

Sustainable Radiation Protection using Kenaf Fibre-Reinforced Composite Walls

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Abstract—The removal of unwanted radiation that might harm people or interfere with machinery led to the development of a microwave absorber. Kenaf fibre is employed to build partition walls due to its advantageous qualities. The objectives of this project are to design and simulate an anti-radiation partition wall using kenaf fibre, as well as to assess and evaluate the best absorption capabilities of a kenaf fibre partition wall with various dielectrics. The kenaf fibre used in the microwave absorber has similar dimensions but varies in dielectric constant. This paper decided to use Palm Oil Fuel Ash (POFA), kenaf fibre, cement, aluminium powder, and water in various ratios to develop anti-radiation partition walls. 20% and 5% of kenaf fibre, as well as 25%, 35% and 45% of POFA, were utilised in this paper. Naval Research Laboratory (NRL) Arch free-space method measured between 1 and 12 GHz the absorption performance of the constructed anti-radiation partition wall. Prototype C3 showcases remarkable reflectivity, registering -55.649 dB at 10.5 GHz (X-band), and attains optimal performance with a blend of 45% POFA and 5% kenaf fibre. Future investigations should prioritize additional research on kenaf fibre to enhance and refine its influence on reflectivity performance.

Index Terms—Kenaf fibre, Microwave absorber, Palm Oil Fuel Ash (POFA), partition wall.

I. INTRODUCTION

In contemporary times, escalating concerns surround the potential health ramifications of increased exposure to electromagnetic fields emanating from Global System for Mobile Communications (GSM) devices [1]. The focal point of this apprehension is the perceived link between high-frequency fields and specific cancers, given the human body's susceptibility to such radiation. Excessive electromagnetic power absorption may result in hyperthermia, causing

uncontrollable increases in body temperature and subsequent thermal damage [1]. Moreover, studies underscore the ability of certain radiations to induce chemical activity, potentially leading to cancer or cell death [2]. Residents living in proximity to communication towers echo these concerns, reporting symptoms ranging from headaches to severe health conditions, prompting a call for further research and stringent regulations [3]. Prolonged exposure to electromagnetic (EM) radiation has been associated with potential biological effects, including thermal stress, neurological disorders and cellular instability [4], [5]. Consequently, the design of passive electromagnetic shielding materials that are cost-effective, lightweight and environmentally sustainable has attracted considerable attention from materials scientists, researchers and engineers [6][7].

Microwave absorbers, a key mitigation tool, play a vital role in anechoic chambers, which commonly use wedges or pyramid-shaped structures filled with lossy dielectric materials [8]. Research emphasizes the significance of heterogeneous composite materials for effective microwave absorption [9]. In response to these concerns, the development of microwave absorbers from biomass materials [10] sourced from agricultural waste emerges as a potential solution. Materials such as oil palm empty fruit bunches and rice husks can serve as building materials, absorbing microwave radiation and offering a promising avenue for creating useful products, including pyramidal microwave absorbers for anechoic chambers.

In modern settings, the electromagnetic field (EMF) spans a spectrum, and segments within the 200 MHz to 5 GHz range [11] pose risks to essential electronic systems for information and communications technology (ICT) services. The implementation of microwave absorbers crafted from biomass materials offers a solution to manage electromagnetic interference (EMI) and enhance the stealth capabilities of radar systems. This presents potential advancements across industries by not only decreasing radar cross-section but also optimizing various aspects such as signal reception, transmission efficiency, radiation pattern, high-frequency circuit performance, and signal integrity. Rigorous electromagnetic compatibility (EMC) testing ensures compliance, proper device operation, and minimal crosstalk, contributing to the enhancement of signals in wireless communication systems. The adoption of these advanced absorbers signifies a comprehensive improvement across industries, ultimately

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boosting electronic system performance, reducing interference, and enhancing signal integrity.

The objective of this study is to evaluate and quantify the absorption performance of anti-radiation partition wall prototypes through an experimental investigation, using the NRL Arch free-space method to obtain accurate measurement results. This project focuses on enhancing partition walls by incorporating anti-radiation materials, namely palm oil fuel ash (POFA) and kenaf fibre. The proposed specifications suggest dimensions of 60 cm length, 60 cm width, and a thickness of about 6 cm for these walls. Achieving the desired properties involves a weighted mixture calculation with varying ratios of cement, water, POFA, and kenaf fibre. The free-space arch reflectivity measurement method is then employed to assess the reflection loss or absorption performance of the designed partition walls. The dielectric constant, an important parameter, is assigned values based on research for each ratio, exhibiting variations. Both simulation and measurement activities are conducted over the frequency range of 1 GHz to 12 GHz, providing a comprehensive evaluation of the partition walls' performance and improvements in impedance match with the surrounding open space [10].

Constructing partition walls with renewable and environmentally friendly biomass materials presents a sustainable approach to building construction, enhancing efficiency and affordability while reducing environmental pollution [12]–[14]. Biomass materials, due to their accessibility and cost-effectiveness, stand out as attractive options for such purposes. Incorporating these materials aligns with the Sustainable Development Goals and contributes to greenhouse gas emission reductions. The ubiquity of partition walls in the UK, as highlighted in the research paper "Life cycle energy and environmental analysis of partition wall systems," emphasizes their role in spatial division, privacy, and sound insulation across various industries [15]. From office buildings and healthcare facilities to educational institutions, retail spaces, manufacturing facilities, data centres, and laboratories, partition walls offer versatile solutions in creating defined spaces. The paper finds applications beyond these sectors, extending to warehouses, transportation hubs, and recreational facilities.

Kenaf fibres, renowned for high tensile strength, lightweight composition, excellent absorbency, and biodegradability [16], are particularly suited for industrial and commercial applications with an emphasis on environmental sustainability. Industries such as textiles, automotive, construction, packaging, and paper manufacturing leverage kenaf fibre to produce diverse products, including biocomposites, textiles, ropes, mats, and insulation. The material's eco-friendly qualities and adaptability make it a preferred choice for industries seeking sustainable and renewable materials.

Palm oil fuel ash (POFA) primarily consists of ash rich in silicon dioxide (SiO_2). In addition to this major component, POFA contains a small amount of residual oil derived from palm oil shells, along with several metal oxides such as aluminium oxide (Al_2O_3), iron(III) oxide (Fe_2O_3), calcium

oxide (CaO), magnesium oxide (MgO), sodium oxide (Na_2O), potassium oxide (K_2O), and sulfur trioxide (SO_3) [17]. Owing to its chemical composition, POFA has been widely explored for various applications, including construction materials [17–20], soil conditioning, renewable energy production, and microwave absorption technologies [21–22].

For radar system shielding and electromagnetic interference mitigation, POFA's superior performance is attributed to its high carbon content and porous structure. Incorporating POFA into concrete not only enhances durability, strength, and sustainability but also reduces weight and improves thermal insulation, making it a promising avenue for advancing concrete properties. This was also mentioned in [23], higher POFA levels absorbed more microwaves, especially in the X-band frequency range (8–12 GHz), due to the presence of amorphous silica and alumina in POFA, which converted microwave energy into heat.

Cement, a vital hydraulic binder, contributes approximately 8% of global carbon dioxide emissions due to its energy-intensive manufacturing and raw material extraction. The process involves high-temperature conversion of limestone to clinker, heavily reliant on fossil fuels, causing habitat destruction and emitting harmful dust. Palm oil fuel ash (POFA), a byproduct of palm oil production, offers an eco-friendly alternative [24]. When blended with cement, POFA can partially replace traditional cement, offering a promising solution to reduce energy consumption and environmental impacts in construction and promote sustainability in the industry.

Aluminium is widely valued for its low density, high strength-to-weight ratio, corrosion resistance, and excellent electrical conductivity, making it essential in various industries [25]. Its ease of machining, forming, and alloying further enhances its versatility. In aerospace and automotive sectors, aluminium contributes to weight reduction and improved fuel efficiency, while in construction, it is favoured for applications such as window frames and roofing materials due to its durability and aesthetic appeal. The electrical and electronics industries also rely on aluminium for power cables and electronic components to ensure efficient current transmission and signal processing.

Aluminium powder is extensively utilised in the construction industry for the production of aerated or lightweight concrete [26]. When mixed with cement and water, aluminium powder undergoes a chemical reaction that generates gas bubbles, forming a porous structure within the concrete matrix [27–29]. Despite its broad industrial applications, aluminium production raises environmental concerns related to bauxite mining, high energy consumption, and waste generation, prompting ongoing efforts to adopt sustainable production practices.

II. METHODOLOGY

This research aims to develop biomass-based material, specifically kenaf and POFA, for protection against electromagnetic radiation. The study begins with a literature review of microwave absorbers, followed by the design of an anti-radiation partition wall using CST Simulation Software.

The most effective design is then fabricated, and its reflectivity performance is evaluated using the Naval Research Laboratory (NRL) free-space method.

A. Flow Chart of the Project

The goal of this project is to use kenaf fibre to design an anti-radiation partition wall. The dielectric constant, tangent loss, partition dimensions, and fundamental parameters all affect the effectiveness of a microwave absorber. The research is being conducted to figure out the best arrangement for the anti-radiation partition wall's standard measurement and commercial size. The overall flowchart of the project is shown in Fig. 1.

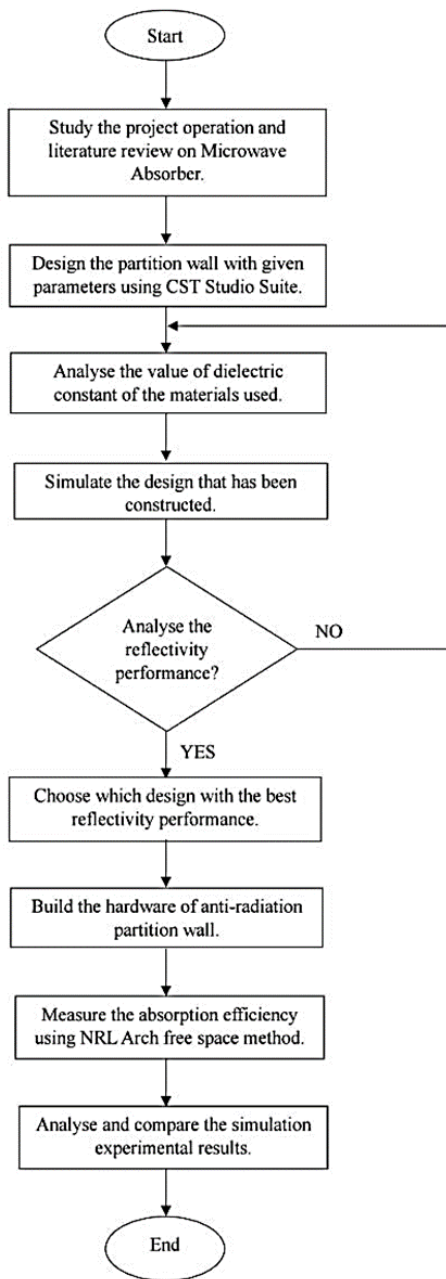


Fig. 1. Flowchart of the project.

B. Design of Anti-Radiation Partition Walls

To establish standardized prototypes, the partition wall was constructed with fixed dimensions. The partition wall was designed with dimensions of 60 cm in length, 60 cm in width, and 6 cm in thickness, as shown in Fig. 2. By adjusting the material parameters and dielectric constant, the partition walls were assembled using CST Software. Three different dielectric constant values were used to compare the partition wall designs. The established partition walls are then measured between 1 and 12 GHz by setting the Zpos, X, and Y boundary values, with Zpos equal to the distance from the waveguide port. The designs are compared because the CST Software enables precise customization of the partition walls.

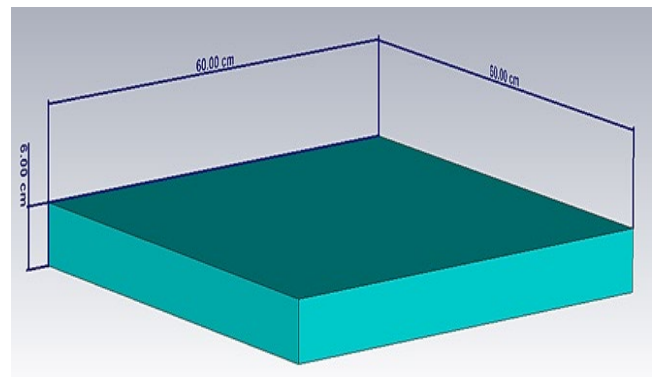


Fig. 2. Design of anti-radiation partition wall using CST simulation software.

C. Development of Anti-Radiation Partition Walls

Fig. 3 illustrates the raw materials used in the fabrication of the anti-radiation partition wall, consisting of palm oil fuel ash (POFA), kenaf fibre, cement, aluminium powder, and water. The fabrication procedure is schematically presented in Fig. 4. Initially, all raw materials, including POFA, kenaf fibre, cement, and aluminium powder, were prepared and weighed precisely according to the mix proportions specified in Table I, Table II, and Table III.



Fig. 3. Raw materials used.

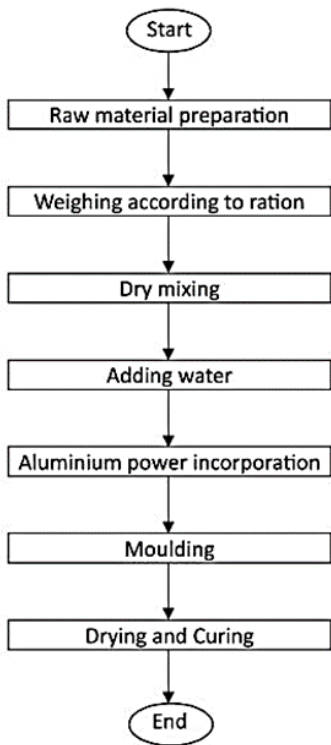


Fig. 4. Process of fabricating the anti-radiation partition wall.

The weighed materials were first subjected to dry mixing for approximately 3 minutes using a mechanical mixer to achieve a homogeneous blend. Subsequently, water was gradually added based on a fixed water-to-cement ratio of 1:1 while continuously stirring the mixture. After obtaining a uniform paste, aluminium powder was slowly incorporated into the mixture and stirred for an additional 1 minute to ensure even dispersion and initiate the foaming reaction. The resulting slurry was then poured into pre-oiled moulds with dimensions (length × width × thickness) of (60 × 60 × 6) cm to prevent adhesion. The specimens were subjected to a curing and drying process for a period of 14 days to ensure complete hydration and structural stability before demoulding. Fig. 5. shows the final fabricated prototype, where the partition wall is sandwiched between two gypsum boards to simulate actual installation conditions.

TABLE I. RAW MATERIAL PROPORTION FOR DESIGN A

Prototype	Ratio (%)				
	POFA	Kenaf fibre	Cement	Aluminium	Water
A1	25	20	55	0.5	55
A3	25	5	70	0.5	70

TABLE II. RAW MATERIAL PROPORTION FOR DESIGN B

Prototype	Ratio (%)				
	POFA	Kenaf fibre	Cement	Aluminium	Water
B1	35	20	45	0.5	45
B3	35	5	60	0.5	60

TABLE III. RAW MATERIAL PROPORTION FOR DESIGN C

Prototype	Ratio (%)				
	POFA	Kenaf fibre	Cement	Aluminium	Water
C1	45	20	35	0.5	35
C3	45	5	55	0.5	55



Fig. 5. Fabricated anti-radiation partition wall.

D. NRL (Naval Research Laboratory) Arch Free-Space Method

The reflectivity performance of the kenaf fibre-based anti-radiation partition wall was evaluated using the NRL free-space measurement technique. This method employs a vertically mounted semi-circular wooden frame, as illustrated in Fig. 6., which serves as the main supporting structure for the measurement setup. The system comprises a flat metallic reference plate, a centrally positioned sample holder, and two horn antennas functioning as the transmitting and receiving units. Both antennas are mounted along the curved arch and oriented directly towards the material under test.

During the measurement process, microwave signals were emitted from the transmitting antenna and directed toward the sample, while the receiving antenna captured the reflected signals from the material surface. A flat metal plate was used as a calibration reference, assuming 100% reflectivity and 0% absorptivity, to ensure accurate normalization of the measured data. The entire setup was connected to a Vector Network Analyzer (VNA) interfaced with a personal computer for signal excitation, detection, and data acquisition. The test specimen was positioned on the sample table at the geometric centre of the arch to maintain consistent measurement conditions.

The reflectivity characteristics were determined by analyzing the absorption level expressed in decibels (dB) over a frequency range. In this study, measurements were conducted from 1 to 12 GHz at a fixed incidence angle of 0°, enabling a comprehensive evaluation of the microwave absorption performance of the fabricated partition wall.



Fig. 6. NRL arch free-space setup.

III. RESULT AND DISCUSSION

The NRL Arch free-space method was employed to assess the reflectivity performance of the anti-radiation partition wall, varying the percentages of POFA and kenaf fibre. In Fig. 7, the reflectivity of prototypes for Design A (A1 and A3), Design B (B1 and B3), and Design C (C1 and C3), incorporating POFA at 25%, 35%, and 45%, respectively, mixed with 0.5% Aluminium powder, is depicted across the frequency range from 1 to 12 GHz and at 0°. To distinguish between prototypes with 20% and 5% of kenaf fibre more easily, solid lines were used for the graphs representing the prototype with 20% kenaf fibre, while dashed lines were used for the prototype with 5% kenaf fibre.

The graph in Fig. 7 shows that there is no reflectivity for A0 (black). A0 stands for gypsum boards with a gap; in other words, there is no prototype between the two gypsum boards. Compared to A1 (red), A3 (orange), B1 (blue), B3 (purple), C1 (green), and C3 (yellow), it proves that A0 has no reflectivity because the value is in the range of zero dB. It can be seen that prototype C3 (POFA 45% and kenaf fibre 5%) has the best reflectivity performance compared to prototype A1 (POFA 25% and kenaf fibre 20%). From this result, it can be concluded that the higher the percentage of POFA, the better the reflectivity performance. In addition, the percentage of kenaf fibre (5%) is shown to be adequate to enhance the reflectivity performance.

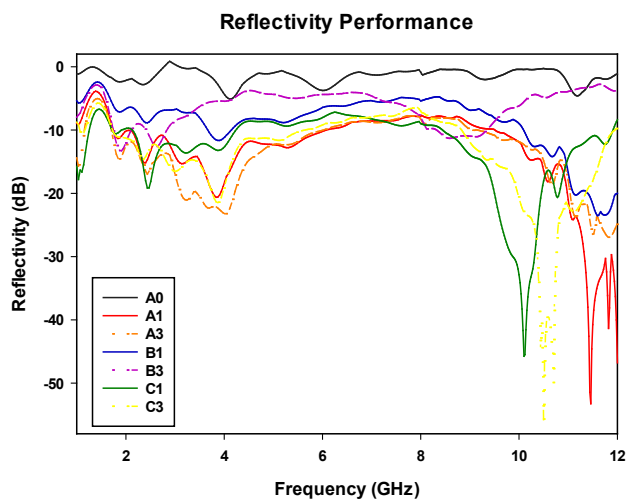


Fig. 7. Reflectivity performance of anti-radiation partition wall prototypes A1, A3, B1, B3, C1, and C3.

In Fig. 8 and Fig. 9, the maximum and minimum data of reflectivity of prototypes for Design A (A1 and A3), Design B (B1 and B3), and Design C (C1 and C3), incorporating POFA at 25%, 35%, and 45%, respectively, mixed with 0.5% aluminium powder, is depicted across the frequency range from 1 to 12 GHz and at 0° of the arch. To distinguish between prototypes with 20% and 5% of kenaf fibre more easily, solid lines were used for the graphs representing the prototype with 20% kenaf fibre, while dashed lines were used for the prototype with 5% kenaf fibre.

Table IV shows the maximum data of reflectivity performance for prototypes A1, A3, B1, B3, C1, and C3 at 0°. Fig. 8 depicts that prototype C1 (POFA 45% and kenaf fibre 20%) has the maximum reflectivity performance at L-band (-17.7031 dB). At S-band and C-band, prototype A3 (POFA 25% and kenaf fibre 5%) has the maximum reflectivity with reflectivity values of -23.0215 dB and -23.1752 dB, respectively. On the other hand, at X-band, the best reflectivity performance is achieved by prototype C3 (POFA 45% and kenaf fibre 5%), with a value of -55.649 dB.

This demonstrates that the percentage of kenaf fibre in prototype C3 (5%) plays a vital role in reflectivity performance; only a small amount of kenaf fibre is sufficient to have an impact on the reflectivity performance of the anti-radiation partition walls. Additionally, it can be seen that the ratio of POFA (45%) in prototype C3 also plays an important role in reflectivity performance; the higher the POFA percentage, the more effective the reflectivity performance.

TABLE IV. MAXIMUM DATA OF REFLECTIVITY PERFORMANCE

Prototype	Reflectivity Performance (dB)			
	L band (1-2GHz)	S band (2-4GHz)	C band (1-2GHz)	X band (8-12GHz)
A1	-11.2909	-20.5879	-18.1005	-53.2031
A3	-15.6698	-23.0215	-23.1752	-26.8894
B1	-7.0744	-11.5688	-11.0328	-23.4409
B3	-13.1792	-12.5352	-9.779	-11.2028
C1	-17.7031	-19.0422	-12.4876	-45.6297
C3	-11.1118	-21.3418	-18.5812	-55.649

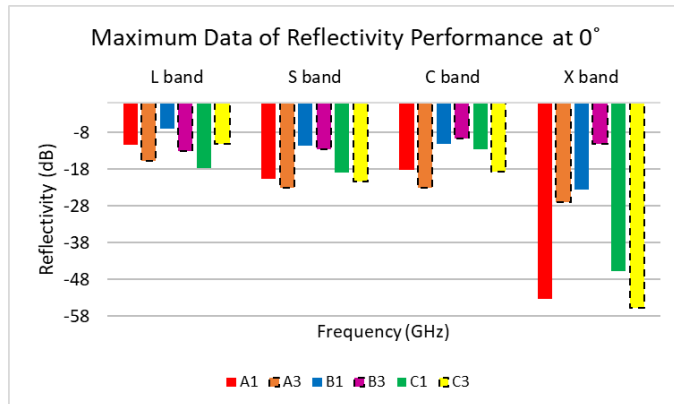


Fig. 8. Bar graph of maximum data of reflectivity performance prototype A1, A3, B1, B3, C1, and C3.

Table V presents the minimum reflectivity data for prototypes A1, A3, B1, B3, C1, and C3 at 0°. As seen in Fig. 9, efficient absorption typically happens when the reflectivity is less than -10 dB. As a result, prototype A3 (POFA 25% and kenaf fibre 5%) can be used as a microwave absorber at the S-band (2-4 GHz) because its reflectivity value is approximately -10 dB.

By referring to Fig. 9, the minimum reflectivity at L-band and X-band is -6.6001 dB and -8.2453 dB, respectively, from prototype C1 (POFA 45% and kenaf fibre 20%). Moreover, the best minimum reflectivity is -11.7954 dB at S-band from prototype A3 (POFA 25% and kenaf fibre 5%), while the minimum reflectivity is -7.7546 dB at C-band from prototype A1 (POFA 25% and kenaf fibre 20%).

This indicates that the percentage of kenaf fibre in prototype A3 (5%) is significant to its reflectivity performance, meaning that only a small quantity of kenaf fibre is required to contribute to the reflectivity performance of the anti-radiation partition walls. The percentage of POFA in prototype A3 (25%) is small, hence the minimum reflectivity performance is minor. However, it shows that 25% of POFA is sufficient to make the anti-radiation walls act as microwave absorbers, as shown in Fig. 9.

TABLE V. MINIMUM DATA OF REFLECTIVITY PERFORMANCE

Prototype	Reflectivity Performance (dB)			
	L band (1-2GHz)	S band (2-4GHz)	C band (4-8GHz)	X band (8-12GHz)
A1	-3.8428	-10.0179	-7.7546	-7.6662
A3	-4.9824	-11.7954	-7.7004	-7.9398
B1	-2.3522	-6.3237	-4.7806	-4.674
B3	-2.794	-5.3178	-3.6633	-2.6737
C1	-6.6001	-9.5918	-7.065	-8.2453
C3	-5.6196	-11.1876	-6.2507	-7.0183

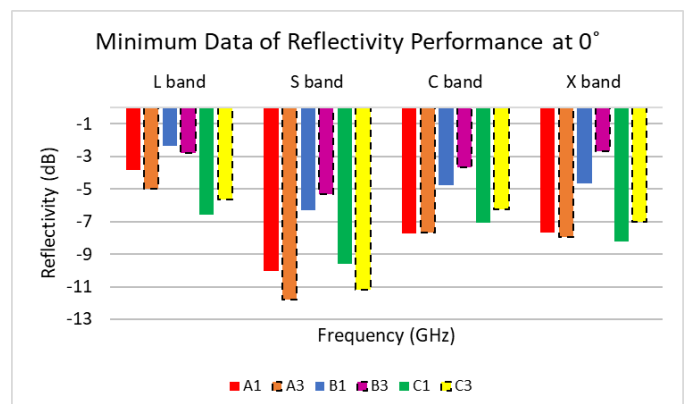


Fig. 9. Bar graph of minimum data of reflectivity performance prototype A1, A3, B1, B3, C1, and C3.

IV. CONCLUSION

This study demonstrates the potential of palm oil fuel ash (POFA) and kenaf fibre as sustainable materials for the development of a microwave-absorbing anti-radiation partition wall. Reflectivity measurements over the frequency range of 1–12 GHz indicate that material composition significantly influences electromagnetic performance. Higher POFA content generally enhances reflectivity performance, while a low kenaf fibre content (5%) is sufficient to improve absorption behaviour.

Among the investigated prototypes, C3 (45% POFA, 5% kenaf fibre) exhibited the best performance, achieving a minimum reflectivity of -55.649 dB in the X-band, whereas A3 (25% POFA, 5% kenaf fibre) demonstrated effective absorption in the S-band. These results confirm that the absorber's performance can be tailored to specific frequency ranges through controlled adjustments in material composition.

The proposed partition wall has the potential to mitigate indoor electromagnetic interference in buildings such as offices and communication facilities. However, this work is limited to normal incidence measurements, and factors such as angular dependence, mechanical durability, and environmental stability were not investigated. The novelty of this study lies in integrating waste-derived POFA and natural kenaf fibre into a gypsum-based partition wall structure, providing a low-cost, sustainable alternative to conventional microwave absorbers.

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