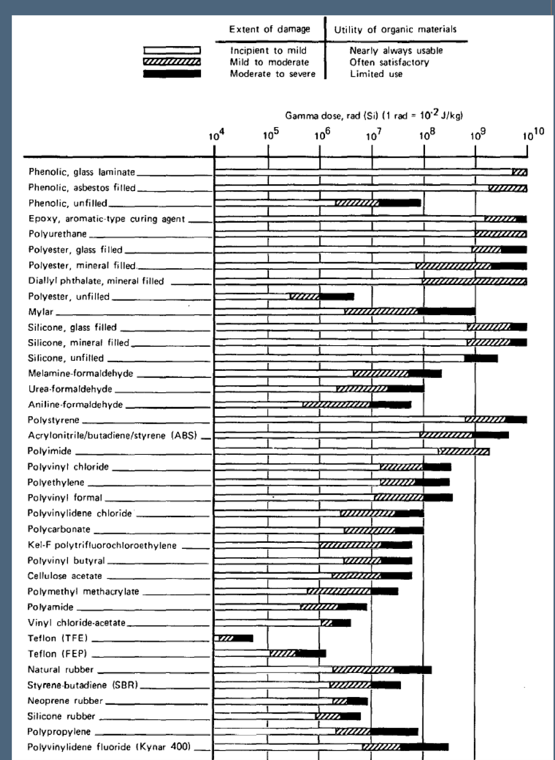
Composite Materials for Space Habitats

EM42 Advanced Manufacturing Branch
2022 Technical Excellence Project

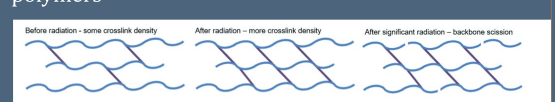
ABSTRACT

Composite materials are an appealing choice for space habitats to **reduce weight** while maintaining **strength** and dimensional **stability** that is required in these sorts of structures. These materials can provide some **shielding** from the radiation that is present in the natural space environment; however, they can become **damaged** in the process. Damage is measured here using **open-hole tension** testing. This study quantifies the mechanical impact of a **10-year Lunar surface** mission on a selection of composite materials.

BACKGROUND – RADIATION & POLYMERS



▲ Figure 1: Relative radiation resistance of organic materials based upon changes in physical properties (1)
▼Figure 2: Visualization of how radiation can affect polymers



A 1970 guide from NASA (1) expressed concern for the effect of radiation on polymeric materials. This guide summarized the effect of different levels of radiation on many common, polymeric materials. Note that this concern, for the most part, is not extended to ceramics such the carbon fiber which reinforces many structural composite materials.

Mechanical effects on polymers due to radiation typically begins with **increased crosslinking** between the long chains of the material and eventually escalates to **chain scission**, presumably once crosslinking sites have been maximized.

On the other hand, the low-z number elements commonly found in polymers – C and H – can result a more effective passive, material-based filter for space radiation. This is due to the lower number (and size) of electron clouds around **atom nuclei**. The majority of space radiation, particular solar particles and cosmic rays, is composed of **positive particles** (2). The protons in atom nuclei can **repel** incoming protons, depending on the energy level and speed. **Hydrogen**, therefore, is a favorite for radiation shielding in space applications.

MATERIAL SELECTION

Two types of **carbon-fiber reinforced polymer** composites were selected for this study, **IM7/8552** and **T1100/3960**. Both composite materials incorporate epoxy matrices that are engineered for **strength**. IM7/8552 is a heritage structural material for NASA studies while T1100/3960 is a rising favorite.

Polyethylene (PE) is a popular material for radiation shielding, due to its high **hydrogen** content, but is relatively weak compared to engineered epoxies like 8552 and 3960. Ultra-high molecular weight PE (UHMWPE) further improves upon polyethylene **hydrogen-packing** as well its mechanical capabilities**.** Additionally, fibers made from UHMWPE have a proven application in ballistic shielding, which could contribute to micrometeoroid shielding of a habitat as well. A commercial product that combines **UHMWPE fibers with PE film** is Spectra Shield®. A now-obsolete version of this material was used in this study to minimize material costs.

Miralon®, a film of matted **carbon nanotubes**, was selected as a coating material to use with two of the composites above, T1100/3960 and Spectra Shield®. The author hypothesized that even a single layer of this expensive material could increase radiation-stopping power due to low atomic number yet high intermolecular strength, without a large impact to habitat material costs. Miralon also has a flight history on a Juno spacecraft (3).

1. Nuclear and Space Radiation Effects on Materials, 1970, NASA Technical Reports Server
2. Shielding of Manned Space Vehicles Against Protons and Alpha Particles, 1972, Oak Ridge National Laboratories for the U.S. Atomic Energy Commission
3. Development of carbon nanotube-based composite for spacecraft components, 2013, S. Rawal, Research Gate

FABRICATION

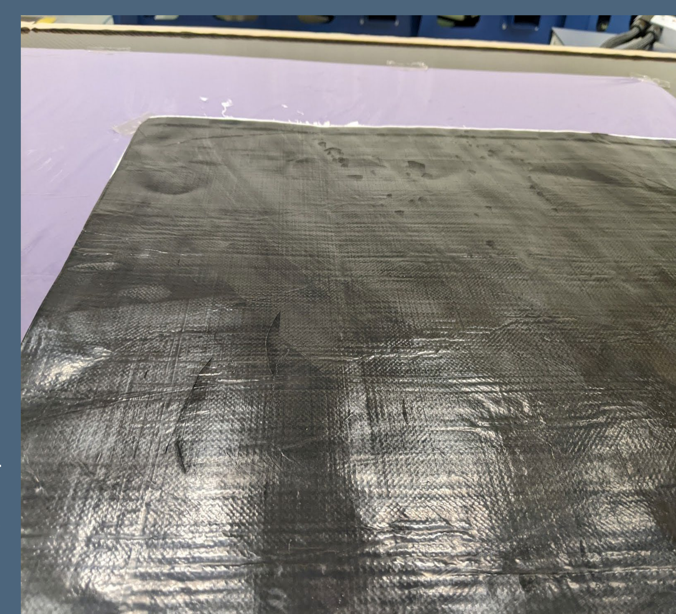
Eight 24"x24" panels were fabricated by combining a sequence of 8 plain weave fabric plies at varying orientations, resulting in a quasi-isotropic layup of $[0_f/45_f/0_f/45_f]_s$.

T1100/3960 and IM7/8552 panels were cured at 355˚ Fand 50 psi for 2 hours, including the Miralon-coated T1100/3960 panel, The fragile, Miralon film was carefully applied to the uncured panel successfully, with no observed tears or wrinkles.

The Spectra Shield/Miralon panels were at 200˚ F for 1 hour. While the Spectra Shield plies consolidated without issue, the Miralon coating stuck to the bagging materials. A set of bonding trials were performed to eliminate this defective condition. Energetic surface treatment (corona, 1" offset, 60 inches per minute) was successfully applied and eliminated the condition almost completely.

◄ Figure 3: Miralon coating stuck to bagging material

► Figure 4: Results of improved process for Miralon coating consolidation



Specimens were cut from panels to approximately 6" by ½" and a a .084" hole drilled in the center. This is a reduced size from the standard open-hole tension (OHT) specimens with dimensional ratios preserved. Sizing was chosen based on the radiation exposure windows in order to maximize the quantity of specimens irradiated in a single cycle and therefore minimize conditioning costs for the study.

CFRP specimens were milled from parent panels. Spectra Shield/Miralon specimens were cut from parent panels using a waterjet. Due the reduced thickness of the CFRP materials, fiberglass tabs (1.25", 15˚ bevel) had to be bonded onto these specimens. A modified process should be pursued for the Miralon surfaces in the future as some of these tabs disbonded during testing.

◄ Figure 5: Prepared specimens and fiberglass tabs, ready for bonding.

► Figure 6: Bonding fixture for reduced OHT specimens.

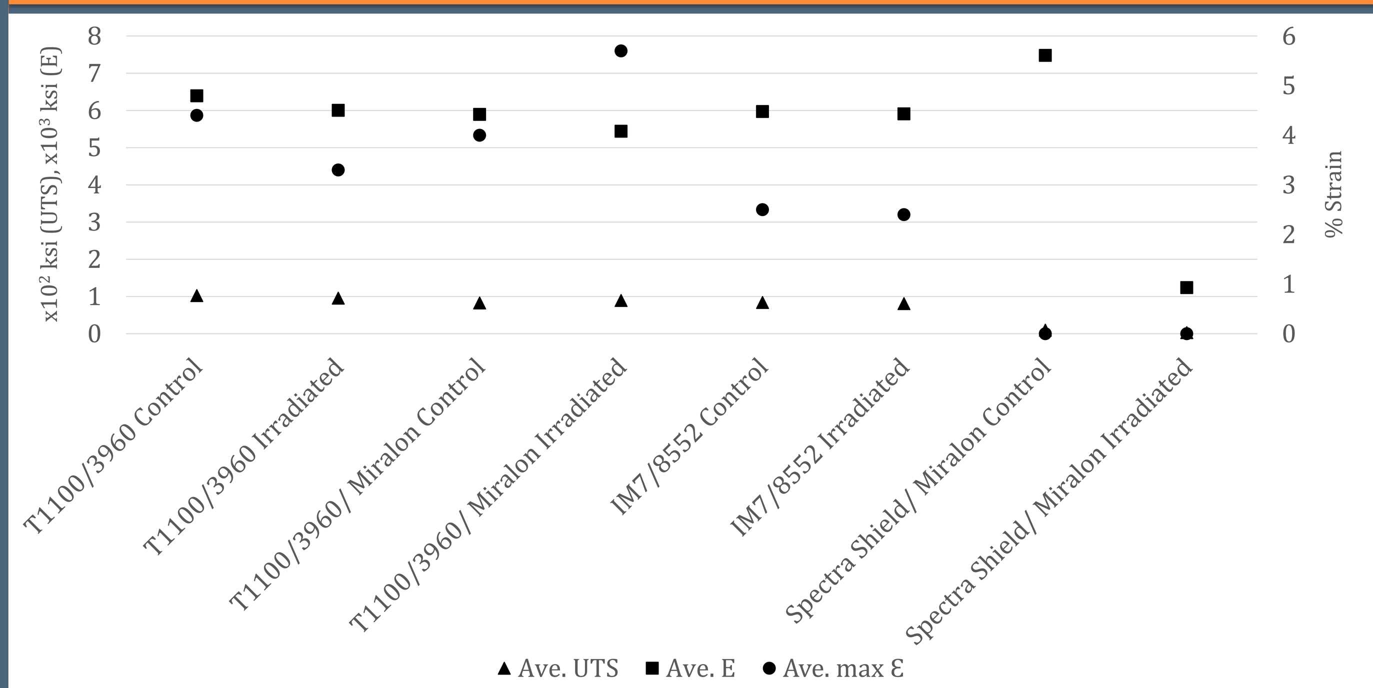
TEST METHODOLOGY

Specimens were irradiated at the MSFC EM41 Space and Environmental Effects laboratory. The dose selected for this study was taken from a 2014 study by EM41 on textiles, for a lunar garage concept (4). First, specimens were exposed to a combination of ultraviolet radiation and vacuum ultraviolet radiation, which are two wavelengths of electromagnetic radiation found in space. This dose was delivered over a span of 30 days. Specimens were then exposed to 250 keV protons over a span of 5 days. No temperature or humidity conditioning was performed on specimens before, after or during irradiation.

Open Hole Tension (OHT) was selected for mechanical testing to a) represent expected tension loading in a pressurized Habitat and b) promote reliable failure from the open hole "defect" as opposed to one from an unintentional material or manufacturing flaw.

4. A One-Piece Lunar Regolith-Bag Garage Prototype, G. Smithers, 2007, NASA Technical Reports Server

RESULTS



▲ Figure 6: Plotted results of average maximum strain, average ultimate tensile strength (UTS) and average modulus (E). UTS and E are reduced by 10^2 and 10^3, respectively, for data visibility.

All specimens exhibited proper failures at the open hole, typically with remnants of angle plies present. Control (minimum 1) and irradiated (always 5) specimens were tested for each material. The Spectra Shield/Miralon tests were stopped manually after reaching peak stress; as a result, maximum (fracture) strain values were not obtained.

Control correlations:

- T1100/3960 control fits within vendor multi-batch data for plain weave fabric, quasi OHT strength range of 88-110 ksi
- IM7/8552 control is higher than vendor technical data sheet for UD (no fabric values found), quasi OHT strength of 62.1 ksi but the reason for this is unknown
- No Spectra Shield OHT results were found.
- The tensile modulus for Miralon yarn of 0.7 Msi fits with the Spectra Shield/Miralon results.

The table below summarizes changes from the control to irradiated condition for each material. Only numbers in bold represent statistically significant changes - calculated using the Anderson-Darling test (α=0.025).

	% Change (Control to Irradiated)			
Material	Max Ɛ	UTS	E	n (# tests)
T1100/3960	**-26**	-7	-6	5
T1100/3960/Miralon	**+39**	+7	-8	5
IM7/8552	-4	-4	-1	5
Spectra Shield/Miralon	-	**-61**	**+38**	5

TAKEAWAYS

The CFRP candidates for a 10-year lunar surface habitat considered for this study have an overall insignificant damage response from simulated radiation when analyzed through open hole tension testing. The Miralon coating on CFRP resulted in increased strain capability; on Spectra Shield, stiffness.

RELATED & FUTURE WORK

- Tech Ex Flammability study, unpublished: Limiting Oxygen Index testing on the above and similar materials to determine risk for an elevated oxygen environment (space habitat). T1100/3960 and IM7/8552 self-extinguish at 38%+ O_2.
- Radiation Effects on Composites for Long-Duration Lunar Habitats by K. Rojdev in 2014 for NASA HLS. 5x higher radiation levels and more extensive testing. Chain scission was observed in similar materials to the CFRP studied here.
- NextSTEP Boeing Study on Primary Structure: A composite primary structure habitat was shown to result in ~34% weight reduction compared to an equivalent aluminum structure.
- CIF 2024 proposal: Composite Habitat Mockup repurposed and retrofitted from a composite cryogenic tank. This mockup would be used for manufacturing demonstrations of secondary structure attachments, Outfitting and human factors studies.

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