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Agricultural Waste based Biocomposite for Electromagnetic Shielding Application

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The enhanced significant use of electromagnetic wave introduces new type of pollution in the environment called Electromagnetic Interference (EMI). Different shielding techniques though successfully works in the present scenario but small efficiency of attenuation and absorption capacity of traditional ceramics demands some alternative potential material for enhanced shielding efficiency, which can be realised from agricultural waste such as rice husk, sugarcane bagasse, etc. Further, the shielding structure and composition of composite are the current issues which depend on the dielectric properties of the fabricated materials. In the current work, rice husk, an organic biomaterial rich in carbon, is combined with epoxy to create a microwave absorber that is flexible, inexpensive, and eco-friendly. The different microwave absorbing property such as complex dielectric, tangent loss, attenuation constant and Reflection Loss (RL) of −14.5 dB at frequency 10 GHz are found to be possessed by the synthesized composite of thickness 3 mm which is determined from composite's dielectric values. The attenuation coefficient supports the measured values of RL, highlighting the significance of the suggested composite material with a power attenuation efficiency of around 87% for legitimate microwave absorption applications. The presence of good percentage of elemental combination like carbon, oxygen and silicon makes it possible for increasing the percentage of activated carbon which is not present in any other synthetic component for the same purpose. Further use of carbon rich waste material is an advantageous impetus for material industries to enhance the percentage of activated carbon for shielding purpose.

Keywords: Attenuation coefficient, Dielectric loss factor, Electromagnetic interference, Shielding techniques, Tangent loss

Introduction

The latest generation of smart electronics uses cutting-edge technology that operates at high electromagnetic frequency and low electric power. Because of this, electromagnetic-based instruments are more susceptible to interference, which greatly amplifies the sources of electromagnetic wave.[1–3] Due to this significant increase in EMI sources, there is tremendous increase in electromagnetic pollution in the open environment creating the different communication issues of Electromagnetic (EM) signal not only to general life but also in space communication and military system.[4–6] So, while evaluating the necessity of dependability and quality of the electrical and electronic instruments, it is essential to reduce EMI signature. Before they can be commercialized, electronic equipment must adhere to the Electromagnetic Compatibility (EMC) regulations, which place restrictions on them.[7–10] These devices are subjected to thorough EMC testing to ascertain the levels of compatibility, shielding effectiveness, reflection-free environments, or anechoic chambers.[11]

This is typically accomplished by using stealth materials, such as specially designed materials for microwave absorption.[12] If the material for absorbing microwaves is lightweight, highly absorbent, and mechanically robust, it can be the ideal one.[13] Even though typical ferromagnetic transition materials have a high efficiency of microwave absorption capability, they need to be replaced by another material or coated because of their limited operating range below 1 GHz and oxidizing effect. Synthetic EMI shielding material made up of polyurethane foam and other polymers are composed of many hazardous chemical such isocyanates and combination of polyether polyol alcohol are lead to serious respiratory issues like asthma and deteriorated lung function.[14,15] The presence of Isocyanate in foam dust though makes the composite attractive but its interaction with environment cause many issues related to health.[16,17]

The primary sources of organic materials are basically the residues of various agro based industries and residues of crop harvesting activities. The

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overwhelming amount of the agricultural waste produced in India is rice husk, which is used as an alternative fuel source for rural areas.[18] Rice husk being a biodegradable organic and highly bioavailable with lossy carbon and easily accomodable with resin polymer can be used as a strengthening agent for building materials as well as an insulator and absorber for EMI.[19–21] Because of the enormous surface area, reduced density, pore volume and carbon, as a necessary and abundant component of rice husk it aids in the absorption of the microwave component of electromagnetic waves.[22]

Most of the past studies concentrates only on computational based simulation work with different synthetic material and very few natural carbon based material with their EMI shielding capability to disperse the electromagnetic noise.[23–25] Almost no work or a few work has been found which analyze these EMI shielding capability with different natural organic material and experimented successfully but the majority of these studies used simulation techniques to study solid shapes that were fashioned as pyramids or wedges. Furthermore, these studies has been carried out with low frequency range and no information was suggested on the development of material like rice husk.

The microwave absorbers considered in this study are made using a fairly straight forward process using rice husks as the base material for composite. Because of its effective dielectric properties and relatively high mechanical strength, rice husk is chosen for the construction of different EMI shielding structures. The nonlinear behavior of the permittivity of the fabricated rice husk reinforced composite is studied by Vector Network Analyzer (VNA) and different microwave related parameters are computed for analysis of microwave shielding effectiveness. Further, two horn method is used to validate the response of electromagnetic wave in epoxy blended rice husk composite.

Materials and Methods

Local rice mills provides the rice husks, which were then immersed in an acetone-ethanol solvent mixture to eliminate contaminants and reduce surface moisture.[26] The alcohol treatment results in hydrophobicity of the rice husk along with formation of high surface roughness which helps for interlocking between the reinforced materials and epoxy polymer resin to enhance the mechanical properties of the fabricated material.[27] The treated rice husks were dried entirely in an oven at a temperature of 80°–90°C for 1 hr, then ground into dust to particle size of 150 µm using a test sieve. This tiny particle, combined with methyl ethyl ketone peroxide as hardener and epoxy resin as polymeric substance allows the reinforced rice husk to tightly bound with the polymer matrix and renders the material mechanically robust.[13] For the manufacture of an X-band sample, rice husk dust mixed with a polymer was poured into a 23 × 11 × 3 mm rectanglar mould as shown in Fig. 1.

Characterization of Sample

The application of surfactants with untreated rice husk modifies the surface, which results the increase in surface roughness along with formation of more reactive sites for the fabrication of shielding material as evident from Fig. 2(a–b). Due to moisture loss and ethanol evaporation from the surfaces, the rice husk's surfaces become rough, leading to boosting of mechanical strength.[28] The Scanning Electron Microscopic (SEM) micrograph of the composite (Fig. 2c) shows that rice husk are dispersed uniformly in the resin matrix forming a compact structure. There is presence of microwave-responsive elements, such as carbon and oxygen with high absorption as evident from Energy Dispersive Spectroscopic (EDS) image Figs. 2(d) together with the percentage of each element's weight in the composite. Again, the lack of silica suggests greater dielectric loss in the sample indicating the material is suitable for application in designing of anechoic chambers.

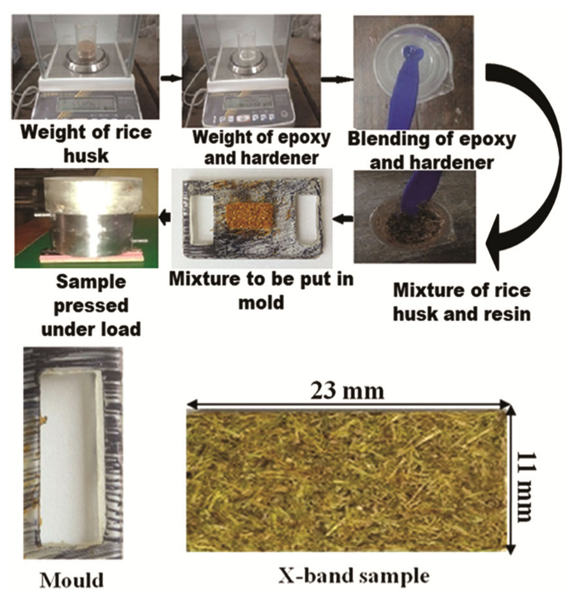

Fig. 1 — Procedures for preparing specimens with rice husk

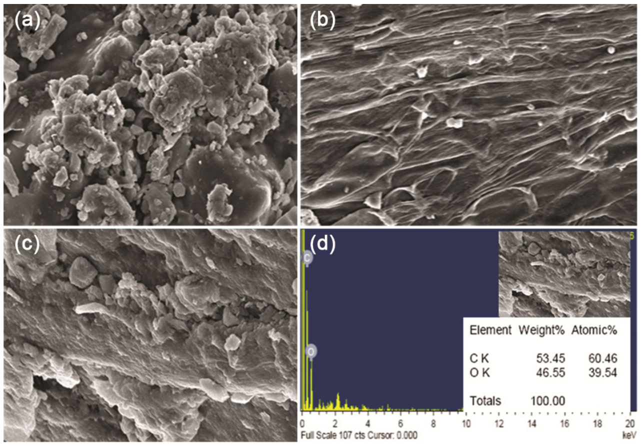

Fig. 2— Scanning electron microscopic image of rice husk: (a) unbleached; (b) modified; (c) reinforced composite; and (d) energy dispersive spectroscopic image of composite

Microwave Absorber Theories

The materials that cause microwave absorption do so by interacting with either one of these two fields, or both, in order to drive light/matter interaction at the gigahertz range of the EM spectrum. This is in conformity with Maxwell's equations, which predict that when one electromagnetic field is perturbed by interacting with a material medium, the other electromagnetic field's response will alter; dissipating the entire electromagnetic wave.[29] Reflection loss is caused by the distinctive electrical interaction between the electric field of the electromagnetic radiation that is being incident and the dielectric substance.

Here absorbers are the composite materials made of filler that contains one or more components that are primarily responsible for absorption. For electromagnetic interactions, the composite was differentiated by characteristics like complex permittivity and permeability. By measuring the material's dielectric characteristics in terms of permittivity and permeability, the effects of electric field and magnetic field on materials are well understood. The composite fabricated from organic biomaterial has the complex dielectric permittivity given by Eq. (1).[(30)]

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

where, ε^* is the complex permittivity, ε' is real part called dielectric constant responsible for retain of EM energy, ε'' is imaginary part known as dielectric loss responsible for dissipation of energy in materials and the value of $j = \sqrt{-1}$. Another important parameter for evaluating the intrinsic feature of the material as an absorber is tangent loss which is expressed by Eq. (2):

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

where, $\tan\delta$ is the loss tangent and δ is the loss angle of the material. The attenuation of waves increases as the material's loss tangent increases.[31] Since the synthesized sample is fabricated from the plant based biomass it has no metallic part and the sample is completely dielectric material which is suitable for guiding the EM wave governed by suitable EM wave equation as:

$$\nabla^2 \vec{E} - \mu^* \varepsilon^* \frac{\partial^2 \vec{E}}{\partial t^2} = 0 \qquad \ldots (3)$$

where, $\vec{E}$ and μ^* are the electric field and complex permeability, respectively. As the fabricated dielectric composite has no metallic part, for simplification the imaginary part of permeability (μ) is ignored and real part of the permeability is assumed to be unity and the above equation is reduced as

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

The attenuation coefficient of the synthesized material as the function microwave frequency (f) and speed (C) of the EM wave is expressed as:

$$\alpha = \frac{\sqrt{2}\pi f}{C}\left(\sqrt{\left(\mu''\varepsilon'' - \mu'\varepsilon'\right) + \sqrt{\left(\left(\mu''\varepsilon'' - \mu'\varepsilon'\right)^2 + \left(\mu''\varepsilon' + \mu'\varepsilon''\right)^2\right)}}\right) \qquad \ldots (5)$$

Results and Discussion

Using the Agilent technologies 85070 software and a vector network analyzer, dielectric characteristics of the samples were examined. The material has solely electrical permittivity because it is made from organic waste, and its permeability factors are disregarded. With the experimental setup depicted in Fig. 3, the microwave properties were analyzed with the free space measurement. The behavior of EM wave through the fabricated material is well described by the variation of dielectric property with the frequency as shown in Fig. 4. The fact that a material's dielectric constant diminishes as frequency increases in the X-band spectrum suggests that it has a limited capacity to retain electromagnetic energy.

The interaction of electromagnetic waves with the material results in the deboning of carbon chains in polymeric resin materials and organic rice husk

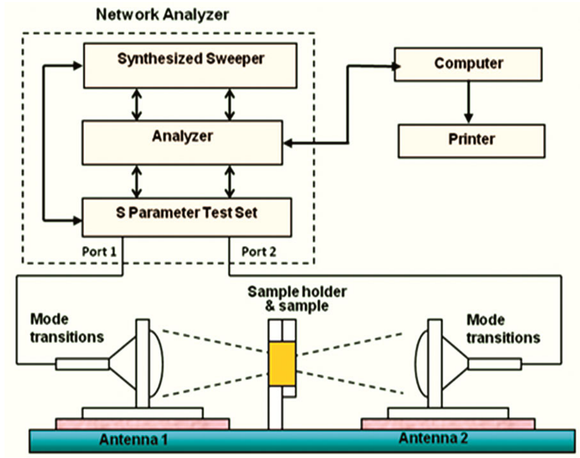

Fig. 3 — Experimental set up of two horn measurement method

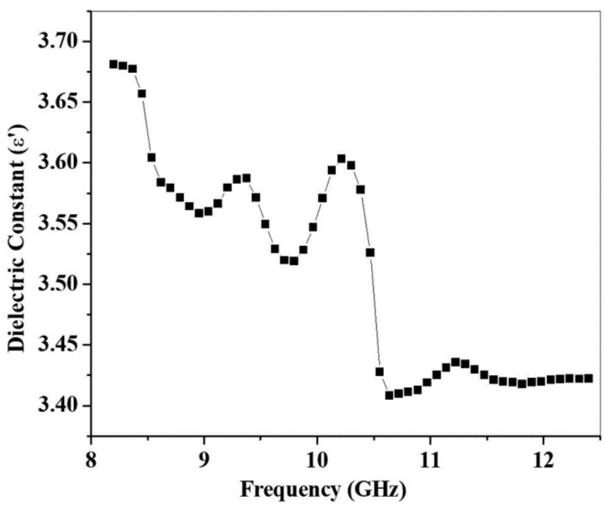

Fig. 4— Variation of real part of dielectric property

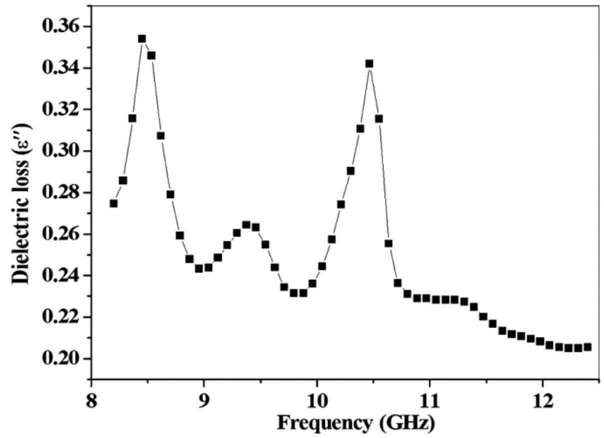

Fig. 5 — Variation of imaginary part of dielectric property

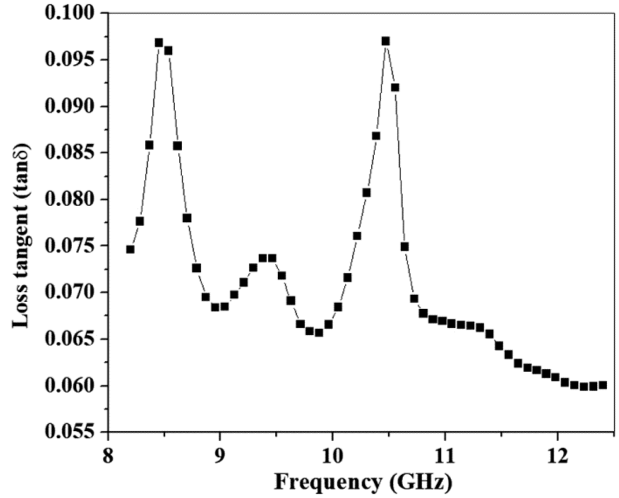

Fig. 6— Variation of loss tangent with frequency

material, which is the source of this fluctuation in dielectric constant. As a result, the number of dipoles formed by various atoms continues to decline, which causes the dielectric constant to drop.[30] With the interaction of electric field E on the fabricated composite, bounded charged particles inside the composite tends to align along the electric field.[32] Due to this interaction some energy is stored by either the charged particles or by the polar groups aligned within the molecules of the composite. It is fact that at higher frequency, E starts oscillating, due to which the polar and dipolar groups tends to change in phase with the electric field.[33] These dipoles lose energy due to an internal elastic frictional resistance causing the phase lag of electric field. The contribution of the various types of polarization induced by atomic and ionic polarization appearing in the frequency range from 11 GHz to 12 GHz leads the material in ionized condition for which the dielectric constant reduced its value from 3.67 to 3.42.

Additionally, the contribution of atomic dipole leads to more interfacial polarization initiating the interaction of microwave with the polymer-blend material.[34] Viscoelastic materials like epoxy polymer inhibit the mechanism of dielectric relaxation which is centered upon the time–temperature superposition principle. The material has high dielectric properties and decreases because of a time lag in the orientation of dipolar polarization. At low frequencies the dipole orientations form without additional dipole creation.[35] Arising frequency-dependent trend in the material's dielectric loss and tangent loss depicted in Figs. 5 and 6. With increase in frequency from 8–12 GHz, relaxation mechanisms also increases and shifts towards right. So there is an increase in mobility of molecules in the bulk composite. Dielectric property of the composite is affected by both ion mobilization and the composite's electrical conductivity at lower frequencies.[36] But in microwave frequency, the dielectric loss factor depends on the vibration of the ions and the dipole relaxation caused by the inner molecules. The mechanism of dielectric loss in polymers is due to their complex chemical structure that includes continuous molecular chain of various segments in length, polar group, and crystalline phase.[37] The graph plotted between frequency and tangent loss is associated with the mechanism of dielectric loss. From the literature it is confirmed that during dielectric measurements the epoxy polymer based composite exhibits two types of relaxation.

In fiber based materials these relaxations are attributed to the continuous chain of epoxy polymer and the structural displacements in the sub-chain system. This happens due to the continuous rotation of hydroxyl groups present in the fiber.[38] With the increase of frequency in microwave range the peaks get broader and finally merge into a single peak showing relaxation. The single peak is obtained due to the increase in volume of the composite allowing dipolar relaxation. There are no ionic losses occurring at microwave range of frequency. This reveals that the material is less capable of retaining electromagnetic energy and it disperses more widely without reflecting anything. The change in dielectric loss is caused by the fact that when frequency rises, the inherent dipole moment and relaxation processes between the ionizing atoms increase significantly, causing greater absorption within the material.[39] The attenuation coefficient increases correspondingly when the material attenuates the electromagnetic radiation intruding on it, as depicted in Fig. 7. The Attenuation Coefficient (α), which results from the loss of energy caused by collisions between neighbours' atoms, is seen to increase with frequency from the profile. This variation of attenuation coefficient identifies that the concerned material is viscoelastic medium through which the EM wave gradually attenuated during its propagation. As the frequency of the electromagnetic wave increases, it is attenuated and converted into heat energy due to collision between the oscillating atoms with the networking structures created by the matrix and rice husk.[40]

Reflectivity of the sample with variation of frequency can be seen in Fig. 8. From the profile it is observed that, the reflection loss of the material significantly varies as the frequency rises. At frequency 10 GHz, it has a value of −14.5 dB, which is less than −10 dB. The material's high dielectric loss and attenuation coefficient, which increases with frequency, reduces the amplitude of electromagnetic wave since the material is a loosy dielectric material to leading to loss of power equivalent to 87% as per the Naval Research Laboratory (NRL) arch test standard data in anechoic chamber. This shows that the material responds well to electromagnetic waves and attenuates them fully inside it.[41]

Power absorption by the material is given by

$$Power\ Loss\ (\%) = 100 * (1 - |\gamma^2|) \quad \ldots (6)$$

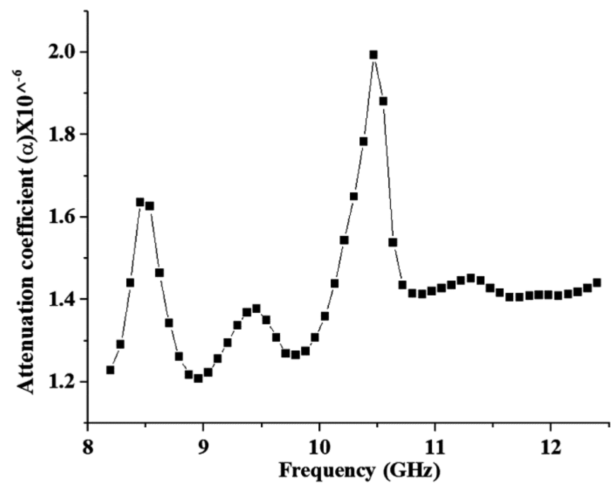

Fig. 7 — Variation of attenuation coefficient with frequency

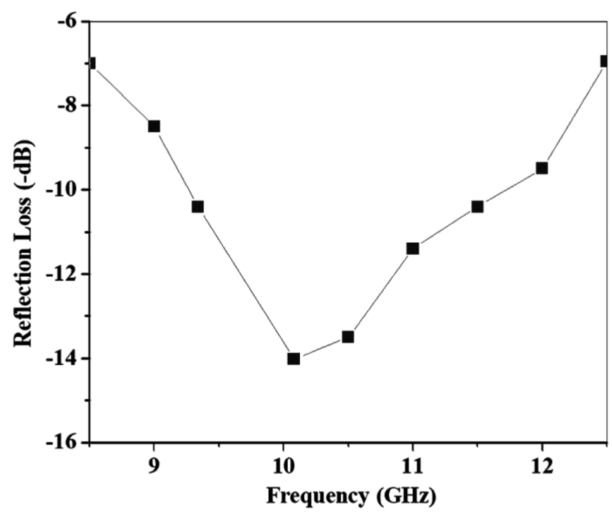

Fig. 8 — Variation of reflection loss with frequency

Conclusions

The experiment proved that mixing epoxy resin with rice husk results in a microwave absorber with a distinct dielectric constant and loss factor. The variation of real and imaginary pat of complex dielectric confirms the ability of the composite for shielding behavior with significant tangent loss < 1. The increase of attenuation coefficient with frequency is much informative, suggesting attenuation of microwave power through different polarization takes place inside the composites. Further, high reflection loss nearly −14.5 dB corresponds to power absorption of 87% suggests that the fabricated composite is suitable for shielding application in the frequency range 8.2–12.4 GHz. The material exhibits good absorption characteristics in the X-band range, which is useful for radar in defence systems and can be a potential replacement of expensive ceramic material. Even though synthesized material have low cost and high efficiency of microwave absorption recommended for stealth application but the biodegradability is a vital issue which is to be considered further. The epoxy resin which was used as polymer for this work can be further analyzed for its modification on its mechanical and dielectric properties before mixing with carbonaceous waste materials.

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