Analysis of Electromagnetic Reflection Loss for Mesh Structure with Al6061 MMC for Aerospace Applications

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Abstract. One of the major problems facing by the aircraft was a lightning strike. To overcome this problem, fiber-reinforced materials have been used. The fiber-reinforced materials have less conductivity. These fiber-reinforced materials can't eliminate the lightning strike effect. For that purpose, the metal matrix composite materials significantly impacted the aircraft's internal circuits and physical components from the lightning strike effect. To meet industries dynamic and ever-increasing demands, Al6061 metal matrix composite reinforced with fly ash must be utilized to build the aircraft to offer HIRF. The material thickness should be kept low as possible then it can be used to cover the plane's surface. To prevent lightning strikes, it might be used to protect electronic components from a concentrated high-intensity radiated field, primarily in Aeroplan configuration. The electromagnetic characteristics of composites are measured using the X-band for normal incidence. The electromagnetic reflection properties of AL6061 reinforced with fly ash are studied in this study for mesh structure. Matlab Software was used to calculate the maximum reflection loss of 33.88dB for 15% fly ash and 85 percent AL6061 at X-band.

Keywords. High intensity radiated fields (HIRF), AL6061, Reflection, Fly ash, lightning strike, and Fiber-reinforced plastic composites (FRPs)

1. Introduction

The lightning strike is one of the significant problems facing aerospace. Commercial flight gets hit by the lightning strike once every year. These lightning strike effects diminished the internal electronic components. Because the airplane skin is frequently composed of aluminum, an electrically conductive substance, the actual harm caused by a lightning strike is commonly limited to consuming lines on the skin and the following edges. During a lightning strike, the airplane's metallic exterior acts as a Faraday cage, protecting the aircraft from electromagnetic interference (EMI) [1][2]

Generally, with the presentation of composite materials in flight progressions, safeguarding airplanes from lightning strikes has turned into a genuine errand, as FRPs are less conductive than their metallic partners [3][4]. A couple of headways in lightning strike protection (LSP) for composite designs have been utilized in flight. The vital capacity of LSP is to give a constant conductive channel all through the plane's outside, especially in regions more helpless against lightning strikes, like the nose, wingtips, nacelles, radomes, and empennage limits. LSP is regularly developed of a lightweight metallic cross-area or foil made for most aluminum or copper, with traces of phosphor bronze and titanium remembered for the external overlay utilized that associates the outer surface to a metallic ground plane engine [5][6].

Another major problem facing by aerospace application was consumption of fuel to overcome these issues less weight materials has been used. The weight of the materials can be reduced by using mesh structure [7] [8]. Nevertheless, the imperfection of FRPs is its low electrical conductivity but having good mechanical properties, which keeps the electric field from going through it when lightning strikes the plane, achieving delamination and embrittlement [9] [10].

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There is a lot of promise in aluminum composite complexes, and their fundamental characteristics may be enhanced by using other materials for reinforcing. Metals such as titanium, nickel, magnesium, copper, and aluminum have been utilized to create metal matrix composites [11]. However, aluminum is most commonly used due to its lightweight, strength, electrical, and reflective characteristics [12] [13] [14]. These Aluminum Metal Matrix Composite materials have the best mechanical properties [15]. Different physical models of lightning strike prevention exist based on their electrical characteristics. AL6061 was presented as an alternative to FRPs because it had suitable qualities such as low density, corrosion resistance, high strength, and good electrical properties [16].

Lightweight materials are commonly requested in the realm of electromagnetic protection. As a result, in actual designing applications, the thickness of the chosen materials should be kept as low as feasible under the constant protecting structure [17]. Because there are so many accidental E.M. waves that are fancifully coordinated, measuring the safeguarding productivity for the ordinary occurrence of E.M. waves on the cross-section sheet may apply to every single feasible application. The investigation is based on the transmission line model (T.L) shown in regular frequency [18]. Being lightweight is an essential inventive requirement for practical EMI protecting applications, especially in planes, cars, and family gadgets. Foamed composites with cell designs are great for the creation of lightweight EMI protecting materials [19]. The reinforced material is fly ash, which improves the electrical properties of AL6061 metal matrix composites [20]. Electromagnetic waves travel through fly ash; it enhances the microwave absorption property because fly ash contains porous carbon grain and Fe$_2$O$_3$ [21]. Zuoyong Dou and Gaohui Wu evaluated the Electromagnetic Shielding Effectiveness (EMSE) of an aluminium composite supported by fly debris and discovered that the electromagnetic protection was between 32 and 102.5 dB. [22]. Casey, Kendall F 1988 proposed the wire mesh screen for the electromagnetics shielding for aluminium’s metal material [23]. The main aim for going to the composite materials mesh structure was less weight than the metallic mesh [24].

This paper is classified into six sections; section 1 explains the introduction, section 2 describes the composite material preparation, section3 explains electrical parameters, section 4 presents the Electromagnetic Reflection calculations, section5 explains the results of reflection loss for the composite material, and section 6 conclusion.

2. Composite Material Preparation

The underlying method used for preparing materials was stir casting. The primary purpose of selecting stir casting was affordable to utilize. This strategy changes the composites into a fluid state at a temperature for every component [25]. The AL6061 melted at the 700°C and fly ash reinforced with AL6061 at the 700°C and required structure can be implemented with molt.

3. Electrical Parameters

The electrical parameters that were considered for calculating the materials' shielding effectiveness were permittivity, permeability, and conductivity of the materials. The vector network analysis (VNA) can estimate these parameters. To calculate the required parameters for calculating the reflection loss of the materials, U.C. Hasar 2009 designed a two-port network analyzer [26]. These characteristics may be calculated by inserting the material with the necessary dimensions within the rectangular waveguide, the electrical parameters with AL6061, and the combination of different percentages of fly ash.

4. Electromagnetic Reflection Loss Calculation

The mesh wire's shielding effectiveness depends on the parameters of the three electrical properties and the materials' thickness. The fundamental cross-section structure is displayed in figure1. At the point when an electromagnetic wave goes through a shielding material, it is weakened by one of three systems: (1) Reflection Loss (RL), (2) Absorption Loss (AL), and (3) Multiple reflection Loss (ML) are three
kinds of misfortunes. The complete EMI SE of safeguarding material might be communicated utilizing the formulae underneath. The going with the condition can infer the particular Reflection Loss characteristics. [17][23][27].

The reflection loss is denoted by.

\[ R_{dB} = 20 \log \left( \frac{Z_0 + Z_S}{4, Z_0 * Z_S} \right) \]  \hspace{1cm} (1)

Here free space is represented as \( Z_0 \) and sheet impedances represents as \( Z_S \).

\[ Z_S = Z_w * a_s + j\omega l_s \]  \hspace{1cm} (2)

\[ l_s = \frac{\mu_0 a_s}{2\pi} \ln \left( 1 - e^{-\frac{2\pi r_w}{a_s}} \right)^{-1} \]  \hspace{1cm} (3)

The radius of the wire mesh is represented as \( r_w \) and \( a_s \) is the mesh size. The internal impedance per unit length as \( Z_w \).

\[ Z_w = R'_w \frac{\sqrt{j\omega \tau_w} \cdot I_0(\sqrt{j\omega \tau_w})}{2I_1\sqrt{j\omega \tau_w}} \]  \hspace{1cm} (4)

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

\[ R'_w = \left( \frac{\pi r_w^2 \sigma_w}{\mu_w} \right)^{-1} \]  \hspace{1cm} (5)

\[ \tau_w = \frac{\mu_w \sigma_w r_w^2}{\mu_w} \]  \hspace{1cm} (6)

The permeability and conductivity of the material employed in the mesh structure are represented by \( \mu_w \) and \( \sigma_w \).

5. Results

The reflection loss of the X-band frequency is calculated. Figure 3 shows the variation in reflection loss for pure AL6061, which ranges from 27.04dB to 10.97dB. Figure 4 illustrates the reflection loss for 5% fly ash and 95% AL6061, ranging from 28.57 dB to 2.93 dB.

Table 1: Comparison of Maximum Reflection loss at X-band frequency for the combination of Al6061 with different percentages of fly ash.

| S.no | Component name                  | Maximum Reflection loss (dB) |
|------|---------------------------------|------------------------------|
| 1    | Pure AL6061                     | 27.04                        |
| 2    | 95%_AL6061 +5%_Fly ash          | 27.42                        |
| 3    | 90%_AL6061+10%_Fly ash          | 33.78                        |
| 4    | 85%_AL6061+15%_Fly ash          | 33.88                        |
Figure 1: Representation of mesh sheet.

Figure 5 shows that the reflection loss for a combination of 10% fly ash and 90% AL6061 ranged from 33.88 dB to 7.134 dB. Figure 6 illustrates the reflection loss for a variety of 15% fly ash and 85% AL6061, which ranged between 33.78 dB and 13.57 dB. As the fly ash reinforcement increases, the reflection loss increases. It is evident from the outcomes that reflection loss decreases as the frequency increases. Figure 7 shows the different combinations of AL6061 with fly ash are compared, and the maximum reflection loss is tabulated in Table 1.

Figure 2: Electromagnetic signal represented with reflection and transmission for normal incidences.
Figure 3: Reflection loss composite material for Pure AL6061.

Figure 4: Reflection loss of composite materials 5% of Fly ash and 95% of AL6061.

Figure 5: Reflection loss of composite materials 10% of Fly ash and 90 of AL6061.
6. Conclusion

The aircraft industry today produces composite materials to defend against high intensity radiated fields. These composites have reduced weight and the best reduction of reflection. The AL6061 metal composite material supports fly ash at different rates in this present work (5 percent, 10 percent, 15 percent). The particular numbers represent the loss of reflectivity for a certain fly ash level. As the fly ash is introduced to the AL6061, reflection loss grows. Pure AL6061 reflects 27.04dB when 5% of fly ash is supported, 33.77dB 10%, 33.88dB is supported, 15%. The composite materials can be used to protect against radiation fields of high intensity.
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