MEASURED ABLATION RATES FROM ABLATIVE ARC MINING

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Introduction

The advancement of human space exploration relies on the ability to harvest local resources at destinations of interest. The ablative arc mining system, first reported as a NIAC Phase I study in 2022 [1,2], is a technology that can be used on the Moon, Mars, or asteroids to extract elements from regolith. The system uses electric arcs to extract materials from the surface and electromagnetic fields to transport and sort the extracted materials into storage reservoirs. Ablative arc mining can extract multiple elements in one system, including low density or trace elements.

Ablative Arc Mining Concept

The ablative arc mining concept uses a plasma arc incited across the regolith surface in combination with electromagnetic fields to bypass challenges related to excavating dusty regolith and capture of element in a rarefied flow environment. The major elements are shown in Figure 1.

1) Two electrodes are placed on the surface of the regolith. A high-voltage is applied to the electrodes to incite a plasma arc across the surface.

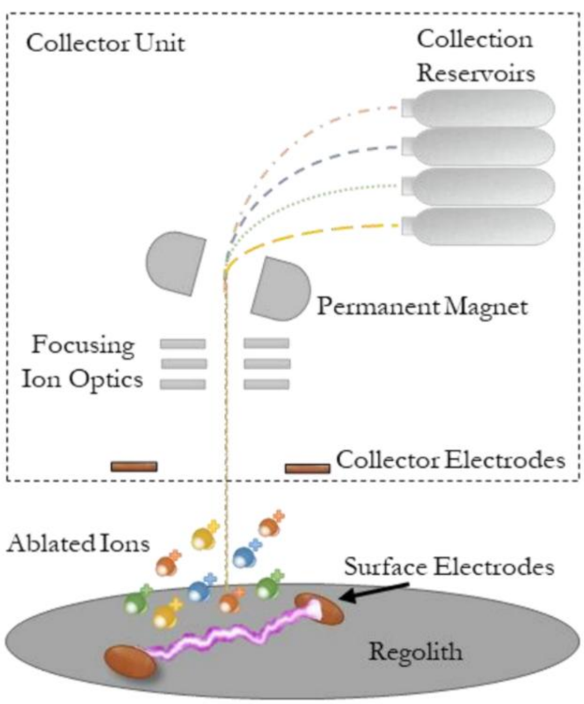

Figure 1: The ablative arc mining system ionizes regolith before transporting and separating the materials using electromagnetic fields

2) The energy of the arc discharge ablates and ionized the regolith into charged ions.
3) The ions are controlled using electromagnetic fields that do not require any minimum background pressure into a nearby collector unit.
4) The ions are focused into a collimated beam using ion optics for uniform velocity profiles.
5) The ions are separated by mass through magnetic deflection, similar to a mass spectrometer.
6) Dedicated collection reservoirs are placed in the path of the respective ion beams to collect and store each material.

Ablation Rate Measurements

Initial lab ablation experiments measured ablation rates inside a thermal vacuum chamber. An open top box of regolith simulant at -25^{o}C was placed into the front of a thermal vacuum chamber. A second identical regolith box (control) was placed in the rear of the chamber to observe changes from ambient effects.

Two copper electrodes with a width of 14mm were placed onto the regolith surface. The electrodes were connected to a Matsuada AU-40P7.5-LC high-voltage power supply supplying a 22.5 kV arc with a current of 17mA pulsed at 1 Hz between the electrodes for 20 minutes. Images of the ablative arc are shown in Figure 2. The progression of the regolith ablation to form a small crater between the electrodes is visible.

After 20 minutes of ablation, the regolith boxes were removed from the chamber and the dimensions of the crater were measured using calipers to determine the total volume of regolith ablated, from which mass loss was inferred from regolith density. The volume of regolith ablated and the regolith density were used to determine the mass of the ablated regolith in place of direct mass measurement as there was no system in place to collect ablated particles and many may have fallen directly on to the regolith surface elsewhere in the box affecting the mass results.

Initial results for arc induced ablation rates are shown in Table 1 for dry and wet (frozen) lunar highlands simulant, Mars global simulant, and carbonaceous chondrite (CI) asteroid simulant. Neither the electrode design nor the applied power parameters have been optimized to suit the regolith type or the environmental conditions and these results should be considered preliminary values only. The preliminary ablation rates recorded in the lab have been extrapolat-

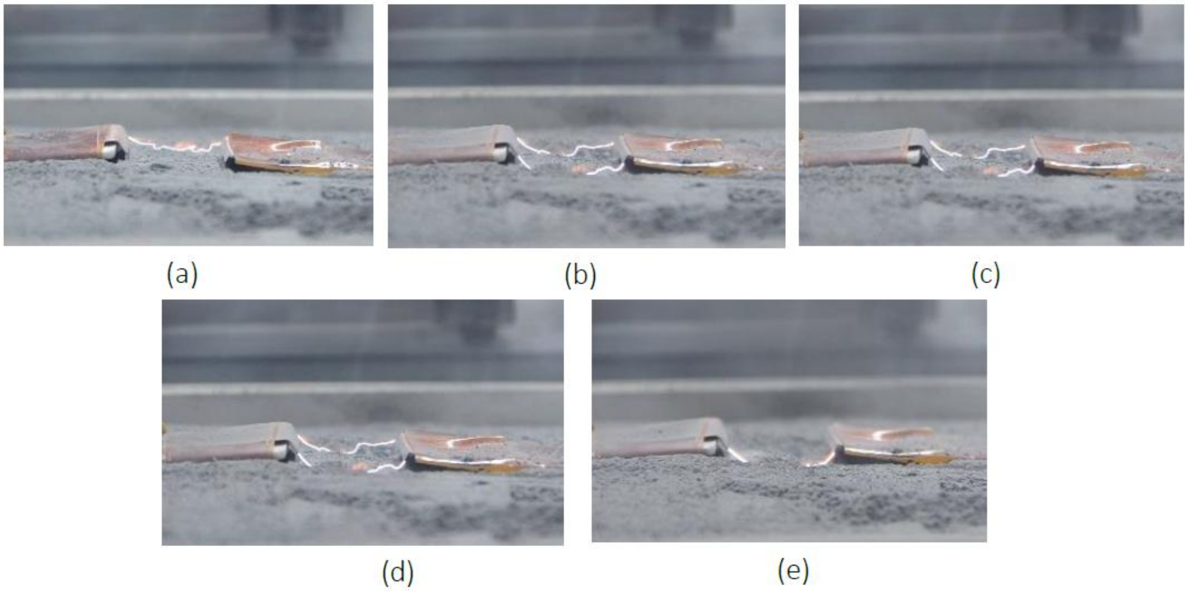

Figure 2: Progressive ablation mining images for Carbonaceous Chondrite (CI) asteroid simulant at (a) 0 min, (b) 5 mins, (c) 10 mins, (d) 15 mins, and (e) 20 mins.

ed to yearly collection rates for a deployed unit with mass of 1 metric tonne and power of 2.5 kW.

Table 1: Early lab experiments showed ablation rates that scale to thousands of kg per year.

Regolith	Ablation Rate (kg/kWh)	Yearly Collection (kg)*
LHS (dry)	0.24	840
LHS (1.8% H_2O)	0.92	3200
LHS (5.7% H_2O)	0.42	1470
Martian Global	0.18	630
CI Asteroid	0.48	1680

** For a 1 metric tonne, 2.5 kW collection unit*

Conclusions

The ablative arc mining system presents an alternate solution for ISRU, enabling simultaneous mining of multiple materials in a compact and maneuverable form factor without the need for excavation or fluid management.

Figure 3: The robotic elements to place the electrodes on the surface are the only moving elements in the mining collection system

Initial lab measurements of ablation rates indicate collection rates on the order of 1 metric tonne of material per year using a 1 metric tonne, 2.5 kW collection unit. However, this technology is very low maturity level (TRL 3/4) and requires additional work to demonstration system level economic applicability.

Recommendations for future work

The initial experiments recorded optical spectra using a ThorLabs CS200 Optical Spectrometer aimed at the arc location using a fiber optic cable passed through a chamber feedthrough. Additionally, a MegaSpeed MS130-K high-speed camera with Infinity K2 DistaMax microscopy lens was focused on the arc to capture high-speed magnified images of the arc. The results from these diagnostics have not yet been analyzed, but this data would provide preliminary indication of the materials being ablated from the regolith. Analysis of these results is noted as future work.

The results of the ablation rate measurements and ablated material profiles should be combined into a technoeconomic analysis to determine the most applicable materials and mining locations to take advantage of the unique characteristics of arc mining, primarily the minimal excavation needs and trace element collection capabilities.

References:

[1] Greig, A., (2022), *Earth and Space Proc.,* 243–254. [2] Greig, A., (2022) *NIAC Phase I Report,* NASA