The Unique Physical Characteristics Of Simulated Lunar Ice

Off Planet Research, LLC

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Background

Mission engineers and scientists must have thorough knowledge regarding the nature of lunar ices so they can design the right hardware for these missions, test the hardware, and execute surface operations during these missions. Commercial operators need this information in order to develop lunar resources, build the basis for a lunar economy, and sustain a human presence in space.

These experiments are intended to replicate the possible natural formation processes of lunar polar ices in and on lunar regolith at the particle level. These ice/regolith mixtures were tested and observed to gain an understanding of their physical nature and how this will affect the design of future mission hardware.

Lunar regolith indicates that they were formed from different processes and components. Off Planet Research (OPR) seeks to accurately replicate these ices in their experiments.

LCROSS Data

Table 1 from Colaprete, A. et al. [2]. Summary of the total water vapor and ice and ejecta dust in the NIR instrument FOV.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecules cm⁻³</th>
<th>% Relative to H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>5.11E-08</td>
<td>1.16%</td>
</tr>
<tr>
<td>N₂</td>
<td>5.05E-12</td>
<td>0.25%</td>
</tr>
<tr>
<td>Ne</td>
<td>3.15E-12</td>
<td>0.00%</td>
</tr>
<tr>
<td>O₂</td>
<td>1.6E-12</td>
<td>0.0%</td>
</tr>
<tr>
<td>CO₂</td>
<td>1.01E-12</td>
<td>0.1%</td>
</tr>
<tr>
<td>CH₄</td>
<td>7.84E-12</td>
<td>0.8%</td>
</tr>
<tr>
<td>OH</td>
<td>3.03E-17</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 2 from Colaprete, A. et al. [2]. Relative abundances of ice components. The uncertainty in each derived abundance is shown in parentheses.

Simulants Used

Lunar regolith simulants:

- OPRH1N (Off Planet Research Highland Group 1-Non-Agglutinaitce)
- Some rounds of experiments also include OPRL1N (Off Planet Research Mare Group 1-Non-Agglutinaitce)

Lunar ice simulant created:

- OPRFLCROSS1 based on the data gathered from the LCROSS impact
- Note: SO₂ and CO components were included in the latest round of experiments. SO₂ and OH were previously not added to the simulated lunar ice for safety reasons.

Sample Preparation

Predetermined masses of simulant are placed into stainless steel containers. Liquid nitrogen was used to cool the regolith simulants and equipment to freeze the components of the simulated lunar ice as they were mixed into the regolith simulants.

The simulated lunar ice/regolith mixtures were produced using the percentage for relative ice abundance in the ejecta plume from the LCROSS impact (Tables 1 & 2). The ice and regolith were mixed so as to produce intergranular ice as this changes the particle morphology and density of the regolith.

Although the LCROSS mission indicated intergranular ices, it is likely that globular and sheet ice/regolith mixtures will be encountered as well. By altering the formation process, these types of ice/regolith mixtures can be formed. Their geotechnical and thermal properties will be different from other water ice/regolith mixtures.

Results

Early observations that show the difference in regolith dynamics between simulated equatorial lunar regolith and lunar polar regolith/ice mixtures can be seen in Graph 1. In this test, a reproduction of the Lunokhod cone-blade penetrometer tip was pressed into icy and “dry” regolith simulant and the resulting stress/strain curves were compared. The penetrometer tip as seen below was super-cooled before being pressed into the simulated polar regolith.

Future Studies/Recommendations

Conclusions:

- Icy regolith simulant appears more “slippery” on the surface and more dense with depth than non-icy simulant
- There are unique geotechnical characteristics of super-cooled regolith
- There are differences between ices formed in Highland and Mare regolith- so test both!

Possible Technical Challenges These Conclusions Present:

- Rovers may struggle to climb the slopes that current plans anticipate, especially smaller rovers
- Drilling into icy regolith will produce friction and heat that may volatilize or partially melt ice and affect the system’s operation
- “Wet” regolith may re-freeze in or on equipment affecting performance
- Material handling systems will need adaptation from “dry” regolith due to increased cohesion and density

Next Steps:

- We plan to further develop our lunar ice simulant with the goal to gain more insights into its physical nature and behavior in a variety of conditions.

We are developing SBIR proposals and research around:

- Geotechnical and thermal properties
- Volatile extraction processes
- Sensor calibration and testing

We are collaborating with NASA Ames to test the NIVS system.

Contact Information

Off Planet Research is currently located in Lacey, WA about 60 miles south of Seattle.

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References

