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MODELING AND ANALYSIS OF SUBMERSIBLE AUV PRESSURE HULL WITH SANDWICH MATERIALS USING FEM

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ABSTRACT

An autonomous underwater vehicle (AUV) is a robot that travels underwater without requiring input from an operator. AUVs constitute part of a larger group of undersea systems known as unmanned underwater vehicles, The structure of an autonomous underwater vehicle (AUV), usually composed of a cylindrical shell, may be exposed to high hydrostatic pressures where buckling collapse occurs before yield stress failure. In conventional AUV, welded stiffeners increase the buckling resistance, however, in small AUVs, they reduce the inner space and cause residual stresses. The Aim of the project work presents an innovative concept for the structural design of an AUV Pressure hull, proposing the use of sliding stiffeners that are part of the structure used to accommodate the electronics inside it. Design of AUV pressure hull using catia software and analysis using Ansys software using sandwich material ,In this project taken total 4 cases.

CASE 1: 2mm C40Steel + 2mm Rubber +2mm C40Steel

CASE 2: 2.5mm C40Steel + 1mm Rubber +2.5mm C40Steel

CASE 3 :2mm Ti-6Al-4V + 2mm Rubber +2mm Ti-6Al-4V

CASE 4 : 2.5mm Ti-6Al-4V + 1mm Rubber +2.5mm Ti-6Al-4V

Finally concluded the which material is suitable on pressure hull based on the stresses, strains, deformation, shear stress in static analysis and In modal analysis find out the modes at Total deformation in different Frequency.

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1.1 INTRODUCTION OF AUV

Autonomous Underwater Vehicles (AUVs) are programmable, robotic vehicles that, depending on their design, can drift, drive, or glide through the ocean without real-time control by human operators. Some AUVs communicate with operators periodically or continuously through satellite signals or underwater acoustic beacons to permit some level of control. AUVs allow scientists to conduct other experiments from a surface ship while the vehicle is off collecting data elsewhere on the surface or in the deep ocean. Some AUVs can also make decisions on their own, changing their mission profile based on environmental data they receive through sensors while under way.

The first AUV was developed at the Applied Physics Laboratory at the University of Washington as early as 1957 by Stan Murphy, Bob Francois and later on, Terry Ewart. The term light hull (casing) is used to describe the outer hull of a submarine or AUV, which houses the pressure hull, providing hydro dynamically efficient shape, but not holding pressure difference. The term pressure hull is used to describe the inner hull of a submarine or AUV, which holds the difference between outside and inside pressure.

Figure 1 Autonomous Underwater Vehicles (AUVs)

1.2 PARTS OF AUV:

There are several aspects in AUV electrical and mechanical design need to be looked at closely so that the design will be successful. In order to design any underwater vehicle AUV, it is essential or compulsory to have strong background knowledge, fundamental concepts and theory about the processes and physical laws governing the underwater vehicle in its environment.

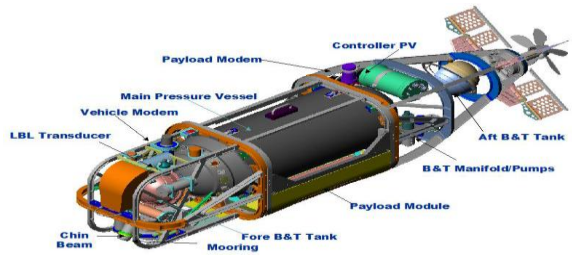

Figure 2 AUV Parts

1.3 PRESSURE HULLL:

Pressure hulls are the main load bearing structures of naval submarines, and autonomous underwater vehicles (AUVs). A pressure hull is a structure that is designed to withstand the compressive forces associated with hydrostatic pressure. The most efficient geometries for resisting these compressive forces are circular cross-sections, and thus, pressure hulls are typically composed of a combination of ring-stiffened cylinders and cones, with spherical or torispherical domes at either end. The design and manufacturing process of a pressure hull is a cumbersome engineering challenge because of the extreme pressure conditions and extremely low tolerances required. The pressure hull has been calculated and designed under the ASME rules, and Finite Element Method (FEM) simulations have been performed. The pressure hull is composed of a steel body with two acrylic spherical sectors; The steel has been specially selected due to its excellent mechanical properties and its high corrosion resistance.

All small modern submarines and submersibles, as well as the oldest ones, have a single hull. However, for large submarines, the approaches have separated. All Soviet heavy submarines and submersibles are built with a double hull structure.

1.4 SANDWICH BEAM CONCEPT:

Sandwich theory describes the behavior of a beam, plate, or shell which consists of three layers—two face sheets and one core. The most commonly used sandwich theory is linear and is an extension of first order beam theory. Linear sandwich theory is of importance for the design and analysis of sandwich panels, which are of use in building construction, vehicle construction, airplane construction and refrigeration engineering. Sandwich Beams are extensively used in the construction of aerospace, civil, marine, automotive and other high performance structures due to their high specific stiffness and strength, excellent fatigue resistance.

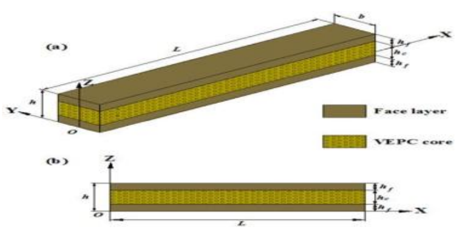

Figure 3 layer by layer Sandwich beam images

2 LITERATURE REVIEW

In the thesis by Altramese Lashe Roberts[1], time-dependent behavior of sandwich beams viscoelastic foam core is predicted. Based on the strength of materials approach, the analytical solution for the deformation in a viscoelastic sandwich beam is determined.

Y.Swathi[2], has done a static and dynamic analysis of a sandwich structure in FRP beams and found out the relation between the core thickness and damping coefficient.

T.P.Khatua[3] , the bending stiffness of face layers have been taken into account in the analysis while the idea of the common shear angle for all the cores have been excluded. More recently higher order shear deformation theories, taking into account the layer wise nature of the material and involving higher order terms in Taylor's expansions of the displacements along with thickness have also been developed.

Frostig et al[4] in treating sandwich beams sub divided the sandwich beam into two sub structures, one representing the shear absorption capability of the core and the other free of shear stresses.

Kant and Swaminathan[5] who expanded the in plane displacements as cubic functions of thickness coordinate, assuming an incompressible core. The equation of equilibrium are obtained using of the principle of minimum potential energy ; closed form solutions for particular cases were developed by solving the boundary value problem through the Navier's technique.

The hypothesis of the core incompressibility was removed, for instance, in the solution proposed by pandit and co workers [6], assumed a transverse displacement varying quadratically within the core, and employed a computationally efficient C0 finite element to solve the problem. In almost all the works published, the models proposed have been validated numerically, comparing the results with exact formulations available in the literature for special laminates whereas little experimental data has been generated on the subject.

Arentzen and Mandel [7]. All small modern submarines and submersibles, also the oldest ones, have a sole hull. However, for massive submarines, the approaches have separated. All Soviet heavy submarines are built with a paired hull structure. The term pressure hull can be describe as the inner hull of a submarine, in which approximately standard pressure is maintained when the vessel is immersed. Submarines are designed to use at great depths. The Hull structure, which is a very important part of the submarine become more and more important since its strength is the main concern. When immersed or submerged, the water pressure on the submarine hull increases while the pressure inside stays the same i.e., one atmospheric pressure

McDaniel, [8]. John R. MacKay [9] presented the paper on “Structural Analysis and Design of Pressure Hulls: the State of the Art and Future Trends” which explains that Pressure hulls are the central load bearing structures of naval submarines, research submersibles and autonomous underwater vehicles (AUVs) and commercial. The many similitude between pressure hull, some civil engineering structures, offshore, and aerospace signify that advances in one group are often relevant to the others, and thus this document is sometimes worried with the whole collection of thin-walled curved structures designed for unreliability, referred to hereafter as buckling-critical shells. The modern pressure hull structural analysis and design is accepted in this document by: 1) reviewing novel design procedures for buckling critical shell structures; 2) explaining the nature of structural strength, and associated weaknesses, in pressure hulls; 3) summarizing traditional and contemporary structural analysis and design methods for pressure and 4) hulls identifying trends with respect to numerical modeling of buckling-critical shell structures. It is proposed that the layered conservatism of the modern design approach could be enhance by the use of nonlinear numerical methods for strength forecast, and a way forward is suggested that would permit pressure hull design

Liam Gannon [10] presented a paper on “Prediction of the Effects of Cold Bending on Submarine Pressure Hull Collapse” which explains Submarine pressure hull frames and shell plating are shaped by cold bending during fabrication. Cold bending introduces significant residual stress in these components which can be detrimental to the strength of the structure. This study evaluates different methods of consolidate cold bending residual stresses in the evaluation of pressure hulls considering different out of circularity mode shapes. Several methods of pressure hull collapse analysis are compared considering interframe and overall collapse modes. These include an empirical method, a finite difference method and the finite element method. Collapse pressures predicted using the methods prescribed in the UK MoD submarine structure design standard, SSP 74, are found to be conservative when compared with results from finite element analysis. Collapse pressures predicted using effective stress-strain curves to incorporate the consequence of cold bending residual stress an finite element models agree well with those predicted by explicitly modeling the cold bending process. This indicates that the use of effective stress, strain curves is an acceptable means of accounting for the influence of cold bending residual stress of the collapse pressure of a submarine pressure hull. Finite element is an essential and powerful tool for solving structural problem. FEM can be used for a variety of linear, nonlinear and structural stability problems. FEA package ANSYS is used for modeling by UNIGRAPHICS and analysis for hypermesh of the structure. ANSYS is a general purpose software used for different types of structural analysis mainly for marine structures .It provides a strong pre and post processing tool for hyper mesh generation from only geometry origin to produce almost any element type. Stiffeners are modeled by beam element and cylindrical shell is modeled by shell elements

3 OBJECTIVE OF THE PROJECT

3.1 SCOPE OF THE PROJECT:

1. Study the different Journals Related to the AUV,Pressure vessel and sandwich materials.
2. Study the complete design analysis concepts about the pressure hull.
3. Study the different materials CASE 1: 2mm C40Steel + 2mm Rubber +2mm C40Steel,CASE 2: 2.5mm C40Steel + 1mm Rubber +2.5mm C40Steel,CASE 3 :2mm Ti-6Al-4V + 2mm Rubber +2mm Ti-6Al-4V,CASE 4 : 2.5mm Ti-6Al-4V + 1mm Rubber +2.5mm Ti-6Al-4V.
4. Create Finite element model of the pressure hull using ANSYS software.
5. Perform static and modal analysis for the hydrostatic pressure of 65 bars.
6. Perform Modal analysis to calculate natural frequencies and mass participations.
7. Implement modifications on the pressure hull based on the results obtained from modal analysis to shift the fundamental natural frequency .
8. Perform structural static analysis for the hydrostatic pressure of 65 bars on the modified model.
9. Perform Modal analysis to calculate natural frequencies and mass participations on the modified model. Perform analysis of the modified pressure hull in X, Y and Z directions.
10. Perform transient dynamic analysis of the modified pressure hull in X, Y and Z directions.

3.2 PROBLEM IDENTIFICATION:

Improper material leads to the failure, The aim of the project undertaken was to do the design and material optimization with different materials(sandwich material) of the cylindrical section of a submarine pressure hull using finite element analysis and strengthen it accordingly using non corrosion material. This pressure hull is subjected to a hydrostatic pressure of 65 Bar due to the difference between outside and inside pressure. So initially a structural static analysis was done to check the deflections and stresses. As the pressure hull is subjected to huge dynamic loads, we have analyzed the pressure hull for vibrations and shock loads. The pressure hull operates in the frequency range of 0-300Hz.So it has to be resonant free. Modal analysis has been carried out on the initial pressure hull model and calculated the natural frequencies. It was observed that there were three natural frequencies in the frequency range of 0-300Hz. Efforts have been made to shift these natural frequencies within the operating range of analysis of the pressure hull.

3.3 METHODOLOGY:

1. Design of pressure hull done using CATIA & CAD software. Design of pressure hull completed based on ISO standard drawing sheet.
2. These stresses are calculated for Four different materials of pressure hulls .
3. Pressure hull design imported in Ansys software for analysis purpose. Structural analysis of hull done for and different material types (C40steel, Ti-6Al-4V).
4. Perform the static and modal analysis
5. Consider the 65 bar applied the external because of this is the hydro static pressure.
6. From these results, concluded the suitable pressure hull proposed under radial pressure conditions with 4 materials.

3.4 DESIGN SPECIFICATIONS OF PRESSURE HULL:

Length overall = 1.8 m.

Pressure hull diameter = 0.8 m.

Layout = double diameter ring stiffened cylinder.

Submerged displacement =1015 tones.

Thickness of the pressure vessel =6mm

3.5 MATERIALS PROPERTIES:

C40 Steel:

C40 Steel is an alloy of iron and carbon containing less than 2% carbon and 1% manganese and small amounts of silicon, phosphorus, sulphur and oxygen. Steel is the world's most important engineering and construction material. It is used in every aspect of our lives; in cars and construction products, refrigerators and washing machines, cargo ships and surgical scalpels.

Ti-6Al-4V:

Ti-6Al-4V (UNS designation R56400), also sometimes called TC4, Ti64, or ASTM Grade 5, is an alpha-beta titanium alloy with a high strength-to-weight ratio and excellent corrosion resistance. It is one of the most commonly used titanium alloys and is applied in a wide range of applications where low density and excellent corrosion resistance are necessary such as e.g. aerospace industry, submarine, shipbuilding etc.

MATERIALS	DENSITY g/cm3	POSSION'S RAITO(u)	YOUNGS MODULUS (gpa)	ULTIMATE TENSILE STRENGTH (Mpa)	YIELD STRENGTH (Mpa)
C40 Steel	7.85	0.3	206	715	537
Ti-6Al-4V	4.429	0.34	113.8	950	880

4 DESIGN PROCEDURE IN CATIA:

Go to the sketcher workbench create the two circle as per dimensions after go to the trim delete the excess circle of the object after go to the part design apply pad as per dimensions after go to the sketcher again same procedure reduce the 2mm total create the 3parts after go to the assembly workbench assembly the 3 parts as shown below final product.

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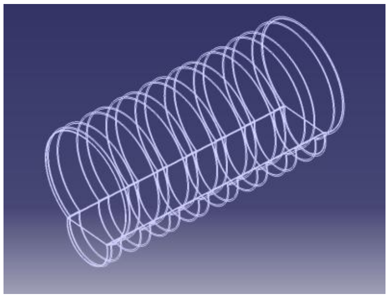

Figure 4 PRESSURE HUB IN WIRE FRAME VIEW

5 STATIC ANALYSIS PROCEDURE IN ANSYS:

Designed component in catia workbench after imported into Ansys workbench now select the STATIC ANALYSIS

1.ENGINEEERING MATERIALS (MATERIAL PROPERTIES).

2.CREATE OR IMPORT GEOMENTRY.

3.MODEL(APPLY MESHING).

4.SET UP(BOUNDARY CONDITIONS)

5.SOLUTION

6.RESULTS

6 Structural Analysis AUV pressure hull: Structure static analysis was done on the pressure hull for external pressure of 65 bars to determine the stresses and deflections. The ends of the pressure hull are fixed in all dof and the external pressure of 65bars is applied on the shells of the pressure hull. The boundary conditions and loading applied on the pressure hull is shown in the figure.

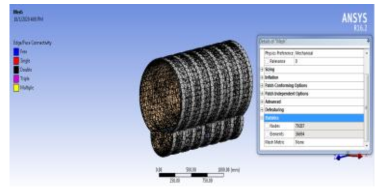

Figure 5 MESHING IN ANSYS WORKBENCH

Maximum number of Nodes: 79287 and Elements: 36694

6.1 BOUNDARY CONDITIONS:

Pressure hull fixed at the two ends and applied hydro statc pressure outside of the pressure vessel

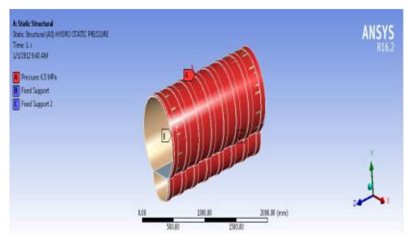

Figure 6 Boundary conditions in ansys workbench

7 RESULTS AND DISCUSSIONS

The constructed AUV pressure hull designed in catia is analyzed using ANSYS V16.0 and the results are depicted below. Fixed at two ends and applied pressure 65 bars. The structural analysis of Sandwich materials with different layers like 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V, 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V, 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel, 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel are done we are taking load conditions are fixed at two Ends and applied hydro static pressure at out side of the pressure hub results are obtained for Equivalent (Von-Mises) stress, shear

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stress, total deformation . These results are obtained as shown below figures.

7.1 2.5MM C40 STEEEL+1MM RUBBER+2.5MM C40 STEEL MATERIAL:

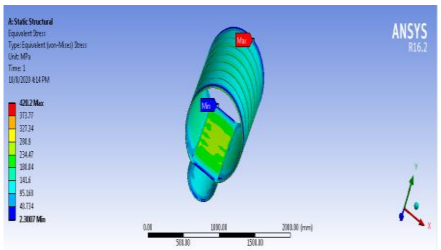

Figure 7 Von-misses stress of 2.5MM C40 STEEL+1MM RUBBER+2.5MM C40 STEEL MATERIAL

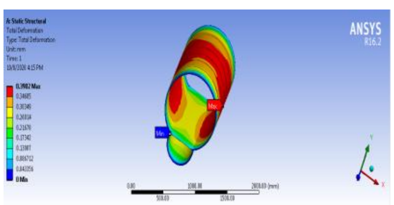

Figure 8 Total deformation of 2.5MM C40 STEEL+1MM RUBBER+2.5MM C40 STEEL MATERIAL

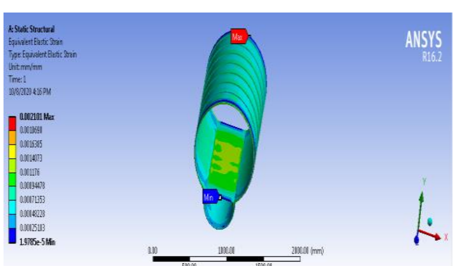

Figure 9 Strain of 2.5MMC40 STEEL+1MM RUBBER+2.5MM C40 STEEL MATERIAL

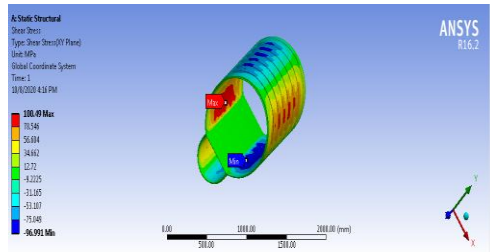

Figure 10 Shear stress of 2.5MM C40 STEEL+1MM RUBBER+2.5MM C40 STEEL MATERIAL

8 MODAL ANALYSIS:

Here find out the Total deformations with different frequencies, we are consider totally 3 modes as shown below graph

8.1 2mm C40Steel + 2mm Rubber +2mm C40Steel:

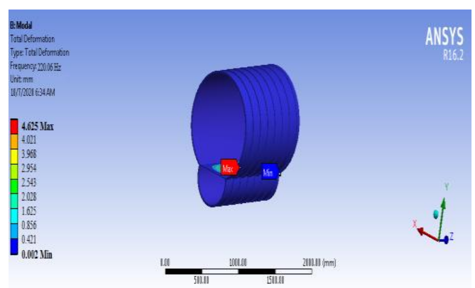

Figure 11 Mode 1 of 2mm C40Steel + 2mm Rubber +2mm C40Steel material

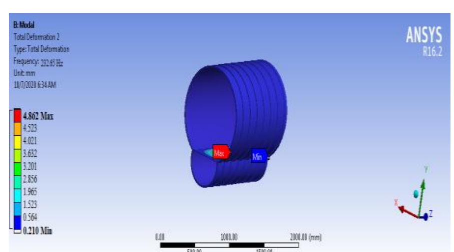

Figure 12 Mode 2 of 2mm C40Steel + 2mm Rubber +2mm C40Steel material

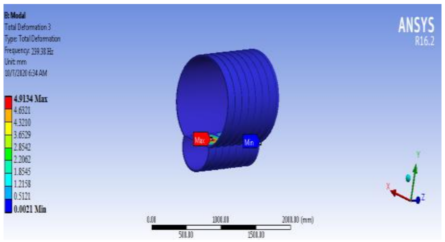

Figure 13 Mode 3 of 2mm C40Steel + 2mm Rubber +2mm C40Steel material

9 GRAPHS:

9.1 VON-MISES STRESS GRAPH:

We can observe that in case of equivalent (von-mises) stress, Sandwich materials with different layers like 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V, 2mm Ti-6Al-4V + 2mm Rubber + 2mm Ti-6Al-4V, 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel, 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel. Finally concluded the 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V is the less Von-misses stress compared with remaining materials.

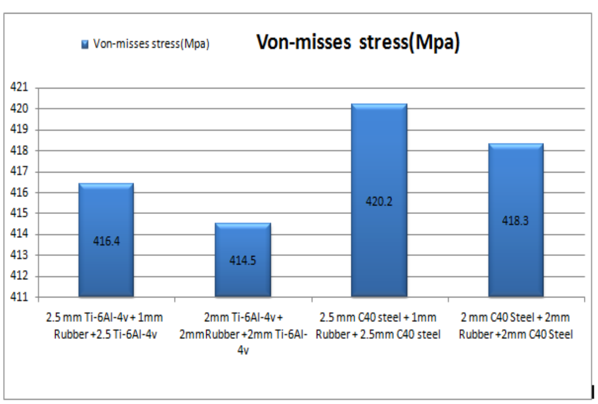

Figure 14 Von-misses stress graph

9.2 TOTAL DEFORMATION GRAPH:

We can observe that in case of Total deformation, Sandwich materials with different layers like 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V, 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V, 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel, 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel. Finally concluded the 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V is the less Total deformation compared with remaining materials.

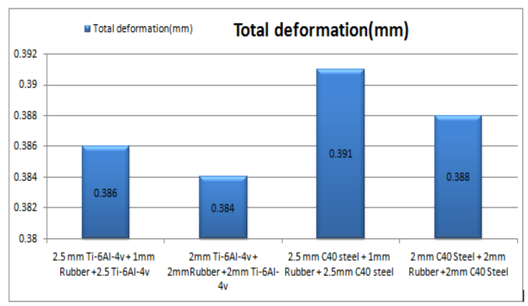

Figure 15 Total deformation graph

9.3 STRAIN GRAPH

We can observe that in case of Strain, Sandwich materials with different layers like 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V, 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V, 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel, 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel. Finally concluded the 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V is the less Strain compared with remaining materials.

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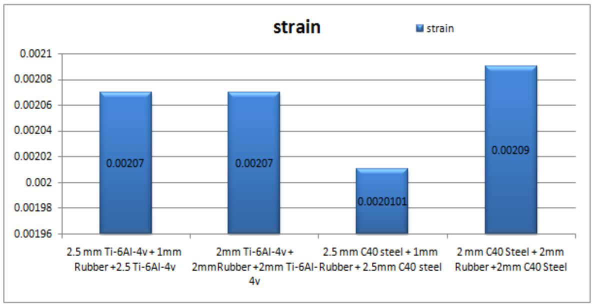

Figure 16 Strain graph

9.4 SHEAR STRESS GRAPH

We can observe that in case of equivalent Shear stress, Sandwich materials with different layers like 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V, 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V, 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel, 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel. Finally concluded the 2mm Ti-6Al-4V + 2mm Rubber + 2mmTi-6Al-4V is the less Shear stress compared with remaining materials.

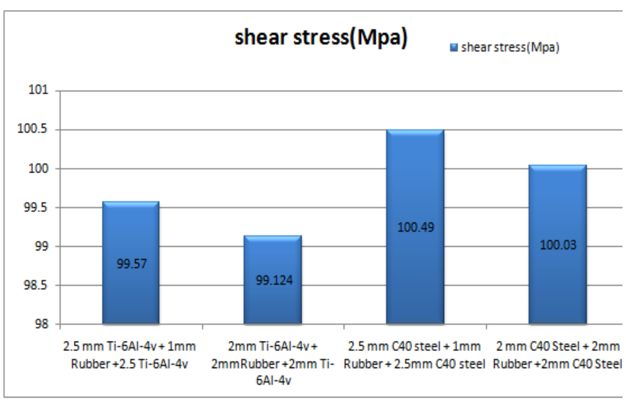

Figure 17 Shear stress graph

9.5 MODAL ANALYSIS GRAPH:

The graph drawn between the different modes of different Frequencies at different deformation as shown below graphs.

9.4.1 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel MATERIAL:

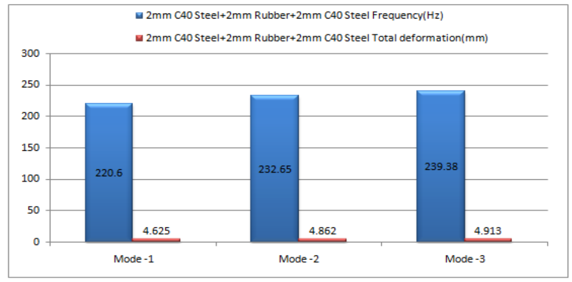

Figure 18 Modal analysis graph of 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel MATERIAL

9.4.2 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel MATERIAL:

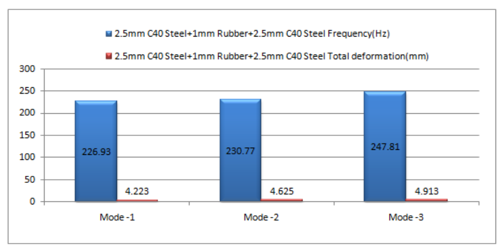

Figure 19 Modal analysis graph of 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel MATERIAL

9.4.3 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V MATERIAL:

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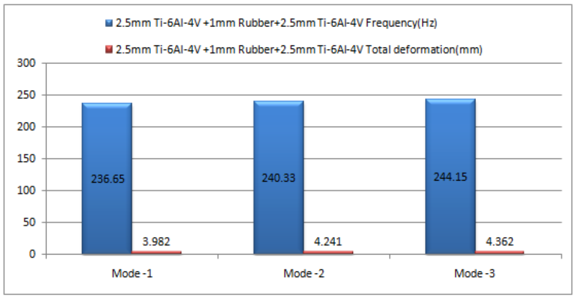

Figure 20 Modal analysis graph of 2.5mm Ti-6Al-4V + 1mm Rubber + 2.5mm Ti-6Al-4V MATERIAL:

9.4.4 2mm Ti-6Al-4V + 2mm Rubber + 2mm Ti-6Al-4V MATERIAL:

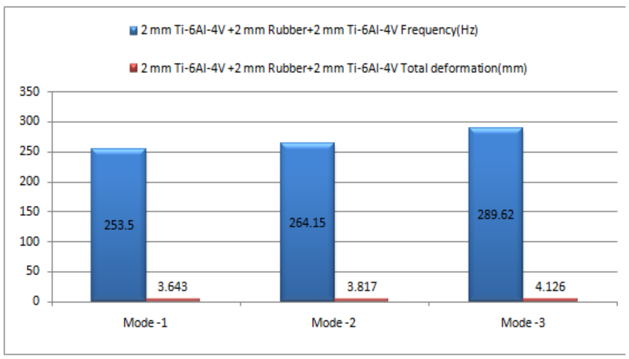

Figure 21 Modal analysis graph of 2mm Ti-6Al-4V + 2mm Rubber + 2mm Ti-6Al-4V MATERIAL

10 CONCLUSION

An autonomous underwater vehicle (AUV) is a robot that travels underwater without requiring input from an operator. AUVs constitute part of a larger group of undersea systems known as unmanned underwater vehicles, Design and analysis of AUV Pressure hull, perform the static and modal analysis . Design of AUV pressure hull using catia software and analysis using Ansys software using sandwich material ,In this project taken total 4 cases sandwich material. CASE 1: 2mm C40Steel + 2mm Rubber +2mm C40Steel, CASE 2: 2.5mm C40Steel + 1mm Rubber +2.5mm C40Steel, CASE 3 :2mm Ti-6Al-4V + 2mm Rubber +2mm Ti-6Al-4V,CASE 4 : 2.5mm Ti-6Al-4V + 1mm Rubber +2.5mm Ti-6Al-4V.

Finally concluded the 2mm Ti-6Al-4V + 2mm Rubber +2mm Ti-6Al-4V sandwich material is suitable on pressure vessel based on the stresses, strains, deformation, shear stress in static analysis and In modal analysis find out the modes at Total deformation in different Frequency this material is suitable for the pressure hull because of less stresses, strains, deformation, shear stress , better with stand capability in dynamic conditions .

REFERENCES

1. Project thesis of Roberts Tompkins submitted to TAMU University- Visco elastic analysis of Sandwich beam having Aluminum and Fiber reinforced polymer skins with polystyrene foam core- December 2009 2. Y. Swathi and Sd Abdul Kalam, “Sandwich Treatment in FRP beams: Static and Dynamic Response”. IJERT, vol1 9,2012,pp 2-5.

3. Noor AK and Burton WS, “Stress and free vibratuion analysis of multilayered composite panels” Compos Structures, vol11,1989,pp 183-204

4. Frostig Y, Baruch M, Vinley O and Sheinman I, “High order theory for sandwich beam behaviour with transversely flexible core”, J Eng Mech, vol 1 18, 1992, pp1026-1043.

5. Kant T and Swaminathan K, “Analytical solutions for the static analysis of laminated composite and sandwich plates based on a higher order refined

theory", Compos Structures, vol56, 2002, pp. 329-344.
6. Pandit MK, Sheikh AH and Singh BN, " Analysis of laminated sandwich plates based on improved higher order zig zag theory", J Sandwich Struct Mater, Vol 12 2010, pp.307- 326.

7. K.Malekzadeh, M. R. Khalili and R.K. Mittal, "Local and Global Damped Vibrations of Plates with a viscoelastic soft flexible core: An improved high order approach" , Journal of sandwich structures and materials, vol7 2005,pp 431.

8. Ju F, Lee HP, Lee KH, "Finite element analysis free vibration of delaminated composite plates". Compose Eng 1995,5(2), pp,195-209.

9. Ahrari, E. (2010) 'Transformation of America's Military and Asymmetric War', Comparative Strategy, 29 (3), pp. 223 - 244.

10. Andrewieb. (2010). Element Aspect Ratio. Available: http://andreweib.wordpress.com/2010/12/14/element-aspectratio/. Last accessed 20 April 2011.

11.British Standards Institution. (2009) 'PD 5500'.[in Specification for unfired fusion welded pressure vessels. London: BSI.

12. Burcher, R. & Rydill, L. (1994) Concepts in submarine design. Cambridge ocean technology series. Cambridge University Press.

13 FAS. (1999). Dry Deck Shelters—Deploying Special Operations Forces from Submarines. Available: http://www.fas.org/man/dod-101/sys/ship/docs/990100-drydeck.htm. Last accessed 20 April 2011.

14. 'Fewer dragons, more snakes' (2010), Economist, 397 (8708), pp. 27-30.

15. Freedman, L. (1998) 'The changing forms of military conflict', Survival, 40 pp. 39-56.

16. Geiger, V. (2009) 'The Submarine as a Potent Weapon For Littoral Water Operations'. www.sea-technology.com. [Online]. Available at: http://sea-technology.com/features/2009/1109/submarine_littoral.html. Last accessed 20 April 2011.

17.Germanischer Lloyd. (2007). World's First Submarine in Class. Available: http://www.glgroup.com/pdf/bravo_zulu_2007-01_E.pdf. Last accessed 20 April 2011.

18. Germanischer Lloyd. (2008) 'Rules for Classification and Construction - Naval Ship Technology'.[in Hamburg: Germanischer Lloyd.

19 Graham, D. (2007) 'Predicting the collapse of externally pressurised ring-stiffened cylinders using finite element analysis', Marine Structures, 20 (4), pp. 202-217.

20 Hoffman, F. G. (2006) 'Complex Irregular Warfare: The Next Revolution in Military Affairs', Orbis, 50 (3), pp. 395- 411.

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