Simulant and Environment Requirements for ISRU Manufacturing Technology Development

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Purpose

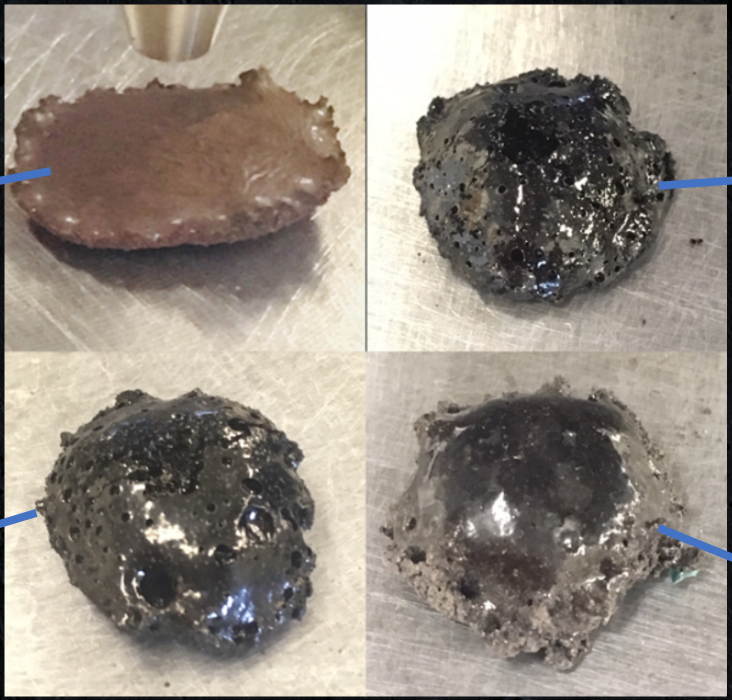
- Previous testing in additive manufacturing (AM) of regolith has been done almost exclusively in air and on older simulants such as JSC-1A
- Powder bed AM on Earth is almost never conducted in air
- JSC-1A is a good geotechnical simulant, but is chemically inaccurate compared to lunar mare samples
- Concentrated solar is likely to be one of the first lunar AM technologies utilized and requires more testing in the lab to reach higher TRL

Scope

- Mechanical tests were performed on spot melted regolith simulant
- 3D printing process parameters were evaluated
- Recommendations for simulants and lab environmental conditions were developed

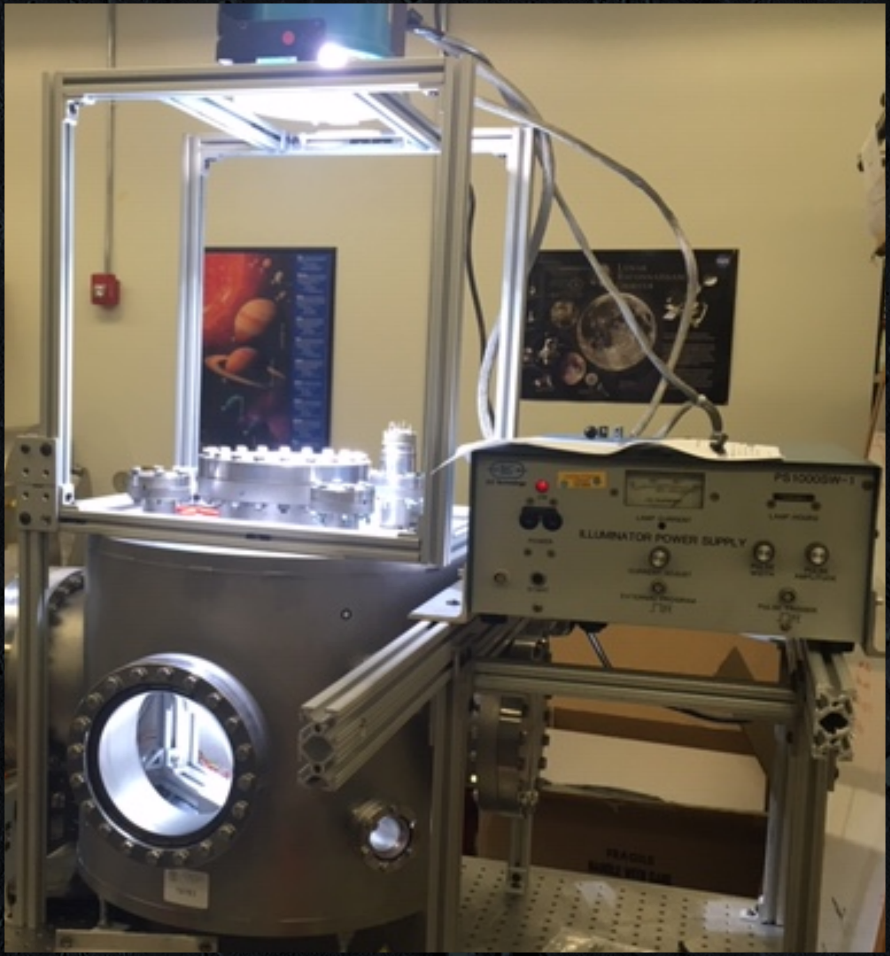
Spot Melting of Regolith

Test Matrix



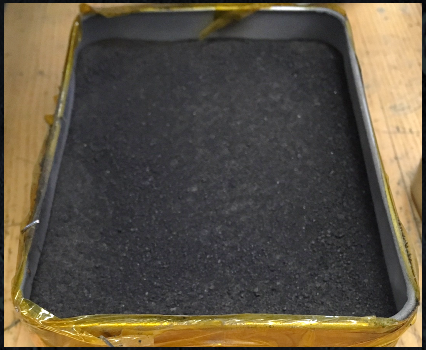
- 10x of each sample type in test matrix were prepared
- Each sample within a type was manufactured and tested on the same day

Test Setup

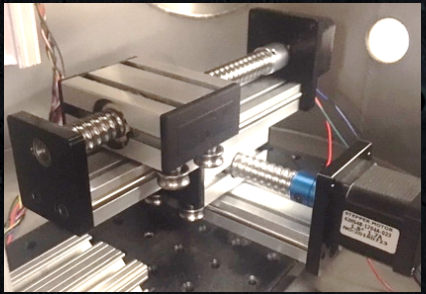


Lamp and Chamber

Internal Optics

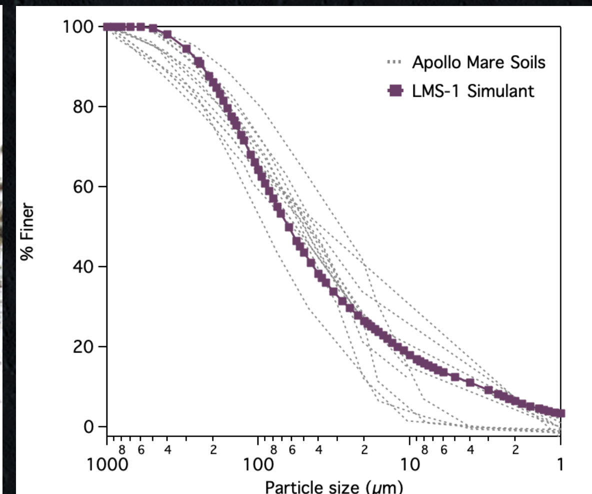


Sample Bed

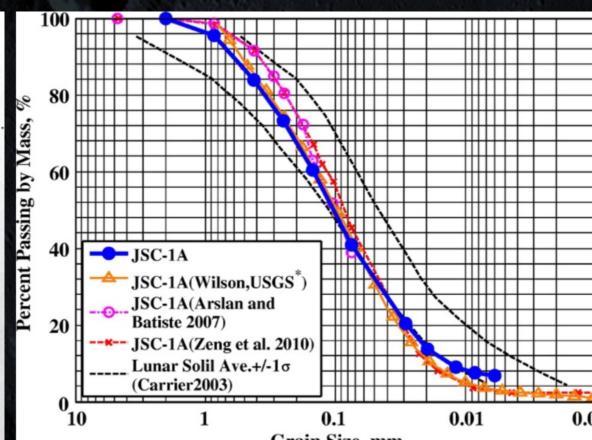


Stages

Simulants



LMS-1 from Exolith Labs



JSC-1A

Images courtesy of Exolith Labs, University of Central Florida

Simulant Geochemistry

Constituent oxides	JSC-1A lunar simulant	LMS-1 lunar simulant	Apollo 17 sample 70051
SiO_2	47.4	42.81	42.2
Al_2O_3	16.1	14.13	15.7
CaO	10.5	5.94	11.5
MgO	7.72	18.89	10.3
FeO	-	7.87	12.4
Fe_2O_3	11.4	-	-
Na_2O	2.94	4.92	0.2
K_2O	0.80	0.57	0.1
TiO_2	1.56	4.62	5.1
P_2O_5	0.59	0.44	-
MnO	0.18	0.15	0.2
Cr_2O_3	0.03	0.21	-
SO_3	-	0.11	-

Data courtesy of Exolith Labs, University of Central Florida

Introduction

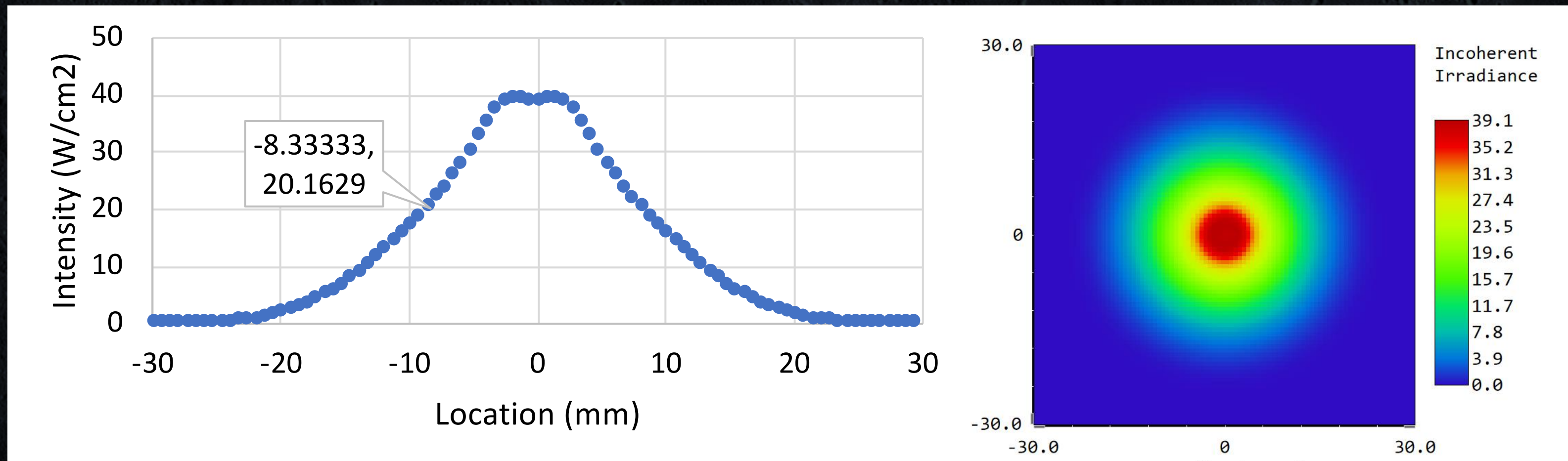
Materials & Equipment

Testing

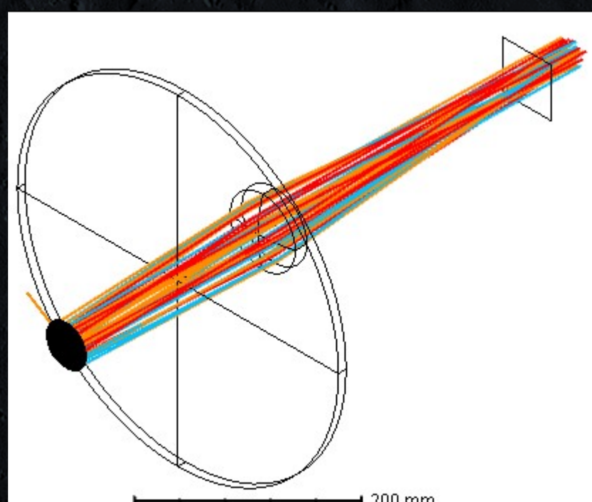
Results & Discussion

Conclusion

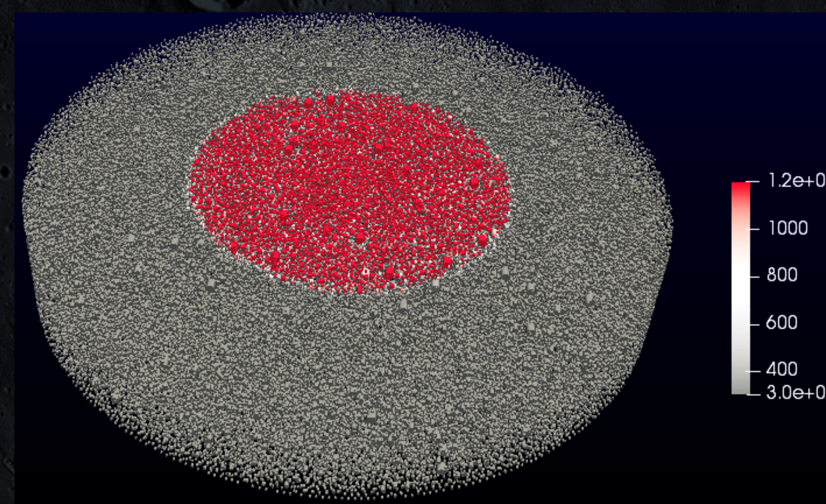
Computational Models



Beam Profile

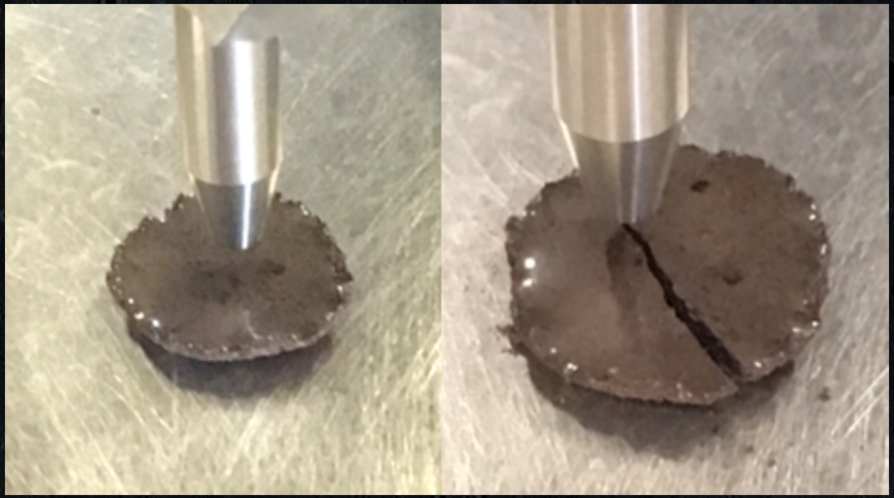


Optical Train

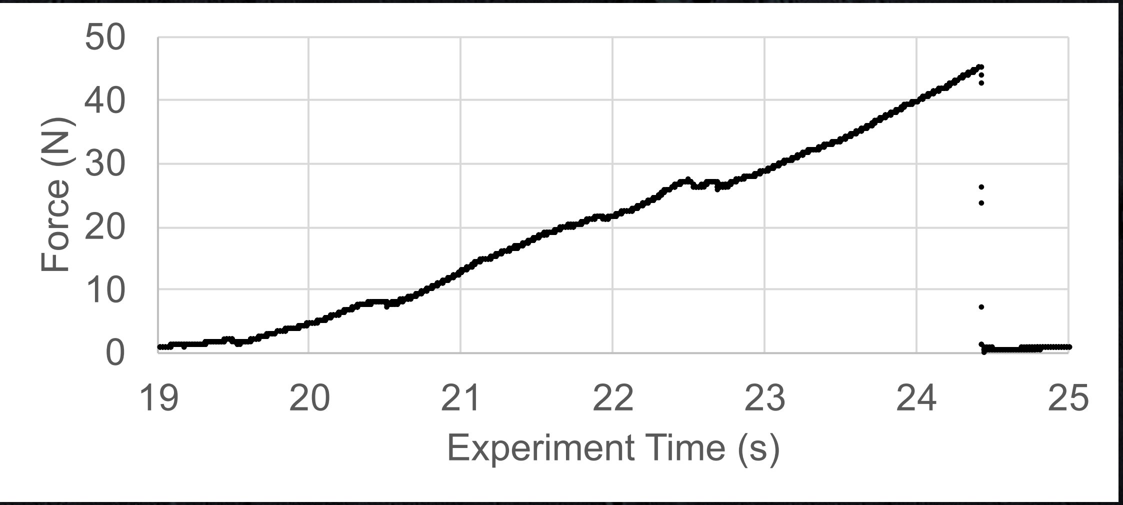


DEM Model

Sample Preparation and Testing



Before and After Penetration Testing



Penetration Curve

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Line and 2D Tests

Line Test, Vacuum, JSC-1A

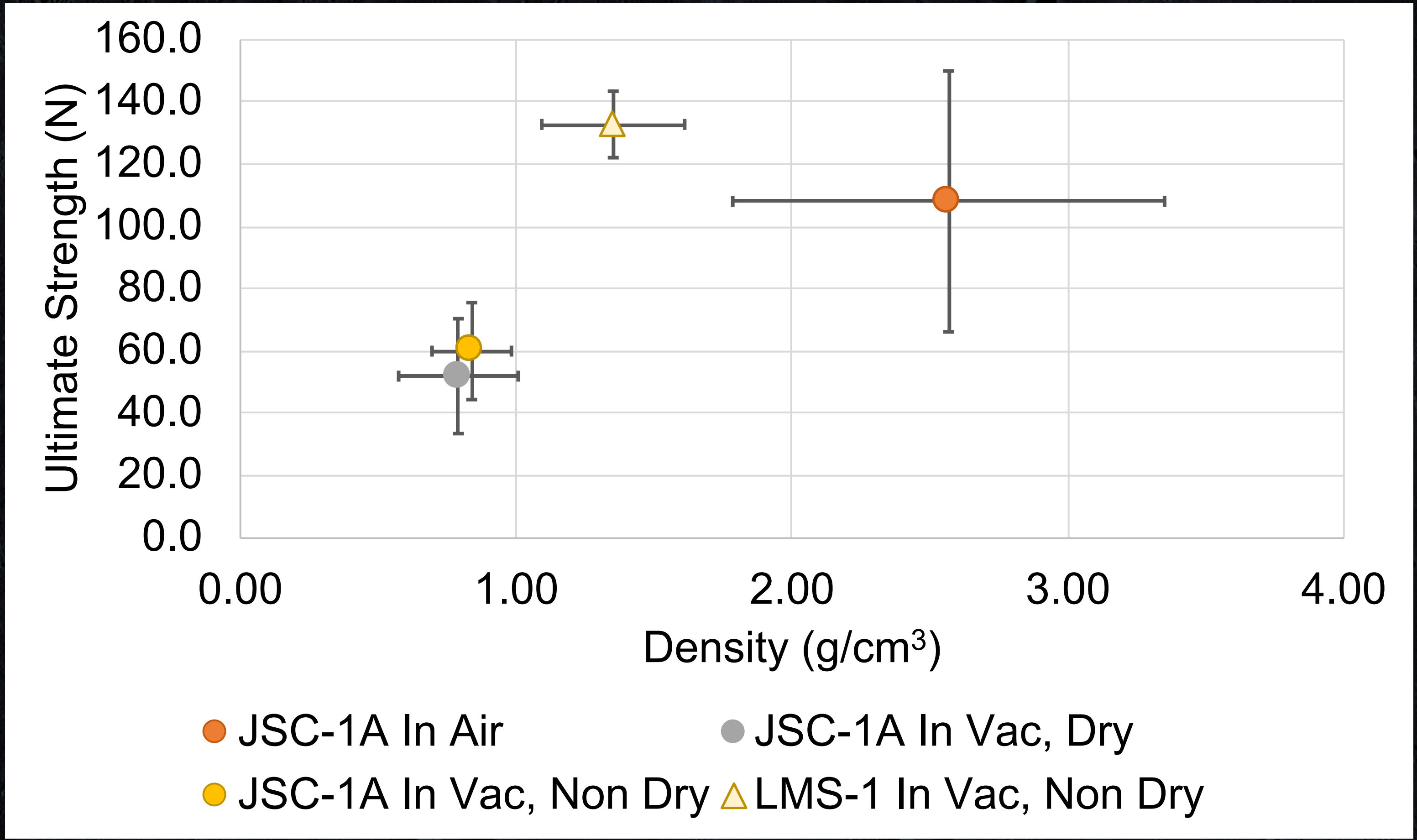
2D Snake Pattern, Vacuum, JSC-1A

2D Snake Pattern, Air, LMS-1

Line and 2D Test Parameters

- At 30 W/cm^2, a minimum scan speed of 7.5cm/min was needed for melting in vacuum
- 1.5cm/min was needed in air
- Higher scan speeds resulted in:
    - Samples that crumbled easily
    - Samples that broke during extraction from the sample bed
    - Flaking and non-homogeneous densities
    - Larger heat affected zones

Mechanical Testing Results



Density vs Ultimate Strength,
Average with Error Bars

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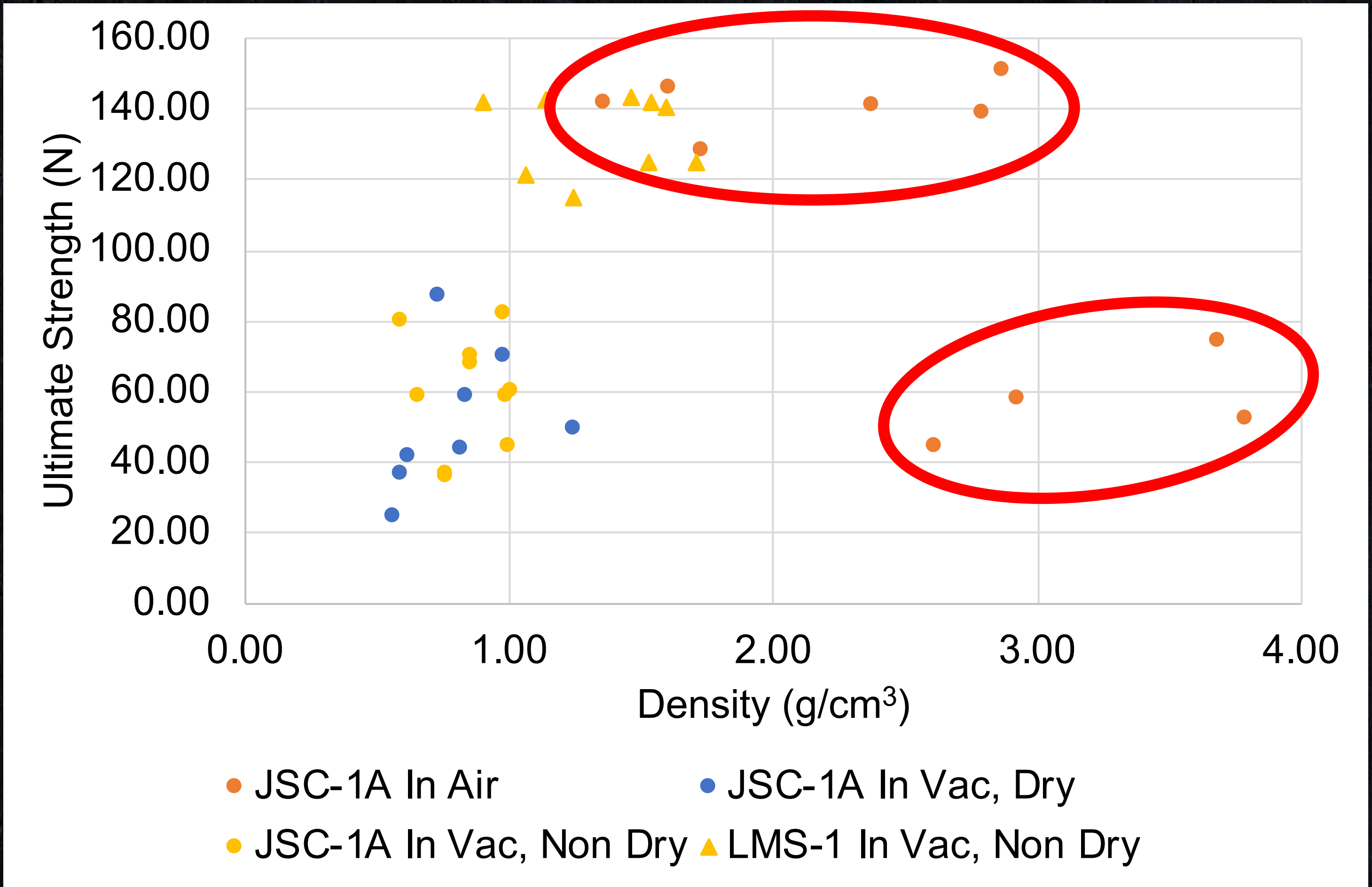
Bimodal Nature of Samples Prepared in Air



Density vs Ultimate Strength, Raw Data

Conclusion

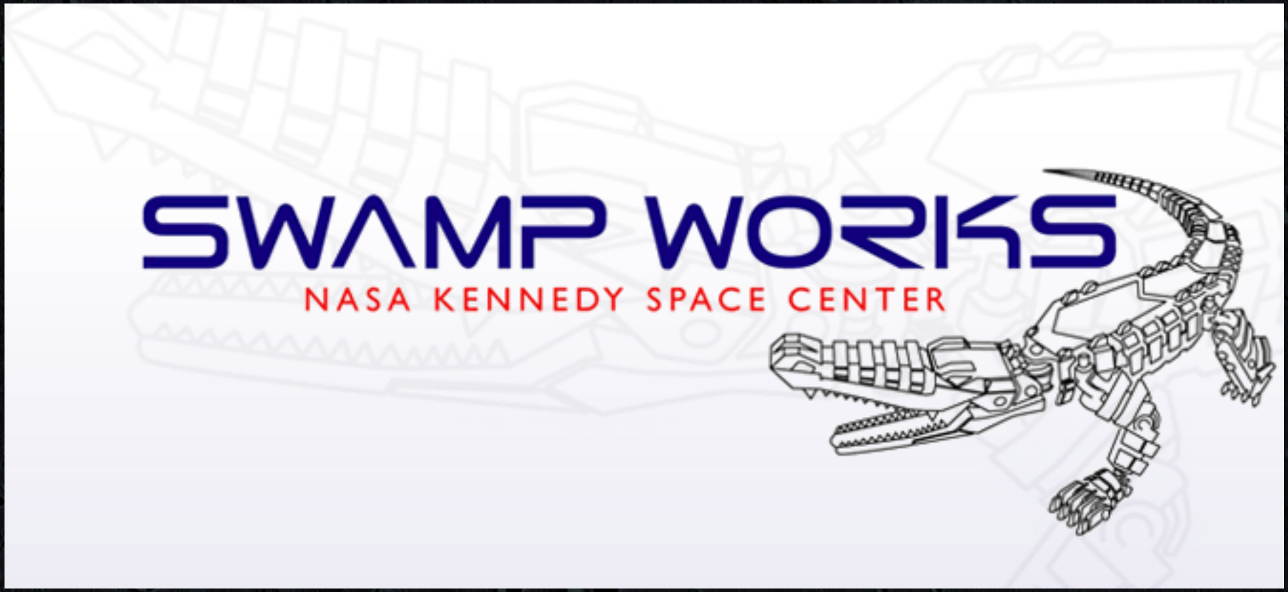
- Samples melted in air have highly variable strength
- Samples melted in air have very different density than vacuum melted samples
- Low thermal conductivity in regolith significantly affects scan speed and print quality
- LMS-1 has nearly double the strengths and density of JSC-1A when prepared in vacuum
- This and other recent studies move concentrated solar AM to TRL 4

Recommendations

- Use higher fidelity simulant for thermal based processes
- Though difficult and costly, use vacuum chambers when melting regolith simulant
- Pre-drying samples does not appear necessary
- Concentrated solar is useful for 3D printing and surface processing, but has low resolution and does not penetrate deeply into the surface

Thank You


Center for Space Resources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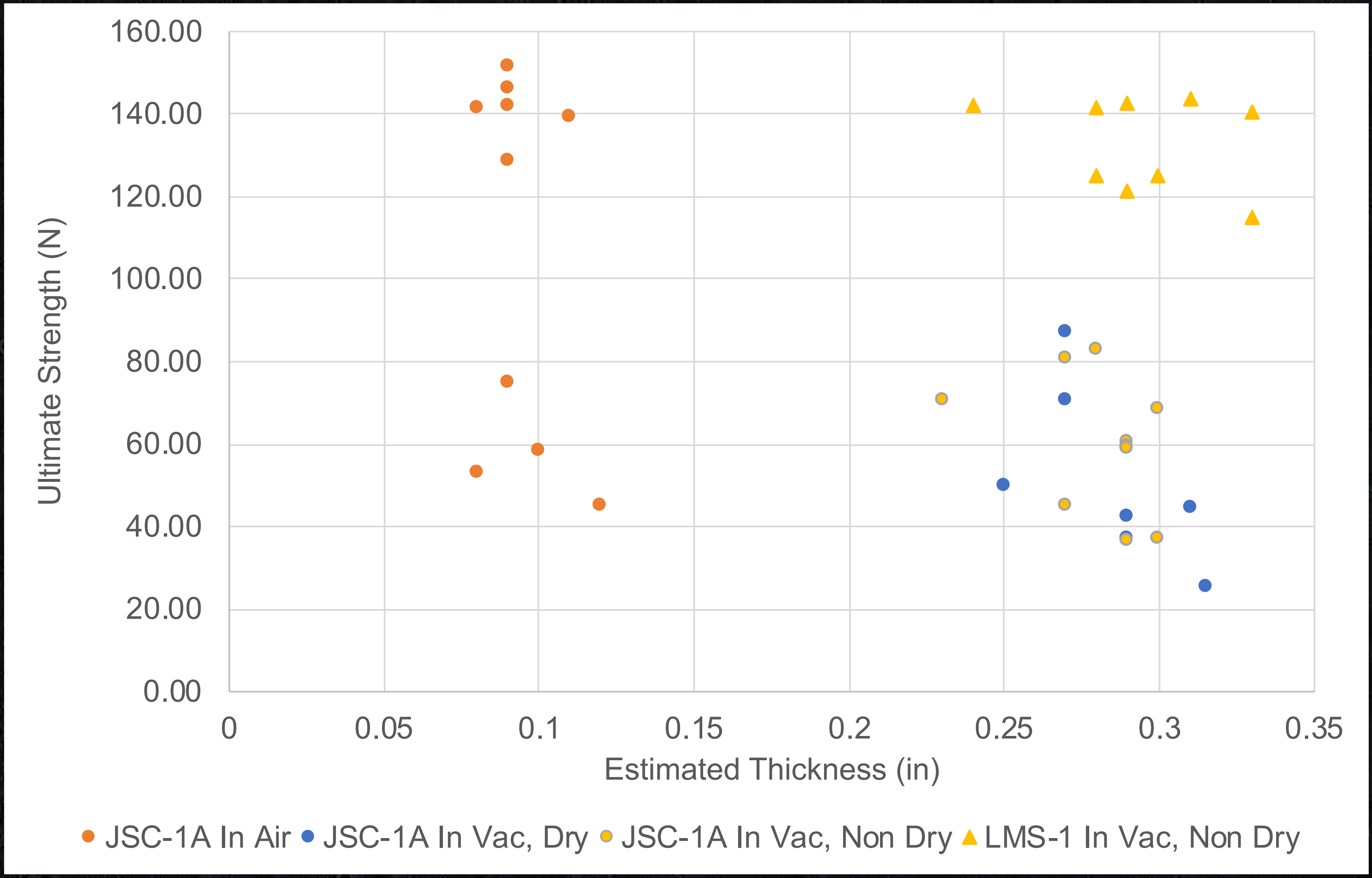
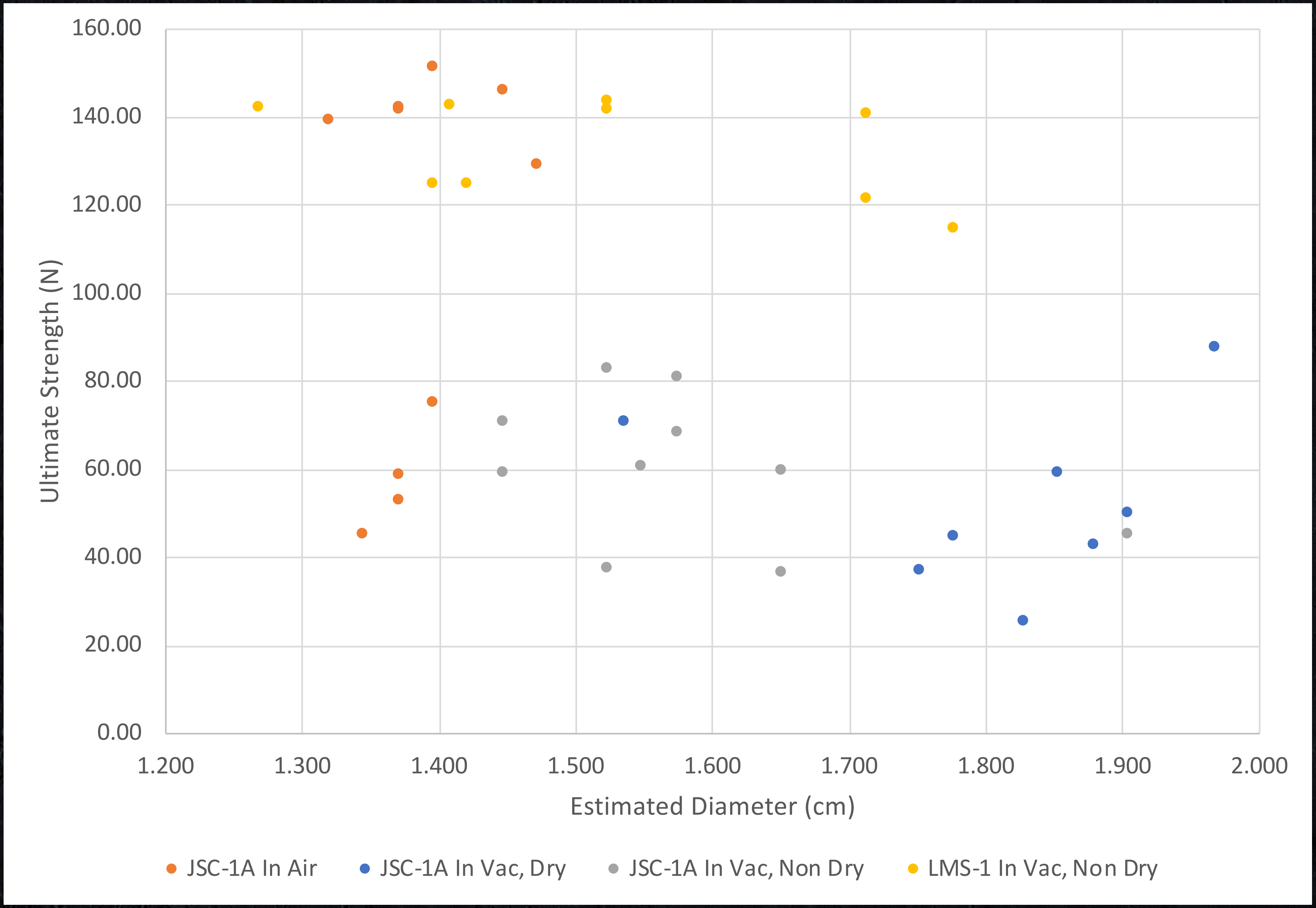
Backup Slides

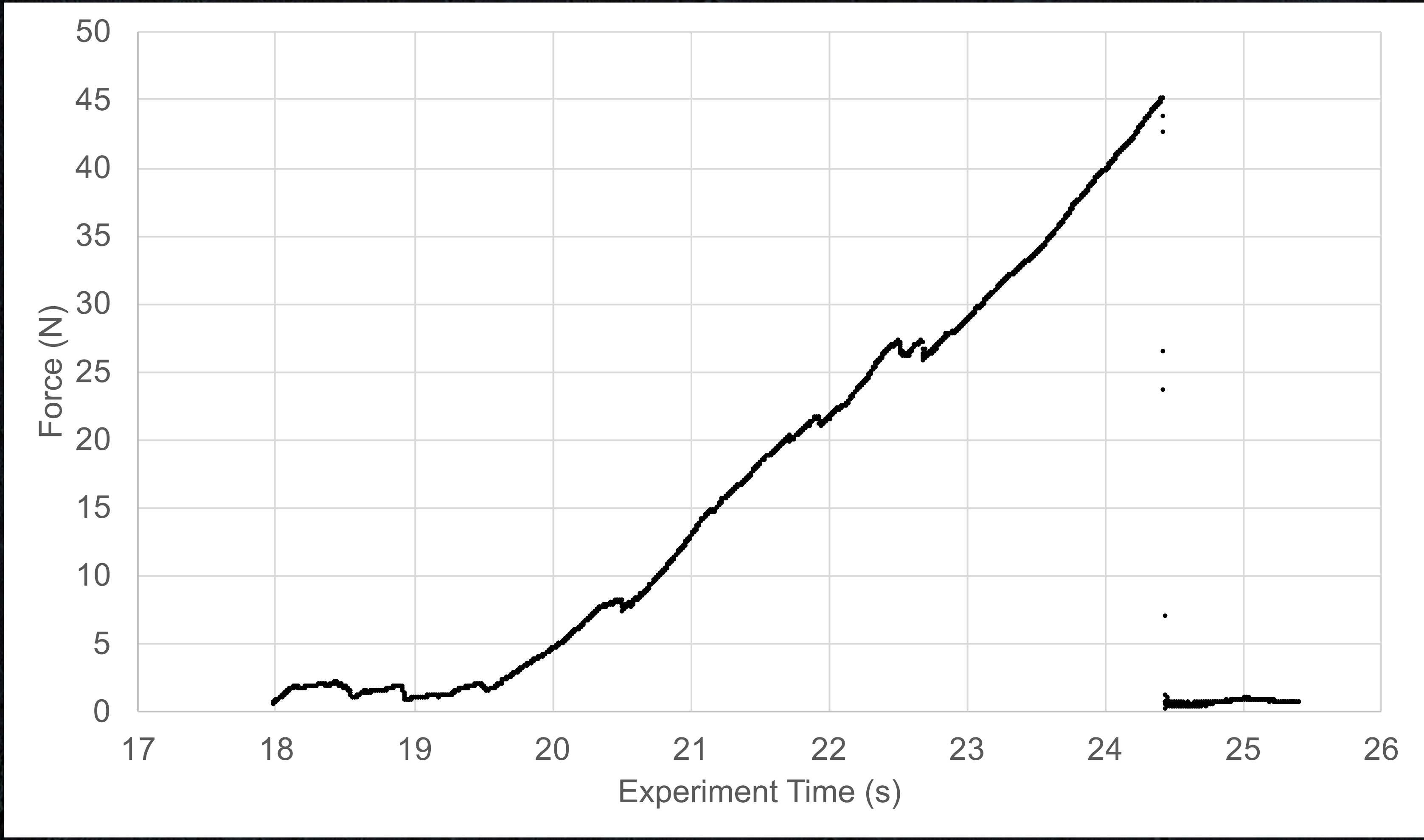
Thickness vs Strength



Diameter vs Strength



Penetration Curve



Key Sample Data

Material	Atmosphere	Pre-Drying	Mean Density (g/cm^3)	Min Density	Max Density	Mean Strength (N)	Min Strength	Max Strength
JSC-1A	Air	No	2.57	1.35	3.78	108.1	45.1	151.4
JSC-1A	Vacuum	No	0.84	0.58	1.01	60.1	36.5	83.0
JSC-1A	Vacuum	Yes	0.79	0.55	1.24	52.0	25.48	87.35
LMS-1	Vacuum	No	1.35	0.90	1.70	132.9	114.7	143.4