Effects on Force, Power, and Wear from Excavating Beds of Icy Highlands Lunar Regolith Simulant Using a Chain Trencher with Point Attack Picks

M.C. Guadagno[1] M.M. Decker[2] J. Hong[3] F. D. Gaertner[4] P. J. van Susante[5]
[1,2,3,4,5]Planetary Surface Technology Development Lab, Dept. of Mechanical and Aerospace Engineering, Michigan Technological University 1400 Townsend Drive, Houghton, MI 49931 (contact: pjvansus@mtu.edu).

Introduction: Excavation of water ice deposits is a critical part in many ISRU architectures, often envisioning long-duration campaigns to collect tons of feedstock to feed refining processes. Continuous excavation systems have been identified as ideal for early ISRU solutions due to low reaction forces and high production rates (Just et al. 2020). However, limited research has been conducted on applying continuous excavation methods for hardened icy regolith deposits which may be in PSRs. This research presents on findings from using full-scale chain trencher excavators for excavating icy lunar regolith simulant.

Methods: A chain trencher excavator was taken from the PRIMROSE rover in the Break the Ice Lunar (BTIL) challenge (Guadagno et al. 2023) and integrated with the new Force Test Stand (FTS) facility in the PSTDL for dedicated testing in a more relevant environment. The FTS was built to operate for long durations in subzero temperatures, collecting excavation data in beds of icy regolith simulant (Gaertner 2025).

A series of five tests were run by excavating 800kg beds of cemented MTU-LHT-1A icy simulant with the chain trencher (Carey and Van Susante 2022). Five to nine trenches were cut per test, varying the chain speed, cutter velocity, number of confining walls when cutting, and bed ice content. Sensors built into the FTS and chain trencher control hardware recorded power, torque and force data during testing (Figure 1).

Figure 1: Icy regolith simulant excavation with chain trencher.

The collected mass and particle size distribution of cuttings were weighed after trenching with wide-diameter particle sieves and precision scale. Percent passing was used to explore the effect of bed ice content on cutting size. The ratio of excavated material collected to excavated and lost by-mass was used to estimate a material retention ratio also as a function of bed ice content (Figure 2).

In each test bed, the point attack picks on the trenchers were removed and weighed. The current pick mass is compared to the original to get a total mass loss (TML) wear metric. In parallel, unconfined compressive strength (UCS) tests were performed on specimens of cemented regolith matching the test bed temperature and ice content to characterize strength.

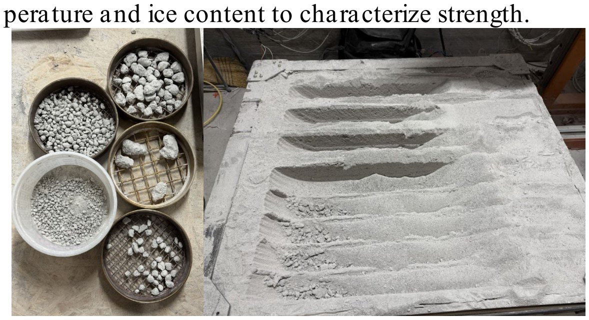

Figure 2: Sieving of collecting cuttings (left) and excavated regolith bed (right).

The previously discussed datasets were then compiled for statistical analysis to explore correlations. Statistically significant results are then used to produce various time and energy dependent figures of merit to compare performance between the BTIL level 3 competition and FTS testing. Pick wear rates and bed hardness are then compared to determine anticipated replacement rates for a mission scenario outlined in BTIL (Leucht et al. 2025) using PRIMROSE performance metrics (Guadagno 2025).

Results: UCS testing of samples representative of the beds used for trenching at -20°C revealed an exponential relationship between ice content and compressive strength (Figure 3). The CLSM used in the BTIL challenge had an average UCS of 0.59 MPa (NASA/MSFC), falling within range of bed strengths used for trencher testing.

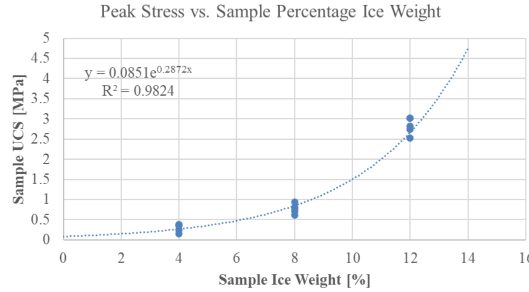

Figure 3: UCS testing of cemented icy MTU-LHT-1A

Initial results from power and force data suggest that excavation performance significantly degrades as bed ice content increases. No strong statistical difference in the responses of normalized force or power data was observed with the number of confining walls, translation rate, or chain speed. Bed hardness typically is the strongest indicator for excavation forces (Table 1).

Table 1: Preliminary results from excavation in the first three successful trenching tests in icy cemented MTU-LHT-1A.

	Test 3	*Test 4*	*Test 5*
Bed Ice Content (%)	8	12	4
Bed Hardness (MPa)	0.85	2.67	0.27
Excavator Current (A)	8	1.8	6.4
Collected Mass (kg)	48.19	20.2	52.746
Trench Length (m)	8.761	10.822	6.99
Excavation Rate (kg/hr)	48.19	67.33	62.07
Energy use (W-hr)	458.2	169.80	310.74
Specific Energy of Excavation (W-hr/kg)	9.51	8.41	5.89
% Passing <7.925 mm	88.4	88.6	99.0

TML of picks was found to vary strongly with bed hardness and the perpendicular offset of the pick from the chain centerline; across 22.3m of trench, teeth close to the centerline experienced only 2% TML while those near the edge experienced over 15% TML. In beds with a higher ice content, the regolith was found to wear away the hardened steel trencher frame, leaving scoring on the trench walls and excavated material

When averaged against the total length of trenches cut in tests 1, 3, 4, and 5 and compared to bed UCS, a clear linear relationship forms. A 10x increase in bed hardness correlates to a 15x increase in wear rate for the point attacks picks (Figure 4):

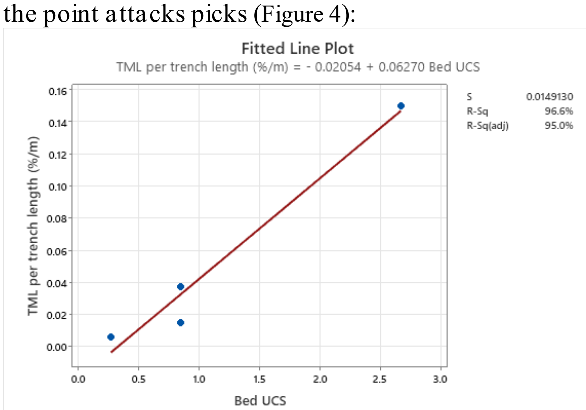

Figure 4: Linear relationship between %TML per meter of trench and regolith bed UCS.

PRIMROSE's performance metrics from the BTIL scenario were reassessed by adding a TML threshold of 20% and using the excavation rates from FTS testing. If excavating 4% icy regolith, mission time increases by 50% but still closes with positive margin. If excavating 12%, then the mission closes in half of the 192-day BTIL PRIMROSE estimate but requires many more replacements of all picks on the chain (Table 2).

Table 2: Updated BTIL PRIMROSE performance using FTS wear data

Parameter	*4% Ice Bed*	*12% Ice Bed*
Days to get 10,000 kg ice	300	96
# of replacement pick sets needed to get 10,000 kg ice	13	55
Total mass of replacements (kg)	12.58	62.92

Discussion & Conclusions: While pick replacement events are needed, the mass of landed spares is marginal compared to returned ice for refining. This model represents a fist-look at the performance of chain trenchers in icy regolith and implications to excavation missions.

Wear rate estimations as a function of UCS can be applied to any mission which uses point attack picks to excavate regolith. Future experimental work includes testing with alternate forms of icy regolith (such as pressure sintered), excavating in beds cooled to cryogenic temperatures, and alternative cutting tools.

References:

Carey, C., and P. Van Susante. 2022. "Michigan Technological Universities' Lunar Highland Simulant MTU-LHT-1A." In: *Session 4 - Individual Poster Presentations*. Golden, CO.

Gaertner, F. D. 2025. "TEST STAND DEVELOPMENT: AN ANALYSIS OF EXCAVATION FORCES WITHIN A SIMULATED LUNAR ENVIRONMENT." Michigan Technological University. https://digitalcommons.mtu.edu/etdr/1900.

Guadagno, M. 2025. "Excavation and Driving Performance of the PRIMROSE Rover during the Break the Ice Lunar Challenge." Oral Presentation and Abstract.

Guadagno, M., P. Bradshaw, H. McGillivray, J. Primeau, and P. J. van Susante. 2023. "Long Duration Testing of a Rover-Mounted Chain Trencher Excavator in Simulated Lunar Surface Conditions." In: *ASCEND 2023*, ASCEND. American Institute of Aeronautics and Astronautics.

Just, G. H., K. Smith, K. H. Joy, and M. J. Roy. 2020. "Parametric review of existing regolith excavation techniques for lunar In Situ Resource Utilisation (ISRU) and recommendations for future excavation experiments." *Planetary and Space Science*, 180: 104746. https://doi.org/10.1016/j.pss.2019.104746.

Leucht, K. W., T. J. Prater, and N. Vetcha. 2025. "Overview and Results from NASA's Break The Ice Lunar Challenge." In: *2025 IEEE Aerospace Conference*, 1–16.