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Experimental Investigation on Composite Cylinder for its Buckling Strength

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Abstract – This work represents determination of the buckling strength of composite cylinders. In order to estimate operating depth of glass vinyl-ester composite cylinder, external hydrostatic pressure test was carried out using Buckling chamber set-up. Strength of the composite cylinder was determined. Finite element analysis was carried out to predict the buckling strength of the cylinder and to compare with experimental results.

Keywords: Design, Buckling, External Pressure, Under Water Shells.

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1. INTRODUCTION

Underwater vehicles have to be designed for hydrostatic pressure induced buckling which is decisive in structural performance and it limits the under water depth of the vehicle. Vehicle structure in the form of circular cylinder, sealed at the ends are preferred as these structures have no reserve buoyancy and can sink to the bottom of the ocean. Composite materials are generally preferred due to their low-weight-to displacement ratio and high strength. The structure of underwater vehicles comprises of three sections, namely the cone, load bearing cylinder and torospherical dome. Load bearing cylinder is the middle portion of this part which is a structural member subjected to high external pressure under deep sea environments. Standard fixture or test rig is not readily available for determining the buckling strength of these structures.

It is common to find literatures on both numerical and experimental studies for determining the buckling strength of cylindrical shells. Baoping et al. [1], conducted external hydrostatic test on carbon fiber/epoxy composite shells. The external hydrostatic pressure test was conducted in a hyperbaric test chamber with a capacity of 50 Mpa. The experimental and analytical results were in close agreement as the buckling took place just above the designed buckling pressure. Chul-jin-Moon et al.[2], conducted experiments in a testing chamber in which carbon-epoxy composite cylinder was submerged in fluid subjected to uniform external pressure considering three different filament winding angles of [±30º], [±45º], and [±60º]. Filament wound at an angle of ±60º showed highest sustainability for the buckling pressure as the Young's modulus was greater in radial direction as compared to Poisson's ratio. This resulted in high circumferential stiffness than the other two cylinders. A deviation of 2 - 23% was observed between analysis and experimental results. Investigations on the failure of composite cylinders with increase in thickness, suggests absence of gradual deformation resulting in a catastrophic failure [3]. However, J Y Han et al. [4], reported increase in pressure bearing capacity of cylinders with increase in thickness to diameter ratio of the cylinders. Seong-Hwa-Hur et al. [5], composite cylinders were tested under external hydrostatic pressure. Fixture was designed to hold the test cylinder between the two metallic flanges. This fixture is submerged in a fluid for testing. Author's stated, pressure respective to the first peak is the buckling load, recorded sudden drop in applied pressure after the buckling and serious damage of composite cylinders. G.farashashi et al. [6], Andrew P.F et al. [7], M.Buragohain et al. [8] conducted buckling tests on thin cylindrical shells in fluid filled chamber in which two closure discs were used to hold the specimen push fit as well as leak proof. Author's reported the effects of manufacturing imperfections of cylinder shells on buckling behavior such as concentricity, variations in the wall thickness of composite cylinders. Deviations ranging from 20% - 50 % was observed from analysis to experimental results.

As these structures operate at greater depths in oceanic environment, it is essential to determine the buckling strength to ascertain performance. In order determine the buckling load of these shells, which in turn indicates operating depth of the cylinders, buckling tester is used. From the literature reviews [1-8] have shown that there is no standard testing fixture to conduct buckling test. So the suitable design of the buckling test fixture is required which holds the shell between two supports inside the buckling chamber.

2. MODELING, ANALYSIS, EXPERIMENT

2.1 Modeling

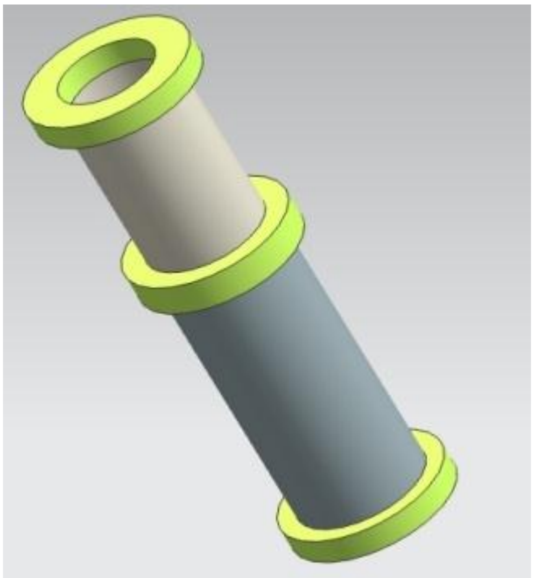

Figure 2.1 (a) and (b) modelled and assembled test rig

Test rig is designed to sustain for the required hydraulic pressure. This test rig was modeled using Uni-grapgics NX 8.0. Fig 2.1(a) and (b) shows modeled test rig. All the elements of the test rig were mentioned in the table 2.1

Sl. No	Part	Quantity
1	Front flange	1
2	Rear flange	1
3	Test cylinder	1
4	Support tube	1
5	Centre flange	1

Table 1. Parts list

This test fixture is designed to test the composite cylinder of length 238mm. The supporting cylinder in this test rig is made of Mild steel and is fabricated by conventional machining accurately maintaining the dimensions of inner and outer diameter equals to test cylinder diameter. Front and rear flanges are made up of Polyurethane rubber. Fig 2 (2) and (b) shows the modelled and assembled test rig.

2.2 Finite element analysis.

The finite element analysis was carried out to predict the buckling behaviour. Initial imperfections of the cylinders were not considered. Ansys 14.5 was used to analyze buckling behaviour of the composite cylinder. Shell 4 node 181 elements were selected for the test cylinder. Both ends of the cylinder are fixed in all degrees of freedom to restrict the displacement. Uniform pressure is applied along the outer circumference of the cylinder. Effect of winding angle was also not taken into account in the analysis of the cylinder.

2.3 Experiment

2.3.1 Test specimen

The specimen was manufactured by a filament winding process using Glass fibre and Vinyl ester resin. This cylinder has 175 mm inner diameter, 238 mm length and 5 mm thickness. The cylinder has winding angle of ±20º.

2.3.2 Hydrostatic pressure test setup

Fig 2.3.2 (a) shows set for buckling test. It is possible to observe inside of the cylinder as one side of the machine is open. To measure the strain response, two strain gauges were mounted around the circumference of the test cylinder (0º and 180º). The cylinder was submerged in oil within the buckling chamber for the testing. The uniform pressure on outer surface of the cylinder is applied by the hydraulic oil. The equipment can apply pressure up to 30Mpa which is equals to the pressure at a depth of 3000m in water.Fig 2.3.2(b) positions of the strain gauges.

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Figure 2.2 (a) and (b) Hydrostatic test set Up

Figure 2.3 (c) Positions of the strain gauges

3. RESULTS AND DISCUSSION

The pressure is tabulated in Bars. Two diametrically opposite strain gauges were mounted and the readings tabulated are in micro strains. It can be observed that the strain readings were in concurrence to a larger extent up to readings of 1151 with the corresponding pressure around 30 bar, suggesting the elastic limit of the composite tube. Thereafter the readings deviated considerably indicating the onset of plastic deformation with the corresponding pressure being 36 bars. Further increasing the pressure, a steep change in the strain readings was observed indicating the onset of buckling. The composite vessel underwent buckling at a pressure of 52 bars. Figure 3.1 shows a plot of micro-strain v/s pressure of two strain gauges. The Critical buckling pressure of the test cylinder manufactured was found to be 5.34 MPA.

Fig 3.2(a) and (b) shows cylinder before and after buckling respectively.

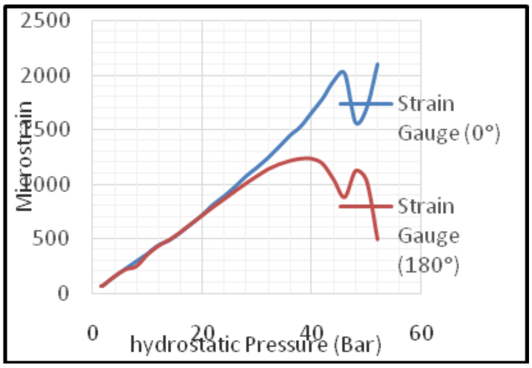

Figure 3.1 Plot of Micro-strain v/s Pressure

Figure 3.2 Glass/Vinyl ester cylinder before buckling And after buckling respectively

4. CONCLUSIONS

This work was aimed at determining the critical buckling pressure of an underwater pressure shell. The critical buckling pressure as predicted by FEA (ANSYS) was 8.2 Mpa whereas experimental value was found to be 5.3 Mpa. The experimental buckling load was found to be 65% of the FEA estimate. Some of the research conducted have shown experimental buckling load to be 40-50% of the finite element estimate. The maximum stain recorded was 2012(for 46 bars) and 1240(for 38 bars) at 0º and 180º respectively.

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