

Analysis of Shielding Effectiveness for Square Mesh Wire with Metal Matrix Composite of Al6061 with Fly-Ash

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Abstract

One of the significant problems facing aerospace applications over the past two to three decades was fuel consumption. The aircraft industry prefers composite materials (Fiber Reinforced Plastic) to resolve this issue. These composite materials have less weight and good mechanical properties. The major drawback with these fiber-reinforced materials was the inability to conduct the high electrical fields and electrical currents, which cause damage to the aircraft's structure when lightning strikes occurred. The designer should consider a lightning strike protection (LSP) system that allows current and field lines to pass freely through the surface while providing EMI shielding for the aircraft. The best method for allowing the current and field through the aircraft surface by the mesh structure. The mesh structure is examined in this study to offset the decreases in density and fuel consumption. This mesh structure was made using the AL6061 metal matrix material. AL6061 metal matrix composite electrical properties were taken into consideration depending up on the reinforcement or strengthening of fly ash particulates at different percentages at X-band. The composites shielding effectiveness is gradually increased to 6 dB.

Key-words: Fiber Reinforced Plastic, AL6061, Lightning Strikes, Electromagnetic Shielding, X-band.

1. Introduction

One of the serious issues confronting the airplane industry was a lightning strike. This issue influences the airplane in two ways, i.e., the electronic circuit and the physical structure of the airplane's plane. Every flight will get struck by a lightning strike between 1000 hrs to 10000 hrs of flight hours [1-2]. When an airplane gets hit by lightning strikes, most of the damage taken place at the point of impact and exit, where electromagnetic field lines, high-intensity currents and can't readily flow through [3]. The massive current created by lightning flows through the structure's surface with little resistance. If the designer fails to account for the lightning effect while protecting the plane's surface, terrible effects like delamination, embrittlement and structural collapse may result. Because of their incompatible strength-to-weight and modulus-to-weight ratios, composite materials are appropriate metal replacements in various industries, defence applications etc.. [4].

For reducing the density of aircraft construction, composite materials are one of the most prominent approach. The Thickness of different structures can be reduced by using wire structure. The primary purpose of selecting the composite materials having the required shielding effectiveness [5-7]. Casey, Kendall F in 1988, proposed the main wire mesh screen for electromagnetic shielding. Compared to the flat metallic sheet, this mesh structure is lighter and more flexible [8]. For the x-band spectrum, the mesh structure using nylon composite materials of 1mm thickness has a shielding effectiveness of 12.5dB [9]. This mesh-type structure has less density compared to the plane sheet. The present work introduces the mesh structure for composite materials. The ideology of developing this research of this work is to reduce the density of the component used in aerospace applications. Most researchers introduce the different metal foam structures to reduce the materials' density, but they have some dimensions and homogeneity issues. To overcome this, fly ash materials are reinforced into the different metal matrix materials to reduce density [10].

Fly ash is one of the waste products produced from thermal power plants. Most of the research uses fly ash as the basic reinforcement materials for the different applications [11]. Fly ash is reinforced with aluminum alloys because it will reduce the density, cost and increase the wear resistance of the materials. Fly ash reinforcement material increases the properties like hardness, and tensile strength will be enhanced, and the composite's ductility will decrease [12]. Dou, Zuoyong, et al. 2007 Experiments with AL2024 metal matrix are reinforced with fly ash and concluded that the enhanced shielding effectiveness of these materials and obtained value of shielding was 32dB to 102dB.[13]. Mishra et al. 2013 examine how the shielding effectiveness varies when expanded graphite is incorporated with fly ash with different reinforcement percentages [14]. Most researchers

reinforce the other materials to the aluminum materials to improve the electrical properties; one of the primary materials used is fly ash. The main reason for the usage of fly ash has good electromagnetic shielding properties [15-16].

This paper focuses on composite material made of AL6061 conductivity material reinforced with fly ash; this how the electrical properties vary concerning the different reinforcement percentages. The overall work is organized by examining lightning strikes, composite material preparation, analyzing the electrical properties of composite materials, calculating electromagnetic shielding effectiveness by electrical parameters, results, and conclusion.

2. Examination of Lightning Strike Protection (LSP)

A lightning strike is striking aircraft/Airplanes, damaging the internal electronic circuits and damaging the physical structure. Most of the physical damage is occurring at the exit and front part of the aerospace's applications. To provide lightning strike protection to aircraft's different methods are used. One of the most common methods was mesh structure. These mesh structures are made up of aluminum or copper materials. But these materials have more density and less mechanical properties. The composite was considered to solve the difficulty mentioned earlier. The use of composite materials in the mesh design was supposed to minimize component density and fuel consumption [17-20].

In this study, varying amounts of fly ash (5%, 10%, and 15%) were to strengthen AL6061 metal matrix compositions. This Hybrid Metal Matrix Composite (HMMC) material produces an astonishing amount of shielding effectiveness. This HMMC is suitable for lightning strike protection (LSP).

3. Material Selection

AL6061 metal matrix material has the best electrical and mechanical properties compared to aluminum metal matrix alloys. The matrix material in this investigation is Al6061, which was obtained from a leading producer and supplier of a wide variety of industrial products in Mumbai. This metal matrix, AL6061, is mainly employed in aeronautical applications.

Fly Ash

It is most prominent byproducts of the thermal plant is fly ash. For decades, fly ash is being utilised as a reinforcing material in the preparation of aluminium metal matrix composites because it reduces composite weight. Iron oxide can increase shielding by absorption, according to Cao and Chung. X-ray fluorescence (XRF) investigation of the chemical composition of the fly ash revealed the presence of iron oxide. [21]. Fly ash (Siliceous fly ash) was used from a thermal power plant in Visakhapatnam to make the composite. Fly ash has an average particle size of roughly $13\mu\text{m}$, a density of 2.1 g/cm^3 and a higher silica concentration than other types of ash. Because the Fe_2O_3 in fly ash is thought to improve electromagnetic shielding efficacy, it included as a mandatory reinforcing material in the planned Hybrid Aluminum Metal Matrix Composite (HAMMC) [22]. Table 1 shows the percentage of chemicals found in fly ash.

4. Composite Material Preparation

Several varieties of methods might be employed to manufacture composite materials. Some of the researchers are employing stir casting techniques. The primary purpose of using stir casting was economical. This method is the simplest method to develop Aluminum Metal Matrix Composite (AMMC) materials. This method is used to make composite materials with various components utilized as reinforcement. The percentages of reinforcing materials are adjustable. [23-24].

In this research, pure AL6061 was heated to $700\text{ }^\circ\text{C}$ and blended with melted fly ash at $600\text{ }^\circ\text{C}$. Table 1 depicts the chemical combination of various percentages of fly ash compounds. The reinforced material gets shaped into the desired form. The electrical parameters of composite materials vary with respective frequency. These electrical parameters of the composite materials can be estimated using the Vector Network Analyzer (VNA). U.C. Hassar suggested it [25]. These HAMMC have the best mechanical properties for the plane sheet [2,29]. By this, we can say that the mesh wire structure also has the best mechanical properties.

Table 1 - Percentage of the compound in fly ash

Compound	Al_2O_3	Mgo	Ca O	K_2O	SO_3	Na_2O	Fe_2O_3	SiO_2
Percentage	26.23	1.10	4.59	0.95	0.62	0.25	3.17	53.1

5. Electromagnetic Shielding Effectiveness Calculation

Two simplifying assumptions are always assumed while investigating the shielding performance of a metal grid enclosure as a wire grid mesh: i) the wire cross-over junctions are in electrical contact, and ii) the mesh is planar [26]. The mesh wire's shielding effectiveness depends on three electrical parameters and the materials' Thickness. Schulz suggested a programmed method to link material properties to shielding absorption loss effectiveness, reflection loss, and multiple reflection loss to secure assimilation. The shielding effectiveness includes absorption loss, reflection loss, and multiple reflection loss [27]. The basic structure of the square mesh is showing in figure1.

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

A_{dB} = Absorption loss, R_{dB} = Refelction loss and M_{dB} = Multiple refelction loss

In this, we will not consider the multiple reflection loss because these losses are very negligible. The formulae for absorption and reflection loss are provided below. The reflection loss and shielding effectiveness of the materials depended on the sheet impedance of the mesh [28,8]

The absorbtion loss represented in equation 2

$$A_{dB} = 20 \log e^{-k_o \cdot \alpha_m \cdot r_m} \quad (2)$$

k_o = wave number, α_m = attenuation losses of mesh and r_m = thickness of mesh

$$A_{dB} = 20 \log \exp\left(\frac{r_m}{\sqrt{2}} \cdot \sqrt{k_o \mu_r n_o \sigma}\right) \quad (3)$$

μ_r = relative permeability, n_o = free space and σ = conductivity

$$k_o = \omega \cdot \sqrt{\mu_o \epsilon_o} \quad (4)$$

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

The reflection loss R_{dB} is given as

$$R_{dB} = 20 \log \frac{(Z_0 + Z_S)^2}{4 \cdot Z_0 Z_S} \quad (5)$$

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

$$Z_S = zw * as + j\omega l_s \quad (6)$$

The sheet inductance l_s is given as

$$l_s = \frac{\mu_o as}{2\pi} \ln\left(1 - e^{-\frac{2\pi r_w}{as}}\right)^{-1} \quad (7)$$

Where r_w is the radius of the wire mesh and a_s is mesh size.

$$zw = R'_w \frac{(\sqrt{j\omega\tau_w}) I_0 \cdot (\sqrt{j\omega\tau_w})}{2I_1 \sqrt{j\omega\tau_w}} \quad (8)$$

R'_w is the dc resistance per unit length of the mesh and τ_w is the diffusion time constant, and $I_n(\cdot)$ denotes the modified Bessel function of the first kind of order n.

$$R'_w = (\pi r_w^2 \sigma_w)^{-1} \quad (9)$$

$$\tau_w = \mu_w \sigma_w r_w^2 \quad (10)$$

μ_w and σ_w Denote the permeability and conductivity of the material utilized in the mesh construction.

6. Results

The SE of AL6061 with varying amounts of fly ash illustrates it provided in the following figures. The shielding effectiveness is the combination of absorption and reflection loss of the materials. We know that as frequency increases, the effectiveness of the shielding decreases. Figure 2 illustrates the entire SE for pure AL6061, and the shielding effectiveness for pure AL6061 with the greatest and least shielding effectiveness is 31.13 dB and 18.88dB, respectively. Figure 3,4 and 5 illustrates the SE for AL6061 reinforced with 5% fly ash, 10% fly ash and 15% fly ash have the highest and lowest shielding effectiveness in the ranges of 34.89dB - 6.23dB, 35.88dB - 16.82dB, and 37dB - 12.65dB, respectively.

Figure 1 - Representation of mesh with reflected and transmitted signals.

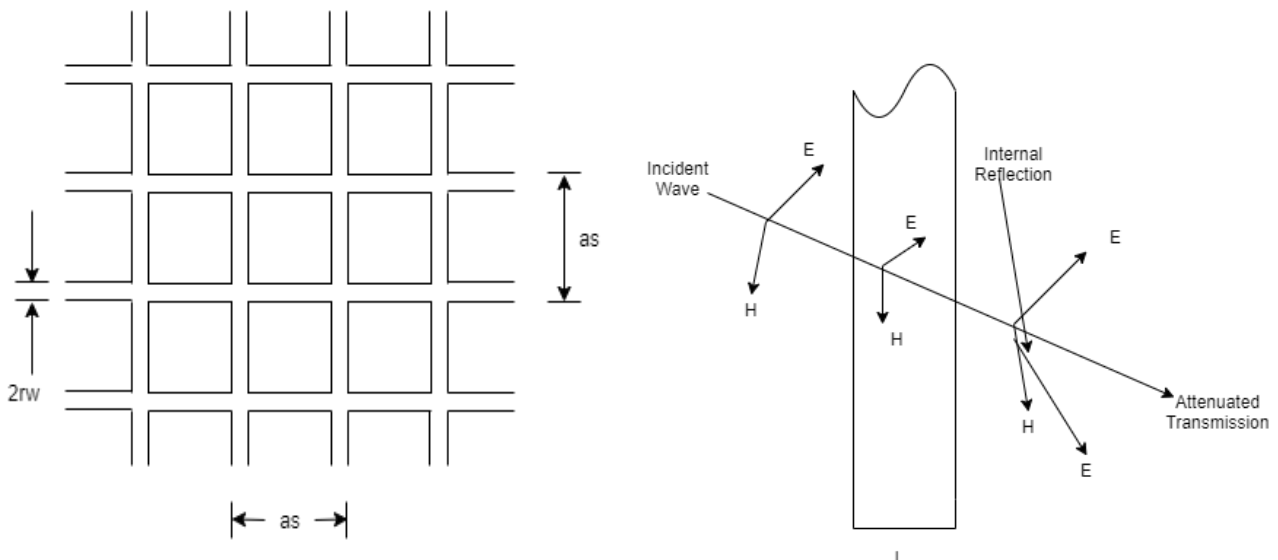


Figure 2 - Shielding Effectiveness for 1mm thickness with Pure AL6061

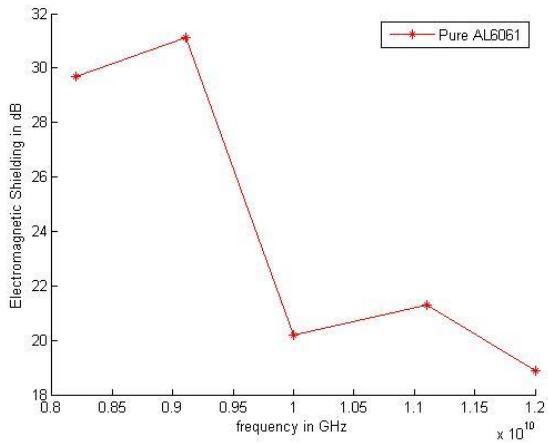


Figure 3 - Shielding Effectiveness for 1mm thickness with 95% AL6061 and 5% Fly ash

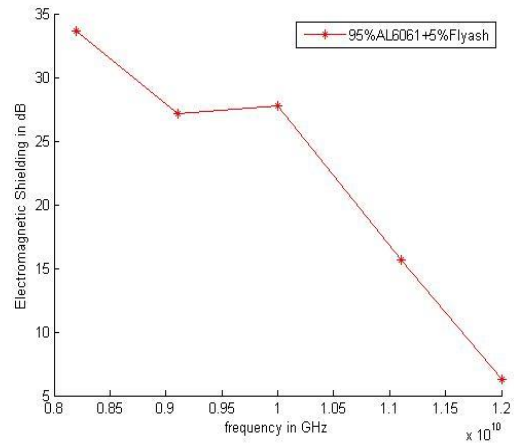


Figure 4 - Shielding Effectiveness for 1mm thickness with 90% AL6061 and 10% Fly ash with 1mm thickness.

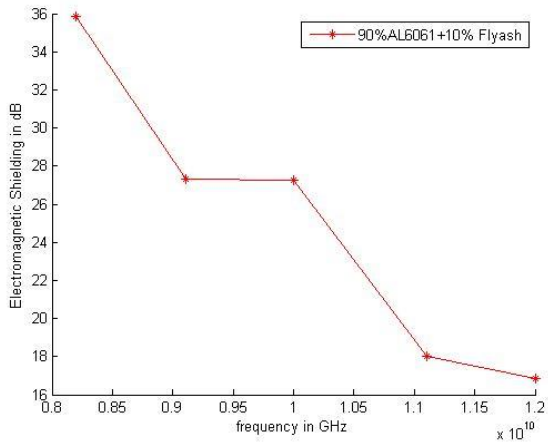


Figure 5 - Shielding Effectiveness for 1mm thickness with 85% AL6061 and 15% fly ash with 1mm thickness

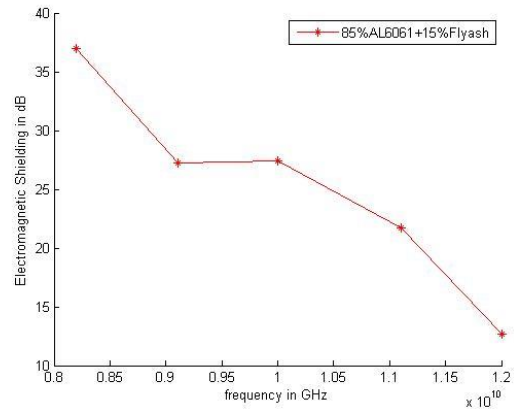


Figure 6 - Comparison of different percentages of fly ash reinforcement with AL6061 with 1mm thickness.

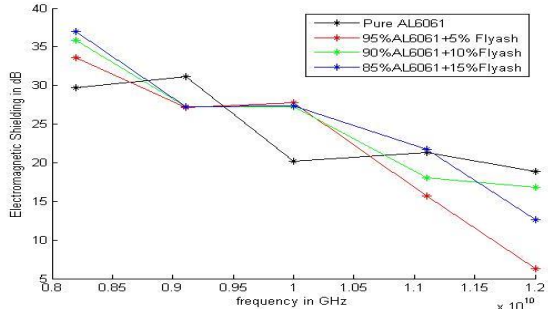


Figure 7 - Shielding Effectiveness for 2mm Thickne with Pure AL6061

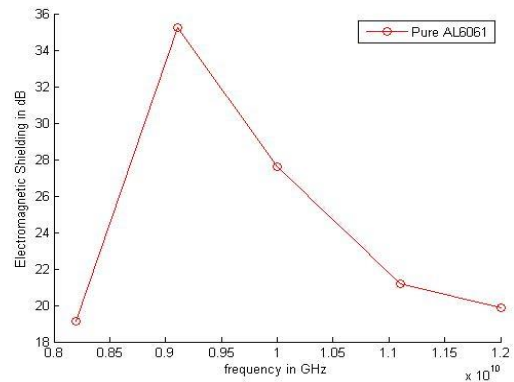


Figure 8 - Shielding Effectiveness for 2mm Thickness with 95% AL6061 and 5% fly ash.

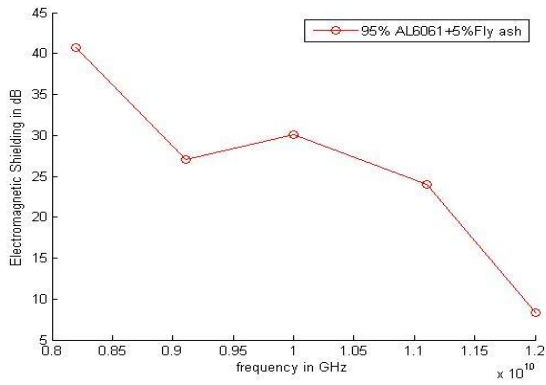


Figure 9 - Shielding Effectiveness for 2mm Thickness with 90% AL6061 and 10% fly ash.

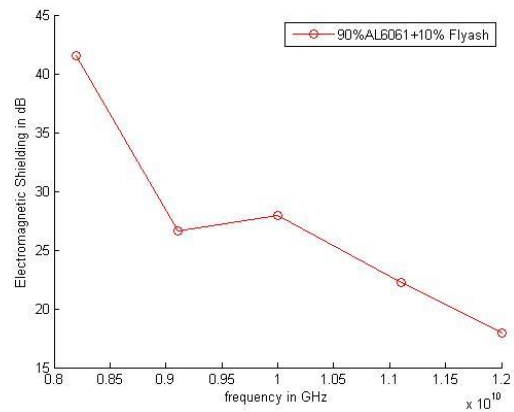


Figure 10 - Shielding Effectiveness for 2mm Thickness with 85% AL6061 and 15% fly ash with ss.

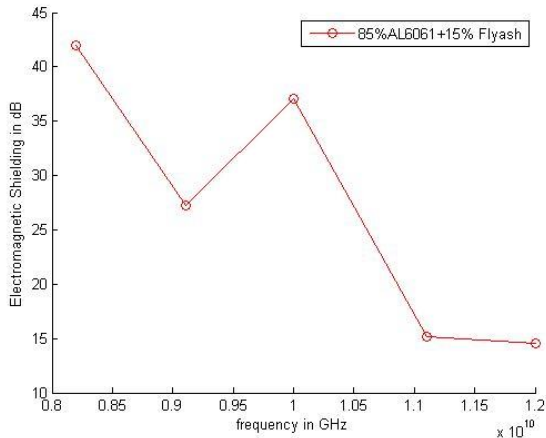


Figure 11 - Comparison of different percentages of fly ash reinforcement with AL6061 with 2mm Thickness

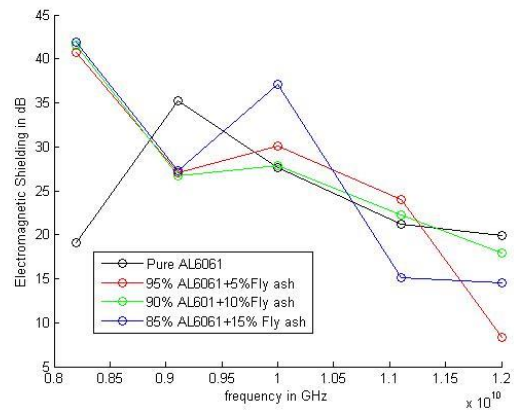


Figure 12 - Comparison of pure AL6061 with different thickness

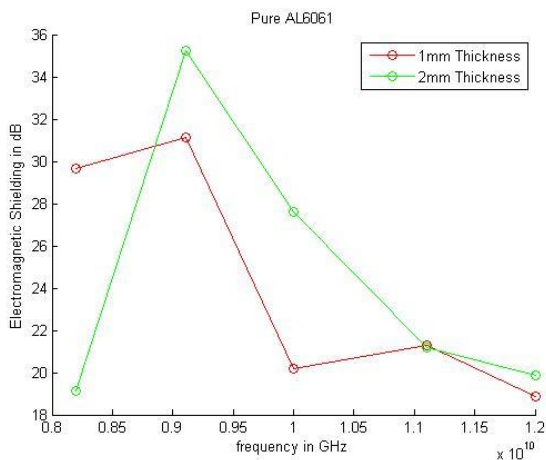


Figure 13 - Comparison of 95% AL6061 and 5% fly ash with different thickness

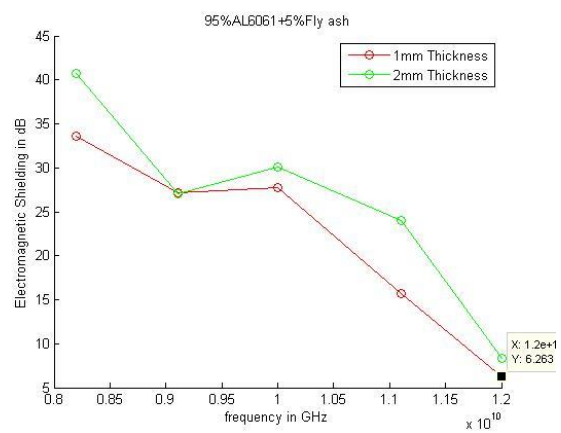


Figure 14 - Comparison of 90%AL6061and 10% fly ash with different Thickness

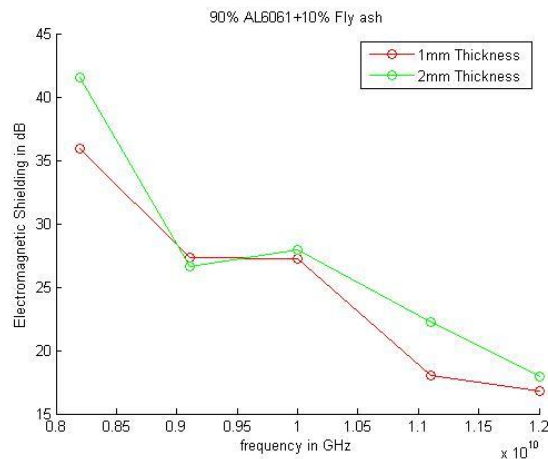
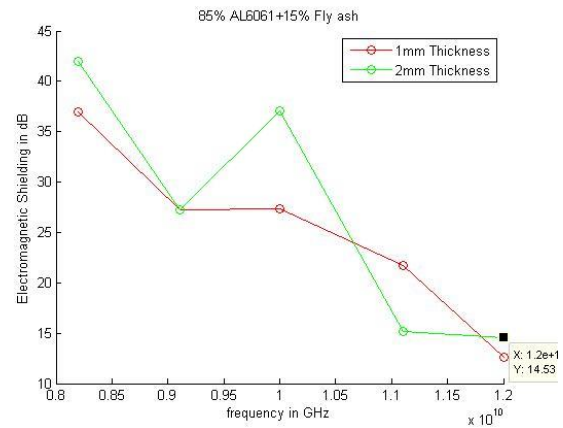


Figure 15 - Comparison of 85%AL6061and 15% fly ash with different Thickness



According to these values, the shielding effectiveness has grown as the fly ash content has increased. Figure 6 illustrates the combination of different rates of fly ash for 1mm thickness. Figure 7 illustrates the entire SE for pure AL6061 with 2mm thickness, and the shielding effectiveness for pure AL6061 with the greatest and least shielding effectiveness is 35.25 dB and 19.86dB, respectively. Figure 8, 9 and 10 illustrates the SE for AL6061 reinforced with 5% fly ash, 10% fly ash and 15% fly ash with 2mm thickness have the highest and lowest shielding effectiveness in the ranges of 40.72dB - 8.3dB, 41.49dB - 17.13dB, and 41.94dB - 14.53dB, respectively. Figure 11 illustrates the combination of different rates of fly ash for 2mm. Because fly ash provides the best micro-absorbing properties, the SE value gets improved. Fly ash containing the iron oxides for that purposes the SE value is enchanting with increasing with the percentage of fly ash volume. Table 2 shows the maximum shielding of all varieties. In the present work, shielding effectiveness for 1mm thickness has improved up to 37 dB with AL6061 composite reinforced with fly ash, and for 2mm thickness, it improves up to 41.94 dB. The comparison plots for 1mm and 2mm Thickness for different percentages of reinforcement are illustrated in Figures 12 to 15.

Table 2 - Maximum shielding effectiveness at X-band

Component name	Maximum Shielding Effectiveness (dB) ($r_w = 1mm$ & $a_s = 1mm$)	Maximum Shielding Effectiveness (dB) ($r_w = 2mm$ & $a_s = 2mm$)
Pure AL6061	31.13	35.25
AL6061_95% + fly ash 5%	34.89	40.72
AL6061_90%+ fly ash 10%	35.88	41.49
AL6061_85%+ fly ash 15%	37	41.94

7. Conclusion

Composite materials have been employed in aerospace applications to mitigate the lightning strike effect. Manufacturers in the aircraft sector seek composite materials with robust mechanical qualities, high shielding, and low weight. The shielding efficacy of AL6061 composite material augmented with fly ash particles at various percentages was evaluated in this work. According to the study, combining fly ash with composite materials increases SE while utilising less weight than pure AL6061. Pure AL6061 had maximum shielding effectiveness of 31.3 dB. The results for an AL6061 composite reinforced with fly ash at varying percentages of 5%, 10%, and 15% with 1mm thickness are 34.89dB, 35.88dB, and 37dB. The maximum SE results for a pure AL6061 and AL6061 composite reinforced with fly ash at varying percentages of 5%, 10%, and 15% with 2mm thickness are 35.25dB, 40.72dB, 41.49, and 41.94dB.

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