Electromagnetic Interference Shielding via Graphene Incorporation in Glass Fibre Reinforced Polymer Composites

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Abstract

The primary objective of the research was to investigate the Shielding Effectiveness (SE) of laminates composed of Glass Fibre Reinforced Polymer Composites (GFRP) by incorporating different quantities of graphene.Employing ANSYS HFSS, the setup was simulated to extract loss signal parameters, which are instrumental in calculating SE for the samples. Through the hand layup technique, GFRP is fabricated with varied graphene additions and glass fibre sequences such as 0°/90° and 45°/90°. The shielded box method enabled them to experimentally derive scattering parameters S11 and S21. The result shows that increased graphene content correlates with an augmented laminate surface area, leading to heightened material SE. Analytically, introducing graphene at levels ranging from 0 to 5% yields a increases improvement in in SE, translating to a 16% improvement. Experimentally, the SE displays a remarkable increase 24.97 % enhancement.

Keywords: *GFRP, shielding effectiveness, scattering parameters,EMI, ANSYSS HFSS.*

1. Introduction

The study of the electromagnetic shielding characteristics of materials has gained global attention due to the rapid proliferation of sensors in our everyday lives [1]. At present, there exists a significant concern regarding Electro Magnetic Interference (EMI), which is a leading cause of data loss, signal degradation, premature electronic device failures, and poses substantial risks to human health[2]. The effectiveness of EMI shielding is a critical attribute quantified in Decibels. It represents the ratio of incident EMI power to transmitted EMI power[3]. This effectiveness hinges on a combination of factors including material properties and the shielding barrier's capacity to diminish signal transmission. This is achieved through mechanisms such as reflecting incoming waves at the material's front surface, absorbing them, and subsequently dissipating outgoing radiation within the material itself[4,5].

While metallic products and alloys have demonstrated impressive EMI shielding capabilities attributed to their heightened electrical conductivity[6]. Their usage in shielding enclosures is constrained by factors like elevated density and susceptibility to corrosion[7]. In a bid to surmount these limitations associated with metals, numerous researchers have delved into the realm of conductive polymer composites and polymer composites reinforced with conductive fillers[8-10]. These alternatives are sought after due to their appealing characteristics, including reduced weight[11], exceptional corrosion resistance[12], and robust environmental stability[13], all of which circumvent the shortcomings of traditional metals. Another noteworthy advantage of polymer composites lies in their processability, enabling the creation of structures of varying sizes and shapes[14]. Furthermore, the electrical properties of these composites can be fine-tuned by controlling the quantity of conductive fillers employed[15-16].

Numerous studies have directed incorporating conductive elements, including metal or alloy particles[17], graphite[18], carbon nanotubes[19], carbon fibers[20], puffed rice-based carbon[21], and cotton-derived their efforts towards enhancing conductivity by carbon fabric[22], into electromagnetic (EM) shielding materials[23]. Furthermore, effective EM shielding necessitates a multi-mode approach that ensures substantial attenuation across a broad frequency spectrum[24]. Carbon particle-reinforced composites surpass metal powder-reinforced polymers in terms of mechanical strength, although their own mechanical properties can be barrier for SE. While many endeavors have centered around cost-effective methods using discontinuous fibers or powders, the utilization of continuous reinforcement presents advantages stemming from exceptional mechanical properties combined with effective EMI shielding[25]. Consequently, researchers often employ carbon fiber-reinforced polymer composites for EMI shielding applications.

Considering the elevated cost of carbon fibers, this study focuses on enhancing EMI shielding efficiency and mechanical properties by introducing graphene powder into glass fiber composites, by both experimental and finite element approaches.

2. Finite Element Simulation

A 3D electromagnetic field simulator, combining solid modeling, simulation, and visualization. It's versatile, accommodating complex structures across medium frequencies. From microstrips to antennas, diverse simulations are possible. Applications span Printed Circuit Board (PCB) modeling, antenna design, and Electro Magnetic Compatibility (EMC) considerations. Workflow entails geometry construction, material assignment, and space definition. Waveports facilitate energy flow. Solution setup covers frequency range, meshing, and tetrahedral adaptive meshing. Simulation ends with solving Maxwell's wave equations. Incorporating High Frequency Structure Simulation Software (HFSS) means selecting modal solutions, unit measurements, visualizing in 3D Modeler, assigning air material, and defining conductive boundaries. Excitations allocate charges, while advanced settings determine frequency range, sweeps, and validation checks assure accurate setups, yielding electromagnetic insights.

In ANSYS Electronics Desktop 2021 R1, a rectangular box measuring 80 mm x 100 mm x 3000 mm is modeled. The box is constructed using air as its material, while finite conductivity material is assigned to its boundaries, thus creating a hollow medium for the propagation of EM waves. Fig.1(a) showcases an isometric view of the model along with the material selection window. To evaluate the EMI shielding effectiveness of the model, finite conductivity is allocated to the geometry's faces. Wave ports 1 and 2, acting as transmitter and receiver ends, respectively, are designated as excitations. Integration lines for mode definition are specified for both wave ports. HFSS assumes each wave port is linked to a waveguide with similar cross-section and material properties. Upon activating each wave port independently, HFSS generates solutions. Finite conductivity boundaries and wave port assignments are displayed in Fig.1(b). Setting the Maximum Number of Passes determines the convergence of the solution. This value represents

the mesh refinement cycles executed by HFSS. It serves as a stopping criterion for adaptive solutions; if the maximum passes are completed, adaptive analysis concludes. If not, analysis persists until convergence criteria are met.

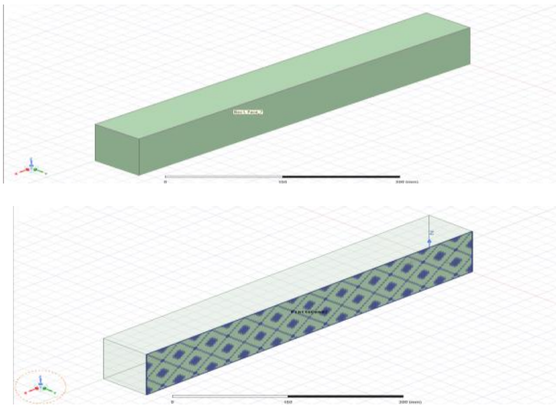

Fig.1: a) CAD Model of the Rectangular Aluminum Box and b) Finite Boundary

3. Experimental Study

3.1 Fabriction of composite specimens

The fabrication process of graphene-reinforced glass laminates involved several steps. Firstly, the hand layup technique was employed for their preparation. Glass fibers, sized at 200 mm x 200 mm, were readied for laminate construction through a cutting process. In a beaker, a predetermined quantity of and araldite resin was mixed with a specific amount of aradur hardener in a 10:1 ratio, ensuring a thorough homogenous blend. Furthermore, a requisite measure of graphene powder (0, 1, 3 and 5%) was mixed with polymer using a mechanical stirrer. The procedure continued with the placement of fiber plies onto the mold, followed by the application of the epoxy-hardener mixture atop them, facilitated by a brush. Subsequent elimination of air bubbles and excess resin was achieved with the aid of a roller. Subsequently, the prepared laminates were left to cure under weight for 24 hours, maintaining room temperature and standard atmospheric conditions. After the curing process, the weight was removed, and the laminates were meticulously cut into the desired specimen sizes, concluding the production procedure.

3.2 Measurements for EMI Shielding Effectiveness

The Vector Network Analyzer (VNA) configuration is comprehensive, encompassing both primary equipment and auxiliary components to facilitate precise measurements. It establishes a baseline for subsequent assessments. The setup involves linking transmitting and receiving horn antennas to the VNA using coaxial cables, which offer shielding to prevent signal interference. Inside the anechoic chamber, the antennas connect to VNA ports through designated input and output coaxial cables. Positioned before the horn antenna's flare, an aluminum box serves as a radiation boundary, secured in place by tape on a foam support. This constructs the experimental setup for EMI shielding measurements.

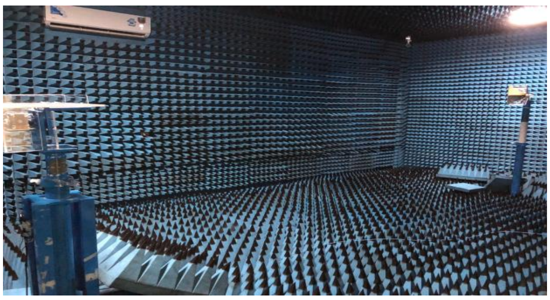

Fig. 2 Anechoic Chamber within Smart Antenna Systems and

Initially, a baseline measurement is conducted without any sample or laminate. This defines reference values for subsequent analyses. User-defined parameters within the VNA encompass the frequency range and measurement points. By transmitting an EM wave and observing return loss, scattering parameters or S-parameters (S11, S12, S21 and S22) are derived, setting the groundwork for further evaluations. The 2-port S-parameters consist of: S11 representing the forward reflection coefficient, S12 denoting the reverse transmission coefficient, S21 indicating the forward transmission coefficient, and S22 representing the reverse reflection coefficient. For evaluating CFRP laminates, the next step involves placing them between aluminum boxes. Return loss is measured similarly. Obtained S-parameters are displayed and can be exported as CSV files, facilitating S-parameter vs. frequency graph plotting for comparative analysis. This procedure is repeated for all prepared laminates. Conducting the same procedure beyond the anechoic chamber shown in Fig. 2, in free space, both with and without aluminum boxes, yields consistent results, validating the approach's reliability. The identical process is applied to all laminates in free space. Initial measurements serve as references, followed by placing samples between antennas using foam support for obtaining scattering parameters for each laminate.

4. Result and Discussion

4.1 Effect of frequency on EMI SE

Fig. 3 and 4 depict the impact of frequency on the Electro Magnetic Interference Shielding Effectiveness (EMI SE) of graphene-reinforced glass epoxy composites, focusing on reflectance and absorption, respectively. Both S11 (reflection coefficient) and S21 (transmission coefficient) exhibit wave-like variations against frequency. The unpredictable and almost nonlinear fluctuations stem from EMI shielding's intrinsic link with the penetrating ray's frequency. This irregular conductivity behavior within the system arises from the introduction of nano-filler reinforcement.

Upon the addition of graphene filler, the EMI shielding effectiveness demonstrates a linear increase, regardless of the measurement frequency band. The curves for transmission and absorption frequencies demonstrate a similar trend. In the absence of graphene, the glass fiber laminates exhibit minimal differentiation between S11 and S21, with both showing nearly identical behavior. However, with the inclusion of graphene, a significant distinction emerges between S11 and S21. S11 shifts upward (reflection coefficient), while S21 shifts downward (transmission coefficient).

Graphene loading consistently enhances EMI SE across the entire frequency range in the case of 0°/90° fiber orientation. Conversely, in the case of 45°/90° fiber orientation, the EMI SE remains relatively unaffected due to the retarding effect of glass fibers on electron movement during conduction. These observations highlight the intricate interplay between graphene reinforcement, fiber orientation, and EMI SE, emphasizing the potential for tailoring composite properties for specific electromagnetic shielding requirements.

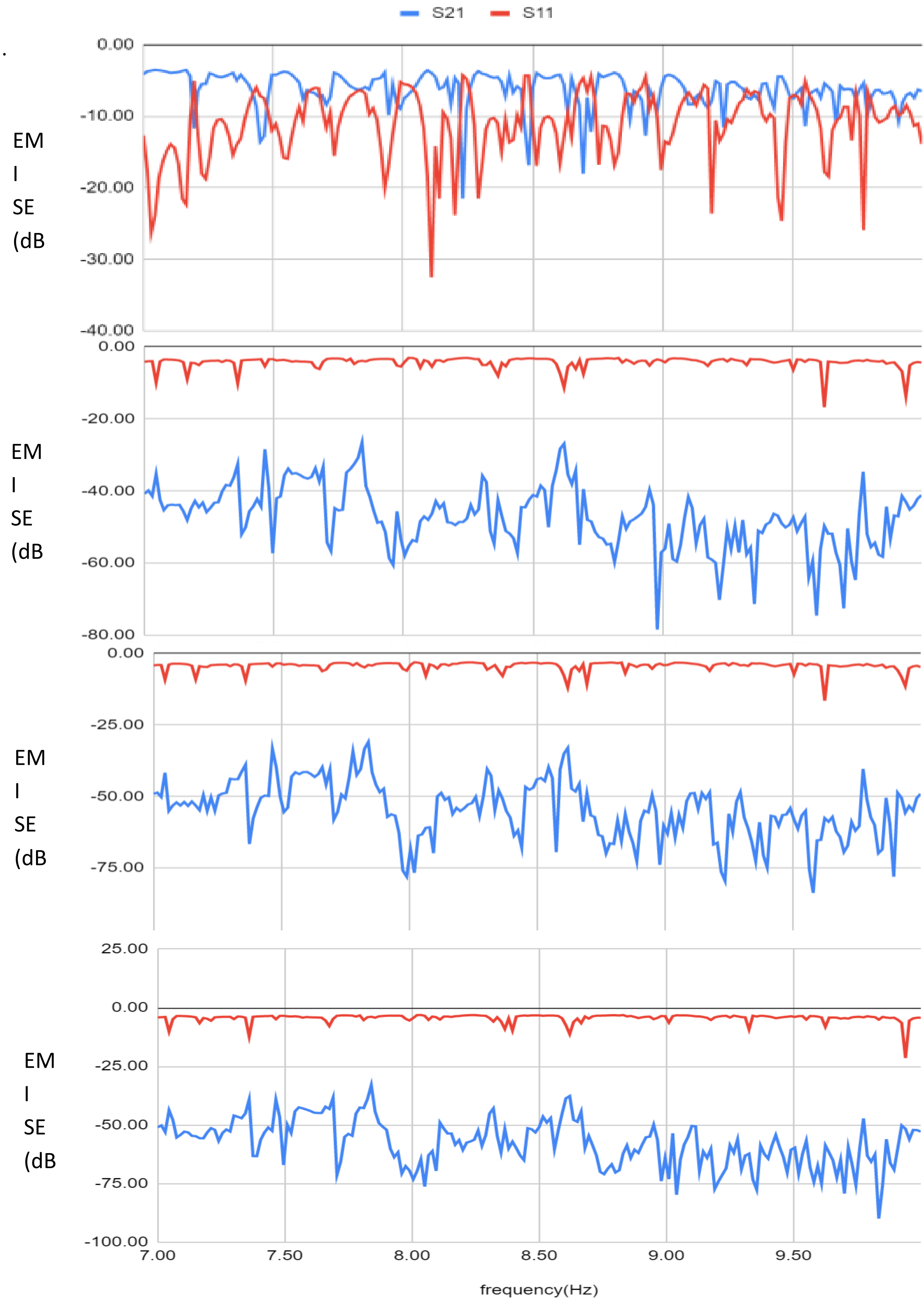

Fig. 3. Profiles of Forward Reflectance (S11) and Transmission (S21) Coefficients for Graphene-Reinforced Glass Fiber Composites (GFRP) with 0°/90° Fiber Orientation: a) GFRP, b) 1% GFRP, c) 3% GFRP, and d) 5% Graphene GFRP

.4.2. Effect of filler loading on EMI SE

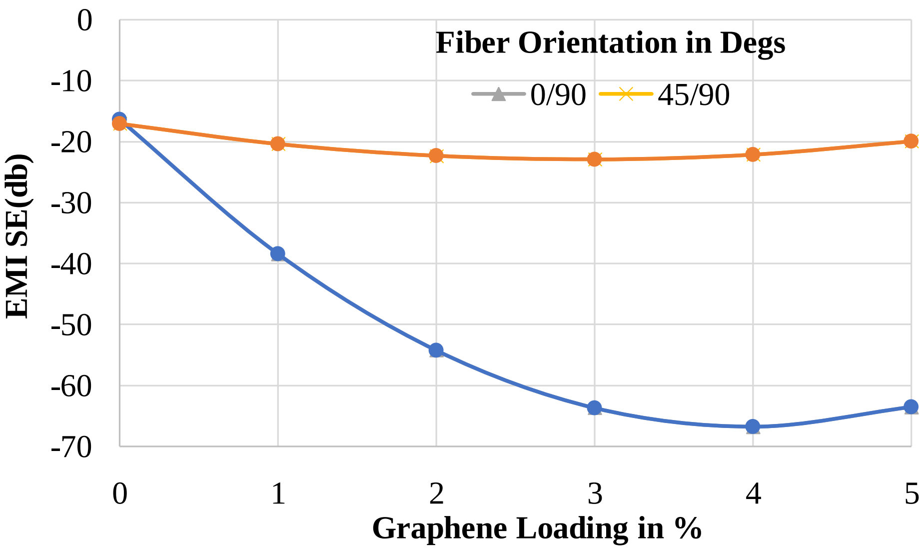

Fig. 5 Influence of Graphene Loading on Electromagnetic Interference Shielding Effectiveness (EMI SE) Performance in Graphene-Reinforced Glass Composite Laminates with Varied Fiber Orientations

Exploring the influence of graphene concentration on EMI SE involves evaluating measurements at a reference frequency of 10 GHz. Fig. 5 showcases EMI SE results at a 10 GHz measurement frequency for composite laminates featuring varying graphene loadings. EMI SE comparisons are extended to encompass filler loading and fiber orientation. The observed trend reveals an increase in EMI SE with heigher graphene loading, attributed to reduced resistivity stemming from greater filler content.The interplay between EMI SE and resistivity changes underscores the significance of conductive networks formed by the introduced graphene, which leads effectiveness of shielding. Higher loaded composites, the formation of conductive network increase radiation absorption, thus augmenting EMI SE an aspect distinct from the metal-based EMI SE that hinges on reflection. Higher structural attributes facilitate more effortless dispersion EMI and denser conductive networks within the polymer matrix, particularly when compared to the 45°/90° fiber orientation setup. These findings emphasize the complex interrelation between graphene concentration, fiber orientation, and EMI SE, suggesting avenues for refining electromagnetic shielding performance through strategic graphene manipulation and material arrangement.

4.3. Effect of filler loading on EMI Data Loss

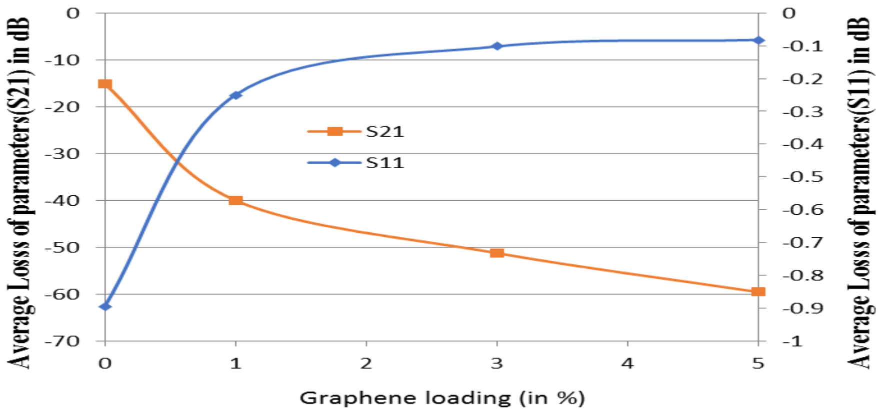

Fig. 6Effect of Graphene Content on Electromagnetic Interference

Fig. 6 illustrates the impact of graphene content on S11 and S21 values in samples with varying percentages of graphene loading. As the graphene content increased, S11 exhibited an upward trend, while S21 showed a deviation towards the negative side. The gradual increase in graphene within the samples resulted in heightened internal multi-reflection, scattering, and absorption processes, ultimately leading to greater discrepancies between S11 and S21 values hence grater data loss.

The attenuation mechanisms in graphene-reinforced glass composite laminates primarily involve interfacial effects and dielectric relaxations. Notably, as 5% graphene was added, S11 values increased from -0.923 to -0.092 dB, while S21 values decreased from -15.12 to -59.26 dB under the same conditions. These findings underscore the substantial influence of graphene content on the electromagnetic characteristics of the composites, highlighting the importance of graphene loading in optimizing their electromagnetic interference attenuation properties.

4.4. Effect of filler loading on EMI Data Loss

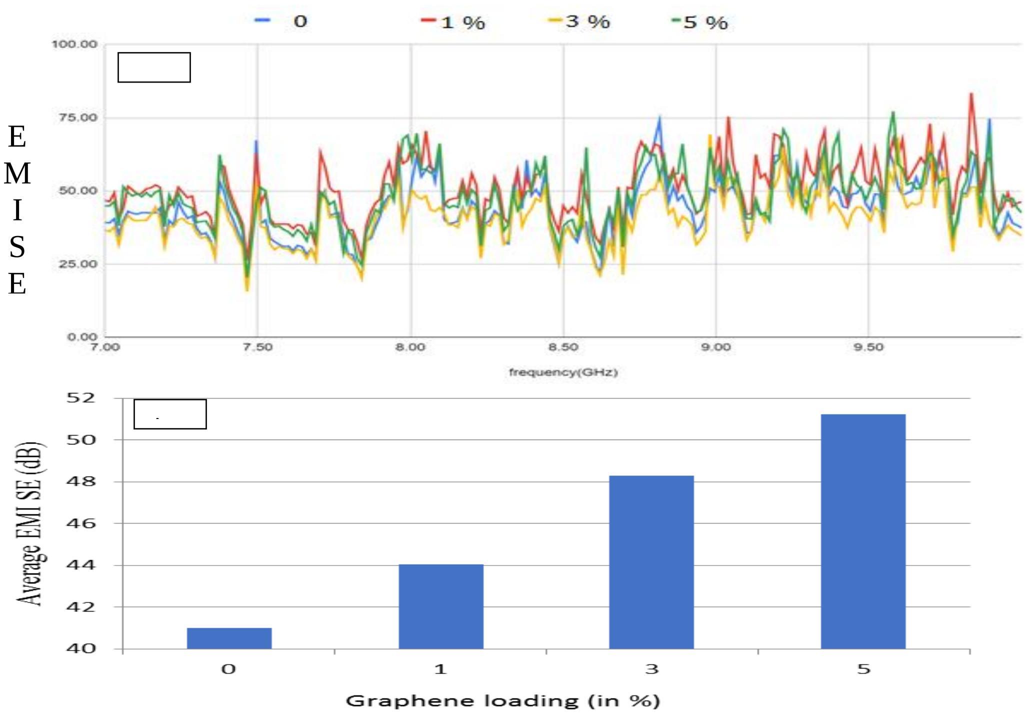

Fig. 7. Electromagnetic Shielding Effectiveness (SE) of composites laminates a) as a function of frequency and b) as a function of

In Fig. 7 (a), a noteworthy observation is the slight upward trend in SE as it progresses towards higher frequencies. However, this upward trend is accompanied by random fluctuations in SE, primarily attributable to environmental EMI. Fig. 7 (b) presents SE values for four distinct laminate compositions: 0%, 1%, 3%, and 5% graphene loading. Notably, the SE values increase systematically with higher graphene content. Specifically, there is a notable SE improvement from 41 dB (0% graphene) to 51.24 dB (5% graphene), demonstrating a substantial 10.24 dB increase. This remarkable enhancement SE to a 24.97%, affirming the positive impact of graphene incorporation on electromagnetic shielding effectiveness within the laminate. These findings underscore the potential of graphene-reinforced composites to enhance EMI shielding, especially at higher graphene loadings

4.5 Comparison between FEM and experimental studies

a)

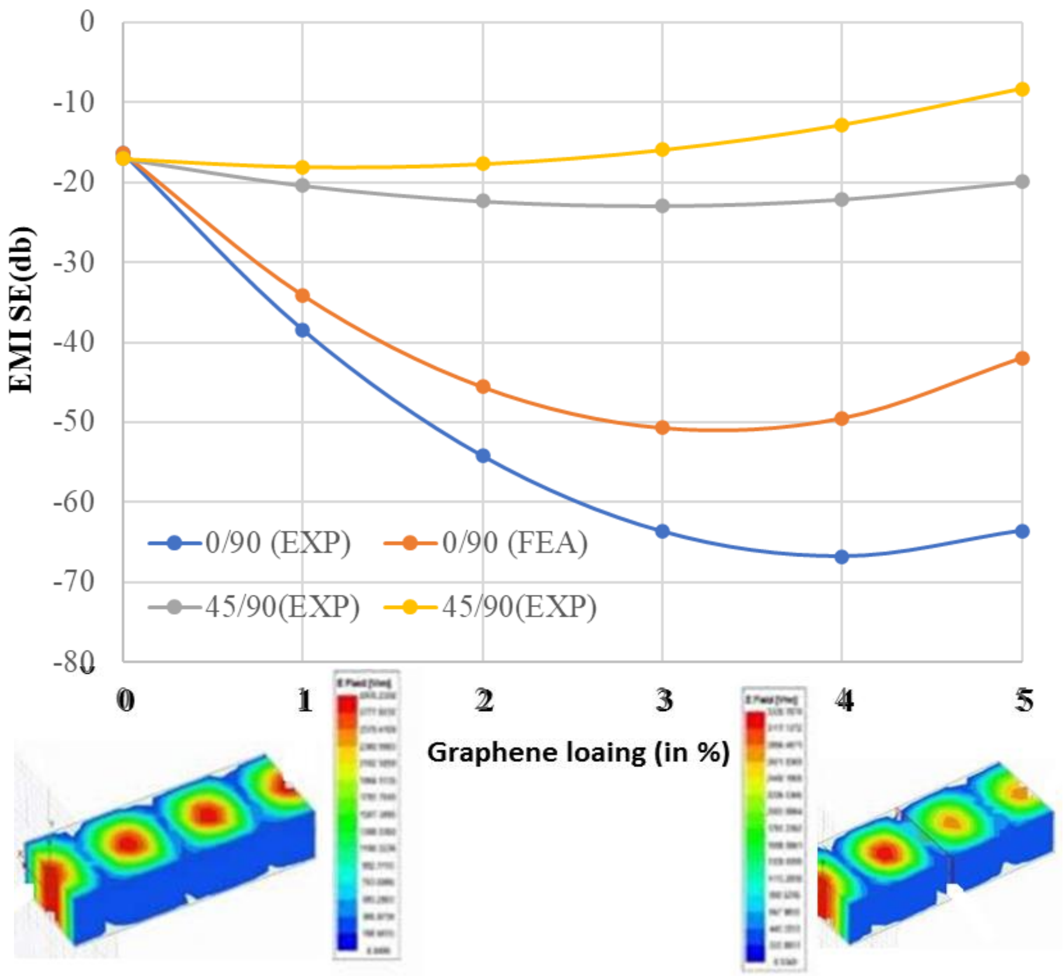

Fig. 8 a) Comparative Analysis of S-Parameters for Epoxy/Glass/Graphene Composite Structures: FEA vs. Experimental Results and (b) Finite Element Method Countour Plots for Unreinforced and Reinforced Graphene Composites (negative EMI)

Fig. 8 illustrates a comparative analysis of computational and experimental results for the shielding effectiveness of an epoxy composties. Computational analysis was conducted using FEM while experimental analysis utilized a VNA and waveguide.

In Fig. 8 (a), the computational results indicate a shielding effectiveness of 13 dB at the X-band frequency for nanocomposites. Conversely, experimental results reveal an exponential increase in shielding effectiveness with an increasing concentration of graphene in the glass/epoxy composites, reaching 17 dB at 11.5 GHz within the X-band frequency range. It's important to note that both approaches display a growing deviation with the rising graphene reinforcement. This deviation can be attributed to the use of a homogeneous solid GFRP in the computational analysis, whereas the experimental composites were produced using the hand lay-up technique, introducing numerous pores into the film. Furthermore, the observed deviation may be influenced by factors related to the experimental setup, including cable losses and port losses.

Fig. 8 (b) illustrates the simulation of the distribution of magnetic and electric fields within the composites when they intercept electromagnetic waves. The model was constructed using ANSYS HFSS Model and was assigned appropriate materials and boundary conditions. To simplify the setup, S1 and S2 were defined to correspond to the transmitting and receiving points of the vector network analyzer. These ports generated electric field excitation and received electromagnetic signals, respectively. The electromagnetic wave transmission mode within the waveguide fixture was defined as the typical Transverse Electric (TE) wave, where the electric field and magnetic field propagate perpendicular to each other. EM waves emitted from the transmitting port (S1) are received by the receiving port (S2). In this scenario, the electric field is strongest at the center and weaker at the edges, while the magnetic field distribution exhibits the opposite pattern.

5. Conclusion

Conclusions from the research on EMI shielding effectiveness of graphene reinforced GFRP composite materials:

✓ The research offers a comprehensive analysis of epoxy thin film SE, utilizing computational and experimental methods.

✓ SEM revealed an initial SE of 13 dB at the X-band frequency, while experimental results (VNA and waveguide) showed a significant increase to 17 dB with graphene incorporation.

✓ Deviations between computational and experimental results can be attributed to material differences; the computational model assumed homogeneity, while the experimental approach introduced structural variations like graphene and glass fiber.

✓ The study also emphasized the influence of experimental setup components, including cable losses and port losses, in contributing to observed deviations.

✓ Consistency across analytical, simulation, and experimental results, reinforcing its value in enhancing the understanding of SE in composite materials and emphasizing the importance of considering diverse factors and analytical methods in SE evaluations.

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