Baseline Characterization of Moisture Adsorption and Thermal Variation in LHS-1E for Lunar Rover Operations

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Lunar-VISE

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RIDER

Motivation

- Understanding the geotechnical properties of lunar regolith simulants and how they vary is essential for future rover operations and *in situ* resource utilization (ISRU) to support long-term lunar infrastructure [1]
- Moisture adsorption and thermal behavior in simulants significantly impact factors such as
  - Compaction
  - Wheel interactions
  - Regolith processing for resource extraction [2]

How is lunar highlands regolith simulant, LHS-1E, compacted/altered as a rover moves through it during surface operations [3]?

How does compacted regolith simulant's moisture content behave with environmental mitigations in place?

RIDER

- RIDER is a large-scale (3.8 m long × 0.9 m wide × 0.5 m deep) testbed located at UCF's Exolith Lab (Fig. 1) [4]
- Testing Configurations
  - Thermal Variation
    - 30 cm deep, uncompacted (Bulk Density: ~1.60 g/cm^3)
  - Rover specs
    - Prototype Astrobotic Polaris Wheel
    - Average speed of 9 cm/s
    - Varying loads between 5 – 50 kg
  - A hardware suite was designed and implemented into the testbed to allow for consistent heating and image locations (Fig. 2)
  - Moisture Content
    - 30 cm deep, compacted (Bulk Density: ~1.75 g/cm^3)
    - 30 cm deep, compacted with ~2 – 3 cm of loose particles on the surface layer

Figure 1: RIDER facility at UCF's Exolith Lab, with dehumidifier unit outlined in orange

Methodology & Results

Figure 2: RIDER Facility with integrated hardware suite for thermal testing

- A Hatco Glo-Ray Infrared Strip Heater was used to heat the simulant until temperature readings were within ±1°C (Fig. 2)
- Images were collected using a FLIR Boson thermal camera, and temperature readings were taken using a Mestek Industrial Infrared Thermometer
- Data was collected in three locations after every 10 wheel passes for a total of 100 (Fig. 3)
- Using ASTM Standard D2216-19 [5], samples were collected from three locations along the length of the bin to examine moisture content in both compacted and loose simulant

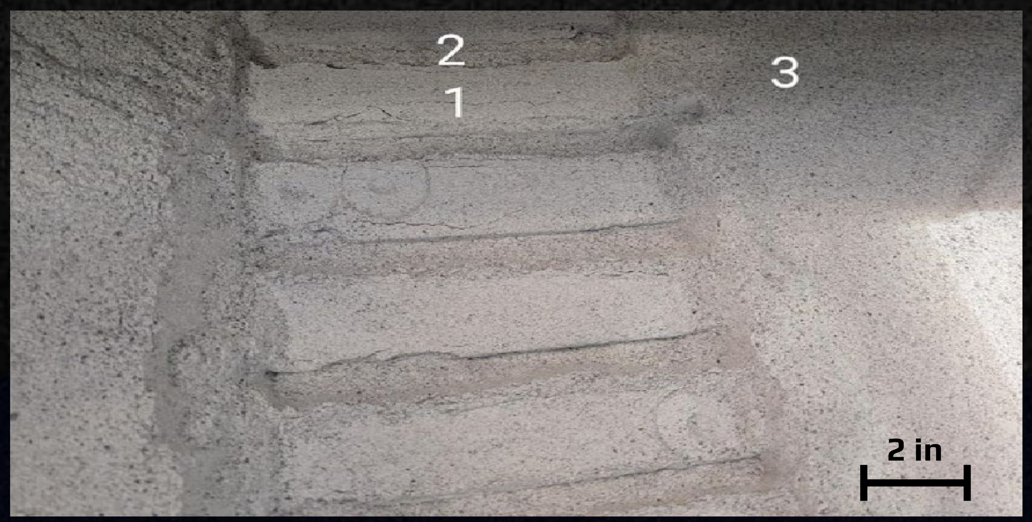

Figure 3: Temperature collection locations (numbered 1, 2, and 3) for wheel passes 1-10

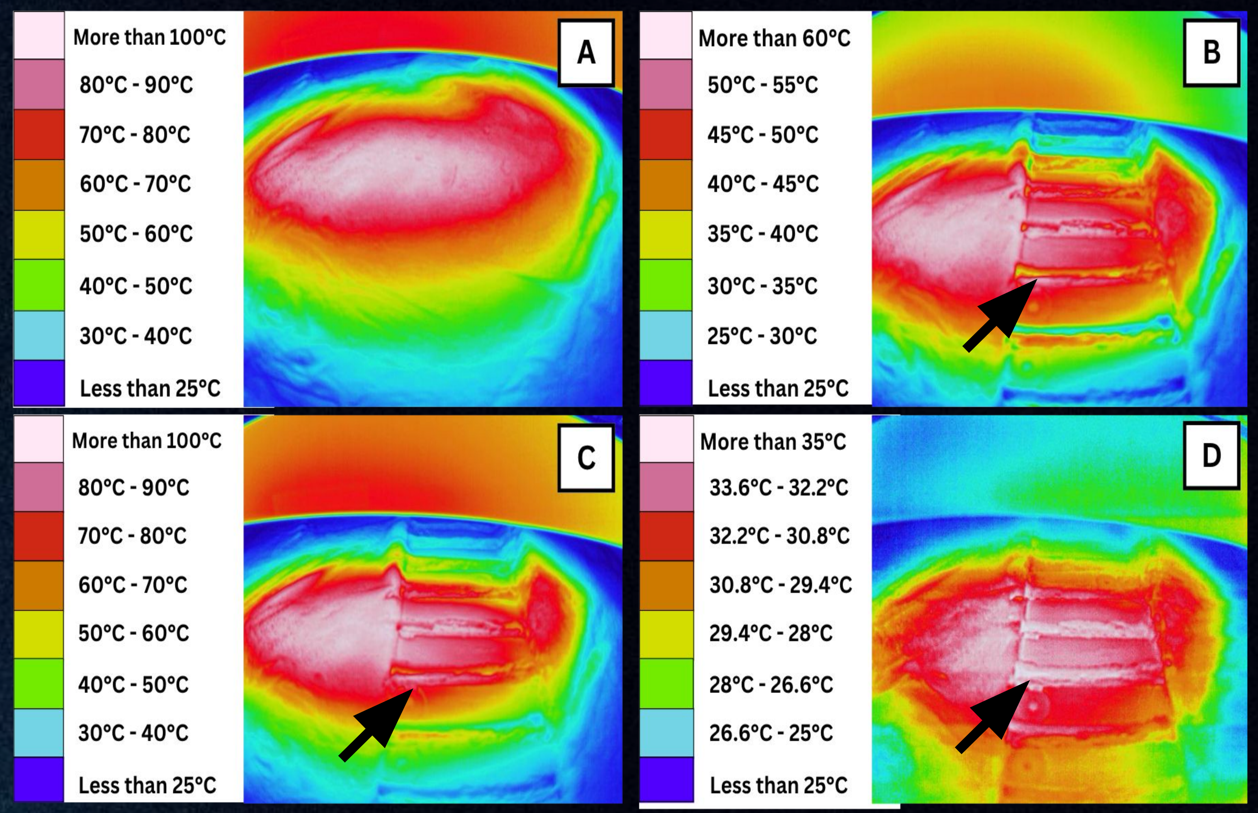

Figure 4: (Top Left) Thermal image of undisturbed LHS-1E; (Top Right) Thermal image of LHS-1E after initial wheel interaction; (Bottom Left) Thermal image of LHS-1E fully heated; (Bottom Right) Thermal image of LHS-1E during cooldown

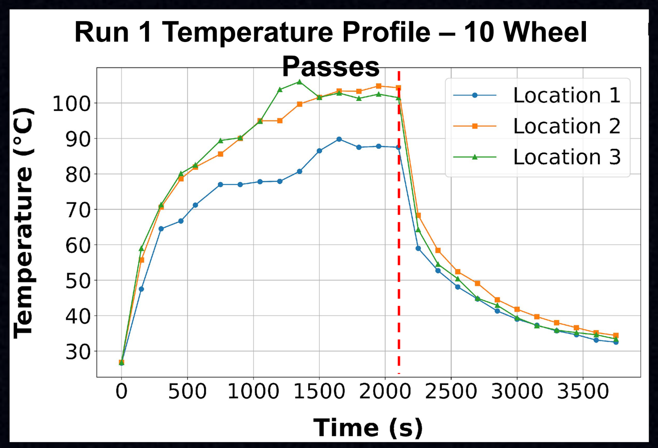

Figure 5: Temperature profile after the first 10 wheel passes, where the red dashed line indicates when the heat source was removed from the simulant

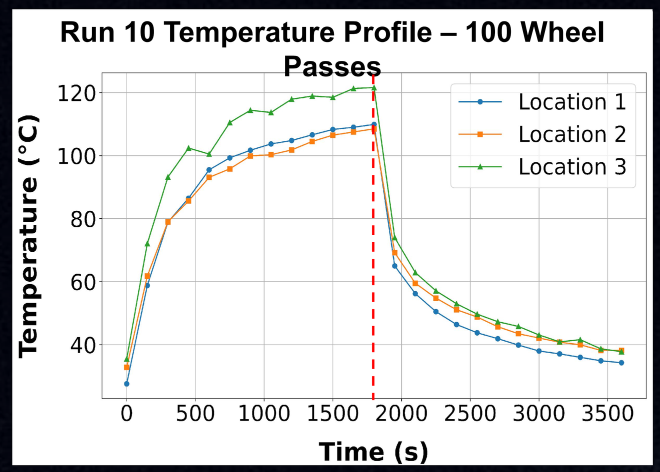

Figure 6: Temperature profile after the final 10 wheel passes, where the red dashed line indicates when the heat source was removed from the simulant

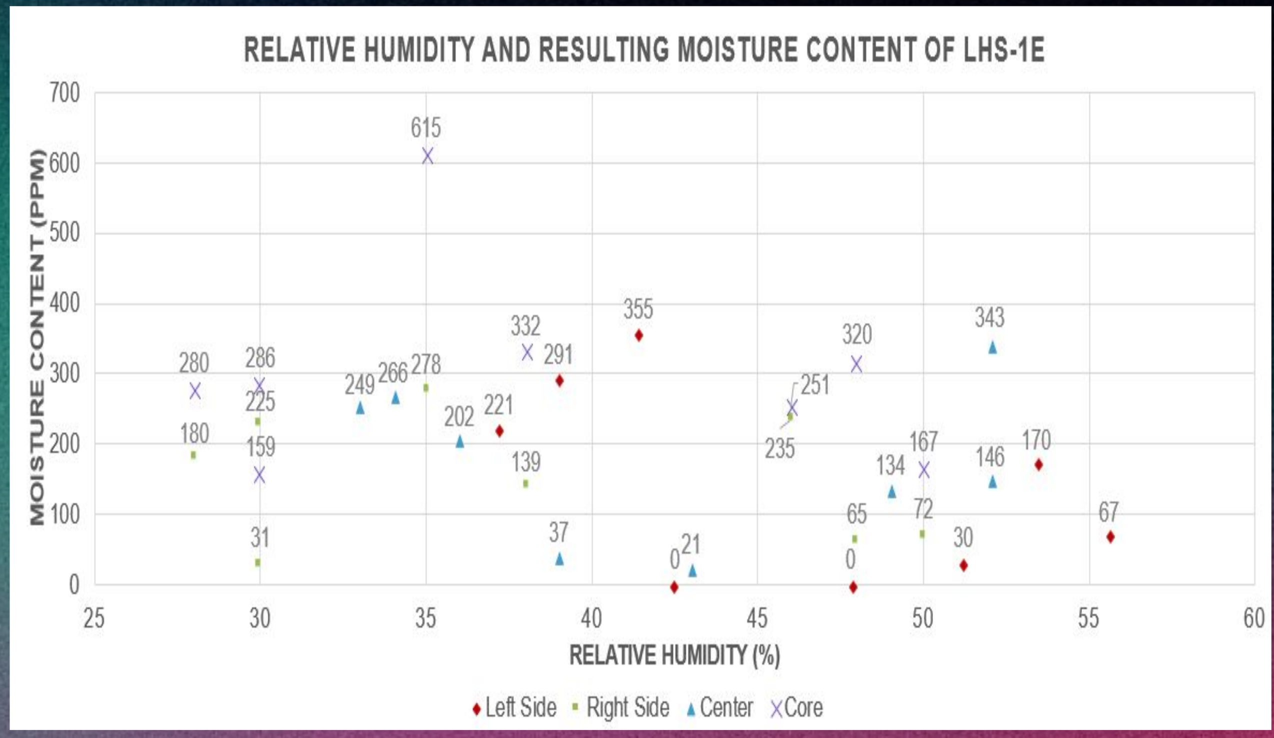

Figure 7: Relative humidity and resulting moisture content of LHS-1E within the RIDER testbed at three different surface locations and core

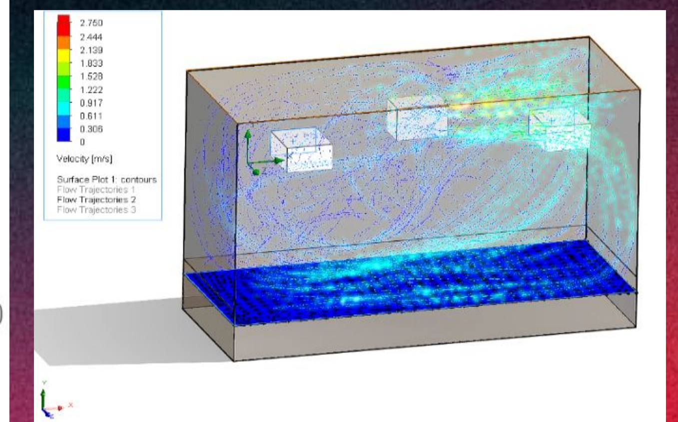

Figure 8: Fluid flow simulation within RIDER

Discussion

- Thermal Variation

Distinct temperature variation for different regions of the rover wheel path (Fig. 4)

  - **Some wheel track grouser locations** pointed away from the heat source **are cooler** due to not receiving direct illumination from the heat source (Fig. 4 Top Right)
  - **After significant exposure** to thoroughly heated surrounding regolith, the **temperatures at and throughout the grouser imprint (location 2) become relatively warmer** than those at the surface due to heat conducting downward throughout the simulant (Fig. 3, 4 Bottom Left, Bottom Right)
- Moisture Content
  - Moisture content across the RIDER testbed exhibited **significant spatial variation** (Fig. 7)
  - The **left side** of the testbed **exhibited unexpected increases** at lower relative humidities
  - The **center demonstrated a steadier trend**, while the **right side consistently showed the lowest average relative humidity**, which agrees with the simulation

Core samples, largely unaffected by surface-level humidity variations, exhibited consistent moisture content readings, indicating the influence of initial compaction conditions

Maximum Temperature by Location			
Wheel Passes	Location 1	Location 2	Location 3
70	103.5°C	109.2°C	★ **123.8°C**
90	107.9°C	**112.1°C**	117.8°C
100	**109.9°C**	108.5°C	121.6°C

★ Highest temperature experienced overall

Conclusions

- This research investigates temperature variations in LHS-1E due to rover wheel interaction and moisture content levels to establish an initial baseline under terrestrial conditions
- The thermal effects due to compaction observed in groused wheel tracks have implications for future rover operations on the lunar surface:
  - Subsurface Heat Retention
  - Thermal Mapping Accuracy
  - Rover Design

References

[1] Dotson et al. (2024) 55th LPSC Abstract #1726. [2] Long-Fox et al. (2022) ASCE Earth & Space. [3] Space Resource Technologies. (Dec. 2022) LHS-1E Spec Sheet. [4] Long-Fox et al. (2024) ASCE Earth & Space. [5] ASTM Standard D2216-19 (2019)

Acknowledgments

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