Indian Journal of Pure & Applied Physics
Vol. 58, August 2020, pp. 629-634

Design and analysis of effective graded microwave absorbing material for low observable technology

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Received 7 December 2019; accepted 22 June 2020

Compositional designing of effective graded radar absorbing material for low observable technology is always a challengeable task in material science. The micro scale or quantum scale interaction of electromagnetic radiation is depends on the characteristic property of each atom or their assembly in a material composition. The filler and matrix in a composite structure plays a vital role between the advantages in electromagnetic absorption capability and the disadvantage due to difficulties in practical homogenous dispersion with weight concentration. The present work describes synthesis of biomaterial based effective graded radar absorbing material (RAM) for application in stealth technology. Ultrasonic treated rice husk raw material shows a significant increase of dielectric property of the composite material blended with epoxy resin. The significant modification in surface of the biomaterials with ultrasonic wave provides the enhanced mechanical strength as well as hardness of the material. Bio ceramic material composed of china clay and carbon rich waste rice husk ash possesses good dielectric loss for frequency 10 GHz and reflection loss -24.5 dB which is quite significant for stealth technology. Scanning electron microscopy (SEM) study shows good dispersion of rice husk ash in the epoxy matrix. Frequency dependence of both dielectric constant and dielectric loss are measured in the X band frequency range (8.2-12.4GHz). This low cost laboratory scale synthesized RAM find its application in designing of stealth aircraft and jet fighter for military purposes.

Keywords: Rice husk ash, electromagnetic interference, ultrasonic treatment, microwave, dielectric properties, radar absorbing material

1 Introduction

Very recent lunching of 5G network to the atmosphere and modernized digital life style of human beings not only traps the human life by electromagnetic radiation but also deactivate our communication system in radar and satellite as discussed at Baltimore, USA in march 2018 data published in American Institute of Physics. Thus to reduce the signature of electromagnetic interference (EMI) though, there are many method available as discussed by the researcher[1] but almost have given importance on new kind of stealth material. Low operating frequency range like 1GHz and many limitations in synthesis of such material and their operating limitations enforces the researcher for alternative potential carbon rich material for synthesis of EMI responding material and reduction of the radar cross section. The present paper encompasses carbon rich material from waste like rice husk ash and some metallic part like china clay which possesses good microwave responding properties by providing the data for dielectric loss, tangent loss and reflection loss. The variation of dielectric loss, tangent loss with frequency confirms the microwave absorption through the material. As a result the work keep its importance in developing low cost stealth material from waste with operating in X-band frequency 8.2-12.4GHz. The resulting material has good microwave absorbing property with nearly 90% power attenuated. The minimization of aircraft signature or reduction of radar cross section depends on the nature, composition and different characteristics property of surface absorbent of radar. As the material characteristics analytically calculated from the basic theory of reflection so it is used for designing of any radar absorbing material (RAM). The processing of RAMs is carried out by sufficient mixture of absorbing centres such as fillers in polymeric matrix which adjust the dielectric characteristics in a given frequency range[2]. The sufficient change in behaviour for filler material is allows the material to change its dielectric properties. The dielectric material is mainly characterized by two properties such as dielectric constant and dielectric loss factor. During the propagation, EM wave strikes on absorber or interface and undergoes the basic phenomena like reflection,

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transmission and absorption. Thus the permittivity of bio ceramic material, is the complex in nature and is given as:

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \quad \ldots (1)$$

where ε' is the dielectric constant represents the real part and corresponds to storage of electromagnetic energy and is the loss factor represents the imaginary part and corresponds to conversion of electromagnetic (EM) energy in to heat. The effectiveness of a material as an absorber is determined by loss tangent which results in attenuation of EM wave is given as[3]

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \quad \ldots (2)$$

2 Materials and methods

Rice husk raw materials are collected from local rice mill after para boiling processes for generation of stem which contain 75% of organic volatile. The rest 25% of the weight of this husk is converted into ash during the firing process which is called rice husk ash (RHA) which contains 85-90% of silica. The characteristics like high porosity, lightweight, and a large external surface area makes the silica become an alternative material for a good microwave absorber[4, 5]. The study of this material for microwave absorber mixed with china clay which contains different weight percentage of materials like aluminium, potash feldspar and quartz are expected to contribute for development a new type of bio ceramic which is expected to carry many technical characteristics related to microwave properties.

2.1. Sample preparation

For collection of rice husk silica the collected rice husk from rice mill was mixed with NaOH and then washed with distilled water three times so that dust and volatile materials removed from the rice husk. The dried rice husk was burnt at a temperature of 4000 °C for 5hr in an electrical furnace from which the black ash will produced. The black ash will again grinded and again heated to 6000 °C to complete the combustion processes. Further, by burning this RHA in a muffle furnace to a temperature of 8000C pure amorphous white silica will obtained called rice husk silica (RHS). China clay (Kaolin) was purchased from the *Loba Chemie* laboratory supplier. By the help of test sieve method both china clay (Kaolin) and rice husk ash powder were collected of size 150 μm. The epoxy resin was mixed with hardener and stirred properly to remove the air voids. Both the raw materials were weighed separately and with proper weight combination dropped in to the beaker containing the mixture of epoxy resin and hardener. All the mixtures were stirred for 30 minutes with a glass rod in the starting process and then with a sonicator for 30 minutes more. The dispersed mixture was poured in to the rectangular mould of size (23x11x3) mm. The mould containing the mixture placed at a cleaned dry place and loaded heavily at 50^0C for 24 hrs as shown in Fig. 1.

2.2. Characterization of Sample

The surface morphology of the rice husks and the rice husks composites was examined with HITACHI SU 3500 Scanning Electron Microscope. Scanning electron micrographs of rice husks and the rice husks composites are shown in the Fig.2 (a-e) with EDS. SEM micrographs show porous structure in the rice husks and micro voids in the rice husk composites and randomly arrangement of carbon and silica particles. In Fig. 2(a) it is observed that the raw rice husk particles are hexagonal shape arranged in arbitrarily manner. The EDS of the rice husk (Fig. 2(b)) indicates that the major constituents are carbon and silica which are basic components for responding the electromagnetic wave. Fig. 2(c) gives the

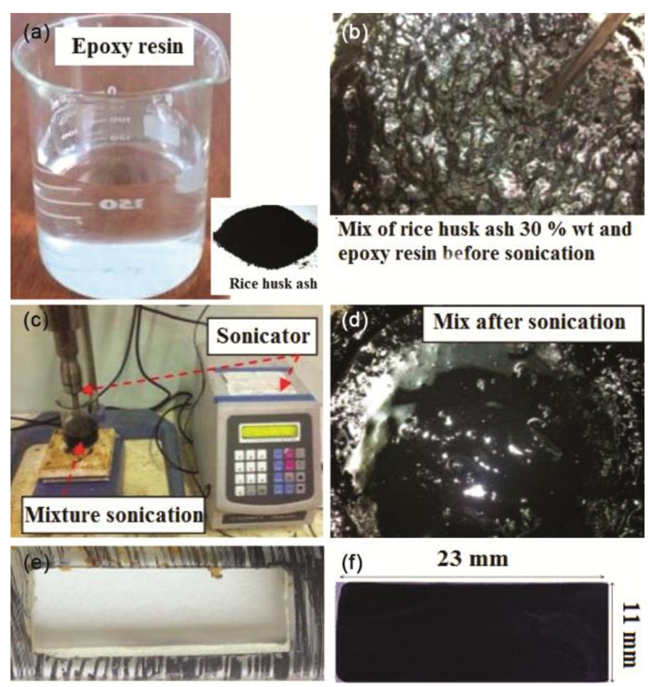

Fig. 1 — a) Ingredients: Epoxy resin and rice husk ash; b) Rice husk ash 30% wt and epoxy-resin manually mixed before sonication, c) Sonication process, d) Rice husk ash 30%wt and epoxy resin mixture after sonication. e) Rectangular mould for X-band sample; f) Synthesized biomaterial for microwave absorption..

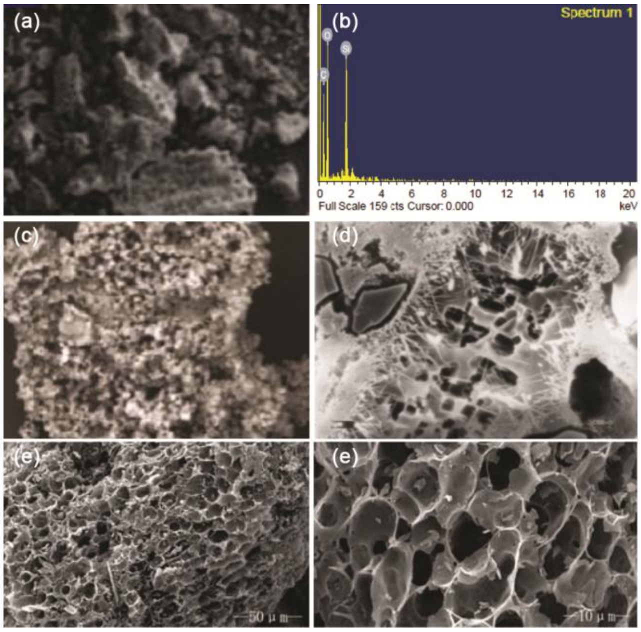

Fig. 2 — a) SEM of raw rice husk ash; b) EDS of Rice husk ash; c) Chemically treated rice husk ash with NaOH, d) Rice husk ash 30%wt and epoxy resin mixture with china clay.e) Porous and increased surface area of composite

SEM of chemically treated rice husk where the micro size particles are found to be enriched with major components of silica and carbon are coagulated giving crystal structure. SEM analysis of RHA and china clay composite as shown in Fig. 2(d) indicates that there is replacement of some components like quartz takes place by RHA and recrystallised secondary mullite needles in the matrix along with some quartz crystals which are small in size as well as less in number. The silica material has highly porous, lightweight, and a very high external surface area. Micrographs containing 30 wt. % RHA showed extensively interlocked secondary mullite needles embedded in the glassy matrix. It was probably due to the well-interlocked structure of mullite needles in the microstructure.

It can be seen that there is presence of the film like formation of transferred materials on the surfaces of composite. Fig. 2(e) suggests honey-comb structure of the composites in a resolution of 10micrometer. As the micrograph shows, the pores are placed very close to each other so that transmission of wave is less and gets attenuated within the randomly arranged carbon particles.

2.3. Microwave measurement

The analysis of microwave characterization performed by measurement of scattering parameters by the use of vector network analyzer from which the real and imaginary part of complex permittivity can be computed[6]. Before the measurement processes the wave guide is calibrated in X-band (8.2-12.4 GHz). Though the materials shows response to magnetic field but this response is very small and the permeability values differ from μ_0 by a very small fraction. In our work the relative magnetic permeability value for free space we have taken unity as there is no ferromagnetic materials are involved.

Fig. 3 — Experimental arrangement for microwave measurement

The electromagnetic radiation interaction study was performed by free space measurement in the laboratory for measurement of microwave absorption and its other properties for microwave analysis. The experimental set up for free space measurement consists of a pair of focusing horn lenses, transmitting and receiving antenna which are mounted on a large aluminium table (1.83 X 1.83 m^2) as shown in Fig. 3. The spot focusing horn lens antenna consists of two equal plano-convex dielectric lenses mounted back to back in a conical horn antenna. The ratio of focal distance to diameter of the horn lens (F/D) is unity and D is approximately 30.5 cm, the corresponding 3 dB beam width is 1λ and depth of focus is 10λ, where λ is the wavelength of measurement frequency. A special designed sample holder is placed at the common focal plane for holding the samples and is mounted on a micrometer-driven carriage. The sample was placed at the focal plane of antennas; measurement of the reflection loss of fabricated absorber with respect to the aluminium metal was carried after calibrating the transmission loss (TRL) calibration of the setup.

5. Result and discussion

The electromagnetic property of the bio ceramic composite containing 30wt% of RHA/china clay has

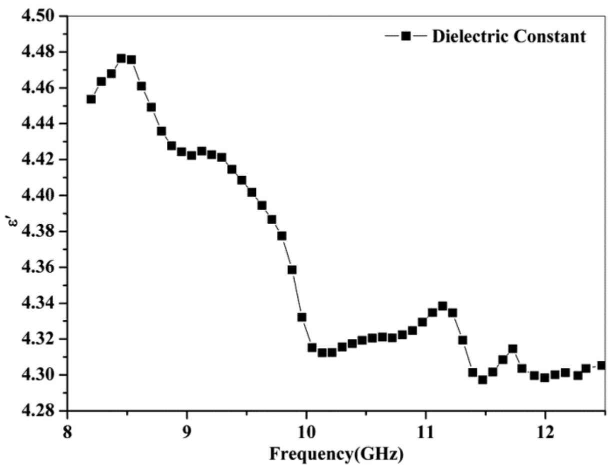

Fig. 4 — Variation of dielectric constant with frequency

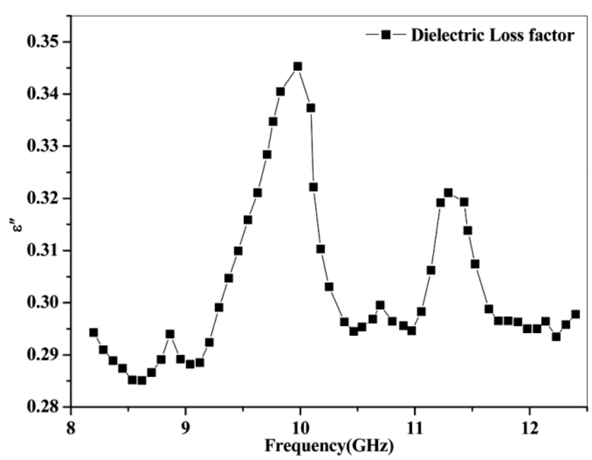

Fig. 5 — Variation of dielectric loss with frequency

been investigated, which are the significant importance to its microwave absorbing performance. The dielectric constant/imaginary part of complex permittivity (ε') represents a material's ability to store electrostatic energy in an applied electric field which is decreases from 4.47 to 4.30 with frequency as shown in Fig. 4. The quantity ε" is a measure of the attenuation of the electric field cause by the material which is increases with increase of frequency indicates that the loss of electrostatic energy up to 10 GHz in X-band frequency range. After this frequency it is further slightly increases as shown in Fig. 5 which may be due to appearance of different type of polarization phenomena[7-8].

The peak in the dielectric loss indicates that the highest absorption occurs at 10 GHz. ε″ decreases with increasing frequency, reaching a maximum value (*i.e.*, 0.345) at 10 GHz and again another maximum (*i.e.*, 0.325) at 11.5 GHz. The greater the loss tangent

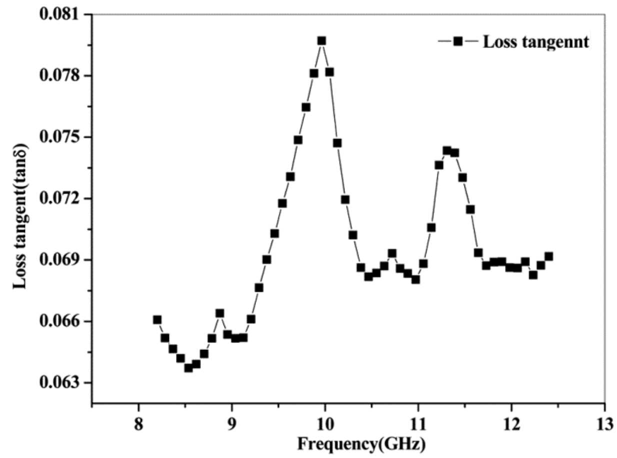

Fig. 6 — Variation of loss tangent with frequency

of the material, the greater is the attenuation as the wave travels through the material. The result signifies that the dielectric constant of bio ceramic material decreases with increase of frequency have high loss tangent at higher frequency like 10 GHz.Thus the material is suitable for microwave communication like antenna application at low frequency but can acts as microwave absorber at high frequency like 10 GHz and 11.5 GHz as shown in Fig. 6. This results is due to fact that the presence of higher percentage of silica in the bio ceramic material.

Further, if the multiple samples of different wt% of RHA is used then absorption will observed at same frequency range but the value of complex permittivity will increase as the percentage of carbon and oxygen will also goes on increasing. Again if the same will exposed for more time to electric field the dipoles number will increase due to different polarization and dielectric constant decreases and the loss tangent will increase which increases the absorption of electromagnetic wave. The reflection loss or reflectivity of the material indicates the correlation of different electromagnetic parameter. The reflectivity of materials indicates that the absorption reflectivity of these materials will increase with increasing real component of the complex dielectric constant. Fig. 7 shows the microwave-absorbing reflectivity of the bio ceramic occurs at ∼10 GHz, and the maximum absorption-peak reflectivity is −24 dB. These experimental results are attributed due to strong interfacial polarization between the compositional parts of bio ceramic composite[9].

From the morphology image of bio ceramic composite it is obvious that there is a no. of Si-O network formed in silica of RHA which increase the

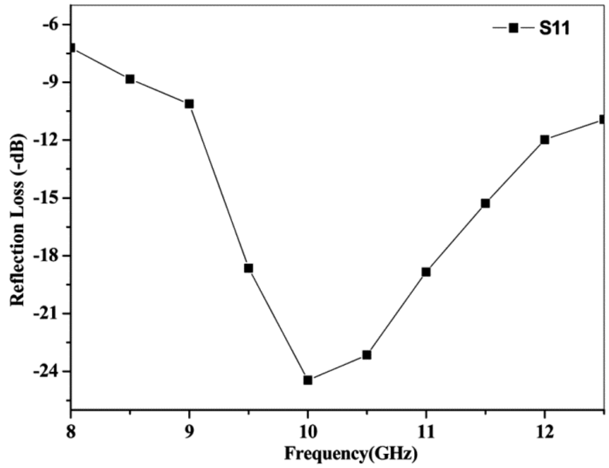

Fig. 7 — Variation of reflection loss with frequency

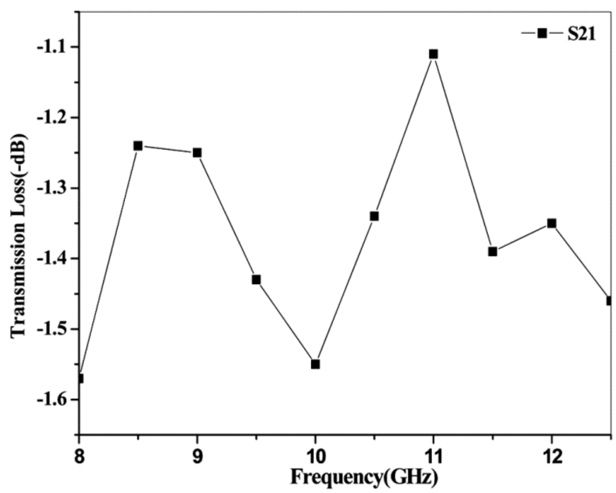

Fig. 8 — Variation of transmission loss with frequency

surface area of components of the composite responsible for interacting with microwave and increases the transparency of the material which helps in decreasing the reflection loss[10-11]. This results is comparable with the other studies where the works described the effect of crystalinity on microwave absorption with the concept of dielectric loss and responsible for reduction of reflection loss substantially in crystallization process[11].

The transmission loss and reflection loss are just reverse trends as observed from the Fig. 8. The transmission loss goes on increasing with frequency and it has low value at 10 GHz indicates that at high absorption frequency there is very less transmission .This may be due to fact that the crystallinity structure of Si-O network with polymer epoxy makes the bio ceramic become less transparent. As a result of which the material behaves as opaque medium at that frequency range. But due to further increase in electromagnetic frequency more dipoles are created due to debonding for which it shows the irregularity in trends.

6. Conclusion

The low cost, green method is successfully applied for synthesis of bio ceramic material. A series of material with different weight percentage of china clay and silica are synthesized containing different amount of silica and aluminium oxide obtained from RHA for microwave absorber was successfully performed but only the microwave characteristics of 30 wt% of composition discussed on the basis of the performance of microwave parameters. The results of dielectric constant, dielectric loss, loss tangent, reflection loss and tangent loss successfully explained the microwave absorption of the bio ceramic as well as microwave communication for antenna application in radar technology. The reflection loss-24 dB which is corresponds to above 90% power attenuation is quite significant in stealth application[12-13].The reflectivity of bio ceramic composite exhibits the effect of crystalline phase as observed from SEM has a close correlation in interaction of microwave radiation. More ever, the bio ceramic made from RHA/China clay can be suitable for both microwave communication as well as for microwave absorption. The benefits by using this material for stealth application are not only to make the stealth flights are specifically designed but also for reduction of radar cross section by reducing the IR signatures.

Acknowledgements

The authors are thankful to TEQIP-III VSSUT, Burla, Sambalpur for financial support under Collaborative Research and Innovation Scheme No.VSSUT/TEQIP/55/2020 and Vice Chancellor, VSSUT giving permission to conduct the experimental work in the laboratory.

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