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December 10, 2009

Dr. Jaydeep Mukherjee, FSGC Director
Mail Code : FSGC,
Building M6-306, Room 7010,
Kennedy Space Center, Florida 32899

Subject: Final Technical Report

Dear Dr. Mukherjee,

Please accept this document as the official final technical report for the research grant titled "Heat Transfer and Stress Investigations of Transparent Material Subjected to Internal Greenhouse Conditions in a Simulated Mars Surface Environment," which is receiving funding under the 2008 Florida Space Research & Education Grant Program.

Design Evolution

The design of the experiment has evolved since the initial conceptualization presented in the grant proposal. This is largely due to our attempts to leverage both the existing infrastructure available and Dr. Andy Schuerger's prior experience with materials testing within the Mars Simulation Chamber in his lab at KSC. Throughout the course of this evolution, efforts have been taken to retain, to the largest degree possible, the original intent of the objectives and data to be collected which were outlined in the grant proposal.

After discussions with Dr. Schuerger, it was realized that the most significant issue which affects the suitability of materials for use in Mars ambient conditions is those material's tolerance to high intensity UV light exposure. This exposure typically results in two phenomenon of concern in our application (transparent greenhouses), the first being the degradation of the mechanical strength of the material, and the second being a decrease in the light transmission of the material. Having come to an understanding of the significance of UV light exposure, this experiment has been adjusted to focus on understanding how this exposure in a simulated Mars environment (including pressure, temperature, and gas composition), affects the mechanical strength and light transmission of potential transparent greenhouse materials.

To accomplish the above stated goals, the experiment has been re-conceptualized to consist of a flat metal plate which would be mounted to a cooling plate within the Mars Simulation Chamber. Resting within depressions in this plate were a number of samples of the materials under test, each of which was replicated 3 or more times to allow for statistical analysis and account for variation in UV beam intensity across the inner vacuum chamber surface. Another flat metal plate was placed on top of this assembly, to hold the samples in place, with openings in this plate that allowed the samples to be exposed to the UV beam and the simulated Mars ambient environment.

Each material sample was tested both prior to, and immediately following, simulated Mars environment exposure for two weeks (high UV, pressure less than 1 kPa and -100°C). These tests included measurement of both mechanical strength, as well as material light transmission.

Materials and Methods

Five clear plastics available in thickness from 1 to 2 mm were selected for testing:

PETG (Polyethylene Terephthalate Glycol)	2 mm thick
Cellulose Acetate Butyrate	2 mm thick
PVC (Polyvinyl Chloride)	2 mm thick
Polycarbonate	1 mm thick
Cast Acrylic (Polymethyl methacrylate)	2mm thick

The UV exposure tests were conducted in the Mars Simulation Chamber (MSC) in the Space Life Science Lab at the Kennedy Space Center, Florida (Figure 1). The stainless steel chamber (Schuerger et al, 2008) is 70 cm long and 50 cm in diameter and is capable of maintaining 10^{-10} Pa. A liquid-nitrogen thermal control system served as the temperature control system for the MSC. The thermal control plate is fully programmable between –100 and +200 ^{o}C. Accelerated UV is provided by a 1000 W xenon-arc lamp (model 6269, Oriel Instruments, Stratford, CA, USA). The lamp provides a UV-exposed area that measures 25 cm in diameter that allows multiple samples to be exposed simultaneously.

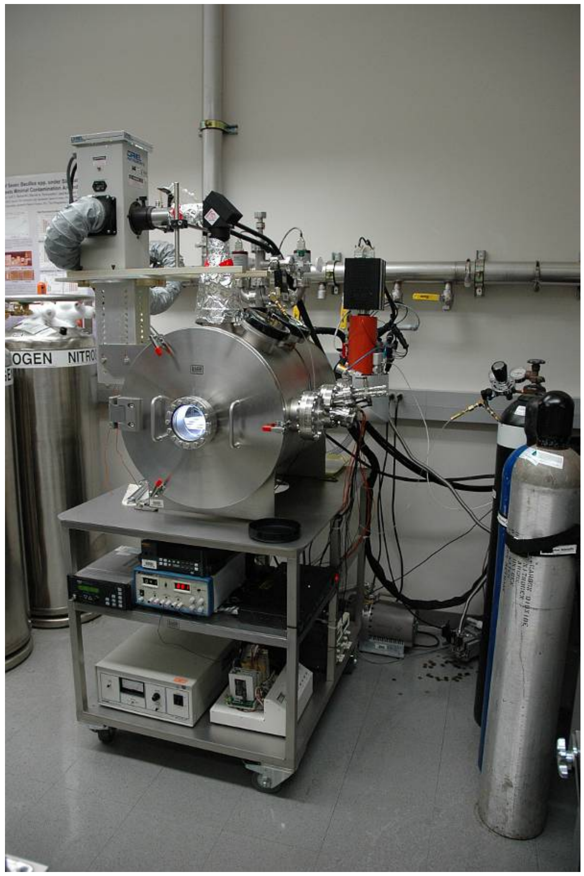


Figure 1. The Mars Simulation Chamber (MSC) at Kennedy Space Center.

An aluminum base plate (Figure 2) was fabricated to mount plastic specimens in the MSC. The base plate provided 24, 4 cm square depressions, but only 20 were used to ensure even light distribution

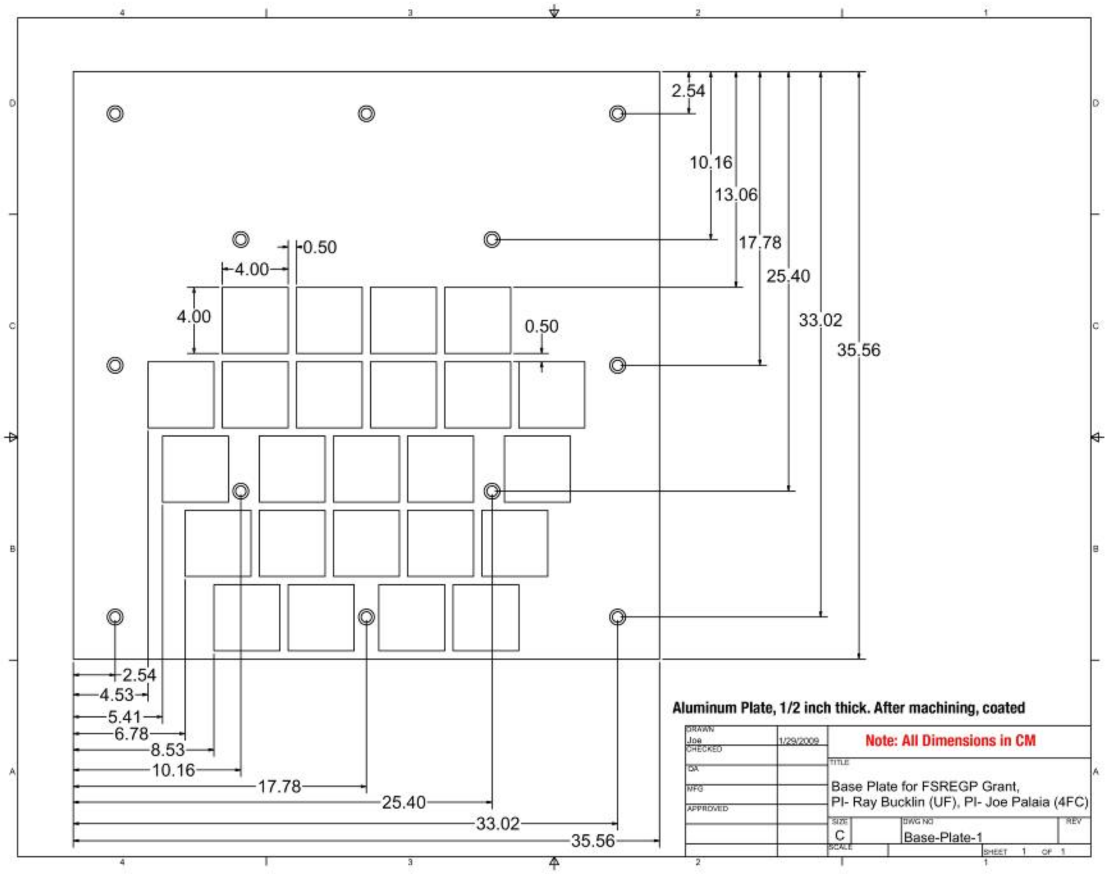


Figure 2. Base Plate Layout

Depressions in the aluminum base were machined to a 0.3 cm depth. Shim material was used to adjust for thickness. A cover plate with openings 2.4 cm square was used to secure the samples in the depressions. The 0.3 cm overlap with the base depressions restrained curling of edges while allowing expansion and contraction of samples.

Testing:

Testing within the MSC was conducted in November 2009. Light transmittance was measured using a spectrometer (Figure 3) in the range of photosynthetically active radiation (PAR) utilized by plants from 400 to 700 nm at 3 nm intervals before placing samples in the MSC (Figures 4 & 5). Following two weeks of continuous exposure to high intensity UV, pressure below 1 kPa and at a temperature of -100°C, the samples were removed from the chamber (Figure 6). They were then tested for post-exposure mechanical strength and light transmission.

Figure 3. Spectrometer

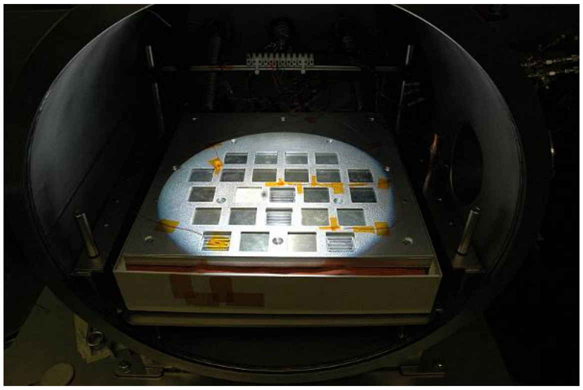


Figure 4. Base Plate and Plastic Samples in MSC Prior to Testing.

Figure 5. Plastic Samples BeforeTesting.

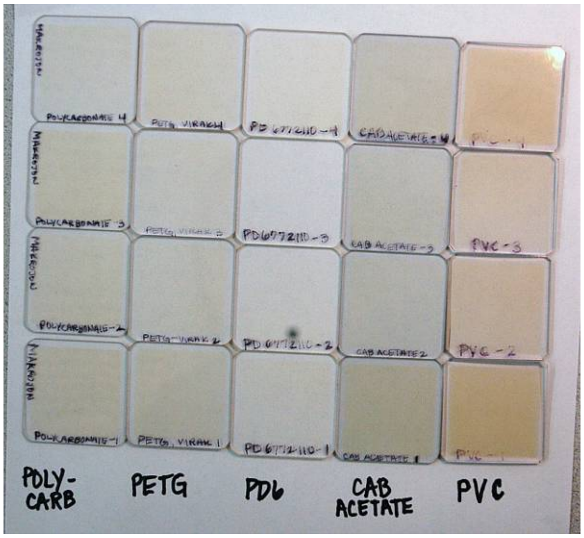


Figure 6. Plastic Samples Immediately after Testing (PD6 is Acrylic).

Tensile strength was evaluated using an Instron universal testing machine following procedures based on ASTM Standard D-2990-01, Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics. Because of the small size of the samples, the test procedure did not follow recommendations for overall length of test samples, but did follow ASTM D-2990's recommendations for proportions and shape of samples and for the loading rate. The loading rate for all samples was 100 mm per minute (Figure 7).

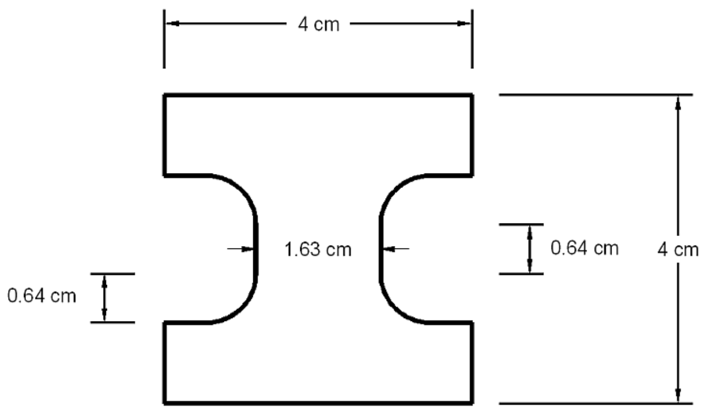


Figure 7. Test Sample for Yield Strength Tests.

All yield strength tests were conducted in a 10 kN Instron testing machine which recorded force and deformation of samples. All of the specimens exposed to UV along with a set of new specimens from the same original stock were machined into the shape shown in Figure 7. Each specimen was loaded until it yielded. Typical behaviors at yield are shown in Figures 8 to 10

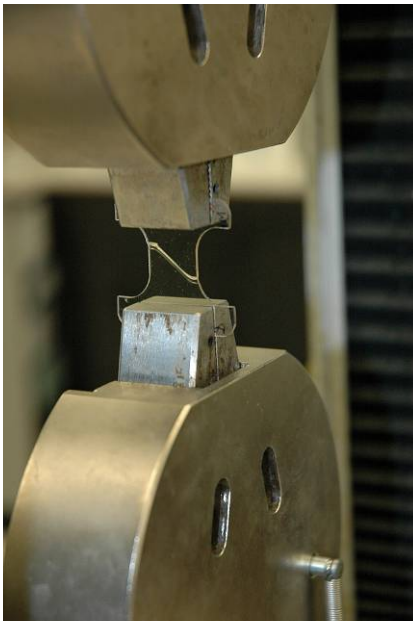


Figure 8. UV treated Polycarbonate

Figure 9. UV treated PETG

Figure 10, UV treated Acrylic

RESULTS

Spectrometer readings in the range of PAR from 400 to 700 nm were converted to transmittance values and statistically analyzed using t tests. As Shown in Table 1, all plastic types showed statistically highly significant reductions in transmittance. The image of the samples, just after exposure to UV shown in Figure 6, shows that all samples showed some discoloration, with PVC showing the greatest change. The values shown in Table 1 show that initial transmittances for all samples were above 0.9 and after exposure to high intensity UV for 2 weeks, the highest transmittance was 0.606 for Acrylic and the lowest was 0.528 for PVC. The transmittances from 400 to 700 nm for each type of plastic are shown in Figures 11 to15

	UNTREATED		TREATED	
	MEAN	SD	MEAN	SD
Acetate	0.916	0.032	0.553	0.059
Acrylic	0.978	0.004	0.606	0.032
PETG	0.961	0.010	0.581	0.048
Polycarbonate	0.947	0.020	0.569	0.055
PVC	0.910	0.041	0.528	0.077

Table 1. Overall Light Transmittance Results (All differences between means for treated and untreated types of plastic were highly significant with $P < 0.001$)

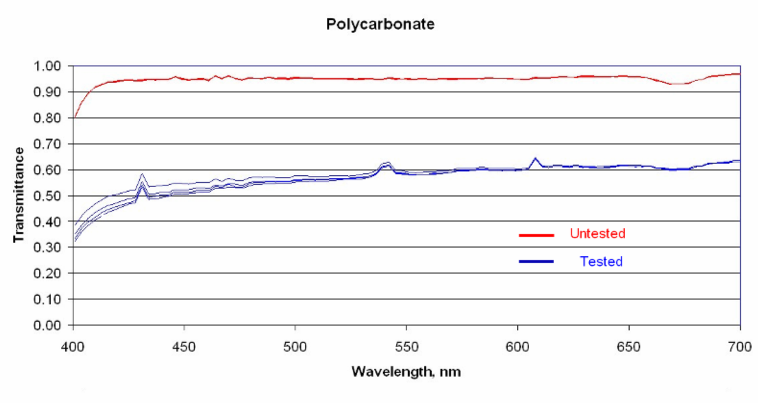


Figure 11. Transmittance for Polycarbonate for PAR (400 to 700 nm)

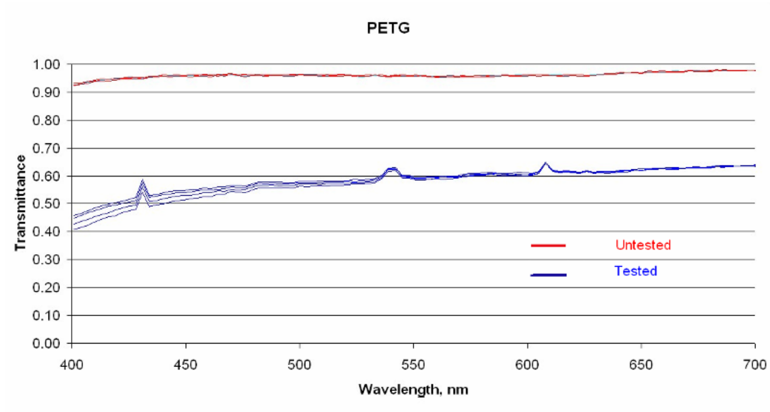


Figure 12 Transmittance for PETG for PAR (400 to 700 nm)

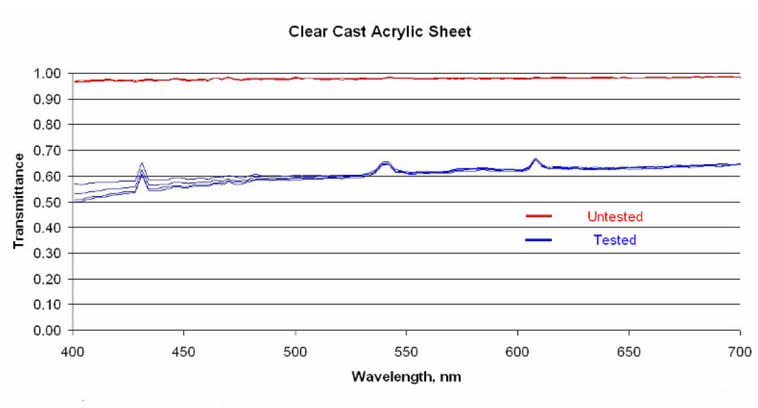


Figure 13 Transmittance for Acrylic for PAR (400 to 700 nm)

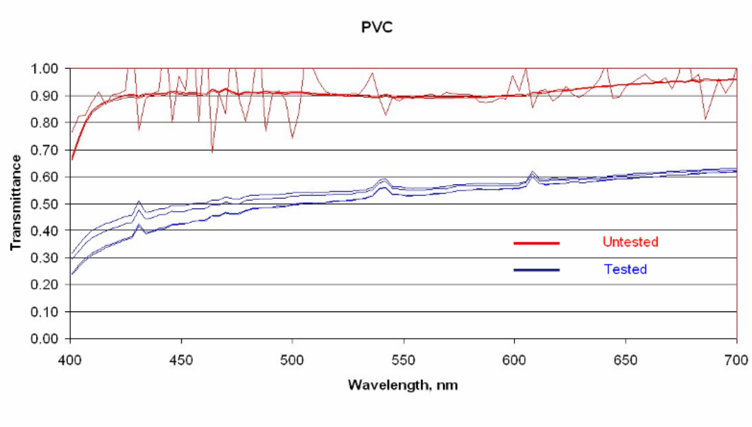


Figure 14 Transmittance for PVC for PAR (400 to 700 nm)

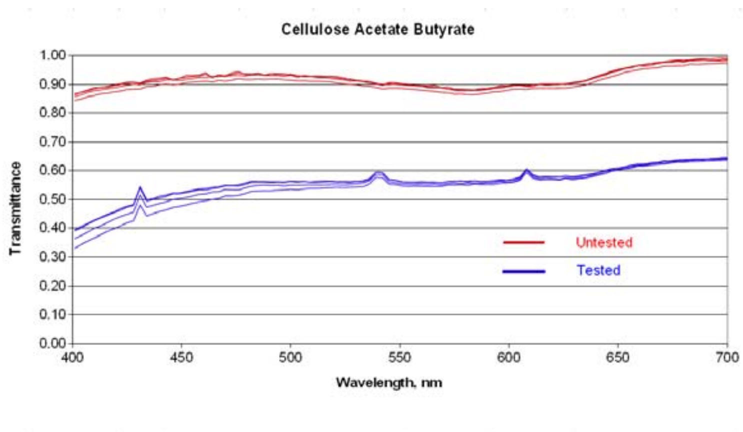


Figure 15 Transmittance for Cellulose Acetate Butyrate for PAR (400 to 700 nm)

Force readings at material yield were converted to yield stresses and statistically analyzed using t tests. As Shown in Table 2, all plastic types showed some reduction in yield stress, but the reduction was statistically highly significant only for Acrylic and Polycarbonate.

		Average (kPa)	SD (kPa)	P
Acetate	**Untreated**	**42186**	**2663**	**0.550**
	Treated	**41183**	**1726**	
Acrylic	**Untreated**	**79867**	**2652**	**0.0003**
	Treated	**57181**	**2211**	
PETG	**Untreated**	**59557**	**358**	**0.878**
	Treated	**59459**	**1171**	
Polycarbonate	**Untreated**	**69712**	**488**	**0.037**
	Treated	**68606**	**318**	
PVC	**Untreated**	**14167**	**733**	**0.939**
	Treated	**14133**	**434**	

Table 2. Yield Stresses for Treated and Untreated Plastics

CONCLUSIONS

The basic conclusion is that the plastics tested showed greater reduction in light transmittance than reductions in yield strength (means were different, but differences were not all statistically significant). This is actually the way it should be from a structural point of view, since the plastic would be replaced before risk of structural failure.

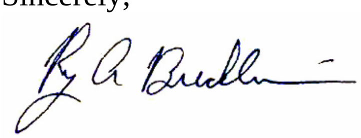
The reductions in transmittance shown by all the types of plastics tested eliminate them for consideration for use as greenhouse glazing materials for the high UV environment expected on Mars and other space applications. The physical and optical properties of plastics can be improved by utilizing different polymers and by the use of additives to the plastics. The equipment and procedures developed in the study will be used to evaluate the strength and light transmission characteristics of new plastics developed based on experience from this study and others. This research group has recently received funding through NASA’s Steckler Space Grant fund to continue development of the engineering systems required to grow plant in greenhouse type structures for Mars and other space applications and the results of this study will serve as the basis of additional projects to develop satisfactory glazing materials for space applications.

REFERENCES

Schuerger , A. C., P. Fajardo-Cavazos , C. A. Clausen, J. E. Moores, P. H. Smith and W. L. Nicholson. 2008. Slow degradation of ATP in simulated martian environments suggests long residence times for the biosignature molecule on spacecraft surfaces on Mars. Icarus, 194, 86-100

ASTM-D-2990-01. (2001). Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics (pp. 20). American Society of Testing Materials, Conshohocken, PA:

This concludes the final technical report
Sincerely,



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