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Development of Microwave Absorbing Material with Organic Waste based Epoxy Blended Composite

Akshaya Kumar Dash & G Nath*

Department of Physics, Veer Surendra Sai University of Technology, Sambalpur, Odisha- 768018, India

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The numerous use of electromagnetic wave based equipment and system leading to electromagnetic interference (EMI)which affects the misinterpretation of information in defense system, space communication and commercial applications. Thus to eliminate EMI, different shielding structures are some of the recent challenging issues which depends on the dielectric based properties of the fabricated material and its composition. The present work encompasses epoxy blendedcarbon riched organic biomaterial like rice husk granule which is a low cost, light-weight, and flexible microwave absorber treated as a promising eco-friendly microwave absorber. An extensive study has been performed for analysis of microwave absorbing property like dielectric constant, dielectric loss, tangent loss, attenuation constant and reflectionloss (RL) which depends on the dielectric values of the composition. The absorbers of thickness 3mm possess a RL of -14.5dBat10 GHz. The measured values of RL are supported by the attenuation coefficient indicating the importance of proposed composite material for practical microwave absorption applications.

Keywords: Noise absorption coefficient; Chemical treatment; Ultrasonic blended solutions; Isentropic compressibility; Surface modification

1 Introduction

The new generation smart electronic devices are based on advanced technology operating at lower electric power and high frequencies of electromagnetic radiations. This makes the electromagnetic based instruments become vulnerable to interference property causing tremendous amplification to the sources of electromagnetic source. As a result, this considerably increase of EMI sources not only causes electromagnetic pollution in the open environment but also affects the sustainability of electronic equipment and their operation in communication system, health related issues and detection of target or aircraft in military system in the radio frequency (RF) and microwave frequency range[1-3]. Thus care must be taken into account for minimization of EMI signature whiles the importance on dependability and qualities of the electronic and electrical instruments are evaluated. This can be usually achieved by use of stealth material which includes designing of special materials for microwave absorption[4]. The microwave absorbing material can be ideal one if it has strong absorbing capability, light weight and mechanically strong[5]. Though there are conventional ferromagnetic transitions materials are have high efficiency of microwave absorption capability but due to their low operating range below 1GHz and oxidizing effect, these materials needs some alternative material to replace them or they need some coating. The bio material residues left after the production of different agricultural products are basically the major source of organic materials in nature. The unwanted heavy deposition of this residues not only cause the environmental pollution but also creates the acute problem for residential life due to accumulation of more space in the earth surface. In India, rice husk is the huge waste produced due to agricultural activity and used for biomass fuel in rural region as alternative power[6]. As a strengthening agent rice husk used as additive in building material as well as absorber and insulator for acoustic insulation in different industries[7-9]. This simple use of rice husk reduces the cost of end product. As rice husk is rich in carbon, it can act as a good microwave absorbing material. Due its large surface area, light weight and high porosity nature, rice husk can be used for manufacturing light weight and highly efficient biocomposite material[10]. In recent years, research works on carbon based materials are in great demand. Microwave absorbing materials using conducting and non-conducting polymers are getting

*Corresponding author: (Email: ganeswar.nath@gmail.com)

high response due to their outstanding performance in the field of electromagnetic wave shielding[11-12]. Recently wood based products are getting attention due to their light weight, low cost and highly porous nature[13-15]. Some researchers chose composite of rice, wheat flour and cotton ton to test the EM shielding property[16]. Luffa and wheat straw have been treated with metal ions to make composite and test the microwave absorbing property[17]. There are many literatures found regarding use of organic biomass in making composite for microwave absorption but still more intensive research is required in the field of designing of microwave absorptive material[18]. This work focuses on investigating the material aspects of the absorbers, which include the synthesis and microwave property analysis of the material. The complex permittivity of the material was measured with two port vector network analyzer. The free space method is deployed in order to get the response of microwave of rice husk composites. The reflection loss of the material represents the absorbing performance which is expressed as the function of frequency and complex dielectric properties of the material.

2 Materials and methodology

Rice husks were collected from local rice mill industries are soaked with acetone blended ethanol solvent mixture to remove the impurities and reduce the moisture part present on the surface[18]. The reaction of surfactants with the rice husk is shown in equation 1.

$$\text{Rice husk} - OH + CH_3COOH + C_2H_5OH$$
$$\downarrow$$
$$\text{Rice husk} - COOC_2H_5 + C_2H_5CH_3 + H_2O \uparrow \quad \dots (1)$$

Where, CH_3COOH is acetone and C_2H_5OH is ethanol. When these surfactants react with the cellulose part of the rice husk fiber they eliminate water from the fiber surface in the form of water vapour. The result of hydrophobicity and bleaching makes the rice husk become more porous so that it leads to better interlocking of rice husks with embedded matrix added to it. These inter binding of the rice husk and matrix increases the mechanical strength to the composites. The treated rice husk were kept at a temperature of 80 - 90 °C in a furnace to make them become completely dry. This small sized rice husk mixed with polymeric material like epoxy resin and hardener such as methyl ethyl ketone peroxide which enables the rice husk reinforced strongly bind with the polymer matrix makes it mechanically strong[19]. The polymer blended rice husk dust poured into a rectangular mold of dimension (23mmx11mmx3mm) for synthesis of X-band sample as shown in Fig. 1.

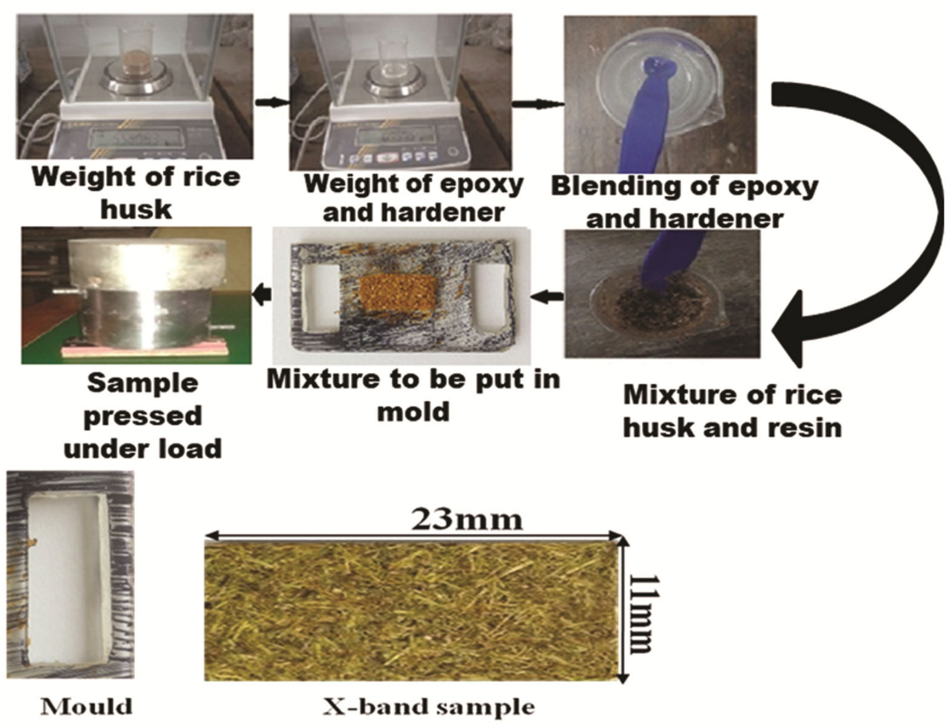

Fig. 1 — Steps for the developing the samples from rice husk.

3 Characterization of sample

The raw sample, bleached and the composite synthesized from rice husk are characterized with Scanning electron microscopy (SEM) are shown in Fig. 2 (a-d). The surfaces of the treated rice husk are become rough after the chemical treatments which are clearly observed from the SEMs of the sample. The roughness of the surfaces of the rice husk is due to removal of moisture and evaporation of the ethanol from the surfaces.

The presence of the more interacting surfaces on the rice husk surfaces makes the rice husk become interlock with the polymer matrix resulting strong binding between them which increase the mechanical strength of the material[20]. SEM micrograph Fig. 2 (c) of composite exhibits the dispersion of rice husk embedded within the epoxy resin polymer with strong networking facilities for interaction of microwave. The elemental analysis on microstructure of composite indicates the microwave responding elements like carbon and oxygen which are responsible for absorption and making the composite became lighter respectively are shown in Fig. 2 (c,d) and with their weight percentage in composite. The absence of silica indicates that the material has higher dielectric loss which implies that the material can be suitable for fitting inside anechoic chamber.

4 Microwave absorber theories

As an incident microwave is a coupling of an oscillatory electric field and magnetic field, the materials which induce microwave absorption do so by interacting with either one of these two fields, or both, so as to drive light and matter interaction at the GHz region of the electromagnetic (EM) spectrum. This action is in accordance with Maxwell's equations, where the perturbation of one of the electromagnetic fields by interaction with a material medium will induce a response change of the other, resulting in the dissipation of the entire electromagnetic wave. Dielectric loss is the characteristic electronic interaction between the electric field of the incident electromagnetic radiation and the dielectric material that results in reflection loss. Microwave absorbers are the composite materials formed by combination of filler which consists of one or more constituents that mostly responsible for absorption. The factors like complex permittivity and permeability distinguished the composite for electromagnetic interactions.

The effects of electric field and magnetic field on materials are well studied by measurement of dielectric properties of the material in terms of permittivity and permeability of the material. As the composite has been synthesized from agricultural waste like rice husk, the material is basically a

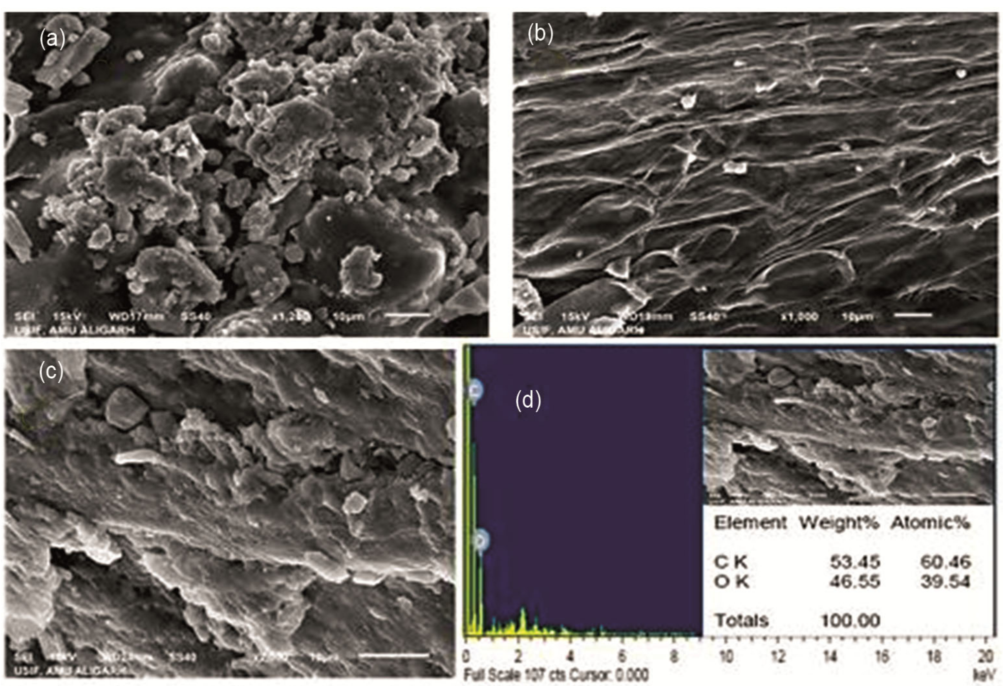

Fig. 2 — SEM of (a) Un treated rice husk (b) Treated rice husk (c) Rice husk composite and (d) EDS of rice husk composites.

dielectric which is mainly characterized by dielectric constant (ε') and dielectric loss (ε'') is defined by complex permittivity as[19]

$$\varepsilon^* = \varepsilon' - j\varepsilon'' \qquad \text{... (2)}$$

where ε^* is the complex permittivity, ε' is responsible for storage of electromagnetic energy and ε'' is responsible for energy dissipation in the materials respectively and j is a complex number ($j = \sqrt{-1}$). Measurement of dielectric loss tangent is another parameter for determination of the intrinsic property of composite as an absorber which results in absorption of EM wave is given as

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad \text{... (3)}$$

Where, $\tan\delta$ is the loss tangent and δ is the loss angle of the dielectric caused due to dielectric polarization leading to heating of dielectric material. With increasing in loss tangent of the material the attenuation of wave increases. Since the fabricated material is dielectric one the fitted electromagnetic wave (EM) equation is same as the propagation of wave in a non-magnetic dielectric medium given as

$$\nabla^2 \vec{E} - \mu^* \varepsilon^* \frac{\partial^2 \vec{E}}{\partial t^2} = 0 \qquad \text{... (4)}$$

Where $\vec{E}$ is the electric field vector, ε^* is the relative permittivity, μ^* is the magnetic permeability. Since the materials is nonmetallic we have to assume the real part of magnetic permeability as a unity ($\mu' = 1$) and the imaginary magnetic permeability as zero ($\mu'' = 0$). Thus the wave equation reduced to

$$\nabla^2 \vec{E} - \varepsilon^* \frac{\partial^2 \vec{E}}{\partial t^2} = 0 \qquad \text{... (5)}$$

The frequency dependence attenuation coefficient of the material is given as

$$\alpha = \frac{\sqrt{2}\pi f}{C}\left(\sqrt{\left(\mu''\varepsilon'' - \mu'\varepsilon'\right) + \sqrt{\left(\mu''\varepsilon'' - \mu'\varepsilon'\right)^2 + \left(\mu''\varepsilon' + \mu'\varepsilon''\right)^2}}\right) \qquad \text{... (6)}$$

Where, f is the frequency and C is velocity of electromagnetic wave.

Power absorption by the material is given by[21]

$$PowerLoss\ (\%) = 100 * (1 - |\gamma^2|) \qquad \text{... (7)}$$

Where, γ is the reflection coefficient.

Electrical conductivity of the fabricated composite has been calculated using the following formula[22]

$$\sigma = 2\pi f \varepsilon_0 \varepsilon'' \qquad \text{... (8)}$$

Here, σ is electrical conductivity of the material, e_0 is the free space permittivity, f is the frequency, ε'' is the component of permittivity.

5 Result and Discussion

Dielectric properties of the samples were measured using Vector Network Analyzer with Agilent technologies 85070 software. Since the material is synthesized from the organic waste it possesses dielectricproperty while its permeability factors are ignored assuming $\mu_r' = 1$ and $\mu_r'' = 0$. The free space measurement of the material was conducted to analyze the microwave property and the experimental set up is shown in Fig. 3

The measured values of real and imaginary part of the dielectric property observed from the data collected by vector network analyser are described with the frequency as shown in Fig. 4. The dielectric constant of the material decreases with increase of frequency in X-band range indicates the material has low capability to store electromagnetic energy. This variation of dielectric constant is attributed due to fact that interaction of electromagnetic wave with the material causes debonding of carbon chain in polymeric resin material as well as the rice husk. As a result of which the formation of dipole between the different atoms goes on decreasing leading to decrease in dielectric constant[20].The decrease in dielectric constant from 3.68 to 3.48 were explained by contribution of the different type of polarization caused by atomic and ionic polarization and their effect are well active at high frequency region like

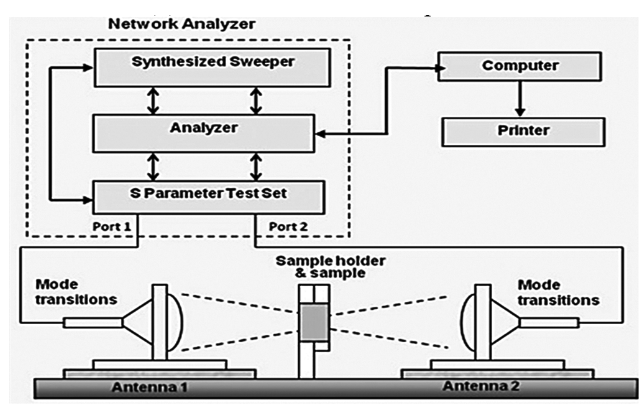

Fig. 3 — Experimental arrangement for microwave property measurement.

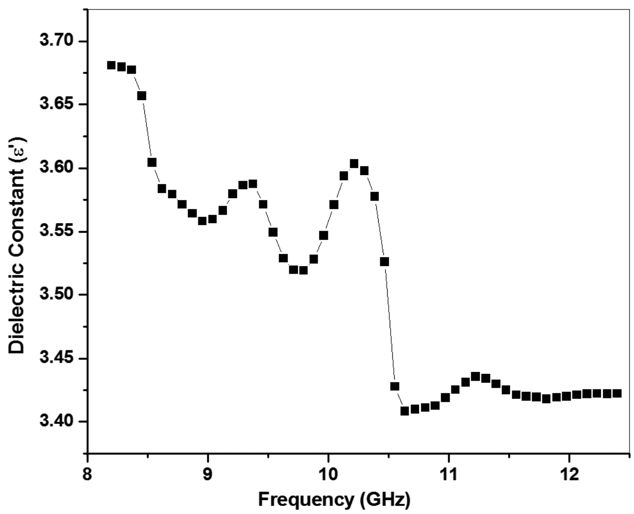

Fig. 4 — Variation of dielectric constant with frequency.

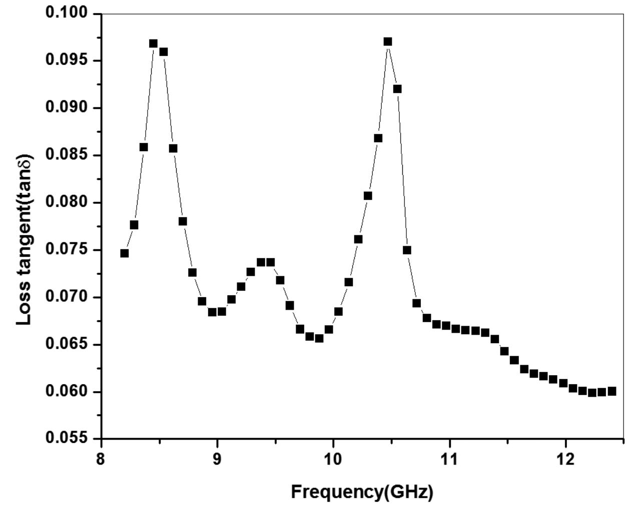

Fig. 6 — Variation of loss tangent with frequency.

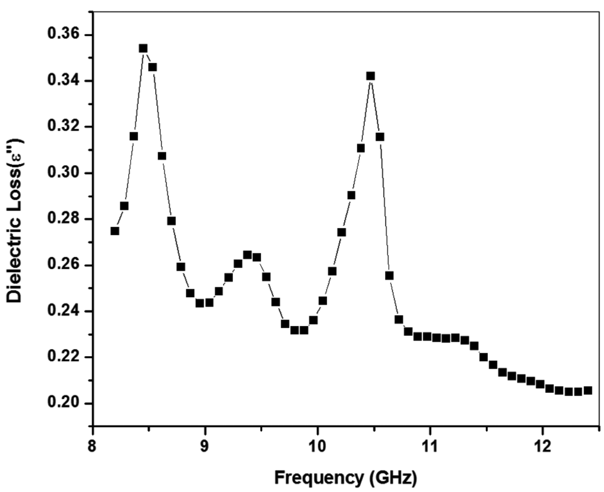

Fig. 5 — Variation of dielectric loss with frequency.

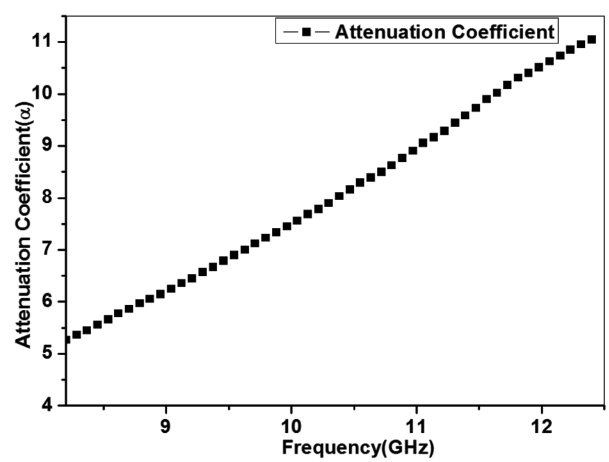

Fig. 7 — Variation of attenuation coefficient with frequency.

11GHz to 12GHz where the entire composite material in fully ionized condition. Further the dipolar polarization is attributed in the composite by the atomic dipole due to interaction of microwave with polymer blended material and whereas conductivity plays the significant role in producing the interfacial polarization in the material[21]. Since at low frequency the orientations of dipole produced without new dipole formation, the material has high dielectric constant and decreases due to time lag in orientation of dipolar polarization[22-23].

The dielectric loss and tangent loss of the material shows an increasing trend with frequency displayed in Fig. 5 and Fig. 6.This indicates that the material have less capability to store electromagnetic energy with more dispersed without any reflection. The variation of dielectric loss is contributed by the fact that with increase of frequency, the intrinsic dipole moment and relaxation processes between the ionizing atoms increases tremendously which leads to more absorption within the material[24].

As the material absorbs the electromagnetic energy incident on it, the attenuation coefficient is also increase proportionally as shown in Fig. 7. From the profile it is observed that the attenuation coefficient (α) increases with frequency due to collisional loss of energy between the atoms of the neighbours. Since the composite material is lossy medium, so the propagation of electromagnetic wave is attenuated as per property of the wave equation.

The propagation of electromagnetic wave is undergoes multiple collision between the networking structures formed by matrix with rice husk and this attenuates the electromagnetic wave with increase of

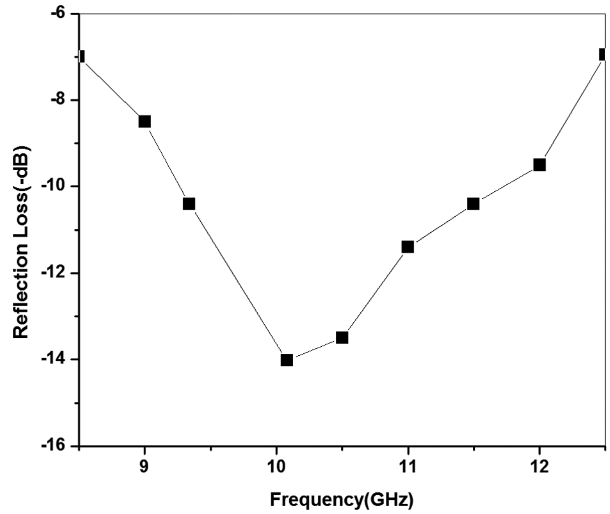

Fig. 8 — Variation of reflection loss with frequency.

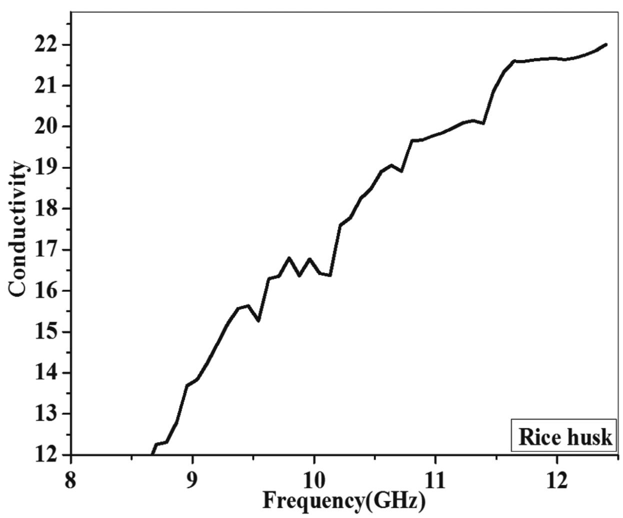

Fig. 9 — Variation of microwave conductivity with frequency.

frequency converting it in to thermal energy. The reflection loss of the material decreases with increase of frequency as shown in Fig. 8. It has a value of -14.5dB which is below -10dB at frequency 10GHz.As the material has high dielectric loss and attenuation coefficient increases with increase of frequency it decreases the amplitude of the electromagnetic wave and power loss corresponds to 90% which was calculated using equation 7.This indicates that material have good response to electromagnetic wave and completely attenuates inside it[25].

The conductivity of the sample was calculated using equation 8. A graph for change in electrical conductivity of the material with respect to varied frequency from 8GHz to 12GHz at room temperature is shown in Fig. 9. From the graph it was observed that with increase in frequency the electrical conductivity is increasing. This trend of increasing conductivity may occur due to hopping mechanism which appears when electrical field is applied on the material[26-27].

6 Conclusions

The investigation confirmed that epoxy resin mixed with rice husk gives different dielectric constant and loss factor of a microwave absorber. The synthesized epoxy blended rice husk material has good microwave absorbing property as found from variation of all parameter. The entire work based on green synthesis without use of any costly and environmental pollution chemicals which gives new direction for use of waste material. The material shows good absorbing property in X-band range which has practical application for radar in defense system and executes as a potential alternative material for high cost ceramic material. Lastly, it can be concluded that the agriculture waste like rice husk have an enormous potential as an alternative material for fabricating microwave absorbers which find its application in designing of stealth material or coating of the same.

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