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EMI Shielding Investigation of Composite Materials against the Lightning Strike Effect in Aircraft

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Abstract

To meet the need to eliminate lightning strikes in aircraft, an efficient technique for producing electromagnetic shielding composite materials has been devised. Stir casting was used to combine AL6061, Silicon Carbide (SiC), and Fly Ash (FA) layers to make thin (1 mm thick) electromagnetic shielding composites. The material created by altering the percentages of AL6061/Sic/FA has a high Shielding Efficiency (SE) of 47.8-55.6 dB between 8 and 12 GHz, making it ideal for electromagnetic shielding in airplanes, because of the interaction between the magnetic field of incident Electromagnetic (EM) radiation and magnetic dipoles and the reflection loss of SiC, the Electromagnetic Interference (EMI) shielding composite attenuated EM waves through the "absorption-reflection" mechanism. The electromagnetic shielding composites reported in this study have enormous promise in precision electronic equipment and aviation systems.

Keywords: *Lightning Strikes, Shielding Effectiveness (SE), Electromagnetic Interference (EMI), Stir Casting, AL6061, Silicon Carbide (SiC), and Fly Ash (FA).*

Introduction

The progress of the automotive and aviation sectors in contemporary society has resulted in the replacement of metal matrix composites (MMCs) for aluminium alloys. This move has tremendously improved the ease of human living. As they are met in all facets of our everyday lives, composite materials have grown more widespread in our contemporary civilization. The automotive industry is investigating the use of MMC as a developing technology to decrease vehicle weight.[1,2,3] have been given by the user. The researchers are working with MMC to improve the composite material's strength and durability. They are working to achieve these improvements without increasing the thickness of the material [4]. The user has included a citation, which indicates that they are citing a particular source of information. As a consequence, there has been a substantial emphasis on high-performance composite material research and analysis.

At first, composites were made using simply the main reinforcement and the matrix.[5] Subsequent investigation revealed the significance of particle addition in improving PMC materials' mechanical and tribological properties. [6,7] However, wire mesh (WM) was added to the composite material since more research on PMC was required. For building purposes, civil engineers have opted to use WM in a variety of forms and thicknesses.[8] WM was used as a structural reinforcement, and its addition enhanced the concrete beams' flexural performance, which was an optimal outcome [9,10] Reinforcing stainless steel (SS) WM with woven glass fibre in the matrix epoxy initiated a revolution in PMC in 2015.[11]

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A few scientists [12-13] have made composite protecting materials made of magnetic materials, dielectric materials, and conducting materials, among others. Specialists involving low-layered structures as components in half-breed materials with EM wave retention and protection applications have obtained enthralling results [14].

Regarding shielding, the high-conductivity material excels in reflection, while the high-permeability material excels at absorption. For example, micro absorbers may benefit from less material loss and more efficiency if these devices' magnetic and dielectric components were strengthened into alloys [15]. Conductors are susceptible to corrosion despite their high conductivity and efficient shielding. In this study [16-17], we selected the Al6061 composite because of its excellent strength-to-weight ratio, corrosion resistance, fluidity, and castability.

In this research, we develop composite materials with varying amounts of AL, Sic, and FA. Electromagnetic waves may easily penetrate composites from free space, but the signal is weakened once it enters the material. Because of attenuation, the microwave signal gets swallowed up. Three different types of composite material were used in conjunction with Al6061 to accomplish the necessary shielding, and their efficacy in this regard was compared to that of Al6061.

Materials and Methods

Al6061

Aluminium (Al) alloys are widely acknowledged for their exceptional versatility in various applications. Aluminium and its alloys are extensively utilised due to their advantageous characteristics, including their lightweight nature, affordability, and profitability [18].

The popularity of 6061 as an aluminium alloy can be attributed to its exceptional mechanical properties and excellent weldability, distinguishing it from other alloys. The precipitation-hardened alloy primarily consists of magnesium (Mg) and silicon (Si), which serve as its key alloying components.

Aluminium 6061 is commonly chosen as a matrix material due to its advantageous properties, such as low density, high electrical resistance, excellent strength, superior corrosion resistance, and enhanced machinability. The user's text is a range of numbers [19-21].

Fly Ash (FA)

The addition of cenosphere fly ash to an aluminium alloy result in a significant decrease in density when compared to precipitator fly ash. The study utilised fly ash, specifically siliceous fly ash, sourced from a thermal power plant located in Visakhapatnam. Fly ash, despite its lack of conductivity, is an economically viable option due to its low cost. It also consists of different oxide components, including Fe_2O_3, which could potentially improve Additionally, it is worth noting that the particulate nature of fly ash allows for easy dispersion, unlike fibres that have a tendency to clump together [22].

SiC

Silicon carbide (SiC) is a highly attractive choice for structural materials in high-temperature applications due to its impressive resistance to oxidation and stability properties. The chemical characteristics and high tensile strength of this material make it suitable for meeting the diverse technical requirements of the electric breakdown industry. SiC ceramic is a member of the ceramic family that offers several advantages in terms of thermo-structural properties. Additionally, it demonstrates satisfactory dielectric loss, making it a promising material for high-temperature structural applications. Moreover, SiC has the potential to be used as a functional material for EMI shielding or microwave absorption at elevated temperatures, as supported by references [23-24].

Stir Casting

Stir casting is the most frequent process for manufacturing liquid composites at the melting temperatures of individual components [18]. Pure AL6061 was heated to 700 °C before being combined with melted fly ash at 600 °C. Moulds are used to mould this slurry into the desired shape. Stir Casting equipment is shown in Figure 1

Figure 1: Stir Casting Process

Measurements

Electrical Parameters

The user mentions that Hasar created a two-port device with a vector network analyzer (VNA) to identify a sample's electrical characteristics. The proposed method utilises transmitted and reflected signals in the waveguide slot to calibrate the conductivity, permeability, and permittivity of the specimen. The composite material was subjected to experimentation using a vector network analyzer. The resulting electrical parameters have been presented in Table 1-4. The electrical parameters, such as permeability (μ), permittivity (ε), and conductivity (σ), of a metal matrix composite can be determined using a vector network analyzer (VNA E8263B Agilent Technologies) with the transmission/reflection technique. This involves introducing a small sample of the metal matrix material into a waveguide to observe the behaviour of electromagnetic waves. This method was described in reference [26].

Table1: Electrical parameters of pure AL6061

S.no	Frequency	Conductivity	Permittivity	Permeability
1	8.2	-3.11E+00	1.66E+01	3.15E+02
2	8.5	1.27E+02	8.57E+00	2.09E+02
3	9.1	3.23E+00	1.04E+00	-6.69E+00
4	9.5	-6.38E-02	6.34E+00	-7.89E-01
5	10	1.53E-01	2.54E-01	-5.66E-02
6	10.5	-1.18E+02	-2.79E+01	1.00E+01
7	11.0	5.57E-02	7.67E-01	1.95E-01
8	11.5	1.73E-02	1.43E+01	4.25E-02
9	12.0	2.03E+03	-1.03E+01	-1.00E-02

An investigation was conducted on the electrical characteristics of the composite material that was implanted in the 22.86 mm x 10.16 mm waveguide. A research was conducted to analyses the estimates about X-band recurrence. Shielding efficacy refers to the transmission coefficient of a conductive planar shield. This coefficient quantifies the effectiveness of the shield in protecting external electromagnetic fields. The effectiveness is commonly quantified using decibels (dB).

Table 2: Electrical parameters of AL6061/10%SiC/5%FA

S.no	Frequency	Conductivity	Permittivity	Permeability
1	8.2	1.95E+00	5.17E+00	-2.88E+00
2	8.5	7.02E-01	7.13E+00	-5.05E+01
3	9.1	5.11E+01	-5.77E+01	9.55E-02
4	9.5	5.82E-01	6.85E+01	-3.91E+01
5	10	6.58E-01	7.41E+01	-3.59E+01
6	10.5	4.40E+01	8.95E+00	8.69E-02
7	11.0	2.17E+00	1.07E+01	-2.93E+01
8	11.5	-1.60E+01	-1.45E+01	2.89E-01
9	12.0	5.74E-01	1.50E+01	1.69E-01

Table3 : Electrical parameters of AL6061/15%SiC/5%FA

S.no	Frequency	Conductivity	Permittivity	Permeability
1	8.2	-8.37E+01	2.04E+00	-3.79E-02
2	8.5	3.24E+01	6.34E+00	2.06E-01
3	9.1	8.33E-02	7.93E+00	-1.05E+01
4	9.5	-8.36E+00	6.26E+00	-6.36E-01
5	10	-2.28E+01	4.79E+00	-1.80E-01
6	10.5	2.08E-02	9.32E+00	-8.99E-01
7	11.0	7.06E+00	8.07E+00	4.85E-01
8	11.5	5.30E+00	1.69E+01	2.30E-01
9	12.0	-5.45E+00	1.79E+01	6.87E-01

Shielding Effectiveness

Electromagnetic interference (EMI) affects aeroplane electronics. Lightning is a high-frequency natural phenomenon that causes EMI [27]. Electromagnetic Shielding (ES) is used to suppress EMI. EMI shielding reduces electromagnetic wave transmission by blocking it with a conductive shield. electromagnetic interference shielding efficacy describes shielding material's effectiveness (EMSE). Electric conductivity, dielectric permittivity, and magnetic permeability determine a material's electromagnetic shielding efficacy. Using the following equations, a vector network analyzer (VNA) may be used to hypothetically determine the shielding efficiency (SE). We can characterise the electromagnetic (EM) energy reflected from an incident surface by measuring the energy lost in the reflection process.

Table 4: Electrical parameters of AL6061/20%SiC/5%FA

S.no	Frequency	Conductivity	Permittivity	Permeability
1	8.2	8.20E-02	3.03E+00	2.25E+01
2	8.5	1.66E-04	6.91E+00	-1.73E-01
3	9.1	5.79E+01	4.50E+00	-1.10E+04
4	9.5	7.20E+01	9.10E+01	1.00E-01
5	10	-5.58E+01	-7.19E+00	-5.45E-02
6	10.5	2.66E+02	1.61E+01	1.56E-02
7	11.0	1.69E+01	2.60E+01	2.68E-01
8	11.5	-1.00E+03	3.52E+01	2.30E-01
9	12.0	-8.49E+00	6.25E+01	3.65E-01

The percentage of EM radiation transferred through a substance is determined by its absorption loss. Figure 3 depicts the protective design layer's vital reflection and absorption loss. Some of the electromagnetic wave's energy reflected off the composite sheet's surface, while another energy was absorbed by the material and transmitted through the mesh. Parameters R, A, and M are found through [28-29] as follows:

$$SE = R_{dB} + A_{dB} + M_{dB} \qquad (1)$$

The reflection and absorption loss are given below

$$A_{dB} = exp\left[\frac{t_m}{\sqrt{2}}\sqrt{k_0\sigma\eta\mu}\right] \quad (2)$$

Where t_m is the thickness of the mesh. k_0 represent the wave number, σ represents the conductivity of the material and μ represent the permeability of the material.

$$R_{dB} = 20\, log\left|\frac{(z_0 + Z_s)^2}{4z_0 z_s}\right| \quad (3)$$

The Z_s represents the sheet impedance of the metal structure.

$$z_s = z'_w a_s + j\omega L_S \quad (4)$$

The sheet inductance L_s

$$L_s = \frac{\mu_0 . a_s}{2\pi} ln\,(1 - e^{\frac{-2\pi r_s}{a_s}}).^{-1} \quad (5)$$

As seen in Figure 2, a mesh with a square aperture length a_s and wire radius r_w has a shielding efficacy [27-30] that may be defined. The z'_w depends on the resistance per unit length.

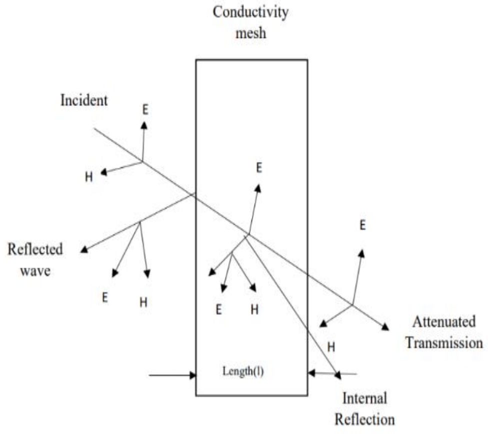

Figure 3: Electromagnetic wave incident on mesh.

$$z'_w = r'_w \frac{(\sqrt{jw\tau_w}).I_0.(\sqrt{jw\tau_w})}{2.I_1.(\sqrt{jw\tau_w})} \quad (6)$$

$$\tau w = \mu\sigma rw2 \quad (7)$$

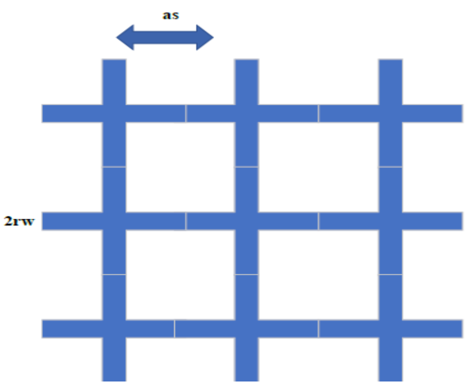

Figure 4: Mesh representation with as and rw [23]

Result

The numerically simulated results of SE are shown in figure 5-8. The SE of pure AL6061 was 33.89dB in the x-band range. To improve the shielding effectiveness of the material, different percentages of SiC and Fly Ash is added to the pure AL6061. When 10% of SiC and 5% of FA is add to the pure AL6061 the SE improved by 13.91dB and maximum shielding obtained was 47.8dB. If Al6061 is reinforced with 15% SiC and 5% of FA, then the maximum SE was 50.6dB, and it was improved by 16.71 dB. If Al6061 is supported with 20% SiC and 5% of FA, then the maximum SE was 55.6dB, and it was enhanced by 21.71 dB. The observed improvement in specific energy (SE) is a result of adding SiC and FA to AL6061. The improvement observed can be explained by the magnetic properties of SiC and the absorbing properties of FA. The data presented in these materials indicate a notable increase in specific energy (SE) when compared to Pure AL6061. Table 5 displays the maximum standard error (SE) values for the mentioned materials. On the other hand, Figure 7 illustrates a comparison between all combinations and pure AL6061.

The determination of shielding is dependent on the electrical properties of the substance under consideration. Reflection loss is a phenomenon that arises when there are materials characterised by high conductivity. On the other hand, absorption loss is linked to materials that possess low conductivity. The interaction between an electromagnetic wave and a mesh surface can be characterised by three main processes: reflection, absorption, and transmission of energy. The shielding properties of a mesh are determined by how effectively it blocks the energy of an electromagnetic wave. This study investigates and evaluates the ability of an airplane's composite surface to resist the impact of lightning strikes [31-34]. Efficiently absorbing electromagnetic waves as they pass through, electromagnetic wave absorbing materials possess the power to be amazing. The permittivity of a material is the influencer of its absorption level. Contacting a shielding material result in the process of absorbing and reflecting electromagnetic waves. The permissible and permeable characteristics of the material steer the level of shielding. Magnetically and dielectrically inclined materials affect the efficacy of electromagnetic shielding. Absorption loss computation depends on examining attenuation in the material. The material's dielectric and magnetic losses increase and significantly affect the correlation between reflection and absorption [35-36].

Composite wire meshes have been identified as a potentially effective solution for protecting aircraft from lightning strikes. The incorporation of SiC and FA into Al6061 is primarily aimed at improving its structural efficiency. The mentioned materials are frequently used as protective coatings for aircraft. The high absorption and reflection properties of these composite materials contribute to their strong structural efficiency. The highest level of sound exposure (SE) recorded was 55.6 decibels (dB), which was obtained using a mixture consisting of 20% silicon

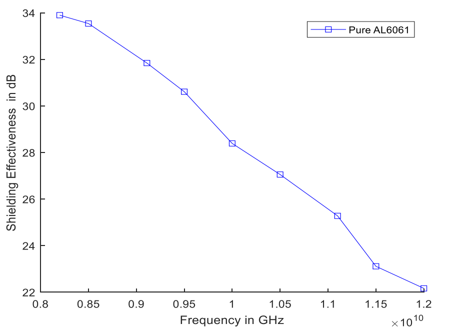

Figure 5: Shielding Effectiveness of pure AL6061.

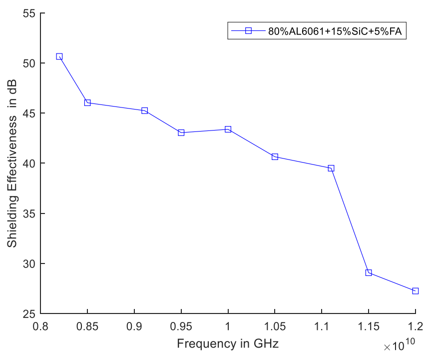

Figure 6: Electromagnetic Shielding 85% AL6061,10% SiC, and 5% FA

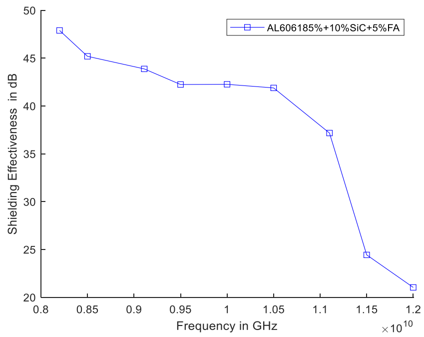

Figure 7: Electromagnetic Shielding 80% AL6061,15% SiC, and 5% FA

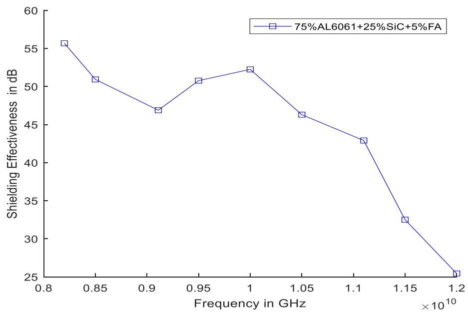

Figure 8: Electromagnetic Shielding 75% AL6061,20% SiC, and 5% FA

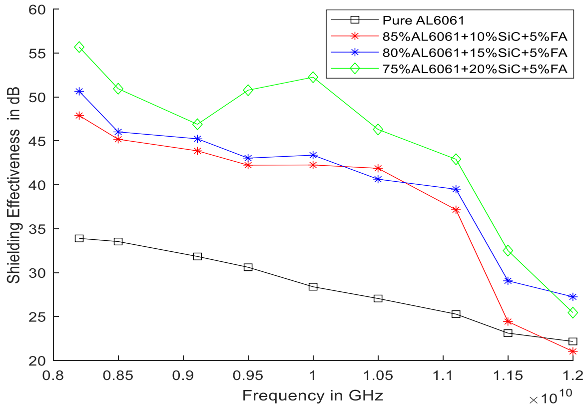

Figure 9: Comparison of pure AL6061 with different percentages of SiC/FA.

carbide (SiC) and 5% fly ash (FA). Silicon carbide (SiC) is composed of a significant amount of silicon (56.6%) and carbide (31.7%). In contrast, it should be noted that FA consists of Fe2O3 material. The utilisation of these materials has a beneficial effect on the overall performance of the SE. The use of these materials in aircraft applications is aimed at ensuring safety and providing protection. The aerospace industry specifies a requirement of 55 dB for
lightning protection [37].

Table 5: Representation of AL6061 with different percentages of reinforcement of SiC/FA

S.no	Composite Materials	Maximum SE (dB)
1	Pure AL6061	33.89
2	AL6061+10%SiC+5%FA	47.8
3	AL6061+15%SiC+5%FA	50.6
4	AL6061+20%SiC+5%FA	55.6

Conclusion

This composite wire meshes can be used in aircraft to protect from lightning strikes. Adding the SiC and FA primarily aims to Al6061 improve the SE. These materials are used as the protecting layer for aircraft. These composite materials have a strong SE due to their high absorption and reflection properties. The maximum SE obtained was 55.6dB when 20% SiC and 5% FA. SiC has the maximum of silicon of 56.6 per cent and Carbide of 31.7 per cent, and FA has the Fe_2O_3 material. These materials improve the SE. These materials can be used in aircraft applications for protection purposes.

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