EFFECT OF INTERCALATION ON THE IONIZING RADIATION SHIELDING OF GRAPHITE FIBER COMPOSITES

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INTRODUCTION

Graphite fiber composites are being used increasingly for the fabrication of aircraft and spacecraft because of their low density and exceptionally high strength and elastic modulus. They are replacing metals, such as aluminum alloys, which have poorer mechanical properties and higher densities. However, the replacement of metal alloys in many applications has proven to be difficult because the very low electrical resistivity of metals compared to the composites. Intercalation, the insertion of guest atoms or molecules between the graphene planes of the graphite fibers, has been found to substantially lower the resistivity of the fibers, and hence the resistivity of fiber composites.[1]

As an example, one application for which intercalated graphite fiber composites have been proposed is electromagnetic interference (EMI) shielding covers. These comprise about 20 percent of the power system mass in a typical spacecraft, and the projected mass savings from a swap out of intercalated graphite composites for aluminum covers is in excess of 80 percent.[2] These mass savings calculations are based on mechanical properties being the limiting factor, which is the usual case. In certain environments, however, the limiting factor is the protection by the covers afforded to high radiation environments. These include the solar wind, particles trapped within the radiation belts, and high energy electromagnetic radiation.

High energy radiation and particles are best shielded by elements with high atomic number. Thus aluminum, with an atomic number of 13 is expected to shield better than graphite polymer composites, with an average atomic number near 6. Intercalation of the graphite fibers with high atomic number elements like bromine (35), and iodine (53) would be expected to increase the radiation shielding characteristics of graphite-polymer composites. Thus, in this study the effectiveness of the X-ray and γ-ray shielding of Br_2 intercalated fiber composites, and IBr intercalated fiber composites was measured and compared to both pristine graphite fiber composites and aluminum sheet.

EXPERIMENTAL

Thornel P-100, P-75, and P-55 fibers purchased from Amoco were selected for this study because of their availability and ease of intercalation. Bromine intercalation of P-100 and P-75 fabrics was carried out in the vapor phase at room temperature, and of P-55 fabric at 0 °C. Epoxy composites were fabricated from these fabrics by Rohr Industries. Details of the intercalation, and composite fabrication and characterization are described elsewhere.[1] Vapor phase intercalation of 2000 filament tows of P-100 by Ibr was carried out at 60 °C for 48 hours. These fibers were then hand woven into 0° - 90° fabrics at a density of 10 tows per inch. Composites were hand made using Master Mend Epoxy (Loctite Corp), which was chosen for its convenient setting time (90 min). Percent fiber volumes for these composites were appreciably lower than those of the Br_2 intercalated fiber composites because of the unavailability of a press. The composites were formed at room temperature between two glass plates on which weights were placed.

Half thickness measurements were made using a 40 μCi ^{210}Pb source and a NaI(Tl) detector interfaced to a Nuclear Data ND2400 multi-channel analyzer. Both the 13.0 keV and the 46.5 kev γ-ray were monitored three times each over 10 sec intervals. Stacks of one to nine 1 mm thick composites were placed between the source and the counter to directly measure the absorption. The thickness and density of each of the composite samples were determined using a micrometer and an analytical balance. Table I summarizes the composites properties.

TABLE I -- Properties of GIC-Epoxy Composites

	Fiber Resistivity $\mu\Omega$-cm	Composite Resistivity $\mu\Omega$-cm	Composite Thickness mm	Density g/cm^3
Al	3		2.0	2.70
Pris	250.	2010.	0.75	1.61
Br_2	50.	490.	0.92	1.76
IBr	45.	2460.	1.90	1.35

RESULTS AND DISCUSSION

The half-thickness of aluminum, pristine fiber/epoxy composites, and composites made from bromine intercalated and iodine bromide intercalated fibers for absorption of 46.5 kev γ-rays and for 13.0 kev x-rays are shown in Table II. The half thickness of pristine fiber composites was four times that of aluminum. That for bromine intercalated fiber composites was comparable to aluminum. The half thickness for iodine bromide intercalated fibers was considerably longer than that of the bromine intercalated fibers. This is due to the nature of the composites themselves, which were hand laid-up in the case of iodine bromide and contained a considerably smaller fiber volume fraction. This table (except for the IBr values) tells the shielding box thickness (volume) penalty that will need to be paid for switching away from aluminum if the application is ionizing radiation shielding limited.

TABLE II -- Shielding Materials Half-Thickness

Material	46.5 keV γ-ray mm	13.0 keV x-ray mm	½-thick / ½-thick Al
Al	7.5	4.2	1.0
P-100	30.	17.	4.0
P-100+Br_2	6.5	4.1	0.9
P-100+IBr	4.9	2.9	0.7

Often, the concern is not volume as much as it mass. Table III shows the mass absorption coefficient. The mass absorption coefficient is the mass of the material which is required to attenuate the intensity of the radiation by a factor of *e*. The mass absorption coefficient relative to aluminum illustrates the mass penalty that must be paid if the spacecraft is to operated in a high radiation environment.

TABLE III -- Mass Absorption of EMI Materials

Material	46.5 kev γ-ray cm^2/g	13.0 kev x-ray cm^2/g	mass abs / mass abs Al
Al	.34	.61	1.0
P-100	.14	.25	0.4
P-100+Br_2	.61	.96	1.7
P-100+IBr	1.0	1.8	3.0

Intercalation with a high atomic mass number intercalate such as Br or I might be expected to improve the radiation shielding ability, that is, to shorten the half-thickness. Since the fibers contain about 18 percent bromine by mass[3], that corresponds to about 3.3 percent by number. There is also a fiber volume expansion of about 10 percent[4]. This leads to an increase in the average atomic number of the composite of less than 10 percent, which leaves it well below the value of 13 for Al. Thus, it was somewhat surprising that the half-thickness of the bromine intercalated fibers composites were measured to be comparable to aluminum.

The density of the iodine bromide intercalated fibers was measured to be 2.36 g/cm^3 using the density gradient method. This, along with the volume expansion, leads to a 24 percent intercalate by mass, also about 3.3 percent by number. The average atomic number for the IBr intercalated composites is calculated to be 8.7, still well short of the 13 of aluminum. This confirmed the bromine intercalated fiber results. Apparently, a few heavy atoms within a light matrix is a more efficient shield that a uniform, slightly heavier substance.

CONCLUSIONS

Intercalation not only makes up the deficiency of conventional composites in shielding components from ionizing radiation, but in the case of IBr, actually confers an advantage over aluminum. Composites made from IBr intercalated graphite fibers can be made with one-third the mass of aluminum shields in those applications where shielding of ionizing radiation is the limiting factor.

ACKNOWLEDGEMENTS

The authors would like to thank D. Beery of Manchester College for his kind assistance with the collection of the ionizing radiation data. J.R.T.B. and M.L.D. were supported for this research by the NASA Lewis Research Center under grant number NCC3-317.

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