Study of surface metallization on the electromagnetic shielding performance of carbon fiber reinforced composite

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Abstract. In order to improve the electromagnetic shielding performance of CFRP structures, a series of CFRP samples were surface metallized with combined chemical then electrochemical plating, coating conducting paints and metal spraying of aluminium, respectively. The shielding performances with different surface metallization methods were compared, and the investigation of thickness of metallization layer and the composites was carried out, which showed that the increase in thickness of metallization layers and the composites contributed to the increase of shielding performance. As a result, we have found a superior improvement on shielding performance with surface metallized in nickel plating comparing with metal spraying, which could substitute the commonly used method of metal spraying with aluminium.

1. Introduction
Carbon fiber reinforced composites (CFRPs) have been widely used in the fields such as aeronautics and astronautics, due to their excellent mechanical property, relatively low density and limited thermal expansivity. The application of CFRPs as an advancing solution in lightweight structures shows preferable performances on structure stability and weight control, comparing with that of aluminum alloys as a conventional solution. However, the poor conductivity of CFRPs generates limited electromagnetic shielding performance and penetration of interfering electromagnetic waves external through the structures, which results in electromagnetic interference risks to the electronic equipments inside. In order to develop the application of CFRPs in the structures of electronic equipment, the improvements on electromagnetic shielding performance have attracted more and more attention [1].

To improve the electromagnetic shielding performance, the investigations mainly focus on the methods such as surface modifying of carbon fibers with metals before forming processes, adding then dispersing the metal powders or nets during forming processes and surface metallizing of the CFRP structures after forming processes [2]. Benefiting from the versatility and applicability, the surface metallizations have been developed in a large number of varieties, which improve the electromagnetic shielding performance by modifying the outmost layer on surface without serious restrictions to the material of composite and forming processes. The frequently used surface metallizations include: 1) combined chemical then electrochemical plating; 2) coating conducting paints; 3) vacuum evaporation and deposition; 4) metal spraying and so on [3, 4].

In our study, a series of CFRP samples were surface metallized with combined chemical then electrochemical plating, coating conducting paints and metal spraying of aluminium, respectively, in order to improve the electromagnetic shielding performance of CFRP structures. The shielding performances with different surface metallization methods were compared, and the investigation of thickness of metallization layer and the composites was carried out, which showed that the increase in thickness of metallization layers and the composites contributed to the increase of shielding
performance. As a result, we have found a superior improvement on shielding performance with surface metalized in nickel plating comparing with metal spraying, which could substitute the commonly used method of metal spraying with aluminium.

2. Experiments

2.1. Samples
Referring to Chinese standard of GJB 5240-2004, the CFRP samples were prepared with MTM28+T700 prepreg (thickness of 0.2 mm per single layer) by hot-press approach then machining the shape into 452 mm × 302 mm × 1–2 mm plates.

According to Schelkunoff’s shielding theory schematized in Figure 1 [5], the shielding effectiveness \( SE \) was contributed with the attenuation of absorption \( A \), reflection \( R \) and multi-reflection inside the materials \( B \) as shown in equation 1~4 [6].

\[
SE = A + R + B
\]

\[
A = 1.314 \cdot t \sqrt{f \mu / \sigma_r}
\]

\[
R = 168 - 10 \cdot \log(f \mu / \sigma_r)
\]

\[
B = 20 \cdot \log(1 - e^{\delta f / t})
\]

where \( \mu_r \) and \( \sigma_r \) represented the relative magnetic and electrical conductivity to copper, respectively, \( f \) was the frequency of the electromagnetic wave, \( t \) equaled to the thickness of sample, \( \delta \) stood for the skin depth which illustrated in equation 5,

\[
\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}
\]

in which \( \mu \) and \( \sigma \) represented the magnetic and electrical conductivity, respectively.

| No. | Surface metallization | Specific type of metallization layer | Thickness of composite/mm | Thickness of metallization layer/μm |
|-----|-----------------------|------------------------------------|---------------------------|-----------------------------------|
| 0   | Blank (the sample was prepared with aluminium for control experiment) | Nickel                              | 1                         | --                                |
| 1   |                       | Copper                              | 1                         | 5                                 |
| 2   |                       | Nickel                              | 1                         | 5                                 |
| 3   | Combined chemical then electrochemical plating | Copper                              | 2                         | 5                                 |
| 4   |                       | Nickel                              | 2                         | 20                                |
| 5   |                       | Copper                              | 2                         | 20                                |
| 6   | Coating conducting paints | Conducting paint                    | 1                         | 40                                |
| 7   |                       | Conducting paint                    | 2                         | 40                                |
| 8   | Metal spraying        | Aluminium                           | 1                         | 40                                |
| 9   |                       | Aluminium                           | 2                         | 40                                |

According to the electromagnetic shielding principle, a series of CFRP samples were designed with surface metallizations of combined chemical then electrochemical plating, coating conducting paints and metal spraying, respectively, as listed in Table 1. To investigate the thickness of composite on the shielding performance, the samples with composite thickness at 1 mm and 2 mm were prepared. The samples were prepared with conventional process of forming, machining and surface metallization, of which basic performances were characterized well in another research.
2.2. The measurement of electromagnetic shielding effectiveness

The electromagnetic shielding effectiveness of the samples was measured with the frequency range from 10 kHz to 18 GHz, referring to Chinese standard of GJB 5240-2004 for more detailed information. The frequency ranges were defined as low-frequency stage from 10 kHz to 30 MHz, mid-frequency stage from 30 MHz to 1 GHz and high-frequency stage from 1 GHz to 18 GHz. The SE was determined with equation 6 or 7,

\[ SE = P_2 - P_1 \]  \hspace{1cm} (6)  

\[ SE = U_2 - U_1 \]  \hspace{1cm} (7)

where \( P_1 \) and \( P_2 \) represented the power magnitudes of receiving antenna with and without samples covering the side window of shielded room, respectively, of which the units was dBm. And \( U_1 \) and \( U_2 \) stood for the voltage magnitudes of receiving antenna with and without samples covering the side window of shielded room, respectively, of which the units was dBμV.

3. Results and discussion

3.1. The results of shielding effectiveness

The shielding effectiveness of samples with different surface metallization was shown in Figure 2.
3.2. The discussion of shielding effectiveness with preparation

3.2.1. The analysis of shielding effectiveness with type of metallization. The shielding effectiveness of samples with specific types of metallization layer was shown in Figure 3. According to Schelkunoff’s shielding theory and equations, the shielding effectiveness depended on the magnetic conductivity, electrical conductivity and thickness of the materials at a fixed frequency. As shown in Figure 3, the shielding effectiveness improved with the increase in frequency of electromagnetic wave, which corresponded well to Schelkunoff’s shielding theory [5]. Comparing the specific types of metallization layer, the shielding effectiveness of samples with them was sorted from high to low as nickel plating, copper plating, conducting paint and metal spraying of aluminium. The sample metalized with nickel plating displayed almost equal shielding effectiveness to the aluminium sample, which showed an excellent performance especially in low-frequency stage. The surface metallization with nickel plating showed a superior improvement on shielding performance comparing with metal spraying, which could substitute the commonly used method of metal spraying of aluminum.

![Figure 3. The shielding effectiveness of samples with specific type of metallization layer.](image)

As shown in Figure 4, the sample with nickel plating showed better shielding effectiveness than that with copper plating at the same thickness of plating, which resulted from the better performance of nickel plating in both magnetic and electrical conductivity than copper plating.

![Figure 4. The shielding effectiveness of samples with nickel plating and copper plating.](image)

3.2.2. The analysis of shielding effectiveness with thickness of metallization and composite. As shown in Figure 5, the shielding effectiveness improved with the increase in thickness of nickel plating, which could be explained with Schelkunoff’s shielding theory [6].
Figure 5. The shielding effectiveness of samples with thickness of nickel plating.

The shielding effectiveness of samples with different thickness of composite and same thickness and type of metallization layer was shown in Figure 6. With the increase in thickness of composite, the shielding effectiveness improved, and other samples with copper plating, conductive paint and metal spraying showed similar tendency as shown in Figure 2. Referring to equation 2 and 4, this phenomenon was explained well that attenuation of absorption and multi-reflection inside composite was strengthened with the increase in thickness of composite [6]. However, the magnetic and electrical conductivity of CFRP was too limited to make significantly improvement on shielding effectiveness by only increase the thickness of CFRP.

Figure 6. The shielding effectiveness of metal spraying samples with thickness of composite.

4. Conclusions
In our study, a series of CFRP samples were surface metallized with combined chemical then electrochemical plating, coating conductive paints and metal spraying of aluminium, respectively. The shielding performances with different surface metallization methods were compared, and the investigation of thickness of metallization layer and the composites was carried out. Then we got conclusions as following:

1) Comparing the specific types of metallization layer, the shielding effectiveness of samples with them was sorted from high to low as nickel plating, copper plating, conductive paint and metal spraying of aluminium.

2) The shielding effectiveness improved with the increase in thickness of metallization layer or composite, which corresponded well to Schelkunoff’s electromagnetic shielding theory
3) The surface metallization with nickel plating showed a superior improvement on shielding performance comparing with metal spraying, especially in low-frequency stage, which could substitute the commonly used method of metal spraying of aluminium.

References
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