Pyramidal microwave absorbers: leveraging ceramic materials for improved electromagnetic interference shielding

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ABSTRACT

This study presents the development and optimization of pyramidal microwave absorbers designed for efficient electromagnetic interference (EMI) reduction in anechoic chambers. Based on prior research, this work transitions from conventional flat cement-carbon absorbers to a novel pyramidal design, incorporating silicon carbide (SiC) as ceramic materials. Introducing ceramic materials into the cement-carbon composite aims to enhance absorption across a broader frequency range while maintaining structural integrity. The study evaluates five sets of pyramidal absorbers with varying SiC content within the 1–12 GHz frequency range. Reflectivity performance was assessed using the naval research laboratory (NRL) Arch free space method at a 0° incidence angle. Among the tested absorbers, the set containing 10% SiC demonstrated superior performance, achieving minimum and maximum reflectivity values of -26.6215 and -55.2752 dB, respectively, particularly in the C-band. The findings highlight the significant impact of material composition and porosity on the absorber's effectiveness, providing valuable insights for the future design of high-performance EMI absorbers.

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1. INTRODUCTION

Electromagnetic interference (EMI) is the transfer of disruptive electromagnetic energy between electronic devices, which can occur through radiated, conducted pathways, or both [1]. Radiated interference occurs when electromagnetic energy generated by a device is transmitted through space to a receptor, while conducted interference, on the other hand, happens when electromagnetic energy from a device is transferred to a receptor via cables [1]. Magnetic permeability and electric permittivity are two properties of absorbers. In an electromagnetic wave, a material's permeability determines how it affects its magnetic component, while its permittivity determines how it affects its electric component [2]. Dielectric properties explain a material's behavior at microwave frequencies [2], [3]. Various absorber types are often utilized in electromagnetic compatibility (EMC) applications based on frequency range [4], such as hollow pyramidal absorbers, pyramidal absorbers, twisted pyramidal absorbers, flat absorbers, wedge absorbers, multilayer dielectric absorbers, and hybrid dielectric absorbers [5].

In recent years, the cement-carbon flat absorber has gained significant attention within the research community, emerging as a prominent material of interest in the field of EMI mitigation. Its growing popularity can be attributed to its unique combination of cost-effectiveness, structural robustness, and promising absorption characteristics. Researchers have increasingly explored its potential, recognizing its capability to meet the demanding requirements of modern EMI reduction applications. Despite the promising results shown by prior research on cement-carbon composite flat microwave absorbers in absorbing radiation, several challenges remain. Conventional cement-carbon composite microwave absorbers have been extensively studied due to their favorable material properties and cost-effectiveness. However, these absorbers have predominantly been designed with a flat configuration, which imposes significant limitations on absorbing a wide range of electromagnetic frequencies effectively. The flat design, while practical, often results in suboptimal performance, particularly in high-frequency applications where efficient EMI reduction is critical. This research focuses on improving and enhancing these absorbers by transforming them into a pyramidal design and incorporating ceramic as a new material. This approach aims to address the limitations in absorption efficiency and further improve EMI reduction across a broader frequency range.

The shape of a microwave absorber is a critical factor in determining its reflectivity performance [6], with the pyramidal shape being the most commonly used design in anechoic chambers. According to Nornikman *et al.* [6], the pyramidal microwave absorber has demonstrated that this shape has the best performance compared to other shapes. The multi-reflections of these pyramidal microwave absorbers contribute to significant attenuation and boost microwave absorption relative to the flat [7]. The high effectiveness of the pyramidal absorber is primarily due to the numerous reflections that exist between the pyramids [6], [8]. Additionally, this study investigates the incorporation of ceramic materials into the cement-carbon composite, aiming to demonstrate that the ceramic-carbon synergy can further enhance the absorber's performance across a broader frequency spectrum. Ceramics have excellent mechanical properties, including high hardness, low density, high strength, and excellent wear resistance—even at extremely high temperatures [9]. Ceramics are defined as inorganic non-metallic materials that are heated to form metallic and non-metallic constituents bonded by ionic or covalent bonds [10], such as silicates, oxides, and non-metallic carbides [11]. Silicon carbide's versatility holds the promise of transformative breakthroughs across a spectrum of industries and applications. Over the past few decades, significant efforts have been directed towards SiC growth [12]. An ordinary non-oxide ceramic in the industrial sector is silicon carbide [13]. Outstanding thermo-mechanical properties of silicon carbide include high wear and oxidation resistance, excellent mechanical properties, and high thermal conductivity [13]. Related research indicates that the SiC material exhibits good absorption qualities in the gigahertz (GHz) band region [14]. Many researchers have acknowledged that SiC is a good fit for random-access memory (RAM) due to its natural traits, but they have mainly concentrated on improving its dielectric properties. For instance, Li *et al*. [15] have created SiC powders with N-doped by combustion synthesis (CS) [16]. Zheng *et al*. [17] have created Si_3N_4–SiC1 ceramic through chemical vapor infiltration with porous Si_3N_4 ceramic [16]. By merging the unique properties of carbon, such as its conductivity and lightweight nature, with the durability and thermal stability of ceramics, these composite materials offer promising avenues for enhancing microwave absorption performance. This innovative combination of material composition and structural design seeks to overcome the existing challenges of performance and efficiency in microwave absorbers, providing a more effective solution for advanced EMI reduction. Moreover, while material innovation has progressed, the integration of diverse materials like ceramics into cement-based absorbers has yet to be fully explored. The potential of ceramic materials to enhance the absorption capabilities of such absorbers, especially in more complex designs like pyramidal structures, still needs to be explored. There is a need for research that not only explores these material combinations but also optimizes the structural design to improve overall performance.

This innovative combination of material composition and structural design seeks to overcome the existing challenges of performance and efficiency in microwave absorbers, providing a more effective solution for advanced EMI reduction. Moreover, while material innovation has progressed, the integration of diverse materials like ceramics into cement-based absorbers has yet to be fully explored. The potential of ceramic materials to enhance the absorption capabilities of such absorbers, especially in more complex designs like pyramidal structures, still needs to be explored. There is a need for research that not only explores these material combinations but also optimizes the structural design to improve overall performance.

2. METHOD

The methodology for this study was organized into three main steps: First, the dimensions of the pyramidal microwave absorber were carefully determined to ensure optimal performance. Second, the development process included material preparation and proportioning, mixing, molding, and finally, drying and curing of the absorbers. Third, the measurement and testing phase involved assessing dielectric properties using vector network analyzers (VNA) and high-temperature coaxial-line dielectric probes and reflectivity performance using the naval research laboratory (NRL) free space method across a frequency range of 1 to 12 GHz, with density measurements conducted to evaluate the role of porosity in optimizing the absorber's effectiveness.

2.1. Pyramidal microwave absorber dimension

Early in the study, the pyramidal microwave absorber's 3D model was meticulously designed using CST Studio Suite software as shown in Figure 1. The dimensions were carefully selected, with a base length of 10 cm, a base width of 10 and 25 cm in height, ensuring a compact and efficient design. These dimensions were chosen in reference to the TDK ICT-030 absorber, known for its compact size. The smaller dimensions were critical in this study because the primary material, cement, is relatively heavy, necessitating a design that balances performance with practicality.

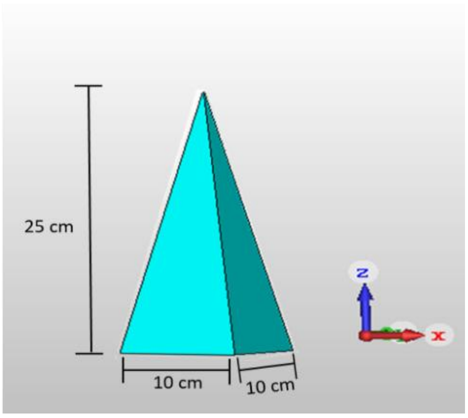


Figure 1. Pyramidal microwave absorber design in CST

2.2. Development of pyramidal microwave absorber

As for the development procedure, initially, a few samples with different composition ratios were produced. Although the ratios for each sample have been determined using prior research, some modifications might be required to enhance the absorber's structure and functionality. The materials used to develop the pyramidal microwave absorber consisted of cement, water, carbon, silicon carbide, and aluminum powder. There are a total of five sets of pyramidal microwave absorbers, with each set comprising 36 units, resulting in a combined total of 180 units of completed pyramidal microwave absorbers. The development process as shown in Figure 2 is divided into four phases: material preparation and material proportioning, mixing, molding, and finally, drying and curing [18]. Preparing the raw materials was the initial step in the procedure. In this study, cement, carbon, ceramic, water, and aluminum powder are used to construct the pyramidal microwave absorber. All of the material will be weighted and proportioned according to the chosen ratio throughout this phase. Next would be the material mixing procedure with a concrete mixer. The proportional material will be stirred for 5–8 minutes to ensure complete blending. Subsequently, the mixture will be placed straight into the mold to begin the molding process. The pyramidal microwave absorber will then be covered with plastic for a minimum of 14 days throughout the drying and curing process.

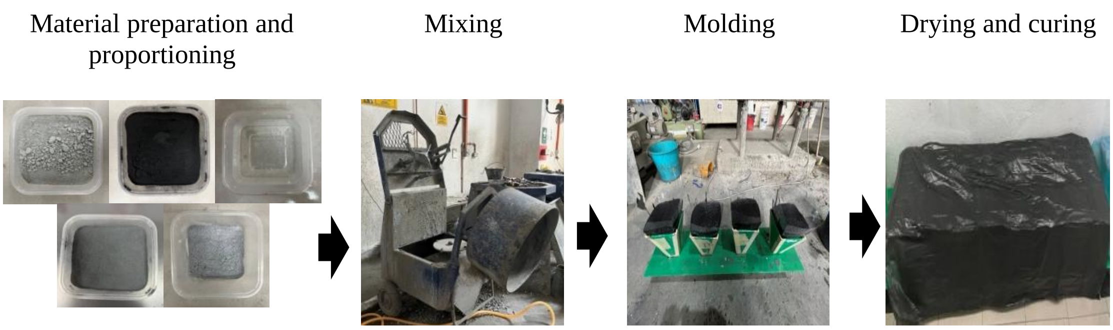


Figure 2. Development of pyramidal microwave absorber

Next, Table 1 shows the material preparation and proportioning of the pyramidal microwave absorber. The cement, carbon, and water ratios that were investigated in a prior study by Narudin *et al.* [19] demonstrate that the anti-microwave brick (flat absorber) performs best when the ratio of 80% cement to 20% carbon is used. Next, aluminum powder is used in this study to build a porosity structure, which enhances the absorber's performance [6]. Shabbar *et al.* [20] showed that 1% aluminum powder can create a greater number of pores. Porous structures contribute to the absorber's performance by improving the ability of electromagnetic waves to be attenuated by giving the reflected EM waves many pathways [3]. SiC has been introduced and varied in this study between 0%, 5%, 10%, 15%, and 20%. The percentage of SiC was determined by adjusting the combined percentage of cement and carbon to 100%, 95%, 90%, 85%, and 80%, corresponding to Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC, and Set 20-SC, respectively. In each set, the total weight of the mixture including cement, carbon, water, and aluminum powder remained consistent, with only the SiC content being varied.

Table 1. Material preparation and proportioning of pyramidal microwave absorber

Set	Cement + carbon (%)	Water-cement ratio	Aluminum-cement ratio	SiC (%)
0-SC	100	0.9	0.01	0
5-SC	95	0.9	0.01	5
10-SC	90	0.9	0.01	10
15-SC	85	0.9	0.01	15
20-SC	80	0.9	0.01	20

2.3. Dielectric measurement

Determining a material's dielectric characteristics, such as conductivity, permittivity, and loss factor, is the aim of dielectric measurement. These properties specify a sample's behavior in an electric field as well as its energy storage and release capabilities [21]. This measurement is crucial because it allows researchers to predict the absorber's performance, providing insights into how effectively it will attenuate electromagnetic waves [21]. Figure 3 illustrates the dielectric measurement setup used in this study, which involves a VNA and a high-temperature coaxial-line dielectric probe. The coaxial-line dielectric probe, connected to the VNA, is placed in contact with the material sample. This setup allows for precise measurement of how the material interacts with an electric field, providing critical data on its ability to store and dissipate energy, which is essential for predicting the performance of the microwave absorber. The high-temperature capability of the probe ensures accurate measurements even under conditions where the material might be exposed to elevated temperatures [21].

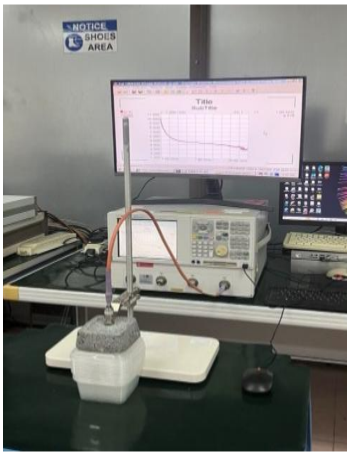


Figure 3. Dielectric measurement setup using VNA and high-temperature coaxial-line dielectric probe

2.4. Reflectivity measurement

Figure 4 depicts the NRL arch free-space method, a widely used technique for measuring the reflectivity of microwave absorbers. In this setup, the microwave absorber is placed within an arch-like structure, which is designed to simulate a free-space environment. The two horn antennas that make up the

NRL Arch are both aimed towards the metal plate at the desired angle [3]. A transmitter emits microwave signals towards the absorber, while a receiver measures the reflected signals [3]. By evaluating the differences between the signals that are transmitted and received, researchers can determine the absorber's effectiveness in reducing reflection. The performance of microwave absorbers in conditions that closely mimic real-world applications, such as in anechoic chambers or other environments requiring minimal electromagnetic interference, is proven using this method. The NRL arch is considered to be standard technology for assessing material reflectivity or absorption. The NRL arch method is a straightforward approach that contrasts a metal plate's reflection with and without absorbers [22]. Reflectivity is the term used to describe the reduction in reflected power that occurs when an absorbent material is added [2]. Antennas were positioned at a perpendicular angle of 0° to the absorber located in the core of the arch in order to detect reflection. There are 36 pyramidal microwave absorbers set under test on a square metal plate (0.36 m^2) from 1 to 12 GHz, as shown in Figure 5.

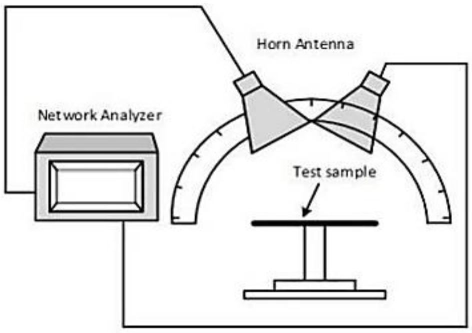


Figure 4. NRL arch free space method [3]

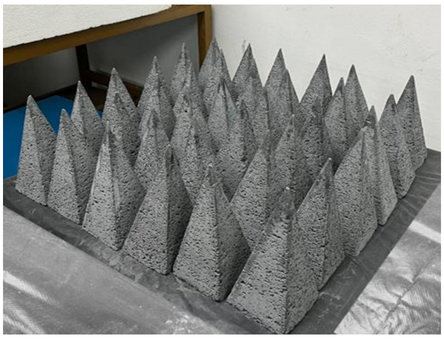


Figure 5. A set of pyramidal microwave absorber

2.5. Density calculation

The calculation of density plays a crucial role in determining the porosity of the pyramidal microwave absorber. The calculation of density is a fundamental step in evaluating the porosity of the pyramidal microwave absorber, as it directly influences the absorber's overall performance. A higher porosity often correlates with enhanced absorption capabilities, as it allows for more efficient trapping and dissipation of microwave energy. Therefore, understanding the density is essential for optimizing its electromagnetic interference (EMI) reduction properties across various frequency ranges. The ratio of a structure's overall volume to the volume of its voids or pores is called porosity [23]. Mass per unit volume is known as density, which is a fundamental feature of matter [24]. The mass and volume of the item or substance in issue must be measured in order to determine its density [24]. The density formula (ρ) can be found in (1), where density is calculated as mass (m) divided by volume (v) [24].

$$\rho = m/v \tag{1}$$

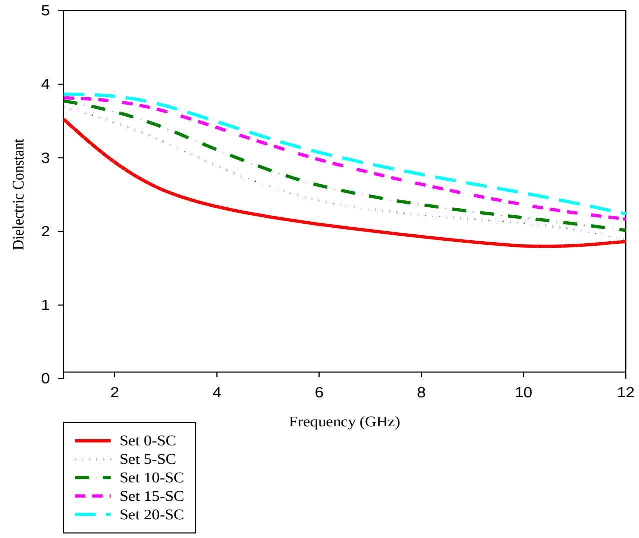
3. RESULTS AND DISCUSSION

This section provides a detailed analysis and discussion of the key experimental findings, focusing on the dielectric measurement, reflectivity performance, and density characteristics of five distinct sets of pyramidal microwave absorbers, each featuring a different SiC composition ratio. The analysis delves into how variations in SiC content influence the dielectric properties, such as permittivity and loss tangent, and how these properties subsequently affect the overall performance of the absorbers in terms of reflectivity across the 1 to 12 GHz frequency range. Additionally, this section explores the impact of material density on the absorbers' porosity and its correlation with wave attenuation capabilities. By examining these factors collectively, the discussion aims to provide a comprehensive understanding of the role that material composition and structural attributes play in optimizing the performance of pyramidal microwave absorbers.

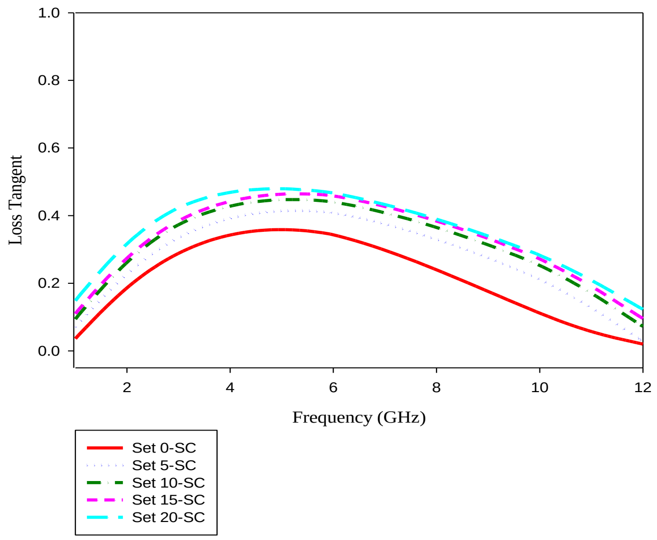
3.1. Dielectric value

Figure 6 presents the dielectric properties of the five different sets of pyramidal microwave absorbers, explicitly showcasing the dielectric constant and loss tangent values. Figure 6(a) illustrates the variation in dielectric constant across Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC, and Set 20-SC, while Figure 6(b) highlights the corresponding loss tangent values for each set. These dielectric properties are critical in understanding how the materials interact with electromagnetic fields and contribute to the absorbers' overall performance. For a more detailed comparison, all the dielectric data have been systematically compiled and presented in Table 2. This comprehensive representation allows for a more precise evaluation of how changes in the SiC composition ratio affect the dielectric characteristics of the absorbers.

Table 3 presents the dielectric measurement results for five sets of pyramidal microwave absorbers, each with varying percentages of silicon carbide (SiC): 0% (Set 0-SC), 5% (Set 5-SC), 10% (Set 10-SC), 15% (Set 15-SC), and 20% (Set 20-SC). The data in Table 2 clearly demonstrate a correlation between the SiC content and the dielectric properties of the samples. As the SiC percentage increases, both the dielectric constant and the loss tangent values show a corresponding rise. As noted by Lee *et al.* [25] materials with a lower loss tangent absorb less electromagnetic energy, whereas those with a higher loss tangent exhibit more excellent energy absorption. This principle suggests that as the loss tangent increases, the material's ability to attenuate electromagnetic waves also improves [26], which is a crucial factor in the design of effective microwave absorbers. Therefore, the results indicate that higher SiC content enhances the absorber's performance by increasing its loss tangent, aligning with the concept that a material in a high-loss condition is better suited for microwave absorption. This finding underscores the importance of material composition in optimizing the efficiency of microwave absorbers across a broad frequency range.



(a)



(b)

Figure 6. Dielectric properties of Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC and Set 20-SC from frequency 1 to 12 GHz (a) dielectric constant and (b) loss tangent

Table 2. Minimum and maximum reflectivity performance of Set SC-0, Set 5-SC, Set 10-SC, Set 15-SC, and Set 20-SC

Band	Frequency (GHz)	Set	Reflectivity (dB)	
			Min	Max
L- band	1-2	0-SC	-7.1917	-13.9684
		5-SC	-6.8558	-31.9475
		10-SC	-7.5473	-22.4245
		15-SC	-7.2509	-30.0706
		20-SC	-8.0017	-16.9517
S- band	2-4	0-SC	-7.9029	-15.8256
		5-SC	-9.6613	-38.2698
		10-SC	-16.2405	-26.534
		15-SC	-6.4606	-28.6876
		20-SC	-5.5518	-40.6209
C- band	4-8	0-SC	-13.3559	-37.0251
		5-SC	-16.5622	-52.4471
		10-SC	-26.6215	-55.2752
		15-SC	-16.4606	-46.0965
		20-SC	-14.6147	-49.8899
X- band	8-12	0-SC	-18.4081	-41.9475
		5-SC	-19.4750	-43.3700
		10-SC	-20.2202	-45.8933
		15-SC	-18.6791	-43.7257
		20-SC	-19.0347	-43.6749

Table 3. Dielectric constant and loss tangent of Set SC-0, Set SC-5, Set SC-10, Set SC-15 and Set SC-20 at frequency 6.5 GHz

Set	SiC (%)	Dielectric constant (ε')	Loss tangent (ε''/ε')
0-SC	0	2.2173	0.3436
5-SC	5	2.4781	0.4036
10-SC	10	2.4990	0.4106
15-SC	15	2.5192	0.4332
20-SC	20	2.6064	0.4402

3.2. Reflectivity measurement at 0° angle

Figure 7 illustrates the reflectivity performance of the different material sets, precisely Set SC-0, Set 5-SC, Set 10-SC, Set 15-SC, and Set 20-SC, when measured at a 0° incidence angle. The results demonstrate how varying the composition of silicon carbide (SiC) within the cement-carbon composite influences the absorber's ability to reduce electromagnetic reflections. The minimum and maximum reflectivity values across the tested frequency bands are summarized in Table 2 to provide a comprehensive analysis. These values are also visually represented through bar graphs in Figures 8 and 9, offering a clear comparison of the reflectivity performance across the different material sets. This data is crucial for understanding the impact of SiC content on the effectiveness of the pyramidal microwave absorbers in reducing electromagnetic interference.

Evaluating the reflectivity capabilities of a pyramidal microwave absorber requires a thorough analysis of both minimum and maximum reflectivity values. The minimum reflectivity value represents the lowest level of electromagnetic wave reflection, indicating the absorber's effectiveness in minimizing unwanted reflections across a given frequency range. Conversely, the maximum reflectivity value denotes the highest level of reflection, which is crucial for understanding the upper limits of the absorber's performance. Together, these metrics provide a comprehensive assessment of the absorber's performance. A higher minimum value suggests better absorption efficiency, while a higher maximum value indicates the absorber's ability to maintain performance under varying conditions. Therefore, achieving higher minimum and maximum reflectivity values indicates a superior pyramidal microwave absorber capable of delivering consistent and reliable EMI reduction across a wide range of frequencies.

Figure 8 shows the minimum reflectivity performance of Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC and Set 20-SC at 0° angle, where it displays that Set 10-SC produces the highest reflectivity performance at all bands except L-band with values of -16.2405 dB (S-band), -26.6215 dB (C-band), and -20.2202 dB (X-band). The best reflectivity value at L-band is -8.0017 dB, obtained by Set 20-SC. Based on the analysis, Set 10-SC shows the best minimum reflectivity performance on three bands: S-band, C-band, and X-band. On the L-band, the Set 10-SC Set performs about -0.5 dB less well than the Set 10-SC. Overall, it can be concluded that the SC-10 Set provides the best minimum reflectivity performance, especially on the C-band.

The maximum reflectivity performance of Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC and Set 20-SC at 0° is shown in Figure 9. Subject to the data analyzed, the Set 5-SC shows the highest reflectivity performance for the L-band with a value of -31.9475 dB. Set 20-SC achieves the best reflectivity value for the S-band, with a value of -40.6209 dB. Moreover, Set 10-SC illustrated the highest reflectivity performance for the C-band and X-band with values of -55.2752 and -45.8933 dB, respectively. Based on the obtained graph, only Set 10-SC can reach the maximum reflectivity value on two bands, namely the C-band and the X-band. Since C-band and X-band represent more than 66% of the selected frequency range from 1-12 GHz, it can be concluded that Set 10-SC produces the best maximum reflectivity performance, especially on the C band. All five sets of pyramidal microwave absorbers demonstrated good performance at the C-band and X-band, with minimum reflectivity values of over -13 dB and maximum reflectivity values of over -37 dB. For the L-band and S-band, the maximum reflectivity performance of all five sets looks quite good, except Set SC-0. However, for minimum reflectivity, most sets cannot reach at least -10 dB, except for the Set SC-10 on the S-band.

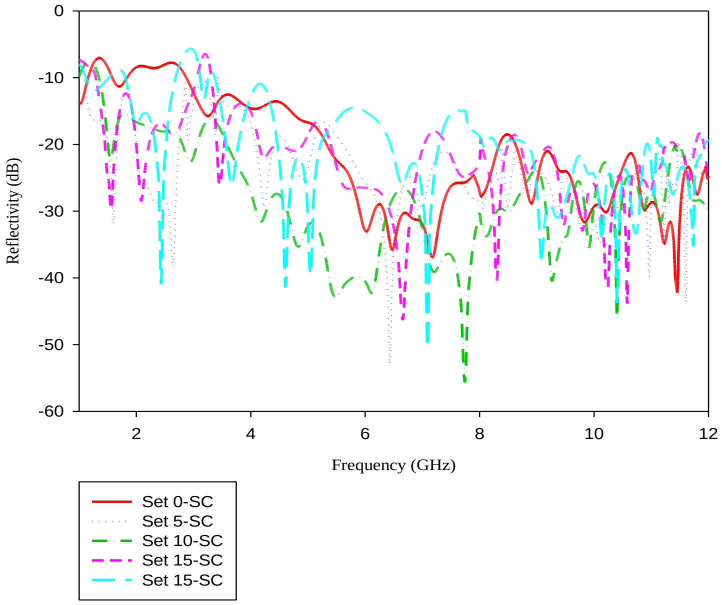


Figure 7. Reflectivity performance of Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC and Set 20-SC at 0° angle

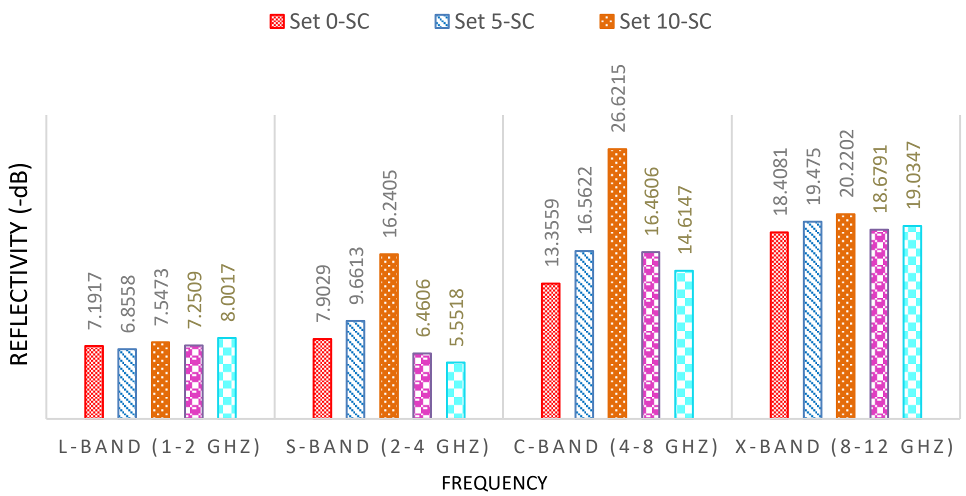


Figure 8. Minimum reflectivity performance of Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC, and Set 20-SC at 0°

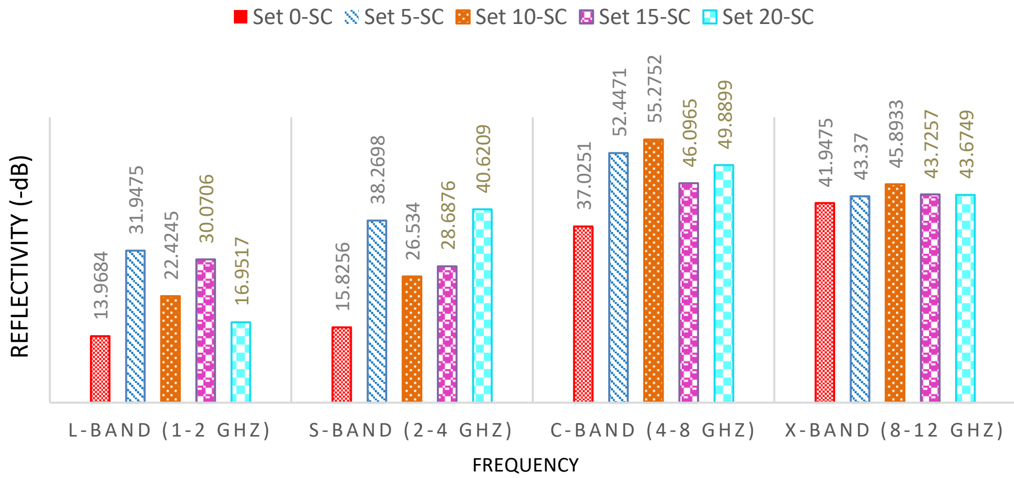


Figure 9. Maximum reflectivity performance of Set 0-SC, Set 5-SC, Set 10-SC, Set 15-SC and Set 20-SC at 0°

3.3. Density value

Table 4 presents the density measurements for individual pieces of pyramidal microwave absorbers, categorized according to their specific set composition. The data in the table reveals a clear trend: as the percentage of SiC increases, the density of the absorbers also rises. This increase in density indicates a reduction in porosity within the structure of the pyramidal microwave absorbers. The correlation between higher density and lower porosity is significant, as it suggests that as SiC content is increased the material becomes more compact, potentially enhancing the absorber's overall performance by reducing the amount of air gaps within the structure, which could otherwise impair its effectiveness in attenuating electromagnetic waves. Porous structures will reflect and disperse the incident wave as it travels through the material, and some of the thermal energy will be produced by converting electrical energy into a microwave signal [6].

Table 4. Density of set 0-SC, set 5-SC, set 10-SC, set 15-SC and set 20-SC

Set	Density (g/cm^3)
0-SC	0.6012
5-SC	0.6132
10-SC	0.6252
15-SC	0.6408
20-SC	0.6552

3.4. Highlights of research outcomes

Based on the dielectric measurement results, Set 20-SC was initially expected to produce the best reflectivity performance due to its high loss tangent value, which typically correlates with more excellent wave attenuation. However, the reflectivity tests revealed that Set 10-SC consistently outperformed the other sets, including Set 20-SC. This unexpected outcome suggests that factors beyond dielectric properties, such as the porous structure of the absorber, play a significant role in determining overall performance. The density test was conducted to examine the relationship between porosity and reflectivity and investigate this further. The results of this test aimed to validate the hypothesis that, while dielectric properties are crucial for absorber efficiency, the material's porosity also substantially impacts its ability to attenuate electromagnetic waves. This finding underscores the importance of optimizing dielectric characteristics and porosity to achieve superior microwave absorption performance.

The evaluation of the five sets of pyramidal microwave absorbers, each measured at a 0° angle across a frequency range of 1 to 12 GHz, provides a comprehensive insight into their reflectivity performance, particularly within the C-band and X-band frequencies. All five sets demonstrate commendable reflectivity, showcasing their potential effectiveness as microwave absorbers. However, a detailed analysis reveals that Set 10-SC consistently outperforms the other sets' overall reflectivity performance across the entire frequency spectrum. Set 10-SC emerges as the most effective absorber, particularly within the C-band, where it achieves remarkable minimum and maximum reflectivity values of -26.6215 and -55.2752 dB, respectively. This superior performance is primarily attributed to Set 10-SC's optimized porosity and the loss tangent value of its material composition, which contributes to more excellent wave attenuation. The findings indicate that the varied ratio of SiC, as demonstrated in this study, plays a critical role in enhancing the reflectivity performance of the absorber, with Set 10-SC offering the most balanced and effective combination of materials for optimal performance. These results highlight the importance of material composition and structural design in developing efficient microwave absorbers, particularly for applications requiring broad frequency coverage.

3.5. Comparative analysis with prior study

As reported in prior studies, Table 5 provides a comprehensive summary of the reflectivity performance of various biomass-based microwave absorbers. It highlights the different materials employed in fabricating these absorbers, illustrating the diversity in approaches within the research field. The table also details the specific shapes of the absorbers, which play a crucial role in their overall effectiveness, and outlines the frequency ranges over which reflectivity was measured. Additionally, it presents the minimum and maximum reflectivity values attained by each material, clearly comparing their performance. This summary underscores the progress made in developing biomass-based absorbers and serves as a benchmark for evaluating the advancements presented in the current study.

Based on the results obtained in this study, a comparative analysis with prior research reveals significant differences in performance, particularly in the reflectivity across different frequency bands. The previous research focused on biomass-based microwave absorbers, such as those made from banana leaves, sugarcane bagasse, and rice husk typically shaped pyramidal. These absorbers exhibited minimum reflectivity values ranging from -16.0 to -33.9 dB and maximum reflectivity values ranging from -34.9 to -45.9 dB across various frequency bands, predominantly from 6 to 20 GHz. In this study, set 10-SC, a pyramidal absorber with a 10% SiC composition, demonstrated superior performance, achieving a minimum reflectivity of -26.6215 dB and a maximum of -55.2752 dB, specifically in the C-band. This performance not only surpasses the reflectivity of absorbers made from biomass materials but also indicates that integrating SiC and the optimized porosity in the absorber's structure enhances its effectiveness.

Moreover, the comparative analysis highlights that while traditional cement-based absorbers with flat configurations, like those made from palm oil fuel ash (POFA) and sawdust, showed limited reflectivity with maximum values of -18.2 and -29.5 dB, respectively, the pyramidal design coupled with SiC incorporation in this study led to a substantial improvement in absorption capability. This comparison underscores the importance of material composition and structural design in developing efficient microwave absorbers. Thus, this research provides valuable insights into the advancement of absorber technology, particularly for applications requiring robust EMI reduction across a wide frequency range.

Table 5. Summary on biomass microwave absorber from prior study

Material	Shape	Frequency	Reflectivity (dB)		Ref
			Min	Max	
Banana leaves and resin	Pyramidal	6.8.5	-33.9	-43.1	[27]
Rice husk, rubber tire dusk and resin	Pyramidal	7-13	-20.1	-34.9	[28]
Rice husk and resin	Pyramidal	0.01-20	-16.0	-45.9	[29]
POFA and cement	Flat (brick)	1-12	-	-18.2	[18]
Sawdust and cement	Flat (brick)	1-12	-	-29.5	[19]

4. CONCLUSION

In conclusion, this research has shown that combining ceramic materials with a cement-carbon base and using a pyramidal design significantly improves microwave absorber performance. The new design offers better absorption across a more comprehensive frequency range, addressing the limitations of traditional flat absorbers. These improvements are beneficial for reducing EMI in sensitive environments like anechoic chambers. The study's findings highlight the potential for further enhancing absorber materials and designs, with applications extending to areas such as radar technology and stealth systems. For the research community, this work emphasizes the need for ongoing innovation in materials and design to develop more effective EMI reduction solutions. Future studies could explore other material combinations, refine shapes, or adapt these techniques for different industrial uses.

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