LOW-ENERGY ADDITIVE CONSTRUCTION FOR THE MOON AND MARS. M. Kuhns[1], C. Andersen[2], T. Vazansky[1], S. Lamb[1], and J. Slavik[1], [1]Masten Space Systems (1570 Sabovich Street, Mojave, CA 93501, mkuhns@masten.aero), [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 for a base. Being able to build these structures with in-situ resources and with a minimal amount of payload from the Earth is the preferred approach. Masten Space Systems and the Pacific International Space Center for Exploration Systems (PISCES) have collaborated on an STTR Phase 1 project for NASA to develop novel construction materials that will meet this need on the Moon and Mars.

Construction Method: Developing a methodology to use regolith as a feedstock for construction of surfaces structures is highly desirable. It is abundant on both the Moon and Mars, which would reduce the payload mass that needs to be transported from Earth for construction materials. Sintering regolith is one proposed method for building landing pad structures, however it is an energy intensive process that may be prohibitive during early phases of buildup for a remote outpost [2]. Instead, the Masten/PISCES team has developed a novel binder-regolith composite that can be cured into hardened construction materials in both vacuum and CO_2 environments. The composite is resistant to high temperatures, making it a useful material for VTVL pads. Additionally, the material can be used to fill joints between fabricated paver bricks and can be used to repair damaged sections of constructed areas as well.

Test Program: To test the efficacy of this material for VTVL pads, PISCES is fabricating multiple pavers that are being tested under Masten's plume surface interaction (PSI) rocket test stand.

Paver Fabrication. 12 pavers are being fabricated by placing a mixture of the binder-regolith material into a mold that is then cured in a vacuum chamber (Figure 1). Conditions in the chamber are varied to replicate surface conditions for both the Moon and Mars. In addition to single pavers, grouted versions are also produced with two types of joint interfaces used for different pavers, a straight profile and a wedge profile (Figure 2). In total PISCES is producing four single Lunar pavers, four single Martian pavers, two grouted Lunar pavers, and two grouted Martian pavers. Most samples are being provide to Masten for hot fire testing, although two single pavers will be retained at PISCES to undergo structural testing. Results from this test will be used as a baseline; other pavers are being structurally tested after being subjected to the rocket plume test.

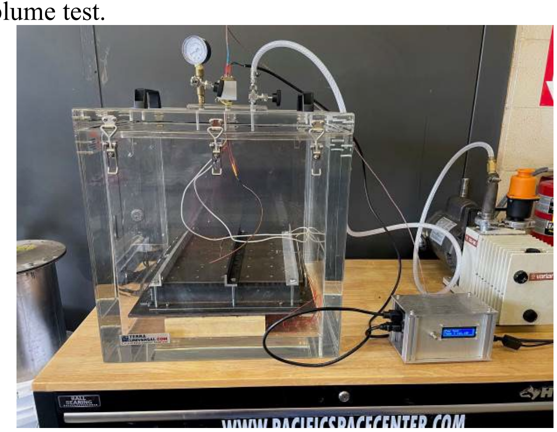

Figure 1: Paver Mold in PISCES Vacuum Chamber

Figure 2: Paver Interface Types

Hot Plume Testing. The fabricated pavers are being tested under a relevant rocket exhaust plume using Masten's 100 pound-force PSI test stand (Figure 3). Each test is conducted at full thrust for two seconds with the engine height set at 0.2 meters. For grouted pavers, the plume fires directly onto the joint.

Figure 3: Active Hot Fire Test

Figure 4: Single Lunar Paver Post-Hot Fire

Paver Repairs. After the initial hot fires, four of the single pavers are being repaired using the same binder-regolith mixture. Before applying the mixture, the surface will be prepped in one of two ways, using a v-shape or inverted v-shape cutout (Figure 5). They will then be cured with the same process that was used to originally produce the full pavers, and they will be retested under the hot plume. Finally, the repaired pavers will be structurally tested to compare their integrity to the original and single-hot fire pavers.

Figure5: Post-Hot Fire Repair Types

Remaining Work: This STTR Phase 1 is currently in progress and testing is on-going. Paver repairs are being conducted with retests under the hot plume, as well as structural testing for all paver samples. Additionally, a prototype extruder design is being developed, which will include a mix and feed mechanism to deploy the construction material in a Lunar environment.

Conclusion: Initial testing under this program has shown promising results. Damage did breach through the pavers in two cases, but all other initial hot fires only produced shallow divots as shown in Figure 4. This test campaign is on track to prove out the novel binder-regolith composite as a useful method for using space resources to construct VTVL pads and other infrastructure elements on the Moon and Mars.

References: [1] Immer, C. *et.al.*, (2011) Icarus, vol. 211, issue 2, 1089-1102. [2] Hintze, P.E. (2010) Space Manufacturing 14, 29-31.