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Experimental Investigation Of Composite Materials And Validation Using Fea For Submarine Radome Design

M.Saikrishna[1], **Y.Anasuya**[2]
1. P.G Scholar Department of Mechanical engineering, Srinivasa Institute of Engineering and Technology, Chheyyuru, Amalapuram, Andhra Pradesh
2. Assistant professor Department of Mechanical engineering, Srinivasa Institute of Engineering and Technology, Chheyyuru, Amalapuram, Andhra Pradesh

Abstract: Radomes are electronic housings used for antennas operating both in maritime and airborne applications respectively. The purpose of radome is to transmit RF waves with minimal loss possible and to withstand under water severities at effective joint sealing and hydro static pressure. In order to withstand hydrostatic pressure up to 75 bar, these structures are made of composite materials possessing high RF transparency, high stiffness and corrosion resistance. The present work emphasizes on designing the shape, thickness, material identification, and Fabrication of laminates using hand layup by various materials and evaluating the mechanical properties by testing specimens as per ASTM standards. Furthermore, structural modeling and analyses of composites (using FEM), stress analysis for symmetrical orientation angles of laminae, buckling modes and failure criteria are investigated.

Keywords: Laminate, Radome, Stress analysis, Failure criteria

INTRODUCTION

Multilayer composite tubes have high stiffness and strength, corrosion resistance and thermal resistance. Research is being conducted to determine stress distribution, deformation, buckling of a composite structure used in submarine applications. Radomes can be constructed in several shapes (spherical, planar, geodesic, etc.) depend upon the application. Its designing process is mainly depending on mechanical strength and electrical (RF) transparency. It can also resistant to environmental effects (thermal exposure, radiation including UV, humidity).

In this study we used different materials for making laminates to determine mechanical strength and RF transparency. Specimens are tested as per ASTM standards. Input the test results to ANSYS software to perform simulations on the structure. We also investigated stress distribution in each and every layer along the thickness of radome.

MATERIAL SELECTION

A composite material is a combination of two or more dissimilar materials with a distinct interface. Greater strength to weight ratio, increased design flexibility is some of the salient features of these materials. These are fabricated by bonding fabrics with resin system; apart from this sandwich composites are also available by fabricating foam between layers of fabric. Various fabrication techniques are available to fabricate composite structures like hand lay-up, filament winding, etc.

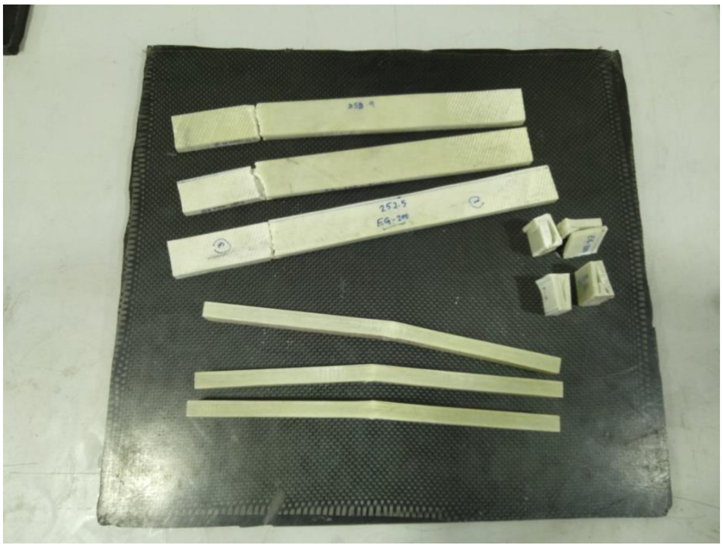
Radom's are electronic housings which protect antennas from environmental effects. The important consideration of radome material is RF transparency with minimal losses and high mechanical strength. All metals are acting as reflectors of RF waves so we can consider composites to make radomes. Both electrical and mechanical properties are depend on type of fabric used and resin system. For choosing material for radome several experiments are conducted with different materials and literature survey also made. Three materials are selected based mechanical strength from the literature survey.

Carbon fibers are fibers about 5–10 micrometers in diameter and composed mostly of carbon atoms. Carbon fibers have several advantages including high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. These properties have made carbon fiber very popular in aerospace, civil engineering and military applications. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

Carbon fiber has a nominal composition of Carbon 93% and Na+K < 50ppm.

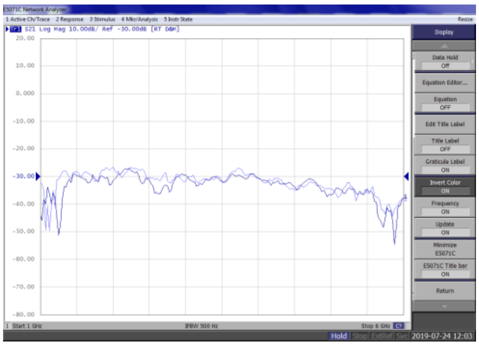
Glass fiber is a material consisting of numerous extremely fine fibers of glass. E-Glass or Electrical grade glass was initially used for electrical purpose. Later it was found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fiberglass. It has a low volatile content, no toxic additives and exhibits a very low emission rate of volatiles during the curing process. It is also known as low alkali glass. It has high strength, stiffness and non flammable. E-Glass has a nominal composition of SiO_2- 54%,with AL_2O_3- 14%,CaO+MgO- 22%,B_2O_3- 5 to 8%,$Na_2O+K_2O < 2\%$and Fe_2O_3- 0.5%.

Basalt fiber is a material made from extremely fine fibers of basalt, which is composed of the minerals plagioclase, pyroxene, and olivine. It has better mechanical properties than fiberglass, but being significantly cheaper than carbon fiber. It is used for aerospace and automobile applications. It has a high elastic modulus, resulting in high specific strength—three times that of steel, it is compatible with almost all resin systems and better chemical resistant than fiber glass. Basalt has a nominal composition of SiO_2- 51.6 to 59.3%, with AL_2O_3- 14.6 to 18.3%, CaO-5.9 to 9.4%, MgO- 3 to 5.3%, Na_2O+K_2O - 3.6 to 5. 2%, Fe_2O_3+FeO - 9 to 14% and TiO_2 -0.8 to 2.25%



Tested Specimens

Material	E-Glass (430Gsm) With Epoxy resin	E-Glass (200Gsm) With Epoxy resin	Carbon fabric(200Gsm) With Epoxy resin	Basalt Fabric(200Gsm) With Epoxy resin
Tensile Strength (MPa)	165.2	135	450	170
Compressive Strength (MPa)	137	148.4	325	123.5
Flexure Strength (MPa)	157	251.6	360	381
Shear strength (MPa)	13	27.1	50.2	--



RF Transparency Testing of Coupon

From the RF transparency test we can evaluate the signal loss value in each of the coupons. The tested values are tabulated below.

Loss in Coupons

Material	Loss (dB)
E-Glass	1.3
Basalt	0.78
Carbon fiber	2.1

From the above tabulated results carbon composite having high mechanical strength compare to others but from RF transmission point of view E-glass gives satisfactory results compare with others. So E-glass (200 Gsm) is consider for analysis.

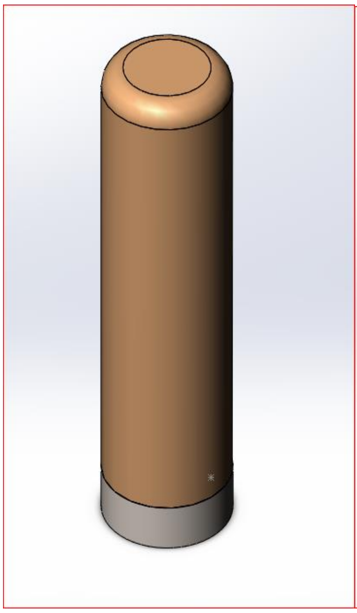
GEOMETRY

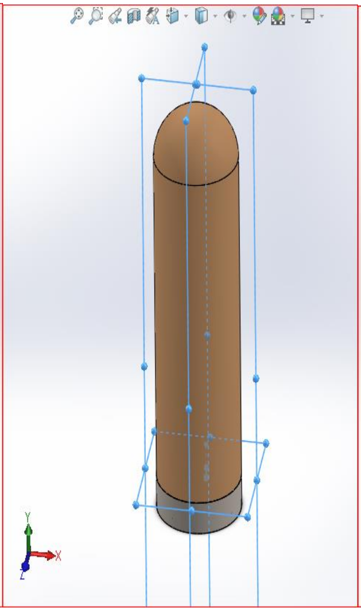
AHU's are made in different type of shapes based on the antenna structure, In this it is made of long cylinder with head. Considering three standard heads used for high pressure applications and finalizing the shape based on RF transparency & mechanical strength. Those three standard head are.

A. Flat Head:
The shape of these heads is just as they are named, due to its shape. More amount of thickness is required to bear the load. This shape can transfer the RF waves with less loss and deviation. Manufacturing process is simple compare with other type of heads.

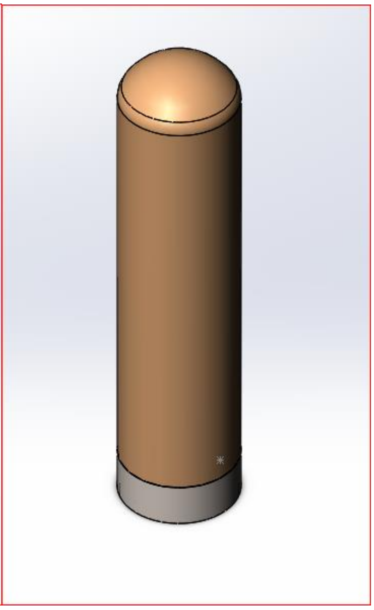
B. Spherical Head:
A sphere is the ideal shape for a head, because the pressure distribution is equal across the surface. The radius (R) of the head is as same as the radius of the cylindrical part of the radome as shown in figure.

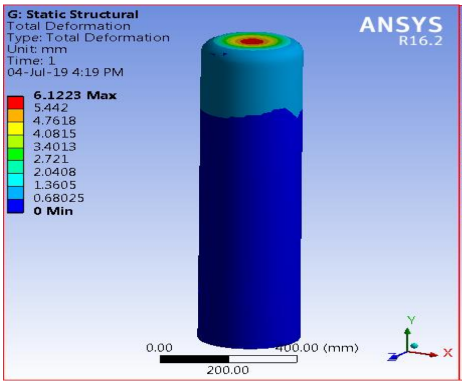
C. Elliptical Head
The shape of this head is more economical, because the height of the head is just a quarter of the diameter. Its radius varies between the major and minor axis this is most commonly used head for pressure vessels and high pressure storage tanks.

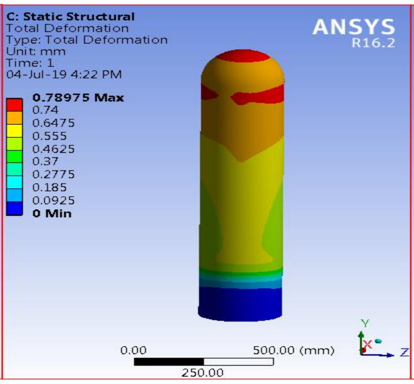

Flat head

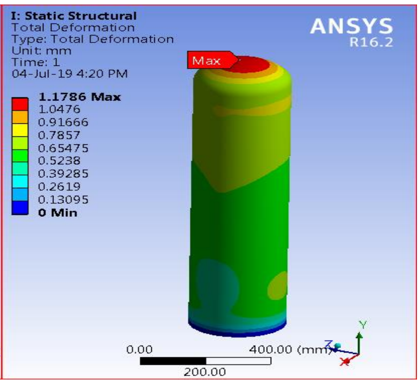


Spherical head


Elliptical head







Application of loads on the geometry to determining the response of structure for loading conditions, From the simulations we can finalize the spherical head because both elliptical and flat head has more deformation due to loading. This elliptical head has more strength to bear internal pressure compare to external pressure. And from electrical point of view spherical head is most desirable because of its very small incidence angles results less RF loss or less electrical degradation.

Thickness:

Thickness of Radome play a major role in RF transparency, this value depends on the frequency range of the antenna used and type of material. Thickness can be calculated by using following equation [4].

$$t = \lambda / 4\sqrt{\varepsilon_r}$$

$$\lambda = C_o / F_r$$

$$C_o = Speed\ of\ Light$$

$$F_r = \text{Frequency} = 3\text{GHz}$$

$$\varepsilon_r = Permitivity\ For\ E - Glass$$

$$\lambda = C_o / F_r = \frac{3X10^8}{3X10^9} = 0.3$$

$$t = \frac{0.3}{4\sqrt{6.13}}$$
=20 mm

From the calculations we can get maximum value of thickness 20mm.This value can be optimized based on strength of the material, but this can be optimized from ref paper.

Radomes are designed to satisfy unique set of specific requirements. The requirement is broadly divided into three branches – Mechanical (weight, stiffness and stress, pressure/altitude, finish and reliability), Electrical (frequency and bandwidth, transmission loss, impact on radiation properties of antenna, reflected power into the antenna),

A very critical parameter for the case under study is load bearing capacity of the radome under various mechanical loads. Analysis calculations are done to theoretically estimate the loads that the radome is subjected to. The following different load cases are considered for arriving at the total cumulative loads acting on the radome.

For under water system, buckling is most dominant failure mechanism when the external pressure reached at elevated level i.e. at deepest position. Which reduce the load carrying capacity also From the FEA analysis we can predict the buckling mode shapes and critical buckling pressure, A cylindrical shell under compression can fail by overall buckling (global/Euler), local buckling or the material strength being reached. Various failure mechanisms of composite cylindrical shells, as affected by initial geometric imperfections, boundary conditions, lamina stacking sequence, anisotropic coupling effects and load eccentricity. Generally linear buckling analysis is performed in two steps, in first step static solution of structure was obtained. In static analysis pre-buckling stress of the structure was computed and in second step solving the Eigen value problem to obtain Eigen value by considers equation given below. The stress stiffness matrix [S] computed in first step.

$$([K] + \lambda_i[S])\ \{\Psi\}_i = \{0\}$$

Where [K] = stiffness matrix, [S] = stress stiffness matrix, λ_i = i^{th} eigen value and Ψ_i = i^{th} eigen vector of displacements.

Once the eigen values are obtained, then critical buckling pressure (P_{cr}) is obtained using equation

$$P_{cr} = \lambda * P_a$$

Where P_{cr} is the critical buckling pressure and P_a is the applied pressure.

Pressure Head acting on the radome

Case (i): Hydrostatic pressure acting on radome (due to under water).

Fluid static law: The fluid static law states that the pressure in a fluid increases with increasing depth. In the case of water, it is termed the Hydrostatic law. And the pressure given.

Water head pressure acting on radome P=ρgh......... Eq (1), where

ρ= density of sea water at average temperature of 3.88° C with salinity of
34.78%= 1000 kg/m^3
g= Acceleration due to gravity = 9.81 m/sec²
H= water head (depth at which object is immersed) = 700m
P_H= 1027 x 9.81 x 700 =7052409 = 70 bar.

Case (ii) Drag force acting when radome platform is travelling under water at speed of 20 knots (10 m/s).

Any object moving through a fluid experience drag the net force in the direction of flow due to pressure and shear stress forces on the surface of the object

$$\text{Drag force is expressed as D (Newtons) } D = C_d * \rho * A * {V^2}/{2} \quad \text{................ Eq (2)}$$

Where C_d= drag co-efficient which depends upon the shape of the object, its velocity of flow, frontal area and roughness of surface

ρ = density of the fluid in Kg/m³ (1,027 Kg/m³)
V = velocity of fluid in m/sec (V= 12.5m/sec)

A= frontal area of the object =0.307 m2
Cd= 1.2 (for the given cylindrical shape)
$D = 1.2*1027*0.307* 12.5^2/2= 29558$ N = 29.58 KN
For comparison of drag load with hydrostatic pressure, equivalent pressure due to drag load,
P_D= D/ A = 0.96 bar.
Case (iii) Pressure acting due to wind speed @ 240 kmph (when object exposed to wind)

$$\text{Wind pressure acting on radome (p)} = C_d * \rho * V^2/2 \text{ ....Eq (3)}$$

Where $C_d = 1.2$ (for given radome)
ρ=1.225 Kg/m³ (air density)
V= 66.67 m/sec
$D= 1.2*1.225*0.307*66.67^2/2=$ 1 kN
For comparison of wind drag load with hydrostatic pressure, equivalent pressure due to drag load,
Pw= 0.03257 bar

From the above three load cases, the hydrostatic pressure acting on radome under water is the predominant load. Hence radome is designed to withstand hydrostatic pressure of 75bar = 7.5Mpa (maximum considered as 75 bar or 7.55Mpa).

For a composite strength is related to the strength of each individual lamina. Various theories have been developed for studying the failure of an angle lamina. The theories are generally based on the normal and shear strengths of a unidirectional lamina.

In maximum stress failure theory, the stresses acting on a lamina are resolved into the normal and shear stresses in the local axes and failure is predicted in a lamina, if any of the normal or shear stresses in the local axes of a lamina is equal to or exceeds the corresponding ultimate strengths of the unidirectional lamina. Failure can be predicted following equation.

$$-(\sigma_1^C)_{ult} < (\sigma_1) < (\sigma_1^T)_{ult} \text{ or}$$
$$-(\sigma_2^C)_{ult} < (\sigma_2) < (\sigma_2^T)_{ult} \text{ or}$$
$$-(\tau_{12})_{ult} < (\tau_{12}) < (\tau_{12})_{ult}$$

$(\sigma_1^C)_{ult}$ = Ultimate longitudinal compressive strength (in direction 1),
$(\sigma_1^T)_{ult}$ = Ultimate longitudinal tensile strength (in direction 1),
$(\sigma_2^C)_{ult}$ = Ultimate transverse compressive strength (in direction 2),
$(\sigma_2^T)_{ult}$ = Ultimate transverse tensile strength (in direction 2) and
$(\tau_{12})_{ult}$ = Ultimate in-plane shear strength.

In maximum strain failure theory, the strains acting on a lamina are resolved into the normal and shear strains in the local axes and failure is predicted in a lamina, if any of the normal or shear strains in the local axes of a lamina is equal to or exceeds the corresponding ultimate strain values of the unidirectional lamina. Failure can be predicted following equation.

$$-(\epsilon_1^C)_{ult} < (\epsilon_1) < (\epsilon_1^T)_{ult} \text{ or}$$
$$-(\epsilon_2^C)_{ult} < (\epsilon_2) < (\epsilon_2^T)_{ult} \text{ or}$$
$$-(\gamma_{12})_{ult} < (\gamma_{12}) < (\gamma_{12})_{ult.,}$$

$(\epsilon_1^C)_{ult}$ = Ultimate longitudinal compressive strain (in direction 1),
$(\epsilon_1^T)_{ult}$ = Ultimate longitudinal tensile strain (in direction 1),
$(\epsilon_2^C)_{ult}$ = Ultimate transverse compressive strain (in direction 2),
$(\epsilon_2^T)_{ult}$ = Ultimate transverse tensile strain (in direction 2) and
$(\gamma_{12})_{ult}$ = Ultimate in-plane shear strain.

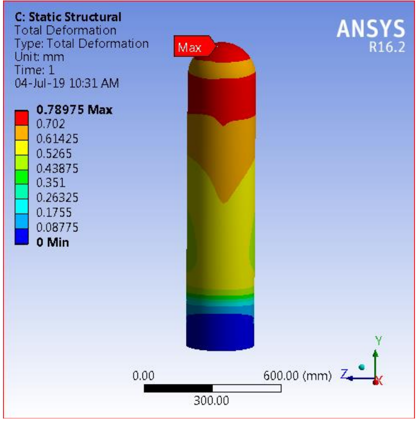
This theory is based on the distortion energy failure theory of Von-Misses distortional energy yield criterion for isotropic materials as applied to anisotropic materials. Distortion energy is actually a part of the total strain energy in a body. The strain energy in a body consists of two parts; one due to a change in volume and is called the dilation energy and the second is due to a change in shape and is called the distortion energy. It is assumed that failure in the material takes place only when the distortion energy is greater than the failure distortion energy of the material. Hill8 adopted the Von-Misses distortional energy yield criterion to anisotropic materials. Then, Tsai adapted it to a unidirectional lamina. Based on the distortion energy theory, he proposed that a lamina has failed if not satisfying the following condition.

$$\left[\frac{\sigma_1}{(\sigma_1^T)_{ult}}\right]^2 - \left[\frac{\sigma_1\sigma_2}{{(\sigma_1^T)_{ult}}^2}\right] + \left[\frac{\sigma_2}{(\sigma_2^T)_{ult}}\right]^2 + \left[\frac{\tau_{12}}{(\tau_{12})_{ult}}\right]^2 < 1$$

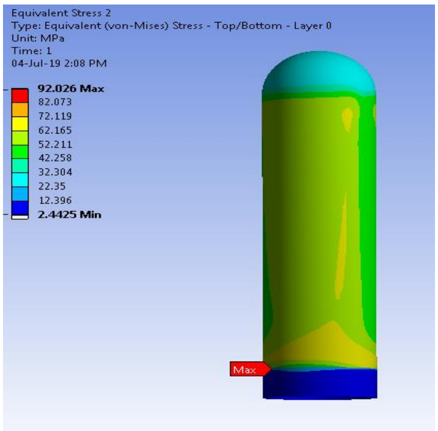
ANALYSIS

3D structure is created by using solid works tool and finite element analysis is performed on the structure to identify stress distribution, deformation while it is subjected to loading using Ansys. Input the material properties in engineering data. Meshing is done on the structure to perform analysis and then boundary conditions are applied. From this analysis we can determine the deformation of the structure and stress distribution. Buckling analysis is performed to know the critical buckling pressure of the radome and failure analysis is to be performed for checking failure criteria of the composite. Layup angle play a crucial role in composite strength, so in this composite layers with ±55° angle is used & Inter-laminar shear stresses is the one source of failure for composite structure. Failure can happen by delamination of layers. Thickness of the radome is 18mm, each layer thickness is considered as 0.2mm.

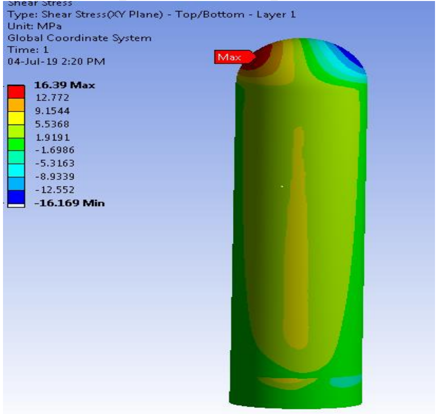
Meshing of composite radome

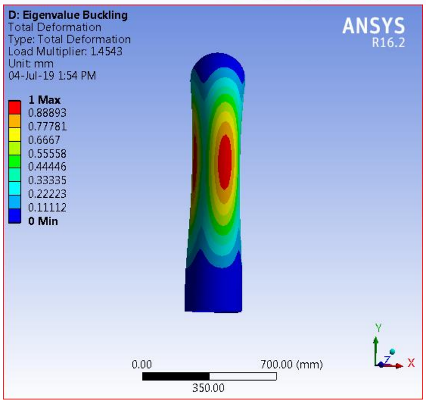


Maximum deformation observed on radome is 0.78 mm due to loading of hydrostatic pressure of 75 bar at spherical portion.

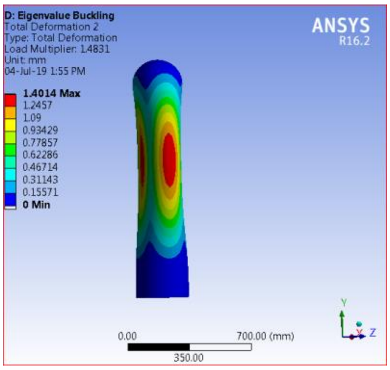


Max stress 92 MPa is observed on composite part at Composite and metal interface.

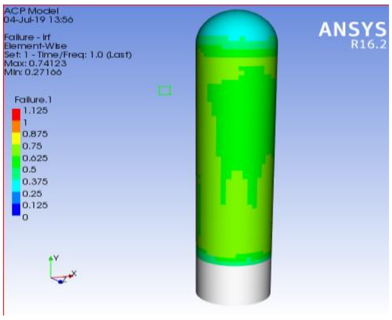




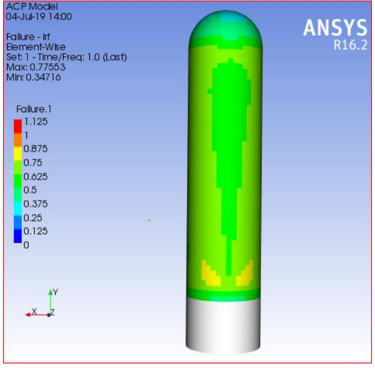
First buckling mode



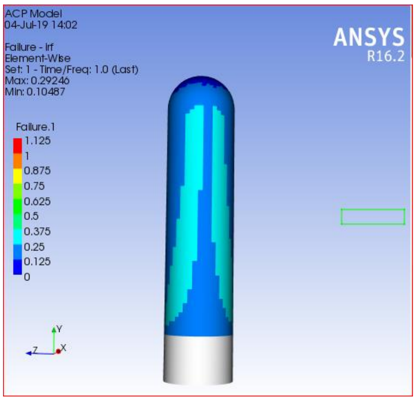
Second buckling mode



Tsai-Hill theory



Maximum stress theory



Maximum stress theory

Failure criteria	IRF value
Maximum stress theory	0.77
Maximum strain theory	0.29
Tsai-Hill theory	0.74

RESULTS AND CONCLUSIONS

Maximum deformation 0.78mm observed at spherical portion on top of the radome.

Maximum stress observed on composite part is 75 MPa at composite metal interface. Observed stress is less than the ultimate stress of E-Glass (137MPa) so the design in safe condition.

Maximum shear stress observed is 21.85 MPa on composite at metal composite interface region. Observed shear stress is less than the ILSS of E-Glass (27MPa).

Critical buckling pressure obtained from the analysis is 10.87 MPa, it is 1.45 times more than applied load.

Obtained IRF values are less than one so the design is in safe condition from failure criteria point of view also.

E-glass having high RF transparency compare with carbon and basalt.

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