5.8281
Specimen with cutout -2	6.0194
Specimen without cutout -1	10.1750
Specimen without cutout -2	12.4719

IX. Conclusion

The cylindrical shells are fabricated for buckling test using filament winding machine and sized to test the specimens in computerized UTM machine. Testing procedure is established for buckling test under axial compression. Buckling test is carried out in UTM machine; shell with cut outs and without cut outs. The load bearing capacity of the shell decrease for shells with cut out compared to the shells without cut outs. As per the obtained results the shells with cutouts buckled at 5.8281KN & 6.0192KN whereas the shells without cutouts buckled at 10.1750KN & 12.4719KN. The above work has to be validated theoretically or numerically.

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