Moon Adaptive Technology for Extraterrestrial Architectural Robotics (MATEAR). Candela Solis Zampini, Space Resources Technologies. 532 S Econ Cir #100, Oviedo, FL 32765. Cacndela@gmail.com.

Introduction: The development of sustainable infrastructure on the Moon relies heavily on in-situ resource utilization (ISRU), where locally available materials are used to construct structural components such as landing pads, roads, and protective habitats [4, 5]. Lunar regolith is an abundant granular material formed from billions of years of meteoritic impacts and space weathering [2]. Unlike Earth environments, the Moon has an extremely tenuous atmosphere with a surface pressure on the order of 10^{-12} bar (≈10^{-7} Pa), effectively creating a near-vacuum environment [2, 4]. Under these conditions, construction materials must withstand mechanical loads without atmospheric confinement or moisture binding. Therefore, understanding the compressive strength and deformation behavior of regolith-derived materials is critical for evaluating their feasibility as structural elements for lunar infrastructure [1, 3].

Regolith Simulants: Two high-fidelity lunar regolith simulants were investigated in this study: LHS-1D (Lunar Highlands Simulant) and LMS-1D (Lunar Mare Simulant). LHS-1D represents the mineralogy of the lunar highlands and is primarily composed of anorthositic material rich in plagioclase feldspar, with minor pyroxene and olivine phases. LMS-1D simulates mare regions and is derived from basaltic compositions, containing higher concentrations of pyroxene, olivine, and iron-bearing minerals. Both simulants were developed to replicate the particle size distribution, angular grain morphology, and mineralogical composition of lunar soils, making them suitable for experimental studies involving ISRU technologies and construction materials.

Procedure: Regolith simulant samples were prepared using two high-fidelity lunar regolith simulants: LHS-1D representing lunar highlands material and LMS-1D representing basaltic lunar mare regolith. The samples were subjected to thermal treatment in a laboratory furnace in order to simulate sintering conditions and evaluate how heating profiles affect the mechanical performance of regolith-derived materials.

Each specimen was heated following a multi-step thermal schedule, where temperature and duration were varied between tests to investigate the influence of heating profiles on material consolidation. The furnace programs consisted of up to three heating stages, gradually increasing the temperature until reaching a maximum temperature of 1000 °C, which was maintained for different durations depending on the test configuration.

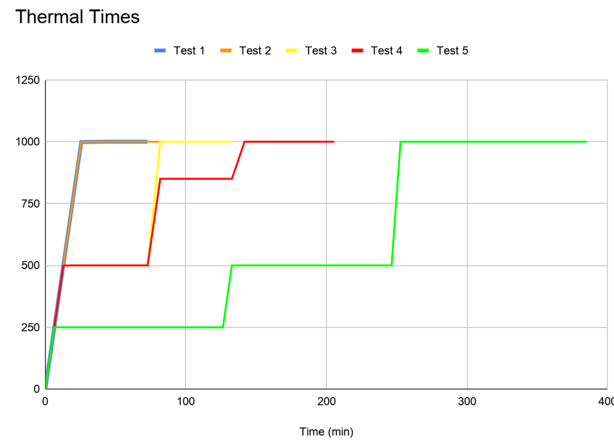

Figure 1: Graphs showing the different sintering times of the lunar bricks

After thermal treatment, the samples were allowed to cool and were then subjected to uniaxial compression testing to determine their mechanical properties, including maximum stress, compressive strength, displacement, and strain at failure.

Figure 2: Uniaxial compression test on rectangular lunar bricks, to analyze their mechanical response and failure modes under applied load.

Results: The mechanical performance of the thermally treated regolith simulant samples was evaluated through compression testing.

The maximum stress results show significant variability among the tested samples. Specimen T5A exhibited the highest maximum stress, reaching approximately 15,373 psi, indicating a strong resistance to applied load. The second highest value was observed in T2 LHS-1D, which reached approximately 10,344 psi. In contrast, T3 LHS-1D and T5 LMS-1D recorded the lowest maximum stress values, indicating weaker structural performance under compressive loading. These results suggest that the thermal treatment used in Test 5 for LHS-1D produced a material with significantly improved mechanical strength. Under Earth's gravity, this load corresponds to a supported mass of approximately 3,560 kg, while under lunar gravity the same structural element could theoretically support approximately 21,600 kg due to the Moon's reduced gravitational acceleration (1.62 m/s²).

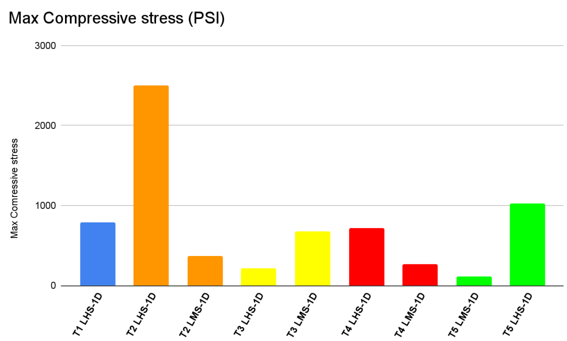

Figure 3: Graph showing the different stress levels of the samples.

The maximum compressive stress results further highlight differences in load-bearing capacity. Sample T2 LHS-1D demonstrated the highest compressive strength at approximately 2502 psi, indicating the best structural performance among the specimens. Sample T5 LHS-1D also showed relatively high compressive stress values (~1023 psi), suggesting that the extended heating profile in Test 5 contributed to improved consolidation of the material. Conversely, T5 LMS-1D showed the lowest compressive strength (~112 psi), indicating that the LMS simulant processed under the same thermal conditions produced a weaker structure compared to its LHS counterpart.

The average displacement results provide additional insight into the stiffness of the materials. Sample T5 LMS-1D exhibited the lowest average displacement (~0.026 in), indicating the highest stiffness among the tested samples. However, despite this stiffness, the material failed at relatively low stresses, suggesting brittle behavior. On the other hand, T3 LHS-1D exhibited the highest displacement (~0.152 in), indicating greater deformation before failure. Samples such as T2 LHS-1D demonstrated a balance between moderate displacement and high compressive strength, suggesting more favorable mechanical properties for structural applications.

Overall, the results indicate that thermal treatment conditions significantly influence the mechanical behavior of regolith simulants, affecting both their strength and deformation characteristics. Among the tested specimens, T2A demonstrated the most favorable combination of compressive strength and controlled deformation, while T5A achieved the highest maximum stress values. These findings suggest that optimized thermal processing may improve the structural performance of regolith-derived materials for potential lunar construction applications.

Applications: The mechanical performance observed in these experiments suggests that regolith-based materials could be viable candidates for lunar surface construction. Potential applications include landing pads to mitigate plume ejecta during spacecraft descent, regolith-based roads for rover mobility, radiation shielding structures, and structural components for lunar habitats. Because the lunar surface environment lacks atmospheric pressure and experiences extreme temperature fluctuations, materials with sufficient compressive strength and deformation tolerance are essential for maintaining structural integrity under mechanical loads.

Future Work: Future studies will focus on improving the mechanical consistency and strength of regolith-derived materials through optimized processing techniques such as sintering. Research will focus on finding effective methods to bond these bricks together to create cohesive, load-bearing systems. Developing a reliable way to "weld" these elements will be a critical step toward the robotic construction of landing pads, habitat walls, and vaulted structures. Furthermore, testing these joined assemblies under simulated lunar vacuum and thermal cycling will be necessary to validate the structural integrity of the bonds against the Moon's extreme environmental conditions

References: [1] Cannon K. M. and Britt D. T. (2019) *LPSC L*, Abstract #2132. [2] Exolith Lab (2021) *LHS-1D and LMS-1D Technical Data Sheets*, University of Central Florida. [3] Isachenkov M. et al. (2022) *Planetary and Space Science*, 211, 105400.[4] Long-Fox J. et al. (2023) *Advances in Space Research*, 71, 5400–5412. [5] Schrader C. M. et al. (2010) *Lunar Regolith Simulant User's Guide*, NASA/TM—2010–216446.