The first lunar roads? Thermoplastic and regolith surface improvement vacuum demonstration and durability testing.

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Introduction:

On the path to a permanent human presence on the moon supportive infrastructure on the lunar surface will be required for sustainability. NASA has recognized the need for developments such as landing pads, habitat structures, roads and berms to facilitate surface operations, greater mobility, and protect astronauts and mission assets.

Lunar roads will improve future lunar surface mission operations in many ways, from minimizing dust generation and mitigating exposure to deployed assets traversing to and from habitats, processing plants, and landing pads to increasing the speed and efficiency of lunar mobility. Road construction has huge potential for increasing sustainability.

Spacefactory was awarded the Phase I STTR under Exploration Destination Systems, proposing MATRI(x): Multi-Application Technology for Regolith Infrastructure. Partnering with the PSTDL at Michigan Technological University, their Phase 1 prototype for deploying lunar road material comprised of polymer-coated regolith feedstock was demonstrated under a vacuum environment. This paper will showcase the methods and test results of deploying and curing this road surface, constant force tweel loading of the road surface and comparable tweel testing of the improved subsurface layers, compacted and uncompacted regolith.

Methods:

Phase I testing was conducted in the PSTDL's DTVAC. Five test operations were conducted as follows:

1. Deployment and curing of a 5 mm x 60 mm x 800 mm polymer-coated regolith feedstock material.
2. Constant 10 psi tweel loading of the road surface on top of an improved subsurface for a total travel distance of 0.72 km.
3. Constant 10 psi tweel loading of the improved subsurface layering of size sorted particles and regolith fines with a thermoplastic mesh inclusion.
4. Constant 10 psi tweel loading of compacted MTU-LHT-1A
5. Constant 10 psi tweel loading of uncompacted MTU-LHT-1A

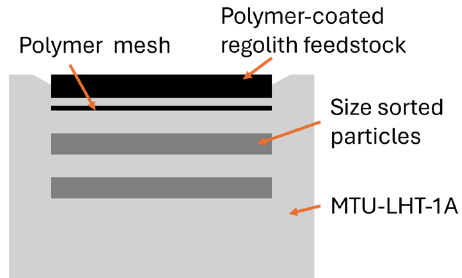

Figure 1: Subsurface layering and road surface configuration for test T002

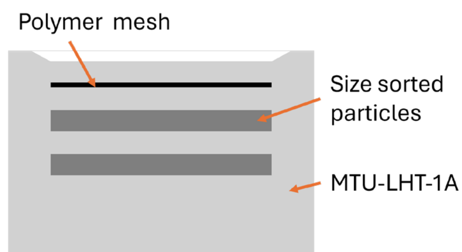

Figure 2: Subsurface layering configuration for test T003

The MTU-LHT-1A regolith test bed was initially compacted to ~1.7 g/cc after which a trench was excavated and layering of the size sorted LSP-2 and regolith fines were added. The top of the layered subsurface featured a thermoplastic mesh inclusion below the top surface of 5 mm of regolith fines. The polymer-coated regolith feedstock pellet mixture was then deployed using Spacefactory's prototype surfacing mechanism. Curing of the road surface material was done using an IR lamp under 10E-3 Torr. (Figure 1)

After the curing of the road surface, a constant 10 psi tweel mechanism was installed on the gantry attached to the regolith bed and a total of 900 passes (0.72 km) was traveled over the length of the ~0.8-meter length road sample.

Tweel testing was then conducted on the subsurface layers after removing the cured road surface sample and wheel sinkage was measured after 700 passes (0.5 km) of total travel. (Figure 2) This same test was then conducted, measuring wheel sinkage, on compacted and uncompacted MTU-LHT-1A over 700 passes (0.5 km) and 200 passes (0.14 km) respectively.

Once all tweel testing was completed, three-point bend tests were performed on 5, 80 mm span sections of the cured road surface to measure the peak load and peak stress of the resulting road material.

Results:

Deployment of the regolith and thermoplastic pellet material was successful in creating a 5 to 10 mm thick road surface 60 mm wide and 0.8 m in length. The IR lamp was set to 75% and 100% of its duty cycle and was successful in curing the road surface after 5 complete passes under 10E-3 vacuum conditions. (Figure 3)

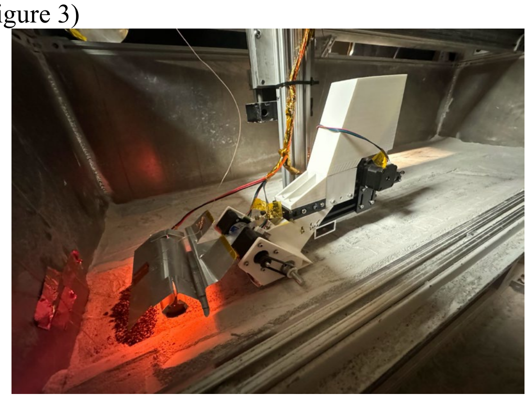

Figure 3: Road surface material deployment and curing prototype mechanism

The constant 10 psi tweel loading of the road surface resulted in no measured or observed failure of the road surface and no observed amount of regolith contamination of the tweel. A total distance of 0.72 km (900 passes) was traveled over the ~0.8 m length road surface under vacuum conditions. No sinkage of the tweel or road surface was measured or observed. (Figure 4)

Figure 4: Constant pressure tweel testing for a total distance of 0.72 km

After successfully testing the durability of the road surface with applied wheel loading, the road surface was cut into 5 equal length samples of 80 mm spans. Three point bending tests were conducted on these samples and the average peak load measured was 4.6 lbf and the average peak stress measured was 237.2 psi. These results inform the strength of the resulting scaled road sample.

Constant 10 psi tweel loading of the subsurface improvement layers was successfully demonstrated with a total distance of 0.5 km (700 passes) traveled. (Figure 2) Wheel sinkage was measured and the resulting depth of the tweel impression was measured to be 1.5 cm from the top surface of the surrounding compacted regolith. During the course of this testing, the top layer of regolith fines was deposited on either side of the tweel exposing the thermoplastic mesh. (Figure 5)

Figure 5: 10 psi tweel loading of the subsurface layered improvement resulting in a 1.5cm impression

Similar testing was conducted on compacted and uncompacted MTU-LHT-1A. The resulting wheel sinkage was measured to be 2 cm and 3.4 cm respectively.

Discussion:

The results from testing are promising for the outcome of this STTR proposal. The road surface performed better than expected and the resulting peak load and peak stresses of the final material cured under vacuum were significant. Sinkage measured from the subsurface layering compared to the compacted and uncompacted wheel sinkage is indicative of improved surface bearing capacity. The addition of the top surface road mitigated dust generation and contamination of the tweel which is likely to reduce degradation of mobility systems.

Conclusion:

These tests were successful in demonstrating the deployment and curing of a road surface in a vacuum environment with additional subsurface preparation. The proposed technology has merit in supporting future sustainability on the lunar surface.

This system design targets under 2% non-lunar sourced material and 20% of the power required for regolith sintering. This STTR contract has progressed to Phase II where additional DTVAC testing will be conducted on improved load bearing surfaces, berms, and walls. The Phase II outcome is a fully integrated system, including methods, materials, and prototype apparatus, validated in a simulated lunar environment (DT-VAC) and designed within the mass and energy constraints of a CLPS type payload.