Experimental Characterization of Sandwich Radome for Airborne Applications

S. Ilavarasu, A. C. Niranjanappa, P. A. Aswatha Narayana

***Abstract:** Radome is a structural weather proof enclosure that protects radar system from the environment. Radomes are manufactured using composite materials that have low dielectric constant and low loss tangent. The selected materials should have high mechanical strength to withstand aerodynamic and bird impact load conditions. Thus, the design of a radome is always a trade-off between electrical and structural requirements. In the present study, set of Uni-directional (UD) and Bi-directional (BD) glass fabric used as high density face sheet with low density foam ROHACELL 71 Hero grade and Nomex honeycomb as core materials are used to form sandwich radomes. These samples are tested for mechanical performance as per ASTM standards. The maximum load bearing capacity was found higher for the Nomex sandwich with UD face, by 27% than the Rohacell sandwich with UD Face sheet. Nomex sandwich with BD face sheet have higher compressive modulus among other three configurations. The bird impact simulation results show sandwich panel selected is capable of withstanding bird impact load at a velocity of 150 m/s. The measured antenna patterns with and without radome material for frequency range from 2.5 GHz to 4.5 GHz is also discussed.*

Keywords: Radome, Sandwich structure, Bird impact.

I. INTRODUCTION

Radome is a structural weather proof enclosure that protects the antenna and associated electronics from its physical environment. The radar system transmits and receives the signals and hence the radome is designed, not only to minimally attenuate electromagnetic signals transmitted but also have high mechanical strength [1]. Radome are manufactured using composite materials consisting of low density core material and high density skin or face sheet material. E-glass, S-glass D-glass, Quartz, Kevlar are the most common reinforcement fibers for the radome face sheets. Epoxy and polyester are common matrix materials used for radome applications [2]. A and C type sandwich are common styles of radome for airborne application. The A-sandwich consists of three layers: two dense high-strength skins separated by a low density, low dielectric core material such as foam or honeycomb.

Low-observable radomes are constructed using aramid/epoxy composites faces, foam core due to low dielectric constants and high strength. Composite sandwich materials lack reliable data and hence an accurate experimental characterization of the materials is essential. The mechanical properties of the radome is measured by the 3-point, 4-point bending test and edgewise compression test. The mechanical results are used as input data to implement the finite element analysis by commercial code. Electrical properties are measured by the free space measurement method and in planar near field measurement facility [3, 4].

Stacking sequences has a greater influence on the impact damage behavior. The stacking sequence and reinforcement form like UD, BD or woven will have significant effects on the impact resistance [5].

Bird impact is one of the design driving load case for radome. Radome has to be designed for specific impact mass and velocities. Several choices for bird model exits, adaptive remeshing involve remeshing the region of severe mesh tangling. This mapping procedure increases numerical errors. The Lagrangian method became standard approach for bird impact modeling. It was used by several researchers for impact simulation [6]. Bird is modeled using a meshless Lagrangian technique called smooth particle hydrodynamics (SPH). The fluid is represented by a group of moving particles changing their position with respect to fluid velocity. The bird body is modeled in the shape of a cylinder with hemispherical ends. Bird modeling is carried out by smooth hydrodynamic methods [7, 8]. The acceptance criteria for impact load is as follows. The bird should not penetrate the structure or debris due to damage should not come out. Any crack on the test specimen as a result of impact is acceptable.

II. THE SANDWICH UNDER STUDY

The present work is focused on the fabrication of composite sandwich panels of different combination and characterize them through various mechanical test for use in airborne applications. UD glass fabrics and BD glass fabric of 200 gsm is used as face sheet and tested with continuous foam and discontinuous honeycomb as core materials with thickness of 36 mm. Six layers of outer skins with (0/90/45/-45/0/90/45/-45/0/90) lay-up sequence has been used. The sandwich core materials selected for the test are Nomex Honeycomb and Rohacell foam (71 Hero grade) with density of core material 80 kg/m^3. The epoxy resin LY5052 and HY5051 is used for the fabrication of samples using hand layup technique and post curing at 60^{o}C. Table I shows the combination of sandwich samples chosen for the study.

Revised Manuscript Received on October 15, 2019

S. Ilavarasu, Research Scholar, Department of Aerospace Engineering, Jain University, Bangalore, Scientist, Centre for Airborne Systems, DRDO, Bangalore, India. Email: ilavarasu@cabs.drdo.in

Dr. A C Niranjanappa, Scientist, Centre for Airborne Systems, DRDO, Bangalore, India

Dr. P A Aswatha Narayana, Visiting Professor, IIAEM, Jain University, Bangalore, India.

Table I. Sandwich combinations under study

Sl. No	Core	Fabric
1	ROHACELL foam	UD glass fabric
2	ROHACELL foam	BD glass fabric
3	Nomex honeycomb	UD glass fabric
4	Nomex honeycomb	BD glass Fabric

III. EXPERIMENTAL RESULTS AND DISCUSSION

Extensive coupon tests have been carried out to characterize the material properties. The data generated is used in numerical procedure to assess the stress field in the sandwich panel. Flatwise, compression, tension and flexure tests are carried out as per ASTM standards to estimate the mechanical properties of sandwich radome.

A. Rohacell sandwich structure with UD face sheet

Fig. 1 shows stress *versus* strain plot of flatwise compression test. The plot indicates the compressive response of the sandwich with UD face sheet. Initially the curve was linear in the elastic region

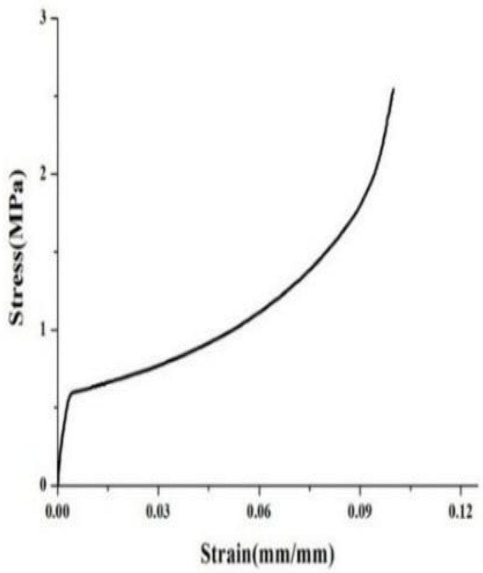

Fig. 1. Stress vs. Strain plot for flatwise compression test

Further, the stress increases with the strain consistently. The yield region is observed at an average stress of 0.605 MPa attributing to the buckling of the Rohacell foam structures. Further loading results in densification of the foam due to closure of the cell/void exhibiting higher strength. The ultimate compressive strength was approximately 2.53 MPa. Fig. 2 shows the stress *versus* strain curve for tensile test. The average ultimate tensile strength was 2.034 MPa

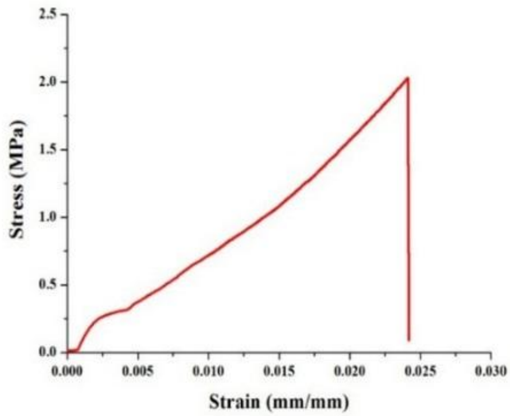

Fig. 2. Stress vs. strain plot for flatwise tensile test

B. Edgewise compression test (ASTM C364)

This test determines compressive properties parallel to the sandwich facing plane. Fig. 3 shows the load *versus* displacement plot of the sandwich with unidirectional face sheet for edgewise compression test. The sample was held rigid between the fixtures so that the behavior of the curve should be smooth without any distortion.

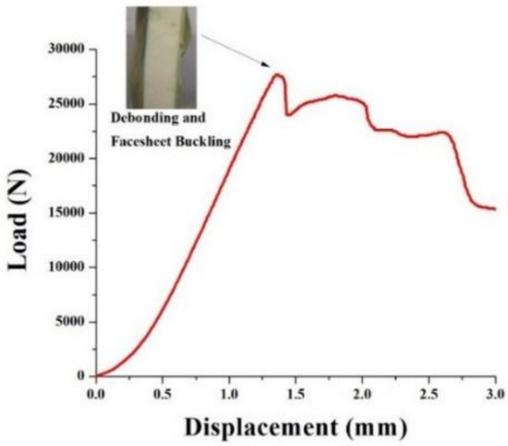

Fig. 3. Stress vs. strain plot for edgewise compression test

The maximum load carrying capacity of the sample is 27700 N at a displacement of 1.35 mm. The damage was initiated as debonding between the face sheet and core, causing the ultimate failure of the sample by global face sheet buckling failure. The facing compressive strength was calculated to be 1.44 MPa.

C. Flexural Test - ASTM C393

The flexural tests provide data for design, pertaining to flatwise flexural strength and stiffness of sandwich panel. Short span, three-point test is carried out to determine the core shear strength and panel shear rigidity. Four point and three point tests are performed to determine the flexural parameters like facing modulus and panel bending stiffness. The short beam flexural samples had facing strength and core shear strength of 23.37 (MPa) and 0.764 (MPa), respectively. Failure occurred by wrinkling of top face sheet at the loading point.

During flexural 3-point and 4-point loading, the specimens predominantly failed by localized effects due to concentrated loads causing inward local bending and wrinkles in the face sheets at compression side resulting in lower stiffness and strength. Fig. 4 shows the comparison of strength for different tests.

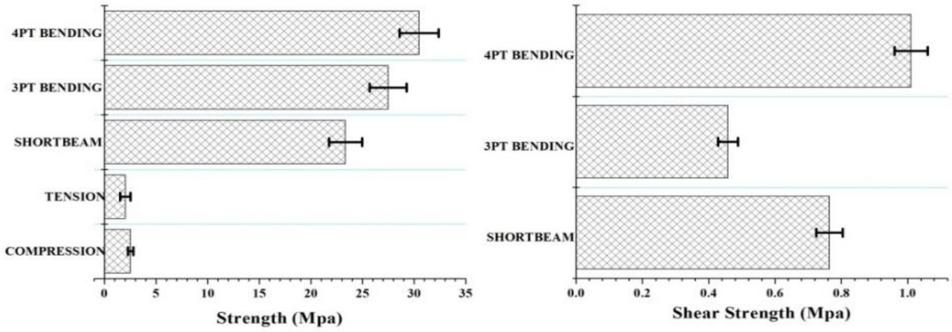

Fig. 4. Comparison of strength for Rohacell sandwich with UD Face sheet

IV. ROHACELL SANDWICH WITH BI-DIRECTIONAL FACE SHEET

A. Flexure Test

The short beam flexural samples had facing strength and core shear strength of 13.90 MPa and 0.3104 MPa, respectively. The localized buckling of core contributes poor strength / stiffness resulting in shear failure through core thickness. The 3-point flexural samples have facing strength and core shear strength of 40.7 MPa and 0.452 MPa respectively. The 4-point flexural samples have facing strength and core shear strength of 19.414 MPa and 0.432 MPa, respectively. Comparison of strengths for different tests are shown in Fig.5.

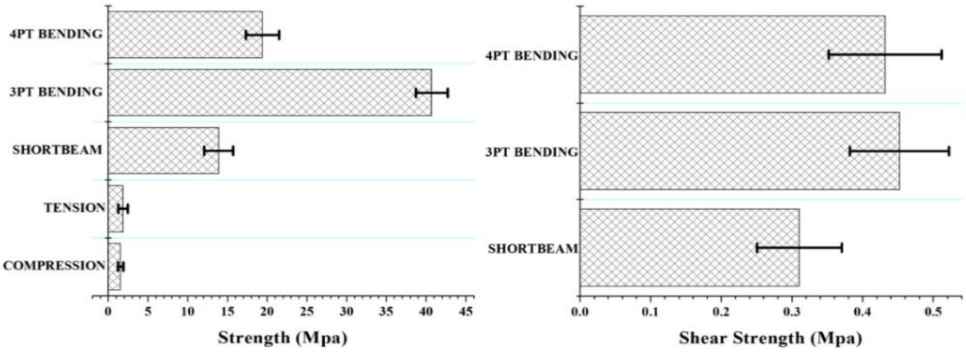

Fig. 5. Comparison of strength for Rohacell sandwich with bidirectional face sheet

V. NOMEX HONEY COMB SANDWICH WITH UD FACE SHEET

Fig. 6 shows the load-displacement plot for Nomex sandwich with unidirectional face sheet for edgewise compression test. The loading behavior was initially linear similar to conventional laminates. However, beyond a displacement of 1.3 mm non-linearity occurs. The samples resisted a maximum load of 35300 N at a displacement of 3.64 mm. The facing compressive strength is calculated to be 1.83 MPa.

5.1 Flexural Test - ASTM C393

The comparison plot for Nomex sandwich with UD as face sheet for shear strength is shown in Fig. 7. The core shear strength and facing bending strength is calculated to be 0.665 MPa and 19.95 MPa, respectively. The loading behavior was similar to the 3-point flexural test where linearity up to certain load of 3790 N with related displacement of 8.91 mm is observed. The facing bending strength and shear strength was calculated as 18.26 MPa and 0.60 MPa, respectively.

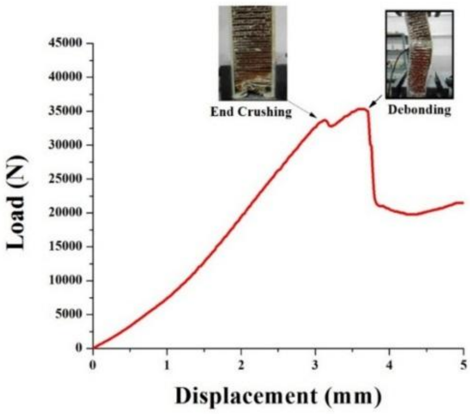

Fig. 6. Stress vs. strain plot for edgewise compression test (Nomex with UD face sheet)

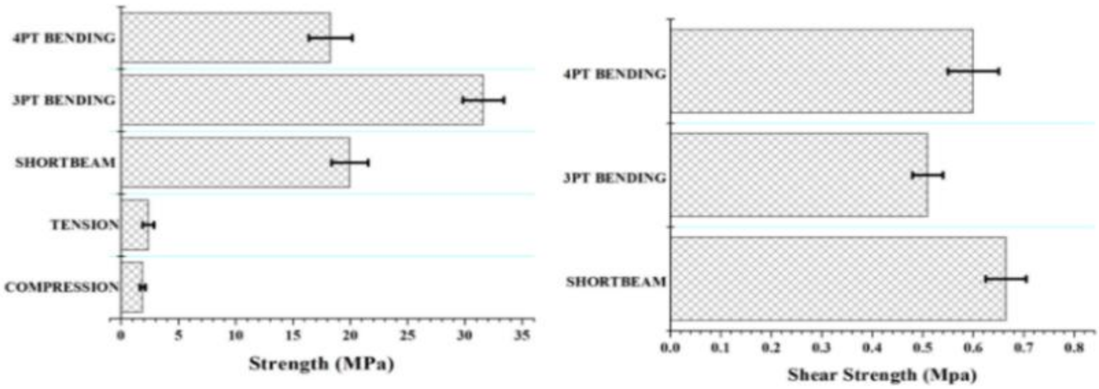

Fig. 7. Comparison plot for Nomex honey comb sandwich with UD configuration

VI. NOMEX SANDWICH WITH BI-DIRECTIONAL FACE SHEET

A. Flatwise compression Test - ASTM C365

The curve for flatwise compression loading can be divided into crushing and collapsing stages.

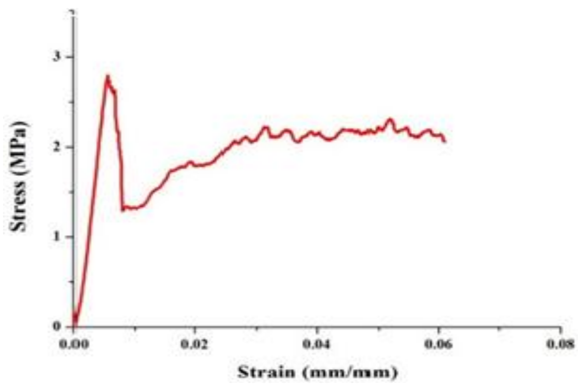

Fig. 8. Stress vs Strain plot for flatwise compression test for (Nomex with BD face sheet)

The compressive load increases almost linearly up to the peak point of 7000 N which relates to the collapse strength of the about 2.78 MPa as shown in Fig. 8.

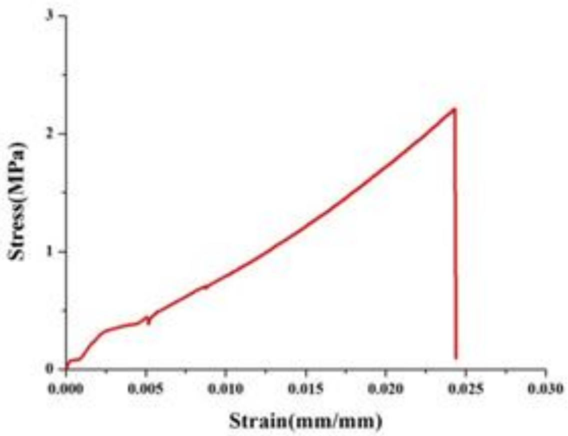

Fig. 9. Stress –vs strain plot for flatwise tensile test (Nomex with BD face sheet)

Fig. 9 shows the stress strain plot for flatwise tensile test. As the loading is applied, the response obtained was linear-elastic, however a slight non-linearity appears as the specimens start to rupture through internal crack. This failure and separation did not occur instantly; Non-linearity was attributed to tensile resistance of the core. The maximum strength achieved by the specimen is 2.19 MPa, with a related strain of 0.024. The equivalent tensile strength of the core is about 1.26 times of the equivalent compressive collapse strength. Fig. 10 shows load displacement curves for four different sandwich samples under edgewise compression test. Sandwich sample with Nomex honey comb core with UD face sheet resisted a maximum load of 21200 N at a displacement of 2.04 mm. The facing compressive strength was calculated to be 1.093 M pa.

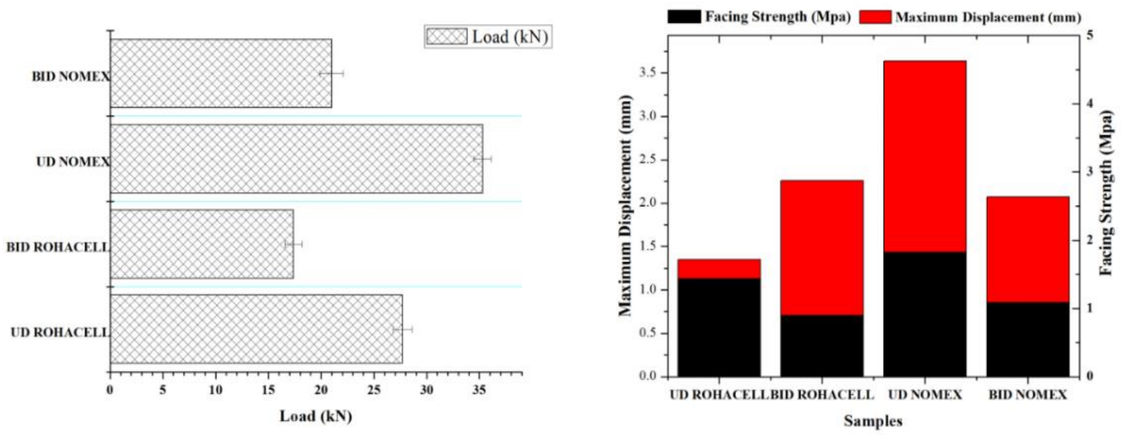

Fig. 10. Comparison of load-displacement and facing strength for sandwich samples.

VII. COMPARISON PLOT FOR TENSION, COMPRESSION AND FLEXTURE TEST FOR DIFERENT CONFIGURATION

Fig. 11 shows the comparison plot for tension, compression and flexure for four different sandwich panels. In general, tensile load carrying capacity of sandwich with Rohacell foam as core is higher than sandwich with Nomex honey comb as core material. The maximum load bearing capacity was higher for the sandwich samples with bi- directional face sheets. The compressive load for Nomex core with UD face sheet, increases almost linearly up to the peak point of 7000 N, which relates to the collapse strength of the about 2.78 MPa. Then the load drops significantly to an initial plateau load of 3200 N with the related displacement of 2 mm. The compressive load for Nomex core sample with BD face sheet has similar trend with marginally lower load. Facing strength for different sandwich configuration is also shown in picture.

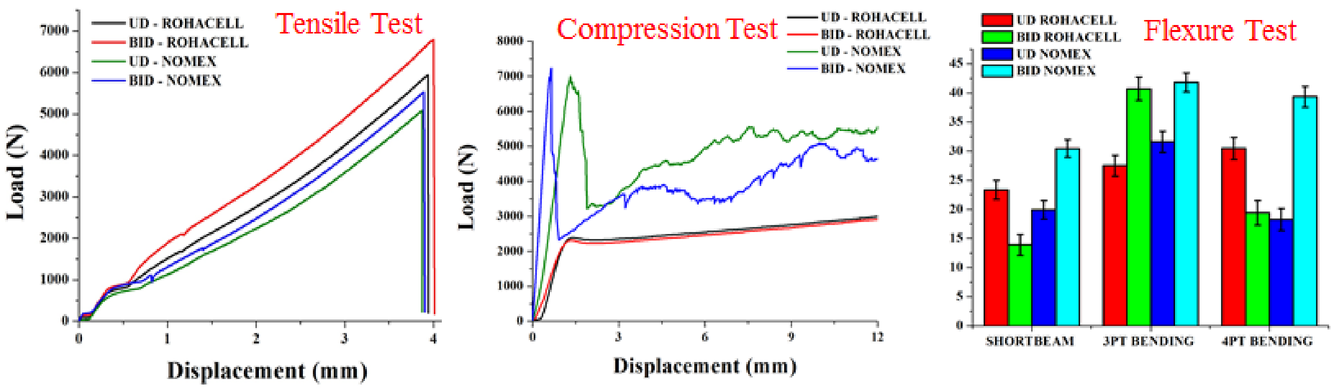

Fig. 11: Comparison plot for tension, compression, flexure tests

VIII. BIRD IMPACT ANALYSIS

As per FAR-25 standard, radome must be capable of successfully completing a flight during which likely structural damage occurs as a result of impact with a 1.8 kg bird when the velocity of the airplane relative to the bird along the airplane's flight path is equal to cruise velocity at sea level or 0.85 times cruise velocity at 8000 feet, whichever is more critical.

Finite element modelling was done using Hypermesh 13.0 and LS Dyna as solver for the bird impact simulation. Bird impact analysis was carried out on a flat A-sandwich panel of size 1 m x 1 m. Honeycomb is idealized using solid elements and skin layers are idealized with shell elements. To model the bonding between the core idealized with solid elements and face sheets as shell a penalty based AUTOMATIC_ SURFACE_ TO_SURFACE_TIEBREAK contact interface is defined. The material properties obtained from the coupon test for Nomex with BD as face sheet has been used for impact analysis. Bird is modeled using a meshless Lagrangian technique called smooth particle hydrodynamics (SPH) [8,9]

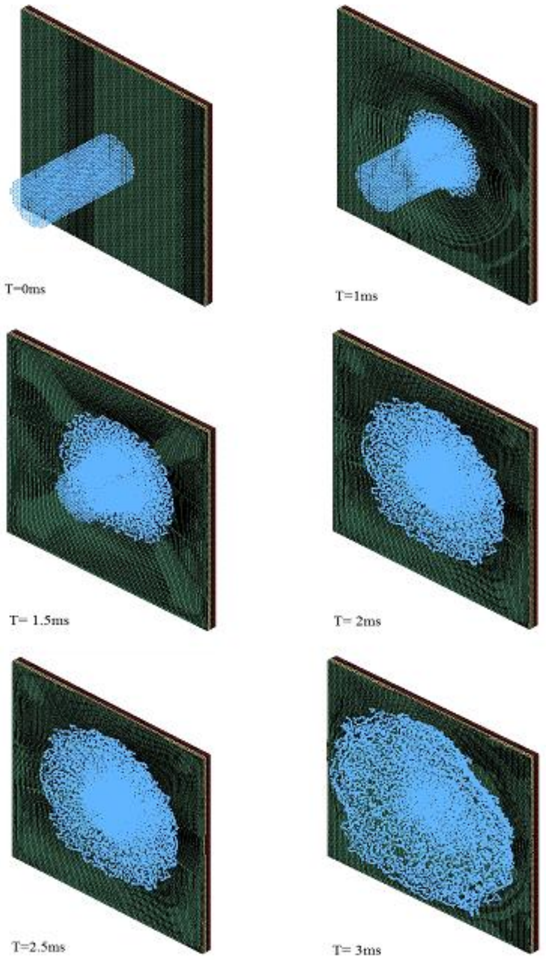

Fig. 12. Bird impact on 1 Sq. m sandwich panel at different time intervals

The fluid is represented by a group of moving particles changing their position with respect to fluid velocity. The particles of SPH are denoted as an interpolation points on which all fluid properties are known. Particle distribution of bird is similar to mesh of the target in order to maintain a proper interaction between nodes to surface contact. The shape of the bird was chosen to be a cylinder to represent an experimental bird model. The bird is modelled such that its length was twice that of diameter and possesses a weight of 1.8 kg with a density of 938.5 kg/m^3. The different stages of the bird impact are simulated on sandwich panel is shown in Fig. 12. The following are the observations for the impact of 1.8 Kg bird at a speed of 150 m/s.

- No penetration observed.
- No fragments of secondary projectiles.

The above condition satisfies that the panel Nomex sandwich with BD face sheet is capable of withstanding bird impact load at a speed of 150 m/s.

IX. ELECTROMAGNETIC TEST

Nomex honey comb sandwich panel with BD face was fabricated using wet layup technique and tested in far field anechoic chamber measurement facility for evaluating electromagnetic properties. A 16 element electronically scanned antenna array is selected and fitted with the radome material as shown Fig. 13. The measured antenna patterns with and without radome material for frequency range from 2.5 GHz to 4.5 GHz shown in Fig. 14 and 15.

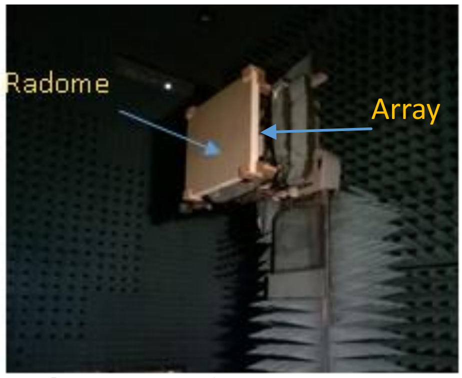

Fig. 13. Electro Magnetic measurement set up

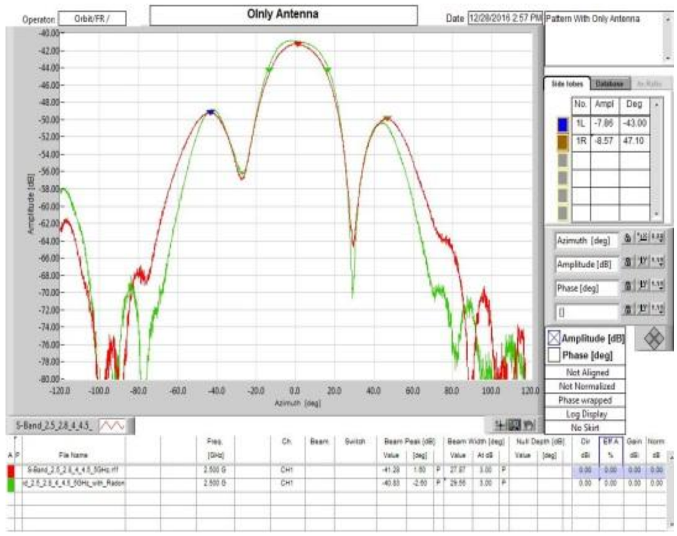

Fig. 14. Pattern for antenna and radome (frequency = 2.5 GHz)

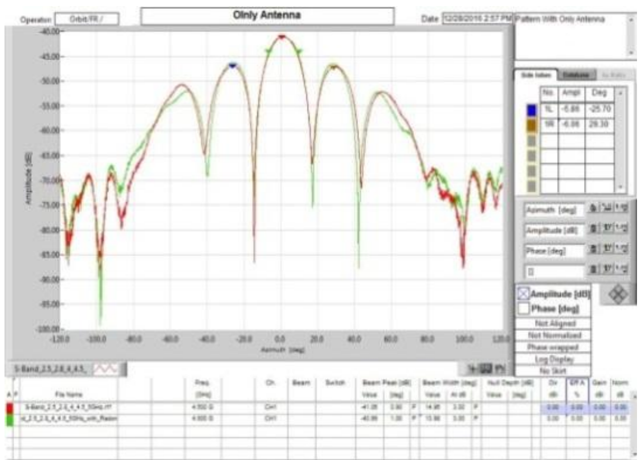

Fig. 15. Pattern for antenna and radome (frequency = 4.5 GHz)

There is no significant change in the antenna patterns in main lobe as well as side lobe level, beam width and the beam pointing angle. The radome hence concluded as electromagnetically transparent with very minimal effect on antenna radiation properties in the S-Band.

X. CONCLUSION

Mechanical tests were performed as per ASTM standards and the results are presented. The bird impact analysis carried out on a sandwich flat panel is discussed. The pattern for antenna and radome for flat panel sandwich radome measured in far field measurement facility is also discussed. The following conclusions are drawn from the study.

1. In general, it is observed from the tests that the maximum load bearing capacity was higher for the sandwich samples with unidirectional face sheets. The Nomex sandwich with UD face sheet had a maximum load of 35300 N which is 27% considerably higher than the Rohacell sandwich with UD Face sheet.
2. But in bi-directional samples, the percentage increase in load was only 23%. The load bearing capacity of the Nomex sandwich was appreciably higher than the Rohacell sandwich in all the sandwich configurations.
3. Overall the facing bending strength of the Nomex sandwich with UD face sheet is 1.83 MPa which is higher than the Rohacell sandwich with unidirectional face sheet of 1.44 MPa.
4. Honeycomb sandwiched laminates deform much lesser than the Rohacell sandwiched laminates which shows that the stiffness of honeycomb sandwiched laminates are higher than that of Rohacell sandwiched laminates.
5. Nomex sandwich with BD face sheet have higher compressive load carrying capacity among other three configurations and capable of withstanding aerodynamic and structural load. The compressive modulus of Nomex honey comb with BD face sheet is 60 MPa. The facing strength and shear strength of the 3-point and 4-point flexural bending is evaluated to be 41.82 MPa, 0.467 MPa and 39.35 MPa, 0.877 MPa respectively.
6. Bird impact analysis was carried out on a flat panel of size 1 m x 1 m. Nomex honey comb sandwich with BD face sheet is capable of withstanding bird impact load at 150 m/s with bird mass of 1.8 kg.
7. Nomex honey comb sandwich with BD face sheet was tested in far field anechoic chamber for the range of frequency. There is no significant change in the antenna patterns with and without radome structure. The loss in boresight due to radome is estimated to be less than 0.5 dB for the frequency of interest and can be concluded as electromagnetically transparent.
8. The design of radome involves multi-disciplinary study that involve electrical, structural requirement. The sandwich under study satisfies the condition of both electrical and structural requirements and hence the Nomex honey comb sandwich with BD as face sheet is considered as a choice of material for radome for airborne applications.

ACKNOWLEDGMENT

The authors would like to thank MS Easwaran, Director, CABS and Suma Varughese, Outstanding Scientist, CABS for their technical support. The authors are thankful to Mr. M. Karthick and Mr. Mandeep Singh for their support during research. The authors express their sincere thanks to Dr. V Arumugam, MIT, and Prof. Dattaguru of Jain University for their encouragement and help during the research.

REFERENCES

1. G. A. E Crone, A. W. Rudge, Sen. Mem and G.N. Taylor, "Design and performance of airborne radomes: A review", IEE PROC, Pt. F, No. 7, Vol 128, December 1981.
2. Russo O, Colasante A, Bellaveglia G, Maggio F, Rolo L, "State of the Art Materials for KU and KA band Mobile Satellite Antenna Radomes". Telecommunications ground segments workshop, ESA/ ESTEC, Noordwijk, The Netherlands, October 2012.
3. Ilbeom Choi, Jin Gyu Kim, Dai Gil Lee, Sung Seo, "Aramid/epoxy composites sandwich structures for low-observable radomes" Composites Science and Technology, 71(2011), pp 1632 – 1638
4. *Alberto Corigliano, Egidio Rizzi, Enrico Papa* Experimental characterization and Numerical simulations of a Syntactic-foam/ glass-fibre Composite sandwich", , Composites Science and Technology 60, 2000, pp. 2169-2180.
5. Strait IH, Karasek & Amateau MF, Effects of stacking sequence on the impact resistance of carbon fibre reinforced thermoplastic toughened epoxy laminates, J. Comp. Mat 26 (12), pp. 1725-1740, 1992
6. Sebastian Heimbs, "Computational methods for bird strike simulations - A review. Computers and structure", volume 89, December 2011, pp 2093-2112
7. Lavoie M A, Gakwaya A, and Nejad Ensan M, "Application of SPH method for simulation of the aerospace structures under impact loading,"*10th* International LS DYNA users conference 2008, Michigan, US, January 2008, Pp 35 – 42.
8. G. Hanssen, Y. Girard, L Olovsson, T Berstad, M Langseth, 'A Numerical Model For Bird Strike Of Aluminium Foam Based Sandwich Panel'. International Journal Of Impact Engineering 32 (2006), 1127-1144.
9. LS-DYNA, "Application of SPH method for simulation of Aerospace structures under impact loading," in 10th International LS-DYNA users conference.

AUTHORS PROFILE

S. Ilavarasu obtained his M.E (Aeronautical Engineering) degree from Madras Institute of Technology, Chennai and currently pursuing Ph. D at Jain University Bangalore. Presently he is working as Scientist 'F' at Center for Airborne Systems (CABS), DRDO, Bangalore. His area of interest includes composite radomes for airborne surveillance applications and structural assembly of airborne structure. His contribution to present paper is towards simulation of bird strike impact, fabrication of coupons, testing and analysis of the results obtained.

Dr. A C Niranjanappa obtained his Ph. D from Indian Institute of Science, Bangalore. India. At present he is Group Director and taking care of aircraft operations and mechanical engineering group. His area of interest involves damage characterization of composite radome. His contribution to the present work are arriving at test methodology and analysis of results obtained from the test.

P. A. Aswatha Narayana obtained his Ph. D from Indian Institute of Technology, Madras. He has served 35 years as professor at Indian Institute of Technology, Chennai. He has published more than 70 papers in international journals His area of interest includes Computational Fluid Mechanics, Aerodynamics, Flight mechanics. His contribution to the present work are to provide overall guidance to the research team.