Journal of Brilliant Engineering 4 (2024) 4967

Brilliant Engineering

journal home: www.acapublishing.com/journals/4/ben

Research Article

Power Loss, Attenuation and Electric Field Intensity Determination Of PCL/Rice Husk Using Numerical Technique For Microwave Application

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Keywords

Power loss,
Microwave absorbers materials (MAM),
Finite Element Method, Substrate,
Electric field intensity,
Attenuation.

Abstract

Materials used as microwave absorbers for electromagnetic waves interference is dependent on the ability of such material to absorb or cutoff transmission of energy from the incident radiation. The measurement of these properties responsible for the absorption had been exploited using theoretical and experimental methods. There is a dearth in the use of numerical technique to calculate these properties in the field of radio frequency characterization. Finite element method (FEM) was used to calculate the power loss, attenuation and electric field intensity of an absorber placed inside a rectangular waveguide. For the calculation, five different thicknesses (5, 10, 15, 30, and 50 mm) of rice husk/PCL samples were used. The result of the numerical calculation showed that the power loss the 50 mm has the least power loss of 0.76 at 12 GHz, an attenuation of -16.57 GHz was obtained for the 50 mm thick substrate at 12 GHz and there was a decrease in the electrical field intensity as the substrates thickens. The results indicated that the 50 mm thick sample absorbs the highest radiation and is good for small radar absorber applications. The numerical technique used was able to calculate these parameters with ease and simplicity.

1. Introduction

The high rise in demand for microwave technology in telecommunications, electronic component, radar system and satellite devices has raised concern for the protection against excessive radiation being generated by these devices and protection against radar detecting system for surveillance in military war fare. Material with efficient absorbing properties is highly in need for use as interferences against these radiations from interfering and causing damages to the surrounding, these materials are referred to as microwave absorbers materials [1].

These microwave absorbers materials (MAM) attenuate the energy in electromagnetic waves (EM) and are used to suppress EM from travelling further beyond a boundary [2]. These absorbing materials are of various form ranging from the biodegradable to non-biodegradable ones. More research has focused on the on the use of biodegradable material as it possesses the ability to decompose after a certain period of time. Agricultural waste such as oil palm empty fruit bunch, rice husk, plantain husk and among others are mostly biodegradable and they have been proven to be valuable in the fabrication of microwave absorbing materials which further helps to cut down the environmental pollution arising from these agricultural wastes.

Several methods have been used to investigates the electromagnetic properties of different materials. Methods such as resonant cavity perturbation, Open-ended Coaxial Probe Technique, transmission/reflection waveguide method (TR) and free space are some of the methods widely used to investigate these properties. The EM properties that are investigated for material are transmission coefficient, attenuation coefficient, the response to electric field. To effectively know which material can be used for microwave absorber, a good understanding of its attenuation coefficient and the way the electric field interact with the material is necessary to get useful information from materials proposed for use in microwave absorption [3]. Attenuation is a measure of loss of signal through a material medium.

Attenuation coefficient characterizes how easily a volume of material can be penetrated by a beam of light, sound, particles, or other energy or matter [4].

The FEM is a numerical technique for finding approximate solutions to Partial Differential Equations (PDE) by dividing the whole computational domain into subdomains of simple geometry called finite elements. Through the FEM, the PDE problems can be translated into a set of linear algebraic equations [5]. The FEM is applied to the numerical modelling of physical systems in a wide variety of engineering disciplines.

Radonic et al., investigated the effect of sample thickness for dielectric measurements using the transmission phase-shift method and made comparison with the values obtained using FEM. Various thicknesses of acrylic, FR-4 and RT/droid 5880 substrates samples placed in the X-band WR 90 type rectangular waveguides. The measured S11 and S21 were compared with the simulated values using FEM, in his comparison, it was found that the measured value of S11 and S21 for the three samples indicates a good agreement with the simulated results. He was able to show that the FEM is a good technique to determine transmission coefficients. To approach the simulation of the electromagnetic field scattered by the cube satellite covered with

*Corresponding Author: ahmedjimyy@email.com
Received 21 Dec 2024; Revised 03 Feb 2025; Accepted 03 Feb 2025
https://doi.org/10.36937/ben.2024.4967

radar absorbing materials (RAM), the COMSOL software has been used to perform a FEM analysis on the cube satellite [7].

Yakubu et al., [8] used finite element method to investigate the radiation absorption in brain tissue. Their analysis showed that adolescents tissue absorbed more radiation than adults from mobile phone radiation which is due to the higher dielectric property of adolescent brain tissue which indicates that the adolescents are prone to danger which might arise due to higher radiation absorption in brain tissues.

Alhaji et al., [9] explored PTFE composites with varying amounts of soda lime silica glass (SLSG) ranging from 5 wt.% to 25 wt.% as potential substrates. The complex permittivity and S-parameters of these composites were analyzed using the rectangular waveguide (RWG) technique across the X-band (8.2 GHz–12.4 GHz). Results showed that increasing SLSG content led to higher complex permittivity and lower reflection coefficients (|S11|) while enhancing transmission coefficients (|S21|). Power loss due to material absorption also increased with SLSG content. Simulations using finite element method (FEM) in COMSOL software closely matched experimental results, validating the RWG measurement technique. Overall, the composite with 5 wt.% SLSG exhibited the best performance for microwave substrate applications.

Yakubu et al. [10] investigated the attenuation of unripe plantain husk with respect to particle size and frequency of operation. They reported that the there was a clear indication of a sharp increase in attenuation as milling hour of sample increased.

Due to the shortage of literature and research in numerical methods for the calculation of electromagnetic properties, this work will try and use a simple numerical technique (FEM) for the calculation of power loss, attenuation and electric field intensity of an absorber placed inside a rectangular waveguide.

2. Theory and Method

In this research, 14 laboratory specimens in two Sadiku [11] states that finite element method for analysis involves the following steps:

- Discretizing the solution regions into finite number of elements.
- Deriving governing equations for a typical element.
- Assembling of all elements in the solution region, and
- Solving the system of equations obtained

In the methodology, the finite element method was used to obtain the values of transmission and reflection coefficient (S21 & S11) and the electric field intensity for the sample using the graphical user interface Comsol Multiphysics. In order to obtained these values, the equation of the waveguide was put into consideration. The equation of the waveguide was given as [12].

$$\nabla \times (\mu_r^{-1} \times \nabla \times E_z) - \left(\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0}\right) k_0^2 E_z = 0 \quad (1)$$

Where μ_r is relative permeability, k_0 is free space wave number, j is imaginary unit, σ is conductivity, ω is angular frequency, ε_r is relative permittivity, and ε_0 is permittivity of air.

Dongfang [13] provided the wave equation for a transverse field when there is no conduction current as:

$$\nabla_t^2 E_t + \nabla_t [E_t . \ln\varepsilon^*(x,y)] + [k_0^2 \varepsilon^*(x,y) + \gamma^2] E_t = 0$$

(2)

$$\nabla_t^2 E_t + [\nabla_t \ln\varepsilon^*(x,y)] \times (\nabla_t \times H_t) + [k_0^2 \varepsilon^*(x,y) + \gamma^2] H_t = 0$$

where $k_0 = 2\pi/\lambda_0$ is the free space wave number, γ is the propagation constant, $\varepsilon^*(x,y)$ is the complex permittivity profile, and ∇_t is the vector Laplacian operator.

In simulation with the finite element method, first we assign the work in 3d work plane before going into the RF module, where electromagnetic wave is selected for harmonic waves. The length of the waveguide used in this work was 20cm long while the length and width of the port of the wave guide was 2.228 cm by 1.1143cm. This dimension was used to set up the axis grids, parameter constant and cut-off frequency for the simulation.

The waveguide was simulated using FEM by applying the TE_{10} mode as the transmission mode in the waveguide. The complex permittivity of Rice Husk/PCL used is 2.03-j*0.002[10].

The simulated rectangular waveguide was divided into three regions. Regions I, II and III. The regions are shown in the simulated waveguide shown in Figure 1.

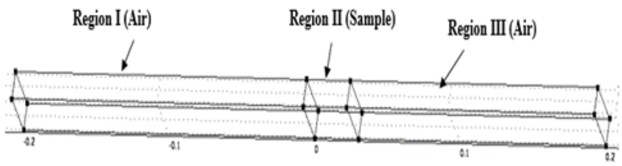

Figure 1. Simulated Rectangular waveguide

For the calculation of power loss and attenuation, the equations listed in (3) and (4) were used respectively, [14];

$$Power\ Loss = 10log(1 - |S_{11}|^2 - |S_{21}|^2) \quad (3)$$

$$Attenuation\ (dB) = -20\log\,(S_{21}) \quad (4)$$

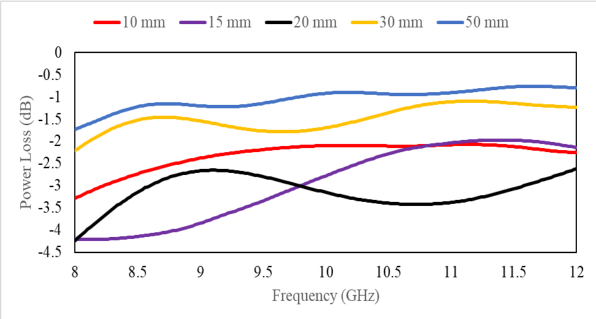

Figure 2. Power Loss (dB) for PCL/Ricehusk

3. Results and Discussion

3.1. Power Loss (dB)

The power loss of the substrates was calculated using equations (3). The raw scores obtained for the calculated S11 and S21 of the substrates were simplified in the equation. Figure 2 is the representation of the variation in power loss for the five different thickness 10 mm, 15 mm, 20 mm, 30 mm and 50 mm of the PCL/Rice husk samples in the range of 8 - 12 GHz range. There is a gradual increment in the power loss as the frequency increases across all the different samples. In the 20 mm thickness at the 9 GHz there was a drop in the power loss as the frequency increases then the frequency began to rise at 10 GHz. The 50 mm has the least of power loss of 0.761 at 11.68 GHz while the 20 mm thickness sample has the highest of power loss of 4.23 at 8 GHz. This significantly indicate that the 50 mm thick sample absorbs most of the transmitted signals at 11.68 GHz. From 8 GHz to 8.8 GHz, the 15 mm has a large percentage of power loss of 4.2 dB averagely within that range of frequency. The 50 mm thickness samples with a power loss of 0.761 at 11.68 GHz, is associated with loss of electromagnetic energy in the materials [15] (Mensah et al, 2020).

3.2 Attenuation (dB)

Equation (4) was used to calculate the attenaution from the raw scores for S11 and S21. The result obtained in shown in Figure 3. The results showed that at 12 GHz, the 50 mm thick substrates were able to attenuate radiation by -16.57 dB. This result is in agreement with the results obtained for organic materials attenuation where the thickest substrate had the highest attenuation [10]. The increase in attenuation as substrate size increases is attributed to the disintegration of the powder sample resulting in increased surface area hence increase in attenuation [16].

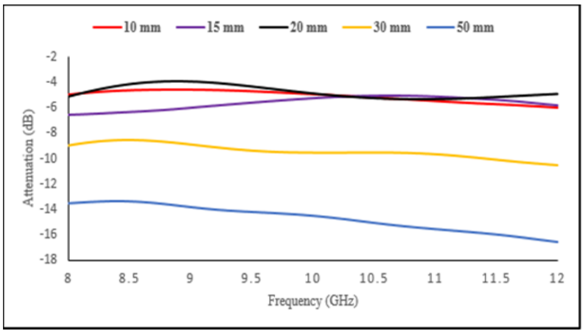

Figure 3. Attenuation (dB) for the Thicknesses

3.3. Electric Field Intensity

The initial excitation radiation intensity for all the thicknesses was 4000 v/m at the excitation port of the waveguide. The result for the field intensity is shown in Figure 4.

Observation on the numerically calculated field intensity showed that the 50 mm has the least transmitted field intensity with value of 1032.86 v/m while the highest transmitted field intensity was 1978.34 v/m for the 10 mm thick substrate. The decreases in the transmitted intensity as thickness increases is in agreement with the work of [17] which reported stated that when the diameter of a material increases, the electric field intensity decreases gradually. The results from the three investigations showed that the 50 mm thick substrate is a suitable for the absorption of radiation for small radar absorber applications.

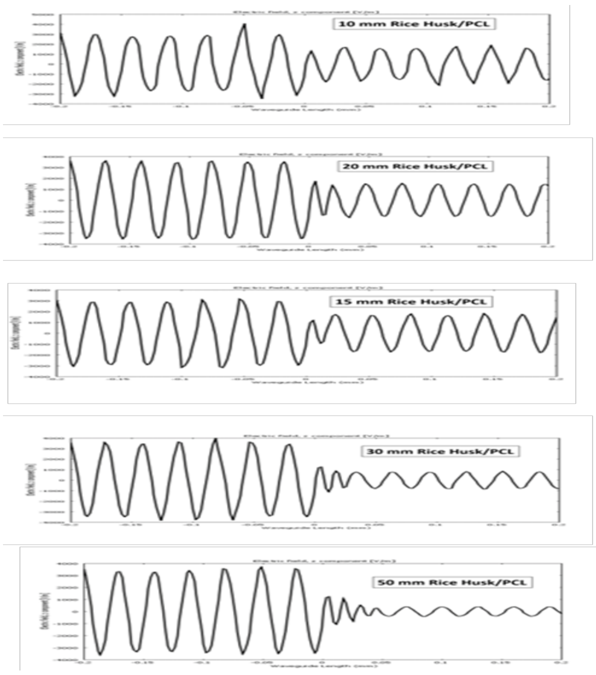

Figure 4. Electric Field Intensity

A summary for the transmitted field intensity for the five thicknesses is shown in Table 1. The graphical representation of table one clearly shows the pattern for the field intensity as the thickness increases (Figure 5).

Table 1. Summary of Transmitted Intensity

S/N	Thickness (mm)	Transmitted Intensity (v/m)
1	10	1978.34
2	15	1859.98
3	20	1765.45
4	30	1346.75
5	50	1032.86

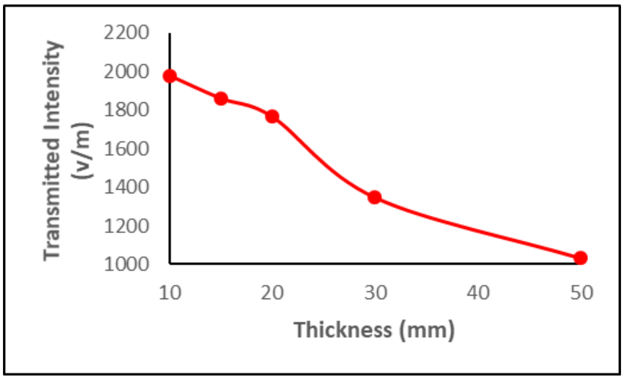

Figure 5. Transmitted Intensity for the Thicknesses

4. Conclusion

In this research the Finite element techniques was successfully used to obtained the power loss, and attenuation coefficient of the PCL/Rice Husk samples. The 50 mm substrate with power loss of 0.761 at 11.68 GHz significantly indicate that the sample absorbs most of the transmitted signals at that frequency. At 12 GHz, the 50 mm thick substrate was able to attenuate radiation by -16.57 dB.n The calculated field intensity showed that the 50 mm has the least transmitted field intensity with value of 1032.86 v/m. The result of the power loss indicated that the 50 mm is the material with the highest loss of electromagnetic energy this is consistent with the result obtained from the attenuation of the samples. The finding revealed that the 50 mm thickness will be suitable for possible application as microwave absorbers.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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How to Cite This Article

Jimoh, A., Yakubu, A., Bilyaminu, U., Usman, S. and Nagogo, S., Power Loss, Attenuation and Electric Field Intensity Determination of PCL/Rice Husk Using Numerical Technique for Microwave Application, Brilliant Engineering, 4(2024), 4967. https://doi.org/10.36937/ben.2024.4967.