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Space Environmental Effects on Materials and Processes

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## **Introduction and Abstract**

The Materials and Processes (M&P) Branch of the Structural Engineering Division at Johnson Space Center (JSC) seeks to uphold the production of dependable space hardware through materials research, which fits into NASA's purpose of advancing human exploration, use, and development of space. The Space Environmental Effects projects fully support these Agency goals.

Two tasks were assigned to support M&P. Both assignments were to further the research of material behavior outside of Earth's atmosphere in order to determine which materials are most durable and safe to use in space for mitigating risks. One project, the Materials on International Space Station Experiments (MISSE) task, was to compile data from International Space Station (ISS) experiments to pinpoint beneficial space hardware. The other project was researching the effects on composite materials of exposure to high doses of radiation for a Lunar habitat project.

## **Goals and Purpose of Project**

### *MISSE*

MISSE is a set of experiments thought of and integrated across NASA, the Military, universities and others interested in space experiments. Material samples flew externally on ISS to test the synergistic effects of the space environment on each material. With information from MISSE, better decisions can be made in selecting spacecraft materials. Ten Passive Experiment Carriers (PEC) have each orbited Earth for at least one year, each holding hundreds of small samples of materials. These PECs are flown externally on ISS to be exposed to the atmosphere of Low Earth Orbit (LEO), the altitude above the Earth at which the Station flies. In LEO, ISS encounters Atomic Oxygen (AO), Solar ultraviolet (UV) rays, ionizing radiation (IR), and extreme vacuum.

The goal of the assigned MISSE project was to create a systematic method for organizing the data that has been obtained from the MISSE samples submitted by the ISS Materials team. This group seeks to evaluate materials for potential use in external applications on ISS and to extend this knowledge to future space applications. This included gathering data from both the control and flight samples and organizing all available data from the MISSE investigators. The importance of the project lies in having a concise location for information concerning material behavior in LEO. Having a catalog of information for spacecraft designers is more efficient than having to search many locations for a piece of necessary data. Previously, the MISSE pre-flight information was in a notebook that accompanied the ground samples. The post-flight information was stored in several Excel spreadsheets, conference papers and presentations because the team is comprised of people from many different NASA Centers.

After the samples flew in space, they were deintegrated and shipped to their various principal investigators. Some ISS samples were never returned to the group, while others were sent to different Centers for post-flight analysis. Not all of the post-flight analysis groups were aware of the data that were to be collected from the samples. Some things that were being evaluated were thermal optical properties, the spread of contamination, the decomposition of the material, and color changes. After flying, most materials had their Solar absorptance ( $\alpha$ ) and infrared emittance ( $\epsilon$ ) measured. However, for samples where decomposition data was sought, that data is limited because there is no corresponding pre-flight data to which it can be compared. In this summer's project, it was to be determined what data was missing. In the aforementioned example where the decomposition of the particular material was being sought, it was found that the weight of the post-flight sample needed to be measured. This project required locating and searching through the pre-flight sample data and finding the corresponding post-flight data.

The final product of what was begun this summer will be a concise location for hardware designers to find pertinent information about materials' performance in LEO. Without this information, a piece of hardware may be perfectly designed, but fail upon exposure to AO fluence or UV rays because of unawareness about the material.

#### *COMPOSITES LUNAR RADIATION STUDY*

The second summer project revolves around the long-term effects of Lunar radiation on composite materials. A goal of NASA's Constellation program is to return humans to the Moon and establish a permanent outpost on the Lunar surface. This raises more questions about what materials to use because longer exposure to an environment can cause further problems when the materials have more time to react with the surroundings. The environment on the Moon is different from Earth and LEO, so new experimentation must be done. The assigned project was a development under the Lunar Habitat Focus Investment Group (FIG). The FIG is dedicated to building technologies and a knowledge base to cultivate the design of the Lunar habitat to its full capacity.

The aspect of the Lunar environment that was being researched in this project is Solar proton radiation. Because the Moon has no atmosphere, there is nothing to protect its surface from the harsh radiation that the Sun emits. Radiation can cause degradation of materials, which becomes hazardous when the materials are necessary for sustaining life away from planet Earth. The amount of radiation that the materials were subjected to was  $5 \times 10^5$  rads. This was based on the anticipated amount of radiation from Solar Particle Events (SPE) over thirty years. This amount was found to be much greater than Galactic Cosmic Rays (GCR), so the more extreme case of SPEs was tested. Another factor which is considered is tension because pressurized vessels fail in tension. The habitat must be pressurized for supporting life, so tension was also a material treatment in this experiment.

For this project, three composite materials were chosen to be tested. Composite materials have the potential to be lighter weight, have higher strength capabilities, and better shield crewmembers from radiation than the metals that are typically used. Using composite materials is new in the space field, so data is not readily available, which means that extensive testing was required for the project.

The purpose of this project is to discover how three composite materials behave or change when exposed to high doses of radiation exposure and tension. This required testing, characterization, and analysis. For proprietary reasons, these materials will be identified as Composite-1, Composite-2, and Composite-3. Composite-1 is a mixture of boron and carbon fibers in an epoxy resin matrix. Composite-2 is a carbon fiber in an epoxy matrix. The third material, Composite-3, is a high-modulus polypropylene fiber in an epoxy matrix.

Three treatment groups were identified and the exposures were performed. The control group (G1) was not altered at all so as to be information to which the other groups can be compared. The second group (G2) was held in biaxial tension of 40.72 MPa of stress for thirty-five days. The third group (G3) was held in biaxial tension of 40.72 MPa of stress for thirty days and exposed to  $5 \times 10^5$  rads of proton radiation. A diagram of these test groups can be seen in Figure 1.

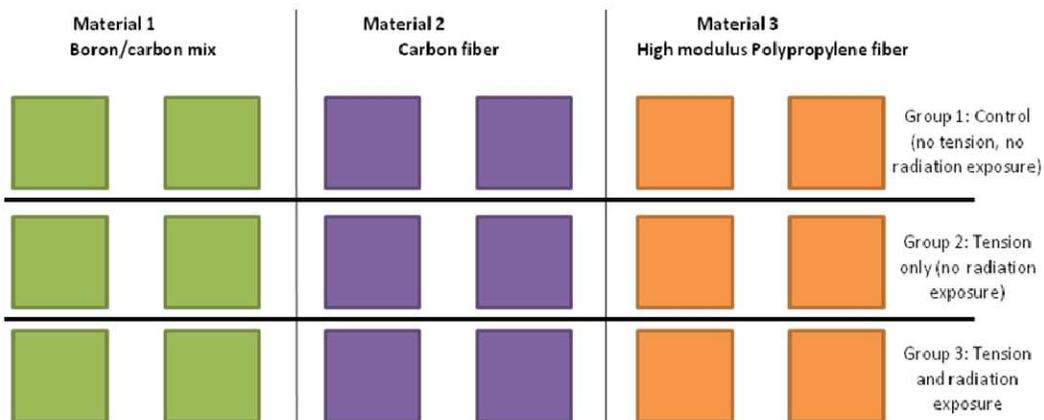
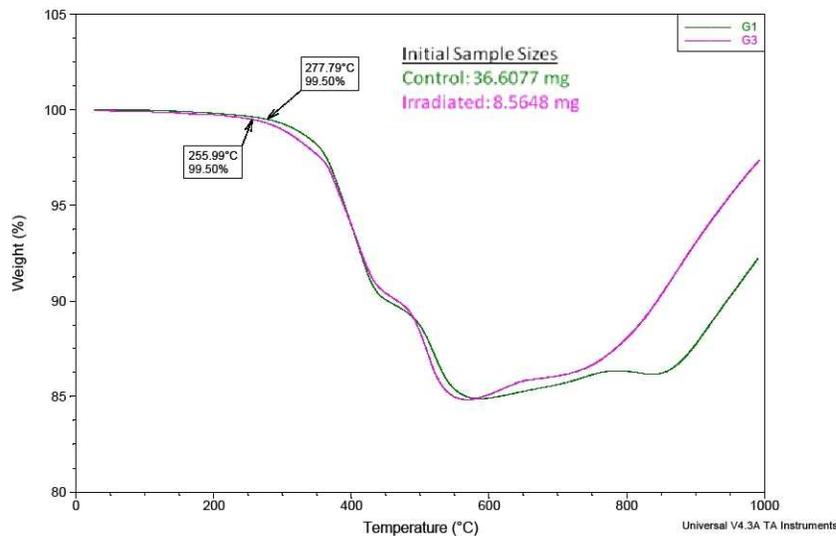


Figure 1

The second phase of the project was to characterize the samples. At the time of this writing, the G2 samples have not been returned from tension exposure. The G3 samples were returned to JSC in May after being exposed to radiation and biaxial tension at the Indiana University Cyclotron Laboratory. Because this is new work that is being done, the results of the radiation and tensile loading on the composite materials are unknown, so many characterization tests needed to be performed to get a good picture of the results.

The Thermogravimetric Analyzer (TGA) is an instrument that increases the temperature of a sample while taking weight measurements. TGA was performed in both Air and the inert atmosphere of Nitrogen. Figure 2 is a plot of the weight percent of the material against the temperature. It can be seen that only 0.5% of the control material has decomposed at 277°C.



**Figure 2: Composite-1 TGA in Air**

With the decomposition temperature information obtained from TGA, the Modulated Differential Scanning Calorimeter (MDSC) becomes a useful instrument. The MDSC increased and decreased the temperature of the sample while recording the amount of heat being added to the closed system. The maximum temperature is programmed in by the user, making sure that it is below the decomposition temperature found from TGA. Figure 3 shows how much heat the

system is taking in at different temperatures with Composite-3. Information about melting, crystallization, and glass transition temperature can be found from this type of plot. Figure 4 tells the specific heat capacity of Composite-2 at different temperatures.

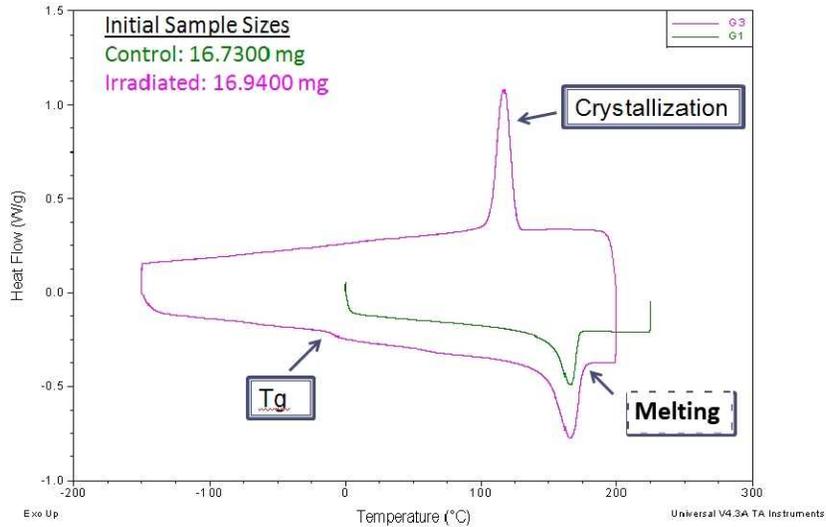


Figure 3: Composite-3 MDSC Heat Flow

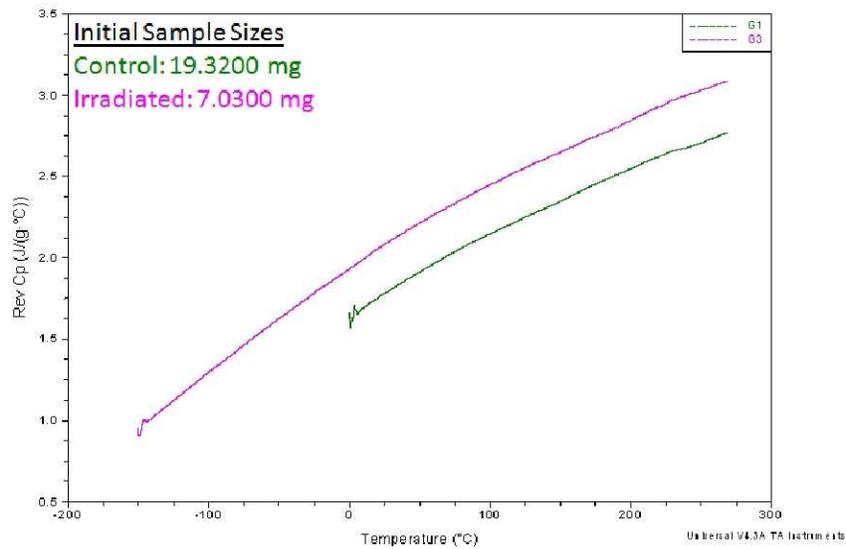


Figure 4: Composite-2 Heat Capacity

Another instrument that was used to characterize the samples was the Raman Spectrometer. Raman Spectroscopy is a vibrational spectroscopy that uses the scattering of light to detect the vibrational modes of a material. This gives information about the chemical composition or bonding of the material.

The Raman Spectrometer in the M&P laboratory has three unique lasers. Usually, one of the lasers would show a more detailed spectra than the others. The G1 samples were used to determine which laser and at what intensity the laser should be used. After recognizing the most telling options to use in the setup of the instrument with G1, the G3 samples were scanned using the same options. Each material had different scanning setups, meaning that different lasers and different intensities were used between materials so that the best spectra would be seen.

The Composite-1 coupons were scanned with the 514 nm edge laser, 2400 l/mm grating at 10% intensity, and at 50x magnification. Every Composite-1 coupon was scanned three times each at five locations along the sample. After looking at the five resulting spectra, one was selected as the best representative of the coupon. The spectra of the different Composite-1 coupons were compared to each other, as can be seen in Figure 5. It can be seen that the peaks have changed between the control sample and the irradiated sample, particularly between 1200 – 1500 Wavenumbers. This is likely due to a change in the chemical structure of the Composite-1 from the radiation and tension.

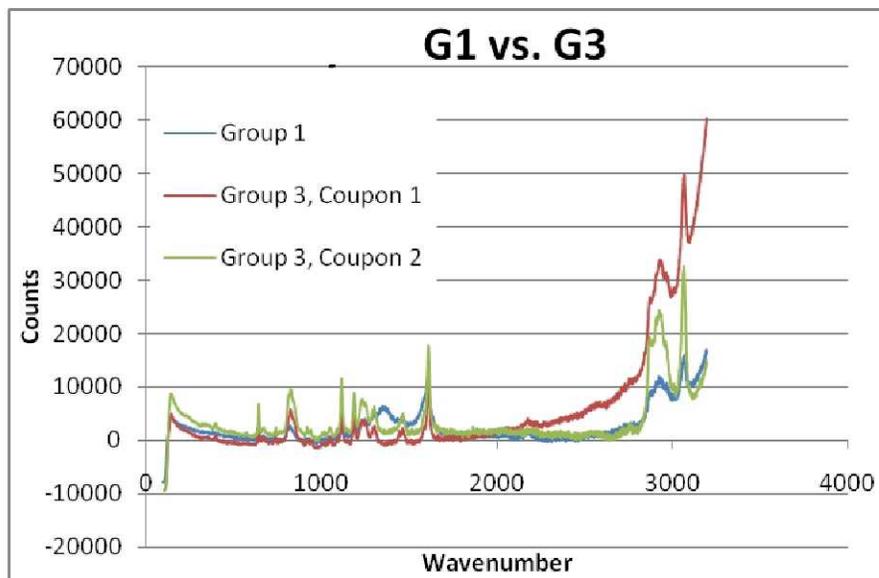


Figure 5: Composite-1 Raman Spectra

The Composite-2 coupons were scanned with the 785 nm edge laser at 5% intensity, and at 50x magnification. Every Composite-2 coupon was scanned three times each at five locations along the sample. After looking at the five resulting spectra, one was selected as the best representative of the coupon. The spectra of the different Composite-2 coupons were compared to each other, as can be seen in Figure 6. There are no large changes between the control sample spectra and the irradiated spectra.

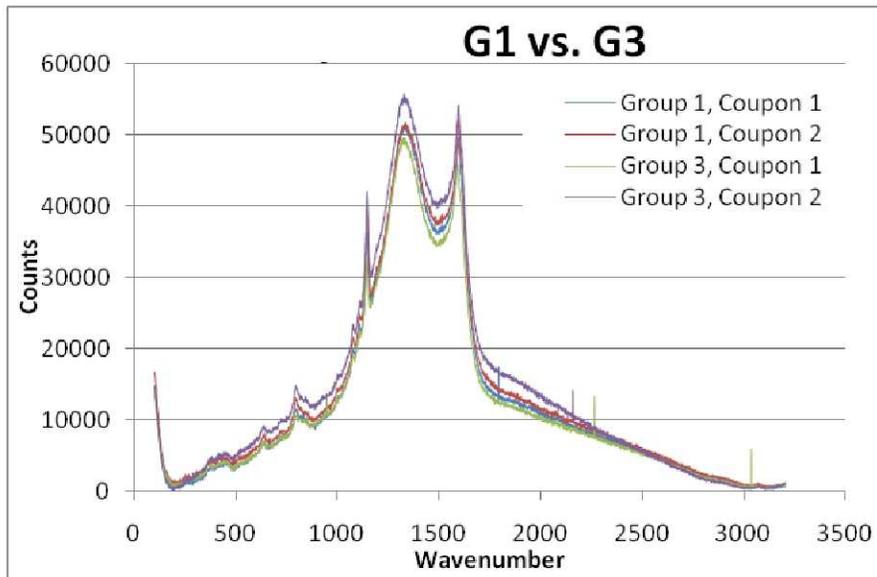


Figure 6: Composite-2 Raman Spectra

The Composite-3 coupons were scanned with the 485 nm edge laser at 1% intensity, and at 50x magnification. Every Composite-3 coupon was scanned three times each at five locations along the sample. After looking at the five resulting spectra, one was selected as the best representative of the coupon. The spectra of the different Composite-3 coupons were compared to each other, as can be seen in Figure 7. There are no large changes between the control sample spectra and the irradiated spectra.

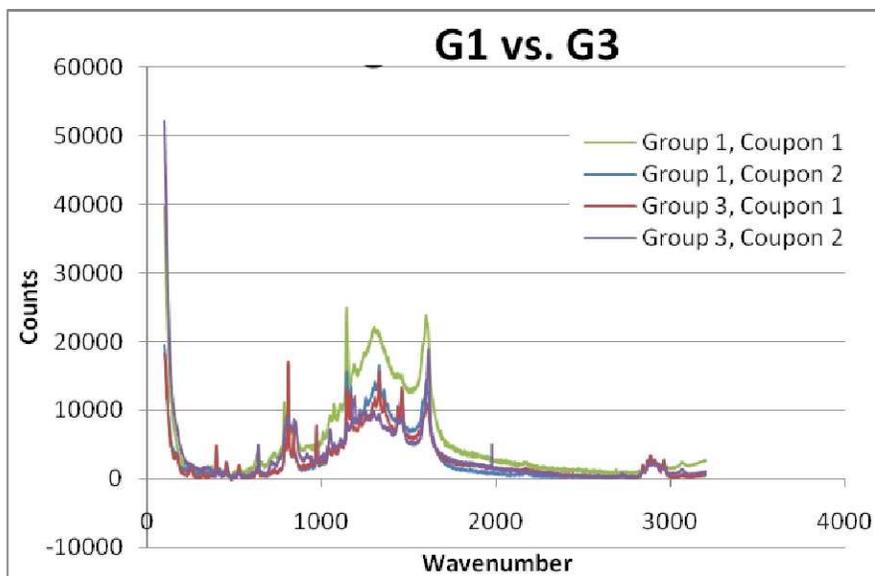


Figure 7: Composite-3 Raman Spectra

### **Impact of the MUST Internship**

I benefitted greatly this summer from all that I learned during my Motivating Undergraduates in Science and Technology (MUST) Internship. Because of my increased knowledge of the materials work that is being done to support NASA's projects, I am able to share with people outside of NASA about what is being done to further our nation's space program. Part of this is sharing the exciting plan to return to the Moon. Many Americans do not know anything about this.

Apart from my new materials knowledge, I found being involved in a government agency to be very beneficial. I learned more technical jargon, safety procedures, the detailed space program thought process, and some of the internal workings of NASA. Without the MUST program, I would not have had this opportunity as an undergraduate.

I will be reaping advantages from this NASA internship for the remainder of my life. I really appreciated this wonderful work experience that will also impact my future employers. NASA is my preferred career employer; I would be proud to work for the Agency. During this internship, I met many civil servants who seemed eager to help me with my career goals.

I am thankful to not only have my foot in the door, as the saying goes, but also to have developed connections with professionals in my degree field and area of interest. These relationships have taught me far more than technical knowhow, but have also trained me in the area of being a professional.

This MUST internship has given me valuable job experience that looks great on my resume. Also, it has exposed me to organizations within NASA. Because of this exposure, I have been contacted about and know others to contact regarding future employment at JSC.

**Key:**

$\alpha$  = Solar Absorptance

AO = Atomic Oxygen

$\varepsilon$  = Infrared Emittance

FIG = Focus Investment Group

G1 = Control Group

G2 = Group Exposed To Tension

G3 = Group Exposed to Tension and Radiation

GCR = Galactic Cosmic Ray

IR = Ionizing Radiation

ISS = International Space Station

JSC = Johnson Space Center

LEO = Low Earth Orbit

M&P = Materials and Processes

MDSC = Modulated Differential Scanning Calorimeter

MISSE = Materials on International Space Station Experiment

MUST = Motivating Undergraduates in Science and Technology

PEC = Passive Experiment Carrier

SPE = Solar Particle Event

TGA = Thermogravimetric Analyzer

UV = Ultra Violet