Investigation of microwave absorption performance of anti-radiation plastic cement brick

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ABSTRACT

The increasing demand for effective anti-microwave radiation materials motivates the exploration of sustainable and eco-friendly alternatives. This research investigates the microwave absorption properties of various brick compositions, including commercial brick (CB) and solid bricks (SB1, SB2 and SB3) incorporating recycled materials, polyethylene terephthalate (PET) and palm oil fuel ash (POFA). The dimension of the developed brick is 200×100×60 mm (length×width×height). The absorption performance of the bricks was measured in 100 mm and 60 mm thickness across the frequency range of 1 to 12 GHz using the naval research laboratory (NRL) free space arch method. At 100 mm thickness, SB3 shows the highest absorption up to-32.2061 dB at 1.98 GHz. At 60 mm thickness, SB1 achieved the maximum absorption at -57.6511 dB at 2.505 GHz. SB2 shows consistent average absorption performance at 15.2064 dB at 100 mm thickness and -19.5 dB at 60 mm thickness respectively. The compressive strength of the brick was measured, and it was shown that SB2 exhibited the highest average compressive strength of 7.17 MPa. Considering the standard wall thickness and brick strength, SB2 shows the most effective performance due to its enhanced composition and consistent performance across frequencies.

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1. INTRODUCTION

An explosion of wireless communication technologies and electronic devices has caused an increase in electromagnetic radiation in our environment. The increased in electromagnetic pollution has raised concerns about potential health risks and interference with sensitive electronic equipment [1], [2]. As a result, there is a growing demand for effective and sustainable solutions to reduce electromagnetic interference (EMI) and protect against microwave radiation [3]. Various sources contribute to increasing electromagnetic radiation, including the growing use of mobile phones, cellular networks, Wi-Fi, Bluetooth devices, internet of things (IoT) devices, 5G networks, and various electronic devices across industries [4]. While research is ongoing, some studies have indicated potential connections between long-term exposure to electromagnetic fields (EMFs) and health issues such as headaches, fatigue, sleep disturbances, and potential increased risk of certain cancers; however, the evidence remains inconclusive [5]. EMI can also have a notable impact on the performance of sensitive equipment in medical, aviation, scientific, industrial, and telecommunications fields. The increasing demand has resulted in a greater need to reduce EMI through shielding materials, EMI-resistant design, absorption materials, and improved grounding techniques [6]. The emphasis on sustainability has led to the advancement of EMI shielding materials made from recycled and biodegradable materials, as well as energy-efficient mitigation techniques. Nevertheless, there are still obstacles in achieving a harmonious balance between EMI protection, device functionality, and aesthetics, as well as in addressing various frequencies, finding affordable solutions, and keeping up with the swift advancements in wireless technologies [7]. With the increasing demand for wireless technologies, the importance of implementing sustainable EMI mitigation solutions becomes more crucial, creating challenges and opportunities for experts to develop innovative ways to tackle electromagnetic pollution and promote technological progress [8].

Building materials capable of absorbing unwanted electromagnetic waves has gained attention due to the increasing electromagnetic pollution [9]. Recently, there has been a rising interest in the construction industry in creating innovative building materials that serve multiple functions, including electromagnetic radiation protection. Incorporating waste materials into construction elements promotes environmental concerns [10], [11]. The global plastic waste management challenge has intensified, with millions of tons of plastic waste generated annually. Recycling and repurposing plastic waste into value-added products has become a critical area of research in pursuit of sustainable development and circular economy principles. Recycled plastic polyethylene terephthalate (PET) has been explored for its use in construction materials that offer benefits such as durability and water resistance [12]. PET is a rigid, firm, robust, and dimensionally stable material widely utilized as a raw material in producing of items such as soft drink bottles, food packaging containers, and various consumer goods. Previous studies have explored the use of recycled PET in concrete and mortar mixes, reporting improvements in tensile strength, ductility, and crack resistance [13]–[15]. Studies also indicate that increasing the substitution of sand with PET plastic waste results in lighter bricks [16].

Palm oil fuel ash (POFA) is a by-product of the palm oil industry, becoming a subject of interest to researchers for its potential applications in construction as a supplementary cementitious material and as a microwave-absorbing material. POFA results from the incineration process of solid waste generated during palm oil production, including palm kernel shells, mesocarp fibers, and empty fruit bunches. This waste is then burned to function as a boiler fuel to generate electricity in palm oil mills or power plants, with approximately 5% of the combusted solid waste being transformed into POFA [17]. The high silica content of POFA makes it an effective pozzolanic material capable of enhancing concrete strength and durability [18]. Studies have shown that POFA contains elements such as carbon and iron oxide that can contribute significantly to microwave absorption [19]. Carbon (C) is an effective microwave-absorbing element due to its electrical conductivity and ability to convert microwave energy into heat. Iron III oxide (Fe_2O_3) present in POFA contributes to microwave absorption through its magnetic properties. Other elements contained in POFA are silicon dioxide (SiO_2), calcium oxide (CaO), aluminum oxide (Al_2O_3) and various metal oxides. The dielectric properties of POFA with high dielectric constant and loss tangents determine the materials' interaction with microwave and dissipate the energy [20], [21]. The porous structure of POFA, due to its carbon content, will enhance the ability of the materials to absorb through multiple internal reflections and scattering of microwaves [22], [23]. A high-strength concrete can be produced from POFA, as it can serve as a pozzolanic material to enhance durability and reduce costs by lessening the need for cement. Hence, in concrete production, POFA plays a huge role in creating stronger, denser, and more durable concrete [24]. It is proven that palm fiber has a notably high ash content of 9.84%, with carbon constituting 43.25% of its composition. POFA contains a significant amount of carbon that contributes to microwave absorption due to its electrical conductivity ability to convert electromagnetic energy into heat [19]. Other compounds in POFA includes iron III oxide (Fe_2O_3) which has magnetic properties that lead to microwave absorption when interacting with electromagnetic waves [25]. POFA also contains other elements that contribute to its microwave absorption properties, including silicon dioxide (SiO_2), calcium oxide (CaO), aluminum oxide (Al_2O_3) and various metal oxides. These compounds can affect the dielectric properties of the material as they interact with electromagnetic waves [23].

In this research, the objective is to develop a plastic cement-brick composite using polyethylene terephthalate (PET) plastic waste and biomass material (POFA) and characterize the microwave absorption properties of the plastic cement-brick composites across frequencies ranging from 1 GHz to 12 GHz. To achieve this, three bricks consisting of different composition percentages of POFA (5%, 10%, and 30%) are fabricated. The percentage of POFA varies to investigate the influence of different concentrations of various elements in POFA that contribute to microwave absorption [26]. The composition of plastic waste is set to 10% of the mixture. Fixing the percentage of plastic waste at 10% could provide a consistent baseline for plastic waste content while exploring the impact of increasing concentrations of POFA. The absorption performance of the developed bricks was compared with the traditional cement bricks. The strength of the brick was tested to ensure that it met the required standard strength. This project makes an impact by preserving the environment by reducing plastic waste.

2. METHOD

The research methodology involves developing and evaluating anti-radiation plastic cement brick incorporating PET and POFA as key materials. The development process involves materials preparation and proportioning, mixing, molding, drying and curing. The measurement and testing process involved measuring the dielectric of the material using high-temperature coaxial-line dielectric probes and vector network analyzers (VNA). The reflectivity of the bricks is measured using the NRL free space method across a frequency range of 1 GHz to 12 GHz. The mechanical performance of the bricks is assessed through compressive strength tests.

2.1. Materials preparation

The PET material utilized in the study was sourced from Glowmore Express Sdn Bhd, located in North Port Klang, Malaysia. It is a byproduct generated from shredded bottles. The PET is approximately 5 mm in size. POFA is obtained from a palm oil mill factory situated in Padang Serai, Kedah, Malaysia. Ordinary Portland cement and fine aggregates were used as base materials for the bricks. The development of an anti-radiation plastic cement brick involves the use of cement as a binder and water. The cement binder to aggregate ratio is set to 1:3. Careful selection and precise proportions of these materials contribute to the structural integrity and performance of the resulting plastic brick absorber.

Developing the anti-radiation plastic cement brick was started by making a few samples to determine the optimal proportions of POFA and PET that would give the desired dielectric properties and the resistivity of the mixture. Three experimental brick mixes were designed as in Table 1. The water-to-cement (w/c) ratio is set to 0.5 for all mixes to ensure adequate workability and strength. The percentage of PET is set to 10% while the percentage of POFA is varied to observe the effect of different proportions of POFA on microwave absorption properties and the overall performance of the composite material.

Table 1. Distribution of material proportions

Prototype	Cement Binder		Aggregate	
	POFA (%)	Cement (%)	PET (%)	Sand (%)
SB1	5	60	10	65
SB2	10	60	10	65
SB3	30	60	10	65

2.2. Fabrication of anti-radiation plastic cement brick

In this project, the dimensions of the anti-radiation plastic cement brick follow the standard size of commercial bricks, measuring 200 mm in length, 100 mm in width, and 60 mm in height as shown in Figure 1. The plastic cement brick microwave absorber was fabricated by mixing PET and POFA with other brick materials, including cement, sand, and water. The mixture was mixed thoroughly using a mixer in the Concrete Lab, UiTM Pulau Pinang, Malaysia. The dry ingredients (sand, POFA, and cement) were first mixed, followed by water which was added gradually while mixing to ensure uniform distribution. PET was added in the final stage as the fiber to the mixture. Once all the components were uniformly mixed, the composite was poured into a rectangular mold previously coated with oil. The bricks were left to cure at room temperature before demolding and then left to dry again for another couple of days. Figure 2 shows the material preparation and the process for the brick's development.

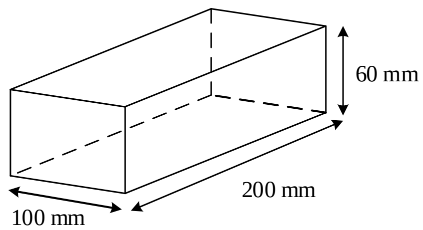

Figure 1. Design and dimension of the brick

2.3. NRL free space arch reflectivity measurement

The naval research laboratory (NRL) free space arch reflectivity measurement setup is a system designed to assess the performance of microwave absorbers in a controlled environment. In this setup, an archshaped structure made up of wood is utilized to direct and measure electromagnetic waves, often in the microwave or millimeter-wave frequency range. This method uses a free-space measurement setup that includes a pair of antennas, a transmitting antenna and a receiving antenna, which are placed facing a metal plate [27]. The absorption was measured by placing the anti-radiation plastic brick at the center of the arch while two antennas were put perpendicular to the bricks. The signal is then emitted towards the bricks and the reflected signal is then measured. Furthermore, the setup usually includes specialized equipment such as a vector network analyzer (VNA), and the data is recorded from 1 to 12 GHz in the range under the arch measurement methods. The free space arch measurement setup is shown in Figure 3.

Material preparation and proportioning Mixing Molding Drying and curing

Figure 2. Development of anti-radiation plastic cement brick

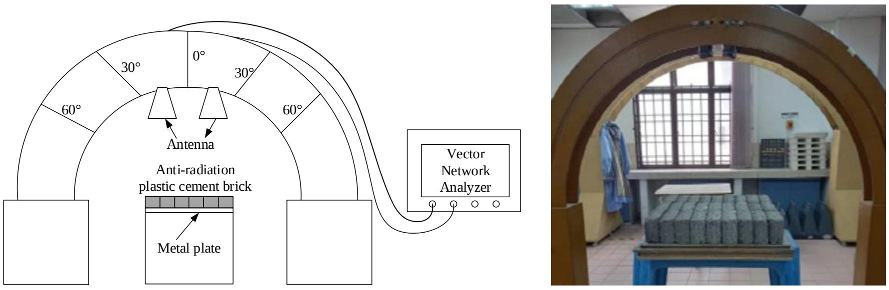

Figure 3. Free space arch reflectivity measurement setup

2.4. Compressive strength test

As depicted in Figure 4, an automatic compression machine was utilized in this project to conduct compressive strength test on SB1, SB2, and SB3. The brick was positioned properly in the center between the compressive test machine’s two flat, circular plates. The machine door was then closed before proceeding with the test due to safety hazards. The bottom plate will be brought close to the test object to apply pressure, and the machine will run. It takes several minutes until the brick has been compressed completely. After the machine stopped, it was observed that the bricks were crushed, the pressure applied to the brick earlier was released, and the compressive strength reading was recorded.

Figure 4. Compressive strength machine

3. RESULTS AND DISCUSSION

The microwave absorption performance of the commercial brick and the developed solid anti-radiation plastic bricks, namely SB1, SB2 and SB3, were evaluated using the NRL free space arch method over a frequency range of 1 to 12 GHz. This frequency range covers L-band (1-2 GHz), S-band (2-4 GHz), C-band (4-8 GHz) and X-band (8-12 GHz). The measurements were conducted for 100 mm and 60 mm thicknesses at an incident angle of 0°. The compressive strength test ensures the fabricated brick complies with Malaysian Standard MS 76:1972.

3.1. Reflectivity performance of anti-radiation plastic brick at 60 mm thickness

The reflectivity performance of four brick compositions of 60 mm thickness is illustrated in Figure 5. The graph in Figure 5 is then divided into Figure 6, which shows the L-band, S-band, C-band and X-band, respectively. Commercial brick (CB) is used as a control brick to serve as a baseline for comparison with the anti-radiation brick (SB1, SB2 and SB3) containing PET and POFA. The purpose of measuring the reflectivity of the control brick is to provide a reference point in evaluating the effectiveness of the bricks in microwave absorption.

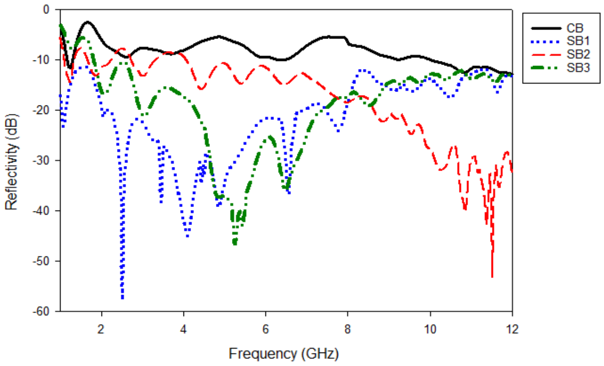

Figure 5. The reflectivity of anti-radiation plastic brick for 60 mm thickness

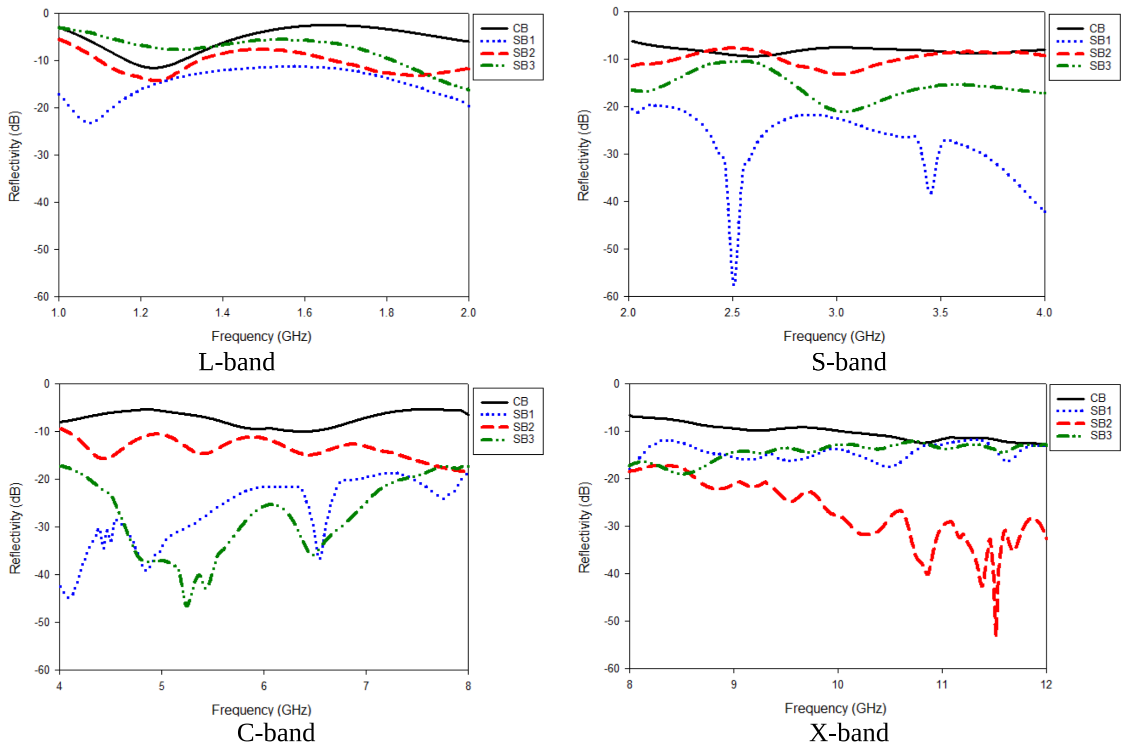

Figure 6. Absorption performance in L-band, S-band, C-band and X-band for 60 mm thickness

In the L-band, all bricks show some absorption but are relatively low. SB1 shows some improvement but fluctuates around -20 dB. This indicates that adding a small percentage of POFA affects the absorption at lower frequencies. In the S-band, CB continues to show minimal absorption. SB1 shows an obvious improvement, with absorption levels reaching more than -50 dB and consistent at -30 dB. SB2 and SB3 perform good absorption across the whole band between -10 dB to -20 dB. In the C-band, all experimental bricks outperform CB significantly. SB1 shows strong absorption with multiple dips up to -40 dB. SB2 performs consistent absorption throughout the band. SB3 stands out as the best in this band, reaching consistently below -30 dB to -50 dB. In the X-band, SB1 shows the absorption performance at this band consistently around -20 dB. In this band, SB2 performs best in absorption up to -30 dB and -40 dB. However, in this band, SB3 maintain an absorption performance of around -20 dB. The maximum and minimum reflectivity of the bricks measured in 60 mm thickness derived from Figure 5 is described in Table 2.

Table 2. Maximum and minimum reflectivity of the bricks measured in 60 mm thickness

Frequency	Reflectivity (dB)							
	CB		SB1		SB2		SB3	
	Min	Max	Min	Max	Min	Max	Min	Max
L-Band (1-2 GHz)	-2.4854	-11.4782	-11.2827	-23.1863	-5.4583	-14.332	-3.0732	-15.7329
S-Band (2-4 GHz)	-6.1696	-9.3837	-19.7635	-57.6511	-7.7078	-13.164	-10.4938	-21.106
C- Band (4-8 GHz)	-5.3347	-9.9688	-18.7011	-44.8345	-9.4286	-18.4613	-17.1786	-46.3767
X-Band (8-12 GHz)	-6.5	-12.7445	-11.7378	-18	-17.2231	-53.1319	-12.1483	-19.0406

3.2. Reflectivity performance of anti-radiation plastic brick at 100 mm thickness

The reflectivity performance of four brick compositions for 100 mm thickness is illustrated in Figure 7. In this study, CB serves as the control brick, while the experimental bricks are labeled SB1, SB2, and SB3. The comparison focuses on evaluating the absorption capabilities of these experimental bricks relative to the control brick when the thickness is increased. This allows for a better understanding of how greater thickness influences the performance of each brick composition in terms of reflectivity and absorption.

The graph in Figure 7 is subdivided into Figure 8, representing the L-band, S-band, C-band, and X-band, respectively. CB exhibits the least effective microwave absorption for all frequency bands compared to SB1, SB2 and SB3. In the L-band, SB1 shows good absorption, reaching up to -20 dB. SB2 and SB3 exhibit better absorption, with the reflectivity reaching approximately -20 to -30 dB. In the S-band, SB1 shows consistent absorption around -10 dB. SB2 shows better absorption, approximately -10 to -20 dB. In this band, SB3 demonstrate the best absorption from -20 to -30 dB. In the C-band, SB3 still exhibits the best performance, reaching up to -30 dB from 4 to 6 GHz and consistent at -20 dB from -20 dB. In the X-band, all experimental bricks showed a similar level of performance, around -10 to -15 dB.

The maximum and minimum reflectivity of the bricks measured in 100 mm thickness is described in Table 3. The analysis of both 60 mm and 100 mm thickness microwave absorption measurements for the various brick compositions reveals distinct performance characteristics across the frequency range of 1-12 GHz. The addition of PET and POFA enhances the dielectric properties of the bricks allowing them to interact more effectively with electromagnetic waves. The impedance matching between air and the brick surface will reduce the reflections at the interface and enhance overall absorption. This is particularly evident in SB3, where high POFA content demonstrates this matching process.

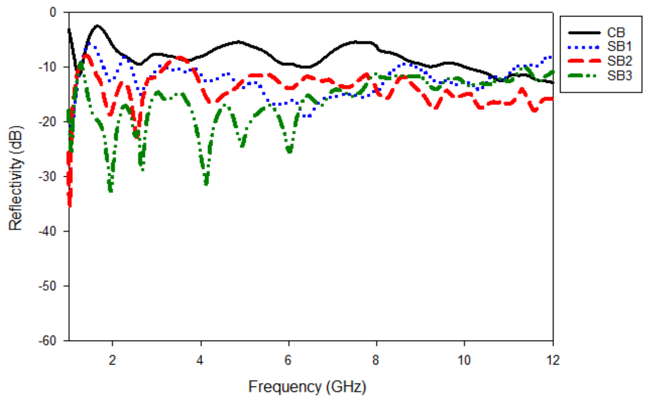

Figure 7. The reflectivity of anti-radiation plastic brick for 100 mm thickness

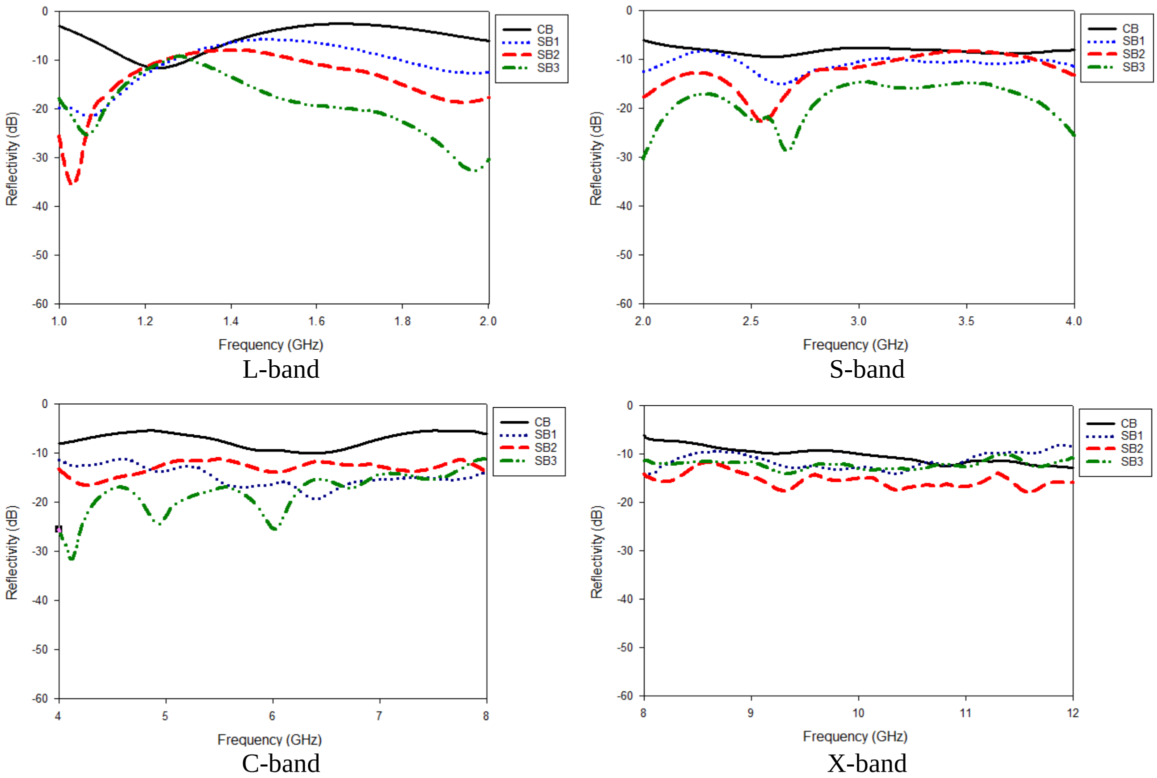

Figure 8. Absorption performance in L-band, S-band, C-band and X-band for 100 mm thickness

Table 3. Maximum and minimum reflectivity of the bricks measured in 100 mm thickness

Frequency	Reflectivity (dB)							
	CB		SB1		SB2		SB3	
	Min	Max	Min	Max	Min	Max	Min	Max
L-Band (1-2 GHz)	-2.4854	-11.4782	-5.6657	-21.5968	-7.9254	-35.5643	-9.1439	-32.2061
S-Band (2-4 GHz)	-6.1696	-9.3837	-8.2022	-14.9448	-8.2868	-22.463	-14.584	-28.7136
C- Band (4-8 GHz)	-5.3347	-9.9688	-11.0292	-19.1832	-11.1841	-16.5251	-11.1979	-31.6021
X-Band (8-12 GHz)	-6.067475	-12.7445	-7.9718	-14.0773	-11.7226	-17.858	-10.0353	-13.9931

3.3. Compressive strength

Table 4 shows the compressive strength test result for the three experimental bricks, SB1, SB2 and SB3. It is observed that SB2 has the highest value for strength, which is 7.16 MPa, followed by SB1 at 5.74 MPa and SB3 at 3.76 MPa. From this result, SB1 and SB2 fulfill the Malaysian Standard MS 7.6: 1972 to be at least 5.2 N/mm^2 for bearing load and SB3 fulfill the nonbearing load to be at least 1.4 N/mm^2.

Table 4. Result of compressive strength test

Prototype	Compressive Strength (MPa)			
		Strength		Average
SB1	11.6	2.14	3.47	5.74
SB2	4.88	12.27	4.32	7.16
SB3	3.21	2.89	5.19	3.76

4. CONCLUSION

This study investigates the microwave absorption properties of anti-radiation plastic cement brick prototypes incorporating POFA and PET across the frequency range of 1-12 GHz. The result demonstrates that SB3 exhibits the best and most consistent microwave absorption compared to commercial bricks across multiple frequency bands. This aligns with initial hypothesis that the addition of PET and POFA would enhance the microwave absorption capabilities. SB3 shows the most effective microwave absorber across all bands due to its high POFA content making it particularly suitable for environments that required electromagnetic absorption. However, since these bricks will be used as construction materials, the compressive strength of the bricks must also be considered. Therefore, overall, SB1 and SB2 are more suitable use as building materials for bearing load and SB3 for non-bearing load due to their microwave absorption capabilities and because they comply with the compressive strength requirements. These findings highlight the potential of using waste materials like PET and POFA in developing sustainable and high-performance building materials for microwave absorption. Future research can further explore the effects of different ratios and additional materials to enhance the properties of these composites.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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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