Ceramic Material Processing Towards Future Space Habitat--- Microstructure and Properties of field-assisted sintering of lunar soil simulant (JSC-1)

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PURDUE MATERIALS ENGINEERING

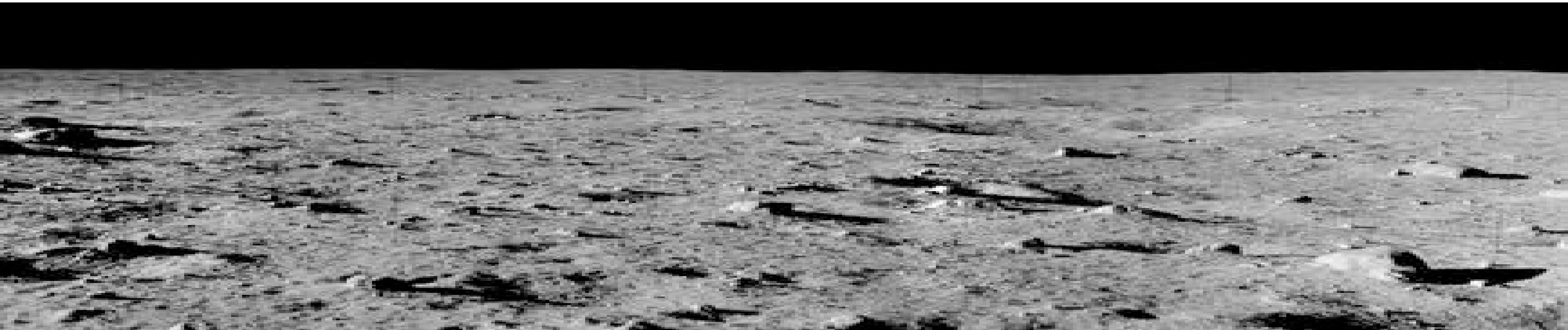
Introduction of lunar habitat

- Goal: long duration human presence on the surface of the Moon
- Reduce mass of essentials from Earth by *in situ* resources utilization
  - Extraction of oxygen for propellant and human sustenance
  - Extraction of metals and other pure materials (e.g. Si) for solar cells (power generation)
  - Construction of habitats and structures for habitation

Complexities of the conditions on the moon

- Lunar exosphere – “hard vacuum”
  - 14 times less molecules/cm^3 than Earth atmosphere
  - Gases: Ar, He, O_2, CH_4, N_2, CO, CO_2
- 17% gravity of Earth
- Temperature range from -173°C to 127°C depending on the sun

Lunar Resource Book.



Lunar regolith simulant JSC-1 to approximate lunar soil

- Lunar soil: $NaAlSi_3O_4$, $CaAl_2Si_2O_8$, $(MgFe)_2SiO_4$…..
- Simulant developed by NASA and Johnson Space Center

Oxide	Lunar soil	Simulant powder
	Concentration (wt.%)	
SiO_2	47.3	47.71 ± 0.10
Al_2O_3	17.8	15.02 ± 0.04
CaO	11.4	10.42 ± 0.03
MgO	9.6	9.01 ± 0.09
FeO	10.5	7.35 ± 0.05
Fe_2O_3	0.0	3.44 ± 0.03
Na_2O	0.7	2.70 ± 0.03
TiO_2	1.6	1.59 ± 0.01

NASA Johnson Space Center JSC-1 datasheet

Previous reports on *in situ* resource utilization using lunar simulant soil

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Acta Astronautica

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Sintering of micro-trusses created by extrusion-3D-printing of lunar regolith inks

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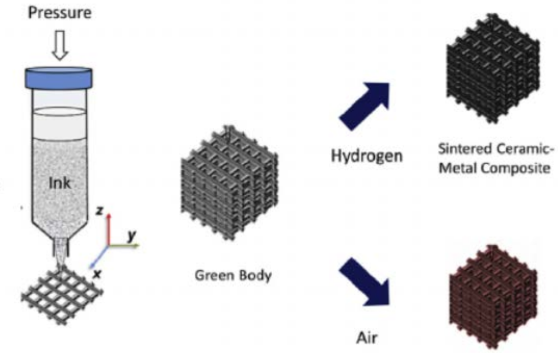

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Journal of Non-Crystalline Solids

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JSC-1A lunar soil simulant: Characterization, glass formation, and selected glass properties

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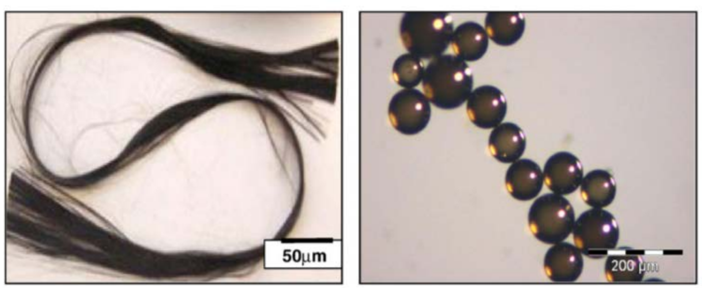
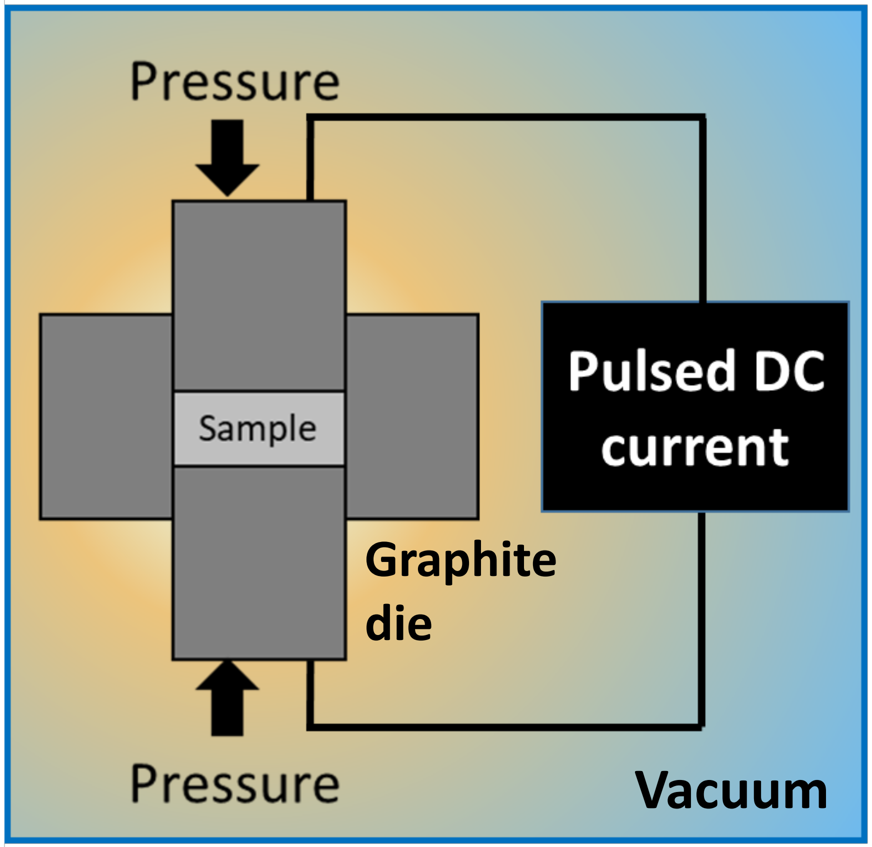


Glass fibers and hollow glass microspheres produced by melting the simulant at 1450°C in air

Allen et al., 1992, high T sintering
Indyk, et al., 2017, high T sintering
Altemire et al., 1993, cold press
Taylor et al., 2005, microwave sitnering

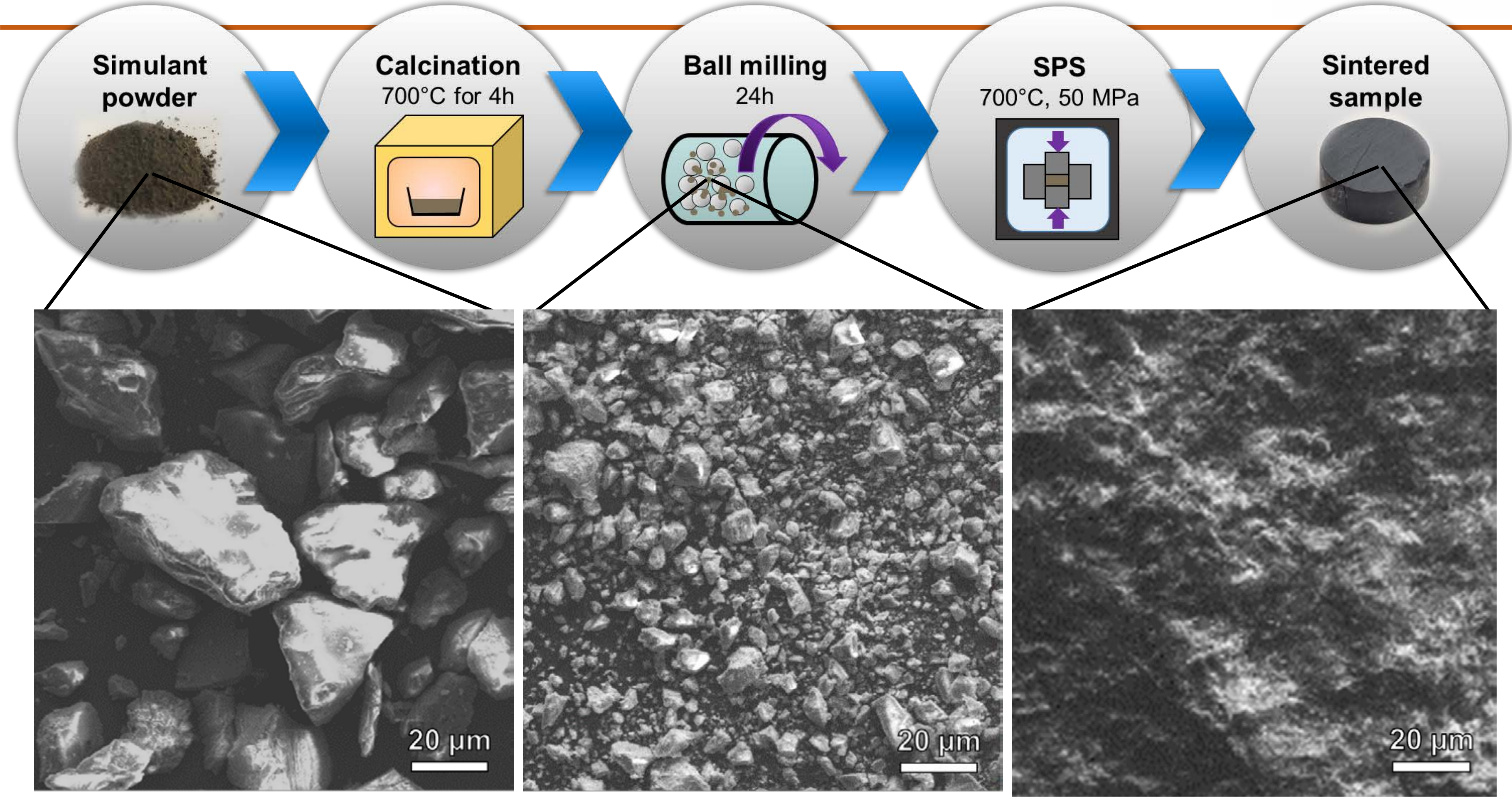
Why field-assisted sintering?



- Also known as spark plasma sintering (SPS)
- Joule heating of graphite die by an applied field
- Significant reduction in sintering temperature and time compared to conventional sintering

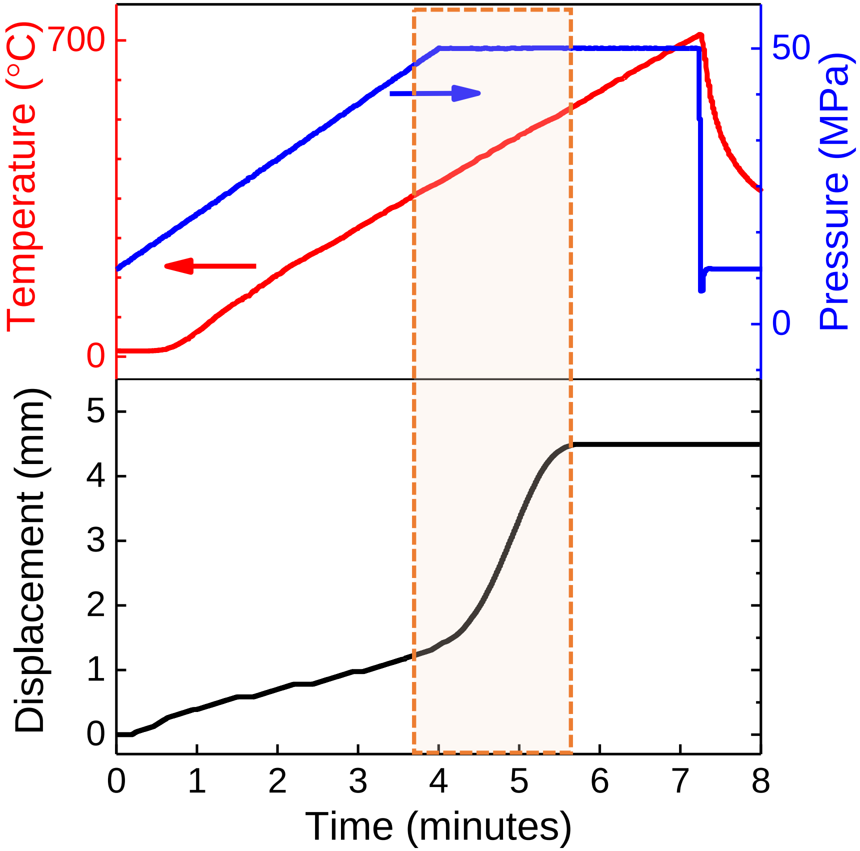
Phuah, Wang, et al, in preparation.

Proposed steps to process lunar soil



Phuah, Wang, et al, in preparation.

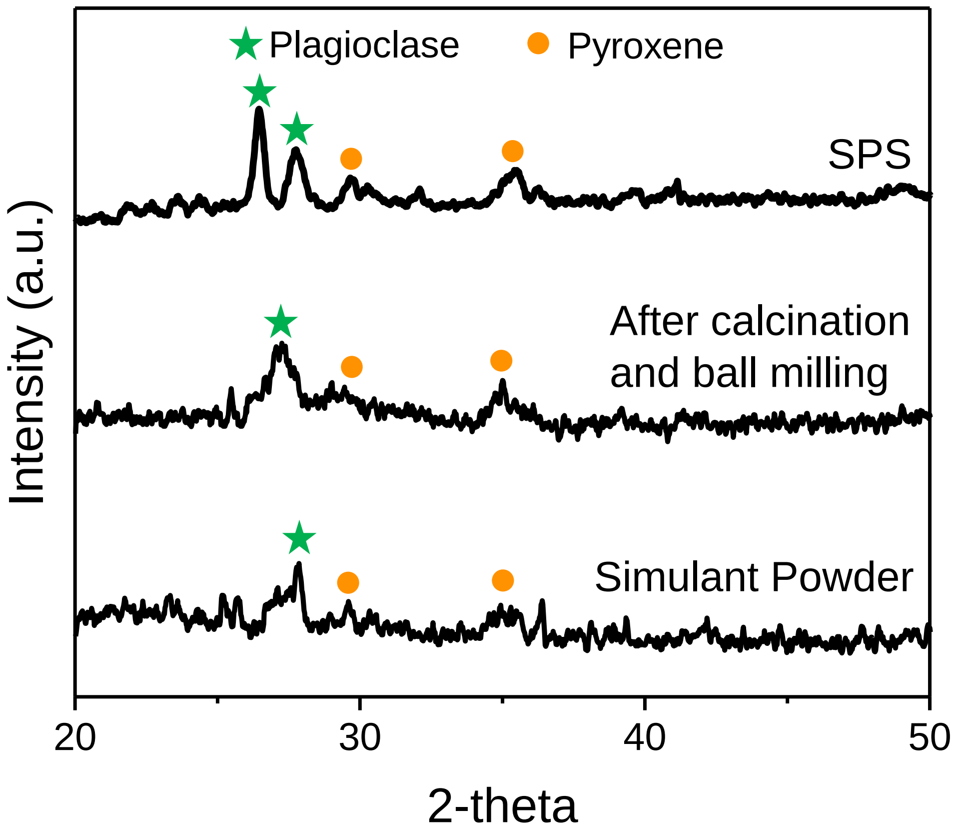
Densification of powder compacts at low temperatures



- Densification occurs between 550 to 600°C

Phuah, Wang, et al, in preparation.

Phase analysis and final properties of the bulk specimens after SPS

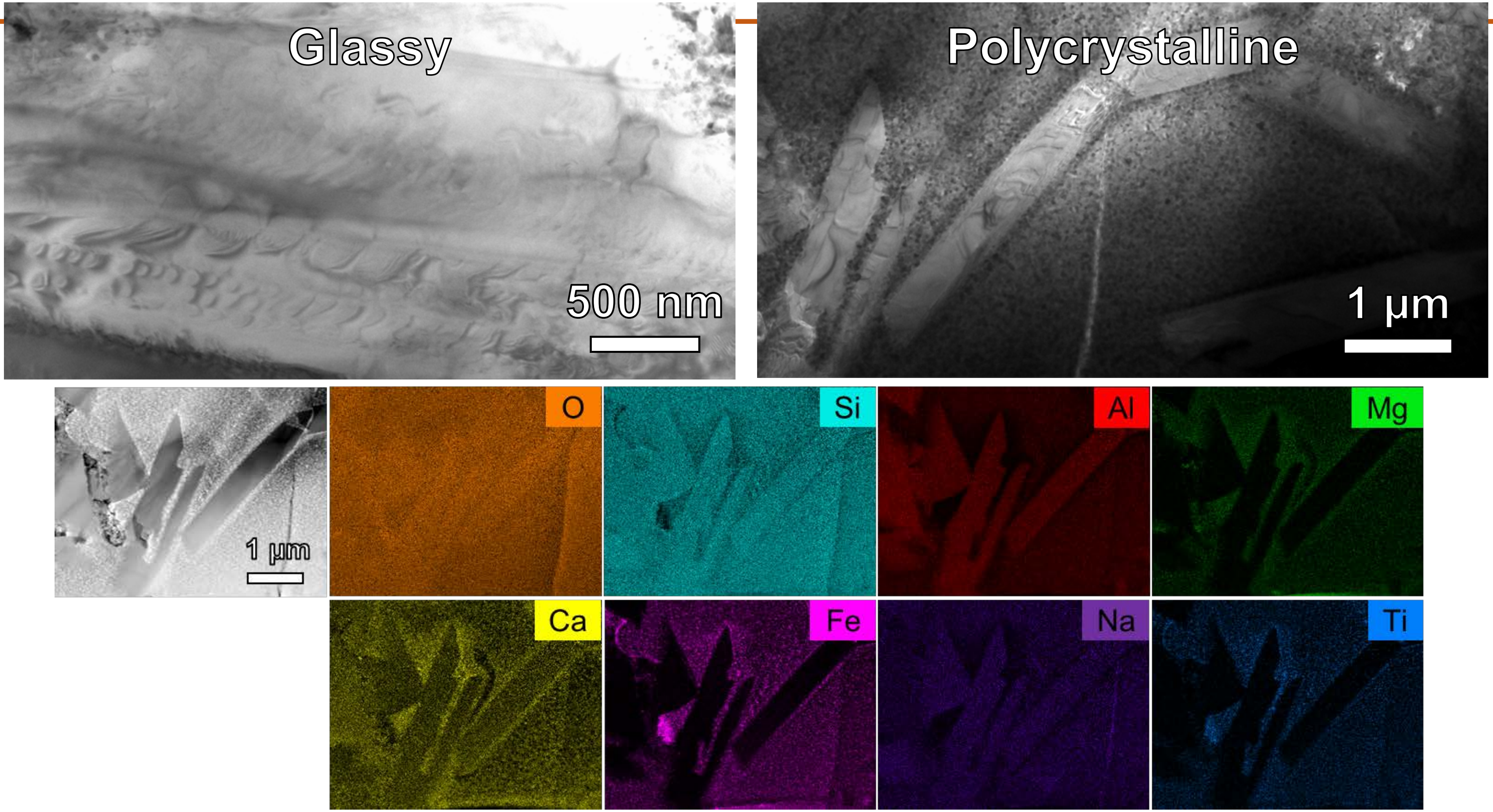


Property	Value
Density	2.85 g/cm^3
Hardness	6.01 ± 0.66 GPa

Much higher compressive hardness and full density compared to prior reports.

Phuah, Wang, et al, in preparation.

Microstructure of the bulk specimens after SPS of lunar soil simulant



Phuah, Wang, et al, in preparation.

Summary

- Ceramic sintering experiment was conducted using lunar simulants.
- The bulk structures sintered by field-assisted sintering under moderate temperatures are of full density, without obvious porosity.
- Such dense sintered ceramic structures present great opportunities for constructing ceramic structures for future human space habitats.
- Much work is very much needed to further reduce the sintering temperature, optimize/simplify powder processing, evaluate structural integrity under lunar surface conditions, and conduct sintering experiments using actual lunar soils and lunar surface conditions.