Graded Carbon Materials Based Radar Absorbing Structural Composite for X Band Stealth Applications

Abstract— The proposed work in this paper describes about the electromagnetic design, simulation and fabrication of a multilayer carbon materials based radar absorbing structural (RAS) composite working for X band application. The RAS laminates have been fabricated using the lossy carbon materials in the epoxy matrix along with the glass fabrics as the load bearing elements. Initially various RAS laminates were fabricated using the vacuum bagging technique and characterized for its permittivity and loss tangent values. Further based on the electromagnetic design and optimization the graded laminates were stacked for final optimized configuration of RAS composites. The developed RAS was characterized for electromagnetic properties using the free space measurement system and shows minimum 10dB reflection loss in X Band frequency region. The fabricated composite shows remarkable mechanical properties, shows its potential application for radar stealth applications.

I. INTRODUCTION

Stealth technology, which includes radar cross section (RCS) reduction, has become essential in the era of electronic warfare. RCS reduction can be achieved by the shaping of aircrafts, by using radar absorbing material coatings (RAMs) and radar absorbing structures (RASs). Shaping of the aircrafts includes the design of external features of the aircraft to reduce the electromagnetic (EM) wave reflection in RADAR direction. The RAM and RAS are developed with an objective to absorb the electromagnetic radiation and thereby minimizing the reflected waves. Shaping of the aircrafts has its own limitations because it may interfere with the external profiles set by aircraft designers to meet the aerodynamic requirements. Therefore, the developments of RAM and RAS have become essential for RCS reduction. RAMs are generally fabricated in the form of sheets which consist of insulating polymer as matrix material and magnetic or dielectric lossy filler materials. RAMs are easily applied to the surfaces of existing structures but they increase the structural weight and have poor mechanical and environment-resistant properties. Thus, RAMs are not stand alone materials and cannot be used as load-bearing structures. Further they require constant maintenance and repair. RAS consists of fiber reinforced composites and lossy materials which are dispersed into the matrix of the composites. The radar absorbing efficiency of RAS is obtained from such materials that provide special absorptive properties and structural characteristics such as stacking sequence of composite layers. The stacking characteristics of the composites facilitate multilayered structures, which are necessary to broaden the reflection loss bandwidth. For a lossy filler to be highly effective, it should have a high conductivity for attenuation of wave, a high aspect ratio to form a conductive network, and a small size relative to the skin depth. The absorption and reflection characteristics of a RAS depend on a number of variables, which includes frequency, incident angle & polarization of EM wave and permittivity, permeability & thickness of each layer of the RAS.

In this study, the RAS for X -band frequency region was designed and developed using porous carbon black and carbon fibers as radar absorbing materials and glass/carbon fabric as reinforcement in the epoxy media. The RAS was developed by stacking the four different layers using vacuum bag molding technique and characterized for their mechanical properties and electromagnetic properties in X band frequency region by free space measurement system. The stacking sequence of the layers for this RAS was derived by carrying out the simulation studies using the layer properties i.e. effective permittivity and thickness. To determine the effective permittivity of an individual layer, it was fabricated separately and was evaluated using Free Space Measurement System.

II. FABRICATION OF RAS LAMINATES

The matrix system used for the fabrication of composites was Araldite 5052 (epoxy resin) and Aradur 5052 (hardener) from Huntsman advanced materials Pvt Ltd. This is a cold curing epoxy system with low viscosity (1000 – 1500 mPaS for Araldite 5052 and 40 – 60 mPaS for Aradur 5052 at 250C) and long pot life (2 hours for 100 ml at ambient).The mixing ratio of epoxy to hardener was 100: 38 parts by weight. E- glass 8H satin weave fabric of 300 gsm was selected as reinforcement. Firstly, the four individual layers of RAS were fabricated by varying the concentration of fillers in a definite order (Table 1). Since the filler materials used in this study are conducting, their proportion in resin system and stacking sequence of these layers is very much critical for fabrication of efficient RAS. First of all, the absorbing fillers were mixed with matrix system until uniform dispersion of each filler material was attained. Then, the modified matrix material was applied on reinforcement plies by wet lay up method. Finally, the individual layers of RAS were fabricated by vacuum bag molding technique.

TABLE I

Weight % of radar absorbing fillers w.r.t. composite layers

RAS Layers	Carbon Fiber (wt % in epoxy)	Carbon Black (wt % in epoxy)
S4	x	y
S3	2x	2y

S2 3.5x 4y

S1 5x 6y

III. ELECTROMAGNETIC CHARACTERIZATION OF RAS LAMINATES

The Free Space Measurement System (FSMS) from HVS Technologies, Pennsylvania State, USA along with Vector Network Analyzer PNA E8364B from Agilent Technologies, USA was used for measurement of complex permittivity and reflection loss of the RAS stacks and final RAS composites in the X band frequency region. The FSMS consists of a pair of spot focusing horn lens antenna to provide focused plane wave illumination at sample measurement plane. The FSMS was calibrated using Thru-Reflect- Line (TRL) calibration technique with time domain gating.

The variation of dielectric constant and loss tangent of composite stacks with frequency at X band frequency region, it can be clearly observed from the graph that permittivity values keep on increasing in ascending order from stack1- stack4. The stack '4' has highest value of real permittivity (14.82-12.32) and it has higher concentration of lossy ingredients which results for loss tangent value varying from 3.20-3.15 whereas RAS stack '1' has lowest value of real permittivity (4.94-4.99) and loss tangent value varying from .04-0.01

IV. ELECTROMAGNETIC DESIGN OF RAS COMPOSITES AND REFLECTION LOSS MEASUREMENT

An electromagnetic traveling along the positive Z direction is incident normally on the RAS stacks which results in a series of waves traveling along positive direction and reflected waves travelling along negative Z direction.

Let ti,?i and denote the thickness, complex intrinsic impedance and propagation constant of i th layer respectively (i=1,2,3………n), , are the permittivity and permeability of free space. Each stacks of radar absorbing structure is analogous to the transmission line of length ti.

Where Z0 is the characteristic impedance of free space i.e 377? and , are the complex relative permittivity and permeability of the ith layer media. In our case the termination layer having intrinsic impedance and thickness t4 (t4= t3= t2= t1) has been terminated with PEC, so its impedance can be expressed as short circuited transmission line

where and are intrinsic impedance and complex propagation constant of the layer. Using eqs.(1)-(2) the overall reflection co-efficient for a multilayer absorber at air interface is given as:

The Radar Absorbing Structure (RAS) was fabricated using the multilayer absorber concept, where stacking of different plies of glass fabric with different filler elements having different concentration were used. RAS composite was designed in such a fashion such that the top most layer facing towards the source side has impedance value approximately equals to free space impedance (377 ?) and gradient of successive layers were configured in such a way that the electromagnetic wave decays exponentially with the different absorbing stacks. The last layer i.e. termination layer consists of conducting carbon fabric which acts as Perfectly Electrical Conductor (PEC) such that no waves come out from the composite structure.

Now in order to validate the electromagnetic design, RAS composites were fabricated using the vacuum bagging process as discussed earlier for two configurations.

It can be observed from the above graph that the fabricated RAS for the configuration S1-S2-S3-S4 shows minimum 10 dB reflection loss having overall thickness of 3.6 mm.

V. CONCLUSION

In this paper we have shown the performance of dielectric material based multilayer radar absorbing structure for X band frequency region. In our design consideration we have taken equal thickness of 0.9 mm of each RAS stacks, in our analysis, it has been observed from our optimized design that a resonance peak was observed at 10.15 GHz having maximum reflection loss of -26.5 dB was observed along with minimum reflection loss of 10 dB across the entire X band frequency region for the composite thickness of 3.6 mm. The fabricated composites show potential applications for radar stealth applications.