Polymer/Regolith Composites for In-Space Manufacturing on the Moon and Mars

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Presentation overview

Overview of ISM system

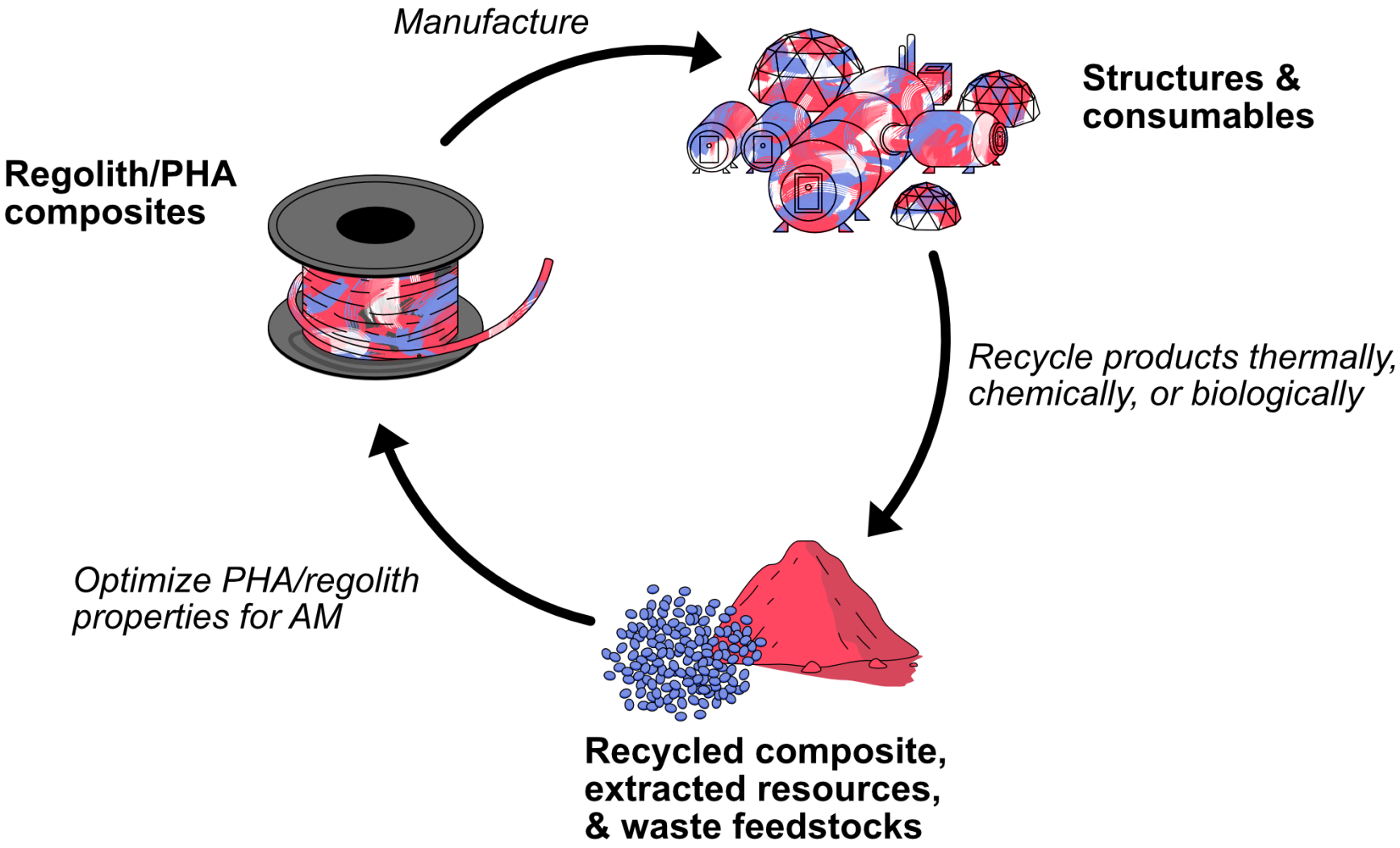
Regolith/PHB Composite Development

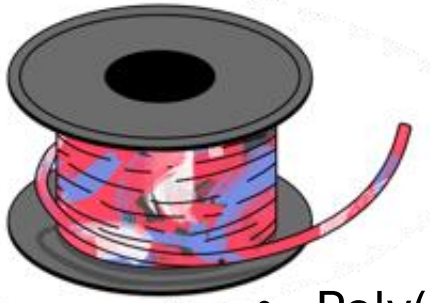
Compression Molded Composites

Injection Molded Composites

Next Steps

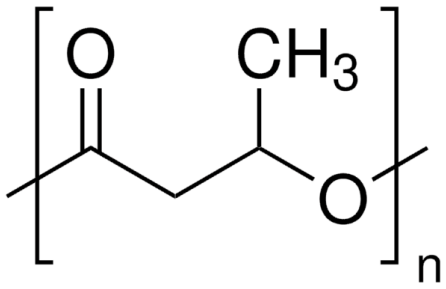
Overview of Closed-Loop ISM System





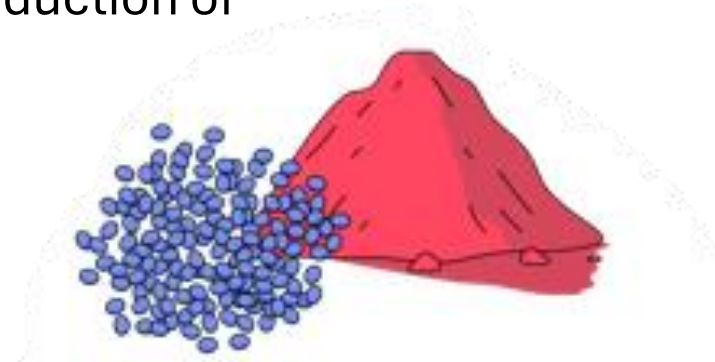
Regolith/Resin Composites

- Poly(hydroxyalkanoate)s (PHAs) are bacterially synthesized resins which offers route to in-situ manufacturing & reduced initial payload requirements for long-duration missions
- PHAs can use various sources of carbon (including waste products, CO_2, polymers etc.) to create more material
- Poly(3-hydroxybutyrate) (PHB) is the most common PHA, but generally requires additives to improve performance & manufacturability due to high crystallinity
- PHB will be used as proof of concept for initial study, although other biosynthesized resins are also viable candidates



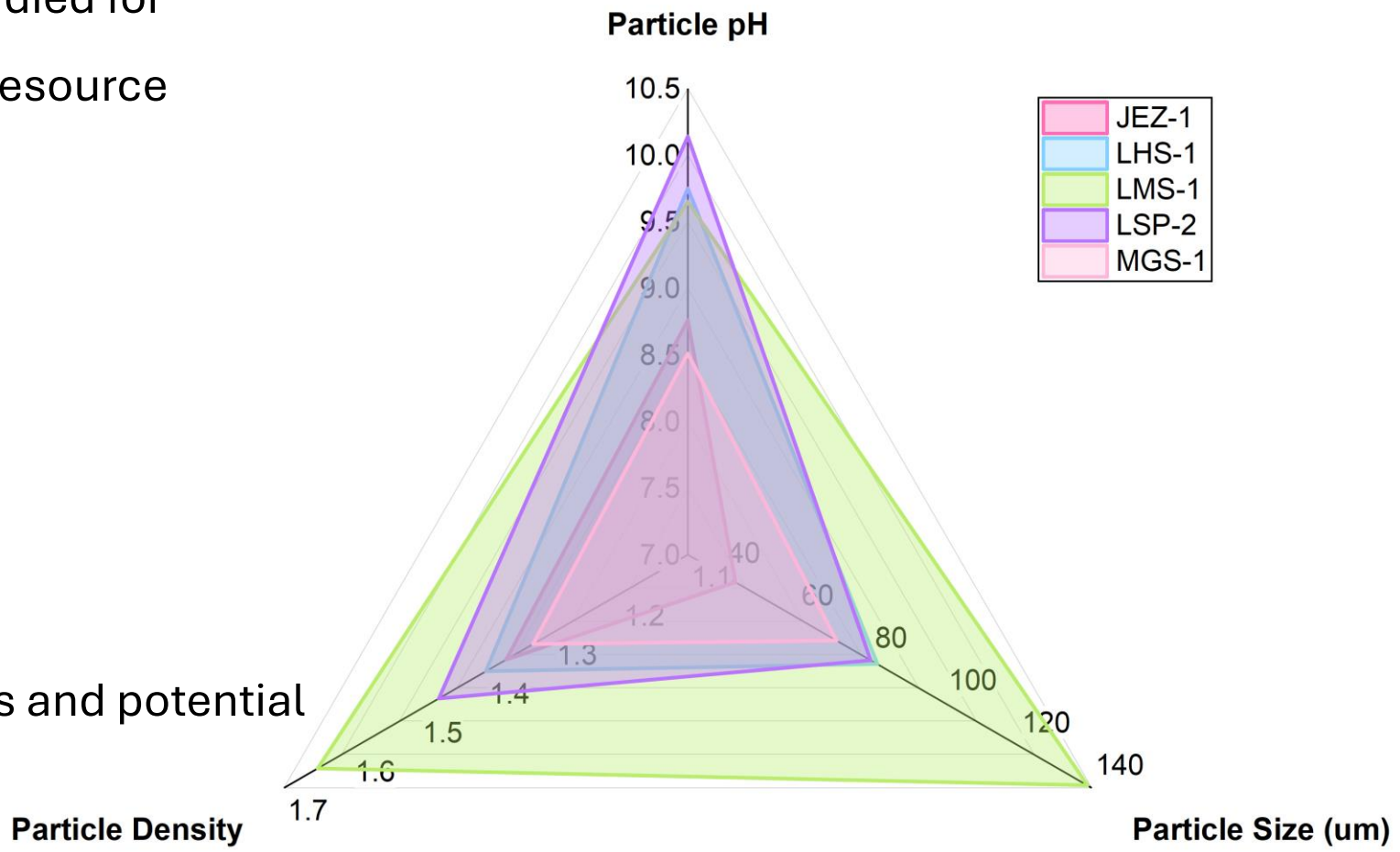
Manufacturing & Closing the Loop

- Manufacturing targets include consumables and outfitting supplies
- Fundamental materials data will guide additional applications
- Multiple routes of manufacturing expand versatility of system
- End-of-life recycling methods include bacterial fermentation and repolymerization, chemical, and mechanical recycling routes
- Closed-loop is key for sustained long-duration missions and reduction of waste



Regolith/PHB Composite Development

- 5 candidate regolith simulants studied for materials screening from Space Resource Technologies
  - Mars Jezero Delta (JEZ-1)
  - Lunar Highlands (LHS-1)
  - Lunar Mare (LMS-1)
  - Lunar South Pole (LSP-2)
  - Mars Global (MGS-1)
- Design system for as many regions and potential applications as possible



Regolith/PHB Composite Development

- Compression molding
  - High loading, high pressures
  - Inconsistent particle distribution
- Injection molding
  - High particle loading, more consistent particle distribution
  - More complex shapes
- Extruding
  - Most consistent particle distribution
  - Lower particle loading
- Additive manufacturing
  - More complex shapes
  - Lower particle loading, thermal exposure

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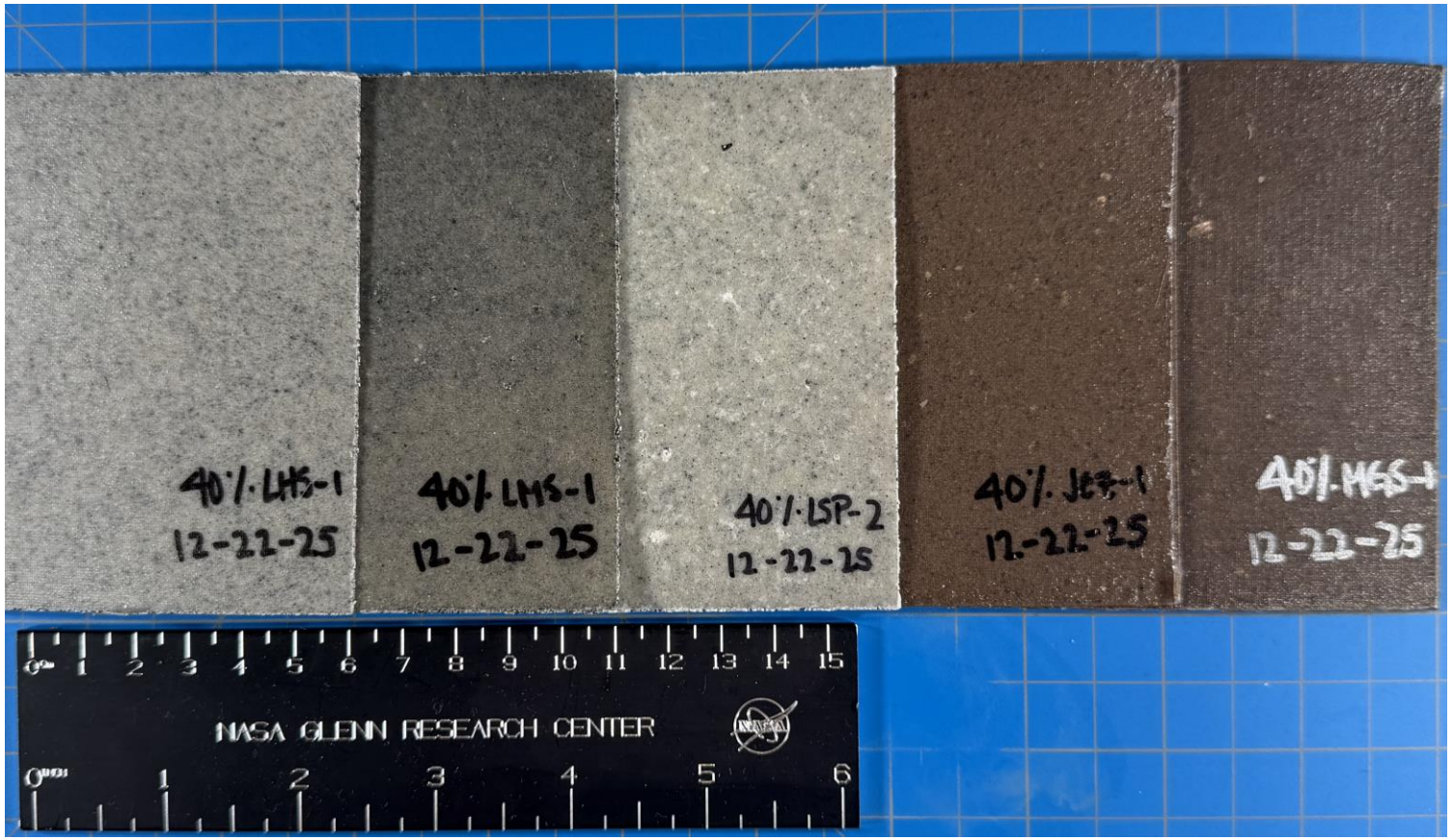
Compression Molded Composites

- Loading up to 80 wt% achieved
- Sufficiently thin films for more in-depth crystallinity study



Compression Molded Composites

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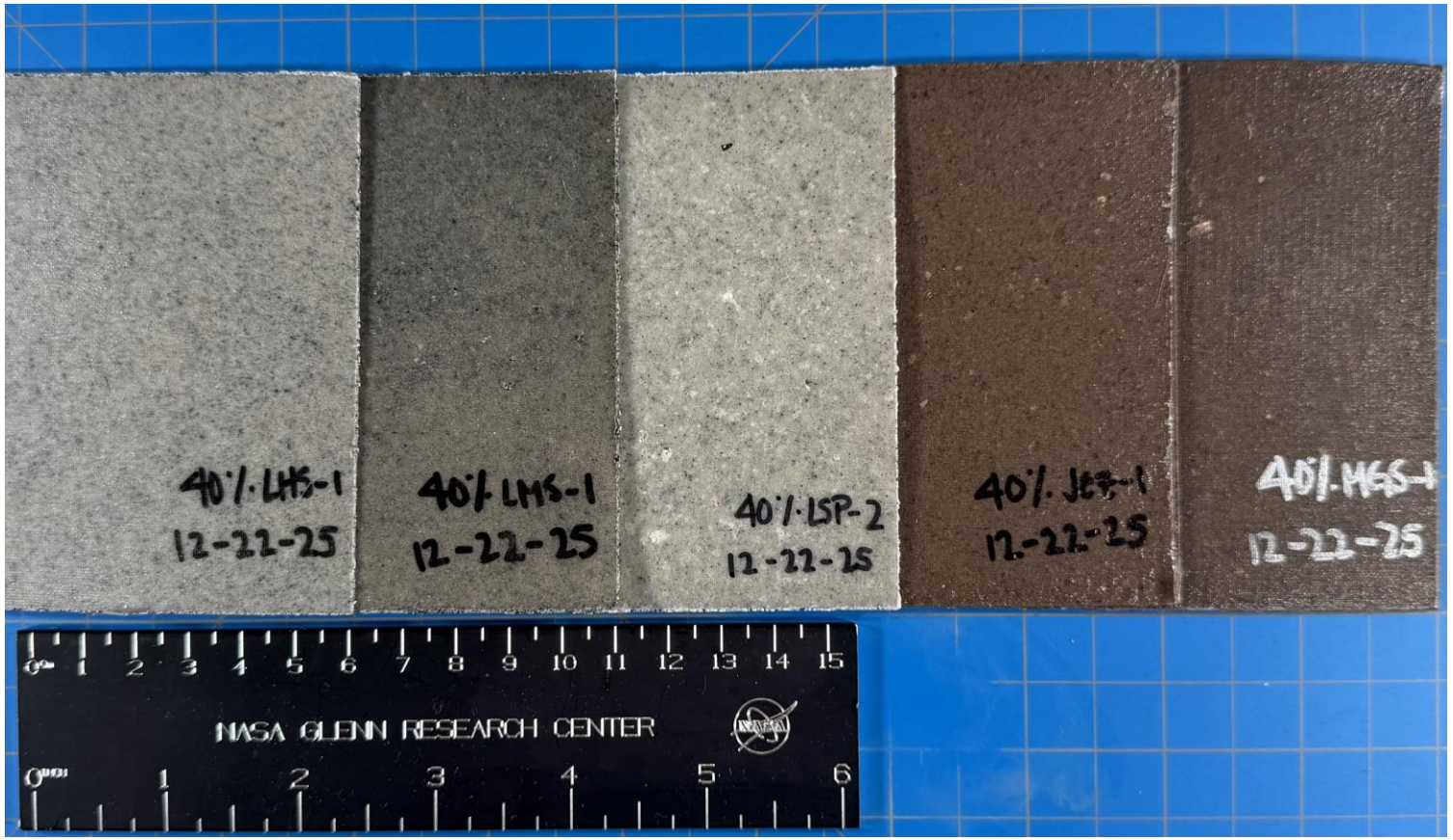
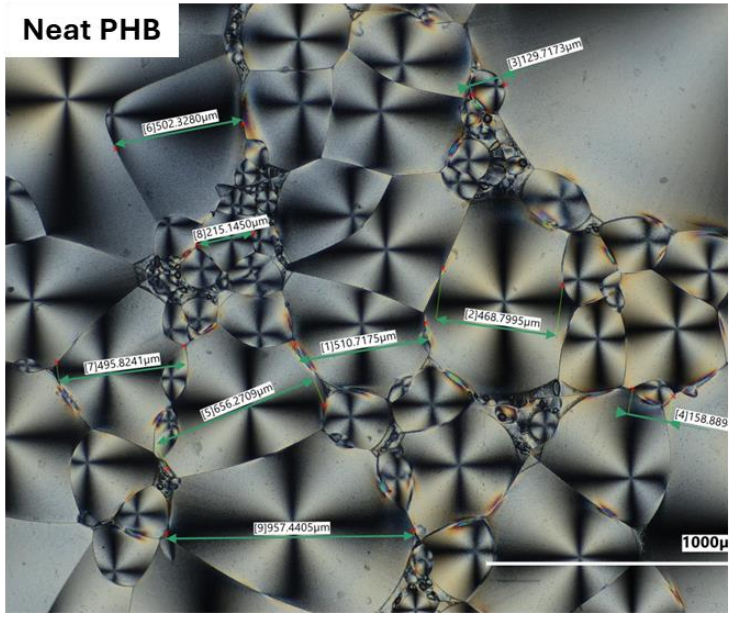
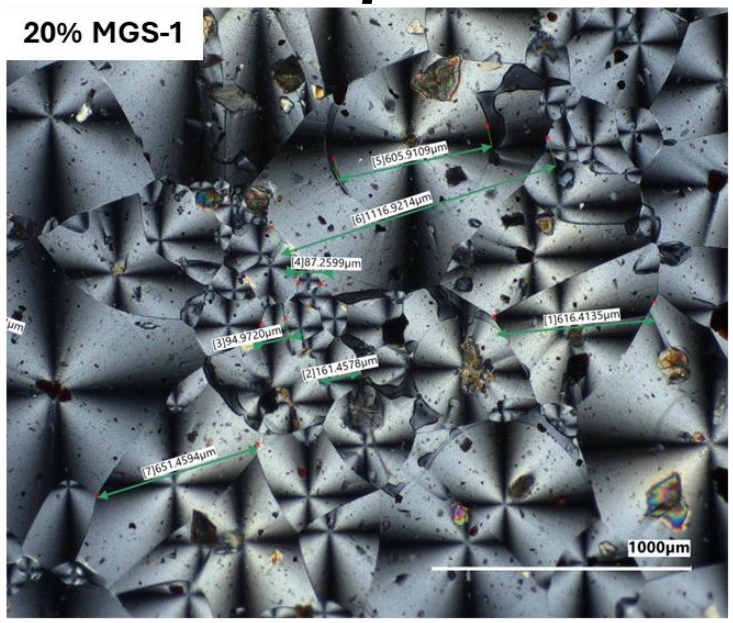
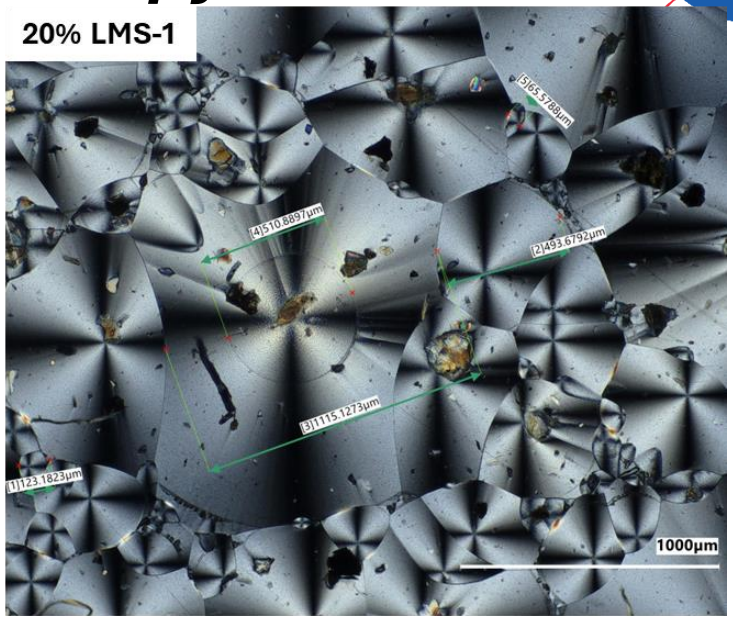
- Sufficiently thin films for more in-depth **crystallinity study***
- ***PHB is highly crystalline with slow crystallization kinetics – benefits to manufacturing/performance if regolith can influence these properties**

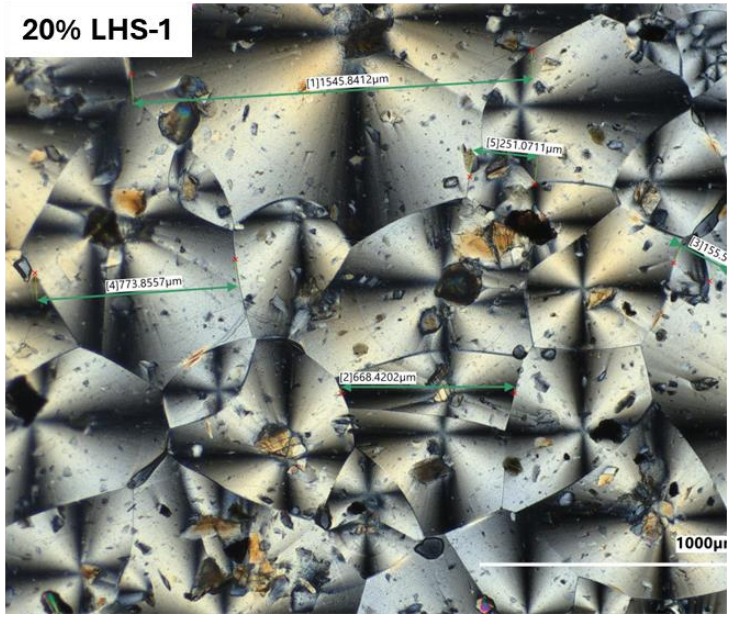


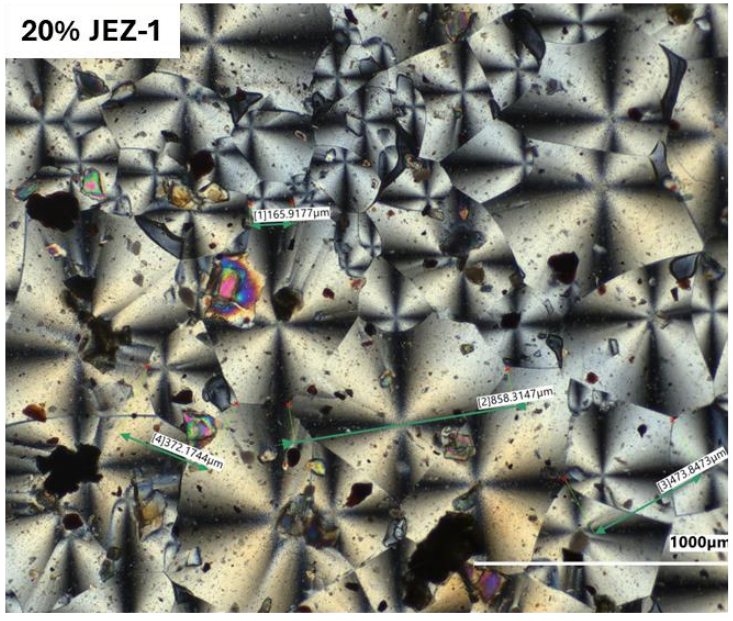
Regolith/PHB Composite Crystallinity – *Cross Polarized Optical Microscopy*

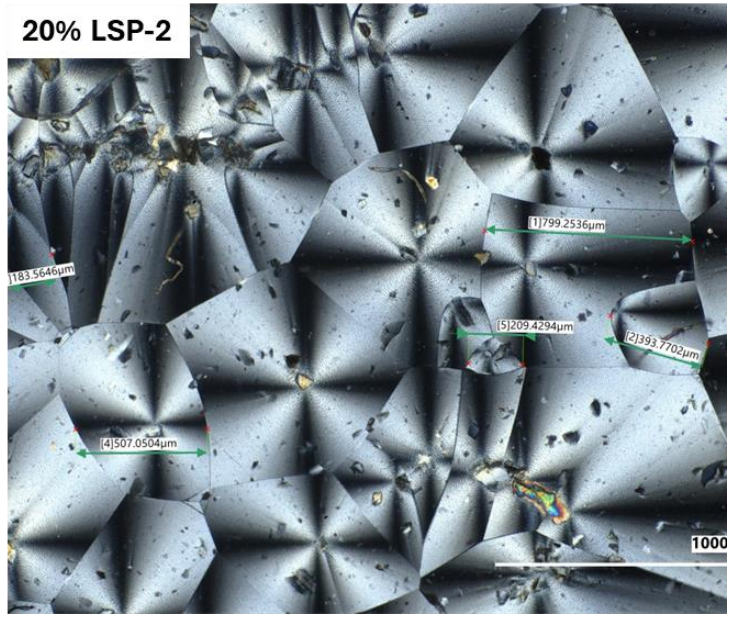






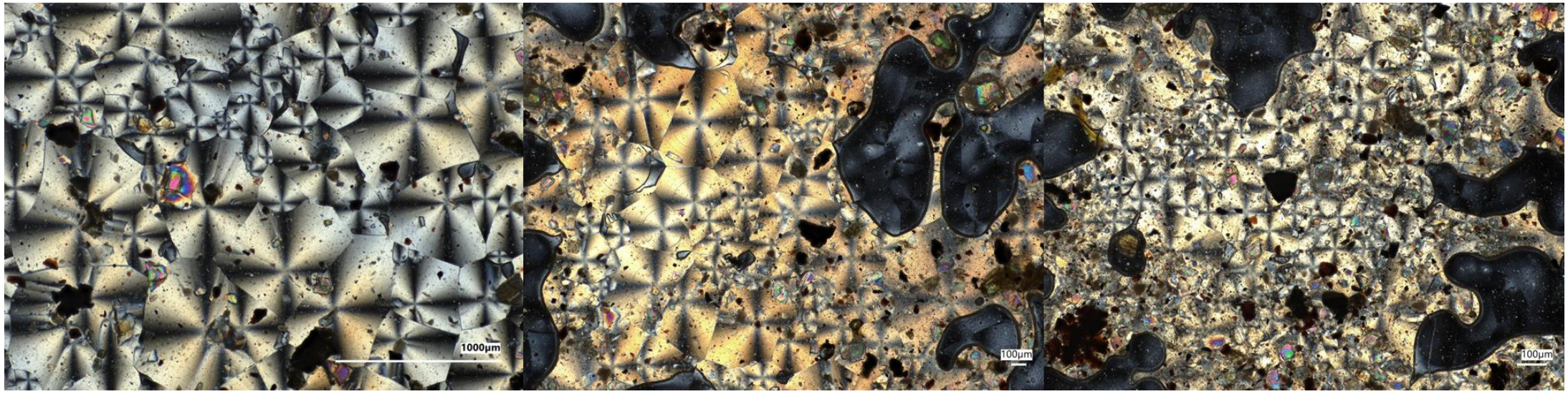




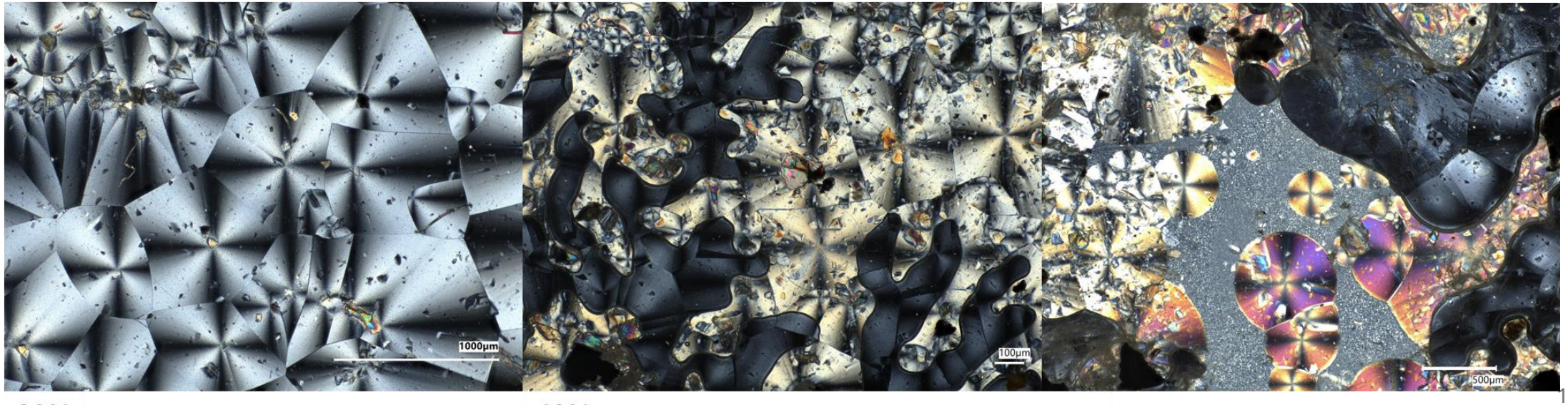


Regolith/PHB Composite Crystallinity – *Effect of Regolith Loading*

JEZ-1

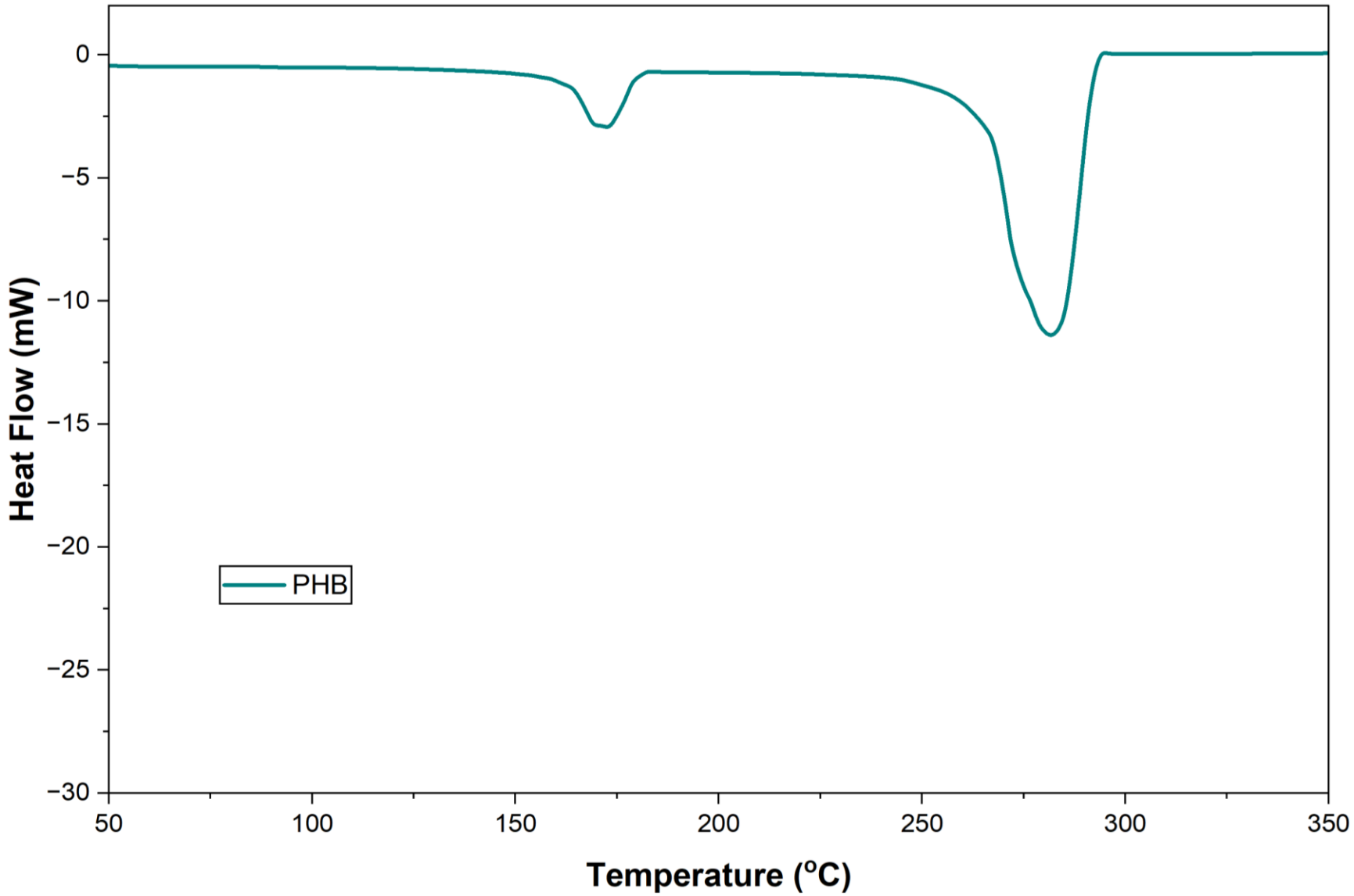


LSP-2

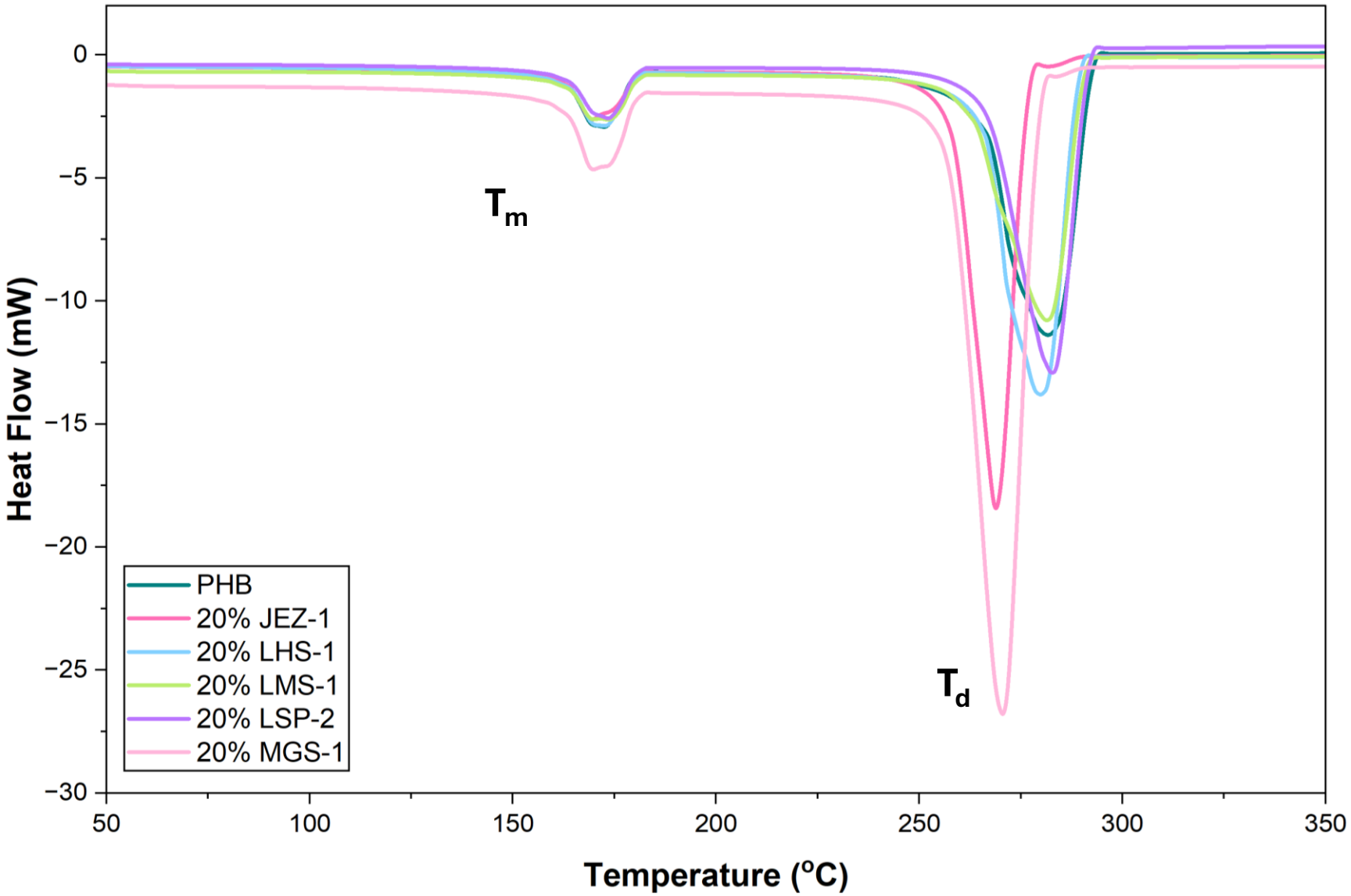


20% 40% 80%

Regolith/PHB Composite Crystallinity – *Differential Scanning Calorimetry*



Regolith/PHB Composite Crystallinity – *Differential Scanning Calorimetry*



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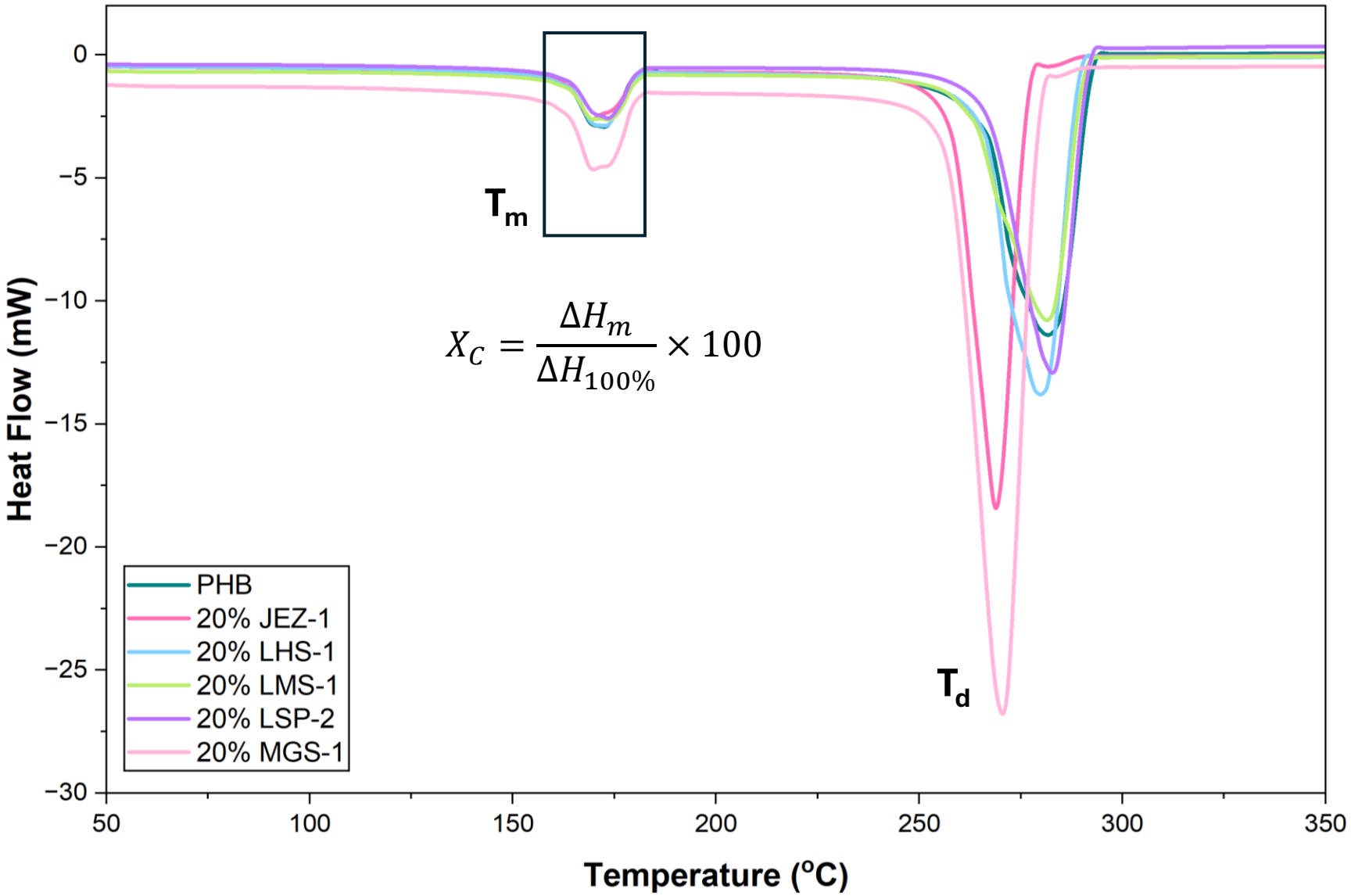

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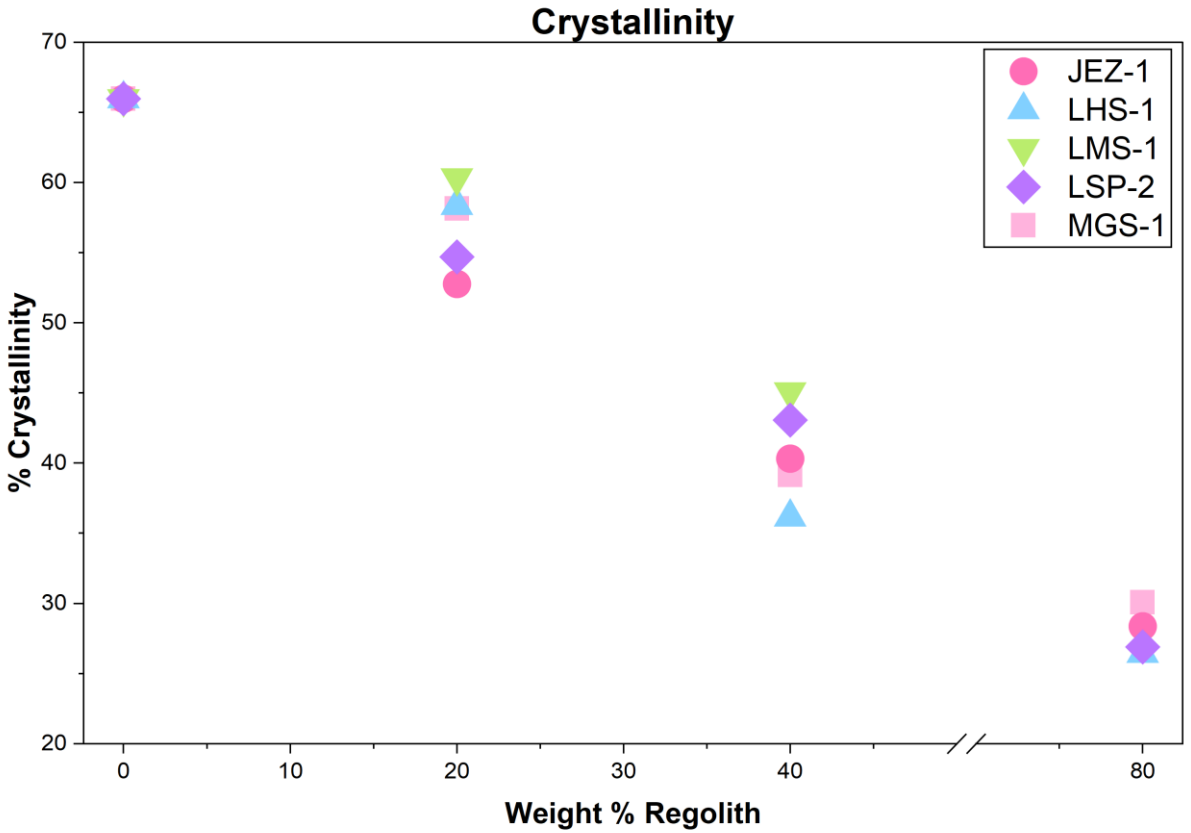

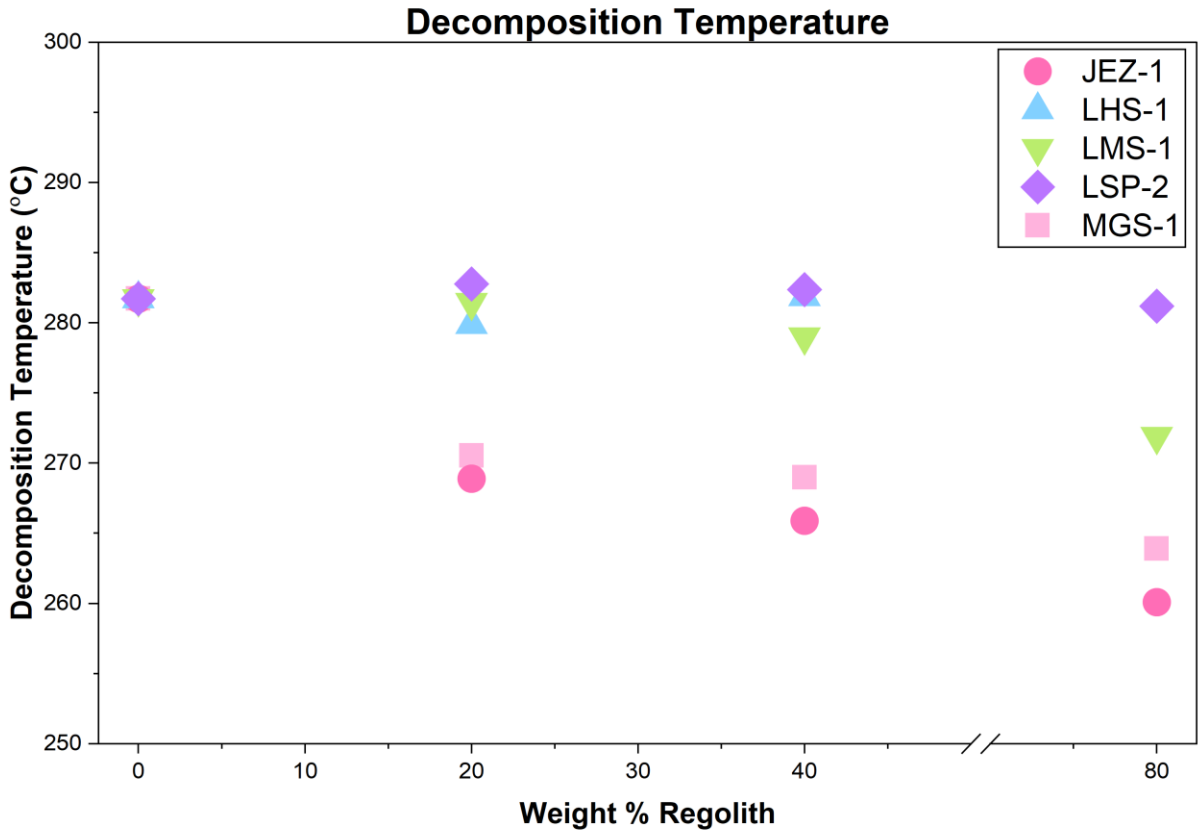

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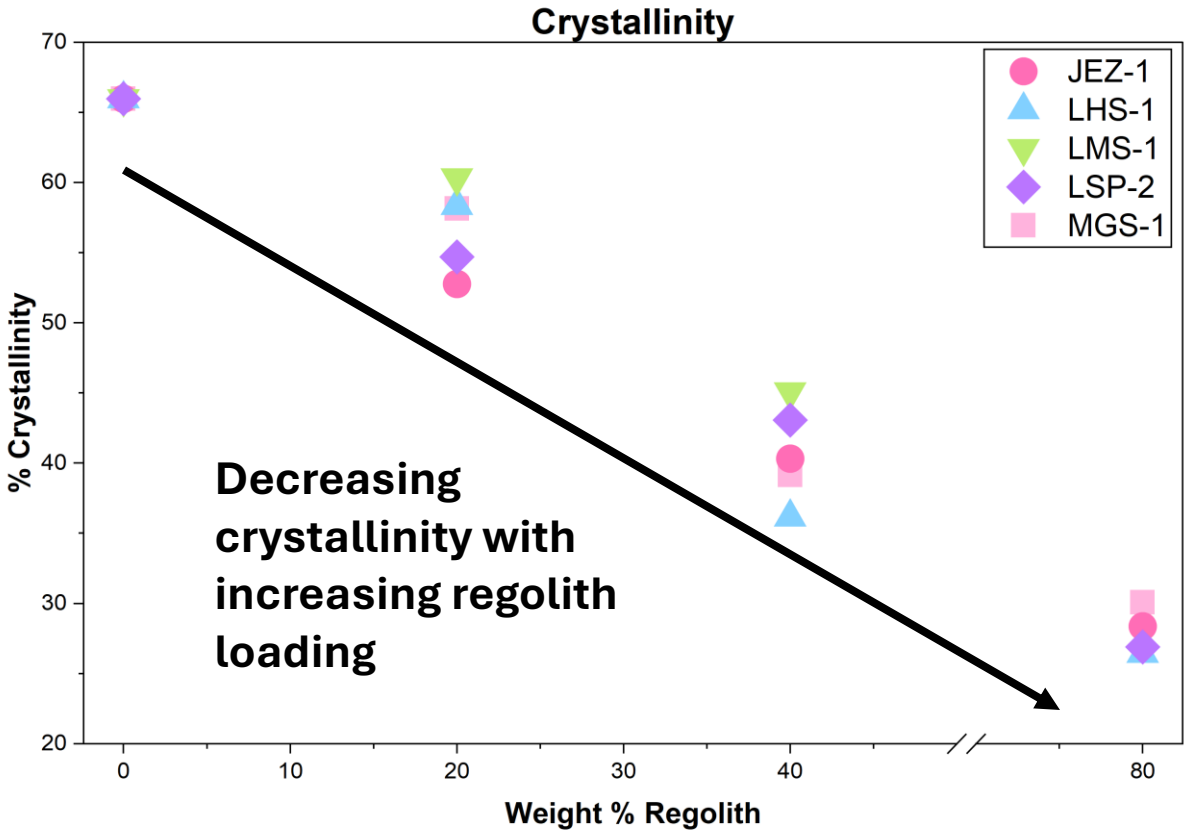

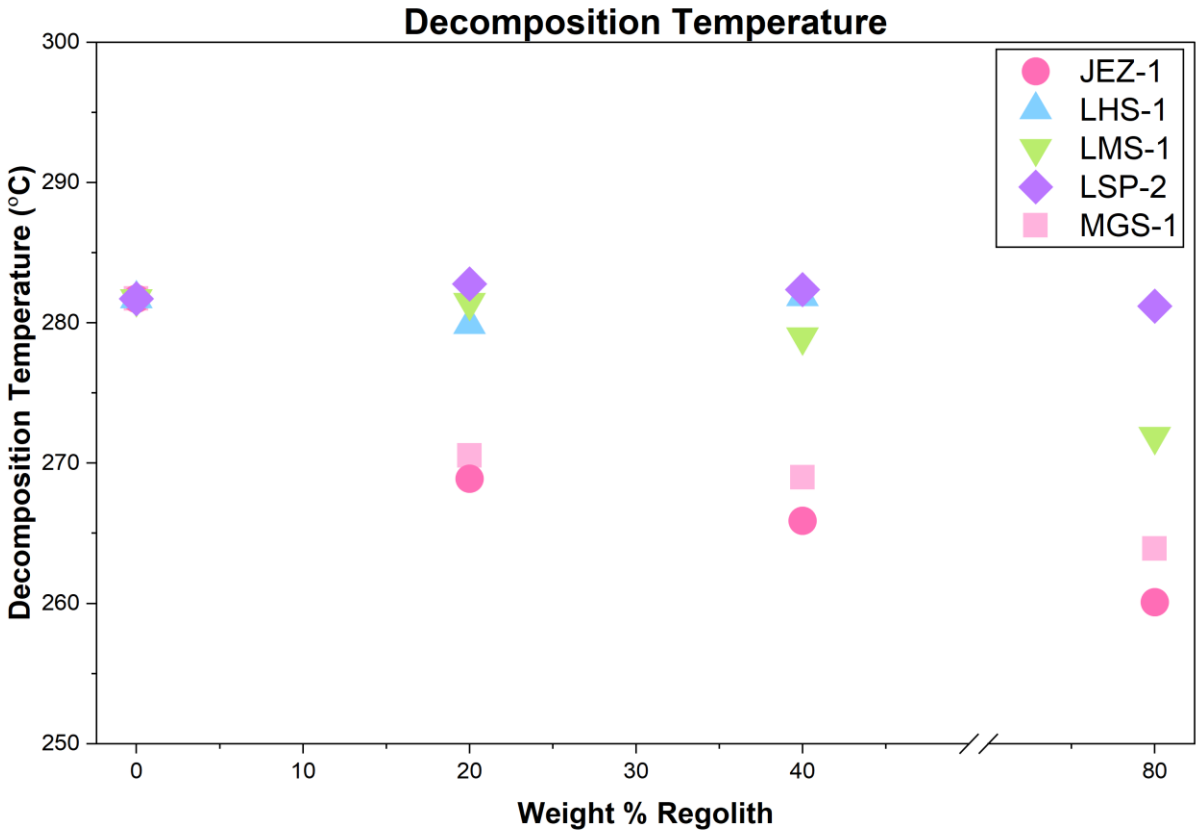

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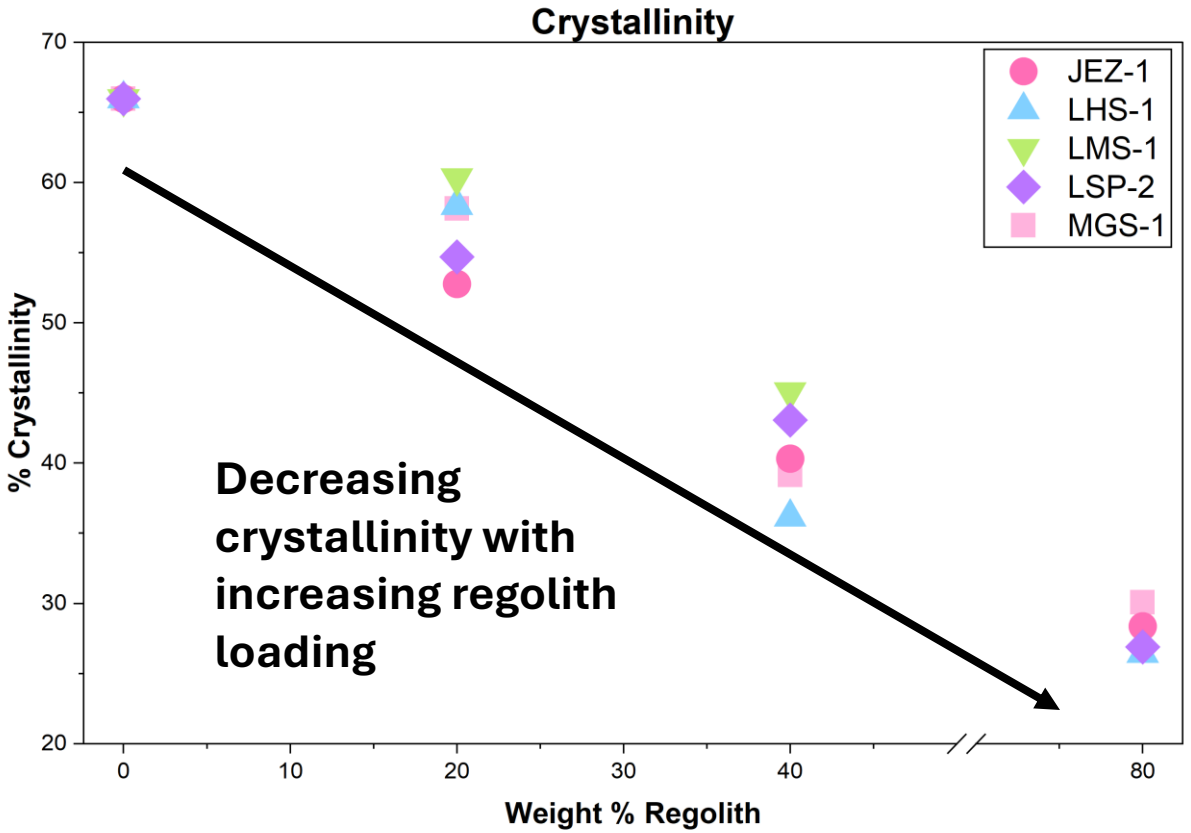
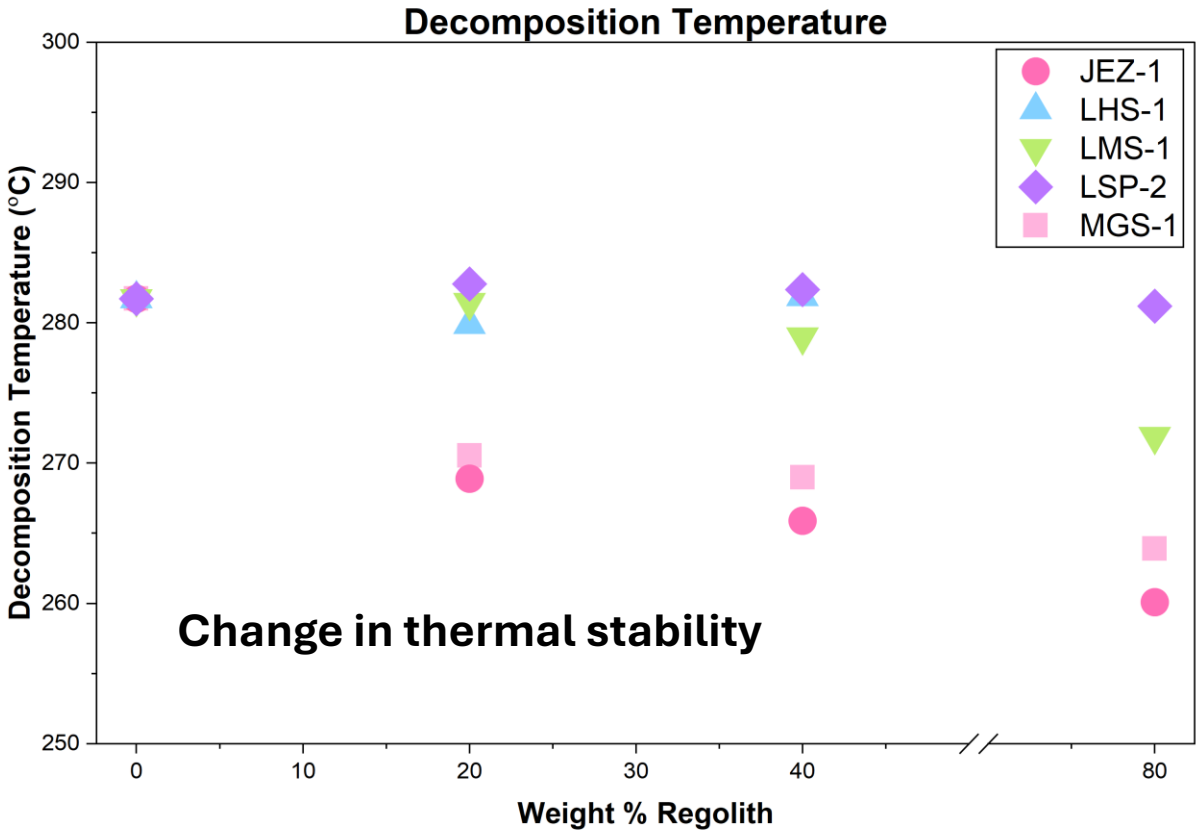
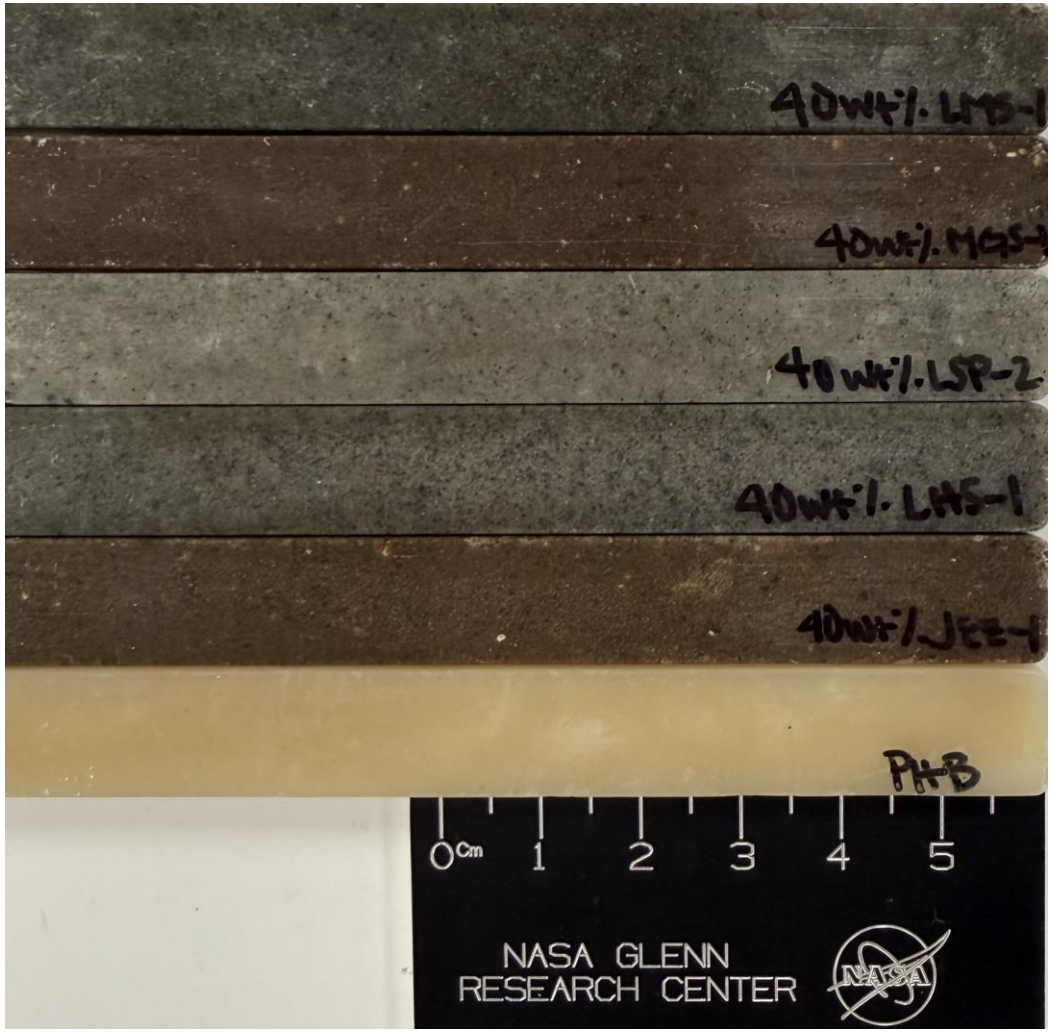




Injection Molded Composites

- 40wt% regolith used for initial materials screening



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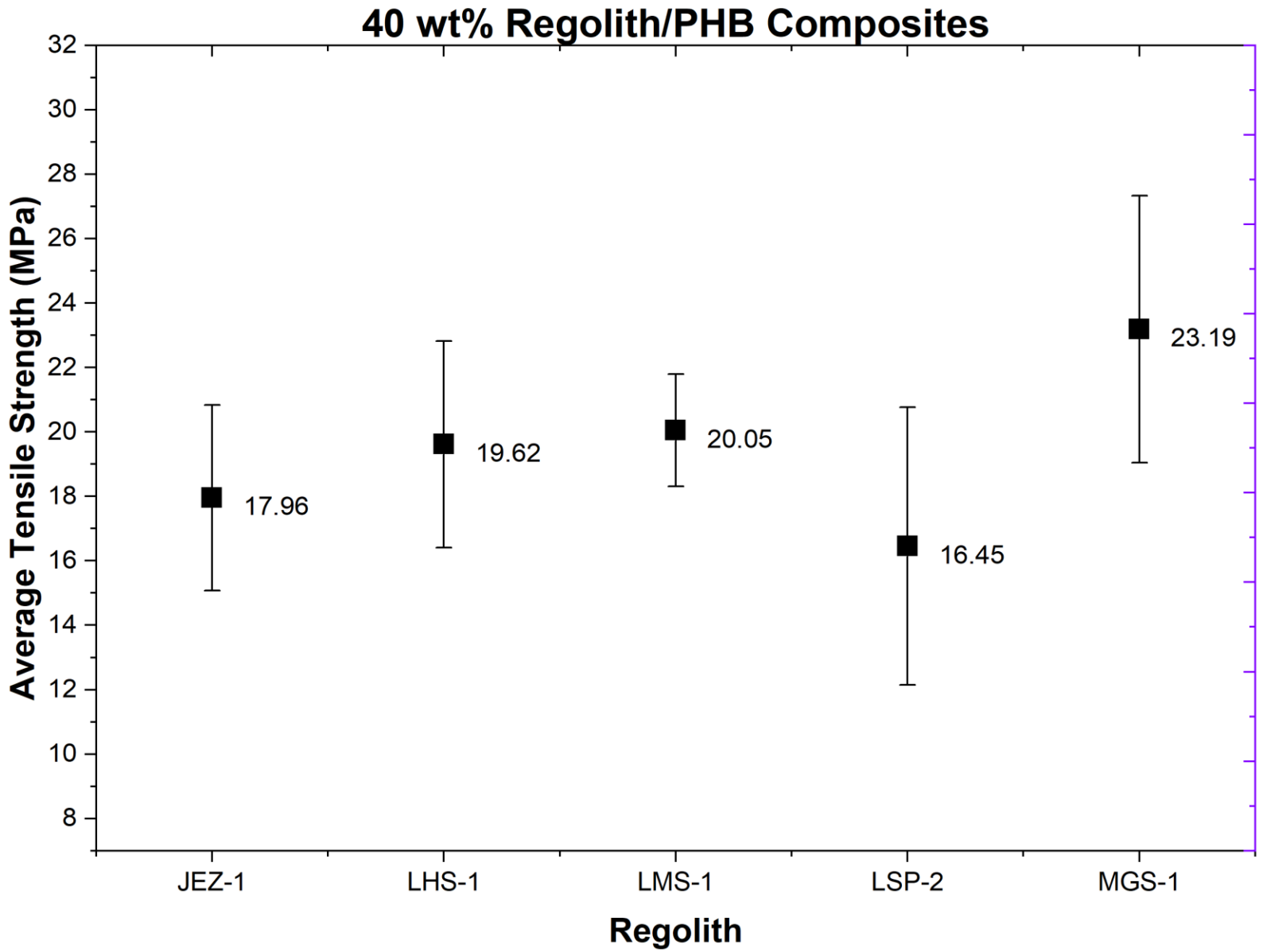


JEZ-1

LHS-1

LMS-1


LSP-2
2
2

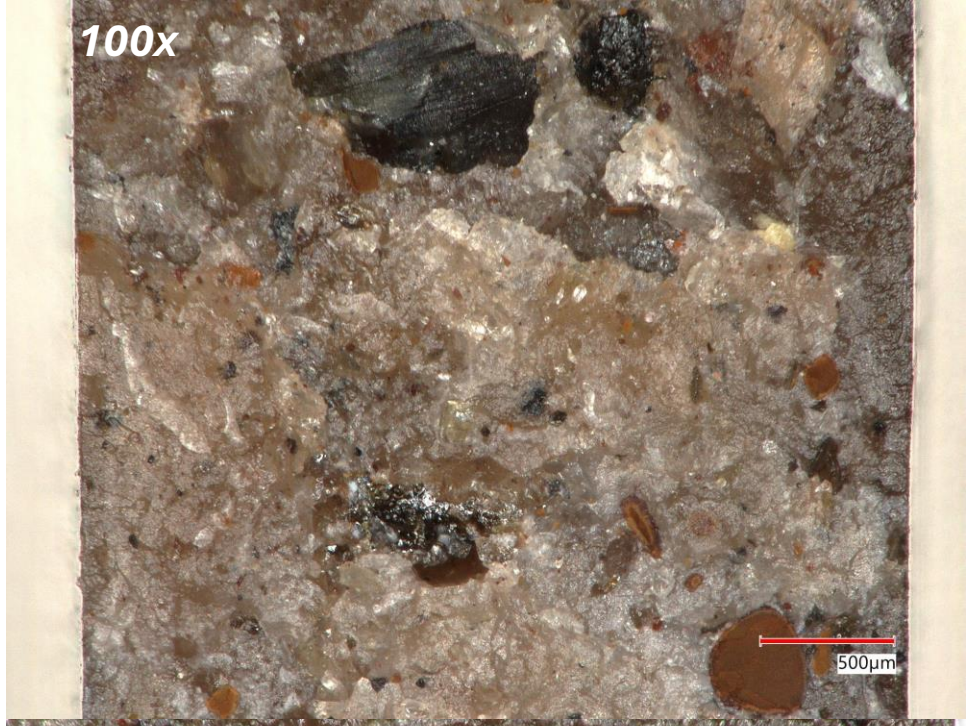

30x


100x
500µm


150x
250µm


MGS-1


30x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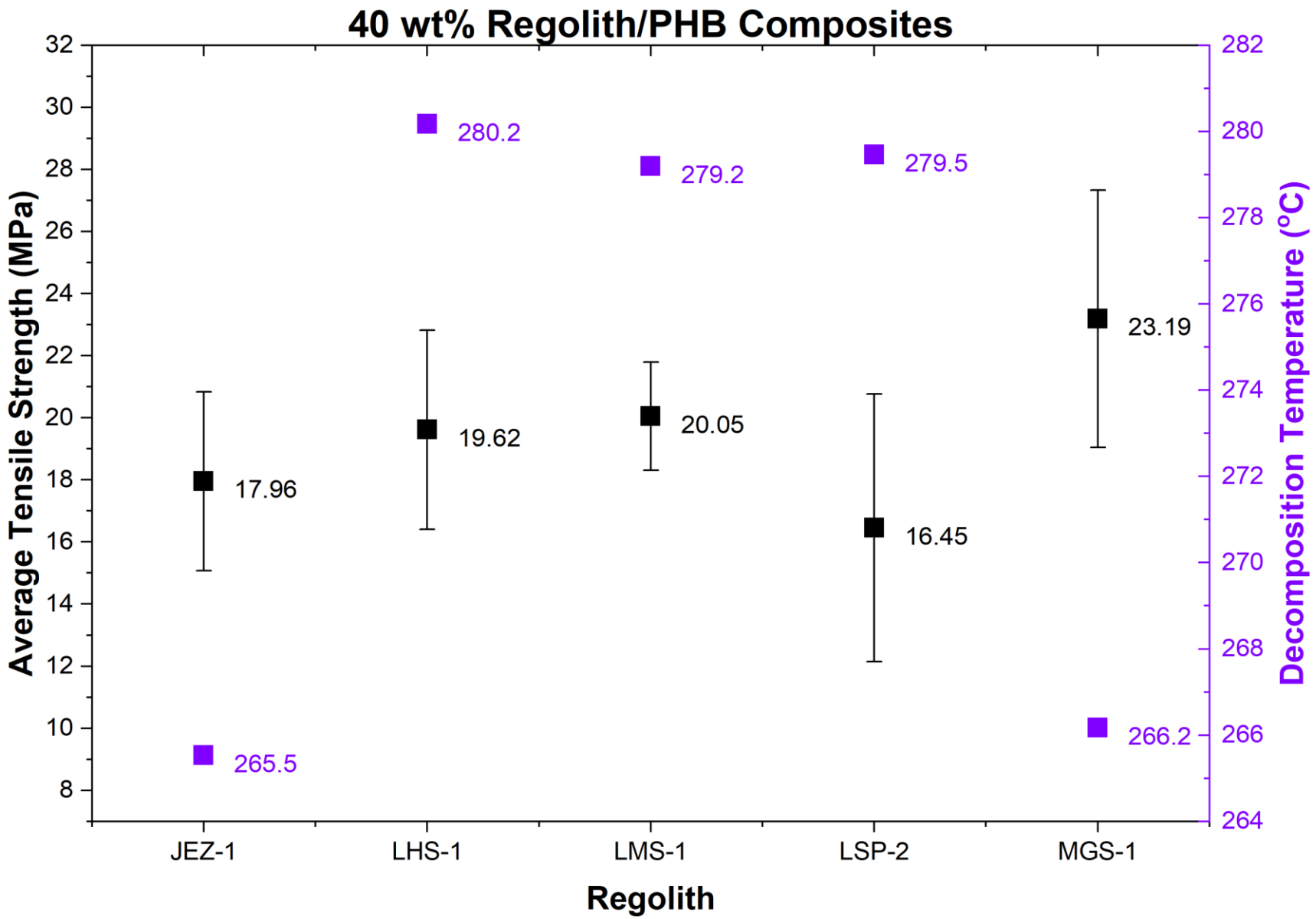

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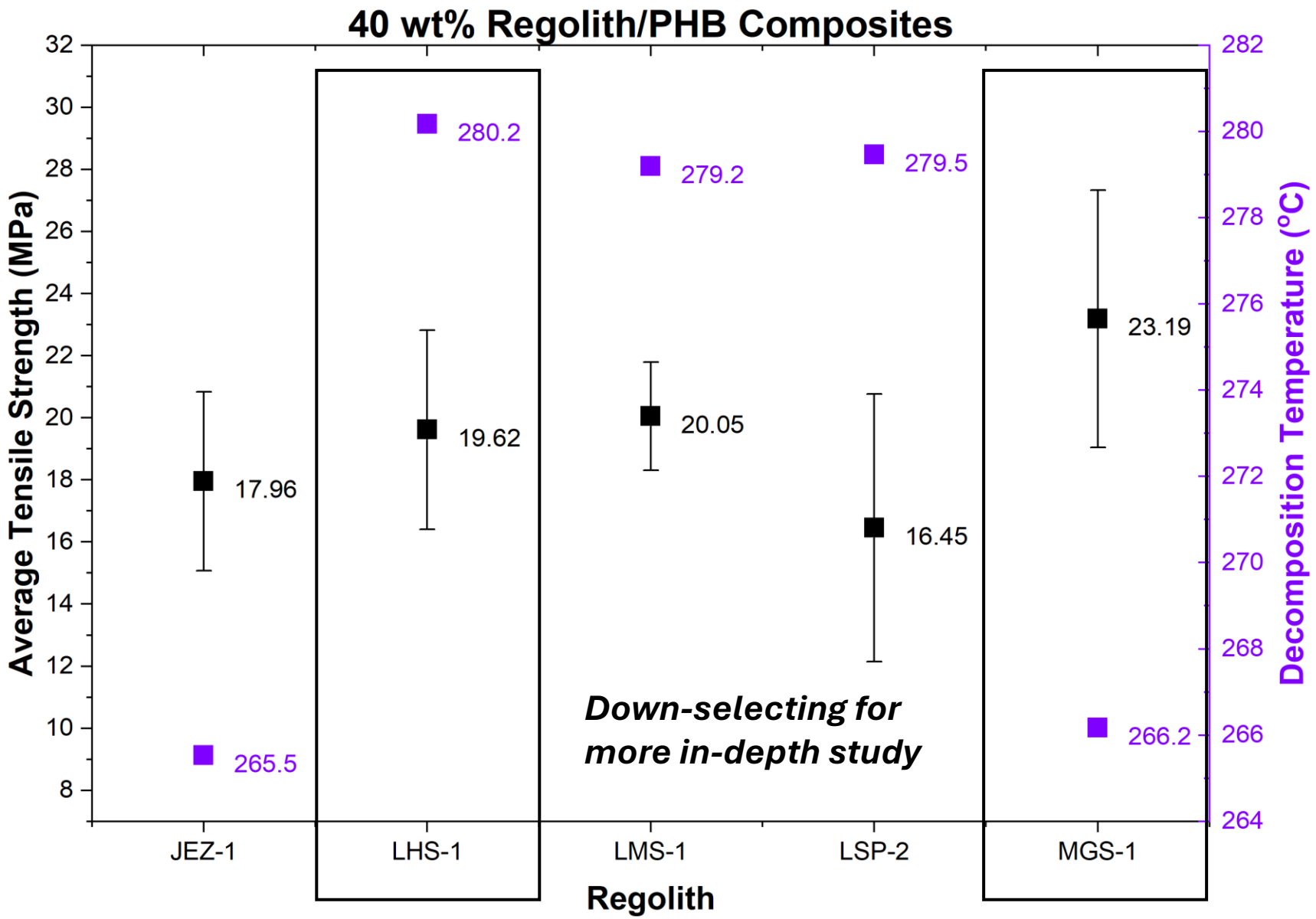
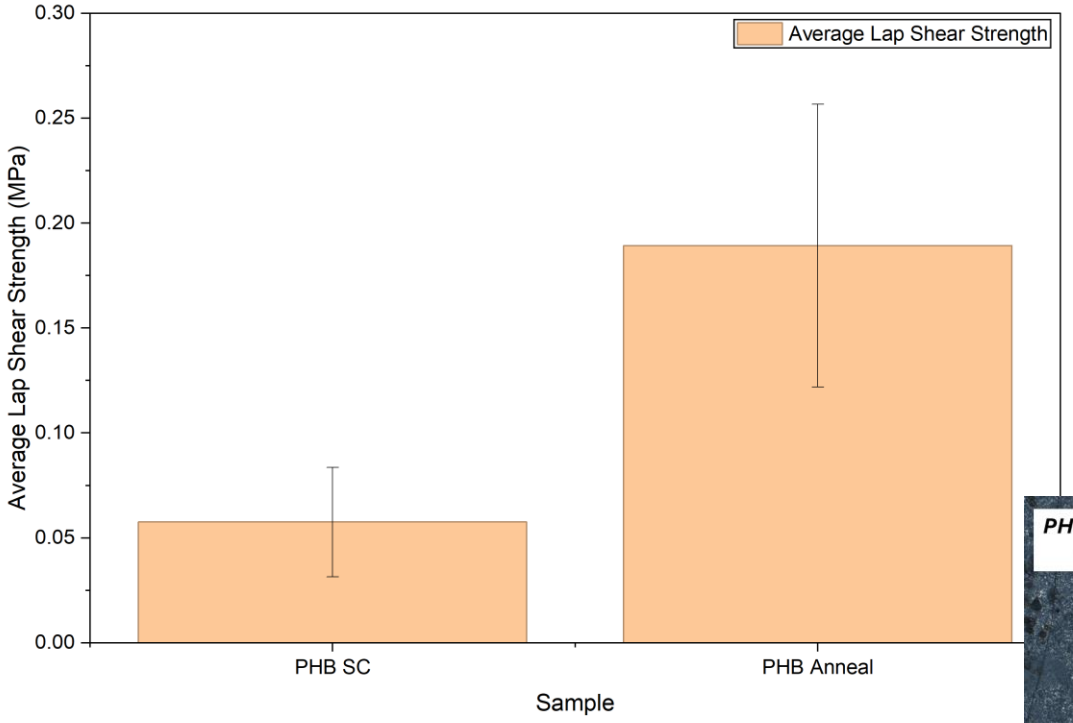
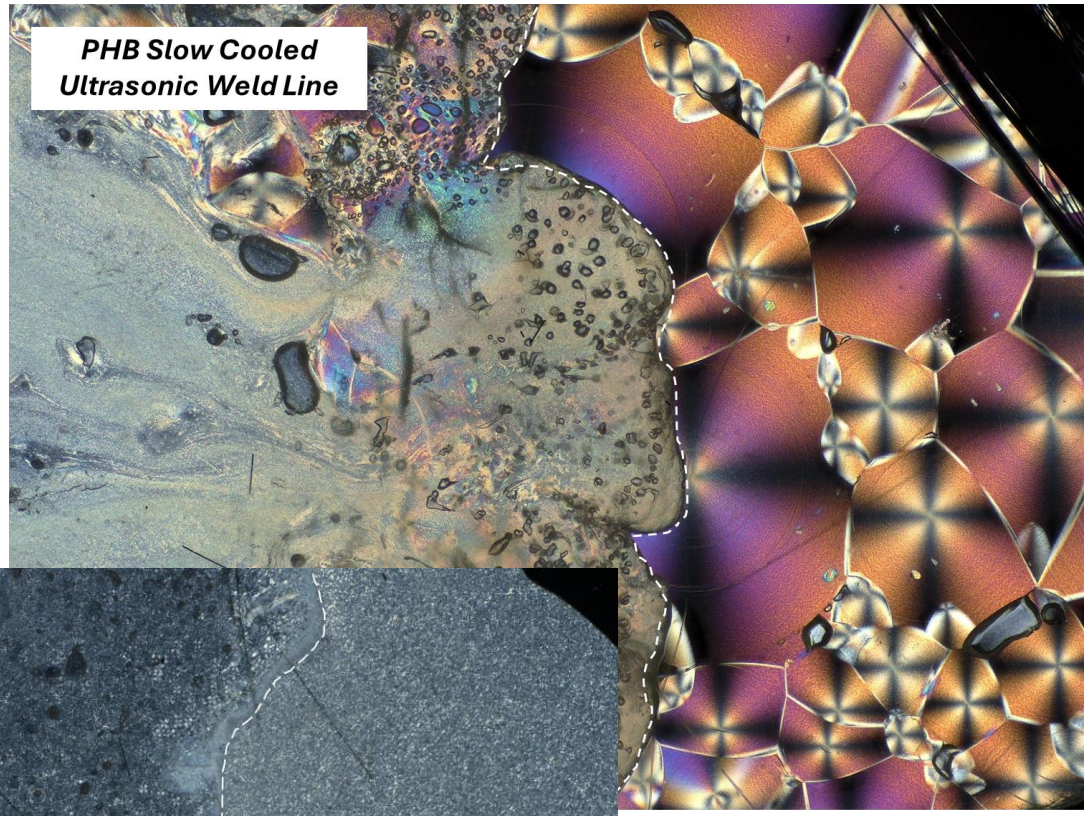
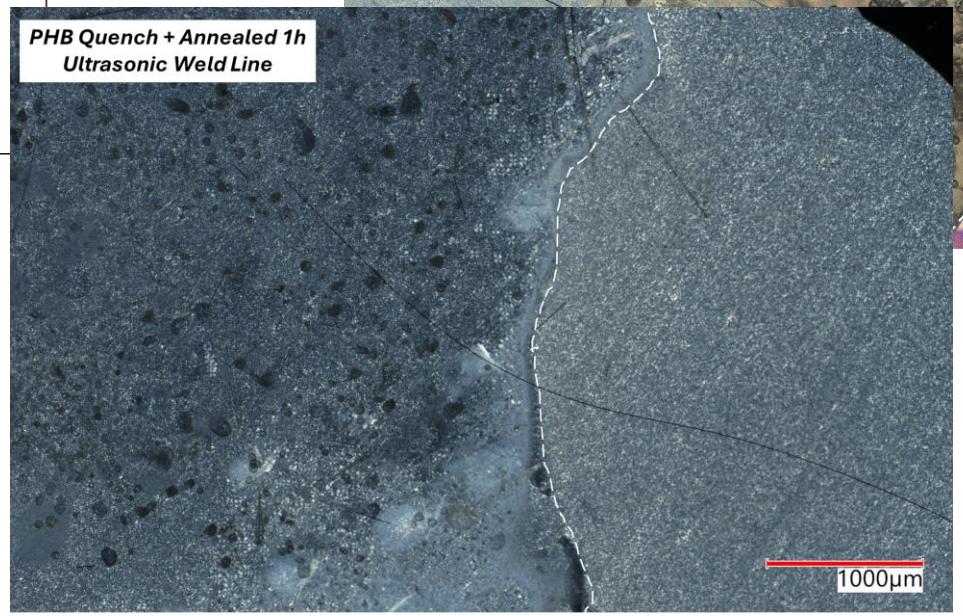


Ultrasonic Welding for In-Situ Assembly and Repair

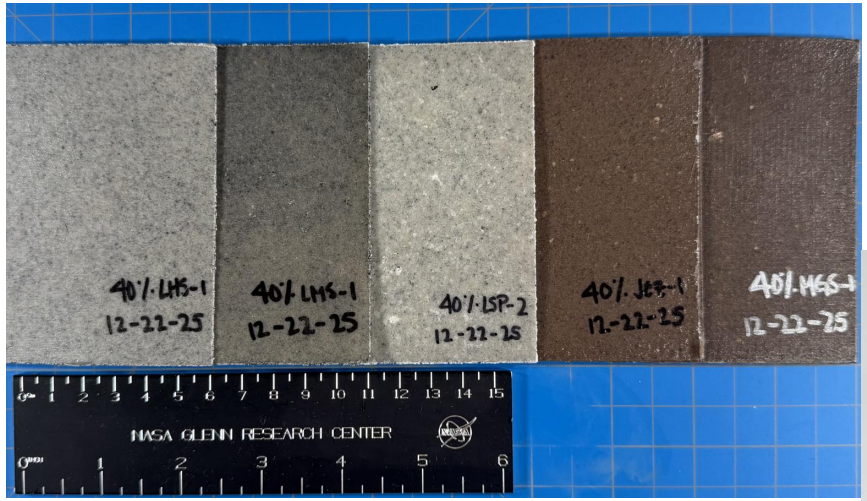


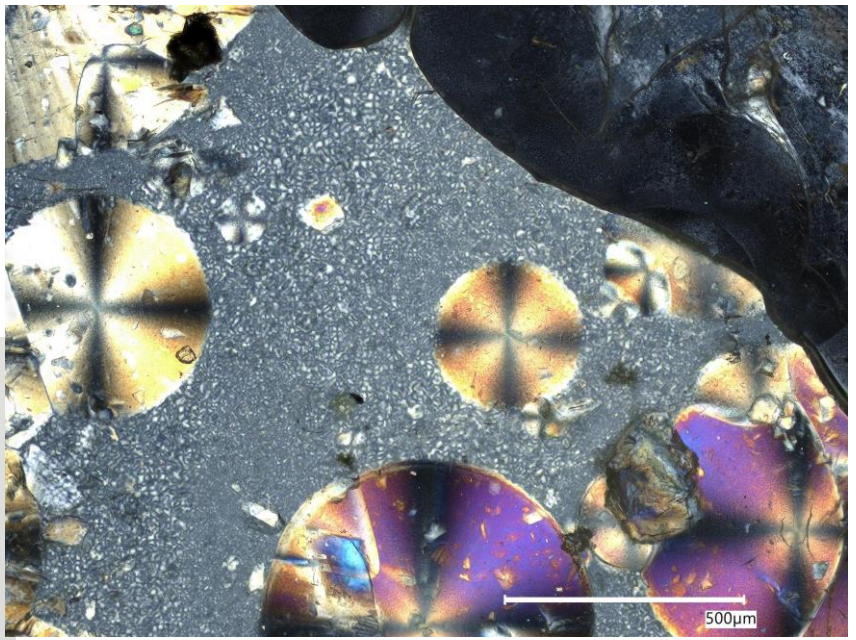




Key Takeaways & Ongoing Work

- **Successful proof of concept!**
  - **Reasonable mechanical properties at 40% loading of ISRU**
  - **Multiple routes of processing with versatile properties achievable**
  - **Ultrasonic welding as a route to complex structures and repair**
- **Type and amount of regolith affects the mechanical and thermal properties of composite**





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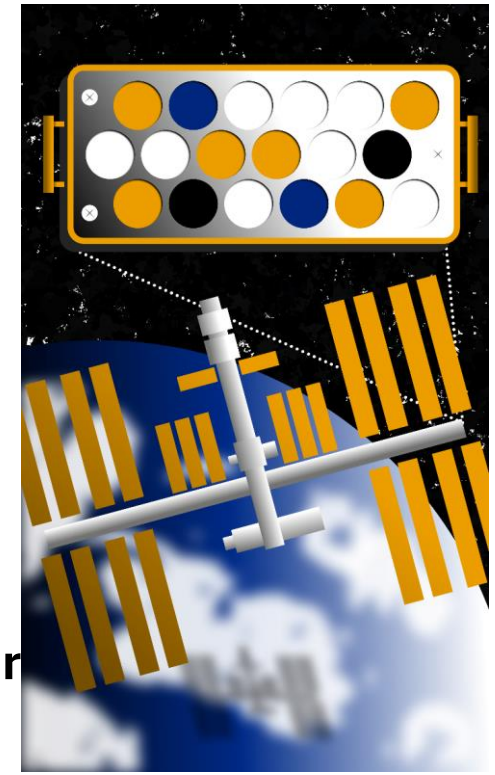
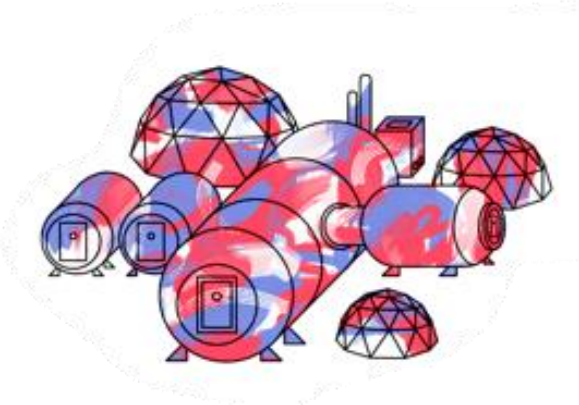
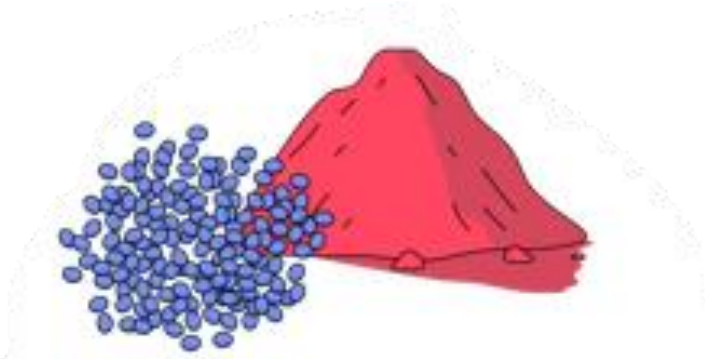
  - Ultrasonic welding as a route to complex structures and repair
- Type and amount of regolith affects the mechanical and thermal properties of composite
- **In-depth characterization of down-selected LHS-1 and MGS-1 injection molded samples**
- **Extruding filament for FFM additive manufacturing; exploring Direct Powder Extrusion printing**
- **Samples on MISSE-23 and MISSE-24 experiments for space exposure evaluation**



Next Steps

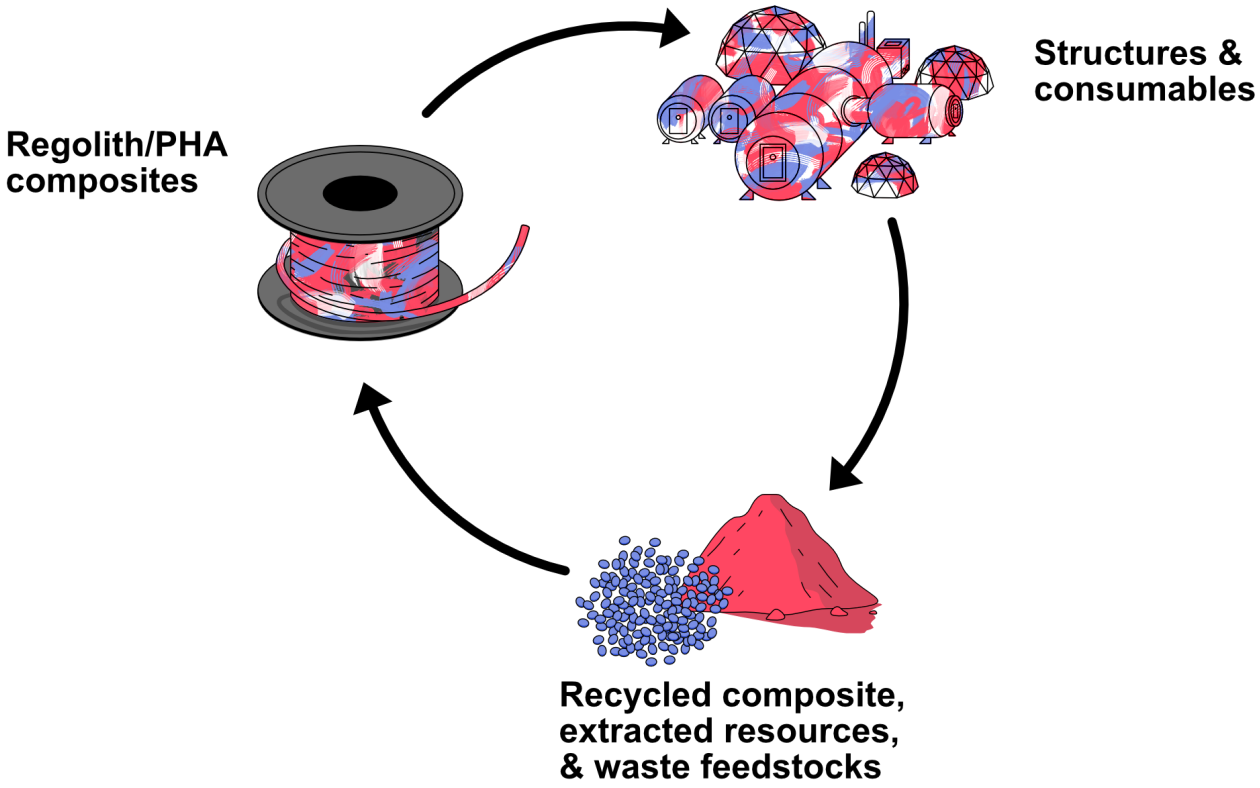
- Manufacturing complex parts and larger structures
- Development of bio-recycling and biosynthesis of resin from waste products
- Explore mechanical recycling methods
- Computational modeling to predict materials performance
- Create materials with bio-engineered PHAs
- Systems analysis





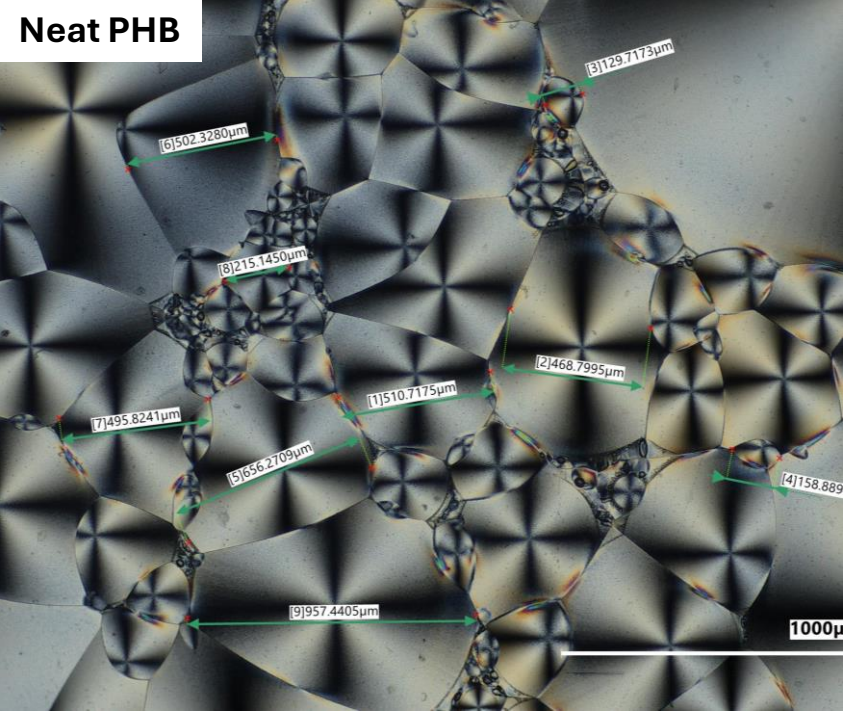
Acknowledgements

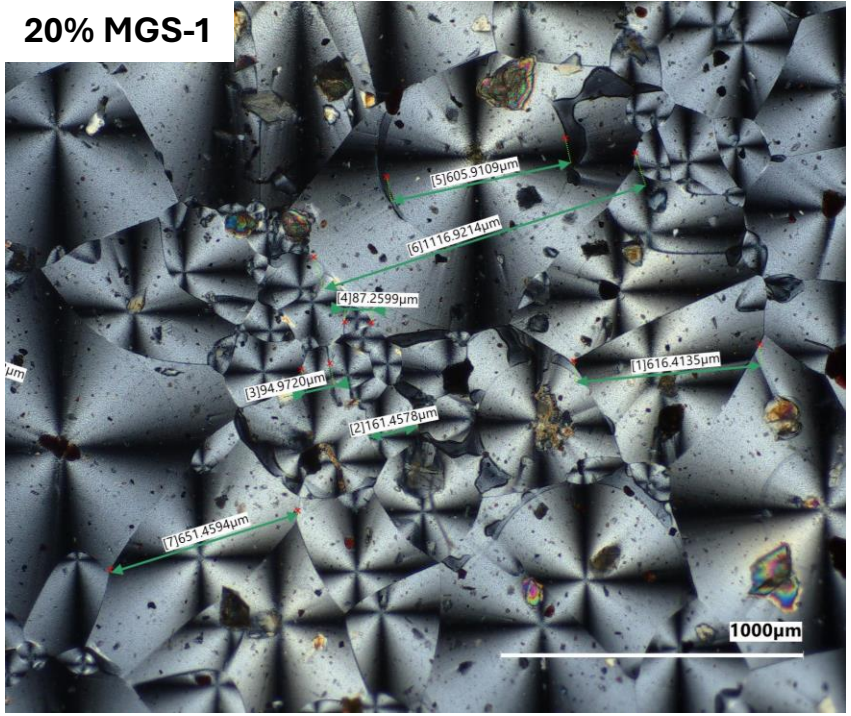
- Dan Scheimann, GRC, Thermal Data
- Laura Wilson & Rich Martin, GRC, Microscopy
- NASA STMD
- Mango Materials
- Frances Donovan & the NASA CUBES Team
- WAMS 26 ☺

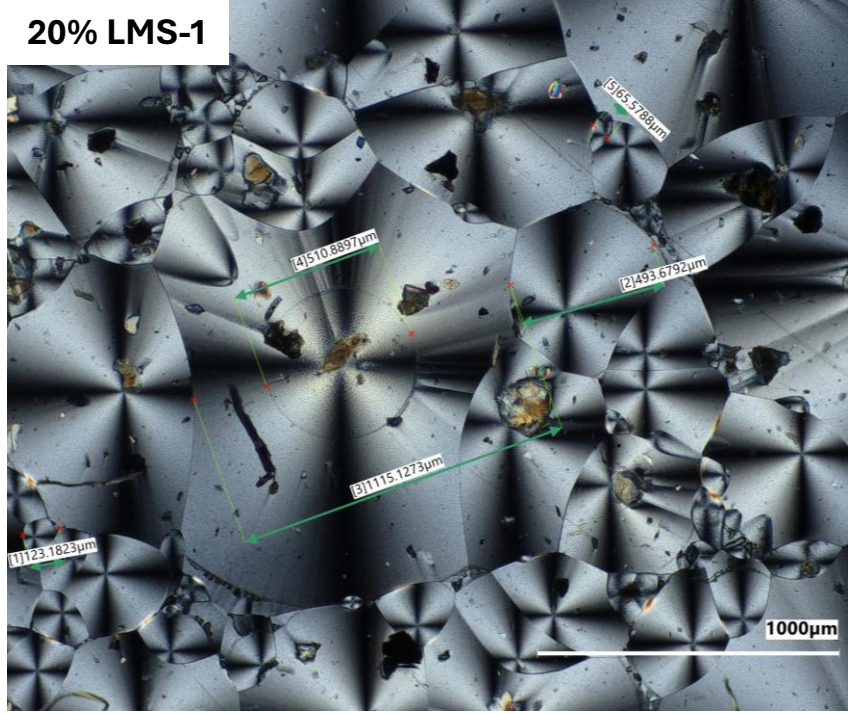


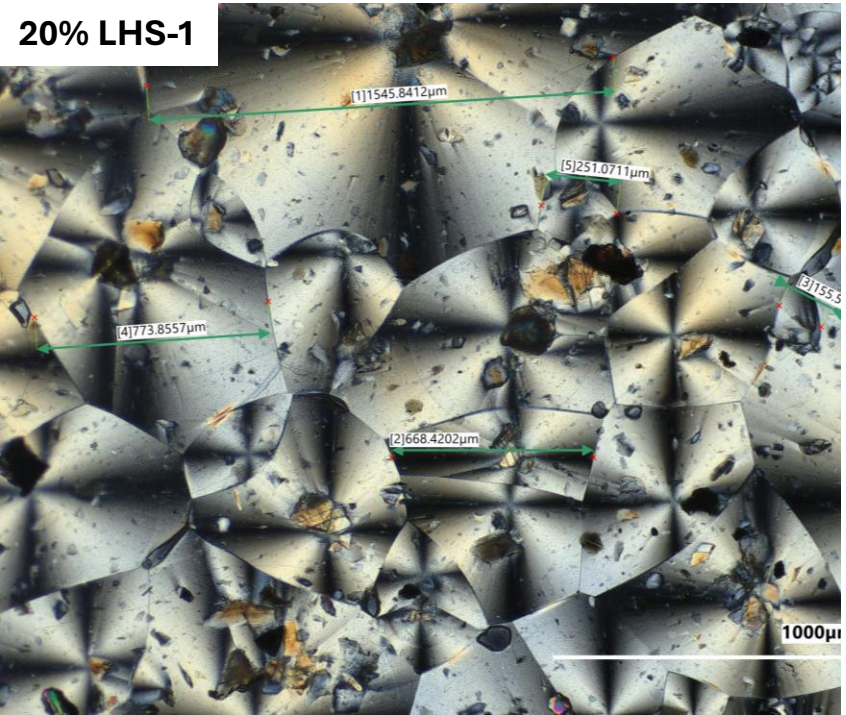

Questions?

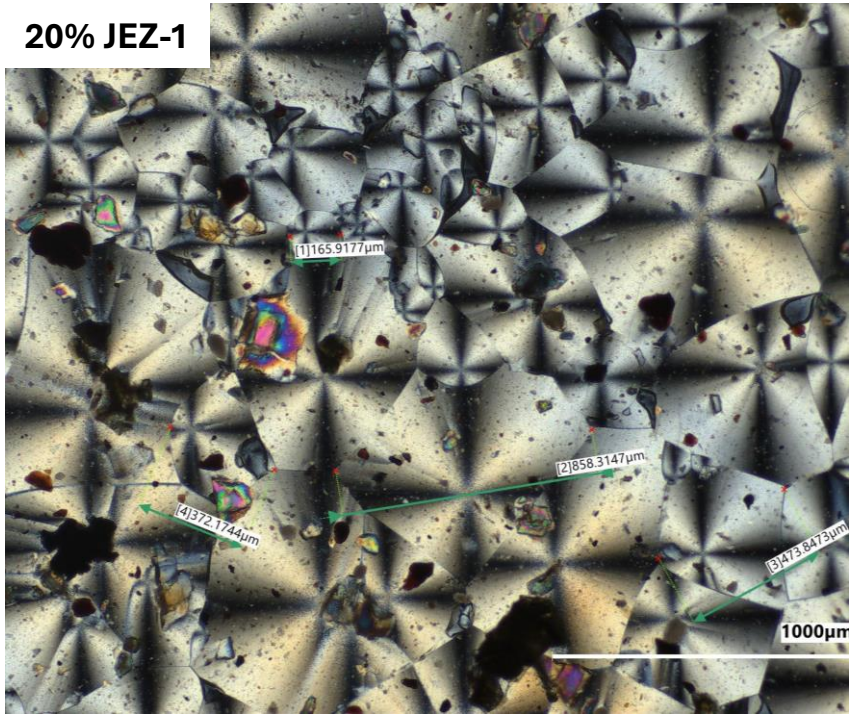
Backup Slides

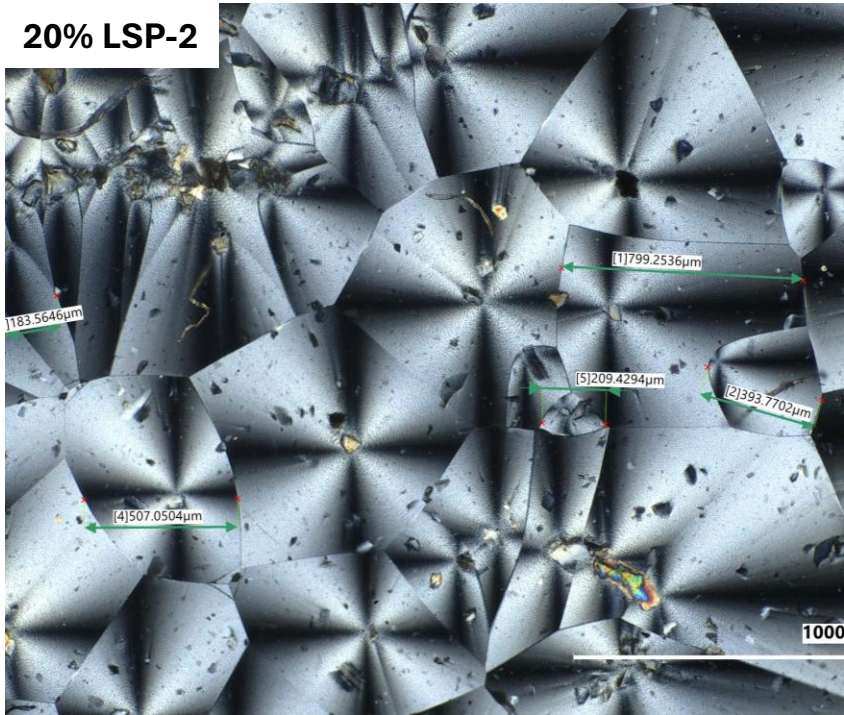

Neat PHB
[3]129.7173µm
[6]502.3280µm
[8]215.1450µm
[2]468.7995µm
[1]510.7175µm
[7]495.8241µm
[5]656.2709µm
[4]158.889
[9]957.4405µm
1000µ

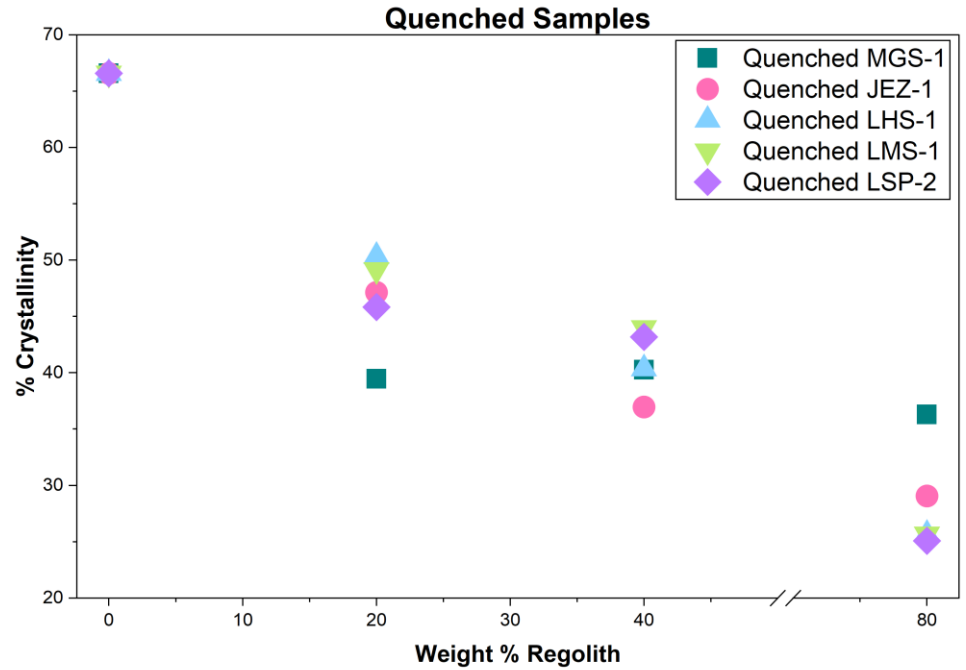

20% MGS-1
[5]605.9109µm
[6]1116.9214µm
[4]87.2599µm
[1]616.4135µm
[3]94.9720µm
[2]161.4578µm
[7]651.4594µm
1000µm

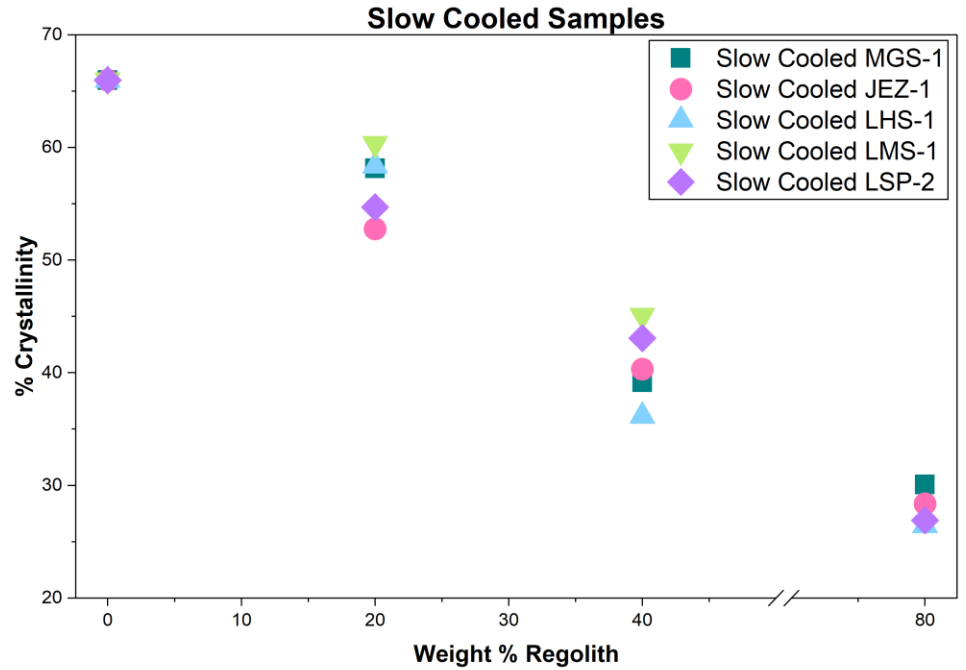

20% LMS-1
[5]65.5788µm
[4]510.8897µm
[2]493.6792µm
[3]1115.1273µm
[1]123.1823µm
1000µm

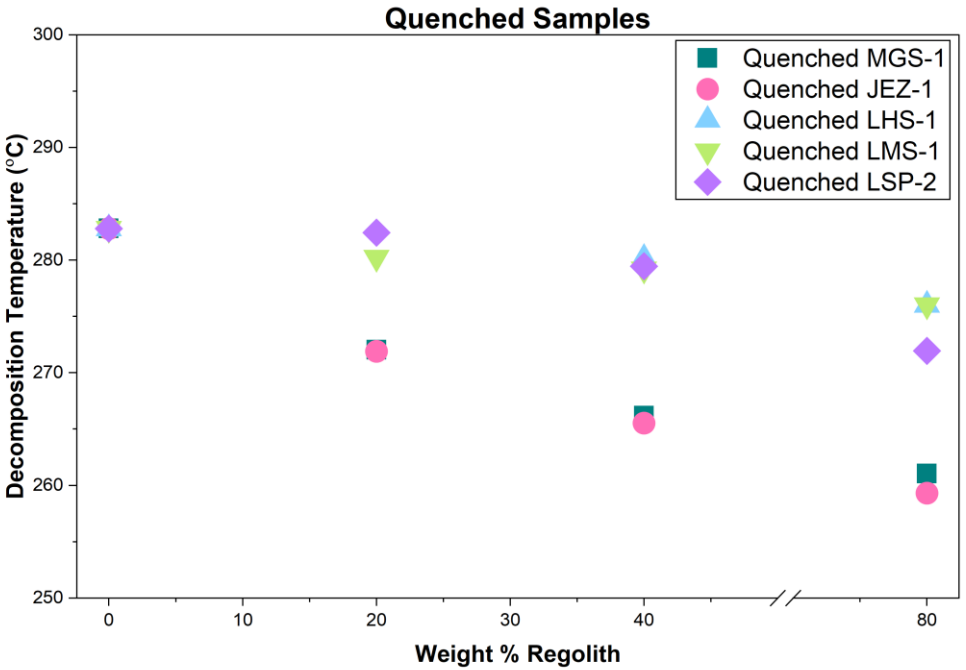

20% LHS-1
[1]1545.8412µm
[5]251.0711µm
[4]773.8557µm
[2]668.4202µm
1000µ

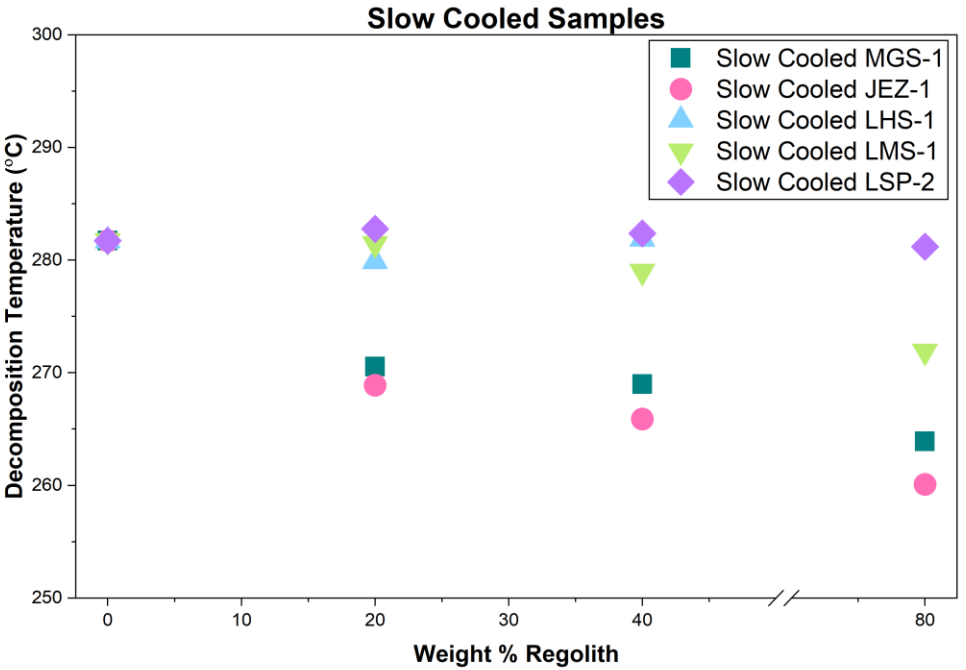

20% JEZ-1
[1]165.9177µm
[2]858.3147µm
[4]372.1744µm
[3]473.8473µm
1000µm


20% LSP-2
[1]799.2536µm
[5]209.4294µm
[2]393.7702µm
[4]507.0504µm
1000


Quenched Samples
Quenched MGS-1
Quenched JEZ-1
Quenched LHS-1
Quenched LMS-1
Quenched LSP-2
% Crystallinity
Weight % Regolith
70
60
50
40
30
20
0
10
20
30
40
80


Slow Cooled Samples
Slow Cooled MGS-1
Slow Cooled JEZ-1
Slow Cooled LHS-1
Slow Cooled LMS-1
Slow Cooled LSP-2
% Crystallinity
Weight % Regolith
70
60
50
40
30
20
0
10
20
30
40
80


Quenched Samples
Quenched MGS-1
Quenched JEZ-1
Quenched LHS-1
Quenched LMS-1
Quenched LSP-2
Decomposition Temperature (°C)
Weight % Regolith
300
290
280
270
260
250
0
10
20
30
40
80


Slow Cooled Samples
Slow Cooled MGS-1
Slow Cooled JEZ-1
Slow Cooled LHS-1
Slow Cooled LMS-1
Slow Cooled LSP-2
Decomposition Temperature (°C)
Weight % Regolith
300
290
280
270
260
250
0
10
20
30
40
80