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James R. Gaier
*Lewis Research Center
Cleveland, Ohio*

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PROSPECTS FOR USING CARBON-CARBON COMPOSITES FOR EMI SHIELDING

James R. Gaier
NASA Lewis Research Center, Cleveland, OH 44135, USA

SUMMARY

Since pyrolyzed carbon has a higher electrical conductivity than most polymers, carbon-carbon composites would be expected to have higher electromagnetic interference (EMI) shielding ability than polymeric resin composites. A rule of mixtures model of composite conductivity was used to calculate the effect on EMI shielding of substituting a pyrolyzed carbon matrix for a polymeric matrix. It was found that the improvements were small, no more than about 2 percent for the lowest conductivity fibers (ex-rayon) and less than 0.2 percent for the highest conductivity fibers (vapor grown carbon fibers). The structure of the rule of mixtures is such that the matrix conductivity would only be important in those cases where it is much higher than the fiber conductivity, as in metal matrix composites.

INTRODUCTION

There are two trends in high technology fabrication of aerospace structures which dominate current thinking. One is the increased utilization of light-weight, high-strength materials, often non-metallic in nature. The other is the increased use of electronic control to replace heavier mechanical or hydraulic controls. Unfortunately, these trends are often at odds with each other because electronic control requires protection from electromagnetic interference (EMI), and non-metallic structural materials do not provide the necessary EMI shielding.

Carbon and graphite fibers are among the light-weight, high-strength materials which are replacing metals in some aerospace applications. These fibers, especially the high modulus pitch-based fibers, have sufficient electrical conductivity to provide low levels of EMI shielding. Most of the shielding work has been with polymeric composites, wherein the matrix is very insulating. This study seeks to quantify the improvement that might be expected if that insulating matrix were substituted by a much more conductive pyrolyzed carbon matrix, such as is found in carbon-carbon composites.

METHODS AND RESULTS

The theory for calculating the EMI shielding ability of homogeneous materials is well developed.¹ When the shield is made of a non-homogeneous material, such as a carbon-carbon composite, several complicating factors enter. The shielding ability is critically dependent upon the resistivity of the material. Composite resistivities are anisotropic, however, and the differences between the conductivity in different directions may differ by orders of magnitude². It is not obvious whether the lowest, the highest, or some average conductivity should be used in EMI shielding calculations.

This dilemma is further complicated by the difficulty in measuring the conductivity of composites. Different measurement techniques can result in values that differ by more than a factor of 5, even for measurements of a single sample in a single direction.³ Faced with such confusing experimental results, we revert to a model which has a great deal of intuitive appeal, that of the rule of mixtures. The rule of mixtures works very well for many other composite properties, and is consistent with multipoint electrical measurements in the laminar direction of composites.

The rule of mixtures for composite conductivity simply states:

$$(1) \quad \sigma_{\text{composite}} = f_{\text{fiber}}\sigma_{\text{fiber}} + f_{\text{matrix}}\sigma_{\text{matrix}}$$

where " σ " is the conductivity, and " f " is the volume fraction. It has been assumed for this study that the rule of mixtures is valid, and that axial conductivity of the fibers is the conductivity which dominates the fiber component. The central defense of the method is that the results using graphite fiber epoxy composites have been consistent with a limited number of experiments.⁴

The interest comes in determining the quantitative effect of replacing an insulating matrix, such as a polymer, with that of a somewhat conductive matrix, pyrolyzed carbon. It seems obvious that the conductivity, and hence the EMI shielding will be enhanced, but by how much?

Before the comparison between polymer composites and carbon-carbon composites can be made, the conductivity of the matrix of a carbon-carbon composite must be determined. This was done using the resistivity of a carbon-carbon composite fabricated by Kaiser Aerotech which was reported to be about $4000 \mu\Omega\text{-cm}$. Our measurements confirmed that resistivity was reasonably accurate. This composite was made with ex-rayon fibers

which have a resistivity of about $5000 \mu\Omega\text{-cm}$. Assuming a 50 percent volume fraction of fiber and solving equation (1) for σ_{matrix} , a matrix resistivity of about $3300 \mu\Omega\text{-cm}$ was calculated. This is a reasonable value considering the processing of the composite.

It is further assumed that the resistivity of a polymer composite is so high as to make the matrix term in equation (1) negligible. For a 50 percent composite volume fraction of ex-rayon fibers in a polymer matrix the resistivity would thus be about $10,000 \mu\Omega\text{-cm}$. The difference between the far field EMI shielding of $4,000$ and $10,000 \mu\Omega\text{-cm}$ composites is shown in Figure 1. The dB shielding is about 2 percent higher at low frequencies and at high frequencies becomes even smaller.

What is the effect if a highly conductive fiber is used? Perhaps the highest conductivity graphite fibers available today are those vapor-grown through a CVD process. Vapor-grown carbon fibers (VGCF) which have been heat treated to about 3000°C typically have resistivities around $75 \mu\Omega\text{-cm}$.⁵ Figure 2 shows the effect on the far field EMI shielding of changing from a VGCF-polymer matrix composite to a VGCF-pyrolyzed carbon matrix in 50 percent volume fraction composite. The dB improvement is just over 0.2 percent at low frequencies, and becomes less as the frequency increases.

DISCUSSION

What is found is that the conductivity of polymer or pyrolyzed carbon matrices has little to do with the EMI shielding of the composite if the conductivity of the fibers is much higher than the matrix. The composite conductivity is then dominated by the fibers. The structure of the rule of mixtures is such that the conductivity will be dominated by the most conductive component. Thus, metal matrix composites will have conductivities dominated by the matrix, and therefore have metal-like shielding properties. The best way, however, to improve the shielding characteristics of carbon-carbon composites is to improve the conductivity of the fibers. The conductivity is already approaching single crystal values in vapor-grown fibers, and this will no doubt be the limit. Conductivity could be further enhanced by intercalation if intercalation compounds with high temperature stability can be formulated, or if processing temperatures of carbon-carbon composites can be drastically reduced.

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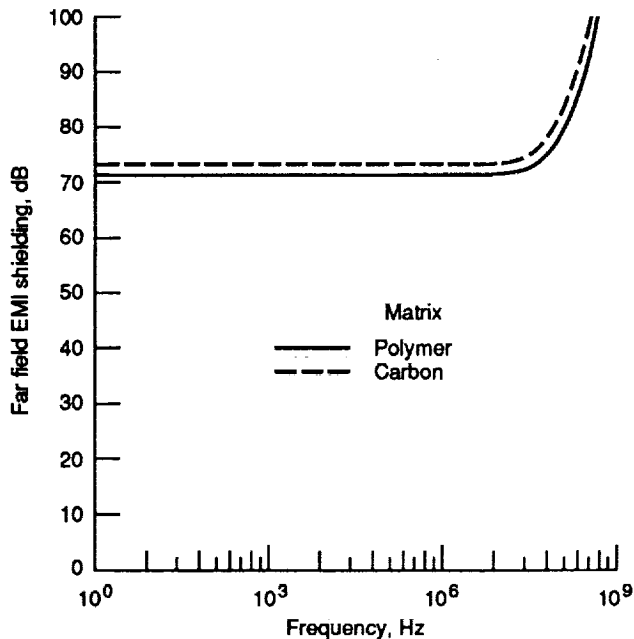


Figure 1.—The effect of changing to a carbon matrix with ex-rayon fibers.

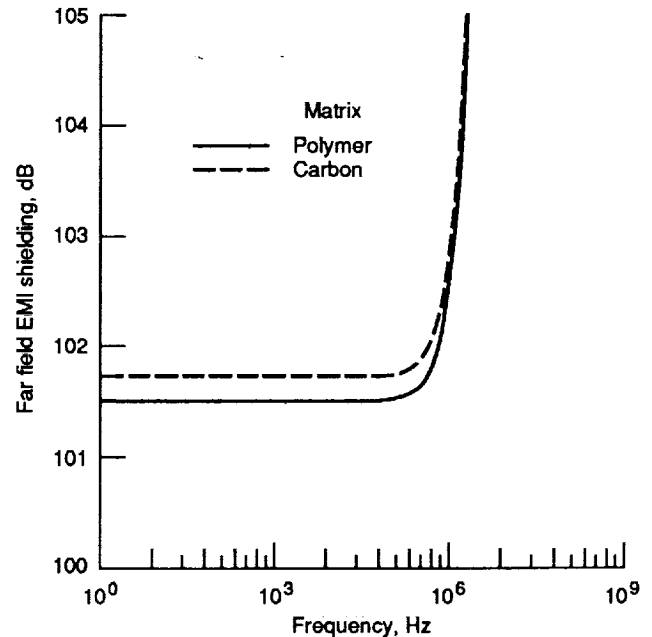


Figure 2.—The effect of changing to a carbon matrix with vapor grown graphite fiber.

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