EFFICIENT TRUSS STRUCTURES FROM REGOLITH GLASS. R. T. Wainner,[1] C. M. Hessel,[1] B. E. Nunan,[1] W. J. Kessler[1], T. Guenther,[2] R. N. White,[2] and M. Stern.[3] [1]Physical Sciences Inc., 20 New England Business Center, Andover, MA 01810. [2]Lucideon M+P, 2190 Technology Drive, Schenectady, NY 12308. [3]Evenline Inc., 336 Mulberry Street, Rochester, NY 14620.
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Introduction: Physical Sciences Inc. (PSI) and collaborators are developing a methodology for the production of robust and mass-efficient truss-based structures from melted and reformed lunar regolith simulant for space construction applications. The effort includes; 1) the development of space-worthy hardware for the fabrication of regolith glass building components (rods and nodes); and 2) the component assembly process to securely and accurately join truss building blocks into hierarchical structures.

The design goal is a 5m rod truss with an aspect ratio ~50 that is built entirely of regolith glass struts and nodes as shown in **Figure 1**. This building block is then assembled in a tetrahedral geometry with 'global nodes' to create larger structures. Strut length and straightness target accuracy metrics of $1x10^{-4}$m and 1.3mm/m lend themselves to the construction of large orbital structures with high precision requirements. Similar straightness requirements are imposed on the glass rods that make up the strut assembly. Truss strength objectives and strength of the regolith glass material dictates the allowable fineness of the rods that comprise it. However, varying construction applications may result in different strength and shape requirements. The method will be flexible for producing parts and building blocks of different character.

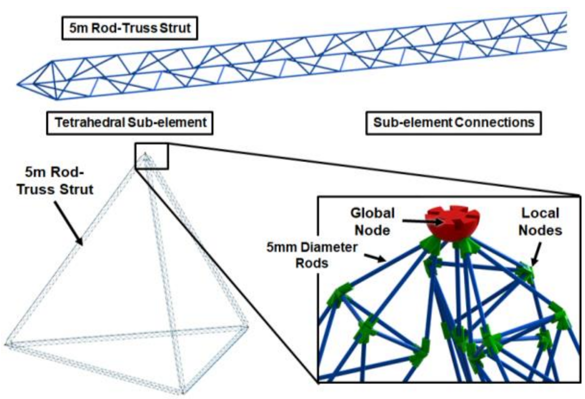

Figure 1. CAD model of rod-truss (top) and tetrahedral assembly of 5m rod-trusses. (inset) Zoom of rod-trusses connected by a 'global node'.

This paper describes results from a DARPA-funded project that will culminate in the fabrication of an exemplar (demonstration scale) 2m long rod truss constructed solely of regolith simulant glass rods that are welded together to produce the (essentially node-free) construction. Molded regolith glass nodes are anticipated to enable the joining of multiple rod-trusses together at their ends.

Material Development/Analysis: The project has developed an in-depth parametric understanding of lunar regolith simulant as a powder, molten liquid, and reformed glass. This deep dive included, for example, the determination of regolith glass strength via 4-point flexural testing. **Figure 2** shows how the rod stock exhibits an impressive 85 GPa modulus of elasticity, which is greather than borosilicate.

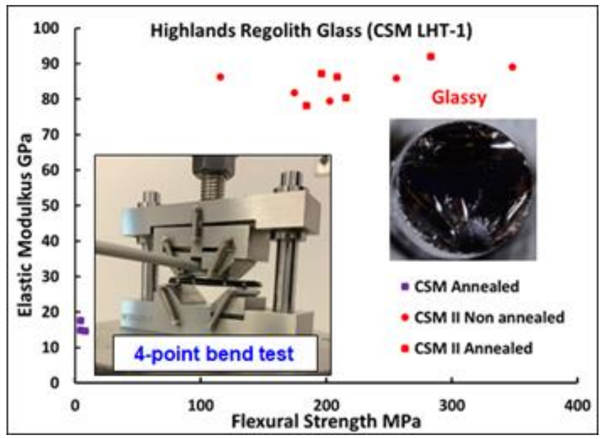

Figure 2. 4-point bend testing of regolith rod specimens. Inset pictures show the test apparatus with regolith rod & deflectometer in place, and cross-section of a sample at its failure surface.

Material Processing and Modeling: A molten regolith fabricator was designed to melt regolith and extrude or cast building components such as rods and hemispherical nodes. The process flow and build materials were chosen to accommodate the intrinsic melt and viscosity properties of the lunar simulant (CSM LHT-1), with particular attention given to the temperature range encompassing T_{glass} to $T_{liquidus}$ range. The fabricator operation was evaluated using glass surrogate material and full-physics modeling of glass thermofluidic flow. **Figure 3** illustrates the comparison of model results to empirical results for soda lime glass in freefall from the outlet nozzle of an available glass 3D printer [1]. This modeling effort aimed to validate the viscous, non-Newtonian flow model across a range of operating parameters in order to provide confidence in modeling results with regolith (simulant). For example, the time-dependent model of the 'free jet' (2-phase (air/glass), moving mesh) converges to a steady-state condition after an initially estimated shape. The molten material flow is gravity driven and accounts for viscosity ($\nu = f$ (T)), surface tension, and radiative, conductive, and convective heat transfer. The COMSOL model provides a jet shape, temperature distribution, and mass flow for varying operating conditions. These theoretical properties were empirically validated by optical imagery, pyrometric imagery, and gravimetric analysis, respectively.

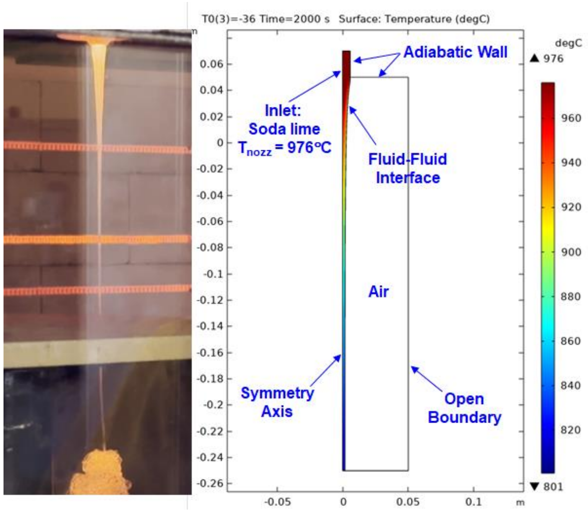

Figure 3. (left) Soda lime glass falling in a free 'jet' from the nozzle outlet of a glass 3D printer [1]. (right) COMSOL model results (shape, temperature) for matching conditions.

Truss Design, Build, Model & Test: Mechanical data derived from testing of regolith glass specimens enabled the design of large (> 200m) mass-efficient truss-based structures. The ring-structure design shown in **Figure 4**, again based on a tetrahedral geometry, is designed to support a flat covering via support cables. Also shown are model results under maximum anticipated dynamic loading which verify achievement of stiffness metrics (max displacement only 3.5mm) and resistance to failure with >2.0 factor of safety.

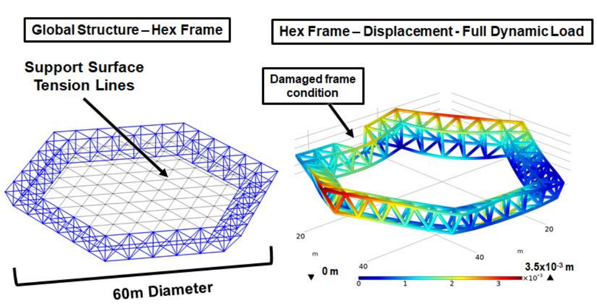

Figure 4. (left) CAD model of 60m hex frame structure. (right) Modeled frame displacement (3.5mm max) under full anticipated dynamic loading, with damage (missing node and connected truss-struts).

In order to reduce mass and complexity, the team developed a novel glass welding approach to join the regolith struts using butt-end and end-to-line welding techniques. This was found not only to be viable, but also an extremely mass-efficient approach. Machinery for the production of regolith 'cane' (rod stock) is still under development, but assembly methods are being refind on conventional (5mm dia.) borosilicate glass rods. This includes weld methodology and jigging for assembly. **Figure 5** illustrates a welded 2m truss of borosilicate glass, as well as the jig employed to allow its precision construction.

Next steps in the project involve the transition to produced regolith rod stock, and regolith glass truss assembly and testing with the same (validated) jigging and strength test instruments used for the borosilicate trusses.

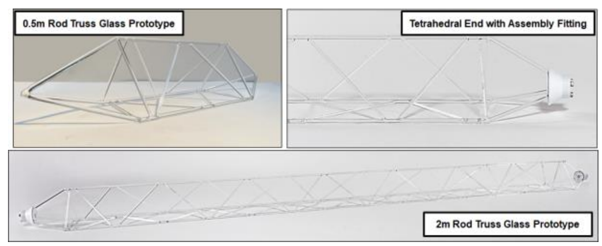

Figure 5. Photographs of the prototype welded glass trusses, built in borosilicate.

References:

[1] Inamura, C., Stern, M., Lizardo, D., Houk, P., and Oxman, N., (2018) *3D Printing and Additive Manufacturing*, vol. 5, no. 4.

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