Multiwall Carbon Nanotube Surface Coatings to Increase Electromagnetic Interference Shielding in Composite Structures

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Introduction

Fiber reinforced polymer (FRP) composite materials are finding increasing application in Army systems due to high specific strength, corrosion properties and insensitive munitions performance. As traditional metal components are replaced with FRPs, properties such as electrical and thermal conductivity that are inherent to metals are sacrificed. This research explores solutions for improving the electrical conductivity of FRPs specifically for missile launch tube applications using nano-material surface coatings. The main areas of concern are electromagnetic interference (EMI) shielding and surface resistivity reduction for electrical continuity requirements.

Shielding Theory

Shielding effectiveness (SE) is provided by a material through three different mechanisms: reflection at the air/material boundary, absorption, and multiple internal reflections. The SE from multiple reflections is usually negligible compared to the other two and thus ignored for this discussion. Reflection, given by the following equation, is a function of frequency,, conductivity, , and permeability, , and is dominant in the lower frequency ranges. The absorption component is a function of skin depth (δ) and thickness (*t*) and is dominant for all thicknesses greater than the skin depth. Adding $(SE)_R$ and $(SE)_A$ will provide the total shielding effectiveness for metal materials, i.e., materials with high surface conductivity.

Experimentation

Epikote™ Resin 862 with Curing Agent W is the epoxy system used for the carbon fiber/epoxy test samples in this study. IM7 carbon fibers were used as the reinforcement for the test panels. The baseline structure of the test panels consists of 8 plies 0/90 degree orientations creating a balanced and symmetric lay-up. Several trials were conducted in the early phases of this study to determine if ply thickness and/or ply orientations would affect the EMI shielding effectiveness. It was determined that within the specified range of 1/32”-1/8” the standard deviation between the minimum values for each thickness was +/-1.7 dB and the standard deviation between the maximum values for each thickness was +/-1.5 dB; therefore implying that there is no significant differences between the levels of shielding for the various thicknesses.

A variety of MWCNT materials were chosen for use in this study, criteria for selection included: short or no post processing requirements, low density, and controlled and continuous manufacturing capabilities. Two versions of randomly aligned MWCNT mats, one pre-impregnated with the chosen epoxy and one without, and a spray able solution of MWCNT and solvent were used to coat the surface of the baseline panels in this study. The table below shows the major criteria used for selection in comparison with a commonly used non-nano EMI shielding solution.

Material Solution	*Processing Time*	*Density (lb/In^3)*
Nano Mat	Little to none	.0079
Buckypaper	Little to none	.0161
Spray Coat	Less than 1 hour	.0506
Choshield 610	8 hours	.0425

Table 1. Material Comparison

Test Method and Apparatus

The SE measurements presented in this paper were conducted using a flanged coaxial test apparatus specified in ASTM D4935-99. Tests were performed at the University of Kentucky-Center for Applied Energy Research.

Results

Results from this study show that the carbon-epoxy baseline panels have excellent inherent shielding effectiveness without the addition of any metal or nano-material. Results from the testing determine that electronics could safely be shielded from radio frequency without any additions to the composite laminate. While EMI shielding may be achievable with carbon-epoxy alone, this structure will still lack the required conductivity to survive other requirements such as lightning strike protection and/or electrostatic discharge.

SE of Baseline Carbon/Epoxy

Panels of varying thicknesses were tested initially to develop a standard processing requirement. Panels with thicknesses between 1mm-3mm provided at least 45 dB of shielding effectiveness across the entire frequency range, proving the inherent properties of baseline carbon epoxy panels provide efficient electromagnetic interference protection for enclosed electronics.

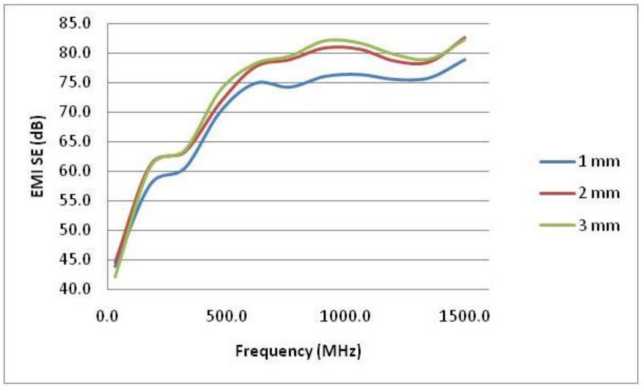

Figure 1: Baseline Thickness Comparison

SE of MWNT Surface Coatings

The addition of a surface coating is a widely used method for increasing EMI shielding effectiveness as well as increasing the conductivity of the surface. Commonly used coatings include metallic meshes and paints. Lightweight, conductive multi-walled nanotubes can also be used as a surface coating to achieve similar results as the metallic solutions. The same coatings can also be utilized for applications fabricated from insulating materials such as fiberglass, also prevalent in missile launch tubes, as the only means for meeting electrical requirements. Figure 2 displays carbon epoxy and fiberglass baseline data as well as data for the surface coatings used as the only shielding mechanism and in combination with the inherent shielding of the carbon fiber panels.

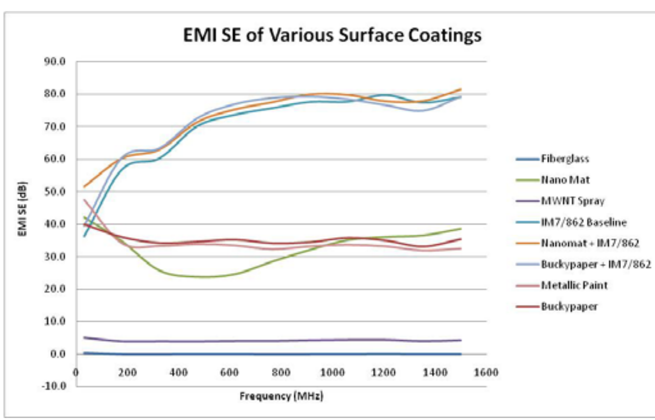

Figure 2. Baseline and Surface Coating Results

The baseline values for three of the surface coatings, metallic paint, nano mat, and prepreg buckypaper each have similar EMI shielding effectiveness. The most noticeable variation is the dip shown between 200-600 MHz for the nanomat. To explore this further we must know how each of the components of shielding is contributing for these materials. Both the nanomat and the buckypaper are comprised of MWCNTs and the metallic paint of copper. Table 2 shows the critical parameters for determining the absorption loss for SE. This is determined using the surface coating thickness from the tests and the skin depth curve for copper and pure carbon to find where skin depth is equal to the sample thickness.

Material	Thickness (mm)	Frequency where t=δ (MHz)
Metallic Paint	0.187	~1
Nanomat	.057	607
Buckypaper	.368	15

Table 2. Skin Depth v. Thickness for Surface Coatings

The metallic paint and the buckypaper are both dominated by absorption across most all frequencies, while absorption contributes little to the nanomat until approximately 600 MHz; this can be seen on the curve in Figure 2 where there is an increase in SE near 600 MHz. Between 0-600 MHz, the reflection and multiple reflection terms dominate.

The SE of the carbon epoxy panels with MWNT surface coatings is not drastically improved above the baseline panel SE value. The addition of these coatings does, however, drastically lower the surface resistivity values of the panels. The nanotube mats showed a surface conductivity that is in line with the current standard metal filled epoxy coating.

Conclusions

The carbon fiber reinforced epoxy used in many missile case applications appears to provide an adequate EMI shield. A major challenge that exists for composite structure designers is the high surface resistivity inherent with polymer reinforced composite materials. Military structures must adhere to the requirements in MIL-STD-464. All joints or bondments that require electrical continuity will need a surface coating that can satisfy the requirements. Several of the technologies explored in this work show promise for providing solutions to this design challenge. The surface coating technologies explored here will also improve EMI shielding for fiberglass and organic fiber composite structures as well as polymers without fiber reinforcement.

References

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