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# Combustion Joining of Regolith Tiles for *In-Situ* Fabrication of Launch and Landing Pads

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# Agenda

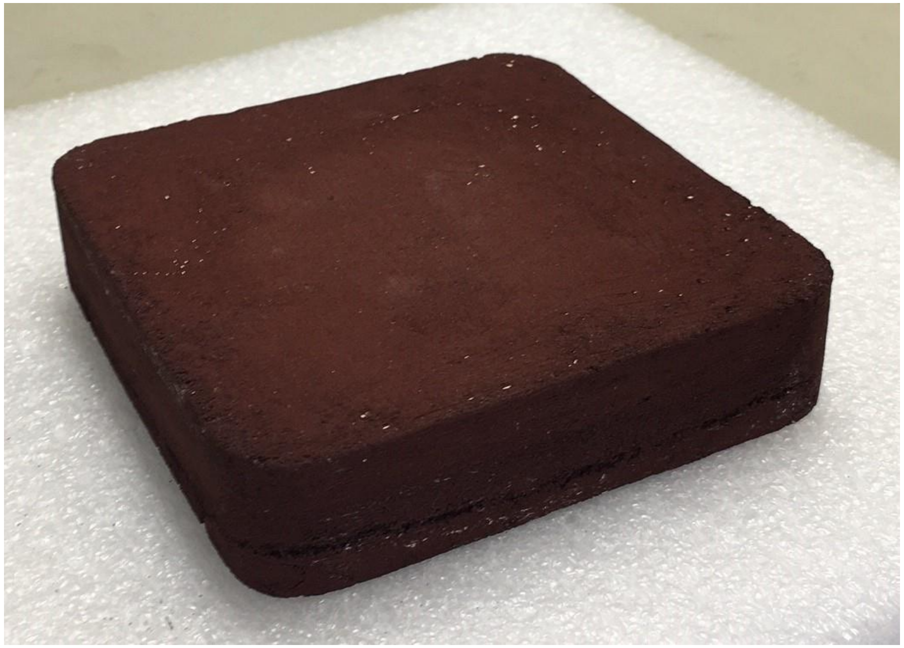
- Background
- Objectives
- Experimental
- Results
- Future work

# Background

- During the Apollo lunar landings, dust concerns were repeatedly noted.
  - Obstructed visibility during landing
  - Affect on nearby equipment
  - Lunar and command module contamination
  - Health issues affecting the astronauts during return

# Dust Mitigation Techniques

- NASA's Granular Mechanics and Regolith Operations Lab at Kennedy Space Center has produced tiles by high-temperature sintering of lunar regolith simulant.



*Credit: R. Ferguson, UTEP*

- *In-situ* resource utilization reduces costs of missions to the Moon and Mars.

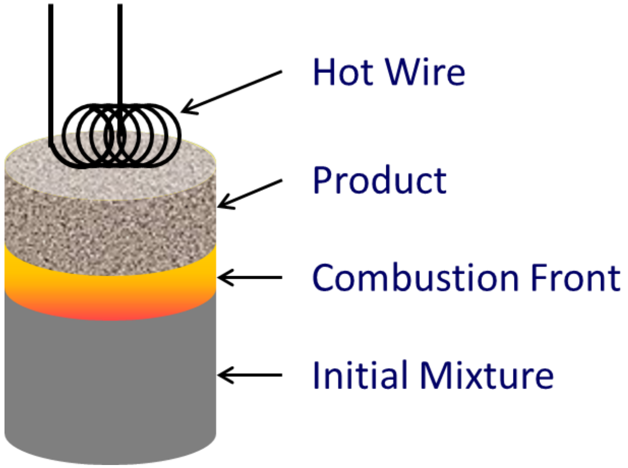
# Joining the Tiles

- A method to join these tiles is desirable.
- By joining the tiles, launch and landing pads could be constructed using *in-situ* resources.
- Combustion joining, a technique based on self-propagating high-temperature synthesis (SHS), shows promise as a joining operation.

A rover built a prototype launch-and-landing pad on Hawaii's Big Island in late 2015. *Credit: PISCES*

# SHS

- Reactive powders are mixed and ignited by an external energy source.
- The released chemical energy provides heat to propagate the combustion front.
- The reaction generates high temperatures and desired products.
- SHS is used to synthesize ceramics and other materials.




**Schematic of SHS process**

# Combustion Joining

- Powders are mixed and placed into a gap between two parts.
  - Thermites or intermetallics
- The powders are ignited, and a self-sustained combustion propagates along the gap.
- This process welds the two parts together *via* the reaction product.

# Present Work

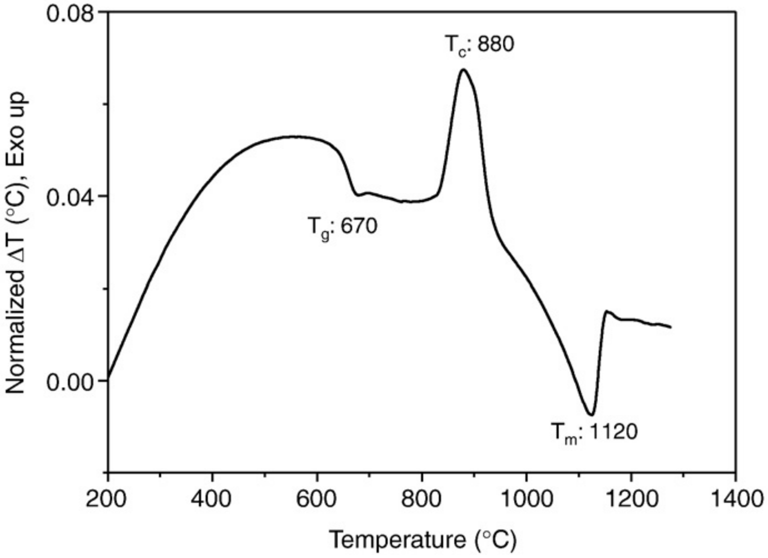
- Apply combustion joining techniques to sintered regolith tiles.
- Powders are mixed and placed between the tiles.
- The mixture is ignited and combustion propagates along the tile gap.
- The reaction heat partially melts the edges of the tiles while forming a new material and welding the tiles together.

# Objectives

- Verify the feasibility of combustion joining of regolith tiles.
- Determine the optimal distance between the tiles.
- Identify an effective mixture for combustion joining of regolith tiles.

# Nickel-Aluminum System

- NI + Al → NiAl
  - Adiabatic flame temperature: 1639 °C
  - 58 % solid NiAl
  - 42 % liquid NiAl
- JSC-1A Lunar Regolith Simulant
  - Partially melts at 1120 °C




**DTA curve for the JSC-1A lunar simulant**

Ray et al., *Journal of Non-Crystalline Solids* 356 (2010) 2369–2374

# Powders

- Nickel
  - 3-7 µm, 99.9% pure, Alfa Aesar
- Aluminum
  - 3.0-4.5 µm, 97.5% pure, Alfa Aesar
- Al:Ni 1:1 mole ratio
- Mixed in a 3D inversion kinematics mixer (Inversina 2L) for 60 min in a $N_2$ environment

*Credit: R. Ferguson, UTEP*

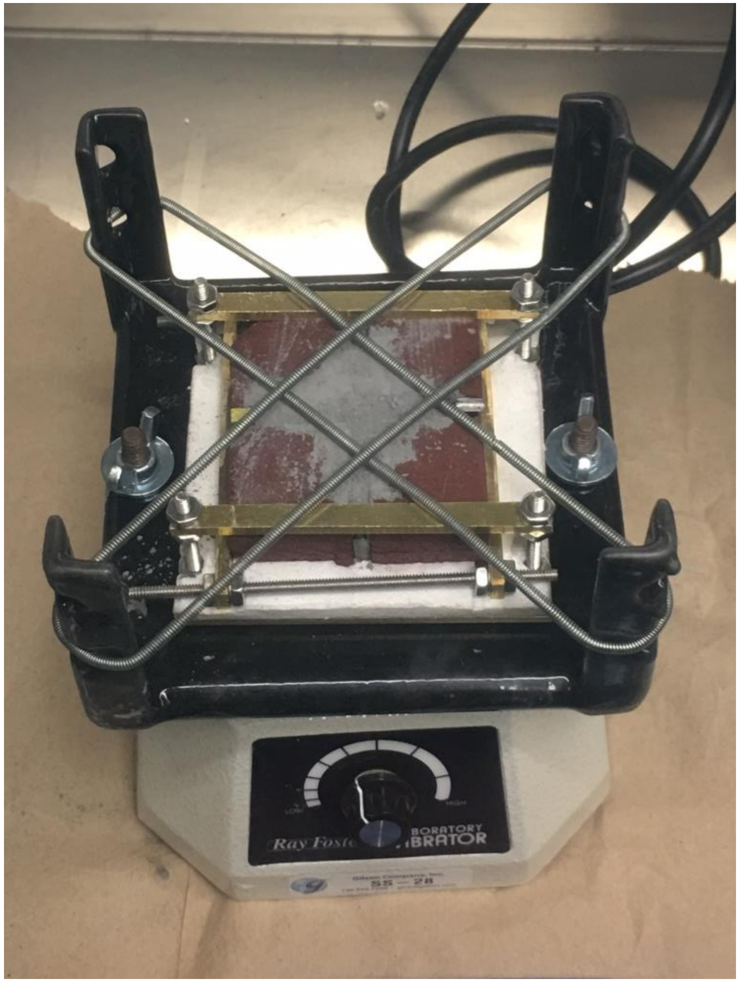
# Tiles

- Tiles made at KSC are cut into 32-mm square segments using a saw.
- The tiles retain their original thicknesses:
  - 6.3 mm
  - 12.7 mm
  - 25.4 mm

*Credit: R. Ferguson, UTEP*

# Tile Holder

- Tiles loaded into holder and locked into place with a preset gap (2, 4, 6 mm).
- Powders are placed into the gaps and settled with a shaker (Gilson SS-28 Vibra-Pad).
- Additional powder is added as necessary.




*Credit: R. Ferguson, UTEP*

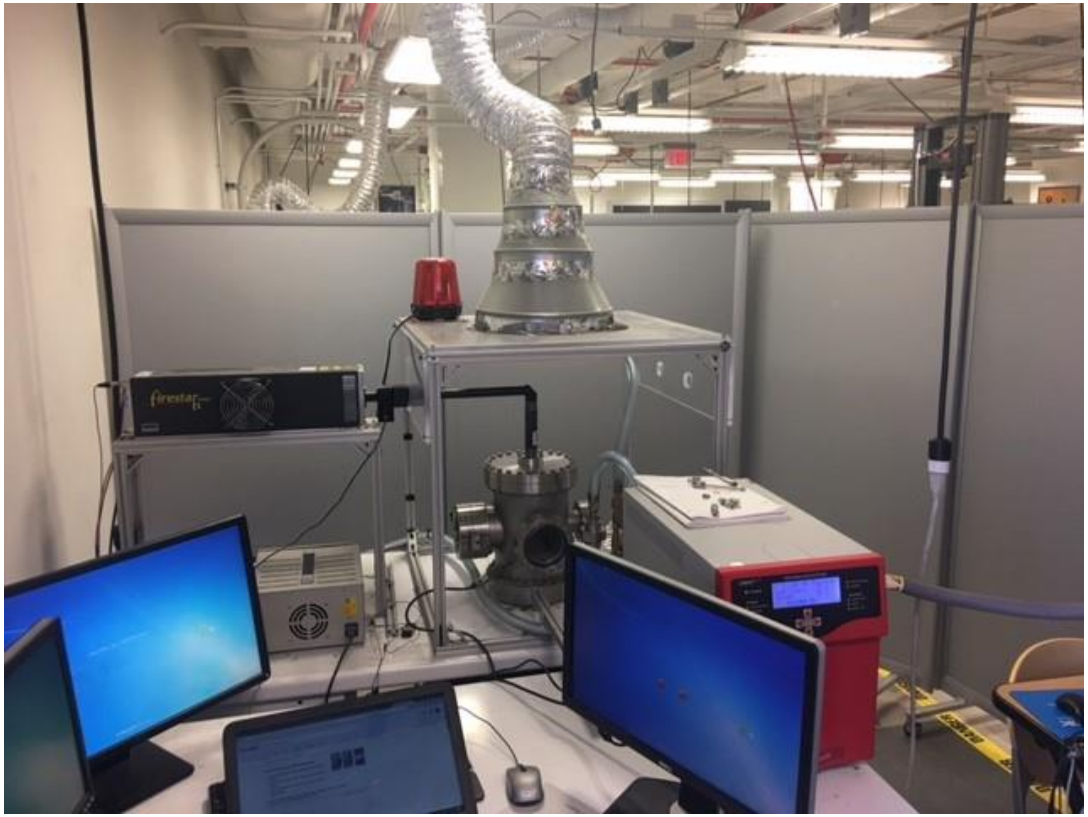
# Laser Ignition Facility

- 11.35-L stainless steel vacuum chamber
- Two door ports, two window ports
- Top-mounted ZnSe window for laser ignition
- Pressure transducer
- Connected to compressed gas cylinders (Ar, $CO_2$) and vacuum pump

*Credit: R. Ferguson, UTEP*

# Laser

- 60-W $CO_2$ laser (Synrad Firestar ti-60)
- Controlled from LabView software




*Credit: R. Ferguson, UTEP*

# Experimental Procedure

- Tile holder is placed into chamber.
- $CO_2$ laser is aligned with the target using laser diode pointer.
- Chamber is evacuated and refilled with:
  - Argon for Moon
  - $CO_2$ for Mars
- Pressure is reduced to 10–100 mbar.
- Laser is pre-programmed for 10-s pulse.
- Photosensor turns off laser upon ignition.

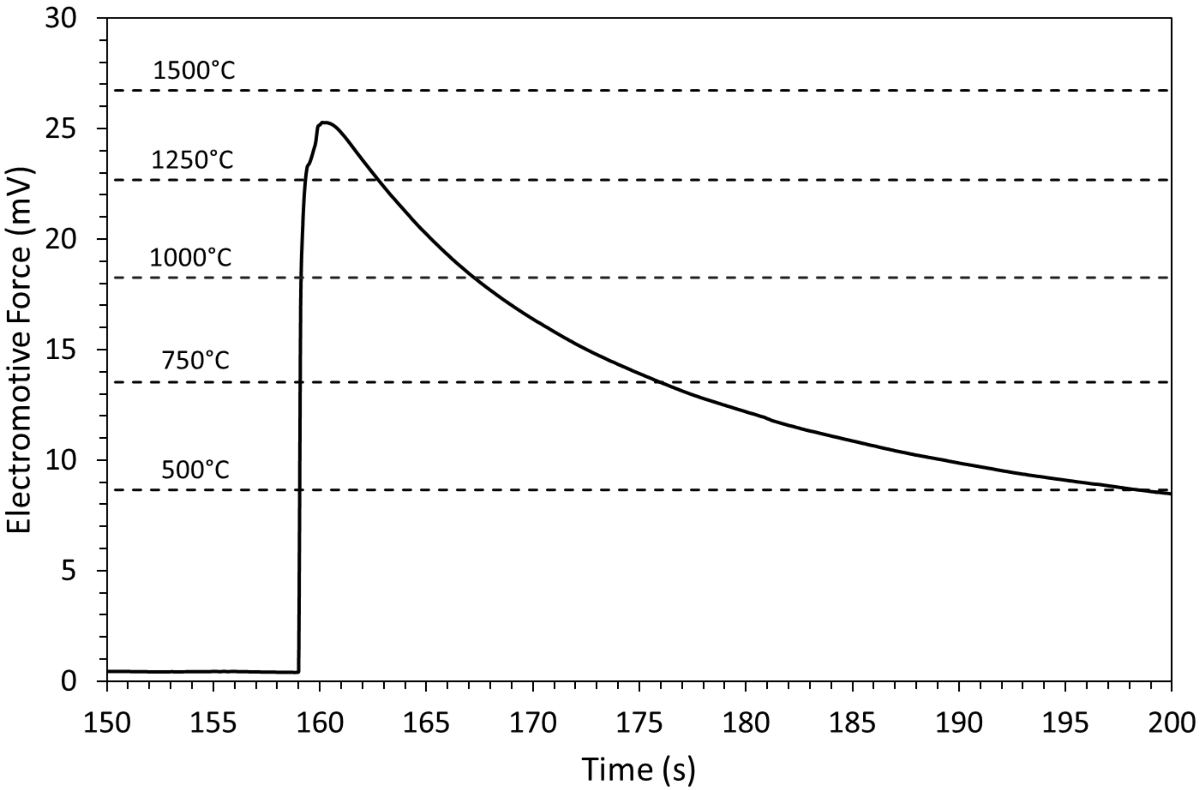
# Initial Results

- Reaction propagates throughout gaps via laser ignition
- Powders combine into product material
- Pressure increase in the chamber was slight

*Credit: R. Ferguson, UTEP*

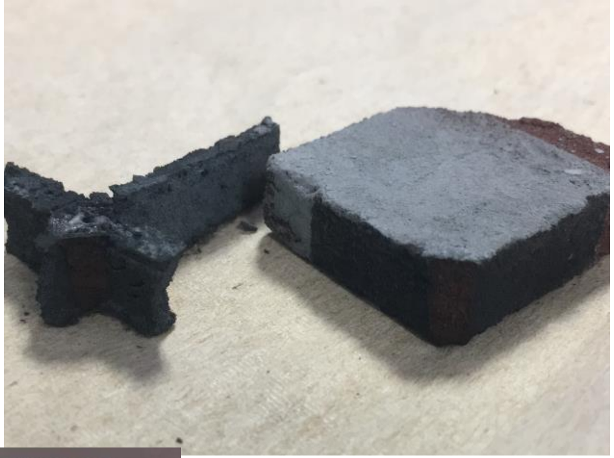
# Temperature Profile

- Test performed at 60 mbar



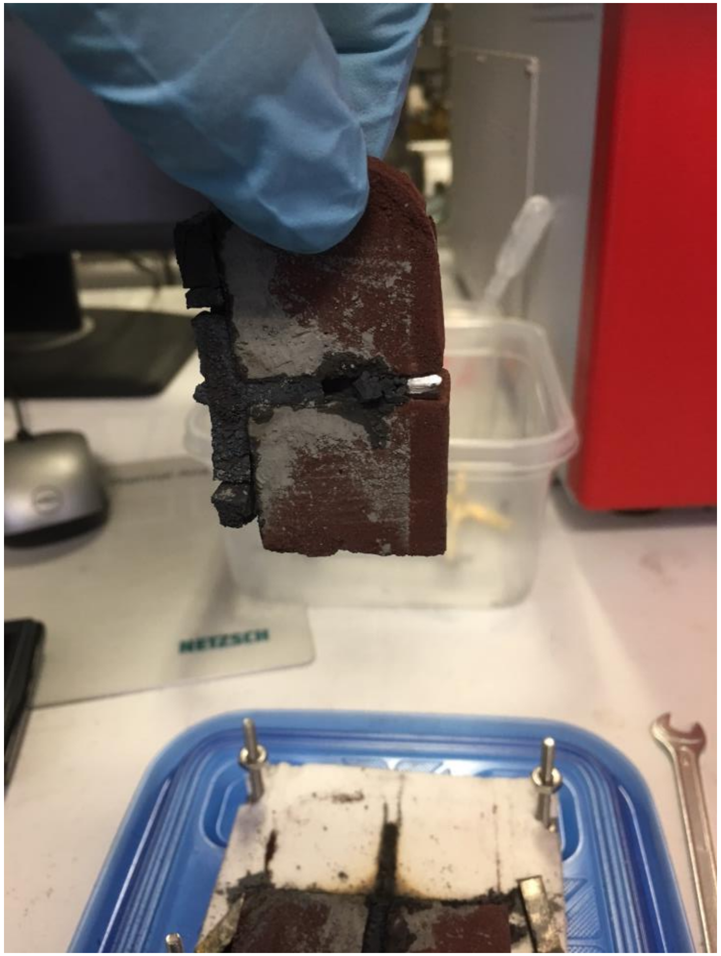
# Initial Results

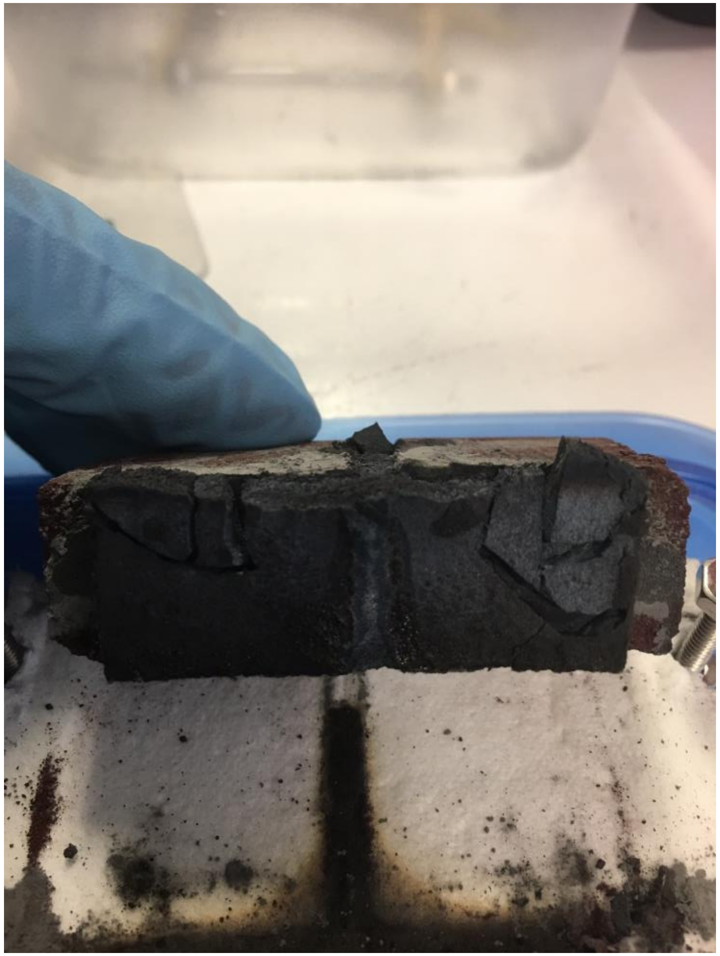
- Joining is occurring but is not consistent.



*Credit: R. Ferguson, UTEP*

# Initial Results



*Credit: R. Ferguson, UTEP*

# Future Work

- Vary tile thicknesses and gaps.
- Measure strength of the welds.
- Determine thermal diffusivity and specific heat of tiles.
  - Differential scanning calorimetry
  - Laser flash analysis
- Develop a model for combustion propagation along the gap, which can be used to scale up the experimental results.

# Thank you!