RENEST: REFURBISHMENT ENHANCED NON-SINTERED EXTRUDABLE SURFACE TECHNOLOGY. H. McGillivray[1], T. Vazansky[1], C. Andersen[2], [1]Astrobotic Technology (1016 N. Lincoln Ave., Pittsburgh, PA 15233, hunter.mcgillivray@astrobotic.com, travis.vazansky@astrobotic.com), [2]Pacific International Space Center for Exploration Systems (200 West Kawili Street, Hilo, HI, 96720, canderse@hawaii.edu).

Introduction: Dust mitigation is recognized to be one of the top priorities for any permanent or long-term outpost on other planetary bodies. Regolith ejected from vehicles upon landing or takeoff has the potential to cause significant harm to personnel or equipment located in the vicinity of the landing area [1]. If multiple vertical takeoff/vertical landing (VTVL) events are to take place in one location due to the presence of a permanent outpost, some form of surface stabilization will be required to prevent the regolith from being ejected into the surrounding areas. Therefore, landing pads are among the first components of infrastructure that need to be completed. To meet this need, Astrobotic Technologies and PISCES (Pacific International Space Center for Exploration Systems) have collaborated on an STTR Phase I and II for NASA to develop RENEST (Refurbishment Enhanced Non-Sintered Extrudable Surface Technology). This is a novel construction material that is heat resistant, uses in-situ materials, and requires low-energy input for construction of landing pads.

Phase I Paver Fabrication: RENEST uses regolith feedstock, binder, and an accelerant, which are combined and then cured into a hardened surface. However, in the Phase I project only the binder and mare-like crushed basalt regolith simulant were used until the accelerant was later found useful in Phase II to speed up the curing process.

Paver Fabrication. 11 pavers were fabricated during Phase I by placing a mixture of the binder-regolith material into a mold that was then cured in a vacuum chamber (Figure 1). The mixture was a ratio of 2.3:1, basalt to binder. Conditions in the chamber were varied to replicate surface conditions for both the Moon (1.5×10^{-3} torr) and Mars (7.5 torr, CO_2) for different samples. In addition to single pavers, grouted versions were also produced with two types of joint interfaces used for different pavers, a straight profile and a wedge profile. These joints were then grouted with the same binder-regolith mixture and re-cured in vacuum.

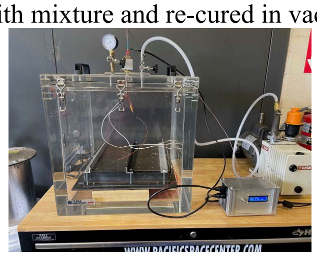

Figure 1: Paver Mold in PISCES Vacuum Chamber

Phase I Hot Fire Test Program: To test the viability of this material for VTVL pads, the fabricated pavers were tested under Astrobotic's plume surface interaction (PSI) rocket test stand.

Hot Fire Testing. The PSI test used a 100 pound-force gaseous oxygen/methane heat sink engine (Figure 2). Each test was conducted at full thrust for two seconds with the engine height set at 0.2 meters above the sample. For grouted pavers, the plume fired directly onto the joint.

Figure 2: Active hot fire test

Paver Reconditioning. After the initial hot fires, four of the single pavers were reconditioned using the same binder-regolith mixture. Before applying the mixture, the surface was prepped in one of two ways, using a v-shape or inverted v-shape cutout. They were then re-cured with the same process that was used to originally produce the full pavers, and they were re-tested under the rocket plume.

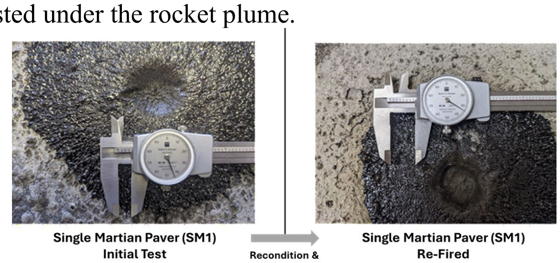

Figure 3: Sample of paver that was tested, reconditioned, then re-tested under the rocket plume

Phase I Results: The pavers maintained good integrity throughout the hot fire test campaign with 9 of 11 pavers surviving un-breached in the first round of testing, and all 4 reconditioned pavers surviving un-breached. Structural testing of the samples showed a compressive strength of 13.7 MPa for lunar pavers prior to hot fire testing and 5.1 MPa afterwards. Martian pavers showed 14.2 MPa before testing and 9.0

afterwards. The pre-test results are roughly around the strength of residential concrete [2], although this obviously degraded after hot-fire. The hot-fire results themselves were promising in terms of viability for RENEST in a plume environment, but further testing and analysis should be conducted to determine whether the structural capacity is fully acceptable for use as a landing pad in reduced gravity environments.

Phase II Production Unit Development: The main objective of the Phase II effort was to develop a system that could produce pavers while fully in vacuum. The system went through several design iterations, but the team settled on a mix-in-mold architecture, which was assembled then tested in a dirty thermal vacuum chamber (DTVAC) at Michigan Technological University (MTU).

Mix-in-Mold Design. The system stores regolith, binder, and curing accelerant onboard, and the materials are dispensed into a mold where they are mixed until homogenous. The mold is contained within a chamber that can be pressurized and de-pressurized at stages throughout the process. The mold is also on a gantry, so once the paver is cured, the gantry lowers, allowing ejection pins to unseat the paver from the mold. Then a wiper actuates to push the paver off the gantry and make way for a new paver to be made. The system is controlled through a custom graphical user interface.

Mixture Optimization. One of the critical issues with the existing CONOPS was the duration of time required for curing. Cure durations in Phase I were approximately 30 hours, which would not be feasible during DTVAC testing. After some experimentation, an accelerant was added to the mixture process, reducing the cure time to as little as 5 hours. The ratio of this mixture was 1.9:1, LHS-1E highlands regolith simulant to binder + accelerant (650 g of simulant, 140 g of binder and 210 g of accelerant).

Phase II DTVAC Testing: The RENEST mix-in-mold unit was tested in MTU's DTVAC chamber, and compression testing was performed on the most viable paver that was produced from these runs.

DTVAC Test Runs. The primary RENEST unit, consisting of material storage, pumps, valves, mold, and mixer were all placed in DTVAC (Figure 4) while the electronics remained outside the chamber. Three paver production test runs were completed. The first test failed to produce a viable paver, but procedures were adjusted to produce a partially successful paver on the second run. Further adjustments led to successful paver production on the third test (Figure 5).

Figure 4: RENEST in DTVAC

Figure 5: DTVAC Test Sample #3

Compression Testing. The paver from the third and final test was cut into segments based on material conditions throughout the paver. Some variations in the mixing process resulted in a non-homogenous final product with corner regions having a higher binder concentration, although the final cured paver was fairly cohesive. The average strength of these sample segments was 3.7 MPa, which is below the sample strengths achieved in Phase I. The exact reason for these variations requires further investigation, although some of the contributing factors may have been the reduced cure time (30 hrs vs. 5 hrs), or change in simulant type. Phase I used basalt material found locally to PISCES on the Island of Hawaiʻi, while Phase II used LHS-1E Highlands Simulant from Space Resource Technologies [3].

Conclusion: The combination of results from Phase I and II of the RENEST program shows promising performance in terms of viability for landing pad construction, although some aspects would benefit from further investigation. Primarily, further mixture studies should be conducted to understand which factors contribute to optimal structural performance.

References: [1] Immer, C. *et.al.*, (2011) Icarus, vol. 211, issue 2, 1089-1102. [2] National Ready Mixed Concrete Association, "Testing Compressive Strength of Concrete," Concrete in Practice, 35, 2003. [3] Space Resource Technologies, "Lunar Highlands (LHS-1E) Engineering Grade Regolith Simulant. Space Resource Technologies," [Online]. Available: https://spaceresourcetech.com/collections/lunar-simulants/products/lhs-1e-simplified-lunar-highlands-simulant. [Accessed Mar. 16, 2026].