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Research Article

Determination of Transmission Coefficient and Electric Field Distribution of Rice Husk/ Pcl Composites Using Finite Element Method for Microwave Devices

Abubakar Yakubu[1], Ahmed Jimoh*,[1], Mustapha Abbas[1], Usman Bilyaminu[2], Adetoro Abdulkadir Wale[1]

[1]*Department of Physics, Kebbi State University of Science and Technology, Aliero, Nigeria*
[2]*Zamfara State College of Education, Maru, Nigeria*

Keywords

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Rice husks,
Electric field visualization,
FEM,
Rectangular waveguide.

Abstract

Material thickness is one factor that is considered in the selection of materials for usage in microwave applications. The demand for microwaves technology is widely needed in modern applications such as cellular telephone, satellite communication, radar system, global positioning system, and microwave remote sensing systems. Experiments and results abound for microwave properties determination for inorganic materials. Focus has recently been shifted to agricultural waste composite for microwave application. It is on this basis that this work primarily focuses on investigates microwave transmission coefficients and electric field visualization of different rice husk/PCL sizes placed inside a rectangular waveguide using the finite element method (FEM). Determination of the transmission coefficient for different thickness of rice husk/PCL composites were performed at X-band frequency using FEM. The thicknesses for the rice husk/PCL composites simulated were 10, 15, 20, 30, and 50 mm. The results of the simulation for the transmission coefficient revealed that the 50 mm composites had the lowest value of 0.148468 for the transmission coefficient at 12 GHz while the electric field visualization showed that the 50 mm composites have the least value of electric field intensity. The results confirms that the 50 mm thick sample absorbs the highest radiation. Based on the results obtained, all sample thickness can be used for microwave dummies.

1. Introduction

The demand for microwave technology is widely needed in modern applications such as cellular telephone, satellite communication, radar system, global positioning system, and microwave remote sensing systems. Microwaves are part of the electromagnetic wave's spectrum with frequencies between 3 GHz and 300 GHz, and a corresponding wavelength between 10 cm and 1 mm [1]. The increase in demand for microwaves in electronic systems and telecommunication has led to the demand for microwave absorbers. Absorbers are materials that are used efficiently to collect energy in an electromagnetic wave. Absorbers are used in a wide range of applications to eliminate unwanted radiation that could interfere with a system's operation. Materials that offer an efficient absorption of high frequency are widely used in microwave technology and as various radar-absorbing coatings.

The use of high-frequency absorbing materials is quite relevant not only for parts of various electronic devices, design of radio-electronic equipment and microelectronics, protection of communications equipment from external electromagnetic interference, but also for personal protection from radiation during working with powerful microwave devices as well [2]. Such materials can be used for radio-camouflage of any surface facilities and aircraft, significantly reducing detection and destruction probability.

To effectively know which material will be suitable for use as a microwave absorber, a good understanding of transmission and reflection measurement of these materials and their attenuation is necessary to get useful information from materials proposed for use in microwave absorption [3].

In [3] it was reported that FEM is a new approach that relies upon 3D electromagnetic simulation results to characterize and calculate the transmission and reflection coefficient. The finite element method has the advantage of not needing to perform complex theoretical analyses of the measurement geometry.

It was shown that the method of mixed finite element method is very effective for the numerical solution of mathematical models of wave-guiding systems with chiral filling [4]. Finite element method was used to investigate the radiation absorption property in human brain tissue, and findings from the research showed that adolescent's tissue absorbed more radiation than adults from mobile phone radiation [5]. In [6], it was reported that FEM could help to improve the understanding of microwave interactions with sea ice and interpretation of Synthetic Aperture Radar (SAR) images over polar areas. In [6] a model based on the FEM was built to study the scattering from sea ice, it was confirmed that the model can accurately account for the scattering from layered sea ice under multi-incidence and multi-frequency waves.

In the search for agricultural waste as an alternative material for microwave absorber material, it was found in [7] that FEM was more accurate for determining the magnitudes of the reflection and transmission coefficients of Oil Palm Empty Fruit Bunch (OPEFB) and Polycaprolactones (PCL) composites placed in a closed T/R rectangular waveguide. In general the S_{21} values are higher than the S_{11} values, which means that an increase in one value results in a reduction in the other value. It was also reported in [8] that FEM was used to simulate a microstrip antenna which was used to calculate shielding effectiveness, reflection loss, and in the visualization of electric field distribution of samples. The usability of Unripe Plantain Husk (UPH) waste material for microwave absorber applications was determined by investigating the dielectric properties and attenuation of the UPH powder concerning particle size and frequency of operation [9]. Some of the properties of the UPH investigated are dielectric constants, loss factor, loss tangent transmission coefficient (S21), and attenuation coefficient. Their result showed that there is high absorption of electromagnetic waves which propagates through the sample (UPH) thereby leading to diminished transmitted waves.

*Corresponding Author: ahmedjimyy@gmail.com
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To the best of our knowledge, the FEM was extensively used in many areas of sciences and engineering, however, not much is seen in the determination of the transmission coefficient of and visualization of the electric field for agricultural waste and polymeric materials. The purpose of this research is to determine the transmission coefficients and electric field visualization of rice husk/PCL composites placed inside a rectangular waveguide using FEM.

2. Theory and Methodology

FEM is a numerical technique for solving problems that are described by partial differential equations or can be formulated as functional minimization. A domain of interest is represented as an assembly of finite elements. Approximating functions in finite elements are determined in terms of nodal values of a physical field that is sought. A continuous physical problem is transformed into a discretized finite element problem with unknown nodal values. For a linear problem, a system of linear algebraic equations should be solved.

There are 4 steps in the utilization of FEM, and these steps are (a) discretizing the solution region into a finite number of elements, (b) deriving governing equations for a typical element, (c) assembling all elements in the solution region, and (d) solving the system of equations obtained [10] .

The FEM technique-based COMSOL software is used to determine the transmission coefficient (S21) of the closed T/R rectangular waveguide. To obtain the value of the transmission coefficient (S21), the waveguide equation was considered.

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

Where μr is relative permeability, $k0$ is free space wave number, j is the imaginary unit, σ is the conductivity, ω is the angular frequency, εr is relative permittivity, and $\varepsilon 0$ is permittivity of air.

The wave equation for a transverse field when there is no conduction current is given as [14]:

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

$$\nabla_t^2 E_t + [\nabla_t ln\varepsilon^*(x,y)] \times (\nabla_t \times H_t) + [k_0^2\varepsilon^*(x,y) + \gamma^2]H_t = 0 \qquad (3)$$

where $k_0 = 2\pi/\lambda_0$ is the free space wave number, γ is the propagation constant, ε is the complex permittivity profile, and ∇t is the vector Laplacian operator.

3D work plane was selected for the simulation, before inputting data for the RF module. Electromagnetic wave selected for the simulation was simple harmonic waves. In the workplane settings in FEM, the waveguide was drawn based on its dimension of 20 cm and the port was set at 2.228 cm by 1.143 cm. Axis grids, parameter constants, cut-off frequency for the simulation, and frequency range of 8 GHz to 12 GHz were set up. The complex permittivity value used in the simulation is (3.50 - $j*$ 0.51) and the permeability value used in our simulation is 1 [15]. A total of five different thickness of the rice rusk/PCL composites were simulated. To ensure accuracy in the simulation, a convergence test was performed using an empty rectangular waveguide to determine the accuracy of the simulation.

3. Result and Discussion

3.1. Convergent test

To ensure accuracy for the simulation of the different rice husk/PCL, a convergence test was carried out by using an empty rectangular waveguide which was used to obtain the transmission and reflection coefficients. Convergence plays an important role in the accuracy of solutions obtained using numerical techniques like FEA [16]. The result obtained from the convergence test (Fig 1) showed that the transmission coefficient (S21) is approximately 1, while the reflection coefficient (S11) has a value that is close to 0. This shows that the simulation inputs are accurate for the intended simulation of the different thicknesses.

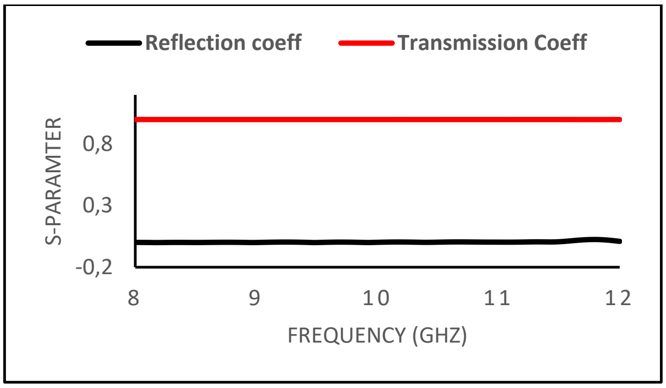

Figure 1. Details of test model

3.2. Transmission coefficient

Careful observation on Figure 2 shows that the transmission coefficients sequentially decreases as the thickness of the rice husk/PCL composites increases across all frequencies. This observation is in agreement with the theory of [1].

The results revealed that the 50 mm thickness has the least value of transmission coefficient of 0.1485 at 12 GHz while the highest value for the transmission coefficient at the same frequency was obtained for the 20 mm thickness with a value of 0.5682. The overlapping behavior for the 10, 15 and 20 mm thicknesses between 10 to 11 GHz was similar to the findings in [17, 18]. This overlapping may be due to impedance mismatch at the interface of the sample surface and signal during simulation [8].

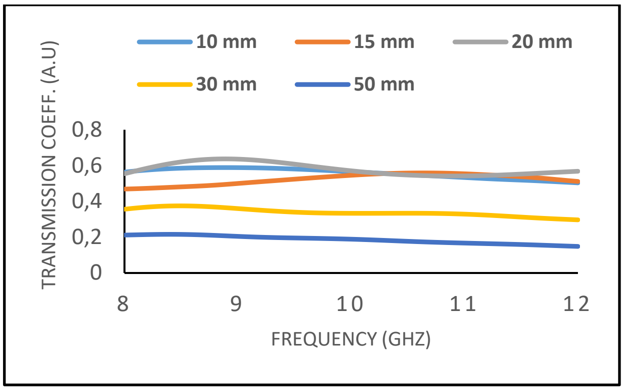

Figure 2. Transmission coefficients of samples

3.3. Electric field distribution

The electric filed visualization showed the electric field pattern in the waveguide for the different thicknesses measured in volt/meter (V/m). The blue color and the red color represents the minimum and maximum value of the intensity, respectively for the electric field. The field revealed that sample thickness is a determinant in what the field look like. Further observation showed that the thicker the sample, the less intensity propagating towards the output due to absorption of the EM waves [19].

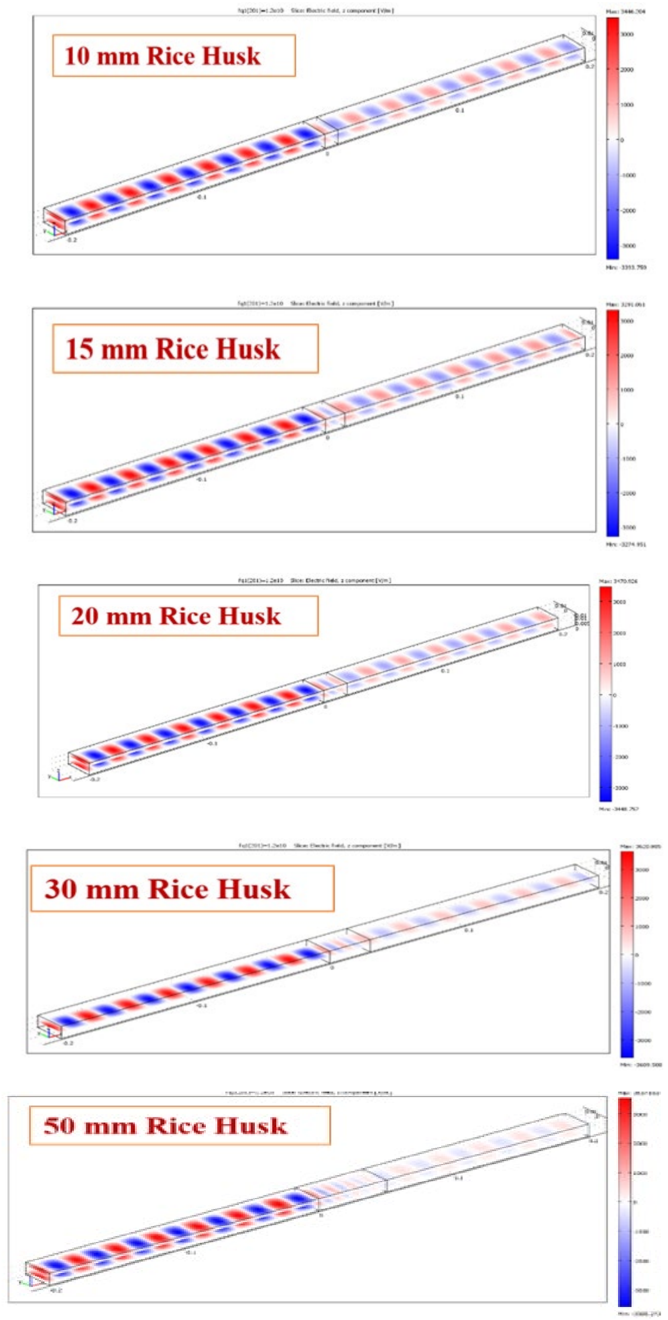

Figure 3. Electric field distribution of samples

This decrease in intensity as the sample thickness increases is in agreement with the work of [20] where the electric field intensity for the intrinsic layer decreases as the thickness of the material increases. The 50 mm thickness has the highest decrease in intensity with a value close to 300 V/m while the 10 mm thickness has the least decrease in intensity with a value close to 800 V/m. This result is evident in the transmission coefficient (Figure 2) where the 50 mm thick composites had the lowest transmission coefficient. This behaviour is attributed to the densification of the composites at different thicknesses [21].

4. Conclusion

The simulation of rice husk/PCL placed with inside a rectangular waveguide was successfully carried out in this work. Determination of the transmission coefficient for different thickness were performed at X-band using FEM. Also, the electric field inside the waveguide was visualized. At 12 GHz, the transmission coefficient for the 50 mm thick sample was the smallest with a value of 0.148469 and this behavior was also manifested in the electric field distribution where the lowest field intensity was 300 v/m for the 50 mm thick sample. The research revealed that the FEM can be used to calculate the transmission coefficient and visualize the electric field of agricultural waste material placed inside a rectangular waveguide. It is then concluded that the 50 mm thickness will be more suitable for application as a microwave dummy material.

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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