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Simulation of AUW Robotic vehicle body using FEA method

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ABSTRACT

An Autonomous Underwater Robotic Vehicle (AUWRV) is a robot that travels underwater without requiring input from an operator. AUWRVs constitute part of a larger group of undersea systems known as unmanned underwater vehicles, the structure of an Autonomous Underwater Robotic Vehicle (AUWRV), usually composed of a cylindrical shell, may be exposed to high hydrostatic pressures where buckling collapse occurs before yield stress failure. In conventional submarines, welded stiffeners increase the buckling resistance, however, in small AUWRVs, 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 AUWRV Pressure vessel, proposing the use of sliding stiffeners that are part of the structure used to accommodate the electronics inside it. Design of AUWRV pressure vessel using Catia software and analysis using Ansys software using sand which beam material in this project taken total 4 cases.

CASE 1: 2mm Steel + 2mm Rubber +2mm Steel
CASE 2: 2.5mm Steel + 1mm Rubber +2.5mm Steel
CASE 3 :2mm Ti64Al + 2mm Rubber +2mm Ti64Al
CASE 4: 2.5mm Ti64Al + 1mm Rubber +2.5mm Ti64Al

Finally concluded the which 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

KEYWORDS: AUWRV, ANSYS, CATIA, Analysis, Materials

1. INTRODUCTION

1.1INTRODUCTION OF AUTONOMOUS UNDERWATER ROBOTIC VEHICLE (AUWRV)

Autonomous Underwater Vehicles (AUWRVs) 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 AUWRVs communicate with operators periodically or continuously through satellite signals or underwater acoustic beacons to permit some level of control.

AUWRVs 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 AUWRVs can also make decisions on their own, changing their mission profile based on environmental data they receive through sensors while under way.

The first AUWRV 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, 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, which holds the difference between outside and inside pressure.

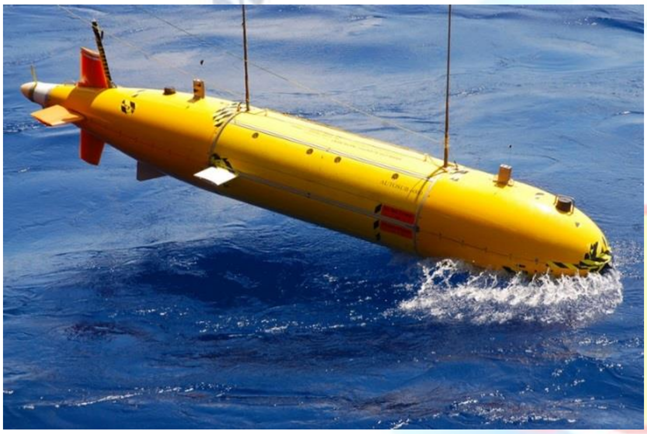

Figure 1: Autonomous Underwater Robotic Vehicles

1.2 PRESSURE HULL

Inside the outer hull there is a strong hull, or pressure hull, which actually withstands the outside pressure and has normal atmospheric pressure inside. The pressure hull is generally constructed of thick high-strength steel with a complex structure and high strength reserve, and is separated with watertight bulkheads into several compartments. The pressure and light hulls aren't separated, and form a three-dimensional structure with increased strength. The inter hull space is used for some of the equipment which doesn't require constant pressure to operate. The list significantly differs between submarines, and generally includes different water/air tanks. In case of a single-hull submarine, the light hull and the pressure hull are the same except for the bow and stern. The constructions of a pressure hull require a high degree of precision. This is true irrespective of its size. Even a one inch (25 mm) deviation from cross-sectional roundness results in over 30 percent decrease of hydrostatic load. Minor deviations are resisted by the stiffener rings, and the total pressure force of several million longitudinally oriented tons must be distributed evenly over the hull by using a hull with circular cross section.

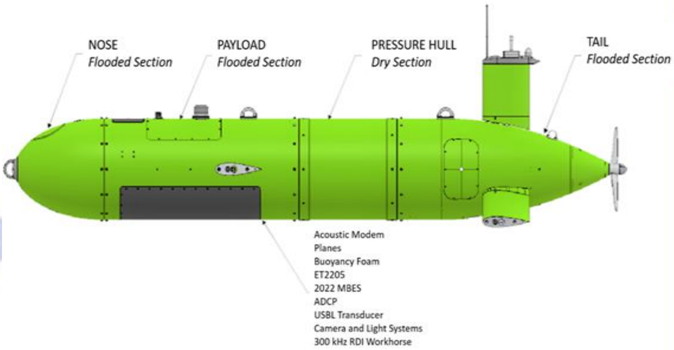

Figure 2 :Outer part of AUWRV

1.3 PARTS OF AUWRV

There are several aspects in AUWRV electrical and mechanical design need to be looked at closely so that the design will be successful. In order to design any underwater vehicle AUWRV, 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.

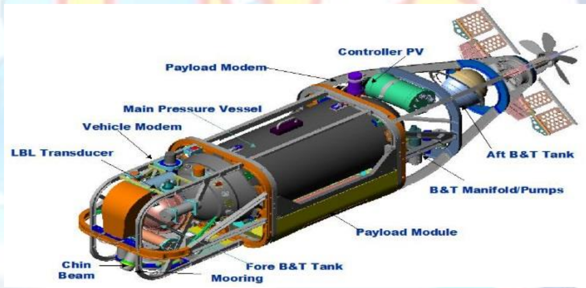

Figure 3 : Parts of AUWRV

1.4 APPLICATIONS

1. The oil and gas industry uses AUWRVs to make detailed maps of the seafloor before they start building subsea infrastructure; pipelines and subsea completions can be installed in the most cost-effective manner with minimum disruption to the environment.
2. A typical military mission for an AUWRV is to map an area to determine if there are any mines, or to monitor a protected area (such as a harbor) for new unidentified objects. AUWRVs are also employed in anti-submarine warfare, to aid in the detection of manned submarines.
3. Scientists use AUWRVs to study lakes, the ocean, and the ocean floor. A variety of sensors can be affixed to AUWRVs to measure the

concentration of various elements or compounds, the absorption or reflection of light, and the presence of microscopic life.

4. Autonomous Underwater Vehicles are today a vital part of marine geosciences. They have eliminated so many challenges to exploring the underwater and have made a lot of difficult underwater tasks easier. They, however, cannot operate with 100% efficiency in some areas. Some areas prove to be more violence and overpower the AUWRV in the tide. For instance,

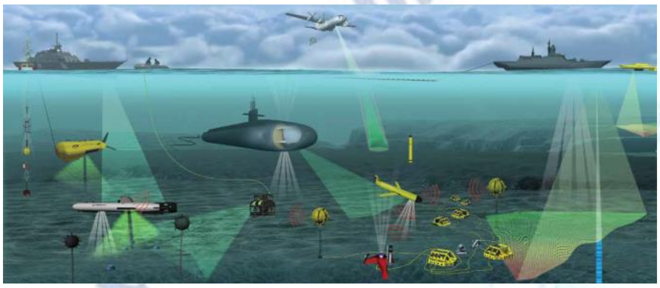

Figure 4 Various applications of Autonomous Under water vehicle

2. METHODOLOGY

- Design of pressure hull done using CATIA & CAD software. Design of pressure hull completed based on ISO standard drawing sheet.
- These stresses are calculated for Four different materials of pressure hulls .
- Pressure hull design imported in Ansys software for analysis purpose. Structural analysis of hull done for and different material types (steel, Ti6al4v).
- Perform the static and modal analysis
- Consider the 65 bar applied the external because of this is the hydro static pressure.
- From these results, concluded the suitable pressure hull proposed under radial pressure conditions with 4 materials.
- with a length of 1000mm were developed in ANSYS 17.0. a) Rules of Mixture adopted to find the material properties like tensile strength, elastic modulus, density etc.
- Different composites used to investigate their failure criteria to provide optimum strength. The basic details like cross sectional dimensions, number of stiffeners used are kept constant for all models.

2.2 SCOPE OF THE PROJECT:

1. Study the different Journals Related to the AUWRV, 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.

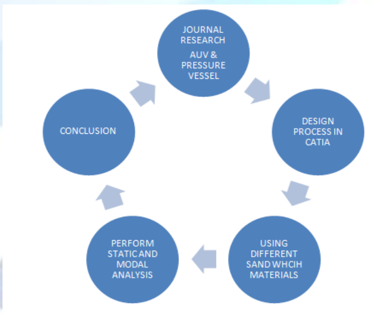

FIGURE 5:SCOPE OF THE PROJECT

2.3 DESIGN SPECIFICATIONS OF PRESSURE HULL

Length overall = 1.8 m.

Pressure hull diameter = 0.4 m.

Layout = double diameter ring stiffened cylinder.

Submerged displacement =1015 tones.

Thickness of the pressure vessel =6mm

TABLE 1: MATERIAL PROPERTIES

3. MODELLING OF PRESURE HULL IN CATIA

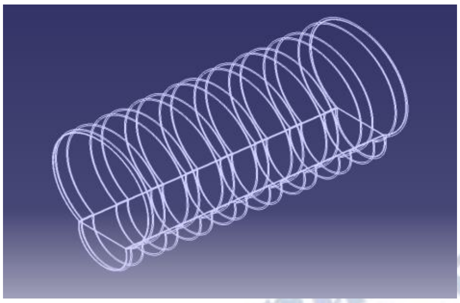

FIGURE6 : PRESSURE HUB IN WIRE FRAME VIEW

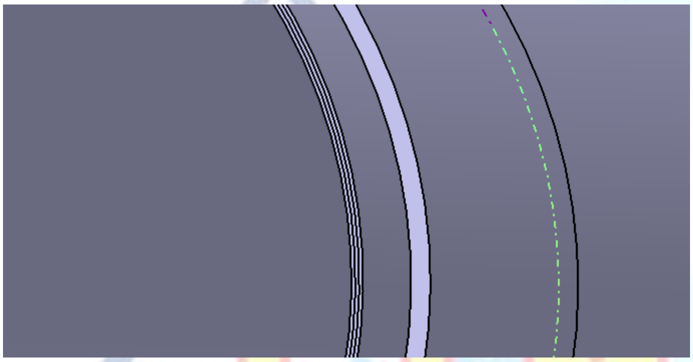

FIGURE 7: LAYER BY LAYER SAND WHICH MATERIAL

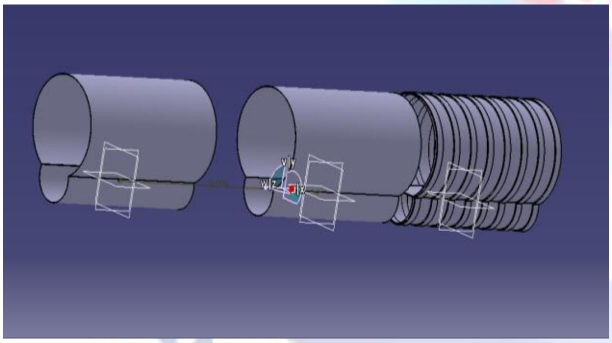

FIGURE 8: EXPLODED VIEW IN ASSEMBLY WORKBENCH

FIGURE 9: MULTI VIEW IN CATIA WORKBENCH

4. ANALYSIS OF 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 @ 6.5Mpa is applied on the shells of the pressure hull. The boundary conditions and loading applied on the pressure hull is shown in the figure.

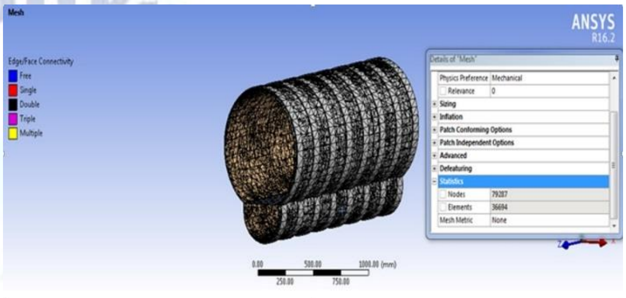

FIGURE 10: MESH IN ANSYS WORKBENCH NODES:79287, ELEMENTS:36694

MATERIAL PROPERTIES	Density(g/cm3)	Possion's ratio(μ)	Young's Modulus (Gpa)
Ti-6Al-4v	4.429	0.30	206
C40 Steel	7.80	0.29	200
Rubber-Core	1.10	0.48	0.2

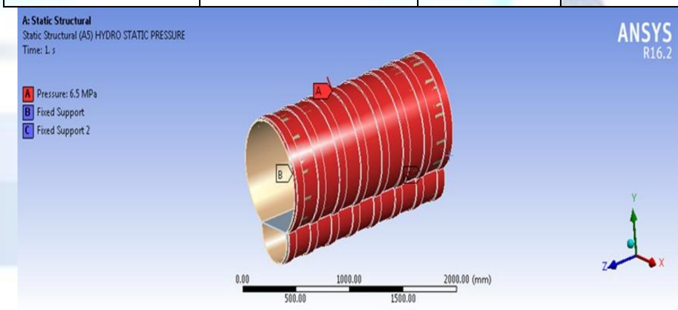

FIGURE 11: BOUNDARY CONDITIONS IN STATIC

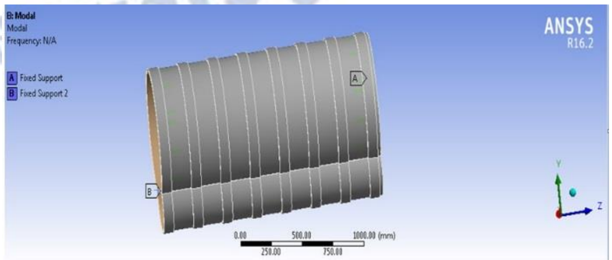

FIGURE 12: BOUNDARY CONDITIONS IN MODAL

5. RESULTS AND DISCUSSION

Structure static and modal analysis was done on the pressure hull for external pressure of 65 bars to determine the stresses and deformations. 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.

5.1 2.5MM C40 STEEEL+1MM RUBBER+2.5MM C40 STEEL MATERIAL:

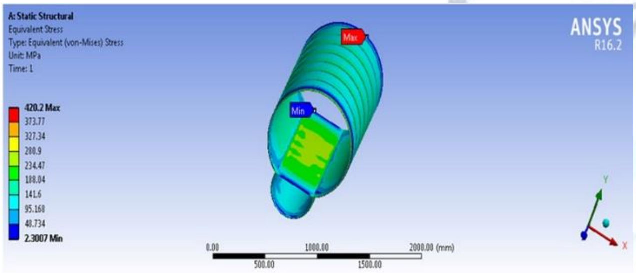

FIGURE 13: VON-MISSES STRESS OF C40 STEEEL+1MM RUBBER+2MM C40 STEEL MATERIAL

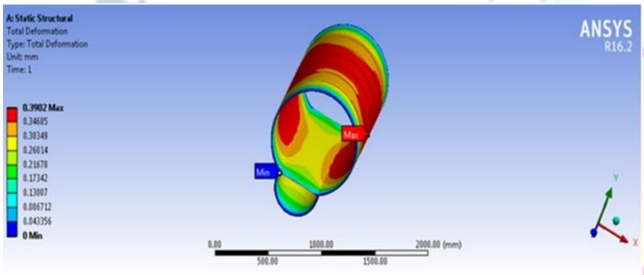

FIGURE 14: TOTAL DEFORMATION OF C40 STEEEL+1MM RUBBER+2MM C40 STEEL MATERIAL

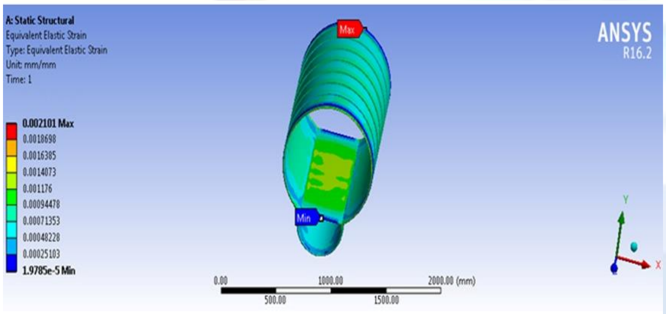

FIGURE 15: STRAIN OF C40 STEEL+1MM RUBBER+2MM C40 STEEL MATERIAL

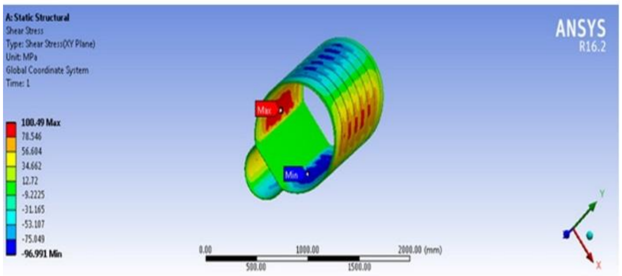

FIGURE 16: SHEAR STRESS OF C40 STEEEL+1MM RUBBER+2MM C40 STEEL MATERIAL

5.2 2MM C40 STEEL+2MM RUBBER+ 2MM C40 STEEL MATERIAL:

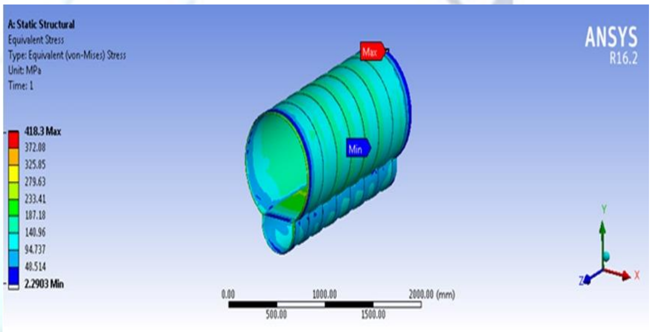

FIGURE 17: VON-MISSES STRESS OF 2MM C40 STEEL+2MM RUBBER+ 2MM C40 STEEL

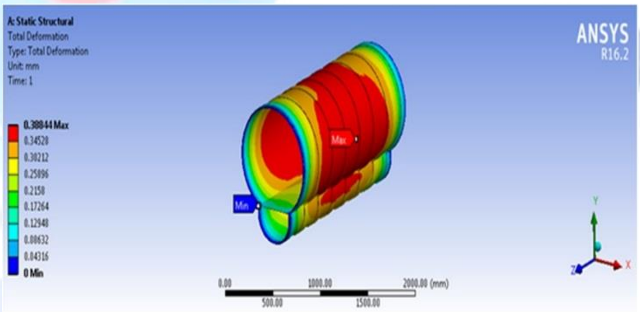

FIGURE 18: TOTAL DEFORMATION OF 2MM C40 STEEL+2MM RUBBER+ 2MM C40 STEEL

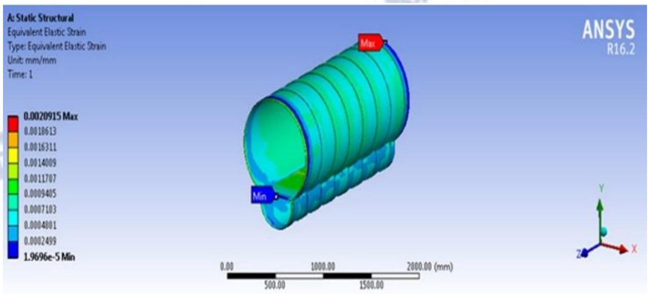

FIGURE 19: STRAIN OF 2MM C40 STEEL+2MM RUBBER+ 2MM C40 STEEL MATERIAL

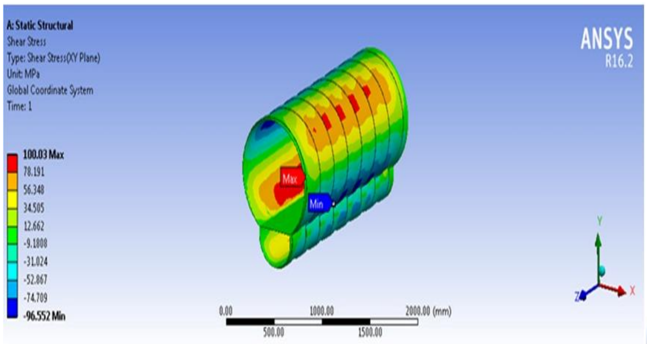

FIGURE 20: SHEAR STRESS OF 2MM C40 STEEL+2MM RUBBER+ 2MM C40 STEEL MATERIAL

5.3 2.5MM TI-6AL-4V +1MM RUBBER +2.5MMTI-6AL-4V:

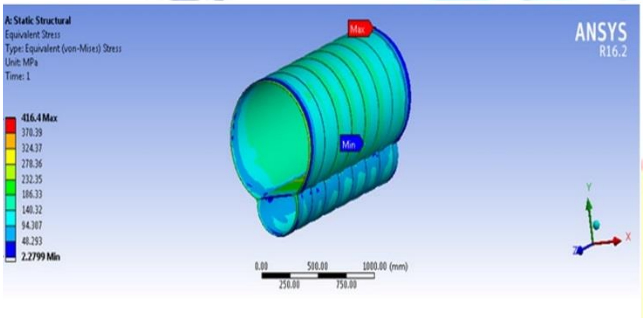

FIGURE 21: VON-MISSES STRESS OF 2.5MM TI-6AL-4V +1MM RUBBER +2.5MMTI-6AL-4V

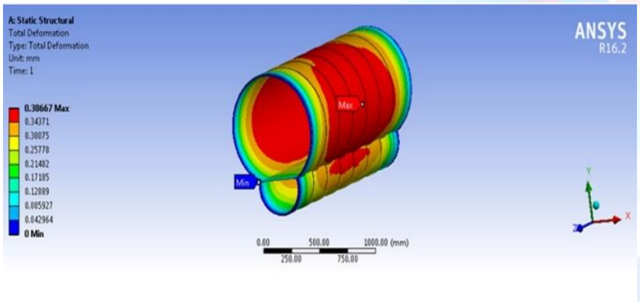

FIGURE 22: TOTAL DEFORMATION OF 2.5MM TI-6AL-4V +1MM RUBBER +2.5MMTI-6AL-4V

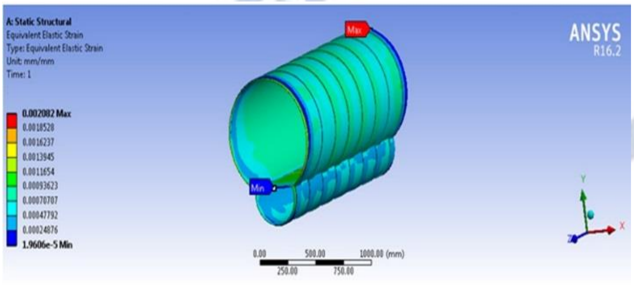

FIGURE 23: STRAIN OF 2.5MM TI-6AL-4V +1MM RUBBER +2.5MMTI-6AL-4V

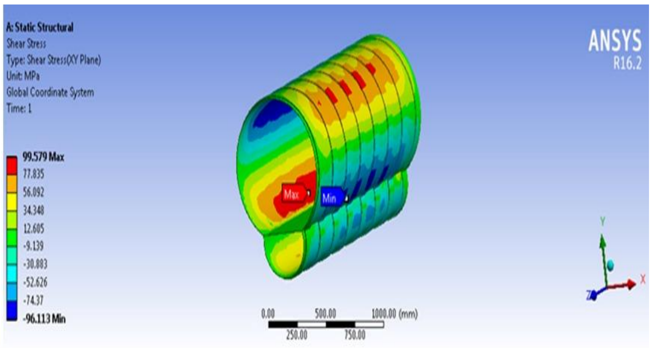

FIGURE 24: SHEAR STRESS OF 2.5MM TI-6AL-4V +1MM RUBBER +2.5MMTI-6AL-4V

5.4 2MM TI-6AL-4V +2MM RUBBER +2MMTI-6AL-4V:

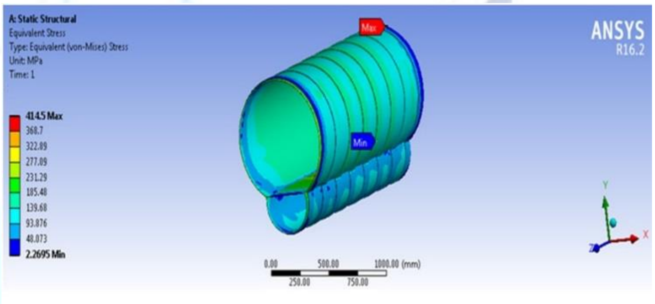

FIGURE 25: VON-MISSES STRESS OF 2MM TI-6AL-4V +2MM RUBBER +2MMTI-6AL-4V

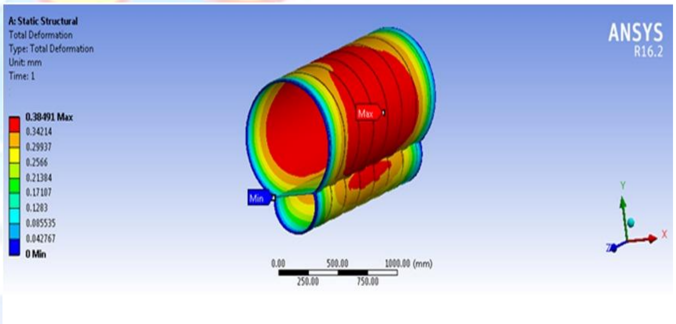

FIGURE 26: TOTAL DEFORMATION OF 2MM TI-6AL-4V +2MM RUBBER +2MMTI-6AL-4V

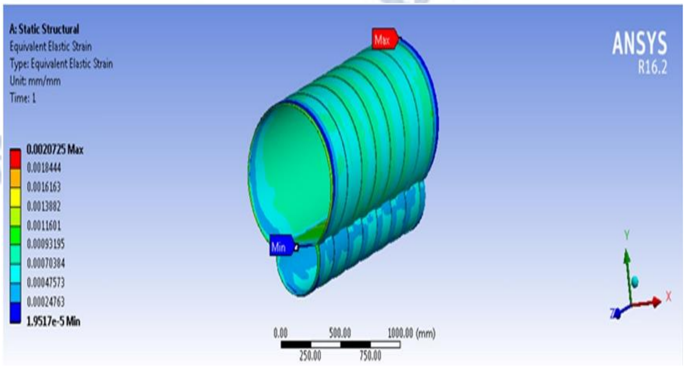

FIGURE 27: STRAIN OF 2MM TI-6AL-4V +2MM RUBBER +2MMTI-6AL-4V

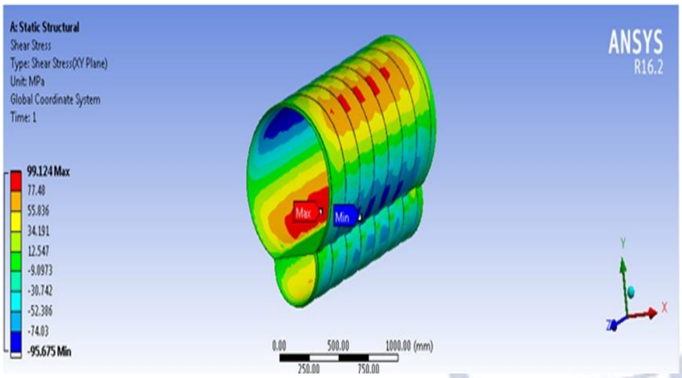

FIGURE 28: SHEAR STRESS OF 2MM TI-6AL-4V +2MM RUBBER +2MMTI-6AL-4V

5.5 MODAL ANALYSIS:

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

5.6 Modal analysis of 2mm Steel + 2mm Rubber +2mm Steel

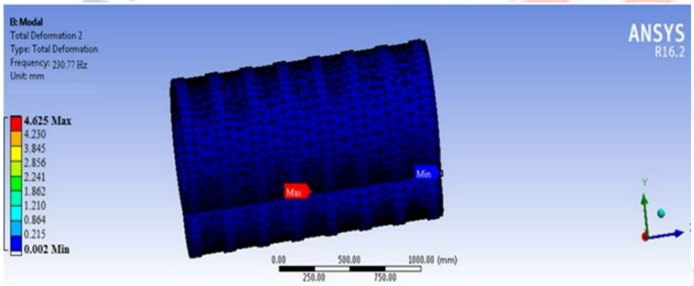

FIGURE 29: MODE 1 OF 2MM STEEL + 2MM RUBBER +2MM STEEL MATERIAL

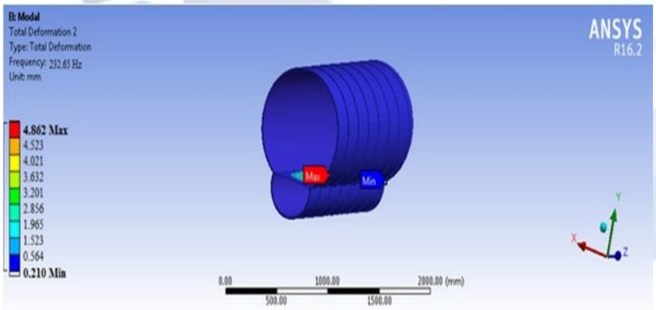

FIGURE 30: MODE 2 OF 2MM STEEL + 2MM RUBBER +2MM STEEL MATERIAL

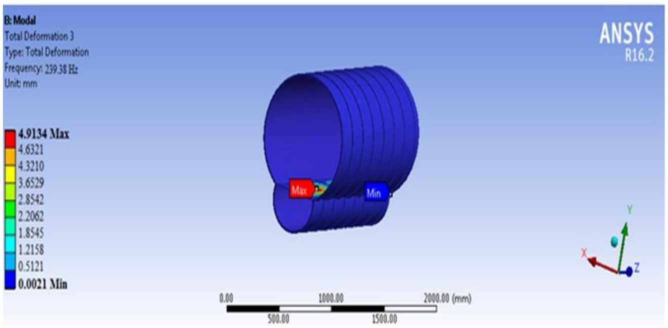

FIGURE 31: MODE 3 OF 2MM STEEL + 2MM RUBBER +2MM STEEL MATERIAL

5.7 2.5mm Steel + 1mm Rubber +2.5mm Steel:

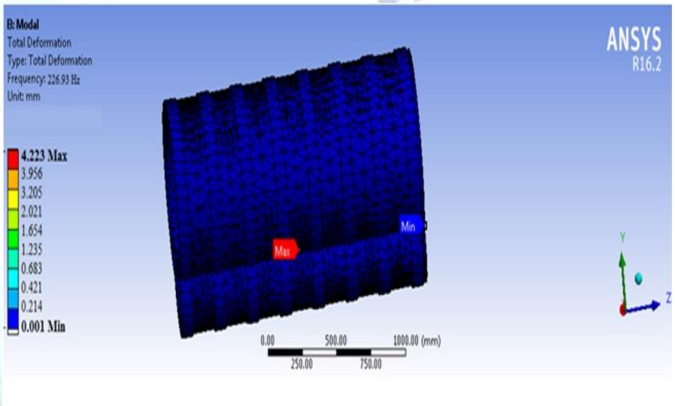

FIGURE 32: MODE 1 OF 2.5MM STEEL + 1MM RUBBER +2.5MM STEEL

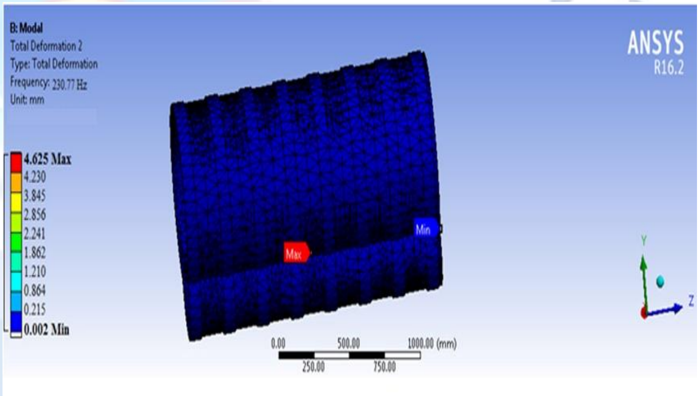

FIGURE 33: MODE 2 OF 2.5MM STEEL + 1MM RUBBER +2.5MM STEEL

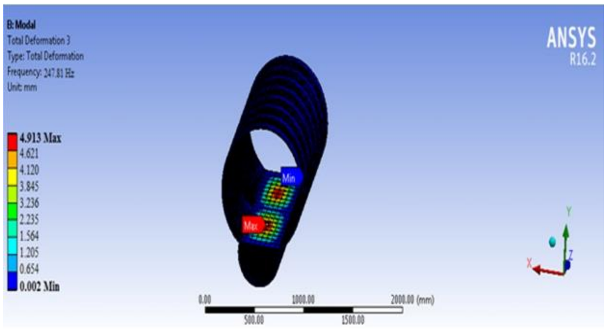

FIGURE 34: MODE 3 OF 2.5MM STEEL + 1MM RUBBER +2.5MM STEEL

5.8 2MM TI-6AL-4V + 2MM RUBBER + 2MM TI-6AL-4V:

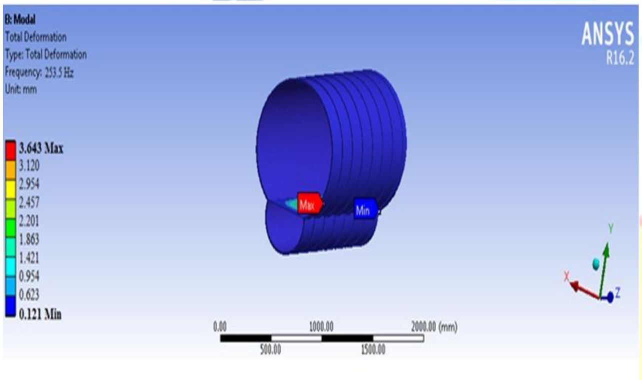

FIGURE 35: MODE 1 2MM TI-6AL-4V + 2MM RUBBER + 2MM TI-6AL-4V

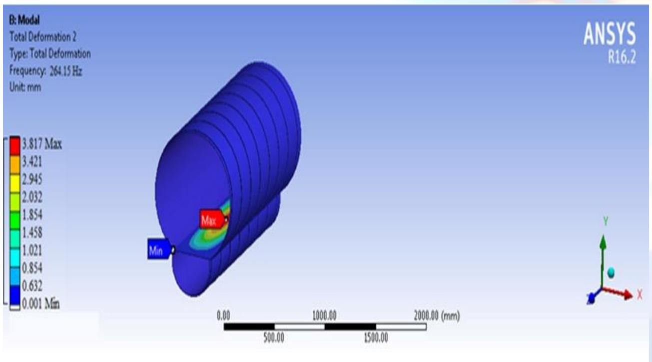

FIGURE 36: Mode 2 2MM TI-6AL-4V + 2MM RUBBER + 2MM TI-6AL-4V

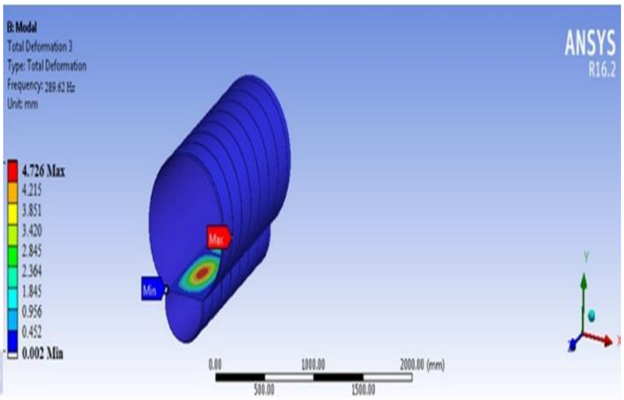

FIGURE 37: Mode 3 2MM TI-6AL-4V + 2MM RUBBER + 2MM TI-6AL-4V

5.9 7.5.4 2.5mm Ti-6Al-4V + 1mm Rubber +2.5mm Ti-6Al-4V:

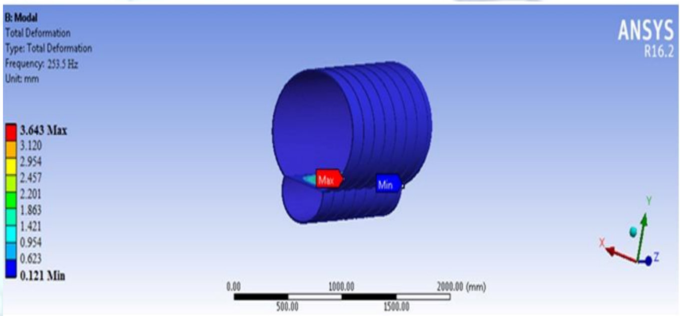

FIGURE 38: MODE 1 2.5MM TI-6AL-4V + 1MM RUBBER +2.5MM TI-6AL-4V

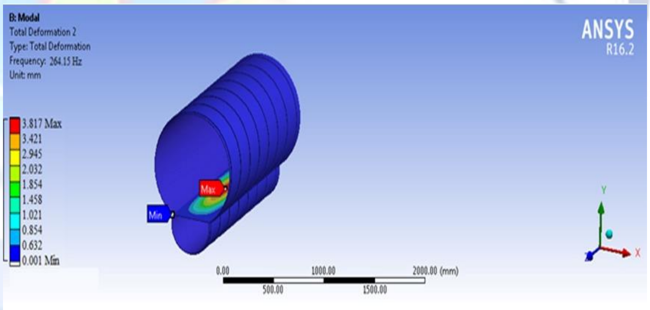

Figure 39: MODE 2 2.5MM TI-6AL-4V + 1MM RUBBER +2.5MM TI-6AL-4V

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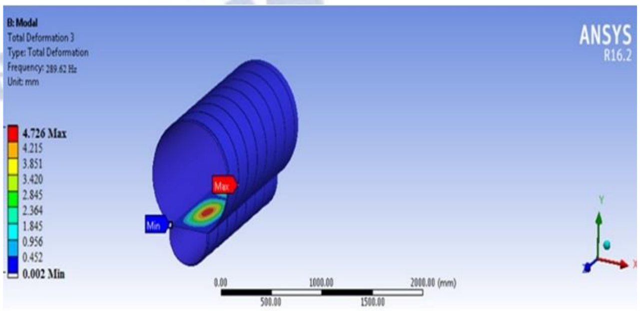

Figure 40: Mode 3 2.5MM TI-6AL-4V + 1MM RUBBER +2.5MM TI-6AL-4V

5.10 GRAPHS

The static structural analysis of Sand which materials with different layers like 2.5mm Ti-6Al-4v + 1mm Rubber + 2.5Ti-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 outside of the pressure hub results are obtained for Equivalent (Von-Mises) stress, shear stress, total deformation. These results are plotted graphically and a comparison is made between these results.

5.10.1 VON-MISES STRESS GRAPH:

We can observe that in case of equivalent (von-mises) stress, Sand which materials with different layers like 2.5mm Ti-6Al-4v + 1mm Rubber + 2.5Ti-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 Von-misses stress compared with remaining materials.

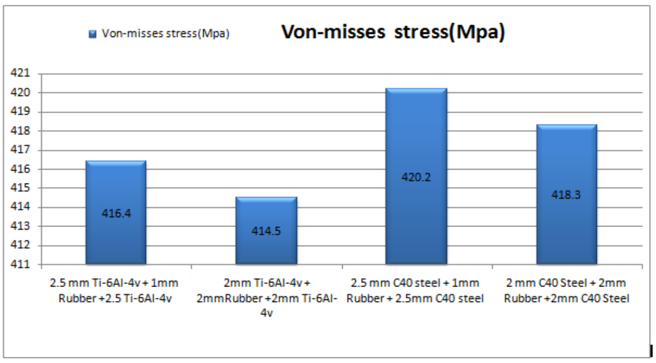

FIGURE 41: VON-MISSES STRESS GRAPH

5.10.2 TOTAL DEFORMATION GRAPH:

We can observe that in case of Total deformation, Sand which materials with different layers like 2.5mm Ti-6Al-4v + 1mm Rubber + 2.5Ti-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.

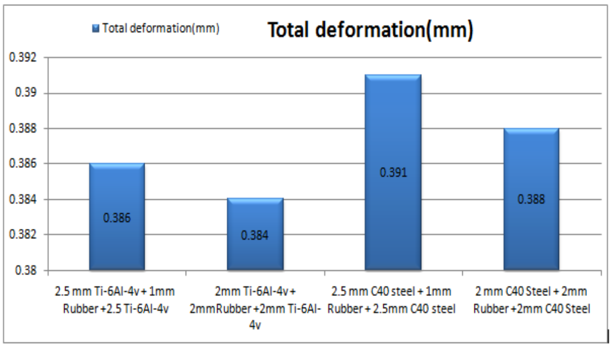

FIGURE 42: TOTAL DEFORMATION GRAPH

5.10.3 STRAIN GRAPH

We can observe that in case of Strain, Sand which materials with different layers like 2.5mm Ti-6Al-4v + 1mm Rubber + 2.5Ti-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.

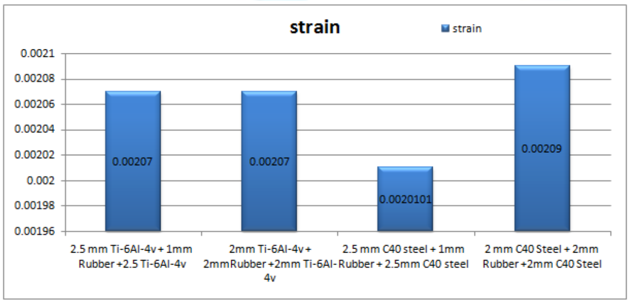

FIGURE 43: STRAIN GRAPH

5.10.4 SHEAR STRESS GRAPH

We can observe that in case of equivalent Shear stress, Sand which materials with different layers like 2.5mm Ti-6Al-4v + 1mm Rubber + 2.5Ti-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.

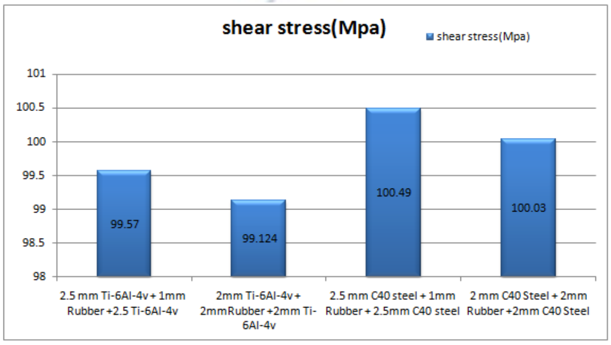

FIGURE 44: SHEAR STRESS GRAPH

5.10.5 MODAL ANALYSIS GRAPH:

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

7.7.1 2mm C40 Steel + 2mm Rubber + 2mm C40 Steel Material:

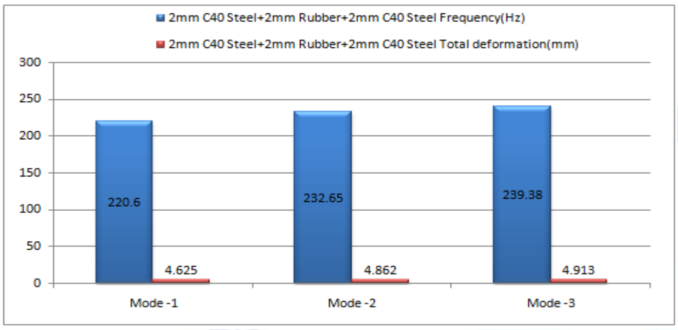

FIGURE 45: MODAL ANALYSIS OF 2MM C40 STEEL + 2MM RUBBER + 2MM C40 STEEL MATERIAL

5.10.6 2.5mm C40 Steel + 1mm Rubber + 2.5mm C40 Steel Material:

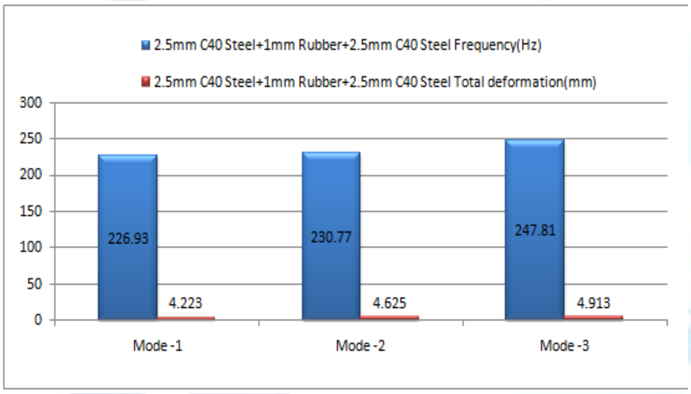

FIGURE 46: MODAL ANALYSIS OF 2.5MM C40 STEEL + 1MM RUBBER + 2.5MM C40 STEEL MATERIAL

5.10.7 2.5mm Ti-6Al-4v + 1mm Rubber + 2.5Ti-6Al-4V Material:

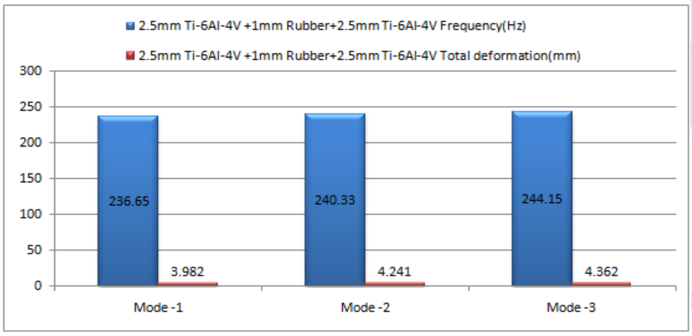

FIGURE 47: MODAL ANALYSIS OF 2.5MM TI-6AL-4V + 1MM RUBBER + 2.5TI-6AL-4V MATERIAL

5.10.8 2mm Ti-6Al-4v + 2mm Rubber + 2mmTi-6Al-4V Material:

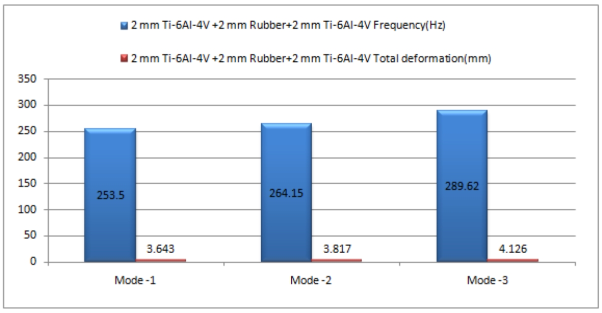

FIGURE 48: MODAL ANALYSIS OF 2MM TI-6AL-4V + 2MM RUBBER + 2MMTI-6AL-4V M

6. CONCLUSION

An Autonomous Underwater Robotic Vehicle (AUWRV) is a robot that travels underwater without requiring input from an operator. AUWRVs constitute part of a larger group of undersea systems known as unmanned underwater vehicles, Design and analysis of AUWRV Pressure vessel, perform the static and modal analysis. Design of AUWRV pressure vessel using Catia software and analysis using Ansys software using sand which beam material, in this project taken total 4 cases sand which beam material. CASE 1: 2mm Steel + 2mm Rubber +2mm Steel, CASE 2: 2.5mm Steel + 1mm Rubber +2.5mm Steel, CASE 3 :2mm Ti64Al + 2mm Rubber +2mm Ti64Al, CASE 4: 2.5mm Ti64Al + 1mm Rubber +2.5mm Ti64Al.

Finally concluded the Ti64Al + 2mm Rubber +2mm Ti64Al sand which 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.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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 vibration analysis of multilayered composite panels” Compos Structures, vol11,1989, pp 183-204
[4] Frosting Y, Baruch M, Vainly O and Scheinman I, “High order theory for sandwich beam behavior 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. Malek Zadeh, 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] Andrewes. (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 pressurized 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.