Lunar Low-Density (LLD-1) Regolith Simulant Development

Kārlis Šļumba, William Foster-Hall, Kevin Farries, Rebecca Muir, Yien Lik Kuo, David J. Harvey, and Brendan T. Scott
karlis.slumba@adelaide.edu.au Adelaide University, Andy Thomas Centre for Space Resources, SA 5005, Australia.

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1. BACKGROUND

Regolith on the Moon and Mars is in reduced gravity. It is extremely challenging to gravity offload regolith:

- Parabolic flights,
- Magnetic field,
- Drop towers.

Special regolith simulant can be made to solve this:

- Mixing in Styrofoam spheres (Li et al. 2015),
- Reduced compaction (Oravec et al. 2010),
- Low particle density (Pratnekar et al. 2025),
- **Low bulk density (1/6th), representative Lunar particle size distribution** (this work).

2. KNOWLEDGE GAPS

How to gravity offload the regolith on Earth for:

- Dynamic rover testing, terramechanics (Figure 1),
- Instrument testing, e.g. excavation, drilling,
- Dynamic testing of bulk movement e.g. chutes, hoppers, drum rollers,
- Construction testing e.g. compaction, settlement (Figure 6).

Figure 1. Rover testing / terramechanics in LLD-1

3. METHODS

Lunar Low-Density (LLD-1) regolith simulant made by milling exfoliated perlite and sieving down to 1.32 mm (Figure 3).

- Perlite exfoliates when heated at 760–900 °C (Reka et al 2019).
- Perlite is amorphous SiO_2 (70–75 wt.%), Al_2O_3 (12–18wt.%).

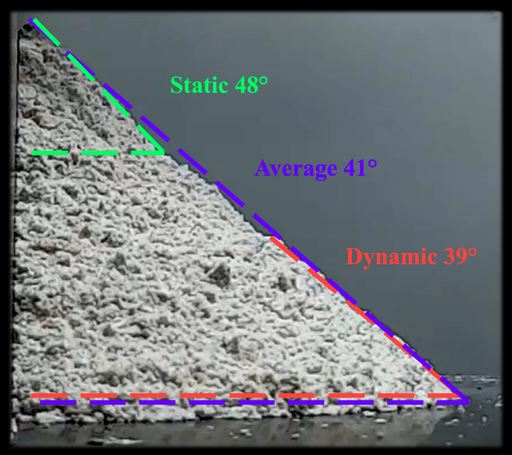

Figure 2. Angle of Repose

4. RESULTS

Geotechnical tests were performed on LLD-1 and LHS-1E.

Min, max, relative, and grain densities were measured according to AS 1289.5.5.1 and ASTM D8540-23, results are in Table 1.

- Min density of LLD-1 is 229 (max 396) kg/m^3
- Density ratio between 6.33 and 5.05 from Eq. 1.
- Gravity acceleration ratio between Moon and Earth is 6.035.
- Macroporosity 0.8-0.88, void ratio 3.90 – 7.47.

The min densities of Apollo 14, 16 and Luna 20 were 1040 - 1200 kg/m^3, max 1700 - 1800 kg/m^3 (Carrier et al. 1991).

Relative densities were calculated with Eq. 2.

Table 1. Min-Max density and density ratio of LLD-1 and LHS-1E (Agarwal et al. 2023)

Simulant	ρ_{min} kg/m^3	$\rho_{10\%}$ kg/m^3	$\rho_{25\%}$ kg/m^3	ρ_{max} kg/m^3	ρ_{grain} kg/m^3
LLD-1	**229**	**239**	**256**	**396**	**1940**
LHS-1E	1450	1491	1557	2000	2770
Ratio	6.33	6.24	6.08	5.05	1.43
Relative density	0%	10%	25%	100%	n/a

$$r = \frac{\rho_{LHS-1E}}{\rho_{LLD-1}} \quad (1) \qquad RD = \frac{\rho_{max}}{\rho} \cdot \frac{\rho - \rho_{min}}{\rho_{max} - \rho_{min}} \cdot 100\% \quad (2)$$

Figure 3. Lunar Low-Density (LLD-1) regolith simulant

Angle of Repose *was* measured using a similar setup to Easter et al. 2024, results are in Table 2.

- Three angles were recorded (Figure 3)
  - Average angle of repose
  - Static - before avalanche
  - Dynamic - after avalanche
- LLD-1 shows steeper angles

When compressed, gains high cohesion – retains vertical walls, similar to Apollo observations (Figure 6).

Table 2. Angle of repose. LHS-1* from Easter et al. 2024.

Simulant	Mass, g	Average, °	Static, °	Dynamic, °
LLD-1	**100**	**41.0 ± 1.4**	**48.0 ± 1.4**	**38.3 ± 2.9**
LHS-1E	500	39.3 ± 0.5	44.3 ± 0.8	37.3 ± 0.5
LHS-1	500	38.6 ± 1.1	43.0 ± 1.8	35.5 ± 3.0
LHS-1*	500	39.8 ± 0.6	41.2 ± 3.9	30.9 ± 4.8

Particle size distribution was measured using Mastersizer 2000 (laser dispersion), results are shown in Figure 4.

Compares well with Apollo and LHS-1

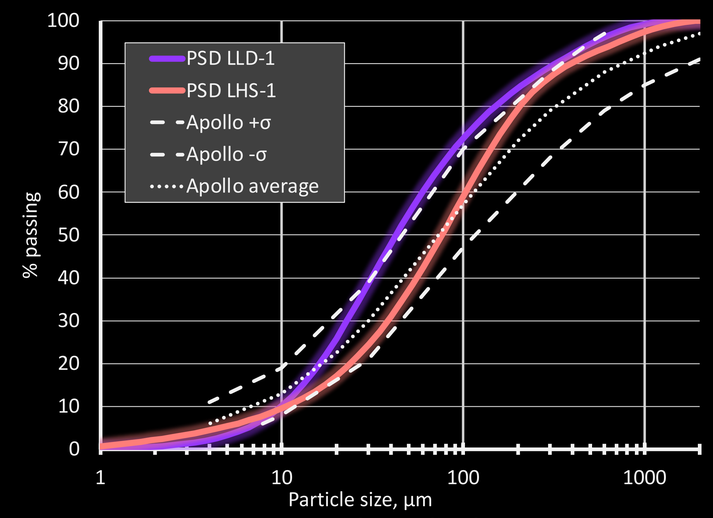

Figure 4. Particle size distribution

Microscope observations (Figure 5) reveal a fine material that looks remotely similar to lunar agglutinates or even snowflakes.

Figure 5. LLD-1 under the microscope

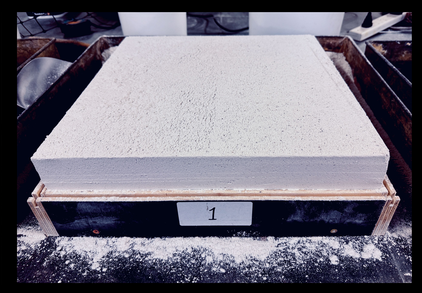

Figure 6. Cohesiveness of LLD-1

5. CONCLUSIONS

- Lunar Low-Density (LLD-1) regolith simulant was developed, tested, and produced in large amounts in Adelaide University.
- LLD-1 has 1/6th density of of other simulants at 229 kg/m^3
- Particle size distribution consistent with Apollo samples.
- Angle of repose comparable, but steeper than LHS-1.
- Retains vertical walls when compressed.
- Looks and feels like lunar regolith.

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