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Linear Accelerator Electron Testing of Composite Materials for Space Applications

E. L. Blansett, D. L. Wrobel, G. E. Thayer, D. A. Calkins, J. L. Lenhart, A. C. Hall
Sandia National Laboratories, Albuquerque, NM, USA

T. F. Wrobel
Ktech Corporation, Albuquerque, NM, USA

1. Introduction

Composite materials are attractive for aerospace applications due to the combination of good structural properties and low density. In space applications, lower density leads to reduced radiation shielding performance. Previous measurements and simulations has determined that for electron-dominated orbits (like MEO or GEO), a combination of composite materials and high-Z materials like tungsten or tantalum results in similar radiation shielding performance to aluminum with an overall reduction in weight [1-3]. The amount of weight reduction depends on both the orbit, the thickness of shielding, and the position of the high-Z material in the composite structure. High-Z materials are also being used by SEI/Maxwell for IC packaging [4,5] for use in space applications.

Though it is possible to predict the performance of these hybrid composite and high-Z materials using coupled electron-photon transport codes, this assumes that the composition and distribution of materials in the hybrid structure is well-known. Depending on the details of the composition of the material and the manufacturing process, this assumption may not be warranted. It is desirable, then, to have an experimental method that can act as a check against the simulations as well as a method of qualifying the material for use in space applications. Previous comparisons between electron testing and simulation predictions has shown the usefulness of such a method [1].

In this paper we present the results of recent measurements performed using an electron linear accelerator National Physical Laboratory in Teddington, UK, on a variety of composite and high-Z materials. The experimental technique combines a well-controlled narrow-spectrum electron beam, the use of aluminum degraders to reduce the energy of the beam, silicon p-i-n diodes for dosimetry, and reference diodes to get high-precision comparisons of the shielding performance of the hybrid samples compared to aluminum.

2. Experimental Set-Up

The NPL linear accelerator was chosen for this experiment due its 270° “pretzel” or achromatic magnet structure. This device allows for precise control of the energy spectrum of the electron beam output as well as uniform spatial energy distribution at the test location. Previous simulations and experiments at a ‘standard’ linear accelerator showed that a well-controlled electron energy spectrum is essential for making precise comparisons between the performance of two material samples. A repeatable spectrum is more important than a narrow spectrum.

Using a pulsed linear accelerator also allows for the use of fast-response silicon p-i-n diodes for dosimetry. Our samples were placed approximately 1 meter from the exit port of the accelerator, at which the beam was sufficiently large to cover two p-i-n diodes separated by about 5 cm, and shown in Figure 1. During every pulse, a signal was measured on the upper reference p-i-n diode which was placed behind 100 mil (2.54 mm)Al as well as on the lower signal p-i-n diode. A computer controlled translation stage was used to alternate between a reference 100 mil (2.54 mm)Al sample and the sample under test.

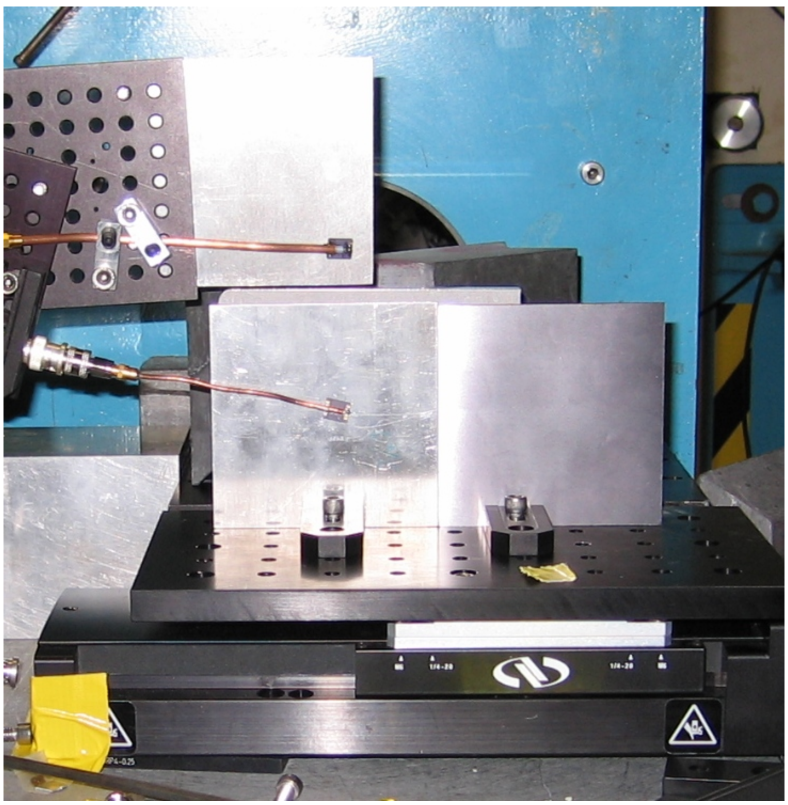

Figure 1. Image of the experimental set-up. The upper reference p-i-n diode is behind 100 mil (2.54 mm)aluminum, and the lower signal p-i-n diode sits behind either the sample under test or a reference 100 mil (2.54 mm)aluminum sample.

The pulses were captured through a bias-T and integrated on a LeCroy LC334A 500 MHz ‘single-shot’ oscilloscope. First, with the 100 mil (2.54 mm)Al reference sample in the beam, the mean and standard deviation of the area under 100 pulses were acquired in ‘sequence’ mode for each of the two p-i-n diodes. This was repeated three times. The stage was then moved to place the sample under test in the beam. Once again, statistics on 100 pulses was obtained three times. The ratio between the lower and upper p-i-n diodes was obtained, and an average of the three values was obtained. Within the 100 pulses, the standard deviation was typically 3% of the mean, and within the three repeated sequences, the standard deviation of the ratio of reference/signal p-i-n diode was typically 1% of the mean. This 1% precision remained even with the overall integrated pulse signal drifting throughout the day by as much as a factor two. The final data point is obtained by dividing the averaged (and normalized to reference p-i-n) data from the sample by the data from the reference 100 mil (2.54 mm)Al sample. Since the reference p-i-n diode takes into account overall drift, this experimental method has a measurement precision of about 1%.

Data was taken with the accelerator set to produce electron energies of 10 MeV, 6 MeV, and 4 MeV. The spectral width of the beam at the output of the accelerator was approximately 0.5 MeV as previously measured by the facility. The samples that were tested were designed to be roughly similar in shielding properties as 100 mil (2.54 mm)aluminum. Since 100 mil (2.54 mm)of aluminum can stop electrons with energies up to about 1 MeV, the range of electrons at which we assume there should be a noticeable difference between the various samples is about 0.5 to 2 MeV. We placed various thicknesses of aluminum in the beam (in front of sample but not reference p-i-n diode) to reduce the beam energy and to produce a wider spread in electron energy. Though it is very difficult to reproduce the space environment spectrum at an accelerator, this method can produce a similar range of electron energies and it is straightforward to calculate the resulting energy spectrum using an electron-photon transport code.

3. Experimental Results

In the conference presentation, results will be presented for a variety of hybrid samples, including a tungsten-epoxy mix attached to carbon fiber composite, a uniform tungsten-silicone mix, and high-Z materials thermally sprayed onto a glass micro-balloons (GMB) epoxy mix. In this paper, we present results using a 80 mil (2.0 mm) carbon fiber composite sample (manufactured by SpaceWorks Inc.) with a 5.0 mil (0.13 mm) solid Ta sheet attached. The areal density of this sample is 0.556 g/cm^2, and the areal density of 100 mil (2.54 mm) aluminum is 0.686 g/cm^2. The sample was placed with the Ta sheet in the front (electrons hit the Ta first) and then rotated so that the Ta was in the back. Measurements were taken with various thickness aluminum degraders for incident beam energies of 10 MeV, 6 MeV, and 4 MeV and given in Tables 1-3. As described above, the data is the integrated and normalized signal behind the sample divided by the signal behind the reference 100 mil (2.54 mm) aluminum sample.

Table 1. Beam electron energy of 10 Mev.

Degrader Thickness (inch)	Tantalum in Front/100 mil Al	Tantalum in Back/100 mil Al	Ratio Back/Front
8/16	0.971	0.954	0.982
9/16	0.994	0.929	0.935
10/16	1.029	0.940	0.914
11/16	1.075	0.996	0.927

Table 2. Beam electron energy of 6 Mev.

Degrader Thickness (inch)	**Tantalum in Front/100 mil Al**	**Tantalum in Back/100 mil Al**	**Ratio Back/Front**
2/16	0.938	0.974	1.038
3/16	0.951	0.944	0.993
4/16	0.997	0.917	0.920
5/16	1.155	1.021	0.884

Table 3. Beam electron energy of 4 Mev.

Degrader Thickness (inch)	**Tantalum in Front/100 mil Al**	**Tantalum in Back/100 mil Al**	**Ratio Back/Front**
0	0.917	0.988	1.077
1/16	0.931	0.929	0.998
2/16	1.102	0.921	0.836

The effect of placement of Ta in these samples is readily apparent by taking the ratio of the Ta in back signal to the Ta in front signal, as given in the last column. With the 10 MeV beam, the Ta in back consistently provided better shielding. With the 6 MeV and 4 MeV beams, whether the Ta in back performed better depended on the thickness of the aluminum degraders. The largest contrast was seen with the lower energy beam and the lower thickness degraders, which results in a more narrow energy spectrum in the desired energy range. Simulations of these experiments are currently underway using the Integrated Tiger Series coupled electron-photon Monte Carlo transport code. Comparisons to the simulations and predictions for various space environments will be made. Initial predictions are that with 4.25 (5.0) mil Ta in the back, the same reduction shielding performance can be achieved as with 100 mil Al, but with a 24% reduction in weight.

References

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