

Investigating radiation effects in polymethacrylimide sandwich structure composites

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Upon radiation exposure, polymer fragmentation causes a sharp degradation in the mechanical and thermal properties of Rohacell foams.

To meet ever-increasing and demanding requirements, new lightweight material systems are being used in the construction of spacecraft hardware.¹ For example, Rohacell² foam core composite sandwich structures are widely used in primary structural components for both launch vehicles and spacecraft applications.³ Specifically, these sandwich structures have previously been used in the fabrication of antennas and radome structures (i.e., for the protection of radar equipment), as well as for wind rotor blades, automotive, and watercraft applications.⁴ The environment for these composites during space flights, however, can be quite aggressive (depending on the flight path and destination). The potential for polymer degradation therefore needs to be assessed when using these material systems.

It is known that radiation exposure can initiate changes in the chemical structure of polymers.⁵ These changes can thus give rise to a variety of mechanisms, ranging from chain scission to additional crosslinking.⁶ The changes may also potentially affect the material's mechanical performance and outgassing behavior.⁷ Indeed, it has been shown that unreacted free radical intermediates (formed after irradiation of the polymer) can follow different reactive pathways, depending on their exposure environment. This leads to a wide variation in the results of mechanical tests on such irradiated materials. For example, in previous work (as part of the Indiana University Atlas project), Rohacell 31 foam was exposed to 9.2Mrad of radiation and showed significant mechanical degradation, whereas other data exhibited only a 20% decrease in flexural strength after a 10Mrad exposure.⁸

In this work,⁷ we have thus assessed the effect of radiation on Rohacell foam material to gain a better understanding of the potential end-of-life degradation of the system. For these tests we exposed this polymethacrylimide (PMI)-based material to different levels of

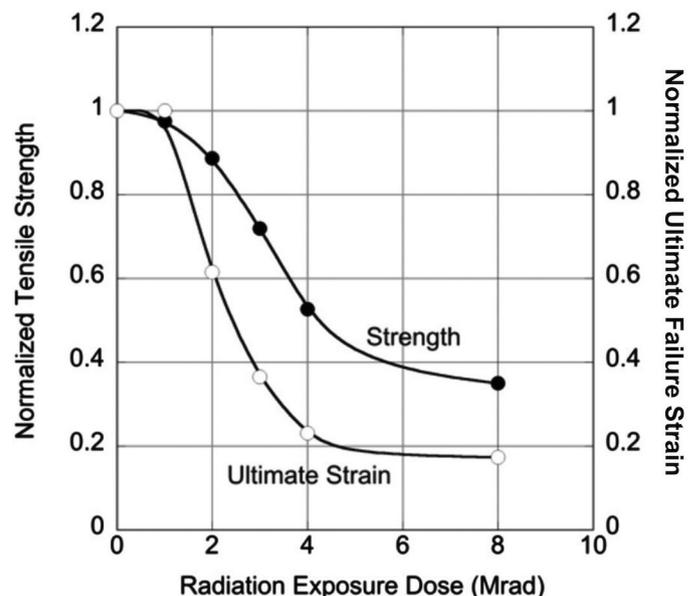


Figure 1. Normalized tensile strength and ultimate failure strain of Rohacell foam 31 HF-HT, shown as a function of radiation exposure.

radiation (1–8Mrad) from a cobalt-60 (Co-60) source. We also measured the tensile strength, failure strain, and thermal degradation of the foam as a function of radiation exposure levels, and correlated these measurements with the fracture behavior.

The mechanical performance (i.e., tensile strength) of Rohacell 31 HF-HT foams—exposed to different doses of radiation—is shown in Figure 1. We find that the normalized tensile failure strength and ultimate failure strain trends with the radiation exposure. For example, the strength decreases by more than 50% after an exposure of only 4Mrad. We also observe a similar trend in the failure strain (75% decrease). These results are indicative of significant embrittlement that may be caused by chain scission of the host PMI polymer after radiation exposure. Although the material tensile strength and failure strain of

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the foam continue to decrease with radiation exposure of more than 4Mrad, the rate of degradation significantly decreases.

In our study, we have also investigated the fracture surfaces of the Rohacell foams as a function of radiation exposure. We show scanning electron microscope images of an unexposed specimen, as well as samples that were exposed to 2, 5, and 8Mrad of radiation in Figure 2. These micrographs indicate that the average cell diameter is about 250 μ m and that the cell walls are on the order of 1 μ m thick. With closer examination, however, we observe that most of the failure seems to occur via decoupling between the cells along the cell wall interfaces. For the unexposed sample—see Figure 2(a)—we see very few cracks on the cell walls themselves. However, with an increased exposure of 2Mrad—see Figure 2(b)—there is a corresponding increase in the population of cracks along the cell walls. With even greater radiation exposure—see Figure 2(c) and (d)—we observe a continued evolution of a larger population of hairline cracks that branch within the interior of the cell wells. This increase in the proportion of fractured cell walls corroborates our mechanical testing results, and suggests that the radiation exposure creates a less compliant and more embrittled structure.

The molar mass distribution of the control and radiation-exposed Rohacel 31 HF-HT specimens, as measured through light scattering analysis, is shown in Figure 3. For these measurements we used a light scattering sensor that has both UV and refractive index detectors. We were thus able to calculate the molecular-weight-average molar mass (or molecular weight distribution, M_w) of the different samples, as

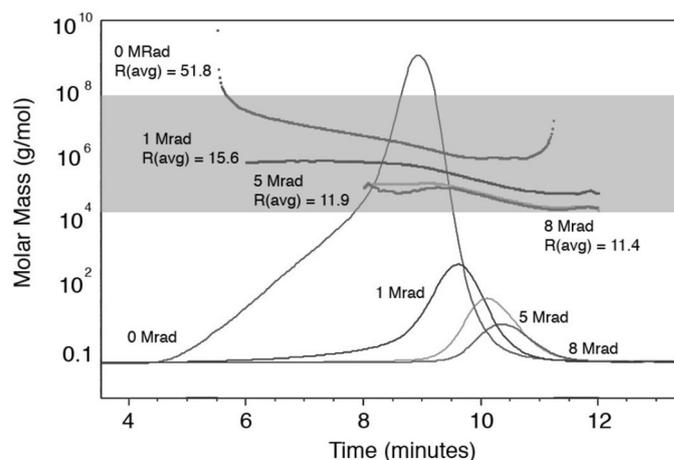


Figure 3. Light scattering analysis showing the average molar mass distribution of the Rohacell foams (0, 1, 5, and 8Mrad samples) as a function of time. The average root mean square radius (R_{avg}) for each sample is also given.

Table 1. Thermal characterization of the Rohacell foams, measured via dynamic mechanical analysis. T_g : Glass transition temperature.

Sample	Exposure level (Mrad)	Tan delta	T_g ($^{\circ}$ C)	Onset of degradation ($^{\circ}$ C)
Control	0	0.78	207	>280
1	1	0.87	208	244
3	3	0.93	208	240
5	5	1.13	209	240
8	8	1.38	210	233

shown by the lines in the gray box. Our results show that the 0 and 8Mrad specimens have the highest and lowest M_w values, respectively. In addition, the peaked spectra in Figure 3 represent the light scattering peaks for the various radiation exposure levels. These spectra suggest that with increasing radiation exposure the observed M_w decreases. We also provide for the average root mean square radius (R_{avg}) for each condition. This value describes a molecule's size, weighted according to the mass distribution about its center of mass. The control and 1Mrad-exposed specimens have R_{avg} values of 51.8 and 15.6nm, respectively. We also find that the 5 and 8Mrad-exposed samples have R_{avg} of 11nm throughout their entire mass range, which is close to the lower detection limit (10nm) for the light scattering system. These results demonstrate that the polymer of the radiated samples has been significantly broken down compared with the control specimen.

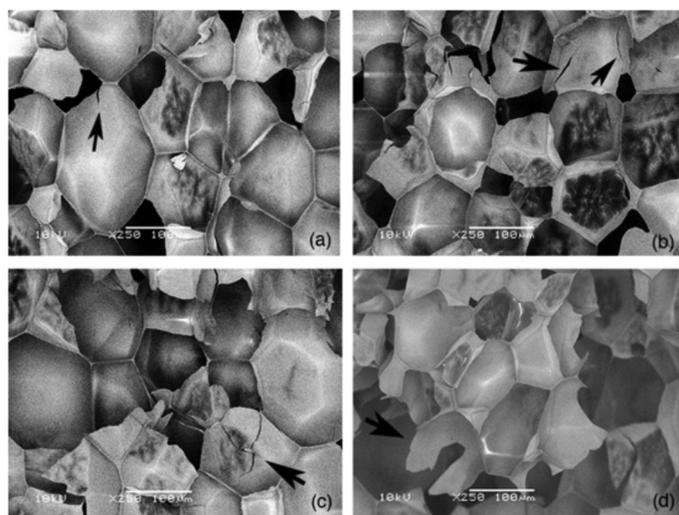


Figure 2. Scanning electron microscope images of Rohacell foam fracture surfaces. Micrographs are shown for the (a) unexposed sample, as well as for the specimens exposed to (b) 2Mrad, (c) 5Mrad, and (d) 8Mrad of radiation. Scale bars indicate 100 μ m.

In the final part of our study, we examined the effect of radiation on the thermal performance of the Rohacell 31 HF-HT foams (see Table 1). Our results indicate that there is a significant decrease in the onset of thermal degradation with increasing levels of radiation, which is related to the fragmentation of the foam network. Although we observe only small changes to the glass transition temperature, an increase in the tan delta peak height suggests that there is an increased amount of damping in the more radiated samples. This result is indicative of increased segmental motion in the polymer caused by fragmentation of the polymer network. We attribute this change to a corresponding drop in M_w that is caused by chain scission.

In summary, we have investigated the effect of different radiation exposure levels on the thermal and mechanical behavior of PMI-based (Rohacell) foams. Our results indicate that the radiation exposure clearly affects the characteristics of the material. To accurately determine the life cycle of these foams, it is therefore essential to evaluate the likely degree of radiation exposure of the composite systems in which they will be used. In our future work we plan to better quantify how radiation exposure affects the fatigue properties of these foams within laminated composites.

The authors acknowledge financial support from the Aerospace Corporation's Research and Program Development Office.

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