TRL 6 TESTING RESULTS FOR THE MASON TOOL SUITE FOR IN-SITU LUNAR CONSTRUCTION BY MICROWAVE SINTERING. L. R. Moss[1], P. F. Flowers[2], V. Rao-Aourpally[3], N. J. Gelino[4], E. A. Bell[5], B. A. Kemmerer[6], D. E. Essumang[7], A. M. St John[8], E. Skirde[9], [1]Redwire Space, 8226 Philips Hwy, Suite 101, Jacksonville FL 32256, lin.rossmann@rdw.com, [2]Redwire Space, patrick.flowers@rdw.com, [3]Redwire Space, vineel.rao-aourpally@rdw.com, [4]Swamp Works, Kennedy Space Center (KSC), NASA, Mailstop NE-L6, KSC, FL, 32899, evan.a.bell@nasa.gov, [5]Swamp Works, Mailstop NE-L6, nathan.j.gelino@nasa.gov, [6]Swamp Works, Mailstop NE-L6, beverly.kemmerer@nasa.gov, [7]Swamp Works, Mailstop NE-TI, deborah.essumang@nasa.gov, [8]Swamp Works, Mailstop LASSO-13, aidan.m.stjohn@nasa.gov, [9]Swamp Works, Mailstop NE-L6, elise.skirde@nasa.gov.

Introduction: Lunar infrastructure such as roads, berms, and landing pads will be critical to lunar operations and long-term lunar presence. Due to the extreme cost of transporting material from the Earth to the moon, in situ resource utilization (ISRU) will be necessary for lunar infrastructure construction. Mason is a platform-agnostic tool suite, currently undergoing Technology Readiness Level (TRL) 6 testing, that uses microwave (MW) heating to sinter regolith into solid material for construction.

The three Mason tools are BASE (Blade for Autonomously Surfacing Environments), which smooths and grades the lunar surface and removes rocks; PACT (Planetary Autonomous Compaction Tool), which compacts the smoothed regolith to 80% relative density or greater; and M3LT (Microwave Melter of Martian and Lunar Terrain), which sinters the compacted regolith into a solid material via microwave radiation controlled using noncontact surface temperature sensors.

M3LT has been tested with four types of lunar regolith simulant including both highlands and mare types. While process parameter adjustment is required when changing simulant types, all tested simulants were successfully sintered, increasing confidence that M3LT can be used on a wide range of lunar and Martian soils. This work presents early results from TRL 6 testing of PACT and M3LT on a highlands type lunar simulant that is relevant to the lunar south pole region targeted by the Artemis program.

Hardware Overview: PACT and M3LT were integrated together inside the Atmospherically Sealed Simulator for In-Situ System Testing (ASSIST) chamber at Swamp Works, shown in Figure 1. Chamber pressure during testing is kept below 1 mTorr, typically near 1e-5 Torr, and cooling loops enable testing on regolith pre-chilled to lunar-relevant temperatures.

Compaction and sintering operations are done within the same vacuum test cycle, preventing disturbance of the regolith during pumpdown and repressurization. To reduce effects of spurious MW reflections, the sandbox inner walls are lined with absorber panels cooled with cooling loops.

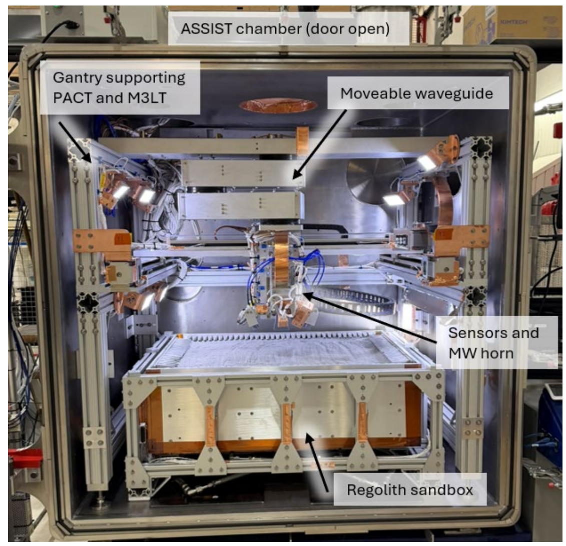

Figure 1: PACT and M3LT in TRL 6 test chamber.

Results: This work presents early results from M3LT's TRL 6 testing, which is currently underway.

Reproducibility of heating. Noncontact temperature measurements of the regolith surface are used to control the sintering process. The heating response of the regolith exhibits excellent reproducibility, as shown by the applied power and surface temperature vs time curves of selected tests in Figure 2.

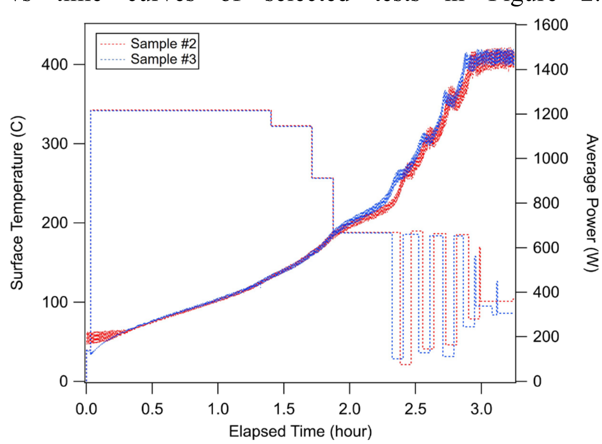

Figure 2: Temperature and applied power for two sintering tests showing excellent reproducibility.

Strength results. Splitting tensile strength testing (ASTM D3967) was done on samples sintered at various temperatures, with tensile strengths ranging from 2.2 to 8.8 MPa (see Figure 3). For comparison, typical Portland cement concretes have tensile strengths between 2 and 5 MPa [1] and ultra-high performance concretes, which contain fiber reinforcement, have tensile strengths up to 10 MPa [2]. Additional tensile strength testing, compressive strength testing, and other mechanical and thermal property testing is ongoing.

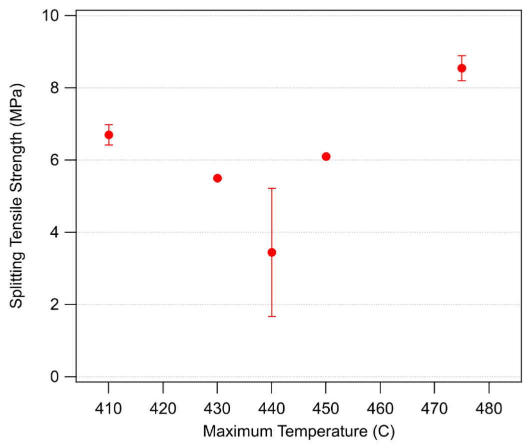

Figure 3: Splitting tensile strength results for regolith sintered at 5 maximum temperatures. N = 1 or 2 samples per temperature, with error bars indicating standard deviation for temperatures with two tested samples.

Extension to large structures. The earliest Mason sintering tests used a stationary MW horn. By incorporating motion, later testing found much higher efficiencies (in terms of sintered mass per energy and sintered mass per processing time) in "pseudo-stationary" tests in which the MW horn continuously moved in a circle, heating a larger region at once. Testing in the larger ASSIST chamber enabled extension from 0D into 1D by moving the MW horn in a row of overlapping circles, creating much longer samples. Upcoming tests will include additional dimensions to demonstrate extensibility of the construction method to large 2D and 3D structures.

The 1D motion tests were conducted with the same total path length (200 mm) and the same MW recipe to investigate the effects of circle diameter and overlap. Table 1 summarizes the parameters tested.

Table 1: Summary of parameters for motion tests.

Sample	#1	#2	#3	#4
Circle dia. (mm)	80	50	50	25
Circle overlap	50%	50%	80%	50%
Total energy (kWh)	7.60	7.07	5.94	5.22
Sintered mass (g)	1124	895	673	1025
Efficiency (g/kWh)	148	127	113	196

For the same total path length, varying the motion parameters has a significant effect on the sintering efficiency as well as resulting sample shape and quality. Efficiency (sintered mass per total energy) was 1.7 times greater for the most efficient parameter set compared to the least; continued improvements are expected with further tuning of parameters. Figure 4 illustrates the effect of motion parameters on sample quality. The two samples shown, #2 and #3, differed only in the number of circles and degree of overlap of the circles. While both had similar efficiency, the 80% overlap test had more uniform heating than the 50% overlap test, resulting in a sample of much more uniform shape.

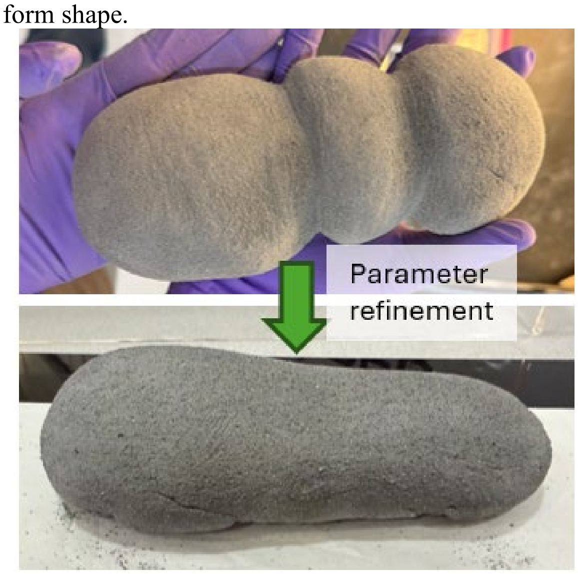

Figure 4: Significant improvement in sample quality achieved by adjusting process parameters. Top: #2 (50% overlap). Bottom: #3 (80% overlap).

Conclusions: Mason's compaction and sintering tools, PACT and M3LT, have been successfully tested in a relevant environment, producing sintered regolith with mechanical strength similar to high-strength concrete. Work is ongoing to complete the planned TRL 6 testing and fully characterize samples. The early results presented herein are promising and suggest this technology is suitable for in-situ construction of roads, landing pads, berms, and other infrastructure for lunar activities. Future testing will focus on process optimization to maximize mechanical properties and eliminate processing defects to ready this technology for flight.

References:

[1] The Engineering ToolBox (2008). *Concrete Properties*. [online] Available at: https://www.engineeringtoolbox.com/concrete-properties-d_1223.html [Accessed 07 April 2026].

[2] Russell H. G. and Graybeal B. A. (2013) *Ultra-High Performance Concrete.*