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Letters

Decreasing the electromagnetic observability of carbon fiber polymer–matrix composites by using epoxy-coated carbon fibers

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Abstract—The electromagnetic observability of epoxy–matrix composites containing continuous carbon fibers was decreased by using epoxy-coated carbon fibers. The attenuation of electromagnetic waves at 1.0–1.5 GHz upon reflection was increased from 1.3 to 1.7 dB, while the attenuation upon transmission was decreased from 30 to 24 dB. The effect is attributed to the decreased transverse electrical conductivity of the composite due to the epoxy coating. The epoxy coating caused the tensile strength and modulus of the composite to decrease by about 10%, while the elongation at break was not affected.

Keywords: Composite; carbon fiber; epoxy; polymer; low observability; electromagnetic.

1. INTRODUCTION

Electromagnetic observability of an object refers to the ability of the object to be observed or detected by electromagnetic waves, particularly by microwaves associated with a radar. Low observability is desirable for military aircraft and ships [1–9].

A dominant structural material for military aircraft is polymer–matrix composites containing continuous carbon fibers, as these composites are lightweight and high in tensile strength and modulus [6]. However, carbon fibers are electromagnetically reflective, and are thus undesirably high in observability. To alleviate this problem, an electromagnetically absorbing layer is attached to the carbon fiber polymer–matrix composite substrate. The absorbing layer material can be a ferrite particle epoxy–matrix composite [10], a carbonyl-iron particle polymer–matrix composite [11], a conductive polymer [12] or other related materials which absorb through the interaction of the electric and magnetic dipoles in the absorbing layer with the electromagnetic radiation [1–5]. However, the attached layer may fall off due to degradation of the bond between the layer and the substrate. Thus, it is desirable to decrease the observability of the carbon fiber polymer–matrix structural composite itself. This is the objective of this paper.

A way to decrease the observability is to decrease the reflectivity. The reflectivity is related to the electrical conductivity. Hence, a way to decrease the reflectivity is to decrease the conductivity. The conductivity of a carbon fiber polymer–matrix depends not only on that of the fibers themselves, but also depends on the electrical connectivity among the fibers. This is particularly true for the conductivity in the transverse direction (direction perpendicular to the fiber direction). In this paper, we decreased the electrical connectivity by using epoxy-coated carbon fibers, thereby attaining the goal of decreasing the observability.

2. EXPERIMENTAL METHODS

2.1. Materials

The carbon fiber used was Thornel P-25 (without sizing or twist) from Amoco Performance Products Inc., Alpharetta, GA. The diameter was 11 μm. The epoxy used was EPON Resin 862 together with EPI-CURE 3234 curing agent in the weight ratio 100 : 15.4, as provided by Shell Chemical Co., Houston, TX.

The coating of carbon fibers with epoxy was carried out by (i) washing the fibers with acetone for the purpose of surface cleaning, (ii) immersing the fibers in a resin solution (obtained by dissolving 2 g of 862 resin and 0.308 g of curing agent in 1000 ml of acetone) for 24 h in the presence of vibrations provided by an ultrasonic cleaner, and (iii) removing the fibers from the solution and drying in air at room temperature.

Unidirectional carbon fiber epoxy–matrix composites with a fiber volume fraction of 35.5% were fabricated by (i) preparing the prepreg, i.e. immersing the fibers (whether prior coated or not) in the resin with curing agent, and then immediately winding the fibers onto a mandrel, (ii) after about 30 min, cutting the prepreg into sheets, (iii) stacking eight prepreg sheets in a steel mold of size 178 × 101 mm, such that the fibers in all the layers were in the same direction, (iv) initial curing of the resin by heating from 25 to 121°C at a heating rate of 4°C/h and at a pressure of 2.0±0.2 MPa, and (v) post curing of the resin by heating at 121°C and 2.0±0.2 MPa for 2 h. Composites were fabricated using separately as-received fibers and epoxy-coated fibers.

2.2. Testing

The electromagnetic transmission/reflection was measured using the coaxial cable method. The set-up, as illustrated in Fig. 1, consisted of an Elgal (Israel) SET 19A shielding effectiveness tester, which was connected to a Hewlett-Packard (HP) 8752C network analyzer. An HP 85032B type N calibration kit was used to calibrate

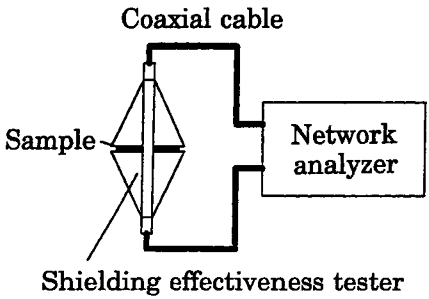

Figure 1. Set-up for electromagnetic shielding effectiveness measurement.

the system. The frequency was scanned from 1.0 to 1.5 GHz and data points were taken in reflection and also in transmission. The attenuation under transmission is equivalent to the shielding effectiveness. The specimens were in an annular form with outer diameter 97 mm and inner diameter 32 mm. The specimens were 2 mm thick.

Tensile testing of composites in the longitudinal direction was performed by using a hydraulic mechanical testing system (MTS Corp., Eden Prairie, MN) at a crosshead speed of 0.2 mm/min. The specimens were of length 162 mm in the stress direction. End tabs in the form of a fiber polymer–matrix composite sheet were applied by adhesion to the ends of each specimen in order to facilitate gripping. The specimen length excluding the end tabs was 105 mm. The strain was measured using a resistive strain gage attached by adhesion to the center of one of the largest faces of each specimen. The specimen width ranged from 8.6 to 9.8 mm for the specimen containing as-received carbon fibers and ranged from 8.2 to 10.4 mm for the specimens containing epoxy-coated carbon fibers. The specimen thickness ranged from 1.0 to 1.3 mm for the specimens containing as-received fibers and ranged from 8.2 to 10.4 mm for the specimens containing epoxy-coated fibers. Four specimens of each type were tested.

The electrical resistivity of composites in the transverse direction was measured by using the two-probe method, using silver paint in conjunction with copper wire for electrical contacts. The same results were obtained using the four-probe method. The specimen was of size about 45 × 18 × 1.6 mm for the composite with as-received fibers and about 31 × 20 × 2.0 mm for the composite with epoxy-coated fibers, such that the longest dimension is in the transverse direction. The distance between the two electrical contacts ranged from 27.2 to 34.2 mm for the composite with as-received fibers and ranged from 23.3 to 24.5 mm for the composite with epoxy-coated fibers. All dimensions were separately measured for each specimen. Four specimens of each type were tested.

Table 1.
Attenuation upon transmission, attenuation upon reflection and transverse electrical resistivity of carbon fiber epoxy-matrix composites at 1.0 – 1.5 GHz

Fiber type	Attenuation upon transmission (dB)	Attenuation upon reflection (dB)	Resistivity (Ω mm)
As-received	29.6 ± 0.9	1.3 ± 0.2	20.7 ± 2.4
Epoxy coated	23.8 ± 0.8	1.7 ± 0.2	70.9 ± 3.8

Table 2.
Tensile properties of carbon fiber epoxy–matrix composites. Standard deviations are shown in parentheses

Fiber type	Strength (MPa)	Modulus (GPa)	Elongation at break (%)
As-received	718 (11)	85.5 (3.8)	0.84 (0.03)
Epoxy coated	626 (21)	73.5 (4.4)	0.85 (0.03)

3. RESULTS AND DISCUSSION

Table 1 shows the attenuation upon transmission (same as the EMI shielding effectiveness) and that upon reflection. The attenuation upon transmission is decreased by coating the fibers with epoxy, whereas the attenuation upon reflection is increased by the epoxy coating. This means that the reflectivity is decreased by the epoxy coating, thus causing the transmissivity to increase. Table 1 also shows that the transverse resistivity is increased by coating the fibers with epoxy. The increase in resistivity is consistent with the decrease in reflectivity.

Table 2 shows that both the tensile strength and modulus are decreased by about 10% by the epoxy coating of the fibers, while the elongation at break is not affected. The decreases in strength and modulus are attributed to the presence of the interface between the matrix and the epoxy coating on the fibers in the case of the composite containing epoxy-coated fibers. This interface is absent in the composite containing as-received fibers.

4. CONCLUSION

The use of an epoxy coating on carbon fibers prior to the incorporation of the fibers in an epoxy–matrix composite resulted in less electrical connectivity between the fibers, thereby increasing the transverse electrical resistivity of the composite and decreasing the electromagnetic observability of the composite. However, the tensile strength and modulus of the composite were decreased by about 10%.

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