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

Robert E. Ferguson,¹ James G. Mantovani,² and Evgeny Shafirovich¹

¹Department of Mechanical Engineering  
University of Texas at El Paso

²Granular Mechanics and Regolith Operations Lab  
SwampWorks / NASA Kennedy Space Center
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Agenda

- Background
- Objectives
- Experimental
- Results
- Future work
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
• NASA’s Granular Mechanics and Regolith Operations Lab at Kennedy Space Center has produced tiles by high-temperature sintering of lunar regolith simulant.

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

*Credit: R. Ferguson, UTEP*
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*
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.
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.
• 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.
Ni + Al $\rightarrow$ 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
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 N₂ 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
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.
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, CO₂) 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
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!