Strategies for Lunar in Situ Resource Utilization: Adaptive Material Extrusion-based Additive Manufacturing using Lunar Regolith

M. H. Rahman, A. Hayes, M. S. Shafae, K. Muralidharan, and D. A. Loy
The University of Arizona, Tucson, AZ

BACKGROUND

Motivation: Combined with strategic in-situ utilization of indigenous resources, additive manufacturing (AM) can greatly:

1. Reduce the complexity of the material supply chain.
2. Resolve logistical problems involved with manufacturing and repair needs in remote environments and extreme conditions.

https://www.nasa.gov/mission_pages/station/research/news/3Dratchet_wrench

Overarching Goal: Develop an advanced manufacturing technology to:

1. Enable the utilization of remote in-situ materials with focus on lunar regolith constituents.
2. Fabricate on-demand parts and components providing straightforward routes for repair and refurbishment in remote environments.

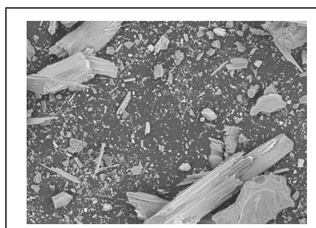
MATERIALS AND METHODS

Feedstock Material Development

- Developed a hydrogel-based material utilizing lunar regolith simulants and Pluronic F-127 (poloxamer 407), considering the water-ice availability at the Moon's poles.
- Enabled using lunar regolith in its unrefined state, only requiring sieving.
- Optimized the material mix for desirable thixotropic properties.
- Synthesized feedstock is formulated to **utilize 90 wt.% of in-situ indigenous materials**

Additive Manufacturing Process Development

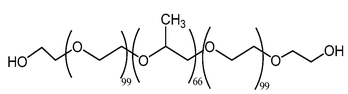
- Developed an extrusion-based additive manufacturing system
- Optimized the printability region in terms of printing speed and extrusion rate
- Systematically investigated the influence of process parameters variations on the shape retention (quality metric) of single-track prints using an experimental design approach



Exolith Lab's LHS-1 Simulant (60 wt.%)

+

Pluronic F-127 (10 wt. %)



+

Water (30 wt.%)

AM System

Single-Track Prints with a different process design for each vertical track

EXPERIMENTAL DATA ANALYSIS AND RESULTS

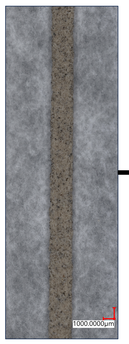
Optimized Printability Region for Lunar Regolith based Feedstock

Speed = 420 mm/min Extrusion Rate Multiplier = 1	Speed = 420 mm/min Extrusion Rate Multiplier = 2	Speed = 420 mm/min Extrusion Rate Multiplier = 3	Speed = 420 mm/min Extrusion Rate Multiplier = 4
Speed = 360 mm/min Extrusion Rate Multiplier = 1	Speed = 360 mm/min Extrusion Rate Multiplier = 2	Speed = 360 mm/min Extrusion Rate Multiplier = 3	Speed = 360 mm/min Extrusion Rate Multiplier = 4
Speed = 300 mm/min Extrusion Rate Multiplier = 1	Speed = 300 mm/min Extrusion Rate Multiplier = 2	Speed = 300 mm/min Extrusion Rate Multiplier = 3	Speed = 300 mm/min Extrusion Rate Multiplier = 4
Speed = 240 mm/min Extrusion Rate Multiplier = 1	Speed = 240 mm/min Extrusion Rate Multiplier = 2	Speed = 240 mm/min Extrusion Rate Multiplier = 3	Speed = 240 mm/min Extrusion Rate Multiplier = 4

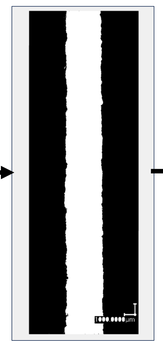
No or Unstable Deposition | Semi-Stable Deposition | Stable Deposition

Image Processing Algorithm for Shape Retention Metric Estimation

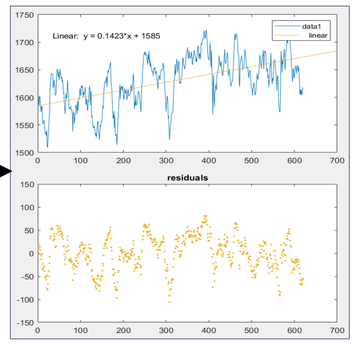
Consistency of the width across the length of the single-track prints was considered as shape retention indicator and the widths slope across the track length was used as quality metric



Printed Track

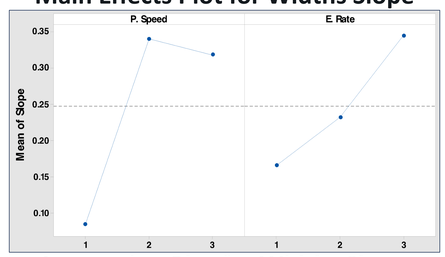


Segmented Image

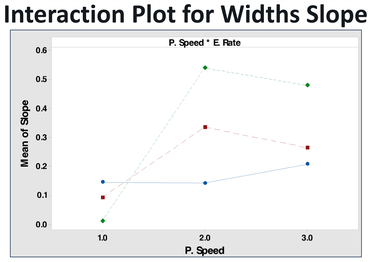


Track Width per Image Row (Top) & Residuals (Bottom)

Main Effects Plot for Widths Slope



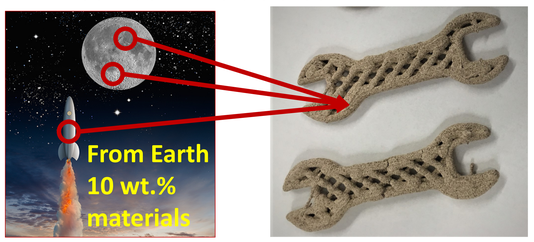
Interaction Plot for Widths Slope



CONCLUSIONS

- Our proposed material and process design **enables printing parts with only 10 wt.% material carried to the remote environment.**
- Using optimized process parameters, **prototype parts were printed successfully.**
- Future work will focus on functional properties testing and improvement and process consistency and scalability.

In-Situ Materials
60 wt.% minerals & 30 wt.% water



COLLEGE OF ENGINEERING
Systems & Industrial Engineering

Contact information: Mohammed S. Shafae, Email: shafae1@arizona.edu

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