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A Computational Study of Buckling Analysis of Filament Wound Composite Pressure Vessel Subjected to Hydrostatic Pressure

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Abstract- In this present study the post buckling cha-racteristics of moderately thick-walled filament-wound carbon–epoxy composite cylinders under external hydrostatic pressure were investigated through finite element analysis for under water vehicle applications. The winding angles were [±30/90] FW, [±45/90] FW and [±60/90] FW. Finite element software ANSYS 14.0 were used to predicted the buckling pressure of filament-wound composite cylinders. For the finite element modeling of a composite cylinder, an eight-node shell element is used. To verify the finite element results for comparison, three finite element software, MSC/NASTRAN, MSC/MARC and an in-house program ACOS were used. Among these software's, the finite element software ANSYS predicts the buckling loads within 1.5% deviation. The analysis and test results showed that the cylinders do not recover the initial buckling pressure after buckling and that this leads directly to the collapse. Major failure modes in the analysis were dominated by the helical winding angles. The finite element analysis shows global buckling modes with four waves in the hoop direction.

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Abstract- In this present study the post buckling cha-racteristics of moderately thick-walled filament-wound carbon–epoxy composite cylinders under external hydrostatic pressure were investigated through finite element analysis for under water vehicle applications. The winding angles were [±30/90] FW, [±45/90] FW and [±60/90] FW. Finite element software ANSYS 14.0 were used to predicted the buckling pressure of filament-wound composite cylinders. For the finite element modeling of a composite cylinder, an eight-node shell element is used. To verify the finite element results for comparison, three finite element software, MSC/NASTRAN , MSC/MARC and an in-house program ACOS were used. Among these software's, the finite element software ANSYS predicts the buckling loads within 1.5% deviation. The analysis and test results showed that the cylinders do not recover the initial buckling pressure after buckling and that this leads directly to the collapse. Major failure modes in the analysis were dominated by the helical winding angles. The finite element analysis shows global buckling modes with four waves in the hoop direction.

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I. Introduction

Filament-wound composite materials have been successfully used in underwater vehicles and ocean structures over the past few years, especially as composite pressure vessels [1–3]; the use of composite materials in civil and military aircraft has also expanded considerably over the past few decades due to their light weight and high resistance to salt wat-er corrosion [4]. Particularly, small underwater veh-icles can be manufactured in one piece with composite ma-terials. Both the filament winding and tape lay-up met-hods can be used to manufacture a small vehicle with-out sub-assembly [6].

Although decades of R&D in composite materials have focused on aerospace engineering, new applications are opening up in various fields where weight or resistance to corrosion is critical. Particularly, caron composites are considered promising materials for future underwater vehicles and ocean structures due to their corrosion resistance [5, 7].

Buckling has become a dominant failure mechanism when compressive stresses generated by the external hydrostatic pressure reach elevated levels for subsea composite pressure vessel. For an underwater vehicle operated in deep sea, hydrostatic pressure-induced buckling tends to dominate structural performance. Furthermore, a cylindrical structure generally experiences unstable buckling, where the loadcarrying capability of the structure decreases after the buckling [7, 8].

Generally, high external pressure vessels such as submarine structures have been manufactured of high strength steel, titanium and aluminum alloy. Large buoyancy is required for the structural weight. Accordingly, the weight-sensitive structures are expected to reduce weight for faster and more efficient peformance. It was observed that the use of composite materials for underwater vehicles can reduce their total weight and expand the depth of operation because the reduced weight can allow for greater structural reinforcement [7, 9, and 10].

In the present work, relatively thick-walled com-posite cylinders (radius- to-thickness ratio, R/t = 18.8) were manufactured by a filament winding process to reduce the material and geometric imperfections for a high depth underwater vehicle [7]. The main objective of this paper is to investigate the buckling, post buckling behavior and failure mode of moderately thickwalled composite cylinders with various winding angles under external hydrostatic pressure for underwater vehicle applications. The helical winding and hoop reinforcement ([±30/90] FW, [±45/90] FW and [±60/90] FW) were used for the composite cylinders.

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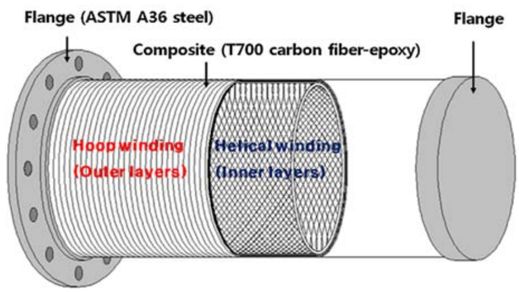

Figure (a)

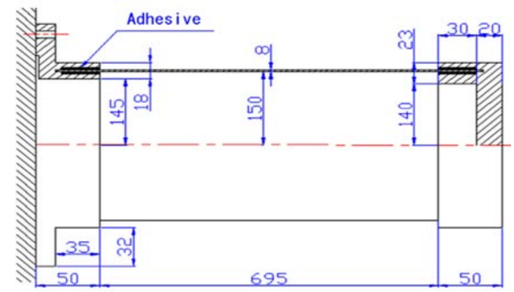

Figure (b)

Figure 1 : (a) Schematic of a filament-wound composite cylinder with flange (b) Dimension of the cylinder

II. Specimen Modeling

The specimens were manufactured by a filament winding process using T 700–24 K carbon fiber and Bisphenol A type epoxy resin. All of the cylinders have a 300-mm nominal inner diameter; a 695-mm nominal axial length and an 8-mm nominal thickness (see Fig. 1). The cylinders have three different winding angles: [±30/ 90] FW, [±45/90] FW and [±60/90] FW. The parameters ±30, ±45 and ±60 denote the helical winding angle, while 90 is the hoop winding. For creating the finite element model, ACOS [15], an in-house program, was used. The carbon composite cylinders were fabricated by a filament winding process and tested in a water pressure chamber. Two commercial software's, MSC.NASTRAN and MSC.MARC, were also used for comparison of the buckling pressure and mode shape. The nominal thickness of the hoop winding is 10% of the total thickness. This value was chosen because the best buckling pressures are obtained when the hoop ratio does not exceed 50% of the total thickness. When the hoop ratio exceeds 50%, the cylinders become very weak with respect to static strength. In this present work the finite element model of composite pressure vessel is made by ANSYS 14.0 APDL, finite element software.

Two commercial software, Msc. Nastran and Msc.Marc and Acos, an in-house program were used to create the model. The cylinders have a 300mm nominal inner diameter, 695mm nominal axial length and an 8 mm nominal thickness. The nominal thickness of the hoop winding is 10% of the total Thickness. In ANSYS 14.0 APDL a 3D shell element element 8 node 281 having 6 degree of freedom at each node is used to recreate the model.

a) *Mechanical Properties*

Property	Symbol	Rule of mixture	Unit
Elastic modulus	E1	149	GPa
	E2	10.6	GPa
	E3	10.6	GPa
Poisson's ratio	ύ12	0.253	-
	ύ13	0.253	-
	ύ23	0.421	-
Shear modulus	G12	4.14	GPa
	G13	4.14	GPa
	G23	3.31	GPa

III. Finite Element Analysis

Finite element analysis was used to predict not only the buckling loads but also the post buckling behavior. Failure analysis was performed using the in-house software ACOSwin, which makes possible nonlinear and progressive failure analysis. The commercial programs MSC/NASTRAN (linear analysis) and MSC/ MARC (nonlinear analysis) were used to validate the buckling loads. The theoretical background for ACOSwin is given in [13]. In the finite element models, four node elements, CQUAD4 in MSC.NASTRAN and Element 75 in MSC.MARC, were used. The ACOS program used an 8-node laminate shell element that had 5 degrees of freedom at each node. In Ansys 14.0 APDL laminate shell element 8 node 281 having 6 degree of freedom at each node were used to predict the critical buckling pressure. For non-linear, post buckling behavior, progressive failure analysis was conducted by ACOS using complete unloading as the stiffness degradation method [16, 17]. The stacking sequence of different composite laminate with different orientation of fibers has shown in fig.2. The enlarge view of stacking sequence and different composite laminate with various thickness have been shown in fig.3.

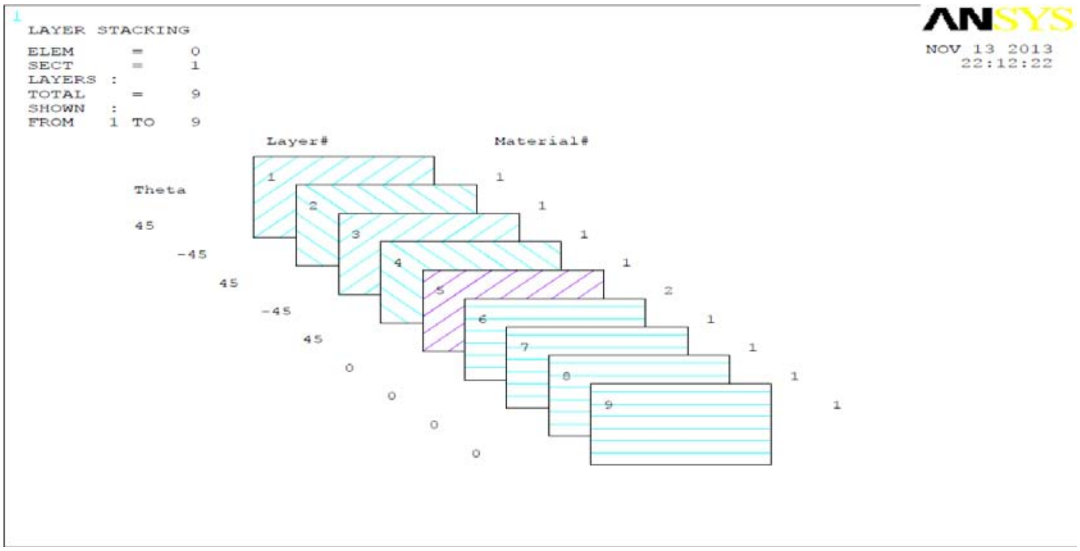

Figure 2 : Layer stacking sequence of composite pressure vessel [±45/0] FW

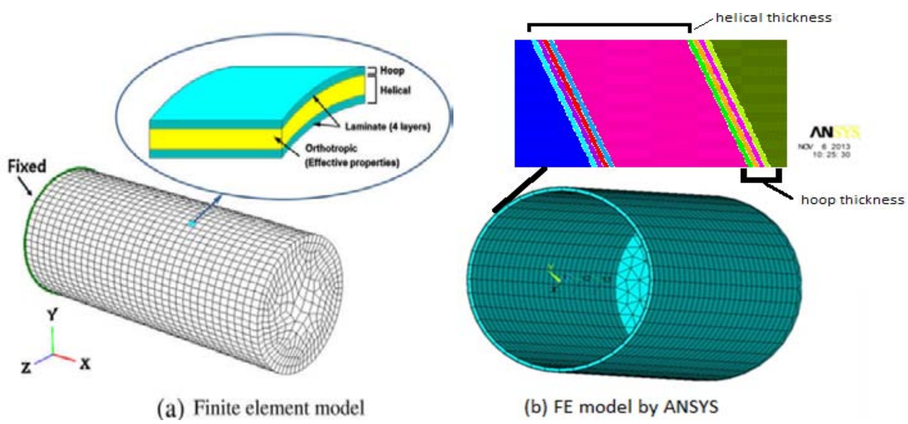

Figure 3 : (a) Finite element model by ACOS win. (b) Finite element model by ANSYS APDL

IV. Simulation

The composite structure that used in under water vehicle application, only hydrostatic pressure will consider which can apply redialy inward direction over the outer surface of the body. The equipment can apply pressures up to 10 MPa, which is equal to the pressure at a depth of 1000 meter of water. At the left end of the composite cylinder all degree of freedom can be restricted and at the right end only two degree of freedom has restricted (x direction & y direction), so that the system will undergo only axial deformation.

The finite element modeling, meshing and simulation of carbon-epoxy composite filament wound pressure vessel have shown in figure 4.

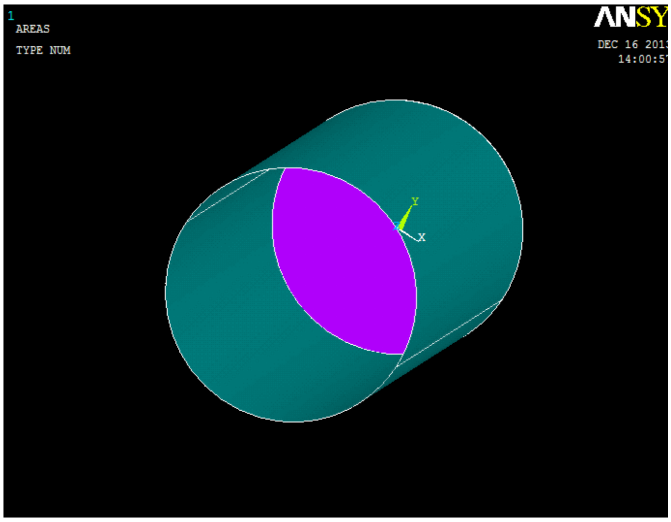

Figure 4 :(a)

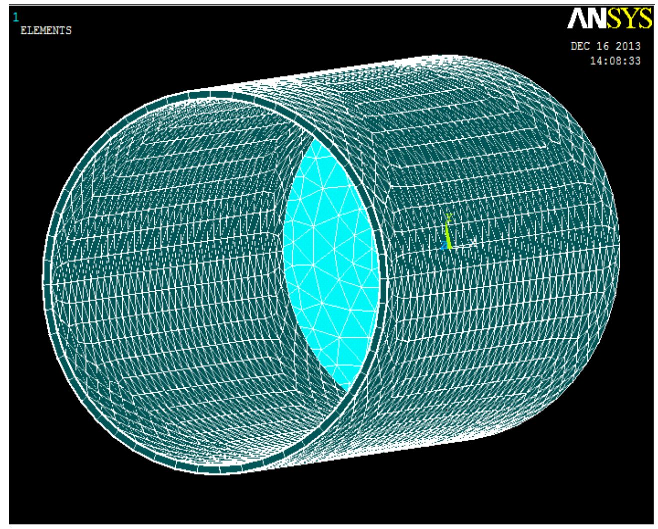

Figure 4 :(b)

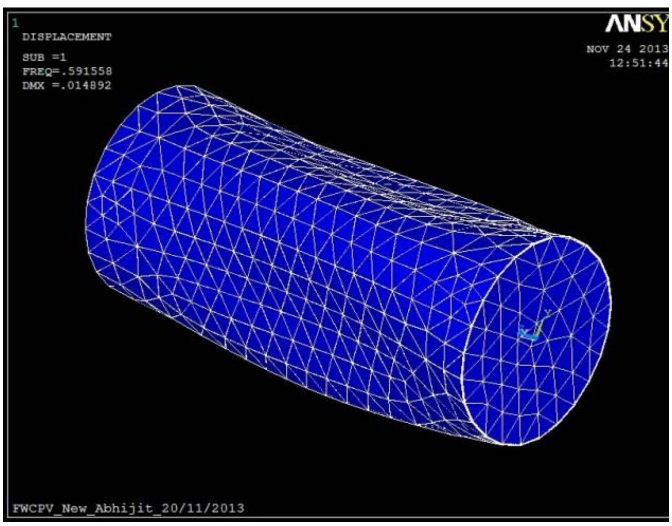

Figure 4 : (c)

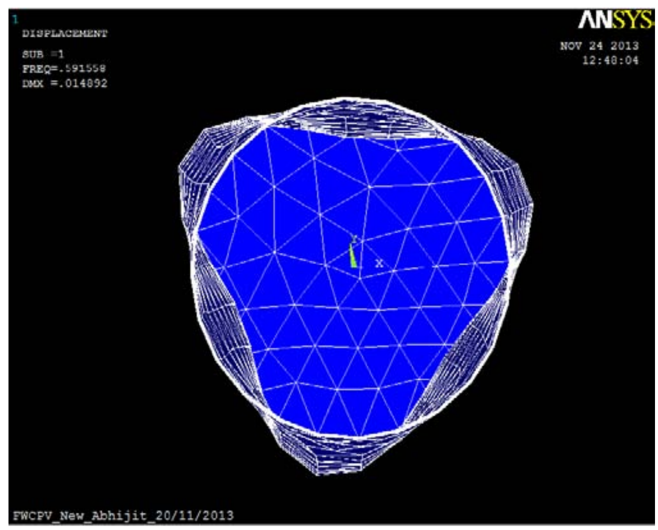

Figure 4 : (d)

Figure 4 : (a) Finite element model (b) Meshed model (c) Buckling Mode shape (d) Buckling Mode shape (Front view)

V. Results and Discussion

The buckling analysis has done by Ansys APDL. It has observed that the result for critical buckling is good matched with the existing experimental results. The figures are describing the comparison study of the composite pressure vessels. Table 3 shows the experimental and finite element buckling pressure. The ANSYS 14.0 APDL results as well as the linear and nonlinear analysis results by MSC/NASTRAN, MSC/MARC and ACO Swin are presented. In ANSYS non-linear buckling analysis has been done. Fig.5 described the different mode shape obtained by MSC/NASTRAN, MSC/MARC, ACOS win and Ansys 14.0 respectively. Here [±45/90] FW specimen was consider for the finite element analysis.

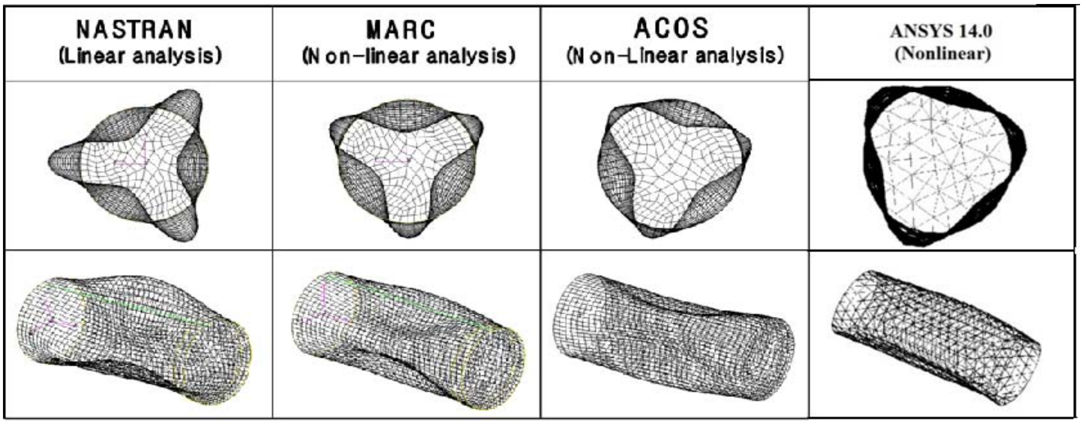

Figure 5 : Buckling modes of the [±45/90] FW composite cylinder

Table 1 : Experimental And Finite Element Buckling Pressure (Unit: Mpa)

RESULT OBTAINED	BUCKLING PRESSURE UNIT(MPa)	PERCENTAGE OF ERROR (%)
EXPERIMENTAL TEST	0.60	-
ANSYS 14.0 APDL	0.591	1.5
MSC.NASTRAN	0.677	12.08
MSC.MARC	0.691	15.2
ACOSwin	0.671	11.8

Figure 6 : Comparison of experimental and computational critical buckling pressure obtained by different software's

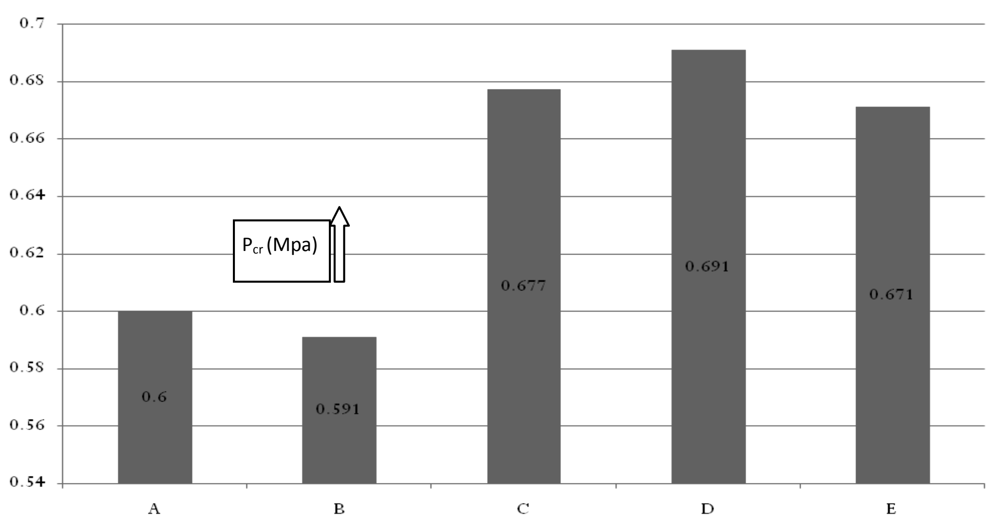

Figure 7 : Bar graph (a) experimental test result (b) result obtained by Ansys (c) result obtained by Nastran (d) result obtained by Marc (e) result obtained by ACOSwin

VI. Conclusion

The buckling behavior of moderately thick walled, filament-wound, carbon–epoxy cylinders subjected to hydrostatic pressure was investigated. A total 9 no. of composite laminates has been considered for finite element analysis. The different orientation of the composite layers has been taken [±45/90] FW. Analyses were conducted using the finite element package ANSYS 14.0 APDL. Three finite element program ACOS win, MSC/NASTRAN and MSC/MARC were used to validate the results. A shell element 8 node 281 was used to create the finite element model. The ANSYS shell element model predicted the buckling pressure with 1.5% deviation from the other three finite element results and experimental results, not considering the initial imperfections of the cylinders. The results show that finite element analysis with shell elements can be used to evaluate the buckling load of moderately thick-walled, filament-wound composite cylinders under external hydrostatic pressure.

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