Enhanced microwave absorption in partition walls using rice husk biomass composites

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ABSTRACT

Currently, electromagnetic pollution (EM) has shown adverse complications and resulted in very negative effects on human health. Therefore, developing efficient microwave absorbers to reduce EM is important. This study aims to produce an anti-microwave partition wall using a biomass composite, which is a combination of rice husk and palm oil fuel ash (POFA). The goal of this project is to produce a partition wall that can act as a microwave absorber and create a healthy and safe environment. The anti-microwave radiation partition wall is designed using rice husk, POFA, cement, water, aluminium, and gypsum board. The composition ratios tested were rice husk content (5% and 20%) and POFA content (25%, 35%, and 45%). This mixture is also supplemented with aluminum (0.5% and 3.0%). The Naval Research Laboratory (NRL) Arch free space method determines the reflectivity performance of anti-microwave partition walls in the frequency range from 1 GHz to 12 GHz. Observation shows that the anti-microwave radiation partition wall for prototype BR5 containing 5% rice husk, 25% POFA, and 0.5% aluminium has the best reflectivity performance.

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1. INTRODUCTION

Nowadays, the rise of faster telecommunications has increased the efficiency of data communication. However, the disadvantages that evolve with technology also need to be addressed. The growing 5G network is also increasing the use of digital devices daily. Electromagnetic (EM) waves that increase in accordance with the use of such technology can have a significant impact on physical health [1]-[3]. Due to the health risks associated with ambient radio frequency fields, exposure to radiofrequency (RF) fields is known to have negative health consequences, including skin burns and eye cataracts [4]. Despite decades of research into microwave absorption (MA) and its mechanisms, the practical implementation of efficient EM wave-absorbing materials remains insufficient to address current health and safety challenges. The increasing exposure to EM radiation, particularly microwaves, in environments such as hospitals, offices, and residential areas necessitates the development of advanced materials with high MA capabilities. Conventional carbon-based fillers, such as carbon black and nanotubes, are effective but expensive. This highlights the need for alternative materials that are both efficient in absorbing microwave radiation and sustainable in terms of resource management. Although the phenomenon of MA has been known for decades and the cause of absorption has been well formulated, it remains important to develop various advanced materials for absorbing EM waves. As a result, absorber design has occupied many materials scientists, researchers, and engineers [1], [4].

The search for inventive building materials and techniques has prompted the investigation of advanced solutions to address safety issues in the built environment, particularly those related to radiation absorption. Both man-made and natural sources of radiation pose risks in a variety of environments, such as research laboratories, hospitals, factories, and space exploration. Conventional building materials used for partition walls often result in insufficient protection against various types of radiation, requiring the creation of advanced mixtures to reduce the potential health hazards associated with prolonged exposure. This research aims to create an advanced anti-microwave radiation partition wall that offers structural stability and ease of installation while incorporating advanced materials and a unique design approach to dramatically improve radiation absorption properties. Partition walls with anti-microwave radiation properties are required to protect effectively in environments where EM radiation is prevalent, such as office buildings, hospitals, and residential areas with high gadget usage. These walls can reduce health risks by preventing the penetration and reflection of harmful EM waves, ensuring a safer living and working environment.

The significance of this research lies in its focus on developing innovative microwave-absorbing materials using agricultural waste. By leveraging the unique properties of biomass materials, particularly palm oil fuel ash (POFA) and rice husks, this study aims to address two critical challenges: mitigating the adverse health effects of EM radiation exposure and promoting environmental sustainability. Biomass materials not only offer high dielectric loss tangents and porosity for superior MA but also provide a cost-effective and eco-friendly alternative to traditional carbon-based fillers.

Carbon is a great absorbent material for microwave absorbers [5]. In general, carbon materials are great microwave absorbers because they are easily heated by microwave radiation. Microwave absorbing materials convert EM waves into heat [6], [7] through dielectric loss tangent, with carbon material being highly effective due to high dielectric loss [8], [9]. Biomass materials are one alternative [10] to replace current carbon-based fillers such as carbon black, carbon nanotubes, and graphene to fill polymers. One of the reasons for environmental pollution is the increase in agricultural waste and loss of resources [11]. In response to that, biomass materials are proposed to be put to good use by humans daily. The recycled material produced from palm oil is POFA. POFA is the result of agricultural waste from the process of burning waste material such as palm oil fiber, shells, kernels, and empty fruit bunches in the boiler of palm oil mills to generate energy. POFA is also potentially used as a building material [12]–[18], renewable energy source, soil conditioner, and microwave absorber [19], [20]. The high silica and alumina content in POFA allows it to absorb microwave radiation and have a high dielectric constant and loss tangent [20].

Additionally, the use of porous biomass materials has gained popularity in a variety of industries for the creation of composite materials because of their rich porous structure, which offers a high surface area and oxygen-containing functional groups, cheap cost, and eco-friendliness. In the context of microwave-absorbing materials, porosity is a significant property that enhances the material's ability to absorb EM radiation [21]-[23]. Many studies have been published on the MA capabilities of various biomass materials, including cotton, rice husk, pineapple skin, wheat straw, and mango leaves [24]. Many engineering applications propose using rice husks in composite structures because of their abrasive properties, low cost, lightweight, renewability, biodegradability, universal availability, and weather resistance [25]. Hence, this research introduces an innovative approach by combining biomass materials like POFA and rice husk with varying proportions of cement, water, and aluminium.

2. METHOD

The purpose of this research is to develop biomass-based methods, such as rice husks and POFA, that can protect against radiation. The planning phase of this project commences with a comprehensive study and literature review of the fundamental principle of microwave absorbers. The CST Simulation Software creates an anti-microwave radiation partition wall with standard measures for testing its reflectivity performance. The design with the best reflectivity will be selected, and then the physical anti-microwave radiation partition wall will be fabricated. The reflectivity of the partition walls will be measured using the Naval Research Laboratory (NRL) free space method.

2.1. Development process of partition walls

The dimensions of the partition wall, as shown in Figure 1, were determined using the CST studio suite software. The anti-microwave radiation partition walls have dimensions of 60×60×6 cm (length× breadth×height), the same as the proportions of the commercial partition wall used to construct them. The process begins with preparing the raw materials, which are rice husk and POFA, as the main ingredients for crafting the microwave absorber partition walls. POFA serves a dual role by enhancing MA while also acting as a medium mixed with cement and water to form the base for these walls. Adding rice husk to the mix increases porosity [26], [27], boosting the overall absorption performance of the partition walls. These biomass composite materials are not only environmentally friendly and lightweight but also contain natural carbon, enhancing MA. To further increase porosity, aluminium is incorporated into the manufacturing process [28]. Meanwhile, cement serves as a primary binding component in the partition wall and is responsible for holding the other materials together. Figure 2 shows all the materials used in making these microwave absorber partition walls, and Tables 1 and 2 present the raw material propotions for prototypes with 20% and 5% rice husk, respectively. Each prototypes varies in the composition of POFA, cement, aluminium, and water allowing the investigation of different ratios on MA efficiency.

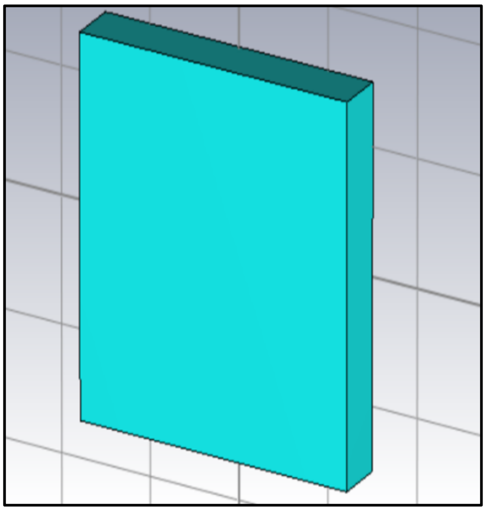

Figure 1. Simulation of microwave absorber partition wall

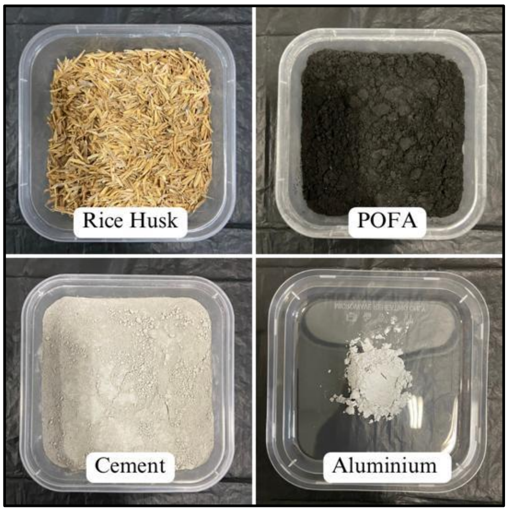

Figure 2. Preparation of raw materials

Table 1. Raw materials proportion with 20% rice husk

Prototypes	Ratio (%)				
	Rice husk	POFA	Cement	Aluminium	Water
AR20	20	25	55	0.5	55
BR20	20	25	55	3.0	55
CR20	20	35	45	0.5	45
DR20	20	35	45	3.0	45
ER20	20	45	35	0.5	35
FR20	20	45	35	3.0	35

Table 2. Raw materials proportion with 5% rice husk

Prototypes	Ratio (%)				
	Rice husk	POFA	Cement	Aluminium	Water
AR5	5	25	70	0.5	70
BR5	5	25	70	3.0	70
CR5	5	35	60	0.5	60
DR5	5	35	60	3.0	60
ER5	5	45	50	0.5	50
FR5	5	45	50	3.0	50

After determining the material ratios, the process of mixing these elements occurs. The different materials are carefully blended. This ensures the even distribution of every material, maximizing the consistency and efficiency of the microwave partition wall. Once the composite material is ready, the molding process begins. The blend is carefully poured into molds, considering the planned size and requirements of the partition walls. Following the molding process, the prototype is allowed to dry. The entire process is shown in Figure 3.

Figure 3. Process of fabricating the partition wall

2.2. Reflectivity measurement using Naval Research Laboratory Arch free space method

Typically, a network analyzer is used to carry out measurements on an NRL Arch, serving the dual purpose of providing the stimulus and doing the measurements. A calibration is conducted on the power reflected off the metal plate across a wide range of frequencies. This is defined as the ideal representation or 0 dB level. Next, the partition wall is positioned on the plate, and the reflected signal is measured, as shown in Figure 4.

The NRL Arch is a vertical semicircular structure constructed from wood. The reflectivity measurement is conducted at a 0° angle to examine the impact of the anti-microwave partition wall on absorption within the specific frequency range of 1 GHz to 12 GHz. One antenna is attached to a microwave transmitter, while the other is attached to a microwave receiver in the NRL Arch. Both antennas are positioned at a fixed distance from the partition wall being tested.

Figure 4. NRL Arch free space setup

3. RESULTS AND DISCUSSION

The NRL Arch's free space approach was used to measure the reflectivity performance of the anti-microwave radiation partition wall at various percentages of rice husk, POFA, and Aluminium. Figure 5 displays the measurement of reflectivity performance at the frequency range of 1 to 12 GHz for a mixture of rice husk at concentrations of 20% and 5%, POFA at concentrations of 25%, 35%, and 45%, and aluminium (AL) at a concentration of 0.5% and 3.0% respectively. Figure 6 illustrates the reflectivity performance for four frequency bands: L-band (1-2 GHz), S-band (2-4 GHz), C-band (4-8 GHz), and X-band (8-12 GHz).

In general, efficient absorption occurs when the reflectivity is below -10 dB [22], [29]. All 12 prototypes can act as microwave absorbers because the reflectivity value is below -10 dB in the frequency range between 2 GHz and 12 GHz, as shown in Figures 5 and 6. However, prototype BR5 (rice husk 5%, POFA 25%, and AL 3.0%) is the best prototype compared to the other prototypes since the reflectivity of prototype BR5 is nearly -10 dB. It can be seen that the minimum reflectivity for the L-band and S-band is -39.3612 dB and -54.7372 dB from prototype BR20 (rice husk 20%, POFA 25%, and AL 3.0%). Next, for C-band and X-band, the minimum reflectivity is -21.6443 dB and -52.5549 dB from prototype AR5 (rice husk 5%, POFA 25%, and AL 0.5%). The red plot line, which consists of only a gypsum board without a biomass absorber, shows that the reflectivity value does not reach -10 dB. This proves that MA is not limited to gypsum board alone.

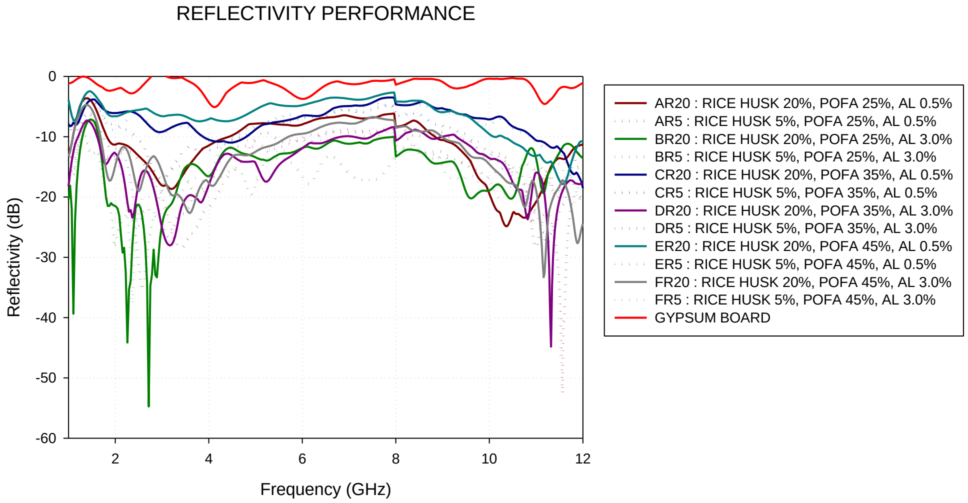

Figure 5. Reflectivity performance of anti-microwave radiation partition wall

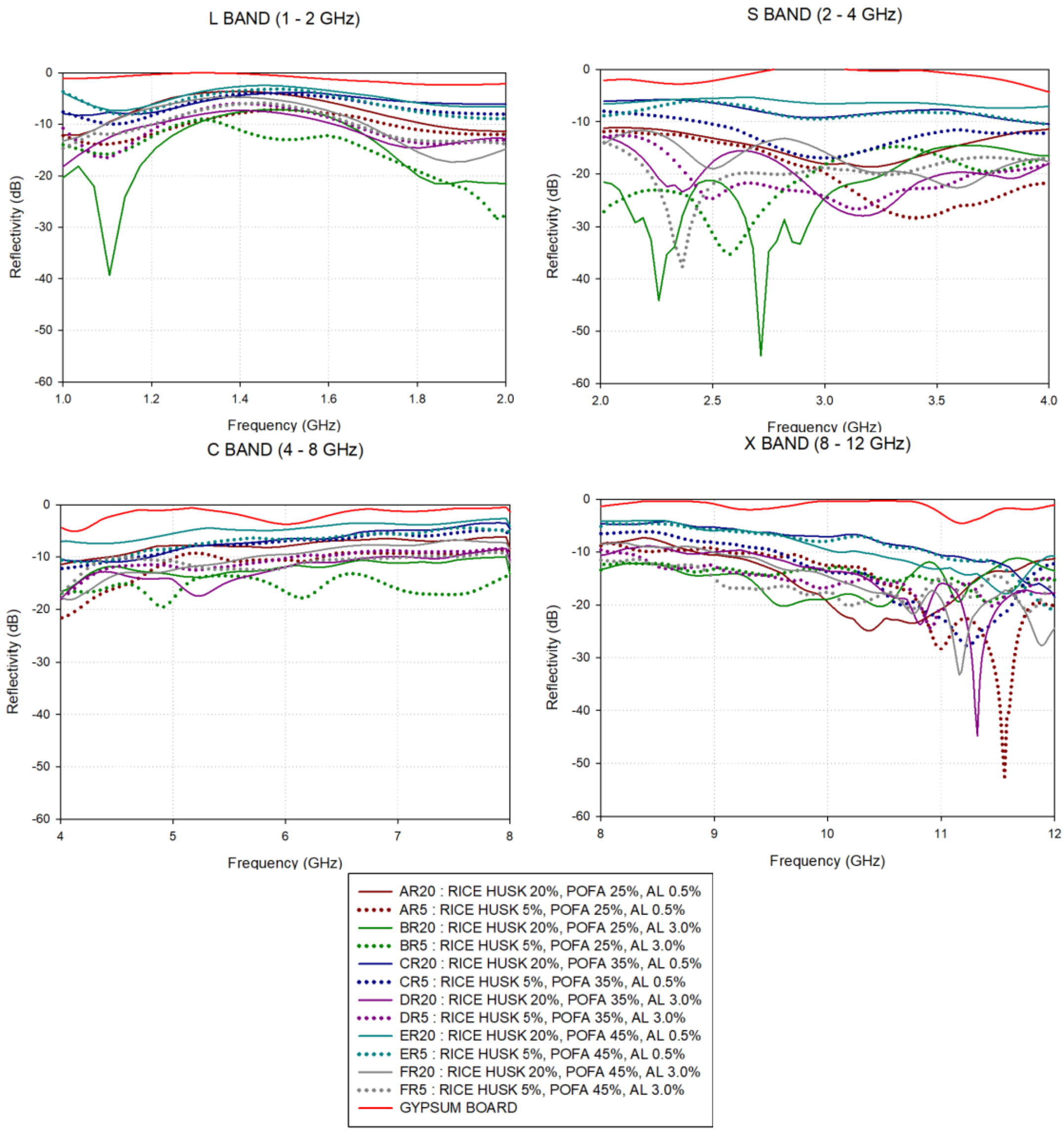

Figure 6. Reflectivity performance all prototypes in L band, S band, C band, and X band

The following phase involves analyzing the reflectivity performance in relation to the percentage of rice husk. Each of the six prototypes has been allocated a rice husk content of 5% and 20%, respectively. The prototype shown in Figure 7 indicates that a 5% rice husk composition has a higher MA capacity compared to a composition containing 20% rice husk. The increase in cement usage in the anti-microwave radiation partition wall mixture is directly proportional to the decrease in the amount of rice husk. The interaction between cement and aluminium powder is observed in the process of their combination to form a composite material. When combined with aggregate and water, cement-typically Portland cement, acts as the binding agent concrete [30], providing strength and cohesiveness. However, due to its high reactivity, adding aluminum powder to cement imparts special characteristics to the mixture. The alkalis in the cement paste react chemically with aluminium powder when it is combined with cement. Hydrogen gas is produced as a result of this reaction [31], which causes many bubbles to form inside the concrete matrix. Foamed concrete, also called cellular concrete, is a lightweight material that is produced when these bubbles form a porous structure.

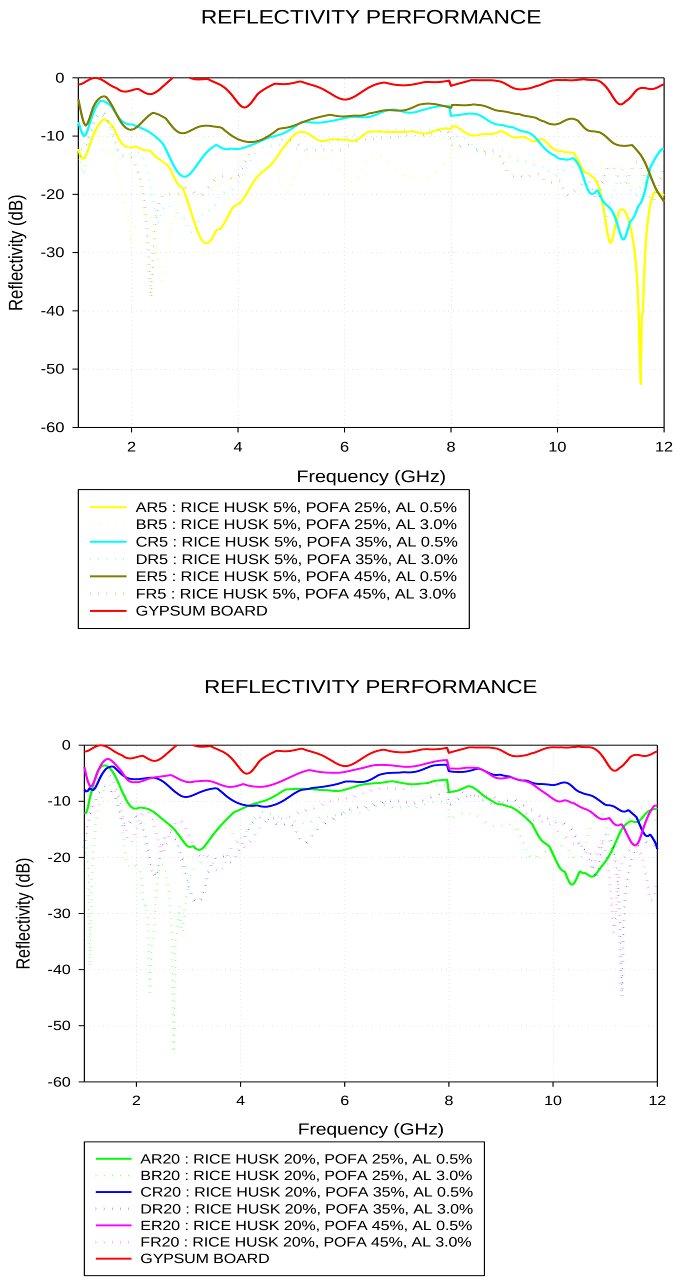

Figure 7. Reflectivity performance of anti-microwave radiation partition wall with different ratio of rice husk

Figure 8 shows the reflectivity performance across varying proportions of aluminium amongst prototypes. The graph shows that an anti-microwave radiation partition wall with a greater proportion of aluminium exhibits a greater capacity to absorb microwaves. Using aluminium mostly helps to produce voids in anti-microwave partition walls. The presence of voids or pores in the material structure is referred to as porosity. In the framework of microwave-absorbing material, porosity is one of the characteristics that improve the EM radiation absorption capacity of the material [21], [22]. This lets the microwaves pass through the material, reflecting inside instead of toward the source. It also enables microwaves to travel more efficiently and interact more intensely with it [32]. The pores can also cause a resonance effect, where certain microwaves become locked inside the porous material and begin to vibrate. This improves the overall wave energy absorption [33].

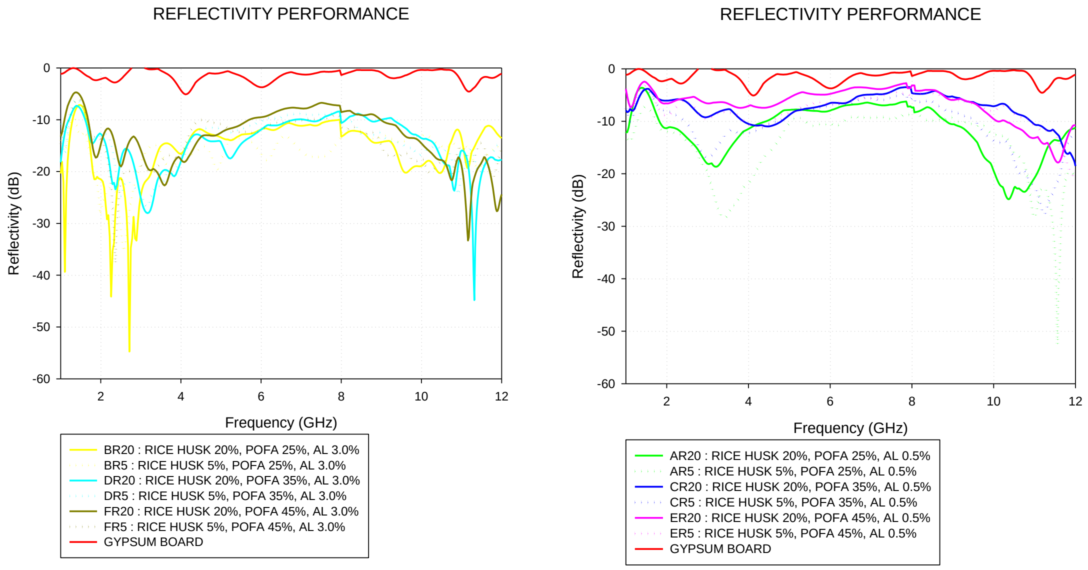

Figure 8. Reflectivity performance of anti-microwave radiation partition wall with different ratio of aluminium

4. CONCLUSION

Based on the reflectivity measurement, the anti-microwave radiation partition wall composed of 5% rice husk, 25% POFA, and 3.0% aluminium has the highest effectiveness as a microwave absorber. The prototype partition wall BR20, composed of 20% rice husk, 25% POFA, and 3.0 aluminium, has a high absorption rate at L-band (-39.3612 dB) and S-band (-54.7372 dB) frequencies. The L-band frequency is 1.105 GHz, while the S-band frequency is 2.715 GHz. The AR5 prototype, composed of 5% rice husk, 25% POFA, and 0.5% aluminium, is the most optimal for C-band and X-band. It has reflectivity values of -21.6443 dB and -52.5549 dB at frequencies of 4.01 GHz and 11.56 GHz, respectively.

From the overall observation, it was determined that the rice husk material generates a porous combination due to its natural form. However, the reflectivity measurement is also influenced by the proportion of rice husk and cement. This occurs due to the chemical reaction between the cement and aluminium, forming a region with increased porosity. The porosity rate is directly proportional to the aluminium content; higher aluminium percentage results in greater porosity. Increased porosity enhances the material’s ability to absorb EM radiation. Future research should explore the optimization of rice husk and aluminium ratios to enhance porosity and EM absorption. Additionally, investigating long-term durability and using advanved characterization techniques could provide deeper insights into absorption mechanisms across frequency bands.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
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I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

Not applicable. This study did not involve any human participants requiring informed consent.

ETHICAL APPROVAL

Not applicable. This study did not involve human or animal subjects.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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