Design and Analysis of Submarine Radome

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Abstract. Radomes are the electromagnetic windows that protect microwave sub-systems from the environmental effects. The major requirement of radome is its transparency to microwaves and for most of the cases mechanical properties are also equally important. Radome for underwater applications has to withstand high water pressure of the order of 45 bars. Composite materials owing to their high strength to weight ratio, high stiffness and better corrosion resistance are potential source for under water applications. The concept of 'tailoring' the material properties to suit the radome is obtained by selecting proper reinforcement, resin matrix and their compositions. The mechanical properties of composite material, evaluated by testing specimens as per ASTM standards, are utilized in designing the radome. The modulus properties calculated using classical theories of composite materials and compared with test results. ANSYS a Finite Element software package used to analyse the problem. As the cross sectional thickness of radome varies, the complexity in fabrication is overcome by adopting matched die techniques. The radome design and finite element analysis validation concluded by conducting the pressure test on radome. On the design a modal analysis is also carried to check for the natural frequency, So that resonance does not occur if the natural frequency of the radome coincides with the excitation frequency of the submarine Clinical information system (CIS) for UNRWA is a computerized distributed application that used in clinics which follows the United Nations Relief and Works Agency (UNRWA) to manage the clinical requirements and services.

INTRODUCTION

A radome, an acronym coined from radar dome, is a cover or structure placed over an antenna that protects the antenna from its physical environment as shown in fig.1. Radomes are composed of panels, which when assembled form a truncated spherical shell, ideally the radome is radio frequency (RF) transparent so that it does not degrade the electrical performance of the enclosed antenna in any way. Today radome find wide applications in ground, maritime, terrestrial (ground), vehicular, aircraft, and missile electronic systems. Radomes can be constructed in several shapes (spherical, geodesic, planar, etc.) depending upon the particular application using various construction materials. Radome design is uniquely challenging in that the performance parameters are generally in direct conflict with each other and the design must be iterated until all competing parameters are optimally satisfied. This design process is a compromise between electrical transparency and mechanical strength. There are many dielectric material options, each with their unique properties, including electrical properties, mechanical properties, environmental resistance, and cost. Finally, the radome design must be evaluated from a manufacturing standpoint.

FIGURE. 1 Radome with antenna

The increased power of modern computers allows a radome designer to evaluate designs in a manner that was not previously possible, such as designs with frequency selective materials, low observable treatments, or meta-materials. In analysing radome electrical performance, it is important to evaluate the electrical properties of possible radome wall materials at various wavelengths. The primary electrical properties of candidate materials are the relative dielectric constant and the loss tangent of the candidate materials at the operational frequencies of the radome. The structural (aeromechanical) and environmental requirements determine other parameters for a candidate radome material and include Mechanical properties, such as flexural moduli, strength, and hardness; Material density; Water absorption; Rain erosion (particle impact) resistance; The variation of both the mechanical and electrical parameters of the material due to temperature variations[8]. Common radome shapes include, but are not limited to the following Hemisphere; Secant ogive; Tangent ogive; from an electrical viewpoint, a hemisphere is most desirable because of its very small incidence angles resulting in small electrical degradations [1].

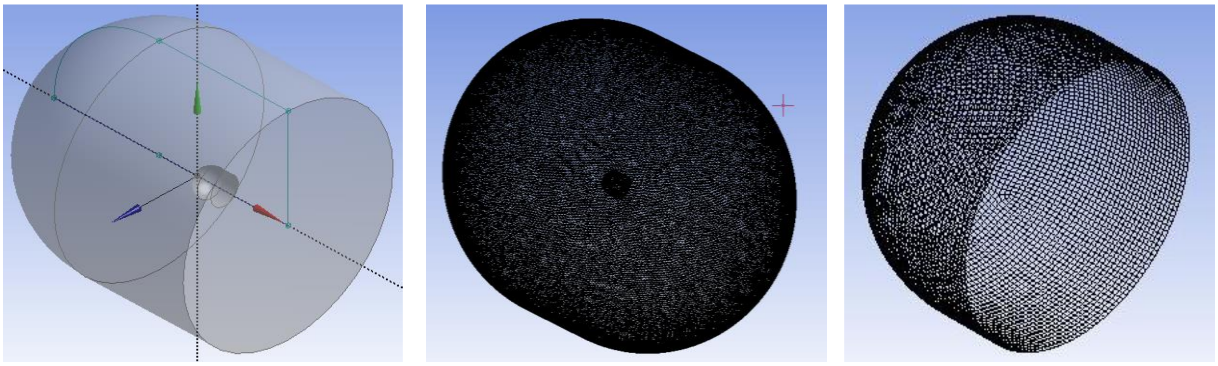
The radome protects the installation from the deteriorating effects of environment and extends the durability of antenna and other equipment. The overall performance of the antenna will be increased with the use of radome. A radome helps to have overall economy and weight reduction and permits the air borne antenna to function with good efficiency under high head of the water over the submarine.

The selection of a manufacturing method for a given Radome design may be based on a number of factors including the Radome performance requirements and the materials of construction. For example selection of a fabrication method for a Radome often starts by the consideration of Vacuum bag or Autoclave moulding using glass fabric reinforcement. Frequency requirements for maintaining uniform electrical properties in the Radome wall might eliminate the less expensive fabrication methods and dictate a filament winding approach whereby this control is more readily accomplished.

SIMULATION METHODOLOGY

It has been conceived aiming at providing reader with the under water bodies applications with the essentials of numerical techniques developed for characterizing the dynamic behaviour of structural systems. Finite element analysis has several methods for solving given problems. The direct approach is only able to solve elementary problems, which is based on the stiffness matrix for structural analysis. This method is even though effective for elementary problems, can be utilized to solve more complex one. This is accomplished by breaking down the complex geometry into elementary problems, with emphasis being placed on nodes that intersect. By utilizing this concept the designer/ engineer is able to determine a stiffness matrix for the give part of that structure. Then by combining the matrices of the parts, the stiffness of the entire structure can be determined. This method has become known as the direct stiffness method and was the first method utilized for solving finite analysis. In this work, environmental and energy-related aspects, have given the subject of concern, which are frequently in relation with structural dynamics. The technique of modal analysis is like, the equations of motion (EOM), which are originally expressed in physical coordinates, are transformed to modal coordinates using the eigenvalues and eigenvectors by solving the undammed frequency Eigen problem[2]. The structure with of the radome is analysed by discretized with a number of elements and then assembled at nodes. The elements of different type and shape with complex loads and boundary conditions have be used simultaneously using FEM. As a magnitude of the past works, it was noted that in order to accurately predict the physical behaviours of the structure under the influence of pressure loading for under water bodies structural integrity need a detailed three-dimensional model is desirable[4], which fully includes the pressure and shear forces acting on mating parts and pretension effect to tie. However, for a large complex structure such as a marine engine, the detailed modelling of the complete model is difficult because of restriction of the problem size and computational cost to analyse the entire structure. Therefore, in this paper, in order to investigate a finite element modelling technique of the structure and modal analysis the fluid analysis input is taken into consideration, two kinds of materials are introduced to known the effective variation between the properties of structure; a solid model aerodynamic results are coupled with structural model. Finally, the radome model proposed in this paper is adopted for a structural analysis of a large marine radome connected to the external surface. All numerical simulations are carried out using implicit FEM software package ANSYS.

Meshing Boundary Conditions and Problem Definition



2a. Fluid Domain with Model 2b. Discretised Domain 2c. Structural Mesh

FIGURE. 2 Geometry of the model for simulation

Major concern in the use of simulations is the mesh as the cases are involved with materials and different domains. The analysis required two types of meshes are in need, one for structural and other for fluid. The structural dynamics in ANSYS Workbench comes into its own building multi-stage workflows, where separate analysis systems work together. In this work initially a fluid flow simulation is carried to find the pressure on radome body. These pressures are applied to a structural analysis simulation to find the performance of the parts. Then, when the deformed shape is calculated, its changed form can be fed back in to find how it affects fluid flow. In simulation terms this type of analysis is extremely complex. Most fluid flow simulation technology uses completely different meshing [6], loading and solving methods compared to structural simulation and this is where the true power of Workbench comes into play.
For solid bodies, the software uses meshing techniques based on algorithms and element shape. One of the technique extensively used are called patch independent meshing for the part using tetrahedral element. Patch independent meshing is a meshing technique in which the faces and their boundaries are not necessarily respected unless there is a load, boundary condition, or other object scoped to the faces or edges or vertices. The domain for the fluid analysis is considered to have least influence from the domain to the body. The below images gives the discretised fluid field shown in fig. 2b and solid structure in fig. 2c to evaluate the equations over the required fields.

TABLE 1. Material Data

Properties	Structural Steel	Epoxy Carbon
Density	7850 kg/m^3	1490 kg/m^3

The function of the boundary conditions is to create and define constraints and loads on finite Element models. To simulate a model, all loads and boundary conditions that occur in the actual loads event need to be modelled. A pressure has to be applied to the body in a manner as to not impart any unrealistic acceleration [3] or cause the simulation to run for an extended amount of time.

RESULTS AND DISCUSSIONS

In order to fulfil the objective of the work first fluid loads are predicted using ANSYS CFX the predicted loads are then applied to the static model and the results are presented for the different materials under same loads as shown in the figures below. In order to verify the simulation results a grid dependent study is performed over the fluid model. The predicted loads are applied over the structural model under water at a depth of 1000m below the sea level where the pressure resulted over the body is 9.5 bar as shown in fig 3 & 4 pressure at the design used in the static structural analysis which is composed of two different cases with densities as presented in table 1, which has a thickness of 0.03m joined with circular attachment to hold the dome [7]. Fig. 5 (a) - 5 (d) and 6(a) - 6(d) shows the simulated results and the positions of maximum and minimum locations of stress, strain and total deformation on the model under the applied loads. Whereas the figures right side is given for structural steel and the left portion is the epoxy carbon material. The simulations are performed are the results are listed in Table 2, the measured stress, strain components and the total deformation occurred over the radome obtained from finite element analyses with two different material models.

The result study indicates that the maximum stress, strain locations are in the frontal portion of the radome. Fig. 5(d) & 6(d) represents the distribution of the equivalent stress of the radome along the direction through strain gauges. As shown in the figure, even though the overall distributions of the stress are similar to each other, large differences are observed in the stress and strain results. Thus, the structural steel is expected to be able to exactly predict the stress distribution due to material properties [11] and contact loads, nevertheless, in order to evaluate the stress distribution over the radome, comparison of the actual measured stress is required.

Through the comparison of the static results, the accuracy of the simulated models proposed in this work are nearly confirmed. However, the experiment gazes simple, it is difficult to verify the usefulness of these models in the structure under various loading conditions using experimental setup, in this cases the FEM advantage has taken to predict the structural dynamics of the model not only static even modal analysis is performed over model. In order to confirm the utilization of the radome design proposed in this study for a dynamic analysis, a series of modal analyses using the FEM are carried out and the comparison of the modal test results [7] is made. Hence, in the next section, a modal analysis is performed over the radome to completely evaluate the load deviation effects and resultant mode of deviations is predicted and presented in fig 7(a) - 7(i) & 8(a) - 8(i) and resultant effects of these models is shown in fig. 9 where the frequency on the vertical scale and the modes of extraction on the horizontal scale indicates that maximum frequency results in the steel material which in the range of 45- 75.7 hz frequency is noticed for nine modes of exaction of steel body and 25 - 40 hz frequency variation is seen for the carbon material which gives the research inputs for the evaluation of model and for adaption of the material this work gives a strong inputs for further study and clearly states the evaluation is carried out using more general loading conditions.

Fluid Analysis Performed on Dome

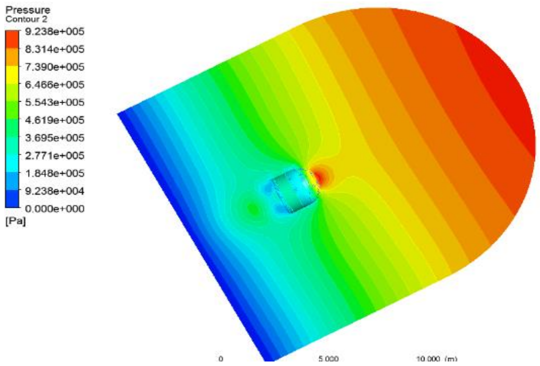


FIGURE. 3 Pressure Variation over the radome with domain

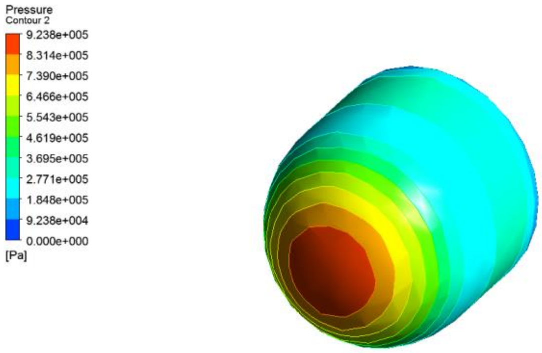


FIGURE. 4 Maximum Pressure Variation over the radome

Structural Analysis Performed on Different Materials

Structural Steel

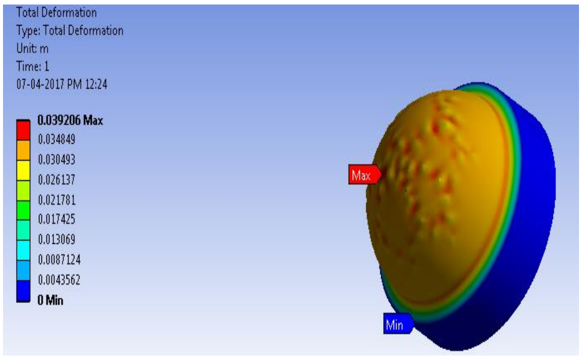


FIGURE.5a Total Deformation of the steel radome

Epoxy Carbon

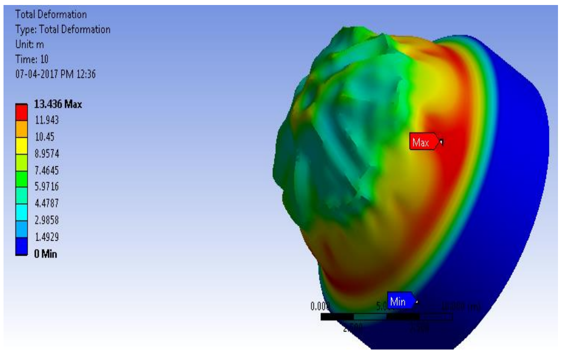


FIGURE. 6a Total Deformation of the Epoxy Carbon radome

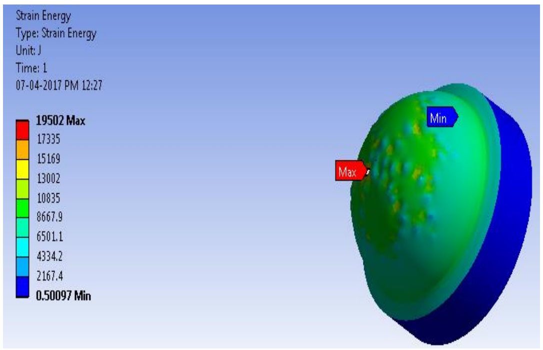


FIGURE.5b Strain Energy of the steel radome

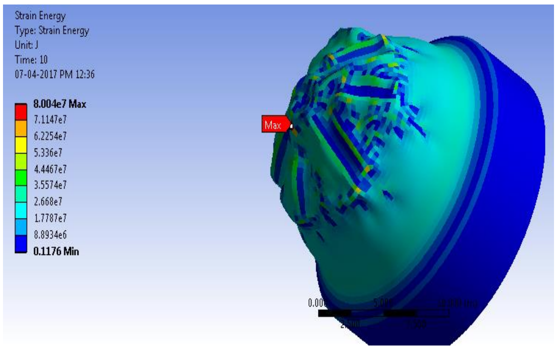


FIGURE. 6b Strain Energy of the Epoxy Carbon

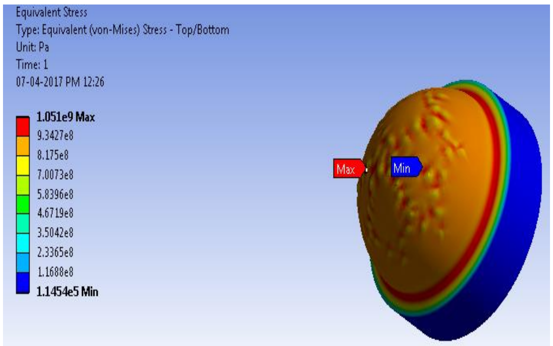


FIGURE.5c Von Misses stresses acting of the steel radome

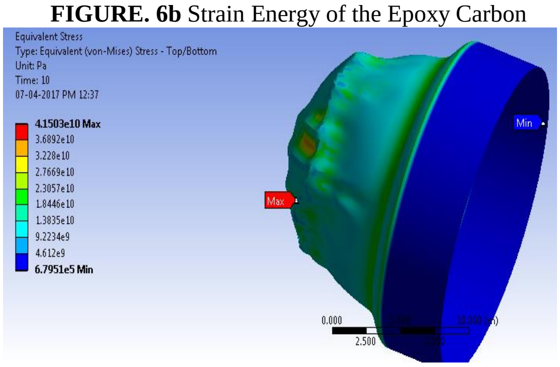


FIGURE.6c Von Misses stresses acting of the Epoxy Carbon

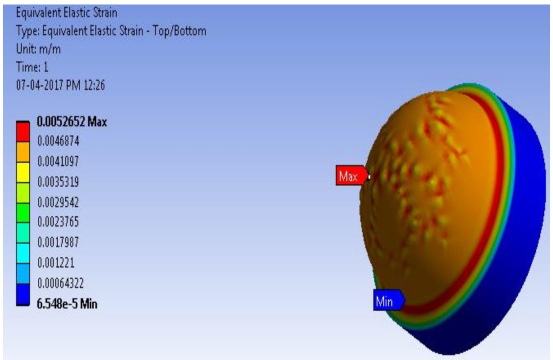


FIGURE. 5d Elastic Strain of the steel radome

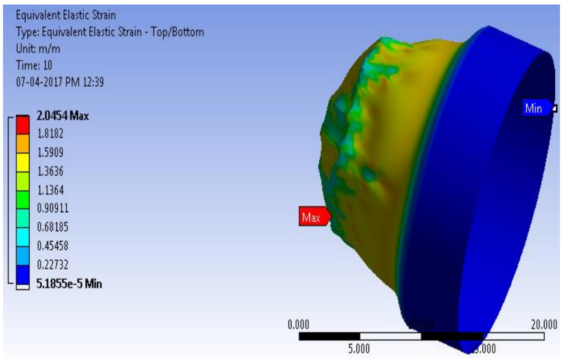


FIGURE. 6d Elastic Strain of the Epoxy Carbon radome

Modal Analysis Performed on Different Materials

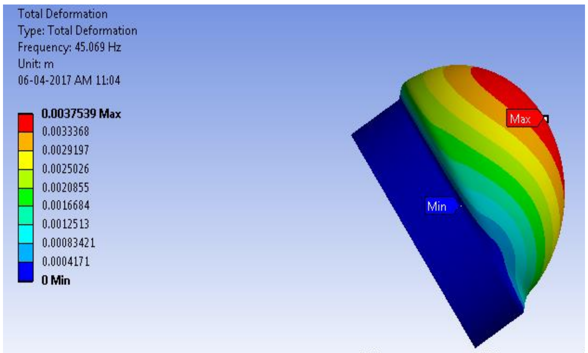


FIGURE. 7a Total deformation of steel Mode 1

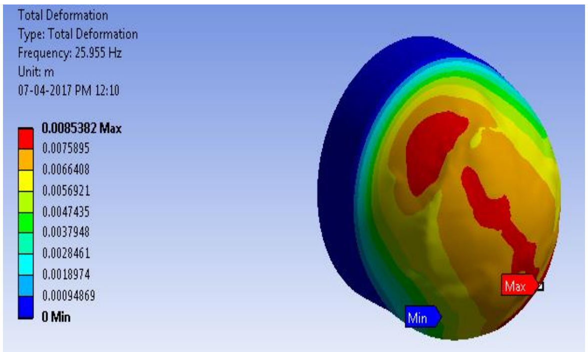


FIGURE. 8a Total deformation of Carbon epoxy Mode 1

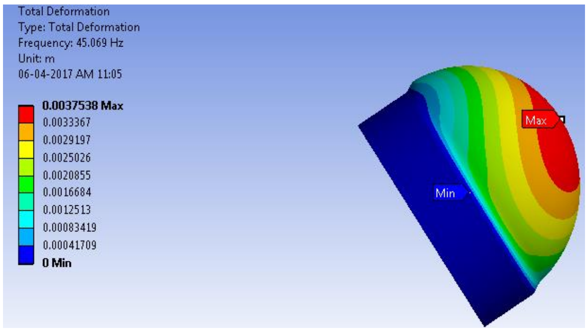


FIGURE. 7b Total deformation of steel Mode 2

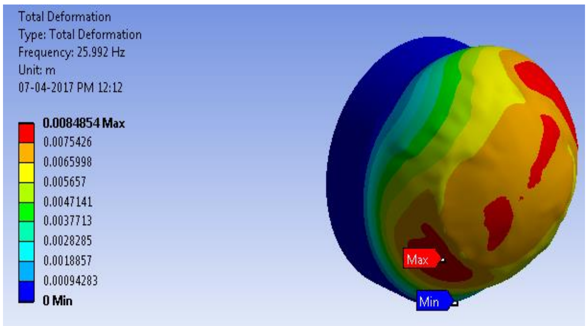


FIGURE. 8b Total deformation of Carbon epoxy Mode 2

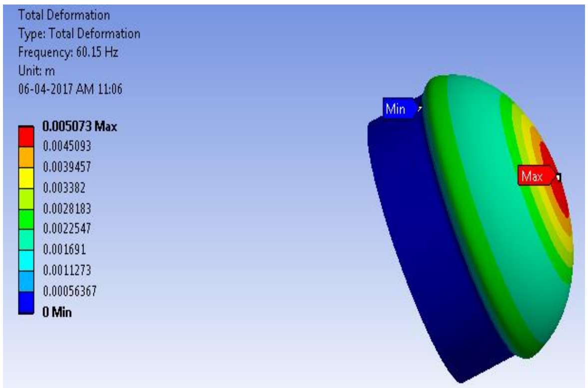


FIGURE. 7c Total deformation of steel Mode 3

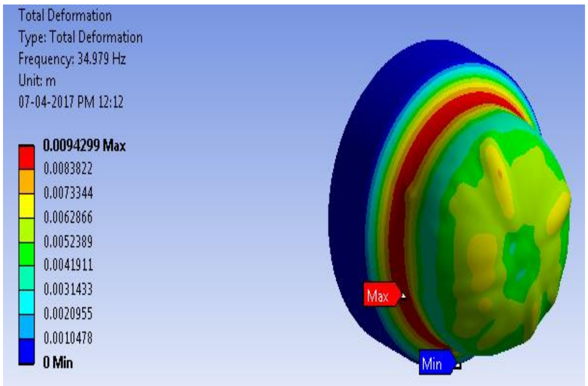


FIGURE. 8c Total deformation of Carbon epoxy Mode 3

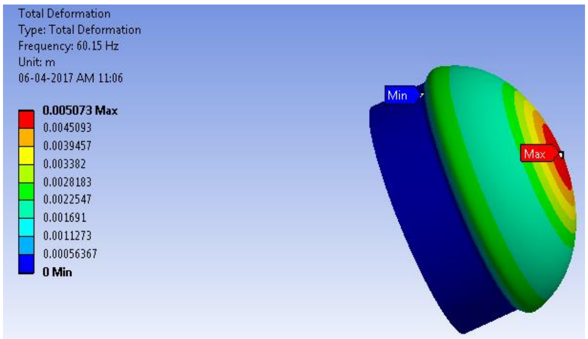


FIGURE. 7d Total deformation of steel Mode 4

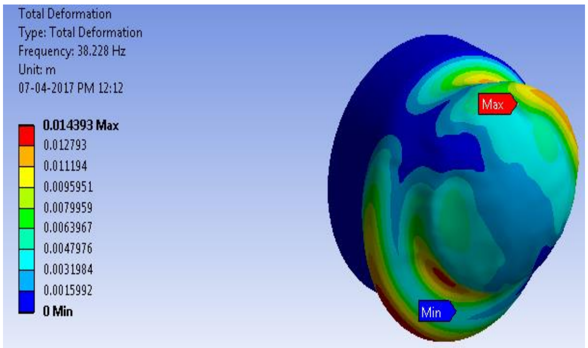


FIGURE. 8d Total deformation of Carbon epoxy Mode 4

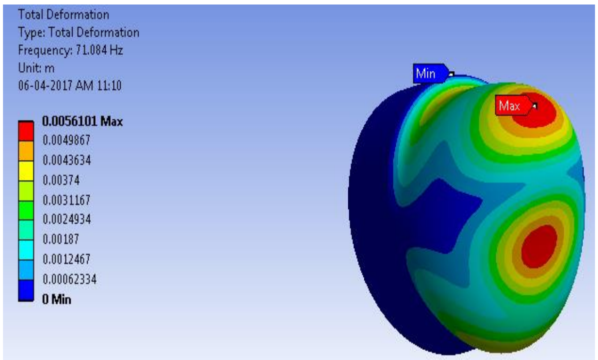


FIGURE. 7e Total deformation of steel Mode 5

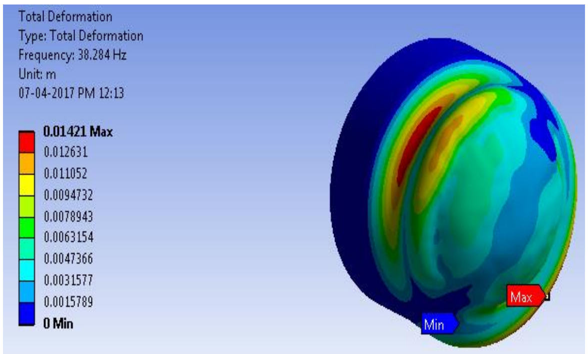


FIGURE. 8e Total deformation of Carbon epoxy Mode 5

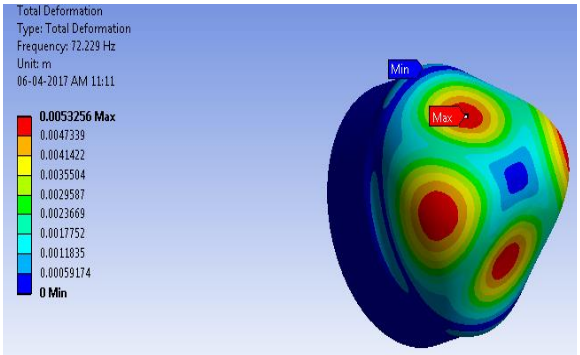


FIGURE. 7f Total deformation of steel Mode 6

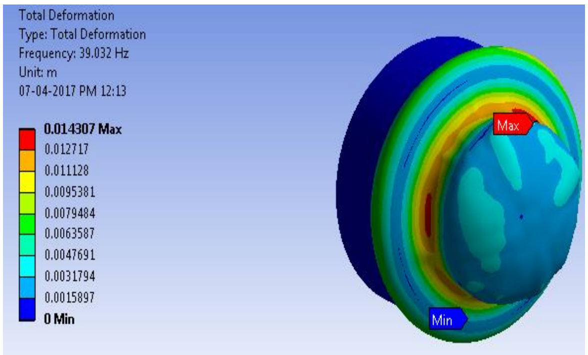


FIGURE. 8f Total deformation of Carbon epoxy Mode 6

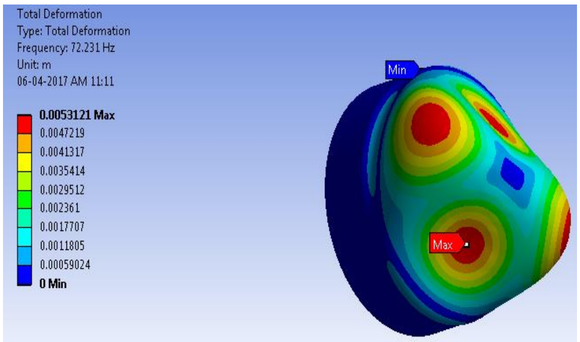


FIGURE. 7g Total deformation of steel Mode 7

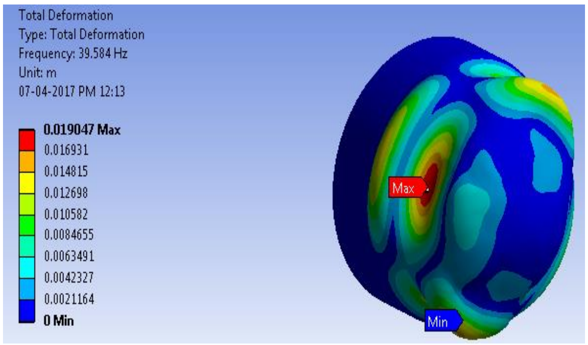


FIGURE. 8g Total deformation of Carbon epoxy Mode 7

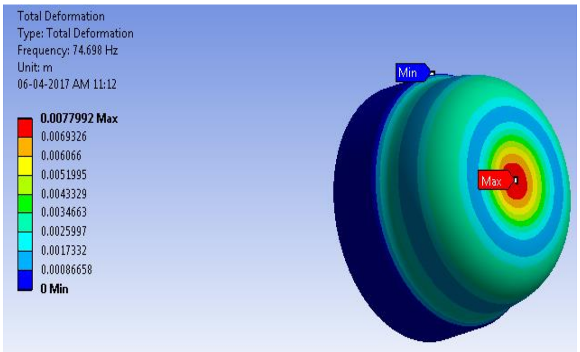


FIGURE. 7h Total deformation of Steel Mode 8

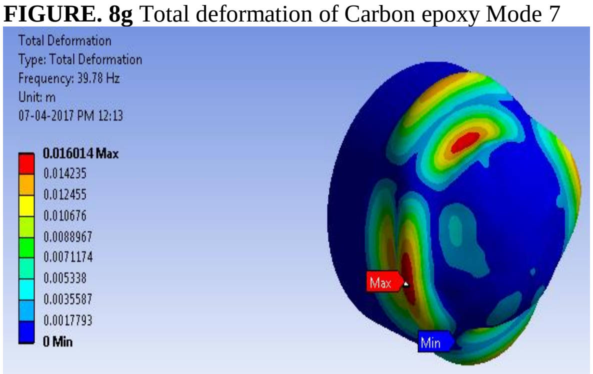


FIGURE. 8h Total deformation of Carbon epoxy Mode 8

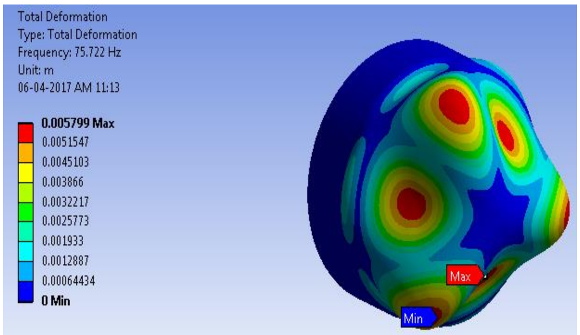


FIGURE. 7i Total deformation of steel Mode 9

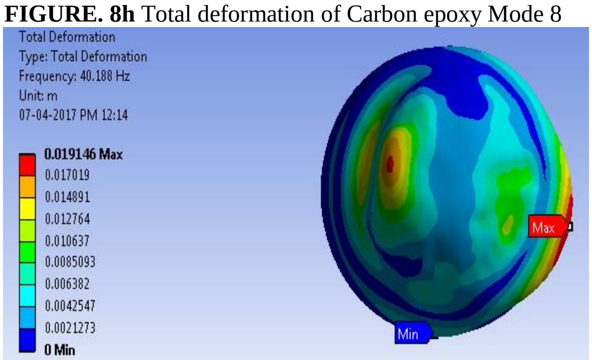


FIGURE. 8i Total deformation of Carbon epoxy Mode 9

Table 2: Properties of materials after deformation and maximum

Material	Total Deformation(m)		Strain Energy(J)		Equivalent Stress(Pa)		Equivalent Elastic Strain(m/m)	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Steel	0	0.0039206	0.50097	19502	1.1454e+005	1.051e+009	6.548e-005	5.2652e-003
Epoxy	0	13.436	0.1176	8.004e+007	6.7951e+005	4.1503e+010	5.1855e-005	2.0454

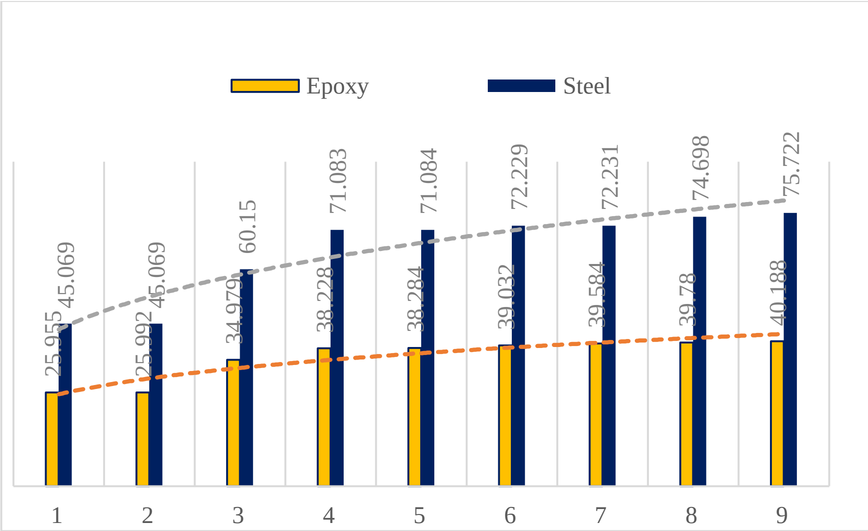


FIGURE. 9 Total Deformation over different materials and their resultant frequency

CONCLUSIONS

In the present paper the determination of the steel and epoxy behaviour, under pressure loading conditions and maximum possible modes of deformation was explained. The results were simulated by means of developed FEM models, and an insight of the occurring stresses within the radome design, leading to its failure modes, was obtained. The effectiveness of the different materials as well as of its cross-sectional geometry on the epoxy and steel strength was elucidated. The conclusions are summarized as followings

(1) In order to generate a finite element model for the structure with a different materials, a fluid analysis is performed over the radome, and the obtained pressure loads are applied on the radome design which states that the structurally suitable material for the design is steel. Among them, the steel could most accurately predict the physical behaviour of the structure.

(2) In the case of modal analysis, there is a major difference has found between the materials since the contact characteristic between interfaces is predominant, distinction with a difference in stress, strain distribution, especially total deformation neighbouring the structure, according to these results the natural frequency at the increased pressures and steel deformation is very high compared to epoxy.

(3) From the result of static analysis, the coupled radome model can save 44% to 47% more deformation is observed in steel material. Therefore, in view of effectiveness of resultant variations epoxy is recommended under high frequency.

Overall, this study established could be a concern if the radome designed with epoxy for underwater applications. So that resonance does not occur if the natural frequency of the radome coincides with the excitation frequency of the submarine Clinical information system (CIS) for UNRWA is a computerized distributed application that used in clinics which follows the United Nations Relief and Works Agency (UNRWA) to manage the clinical requirements and services. To produce an optimized system, further studies should be conducted. Future studies should focus on improving the radius of curvature. Future studies should use optimization techniques to vary multiple design parameters simultaneously.

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