ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Analytical and Finite Element Analysis of a Multilayered Cylindrical Shell for Suitable Winding Angle

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Abstract:

Autonomous underwater vehicles (AUVs) designed for moderate and extreme depth requires minimization of structural weight for increasing pay load performance/ speed/operating range. The material should have a high strength to weight ratio, high specific strength and good resistance to corrosion, and must be affordable. But in the past most used shell materials was Steel, and Aluminum. The major disadvantage of Steel shell is the low strength to weight ratio. The drawback of Aluminum shell is that it is anodic to most other structural alloys, making it vulnerable to corrosion. By virtue of their high strength to weight ratio and high specific strength, fiber reinforced plastics offers major potential weight saving relative conventional metallic shells so in current years the increasing need for light weight structural element has led to the use of fiber reinforced multi layered shells.

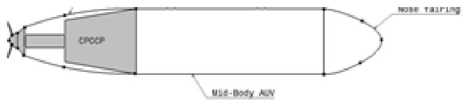
The fiber reinforced multilayered shells mainly depends on three parameters for reducing stresses in underwater loading conditions, those are winding angle, number of layers, laminate sequence, among these winding angle plays a vital role for sustainment of shell at greater depths. Therefore finding a suitable winding angle at which shell can be sustainable for greater depths and also generation of lower stress. Hence in the present work suitable winding angle for the underwater vehicle operated up to moderate depths i.e. up to 400metres has been carried out using FEA. In addition buckling analysis is also carried out for the shell at the obtained suitable winding angle and the obtained results are compared with analytical results which are obtained from Windenburg and Trilling theory.

Keywords:

Autonomousunderwater vehicles (AUVs),fiber reinforced plastics, winding angle,Trilling theory.

I.INTRODUCTION:

Autonomous underwater vehicles (AUVs), also famously known as unmanned under sea vehicles, is a type of deep sea vehicle which navigates on its own. Technically types of robot, AUVs are self-propelled and pre-programmed, and performs it various functions without any human control. These AUVs are made up of several advanced technologies and are mainly used for underwater surveillance, deep sea research or rescue operations. When these underwater vehicles areoperated subjected to hoop stresses that are twice longitudinal and also buckling due to hydrostatic pressure.In 1940's these underwater vehicles are manufactured with Steel, Aluminum and Magnesium alloys are used in underwater loading conditions but these materials heavy in weight and also corrosive, therefore for avoiding these drawbacks a new materials are introduced such as composite materials.Composite materials are light in weight and resist the corrosion. Manufacturing of composite underwater vehicles are initially developed with a closed mould techniques. Later for high performance applications a closed mould infusion technique can be introduced. These closed mould infusion technique is very expensive and often used for large composite structures to reduce volatile emissions and lower resin injection pressures. Further automation and innovation led to advanced process such as filament winding and combination techniques.



II.SURVEY OF LITERATURE:

In order to assess the trend and level of research work done till date, in the area of titled work, an exhaustive literature has been reviewed .A gist of some of the most relevant research work is presented in this chapter under various classified headings. Failure refers to structural damage, which results from repeated or otherwise varying stresses that are well below the static yield strength of the material.

III.ANALYSIS OF STRESSES AND BUCKLING BEHAVIOUR OF UNDERWATER MULTILAYERED CYLINDRICAL SHELL BY ANALYTICAL APPROACH:

Underwater multilayered shells suffer from buckling due to underwater loading conditions which reduces their load carrying capacity. Research on buckling of shells has been carried out over many years with particular attention to isotropic materials. Application of polymer composites for underwater vehicle structures can reduce their weight and expand the depth of operation. Materials for underwater shells must not only be capable of withstanding very high external pressure, but also have the other properties such as good resistance to corrosion as these shells are operated at both shallow and deep sea conditions, high strength to weight ratio and operating life span of the material and the like. Advantage of using fiber reinforced composites over conventional materials is that they can be tailored to the requirements.

E-Glass Fiber:

E - Glass fibers are most common of all reinforcing fibers. The principal advantages of glass fibers are low cost, commercially available, high tensile strength, high mechanical resistance, and excellent insulation properties. The disadvantages are low tensile modulus, relatively high specific gravity (among the other commercial fibers), and sensitivity to abrasion with handling which frequently decreases its tensile strength, relatively low fatigue resistance and high hardness. Even though the carbon fibers have high strength to weight ratio and tensile modulus to weight ratios, it was not preferred because it is having low impact resistance and high electrical conductivity, low transverse strength and high cost.
The properties of E - Glass fiber are
Material : E-Glass continuous fiber EC 2400
Tensile Modulus (E_f) : 73.6 Gpa
Tensile Strength: 3.45 to 3.6 Gpa
Poisson's ratio (μ_f) : 0.22
Specific gravity : 2.54 to 2.56
Density(ρ_f) : 2560 kg/m3
Electrical resistance : 2 x 1013 Ohms
Low alkaline composition comprises
:Silicon, calcium, aluminum, boran.

Matrix:

The matrix plays a minor role in load carrying capacity. The matrix has a major influence on interlaminar shear as well as in plane shear properties of the composite. Interlaminar shear strength is important in design under bending loads. The matrix provides lateral support against the possibility of fiber buckling under compressive loads. Among the matrix materials epoxies are used because of commercial.
The properties of Epoxy matrix are:
Material : Epoxy ResinCIBA-GEIGYmake 205.
Specific gravity : 1.2
Density (ρ_m) : 1200 kg/m3
Tensile strength : 28 to 130 MPa
Compressive strength : 100 to 175 MPa.
Tensile modulus (E_m) : 3.0 GPA.
Poisson's ratio (μ_m) : 0.33.
Specific heat : 0.25 calories /g / °c.

3.3 Theoretical Calculations

The Weight and volume fractions can be calculated using the following equations

a)Calculation of Volume fraction:

The volume of fiber in a cured composite. The fiber volume of a composite material may be determined by chemical matrix digestion, in which the matrix is dissolved and the fibers weighed. Typical values for glass/epoxy based upon the fiber type, are 55-67% fiber.

$$V_f = \frac{W_f/\rho_f}{[W_f/\rho_f] + [W_m/\rho_m]} \quad eq(3.3)$$

$$W_f = \frac{V_f\rho_f}{[V_f\rho_f] + [V_m\rho_m]} \quad eq(3.4)$$

Where,

$V_f = 0.5942\ m^3$

$V_m = 1.0 - 0.5942 = 0.4570\ m^3$

V_m = volume fraction of matrix

V_f= volume fraction of fibers,

W_f= weight of fibers,

W_m= weight of matrix

ρ_f= density of fibers,

ρ_m= density of matrix

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b)Calculation of Density:

Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume.

(Density = mass/volume).

It is usually expressed in kg/m^3. The Density of the composite for the given volume fraction is

Where,

ρ_f= density of fibers, ρ_m= density of matrix,

ρ_c = density of composite

$$\rho_c = \rho_f V_f + \rho_m V_m \qquad eq(3.5)$$

$$\rho_c = 2028 \frac{Kg}{m^3} = 2.028\ Mg/m^3$$

c)Calculation of Elastic Properties of the composite: Modulus of Elasticity:

The ratio of the stress applied to a body to the strain those results in the body in response to it. (OR)The ratio of the longitudinal strain to the longitudinal stress is called young's modulus.

Longitudinal Modulus (E_L)

Where,

E_f = Tensile modulus of fiber,

E_m = Tensile modulus of matrix

$$EL= E_f V_f E_m V_m \qquad eq(3.6)$$

$$E_L = 44.9572\ GPa$$

Transverse Modulus (E_T)

$$E_T = \frac{E_f E_m}{E_f V_f + E_f V_m} \qquad eq(3.7)$$

$$E_T = 8.850408\ GPa$$

d.Major Poisson's Ratio(μ_{12}):

Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio. Poisson's ratio, also called Poisson coefficient, is usually represented as μ.

$$\mu_{12} = \mu_f V_f + \mu_m \qquad eq(3.8)$$

$$\mu_{12} = 0.2646276$$

e.Minor Poisson's Ratio (μ_{21}):

$$\mu_{21} = \frac{E_T}{E_L}\mu_{12} \qquad eq(3.9)$$

$$\mu_{21} = 0.0520953$$

F) Shear Modulus (G_{12}):

Shear modulus or modulus of rigidity is defined denoted by, G, Is defined as the shear stress to shear strain, it is usually expressed in gigapascals (Gpa), Shear Modulus is always positive.

$$G_{12} = \frac{G_f G_m}{G_f \mu_m + G_m \mu_f} \qquad eq(3.10)$$

Where

G_f = Shear modulus of fiber,

G_m = Shear modulus of matrix

$$G_f = \frac{E_f}{2(1+\mu_f)}$$

$$G_f = 29.2063GPa$$

$$G_m = \frac{E_m}{2(1+\mu_m)}$$

$$G_m = 1.127\ GPa$$

$$G_{12} = 0.3334517 \times 10^4\ MPa$$

4.Role of FEM in Structural Analysis:

Structural analysis is probably the most common application of the finite element method. The term structural or structure implies not only civil engineering structures such as ship hulls, aircraft bodies and machine housings as well as under water cylindrical shells. These structural analyses are seven types those are

- Static Analysis
- Model Analysis
- Harmonic Analysis
- Transient Analysis
- Spectrum Analysis
- Buckling Analysis
- Explicit Dynamic Analysis

A static analysis calculates the effects of the study loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can however, include steady inertia loads (such as gravity and rotational velocity), and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacement, stresses, strains and forces in structural

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components caused by loads that do not include significant inertia and damping effects.Steady loading and response conditions are assumed i.e. the loads and the structures responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in a static analysis include.

• Entirely applied forces and pressures
• Steady static inertial forces (such as gravity (or) rotational velocity)
• Imposed (non-zero) displacements
• Temperatures (for thermal Strain)
• Fluences (for nuclear swelling)

A static analysis can be either linear or nonlinear. All types of nonlinearities are allowed- Like large deformations, plasticity, creep, stress, stiffening contact (gap) elements and hyper elastic elements.

Geometry of multilayered cylindrical shell:

The multilayered shell (GFRP) is orthotropic in nature and cylindrical in shape. It consists of glass fibers as the reinforcement material into a polymeric epoxy matrix. Because of the orthotropic nature of the composite materials, the finite element modeling of the multilayered shell requires the determination of nine different properties. The material properties of fiber reinforced composite depends upon the properties of both the matrix and the fibers. The angle of orientation of the fibers in the composite also plays a very important role determination of the properties and the behavior of the composite, since the fibers have superior mechanical properties along its length. The dimension of cylindrical shell of underwater vehicle as shown in below figure 4.1.

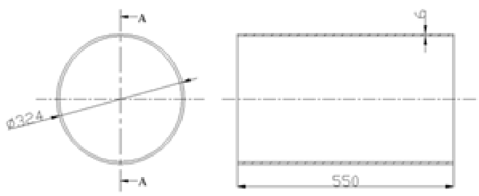
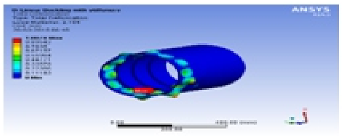


Figure 4.1 Geometry of the cylindrical shell

5.Linear Buckling with stiffeners:

Finite elements analysis was performed on a composite shell with stiffeners having the geometric properties.

By obtaining the maximum load and considering that as a best angle to obtain the maximum critical buckling pressure, different analysis were carried out with angle-ply laminate arrangements and critical buckling pressure with stiffeners as shown in figure 5.2 and critical buckling values are tabulated in the table 5.2.



5.2 Critical Pressure of 8 Layers at ±54° orientation with Stiffeners

Table 5.2 Critical Pressure with Stiffeners

S.NO	Layer Thickness	Orientation (θ^0)	FEM Critical buckling Pressure in MpaWith Stiffeners
1	0.75	$\pm40^0$	5.8632
2	0.75	$\pm42^0$	6.1124
3	0.75	$\pm44^0$	6.1921
4	0.75	$\pm46^0$	6.2715
5	0.75	$\pm48^0$	7.3265
6	0.75	$\pm50^0$	7.3272
7	0.75	$\pm52^0$	8.3089
8	0.75	$\pm54^0$	8.7423
9	0.75	$\pm56^0$	7.6456
10	0.75	$\pm58^0$	7.7868
11	0.75	$\pm60^0$	7.7182
12	0.75	$\pm62^0$	7.6715
13	0.75	$\pm64^0$	7.6279
14	0.75	$\pm66^0$	7.5753
15	0.75	$\pm68^0$	6.5103
16	0.75	$\pm70^0$	6.4392

5.3 Summary:

Based on the above buckling analysis by using FEA the critical buckling pressures was carried out without and with stiffeners of a cylindrical shell the winding angle changes from $\pm40^0$ to $\pm70^0$ with 2 degrees variation. Out of these winding angles the maximum critical buckling pressure was obtained at an angle of ± 540 i.e., 8.7423 Mpa respectively.

CONCULSIONS:

In the present work an underwater shell oriented at made up of FRP material which is higher depths has been taken to consideration and it is analyzed for suitable winding angle which could impart for carrying high buckling pressures and for generation of minimum stresses .1. In the present work underwater shell made up with winding angles from ± 400 to ± 700 with a 2 degree variation is analyzed for stresses generated and also for critical buckling pressure through analytical approach.2. From the analytical approach at a winding angle of ± 540 minimum stresses were calculated and are found to be 240.34 N/mm2.and maximum critical buckling pressure without and with stiffeners of a cylindrical shell found to be at an angle of ± 540 i.e., 2.774 N/mm2 and 7.3245 N/mm2 respectively.3. From the FE analysis at a winding angle of ± 540 the minimum stresses were generated and are found to be 191.24 N/mm2 .And the maximum critical buckling pressure was without stiffeners at an angle of ± 540 found to be 2.174 N/mm24. By using same way of FE analysis providing with stiffeners the maximum critical buckling pressure at a winding angle of ± 540 found to be 8.7423 N/mm2 5. Based on the all results the maximum critical buckling pressure and minimum stresses were generated at an angle of ± 540.

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