ELECTRICAL CHARACTERIZATION OF PRISTINE AND INTERCALATED GRAPHITE FIBER COMPOSITES

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Introduction

The high strength and low density of graphite fiber polymer composites make them attractive materials for many aerospace applications. These composites also have electrical conductivities which could be exploited for many applications such as EMI shielding and electrical ground returns. Few of these applications have come to fruition, and certainly one of the contributing problems has been the difficulty in characterizing these materials,[1] and modeling how current will flow through them. Much of the work that has been done has been with isotropic filled composites, though many of the high performance applications utilize laminar composites.

The route which a ground or fault current would travel through a laminate made up of unidirectional plies or woven fabrics has not yet been resolved. There may be an angular dependence of the resistance in such a material which would affect design parameters.[2] Perhaps electrical current could be routed in preferred directions by utilizing fibers with different resistivities.

The purpose of this study is to attempt to answer some of those questions. The resistivities of composite panels of typical spacecraft component size made up of fibers of different resistivities were measured using both eddy current and four-point techniques to determine both their magnitude and their angular dependence.

Methods and Materials

All fibers were purchased from Amoco and woven into 0°-90° fabrics by either Fabric Development (Quakertown, PA) or Mutual Industries (Philadelphia). The P-100 and P-75 fabrics were intercalated with Br_2 (Fisher) at room temperature for 72-120 hr, and the P-55 was intercalated at 0° C for a similar time. Intercalation was verified by measuring fiber resistivity. Two to four composite panels which were 28 cm square and 1 mm thick were fabricated by YLA (Benicia, CA) from RS-3 polycyanate resin (YLA) and four plies each type of fabric. Composites were also made from fabrics containing Amoco T-300 fibers in the warp direction and P-100 (either pristine or bromine intercalated) in the weave direction. Laminates were fabricated both with 0°-0°-0°-0°, and with 0°-90°-0°-90° ply orientations.

Eddy current composite resistivities were measured at four locations on each composite using a Leheighton 1010A conductivity measurement apparatus which had been factory modified to operate at 55.55 kHz. Four-point measurements were made using a Keithley 228A constant current source operating at 1.000 A and a Keithley 181 nanovoltmeter using silver paint (SPI) contacts. Current was injected at both polarities into one corner of the composite, and returned through a second contact located at 0°-90° in 15° increments relative to the weave direction. The potential was measured from a quarter ring surrounding the corner current contact to 35 grid points spaced evenly across the composite surface. Contour plots were generated using QuattroPro®.

Results and Discussion

The average composite resistivities as measured by the two different techniques are shown in Table I. The four-point values are based on the 45° data, and the PAN/P-100 data are for the 0°-90°-0°-90° composites. It is interesting to note that with pristine samples the four-point value are 4–14 percent higher than the eddy current, but the intercalated fiber composites are 6–13 percent lower. If this effect is real it is certainly puzzling.

Gaier and Yoder reported a (|sin θ| + |cos θ|) dependence of the resistivity for strips of composite with

Table I – Composite Resistivity

Fiber	ρ_{fiber} μΩ-cm	ρ_{eddy} μΩ-cm	$\rho_{4\text{-}pt}$ μΩ-cm
P-55	850	3634	4208
P-75	500	2889	3374
P-100	250	1143	1187
P-55+Br	300	2104	1859
P-75-Br	100	927	869
P-100+Br	50	353	333
PAN/P-100		2361	2201
PAN/P-100+Br		768	501

high aspect ratio (> 10), where θ is the angle of current injection with respect to the weave.[2] On the larger samples used in this study, with the current injected at a corner instead of evenly across the width, no such dependence was observed.

Two of the voltage contour maps generated using the four-point measurements for the composite made from P-55 fibers are shown in Figure 1. Voltage contour maps for all of the homogeneous composites looked similar, except that the scale differed as the fibers became more conductive. The voltage contours were what would be expected from a homogeneous solid, with a highest potential located at the anode, the lowest at the cathode, and a fanning out of the equipotential lines. A painted brass sheet of the same dimensions showed the same pattern. Thus, on a cm scale, these composites acted like homogeneous plates.

The PAN/P-100 and PAN/P-100+Br laminates that were fabricated 0°-90°-0°-90° also had the same pattern as the homogeneous plate. Those laminates with the 0°-0°-0°-0° orientation however, had voltage potential curves that were markedly different. The anisotropy is illustrated in Figure 2 where the equipotential lines run nearly parallel to the P-100 fibers. Thus, current easily flows along the P-100 fibers and then only reluctantly moves row to row along the PAN fiber direction. The implication is that current can be guided through a composite, but that laminate layer to layer communication is efficient enough that the pattern of the underlying layers must be either consistent or insulating.

An interesting phenomenon was observed in the PAN/P-100+Br composites. The potential actually dropped from the reference against the current gradient. That is, there was a region of apparent "negative resistance" (indicated as a white region in Figure 2). This was found to be true for both samples tested on both faces at every orientation. It did not appear to be an artifact of the measurement or of the particular spot where it was measured. Chung et al., recently reported negative resistance in graphite/epoxy samples[3], but the materials and geometry are different from those reported here, so it is not clear whether the phenomena are related. The system remains under investigation.

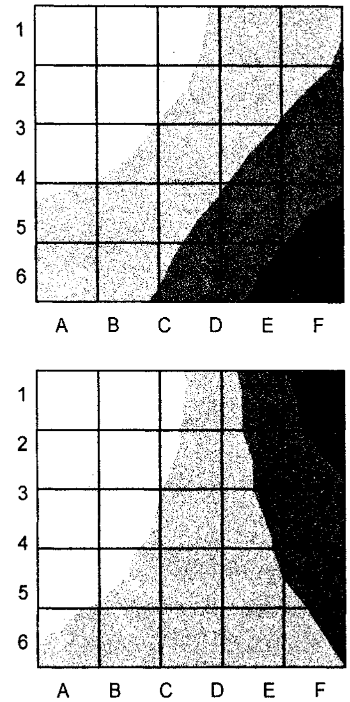

Figure 1 -- Electrical potential contours in 5 mV increments on a P-55 composite when the current is applied 45° (top) and 0° (bottom) to weave.

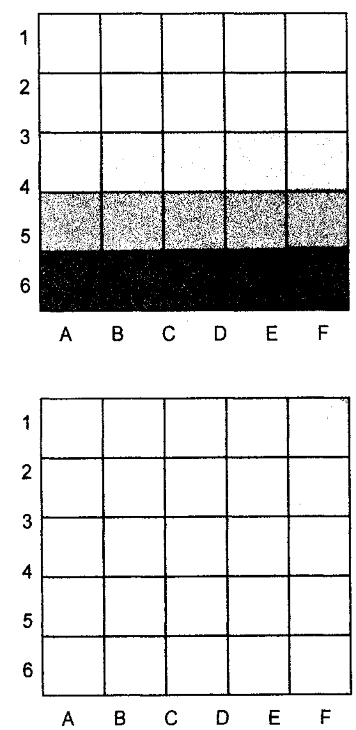

Figure 2 – Electrical potential contours in 5 mV increments on a PAN/P-100+Br composite when current is applied 45° (top) and 0° (bottom) to weave.

References

[1] J.R. Gaier, P.D. Hambourger, and M.E. Slabe, *Carbon* ***26*** (1988) 381.

[2] J.R. Gaier and Y.R. Yoder, Fourth International Conference on Composites Engineering (World Composite Community, New Orleans, 1997) 343.

[3] D.D.L. Chung, Fifth International Conference on Composite Engineering (International Composite Community, New Orleans, LA, 1998).