Some Observations during Carbothermal Reduction of Lunar Mare Regolith Simulant

Extra-Terrestrial Manufacturing Research Centre (ExTeM)

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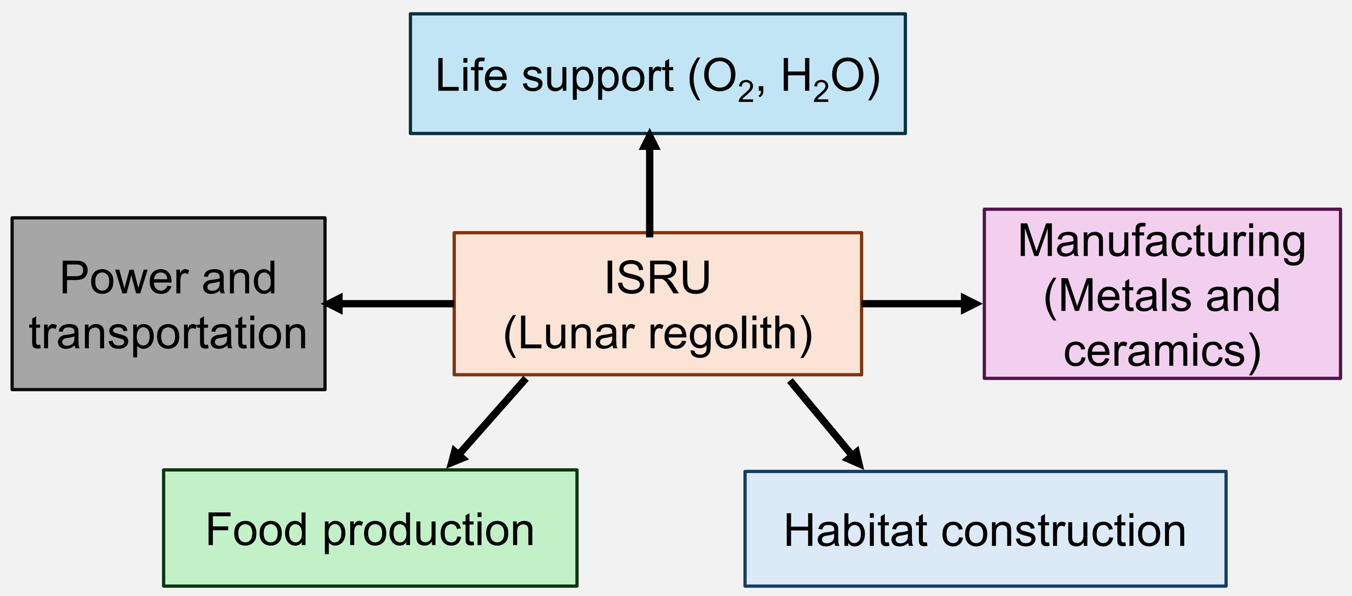
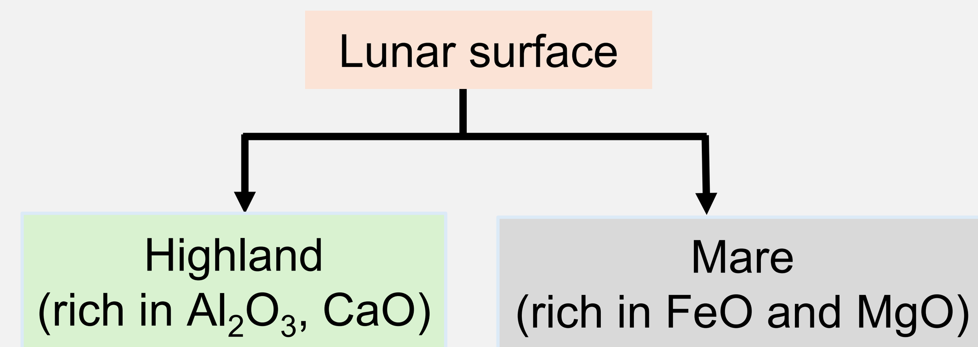
1. In-situ Resource Utilization (ISRU)



2. Mineralogical and Chemical Composition of Lunar Regolith



Major minerals found in the lunar surface:

- Anorthosite [(Ca,Na)(Al, Si)$_4$O$_8$]
- Pyroxene [(Ca,Fe,Mg)$_2$Si$_2$O$_6$]
- Basalt rock
- Ilmenite ($FeTiO_3$)
- Olivine [(Mg, Fe)$_2$SiO$_4$]

Therefore, silicon and its compounds can be extracted in large amounts, given its abundance

Findings from lunar soil samples collected during the apollo missions:

- Majority of the minerals present in the lunar soil are **silicates**
- **Silicon** is the abundant element next to **oxygen**
- In terms of oxide composition, **silicon dioxide** is most abundant (approximately 50%)

3. Why Silicon Carbide?

- Industrially, SiC is produced through the Acheson process

  SiO_2 + 3C = SiC + 2CO (Acheson process)

Similarly,

  SiO_2 (present in regolith) + carbon = SiC ??

- SiC is used as abrasives, semiconductors and reinforcements for composite structures
- SiC is hard and radiation resistant, making it a promising material for applications requiring durability in the harsh lunar environment.

4. Methane – The Source of Carbon

- In the International Space Station (ISS), Sabatier process is used for the conversion of CO_2 exhaled by the astronauts to water and methane
- Methane is vented out to space. So, methane can be used as the carbon source for the synthesis of SiC

5. Objectives

- To synthesize silicon carbide from lunar regolith simulants by using methane as the carbon source
- To use the synthesized SiC as reinforcements for regolith matrix composites

6. Materials and Methods

Fig.1 *LHS-1*

Wt% of SiO_2 - 51.2

Wt% of FeO - 2.7

Fig.2 *LMS-1*

Wt% of SiO_2 - 46.9

Wt% of FeO - 8.6

Experimental conditions:

SiC synthesis temperature - 1600℃ (Dwell time: 6 hrs)

Methane flowrate – 12.5 sccm;

Argon flow rate - 250 sccm

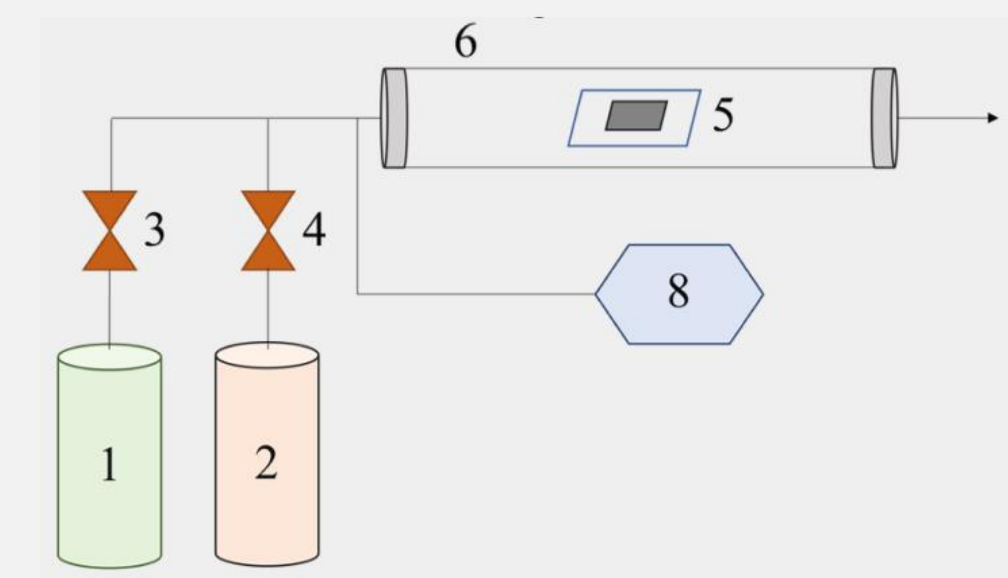


Fig.3 *Schematic diagram of the experimental setup (The components are listed as follows: 1 − Argon cylinder, 2 − Methane cylinder, 3 − MFC for argon, 4 − MFC for methane, 5 − Graphite crucible + alumina plate, 6 − Alumina tube, 7 − Exhaust gases, 8 – Vacuum pump)*

7. Results of Carbothermal Reduction of Lunar Regolith Simulants at 1600℃

LHS-1

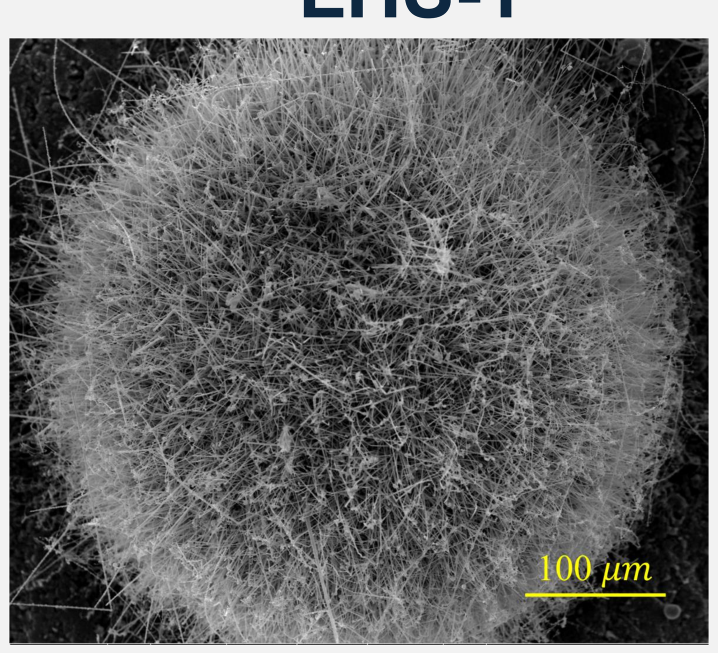


Fig.4 *SEM image of SiC whiskers*

Discussion

- In LHS-1, FeO is only around 2.7 wt%
- Fe vapors released from regolith form micron sized particles facilitating 1-D growth of SiC whiskers

Ref: Srimurugan, N., & Subbiah, S. (2025). Carbo-thermal reduction of lunar highland regolith simulant for in-situ manufacturing of SiC. *Manufacturing Letters*, *44*, 416-423

LMS-1

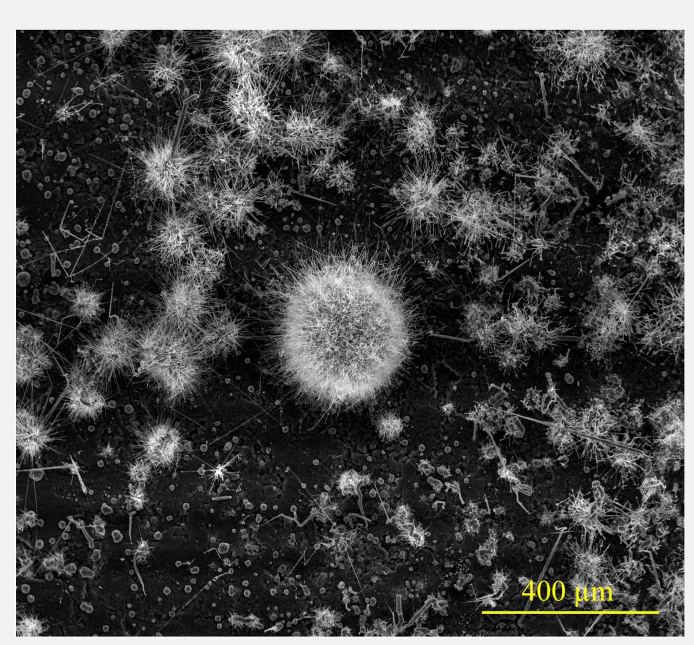


Fig.5 *SEM image of SiC whiskers*

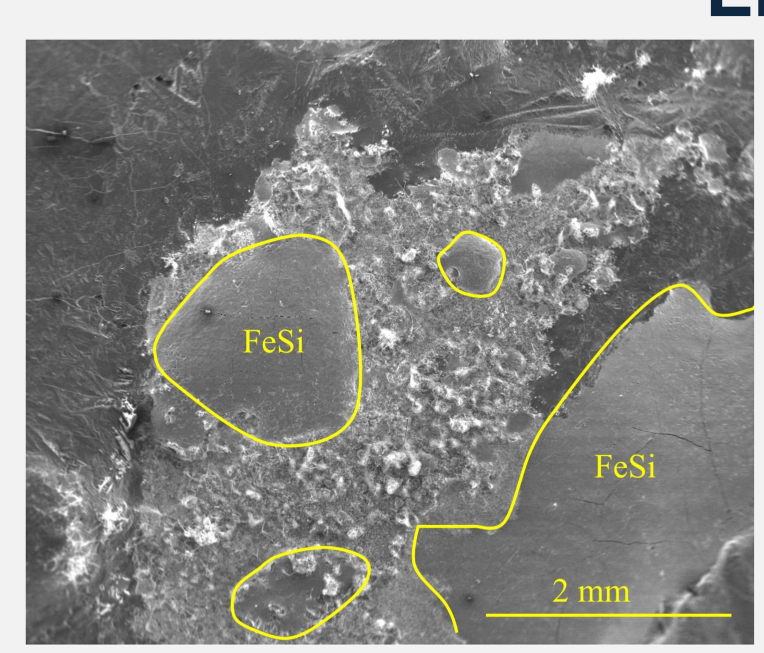


Fig.6 *SEM image of FeSi alloys*

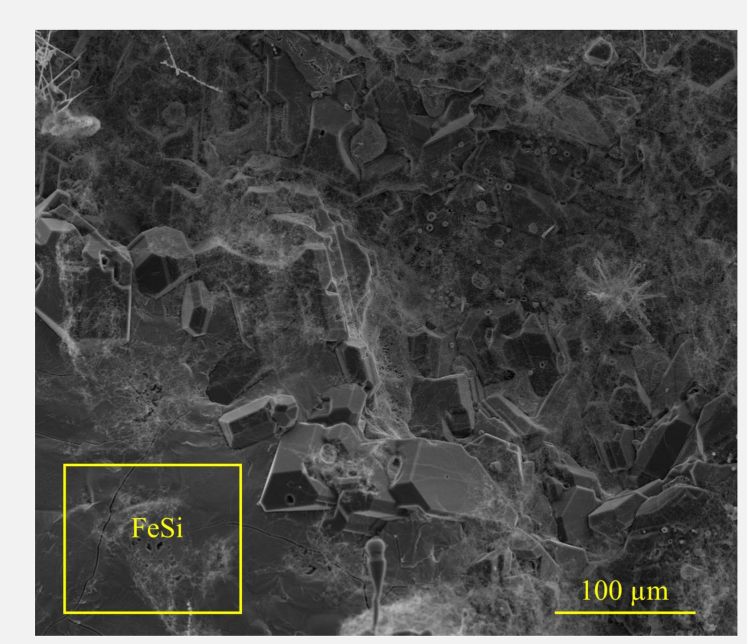


Fig.7 *SEM image of SiC crystals*

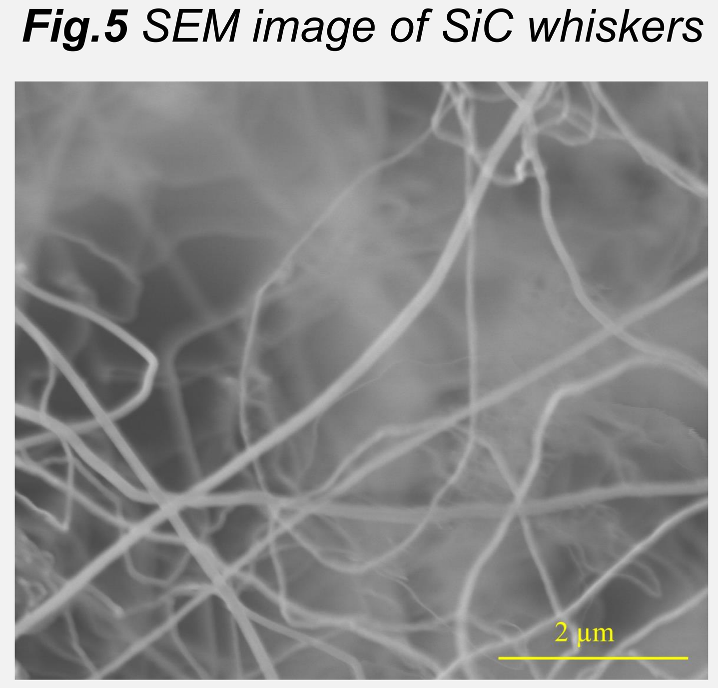


Fig.8 *SEM image of SiC nanowires*

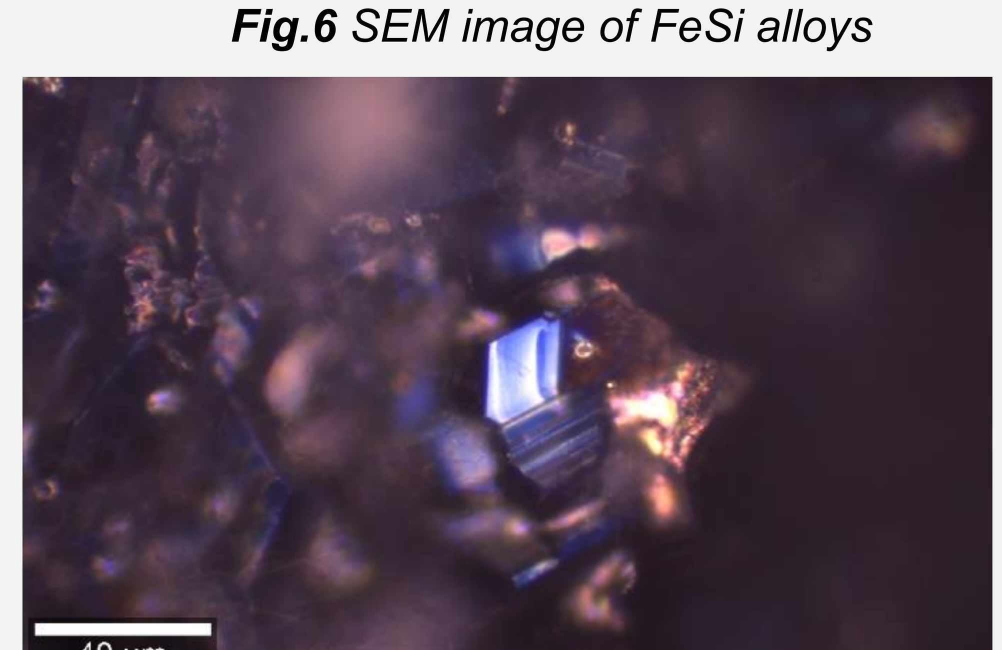


Fig.9 *Region of point scan of SiC crystal during Raman spectroscopy*

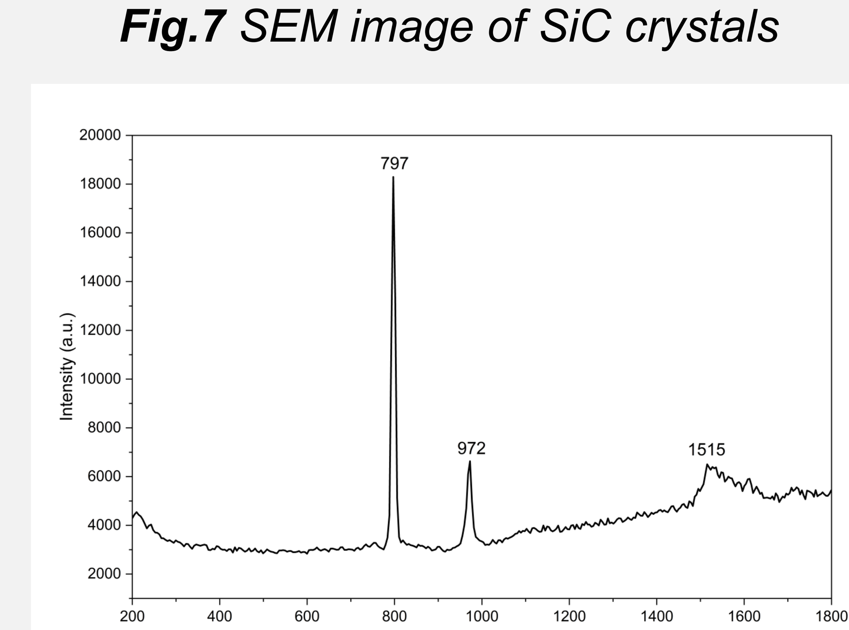


Fig.10 *Raman spectra of SiC crystal Peaks at 797, 972 and 1515 cm^{-1} confirm that the grown crystals are SiC*

Discussion

- In LMS-1, the FeO content is approximately 8.6 wt%.
- Fe vapors released from the regolith react with solid carbon to generate a liquid Fe–C system.
- SiO vapors evolved from the regolith, dissolve into the liquid Fe–C phase, leading to the formation of FeSi alloys.
- Owing to relatively high iron content in LMS-1, the FeSi alloys coalesce into millimeter-sized melt droplets, which promote the solution growth of two-dimensional SiC crystals.
- SiO vapors become supersaturated around the FeSi melt droplets and react with CH_4, resulting in the growth of interwoven network of SiC nanowires