EM40 Non-Metallics Branch

Process Development and Testing for Lunar Habitats

Non-metallic solutions for Lunar bases are appealing due to their light weight and ability to block many forms of radiation. Inserting and manufacturing composite structural materials on the Moon presents several challenges, however: the **oxygen levels** inside pressurized habitats will be relatively high, **radiation** that is blocked causes **damage** and the lack of atmosphere results in a high-magnitude **negative pressure** environment.

In the past two years, the Materials and Processes Lab (EM01) invested in two internal research and development (**IRAD**) proposals for testing and procurement of composite materials.

Tech Ex 2022, Testing, EM42

Goal: determine flammability and radiation damage of various composite materials with a focus on carbon fiber and ultra-high molecular weight polyethylene (UHWMPE).

Tech Ex 2023, Manufacturing, EM41+EM42

Goal: Procure chopped fiber spray equipment and materials which will be used to develop a novel technique for chopped UHMWPE fiber layup.

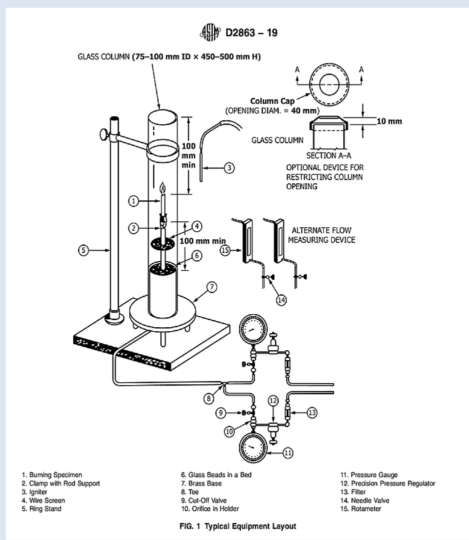
Flammability

Background

- Surface and Transit habitats are targeting elevated oxygen levels up to **38%**.
  - The environment on Earth is approximately 22% oxygen.
  - Elevated oxygen for past/ programs:
    - ISS airlock - 30% (remainder of ISS is 24.1%)
    - Apollo program - 100%
    - Skylab - 70%

Source: "Considerations for Fire in Lunar Gravity", E. Hacopian

- Despite some history with high oxygen levels, new materials are constantly being developed. Furthermore, per NASA-STD-6001B, missions will require test data from within the past 10 years.



Limiting Oxygen Index (LOI) Test

Composite materials were screened using the Limiting Oxygen Index (LOI) test, at JSC.

UHMWPE layups

UHMWPE layup with regolith simulant

Flammability Definition & Measurement (from MAPTIS)

Definition and measurement. Ceramics and glasses do not burn. Metals, if dispersed as a fine powder are potentially combustible, but in bulk, flammability is not normally an issue, even for magnesium. Most polymers, on the other hand, are inherently flammable, although to differing degrees. Here we rank flammability on a four point scale: *Non-flammable, Self-extinguishing, Slow burning* and *Highly flammable*.

There are several ways to characterize flammability of polymers. The most logical is the *Limiting oxygen index (LOI)*: it is the oxygen concentration in % required to maintain steady burning. Fresh air has about 21% oxygen in it. A polymer with an oxygen index lower than this will burn freely in air; one with an oxygen index that is larger will extinguish itself unless a flame is played onto it – then it burns. Thus a high oxygen index means resistance to self-sustained burning. Less logical, but much used, is the *Underwriters Laboratory (UL94) rating* in which a strip of polymer 1.6 mm thick is held horizontally (H) or vertically (V) and ignited. Its response is recorded as a code such as HB, meaning "horizontal burn". The scales are compared in Table 1.

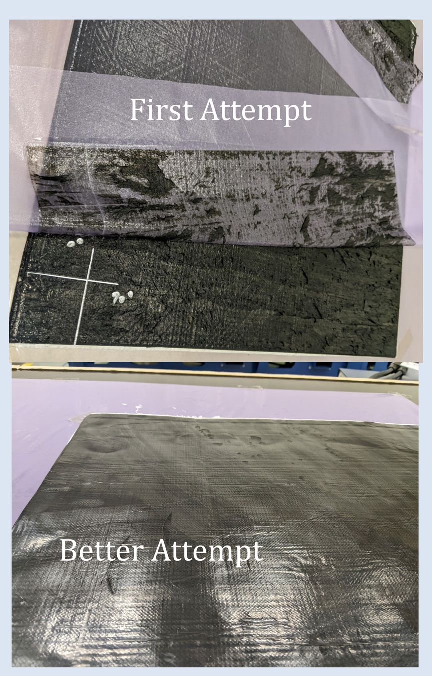
Oxygen index (LOI)	UL 94 (1.6mm) rating	Flammability
Up to 16	Unrated	Highly flammable
16–20	HB	
21–24	HB	Slow burning
25–29	V-2	Self extinguishing
30–43	V-0	
Over 44	V-0 or better (e.g. 5V)	

Table 1. Flammability ratings compared.

Materials and justifications for inclusion in the study:

	Material Name	Format	Vendor	Justification
Substrates	Spectra®	Dry fabric	Cytec (Solvay)	Highly regarded for radiation protection; poor flame-resistance
	IM7/8552	Pre-preg	Hexcel	Heritage use for composite structures
	E-671/S985	Pre-preg	Park Aerospace	Combination of UHMWPE fiber with a more typical structural matrix (epoxy)
	T1100/3960	Pre-preg	Toray	Newly incorporated for composite structures
Coatings	Fyrol PMP	Solid	ICL	Recommended for use with epoxy-matrix composites as a fire retardant
	Miralon®	Mat	Huntsman	Carbon nanomaterial has been shown to improve flame-resistance[1,2]
	JSC-1A	Powder	JSC	Heritage regolith simulant; used for flame-resistance and ISRU status

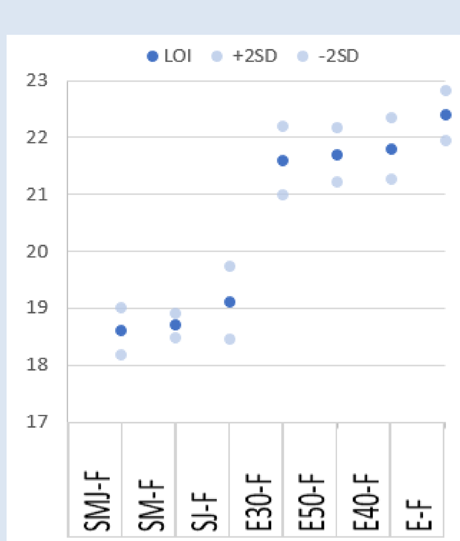
1. "Fire retardancy of a buckypaper membrane" by Q. Wu, C. Zhang, et. al
2. "Improved fire retardancy of thermoset composites modified with carbon nanofibers" by Z. Zhao, J. Gou

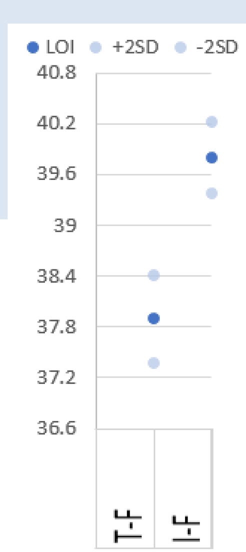


Troubleshooting CNT mat incorporation

Results:

- Spectra panels
  - No significant improvement from CNT or regolith simulant
  - Could be due to improper manufacturing – better methods may exist
  - Overall LOI results in recommendation not to use these coatings for Spectra flame retardance
- Carbon fiber/epoxy panels
  - The heritage material has better flame-retardance
  - Both materials (new and heritage) could be suitable for a 38% oxygen environment
- UHMWPE fiber/epoxy panels
  - No improvement observed with any level of fire-resistant additives in the epoxy
  - Could be due to improper manufacturing – better methods may exist



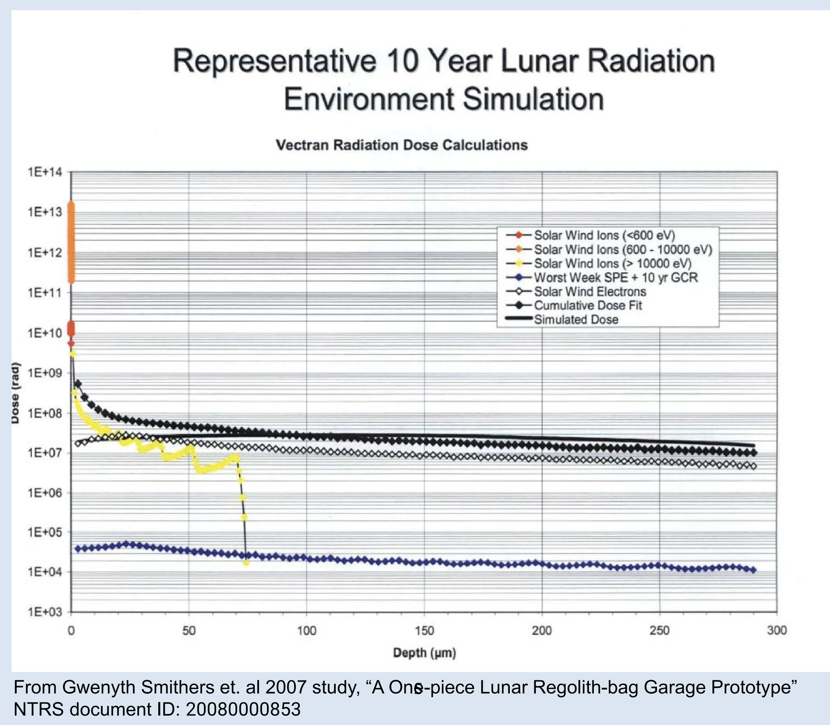


Radiation

Background

- Surface and Transit habitats will be exposed to two primary sources of ionizing (damaging) radiation:
  - Solar Particle Events (**SPE**s) – high energy, high flux, lower frequency of occurrence
  - Galactic Cosmic Rays (**GCR**s) – large energy spectrum but high end is higher than SPE, perpetual occurrence

Source: "Evaluating Shielding Approaches to Reduce Space Radiation Cancer Risks" F, Cucinotta, M.Y. Kim, L. Chappell



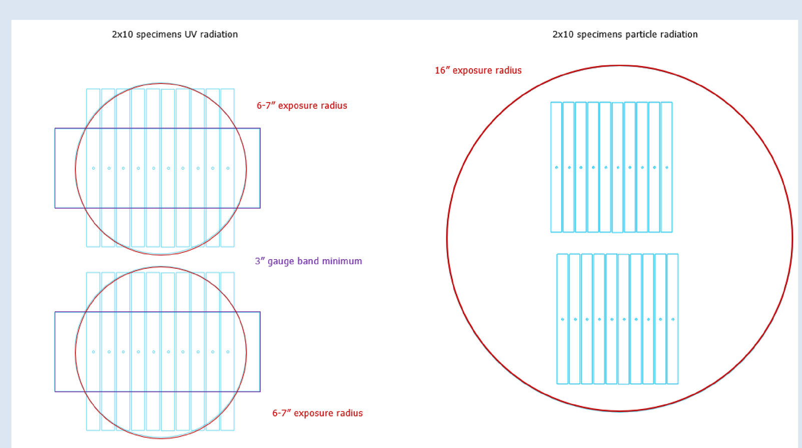
From Gwenyth Smithers et. al 2007 study, "A One-piece Lunar Regolith-bag Garage Prototype" NTRS document ID: 20080000853

Materials Used

- IM7/8552 carbon fiber/epoxy – heritage material for composite structure
- T1100/3960 – new material for composite structures
- T1100/3960 with Miralon – testing impact of CNTs on protection from radiation damage
- Spectra with Miralon – testing impact of CNTs on protection from radiation damage

Testing Methodology

- Open Hole Tension (OHT) used since composites are highly affected by damage
- Target applications suggest tension modes due to pressurized requirements for a habitable volume



Example layout of OHT specimens for two types of radiation exposure (conditioning)

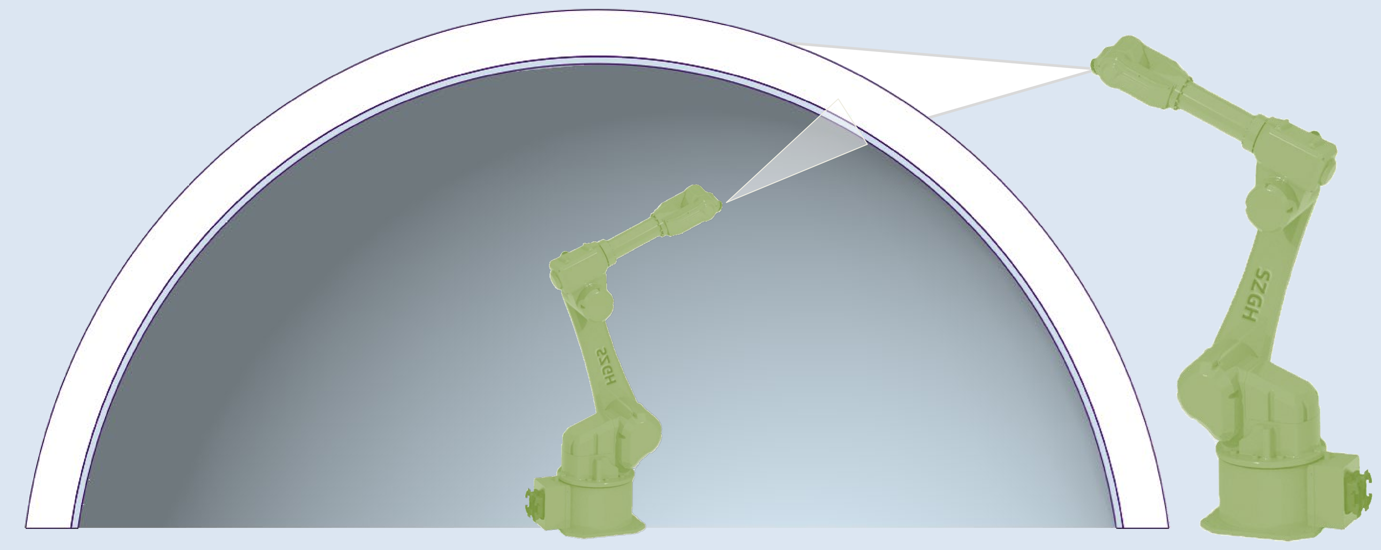
After conditioning in EM41's Space and Environmental Effects (SEE) lab, specimens will be tested using a typical test frame to apply tension load until specimens fail. Results will be compared to control OHT specimens to quantify the effect of radiation damage on non-pristine composite materials.

Status as of 5/31/23

Conditioning: one batch of specimens complete, second to be completed late June 2023.

Testing: anticipated to start early June 2023 and finish July 2023.

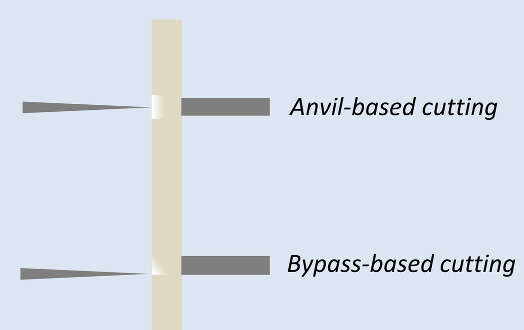
Concept (TRL1): a dedicated or repurposed robotic arm, on the lunar surface, is used to spray chopped fiber with a sticky, uncured matrix on an existing structure. This coating is loaded onto the structural surface until sufficient thickness is obtained for the necessary radiation protection capability.



Development (TRL2+): Develop capability to chop and spray UHMWPE fiber. Determine most suitable matrices for adhesion strength and symbiotic radiation protection from ionizing radiation such as SPEs and GCRs.

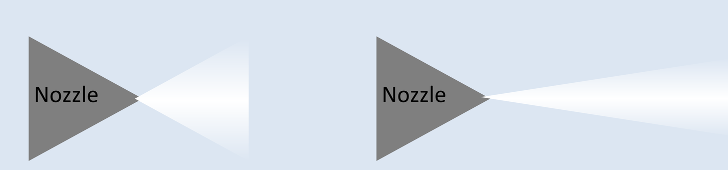
Challenges:

1. UHMWPE has not been used for chopped fiber spray layup before.
2. The fiber may be difficult to cut with traditional anvil-type cutting mechanism due to its low friction and high elastic properties.
   - These properties may be affected by temperature/environment.
3. UHMWPE has low surface energy and may need pretreatment to properly bond with a matrix component.
4. Spray equipment is typically limited to thermoset (two part) adhesives.
5. Vacuum pressure will affect features of a spray plume.
6. "Night"/Shadowed temperatures may be a barrier to adhesion.



Fibers may be cut using an anvil-based or a bypass-based cutting mechanism. Damage may occur in the form of strain-hardening and overall change in crystal size/orientation.

Characteristics of spray processes, in vacuum vs ambient →

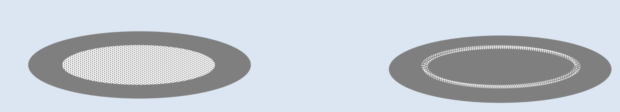


^General size/shape of sprayed particles. Ambient on the left, vacuum on the right.

Sources:

1. "The Structure of Electrospray in Vacuum" by M. Gamero-Castaño

2. "Experimental Studies of Spray Deposition on a Flat Surface in a Vacuum Environment" by E.L. Golliher, S.C. Yao



^General deposition pattern of ambient (left) vs vacuum (right) spray.

Materials (not all confirmed) for future trials:

1. UHMWPE fiber, continuous
   - Potentially with energetic surface treatment or chemical modification
2. Additives – for radiation attenuation
3. Polyester – traditional resin used for chopped fiber spray
1. Epoxy – traditional resin for engineering composites
2. Solvated LDPE – lower melting point thermoplastic with same composition as UHMWPE

Additionally, trials may be done with cutting: modified mechanism, cryogenic temperatures.

Poster POCs: Chelsea Pickett (EM42), John Bloyer (EM41)