Electromagnetic shielding effectiveness for Al6061 metal matrix composite based mesh wire reinforced with Flyash for oblique incidence of EM wave

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Abstract. Nowadays, flywire is used exclusively in aeronautical applications. A plane's complete control is dependent on electronic technology, yet it suffers from high-intensity radiated fields. An electromagnetic shield may be necessary to protect this equipment from external electromagnetic pollution. The current project attempts to create a protective barrier around the operating equipment to enhance its efficiency. AL6061 composite material was used to create a metal matrix mesh shield. It is reinforced with fly ash in various volume fractions, and the electrical characteristics and Shielding Effectiveness are determined (SE). The maximum SE is 45.36dB obtained, which can be effectively used as a shield for aerospace and other applications.

Keywords. Shielding effectiveness, Reflection loss, reinforcement, Flyash, oblique incidence.

1. Introduction

With the promotion of electronic communication equipment in contemporary society, the subsequent electromagnetic (EM) radiation has become genuine contamination that can't be overlooked. Thusly, it is of extraordinary importance to foster electromagnetic interference (EMI) shielding materials. Lightweight and productive electromagnetic interference (EMI) shielding composites are of incredible significance for improving cutting-edge correspondence innovation, wearable gear, and high-power electronic hardware. The impact of high-intensity radiated fields on aerospace applications and wind power generating units is growing. Every commercial flight experiences a lightning strike effect once every 1000 hours [1]. Lightning contact generates electromagnetic interference, which disrupts the normal operation of electrical devices. This also harms the airplane's physical structure [2][3]. Massive currents created by a lightning strike on the plane's surface induce delamination, embrittlement, and structural collapse [4]. Adding lightning strike protection (LSP) is a critical job for protecting aircraft from electrical and physical harm.

When lightning strikes the plane's surface, the resulting currents attempt to travel along the least resistive regions of the surface [5]. To save weight, metal was often transformed into fiber-reinforced materials (FRP) to create the aircraft surface. In most cases, metal was converted into fiber-reinforced materials (FRP) to construct the aeroplane surface in order to reduce weight. Unfortunately, FRP lacks the conductivity required to efficiently flow the enormous currents produced by a lightning strike, resulting in electromagnetic interference and physical damage [6]. To address the poor conductivity issue in FRP composite materials, a new material was created. Electrical and mechanical characteristics of composite materials are adequate. The composites have high conductivity, which may be enhanced by strengthening them with various materials [7]. The Al6061 metal matrix material was used as a composite material in this study, and the shielding characteristics can be enhanced by strengthening the
flyash [8][9]. The electromagnetic wave's incidence is assumed oblique rather than normal, with obliques incidence approximation extremely close to the real scenario [10]. The addition of the mesh structure reduces the total weight, which reduces the operation's fuel usage [11]. The Al6061 metal matrix is employed as a composite material in this study, and it is reinforced with fly ash to increase both shielding efficacy and density.

The total work is organized as section 1 selection of material, section 2 preparation of the material, section 3 shielding mechanism, section 4 results analysis, section 5 conclusion.

2. Selection of material:

Because of their improved strength, hardness, and weight ratio, as well as their superior wear resistance, Al6061-based hybrid metal matrix composites outperform traditional aluminium alloys [12][13][14]. Because the Fe₂O₃ in the fly ash is linked to improving electromagnetic shielding effectiveness, it is included as a mandatory reinforcing material in the preparation of all specimens of the proposed material. The fly ash (Siliceous fly ash) used in this study was obtained from a thermal power plant in Visakhapatnam, and its density and specific surface area were 2.1 g/cm³ and 3449 cm²/g, respectively [15][16].

3. Preparation of the material:

The stir casting procedure was used to create the three separate sets of Composites with variable reinforcing materials since it is a cost-effective way for creating particle reinforced composites. A stir casting system comprises of a furnace, a feeder for reinforcing ingredients, and a stirrer. A stirring rod and blades are included with the stirrer. One kilogramme of Al6061 alloy is placed in a ceramic crucible and heated to 720°C in a resistance-heated muffle furnace. In the furnace, the Al 6061 alloy is heated to a molten condition before being mixed with warmed fly ash particles [17][18]. The experiment conducted for stir casting of flyash with Al6061 and shown in figure 1.

![Stir casting equipment for reinforcement of flyash with Al6061.](image)

After the composite material has been prepared, it may be examined for electrical properties, and the values of Permeability, Permittivity, and Conductivity (µ, ε, σ) can be acquired using a vector network analyzer. Shielding may be quantified using these electrical characteristics.

4. Shielding mechanism:

The major EMI shielding techniques are reflection and absorption. Shielding material should have a reasonably high electrical conductivity in order to achieve considerable electromagnetic radiation reflection. Metals are the most often used materials for EMI shielding, and their primary function is reflection owing to free electrons in them. Absorption is the secondary process of EMI shielding [19]. When electromagnetic waves strike the surface of a protective
emagnetic shield, the shield's capacity to reflect the waves without crossing the sheet offers superior EM shielding for external electromagnetic fields.

The mesh wire's shielding efficiency is determined by reflection, absorption loss, and internal multiple reflections. However, if it is low, numerous reflections cannot be considered. The loss due to reflection and absorption is determined by the material characteristics [20][21].

\[
SE_{dB} = (\text{Absorption loss})_{AB} + (\text{Reflection loss})_{AB} + (\text{Multiple reflection loss})_{AB} \tag{1}
\]

We are calculating the SE for the wire mesh in the oblique case. Let us consider the rectangular mesh with size \(a_s\). For our convenience, we are estimating the wires are skinny. The radius of the mesh is taken as \(r_w\). The mesh structure is shown in figure 3.

The sheet inductances of the mesh are represented as \(L_s\) [22][23].

\[
L_s = \mu_0 a_s \ln \left(1 - e^{-\frac{2\pi r_w}{a_s}}\right)^{-1} \tag{2}
\]

The internal impedance of the wire is represented as \(z'_w\)

\[
z'_w = r'_w \left(\sqrt{j\omega \tau_w}\right) \cdot I_0 \left(\sqrt{j\omega \tau_w}\right) \tag{3}
\]

From equation 3 we are considering the resistance per unit length is \(r'_w\) and \(\tau_w\) is considered as the time constant. \(I_n(.)\) Represent the first kind of the Bessel function.

\[
r'_w = (\pi \tau_w^2 \sigma_w)^{-1} \tag{4}
\]

\[
\tau_w = \mu_w \sigma_w r_w^2 \tag{5}
\]

The sheet impedances are represented as \(z_{s1}\) and \(z_{s2}\)

\[
z_{s1} = z'_w a_s + j \omega L_s \tag{6}
\]

\[
z_{s2} = z_s - j \omega L_s - \frac{\omega L_s}{2} \sin^2 \theta \tag{7}
\]

The reflection\((R)\) and transmission\((T)\) are given as per the angle of incidences\((\theta)\) as given below. The sheet impedance of perpendicularly polarized plane waves is \(z_s = z_{s1}\) and similarly the sheet impedance of parallel-polarized plane waves is \(z_{s2}\)

\[
R_1 = -\frac{1}{1+2(z_{s1}/z_0) \cos \theta} \tag{8}
\]

\[
T_1 = \frac{2(z_{s1}/z_0) \cos \theta}{1 + 2(z_{s1}/z_0) \cos \theta} \tag{9}
\]

\[
R_2 = \frac{\cos \theta}{1+2(z_{s2}/z_0) \cos \theta} \tag{10}
\]

\[
T_2 = \frac{2(z_{s2}/z_0) \cos \theta}{1+2(z_{s2}/z_0) \cos \theta} \tag{11}
\]

Equation 9 represents the TE polarization, and equation 11 represents the TM polarization. From these two equations, the shielding effectiveness is determined as given below

\[
SE = -10 \log_{10} \left(\frac{1}{2} T_1^2 + \frac{1}{2} T_2^2\right) \tag{12}
\]
Figure 2: Composite mesh representation with the rectangular mesh with size $a_s$ and the radius of the mesh is taken as $r_w$.

Figure 3: Oblique incidence of EM wave on Mesh sheet.

5. Results and Analysis:
Shielding effectiveness of Al6061 reinforced with flyash at different percentages executed and corresponding results shown from figure 4 to 7. Comparison has made between all the combinations of the composite materials and shown in figure 8.
Figure 4: SE of Pure Al6061 w.r.t angle of incidence.

Figure 5: SE of Al6061 reinforced with 5% of fly w.r.t angle of incidence.

Figure 6: SE of Al6061 reinforced with 10% of fly w.r.t angle of incidence.
Table 1: Maximum SE of Al6061 with different volume fractions of flyash.

| S.no | Material                  | Maximum Shielding Effectiveness (dB) |
|------|---------------------------|-------------------------------------|
| 1    | Pure AL6061               | 21.35                               |
| 2    | (95%) AL6061+ (5%) Fly ash| 30.17                               |
| 3    | (90%) AL6061+ (10%) Fly ash| 31.89                               |
| 4    | (85%) AL6061+ (15%) Fly ash| 45.36                               |

Table 1 represents the total SE of all composites reinforced with fly ash at different volumes fractions. The shielding effectiveness of the composite mesh calculated at different volume fraction of flyash. Analysis was done for oblique incidence of the electromagnetic wave to approximate practical case. For pure Al6061 the shielding effectiveness of 21.35dB was obtained. For Al6061 with a volume fraction of 95% and 5% of fly ash gives SE of 30.17dB obtained. Whereas for Al6061 with a volume fraction of
90% and 10% of fly ash gives SE of 31.89 dB obtained. Finally, Al6061 with a volume fraction of 85% and 15% fly ash gives SE of 45.36 dB.

6. Conclusion: The primary goal of switching from metallic sheet to mesh is to minimize weight. The current study created the electromagnetic protective layer using a mesh structure, and a good shield was achieved. The composite material Al6061 was utilised as the base material and fly ash was supplemented with to enhance the SE. The highest shielding effectiveness of 45.36 dB is recognized and can be employed in lightning protection systems.

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