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Investigation of Electromagnetic Shielding for Wire Mesh Composite for Aircraft against Lightning Strike

Siva Chakra Avinash Bikkina[1] and **Pappu. V. Y. Jayasree**[2]

[1]*Research Scholar, Department of Electrical Electronics and Communication Engineering, GITAM School of Technology, Visakhapatnam, India; sbikkina@gitam.in*

[2]*Professor, Department of Electrical Electronics and Communication Engineering, GITAM School of Technology, Visakhapatnam, India; jpappu@gitam.edu*

***Correspondence:** sbikkina@gitam.in

ABSTRACT- Nowadays, fly-wire is only used for flying-related things. All plane controls depend on electronics, but they also must deal with high-intensity radiated fields. This equipment might need an electromagnetic shield to protect it from outside electromagnetic pollution. The current work aims to develop a mesh around the operating equipment to protect and make it work better. AL6061 was used to create a shield with a metal matrix composite. Here three combinations of Metal Matrix Composite (MMCs) were considered to protect from the high-intensity radiated fields. These MMCs are AL6061+10%Al_2O_3+5% FA (MMC-1), AL6061+15% Al_2O_3+5% FA (MMC-2), and AL6061+20% Al_2O_3+5% FA (MMC-3) made the process of shielding more effective at different percentages. Explements are Measures that take the electrical characteristics, and they are by Shielding Effectiveness (SE) of different concentrations of fly ash and Al_2O_3.SE of 50 dB is achieved; hence these MMCs can be used in aircraft and other applications as a shield.

Keywords: AL6061, Electromagnetic Shielding, high intensity radiated fields and mesh.

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1. INTRODUCTION

Due to the proliferation of electronic communication devices in contemporary culture, EM radiation has emerged as a significant issue that cannot be ignored. Therefore, it is crucial to develop materials that effectively block electromagnetic interference (EMI). Modern communication technologies, wearable technology, and high-power electronic hardware benefit significantly from lightweight, effective EMI shielding composites. More and more aircraft applications and wind power producers are adversely affected by high-intensity radiation fields. Every 1000 hours, a commercial airliner is struck by lightning [1]. Electrical equipment is rendered inoperable by electromagnetic interference when lightning hits, which isn't very nice for the plane's structural integrity [2-3]. In the case of lightning striking a plane's surface, tremendous currents may be generated. As a result of these currents, structures break down, weaken, and begin to topple [4]. Lightning strike prevention is a critical component of any strategy to safeguard aircraft from electrical and physical damage (LSP)

A plane's currents flow in the direction of least resistance when struck by a flash of lightning [5]. Aircraft were commonly covered with Fiber-Reinforced Polymer (FRP) to reduce weight. To reduce the weight of the plane's skin, metal was often transformed into FRP. The massive currents that are generated when lightning strikes are too large for FRP. Damage to electronic equipment as well as bodily harm results [6]. A novel material was developed to solve the issue of FRP composite materials not being able to conduct electricity. Von Klemperer and Maharaj (2009) examined composite materials made of FRP to see whether they might protect aircraft against electromagnetic interference (EMI). Adding metal powder to carbon-fiber-reinforced polymers may boost shielding performance at a sensible rate [7], according to Liang et al.'s research (2009). Graphene/epoxy composites generated from graphene-based sheets were evaluated for their EMI shielding efficacy. They investigated the composite's ability to block electromagnetic interference using an X-band frequency range of 8.2–12.4 GHz and discovered that it would function well in an EMI shielding application [8].

To make the material stronger and improve its magnetic properties, any composite material can be added to it. Since this is the case, making the Al_2O_3 more potent can help the composite material block radiation better [9]. How much a substance soaks up is shown by how well its impedance matches the open space. When things go together well, a lot of absorption happens. Reflection happens when the content and space don't go together [10]. Adding different dielectric and magnetic elements to the composite can make it a better shield. The amount of filling in the material used to reinforce the shield affects how much the shield absorbs [11]. Because the carbon grain and iron oxide were porous, the electromagnetic waves could stick to the fly ash [12-13]. With the addition of fly ash, aluminium composites' mechanical and tribological properties may be enhanced [14-15]. Inorganic chemical Al_2O_3 is a low-cost metal oxide. It has many valuable properties, including high strength, greater thermal stability, increased electrical insulation, excellent chemical resistance, and low toxicity. With the help of Al_2O_3, researchers are creating polymeric nano dielectrics and other valuable materials with better thermodynamics, mechanics, electricity, and dielectric properties [16-17]. In particular, composite materials are excellent at both electrical and mechanical performance. It can increase composites' strength while maintaining high conductivity [18]. Reinforcing aluminum composites with other materials has the potential to improve their basic properties, which bodes well for the future. Metal matrix composites have been made from various metals, including titanium, nickel, magnesium, copper, and aluminum. Aside from the fact that aluminum is lightweight and robust, it is a popular option because of its ability to conduct electricity and reflect light. A metal matrix of Al6061 was employed in this experiment. Strengthening the Al6061 metal matrix may increase shielding qualities.

The proposed work's innovative aspects include its use of stir casting to produce the MMCs, its use of a vector network analyzer to determine the MMCs' electrical properties, and its use of the transmission line technique to determine the MMCs' Shielding efficacy. Protection of aircraft from the effects of a lightning strike using the transmission line technique of shielding has not been documented in the literature. The theoretical analysis of SE using a metal matrix composite mesh of minimal thickness and the transmission line approach is new to this work.

2. MATERIALS AND METHODS

In the aircraft sector, aluminum 6061 is employed as a lattice material because of its excellent mechanical qualities and its ability to protect. Al_2O_3 is a hard ceramic with a density of 3.97 g/cm3 and moderate weight Al_2O_3 is utilised as a reinforcing material because it reduces the risk of corrosion. Due to this process, they become more robust, durable, pliable, and better at conducting electricity. Aircraft may be built using Al_2O_3 and Al6061 since it is inexpensive and resistant to high temperatures [19]. In hybrid composites, Al_2O_3particles also play an essential role [20].Fly Ash (FA) is a by-product of coal-fired thermal power plants and a solid waste material. Carbon Fibre has been in use for the last several decades as a weight-saving reinforcing material for aluminum metal matrix composites. Fly ash is added explicitly to aluminum metal matrix composites reinforced with SiC to avoid the dissolution of SiC and the creation of unwanted $\boldsymbol{Al_4C_3}$ species [21]. EMSE (electromagnetic interference shielding efficacy) of composites has been much improved by adding FA particles to the mix [22]. It has been shown that increasing the amount of FA in the composite increases the EMSE, improving the composite's shielding properties by increasing its reflectivity. Tensile strength is reduced in composites with higher FA concentrations [23]. Due to its low density and ability to decrease weight and increase energy dissipation (EMSE), FA is considered a potential reinforcing ingredient for the composite. The thermal power station in Visakhapatnam supplied the FA (Siliceous fly ash) needed to make the composite. On average, there will be 13 micrometre-sized particles in the fly ash, and its density is 2.21 grammes per cubic centimetre. Fly ash's $\boldsymbol{Fe_2O_3}$ is supposed to boost electromagnetic shielding effectiveness. Hence, it is employed as a necessary reinforcing material in building the anticipated Hybrid Aluminium Metal Matrix Composite (HAMMC) [24].

2.1 Preparation of MMCS

Particle-reinforced composites like the HAMMC are manufactured using the stir casting method shown in figure1, which is the most cost-effective. It is made by heating the material in a furnace with a reinforcing component feeding and stirring it. A stirrer pole and a set of stirring blades are included with the stirrer. Al6061 alloy and a resistance-heated muffle furnace are all needed to get the temperature to 720 degrees Fahrenheit. The Al_2O_3 and fly ash reinforcing particles are heated to 600°C before casting to eliminate any gases or moisture. As a result, the alloy's temperature doesn't dip too low during casting. Alumina-coated stirrer blades are employed to keep ferrous ions out of the molten alloy. Each composite is made using a different amount of fly ash (5wt per cent) and an equal amount of Al_2O_3, as shown in Table 1. To prevent the liquid composite from collecting moisture from the air, it is poured into a steel mould that has been preheated to 250°C. Cooling begins as soon as liquid metal has started to harden. The hardened composite is removed from the mould. The fabricated materials from the stir casting are represented in *figure 2*.

Figure 1: Experimental setup for reinforcement using stir casting

Figure 2: Fabricated Material from Stir Casting

Table 1: Metal matrix composites with different percentages of reinforcement

Material and weight percentages combined	Representation
85% AL6061+10% Al_2O_3+5% FA	MMC-1
80%AL6061+15% Al_2O_3+5% FA	MMC-2
75%AL6061+20% Al_2O_3+5% FA	MMC-3

2.2 Electrical parameters

A vector network analyzer may be used to evaluate the electrical properties of reinforced composite materials. A vector network analyzer (VNA E8263B Agilent Technologies) can measure the Permeability, permittivity, and conductivity of metal matrix composites by inserting a sample of metal matrix material into the waveguide. It is necessary to evaluate the electrical properties of the implanted material in the waveguide's 22.86*10mm diameter. The X-band was the subject of an experiment comparing recurrence estimates based on VNA measurements [25-26].

2.3 Analysis of Electromagnetic Shielding For Metal Matrix Composite (MMCS) Materials

MMCs arranged in a grid with the same spacing is used to make a wire-mesh composite. Three factors affect how successfully wire mesh blocks out waves in this case: distance between wires, wire thickness, and frequency [27,28]. To improve the effectiveness of this mesh as a shield, we may add extra wires perpendicular to the original set. For a given operating wavelength, we measure the effectiveness of wire-mesh screens in blocking electromagnetic waves. When describing it, the wire-mesh composite corresponding sheet-impedance is utilized [29-32]. When an electromagnetic wave contacts a mesh, it generates a reactive field that is restricted to the region of the mesh surface due to the periodicity of the mesh aperture and the small electrical size of the mesh aperture compared to the wavelength. The reactive field reduces exponentially as you depart from the mesh surface.

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

Above *equation1* represent the absorption and reflection loss. The parameters R and A are defined as follows by [28-31]:

$$A_{dB} = 20\ \log \exp\left(\frac{r_m}{\sqrt{2}}.\sqrt{k_o\mu_r n_o \sigma}\right) \qquad (2)$$

$$\mu_r = relative\ permeability\ , n_o = free\ space\ and\ \sigma = conductivity$$

$$k_o = \omega.\sqrt{\mu_o\epsilon_o} \qquad (3)$$

k_o represents the free space wavenumber with $\mu_o\epsilon_o$

$$R_{dB} = 20\log_{10}\frac{(Z_0+Z_S)^2}{4.Z_O Z_S}. \qquad (4)$$

Here Z_0 represents the free space and Z_S Represent the sheet impedances

$$Z_S = z'_w a_s + j\omega l_s \qquad (5)$$

In addition, the sheet inductance $L_s$and the wire impedance per unit length z'_w (approximated to its DC resistance) are provided by:

$$L_s = \frac{\mu_0.a_s}{2\pi}\ln(1 - e^{-\frac{2\pi r_s}{a_s}})^{-1} \qquad (6)$$

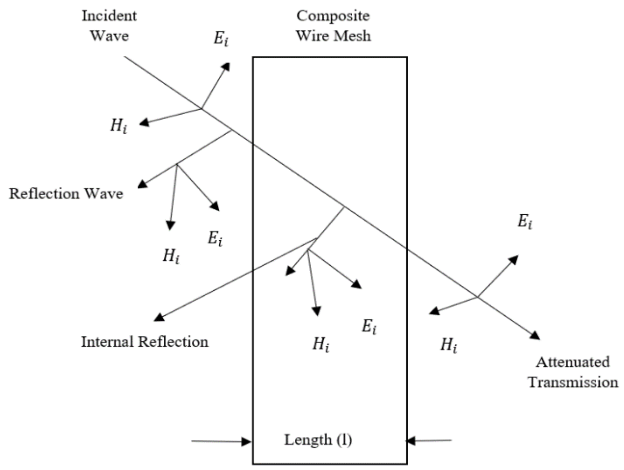

Figure 3: Representation of normal incidences of composite wire mesh

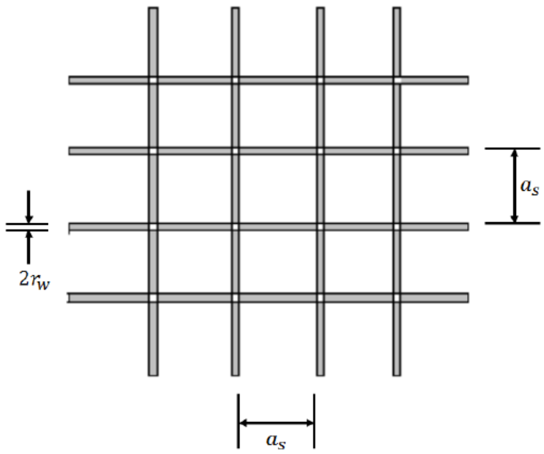

Figure 4: Representation of square mesh [33,34]

The internal impedance of the wire is represented as z'_w. The z'_w depends on the resistance per unit length, a_s is the mesh size. τ_w time constant and $I_n(.)$ first kind of the Bessel function.

$$z'_w = r'_w \frac{(\sqrt{jw\tau_w}).I_0.(\sqrt{jw\tau_w})}{2.I_1.(\sqrt{jw\tau_w})} \qquad (7)$$

$$R'_w = (\pi r_w^2 \sigma_w)^{-1} \qquad (8)$$

$$\tau_w = \mu_w \sigma_w r_w^2 \qquad (9)$$

Since the skin effect had no noticeable impact on the frequencies and structures under discussion, the DC wire resistance was provided as an approximation to the wire impedance rather than the wire impedance (1). Therefore, it is easy to evaluate the effectiveness of a given mesh (with square apertures) as a shielding medium in a variety of settings (and in different directions).

3. RESULTS

The frequency response of a vector network analyzer may be used to deduce the link between an electrical property of a composite material and its frequency by examining the electrical properties of conductivity (σ), permeability (μ), and permittivity (ϵ). Permeability and permittivity interact to determine all electrical characteristics of the material. The quantity of electrical energy stored in lossless materials is proportional to its critical permittivity region. The imagined part of a material's Permeability is just as important as the real part for determining how much magnetic energy the material can store, since it measures the amount of power lost to magnetic fields. The scattering properties may be calculated using a VNA operating at 8-12 GHz. In this research, AL6061 alloys were employed with a backing of Al_2O_3 and FA. The object's reflectance changes when its composition alters, according to the conductivity of the material. Due to its high permeability and conductivity, this material has poor attenuation and reflection properties. When more Al_2O_3 is included into the mix, the composite material gains a more desirable property: higher permittivity. Therefore, the overall absorption loss of the composite increases. The effective shielding efficacy of 48.83 dB, as determined by Zhao et al. [32-33], is deemed sufficient for aircraft applications. According to Fan's research, MXene/graphene hybrid foam has a shielding efficacy of 50.7 dB in Zhimin [36]

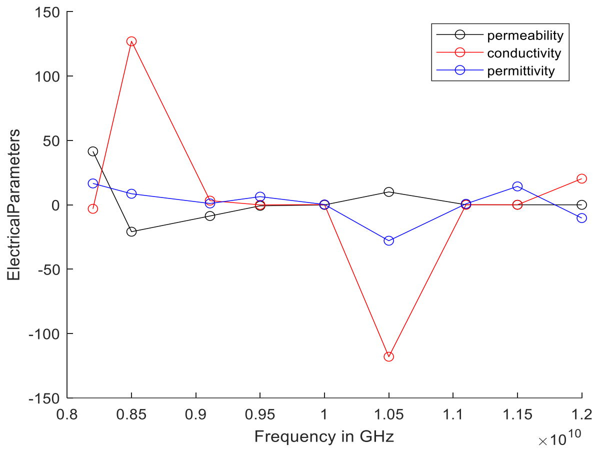

Figure 5: Electrical Parameters of Pure AL6061

The MMC-1, MMC-2 and MMC-3 exhibits shielding effectiveness of 40.88dB, 44.44dB and 51dB. Increase in shielding value is obtained by increasing the Al_2O_3 content by 10% and 15%, respectively, in the same way as stated earlier. It will no longer suit aviation applications if the percentage exceeds that level. The FA content of all combinations is less than 5%.

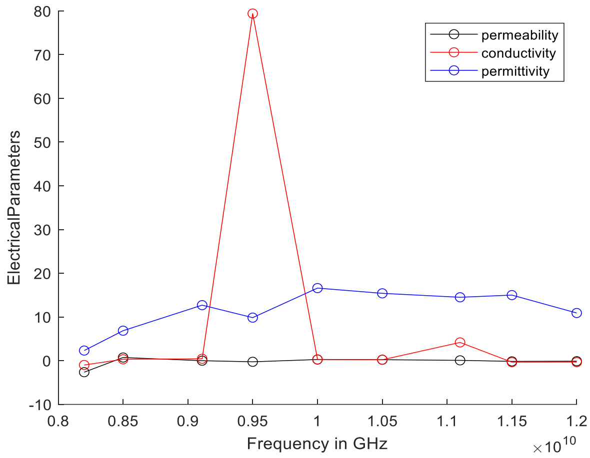

Figure 6: Electrical Parameter of MMC_1

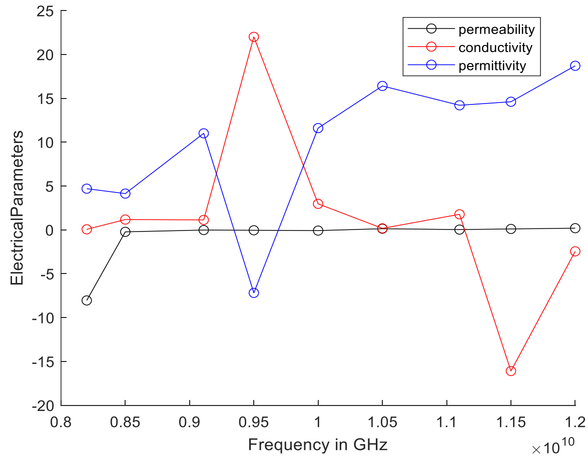

Figure 7: Electrical Parameter of MMC_2

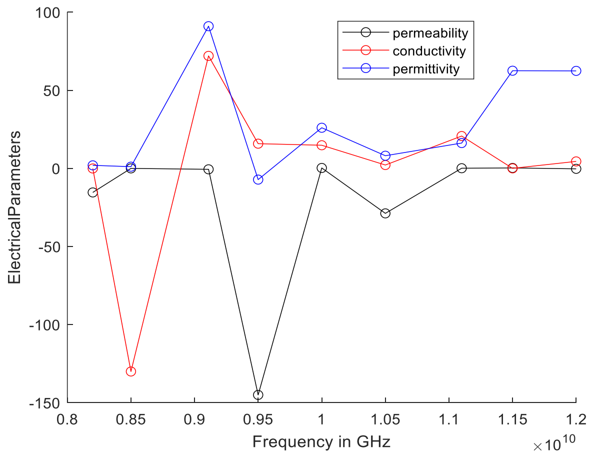

Figure 8: Electrical Parameter of MMC_3

If the concentration is more significant, its strength decreases, and its material properties are lost. The maximum shielding Value of the composite materials is shown in *table 2*.

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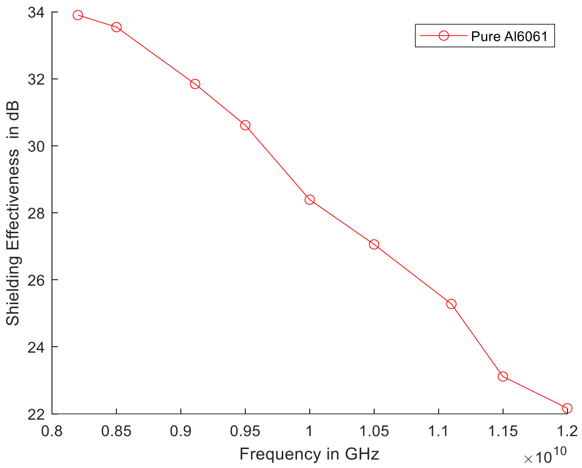

Figure 9: Shielding Effectiveness of Pure Al6061

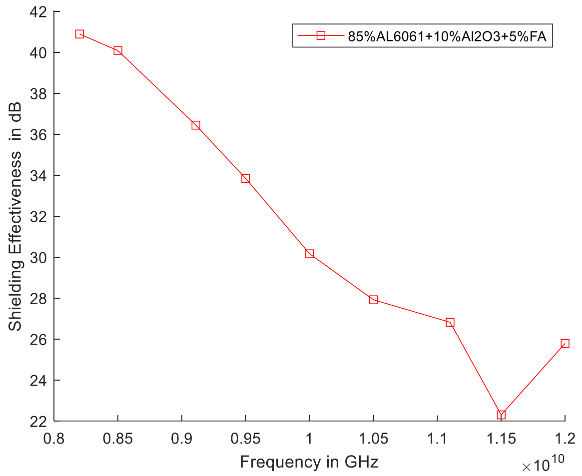

Figure 10: Shielding Effectiveness of MMC-1

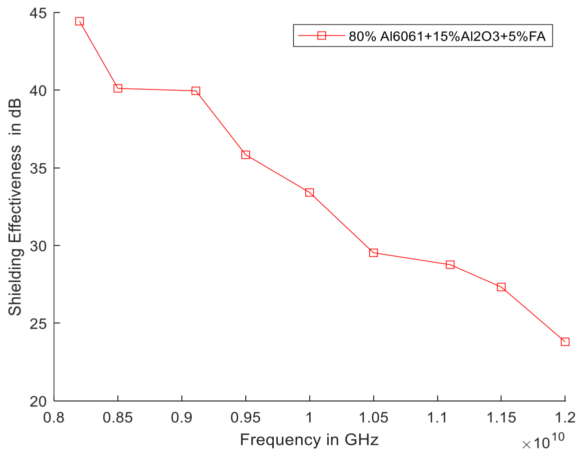

Figure 11: Shielding Effectiveness of MMC-2

4. CONCLUSIONS

In the aviation industry, composite materials with high shielding effectiveness are widely used. The 51dB SE is achievable with the MMC described here. More than 50dB of SE may be found in this MMC-3. Therefore, Aircraft constructed from these materials are more equipped to withstand the effects of lightning. Compared to metal sheets, wire mesh structures are more suitable for covering big buildings due to their physical flexibility and reduced weight. Wire mesh screens provide one major benefit over metal-coated glass windows. When compared to metal sheets, this MMC wire mesh is less effective as a shield (SE). Literature suggests that aero plane surfaces protected by a material with a shielding efficacy of 50 dB are safe against lightning strikes. Preparations for radiation shielding may find use in mobile radar and wind turbine systems. To meet the requirements of various uses, any combination of materials may be used. Some aluminum composite materials may be modified to serve as effective shielding.

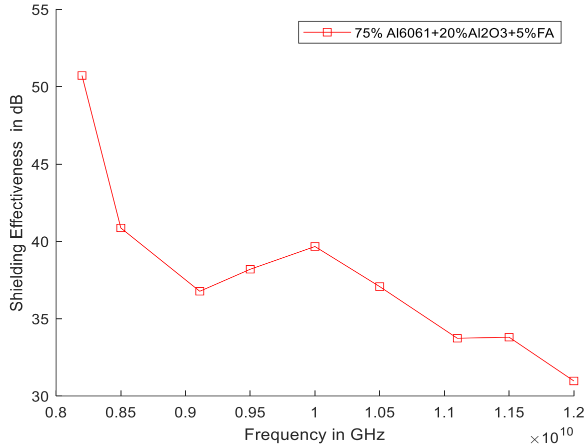

Figure 12: Shielding Effectiveness of MMC-3k

Table 2: Maximum Shielding effectiveness of WMC

Materials	Maximum Shielding Effectiveness(dB)
Pure AL6061	33.8
MMC-1	40.88
MMC-2	44.44
MMC-3	51

Table3: Comparison of work with existing work

References	Frequency	Composite material	Shielding effectiveness
[17]	X band	Al_2O_3/FeSiAl/flaky Graphite	30.4 dB
[37]	X band	Al_2O_3	29-32 dB
Proposed work	X band	Al6061/Al_2O_3/Fly Ash	51 dB

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