ADDITIVE MANUFACTURING OF LUNAR REGOLITH FOR ELECTROMAGNETIC APPLICATIONS

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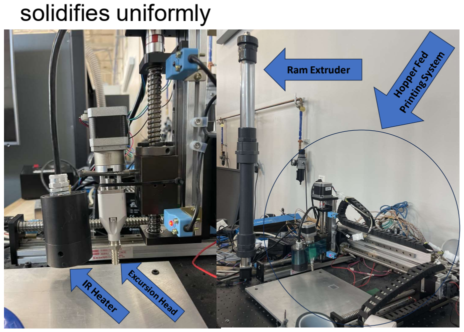
Introduction

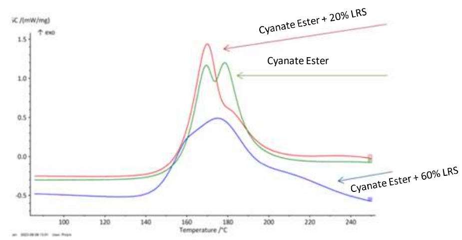
- In-situ resource utilization (ISRU) is critical for establishing a long-term human presence on the moon
- Establish an excursion based additive manufacturing system that leverages ISRU to print lunar regolith for electromagnetic applications

Materials and Excursion Method

- **Mare regolith**, found in the Moon's dark volcanic plains, is rich in basalt while **highland regolith**, located in the elevated regions, consists mainly of anorthosite
- **Cyanate Ester**: High-performance thermoset resin is known for its excellent thermal and electrical properties
- Previously utilizing a hopper-fed system, we modified the setup by adding an extrusion head and ram extruder to replicate the direct ink writing method of extrusion.
- IR Heater: Cures each layer as it is deposited ensuring that the material solidifies uniformly



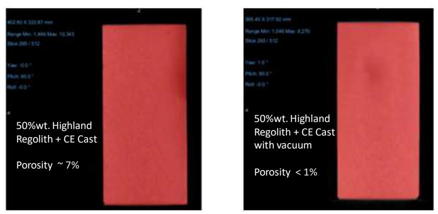
DSC Analysis



- 140°C ensures the resin does not cure during placement. This temperature range maintains the material in a highly viscous state. Post-placement, the temp should be elevated above the Tg.
- 60% LRS shows the lowest energy release, showing that it is the most efficient in terms of energy consumption.

Porosity Analysis (Micro CT Scans)

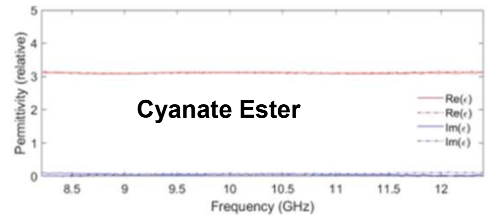
- Cast samples were prepared by molding and then heated in an oven at 120°C for 8 hours

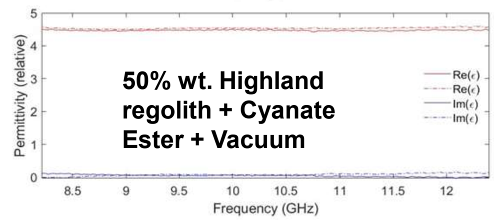


- Porosity are air pockets with a much lower dielectric constant than solid materials. Reduced porosity leads to a more uniform dielectric constant and potentially lower dielectric losses.
- Since casting (w vacuum) the mixture is not feasible in our 3D printing process, we employ pre-printing degassing to eliminate trapped air from the mixture. This technique effectively serves as our "vacuum," significantly reducing porosity.

Electromagnetic Analysis

- Wavelength measurements were conducted under four conditions to evaluate the electromagnetic parameters. The data includes permittivity, dielectric loss, and relative permeability across different material compositions.





	Mean ε (F/m)	Mean tanδ	Mean μ (H/m)
CE	3.104	0.018	1.0191
20% wt. HR + CE	3.530	0.015	1.024
50% wt. HR + CE	4.363	0.007	0.998
50% wt. HR + CE + Vacuum	4.470	0.005	1.010

- Increased ε indicates that the material can store more electrical energy within an electric field.
- For good electronic applications, a high ε and a low loss tangent is required. This allows object of a given size to hold large amounts of electric charge for longer periods of time.
- As the weight percentage (wt%) of the addition increased, the dielectric loss decreased. At 50 wt%, the loss tangent reached zero.
- This allows for a high signal integrity and improved efficiency. Materials with a low dielectric loss consume less power because there is minimal energy dissipation as heat.
- A relative permeability close to 1 means minimal magnetic interference. This is beneficial for preventing unwanted magnetic coupling and interference, which can disrupt the performance of sensitive electronic equipment.
- Non-magnetic materials ensure the stable performance of electronic devices in the presence of varying magnetic fields, which can be crucial for the reliability of lunar communication and navigation systems.

Conclusions and Further Experiments

- Lunar regolith composite shows promising electromagnetic properties suitable for lunar applications
- Future work will focus on refining the IR curing process to prevent the material from becoming overly viscous under heating.
- Rheology data to confirm DSC results for optimal curing temperature and identify the temperature at which the materials exhibit low viscosity.
- Exploring alternative additive manufacturing techniques and printing parameters to optimize layer-by-layer adhesion.

Acknowledgements

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