Self-Propagating Chemical Reactions for Making Materials and Structures from Lunar and Martian Regolith

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Ninth Joint Meeting of Space Resources Roundtable and Planetary & Terrestrial Mining Sciences Symposium
June 12 – 15, 2018, Golden, CO

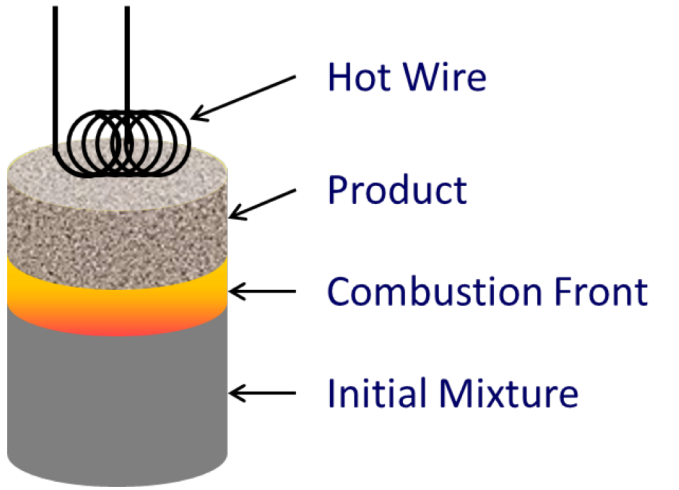
Why Do We Need Materials/Structures There?

- Habitats, radiation shielding
- Launch/landing pads
- …

Lunar base made with 3D printing.
Credit: ESA/Foster + Partners

How to Make Materials/Structures There?

- Bring everything from Earth.
- Use only local materials with energy obtained from a nuclear reactor or (if there is enough sunlight) solar arrays.
- Use mainly local materials with a small amount of materials brought from Earth and a small amount of energy.
  - Exothermic reactions release heat, which may make the process self-sustained.



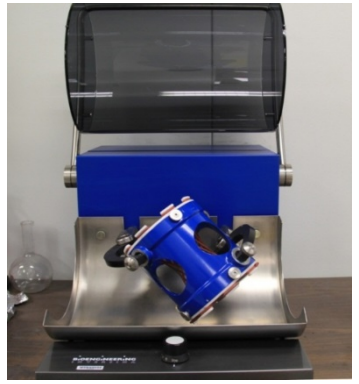
Schematic of Combustion Synthesis

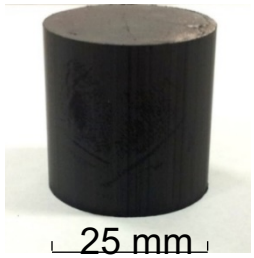
What Reactions?

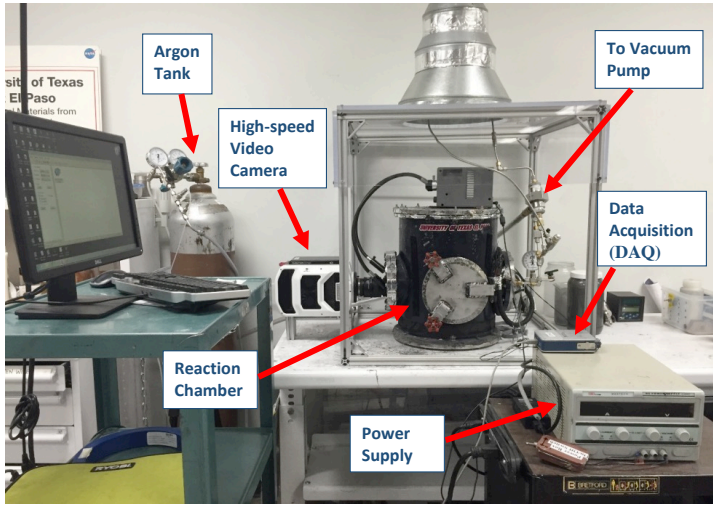
- Inert regolith and reactive mixture
  - Intermetallics: Ti/B, Al/Ni, …
  - Thermites: Al/Fe_2O_3, Al/$FeTiO_3$, …
- Regolith + metal (thermite reaction)
  - Al – hard to ignite, needs an additional component e.g., polytetrafluoroethylene (PTFE)
  - Mg – easy to ignite

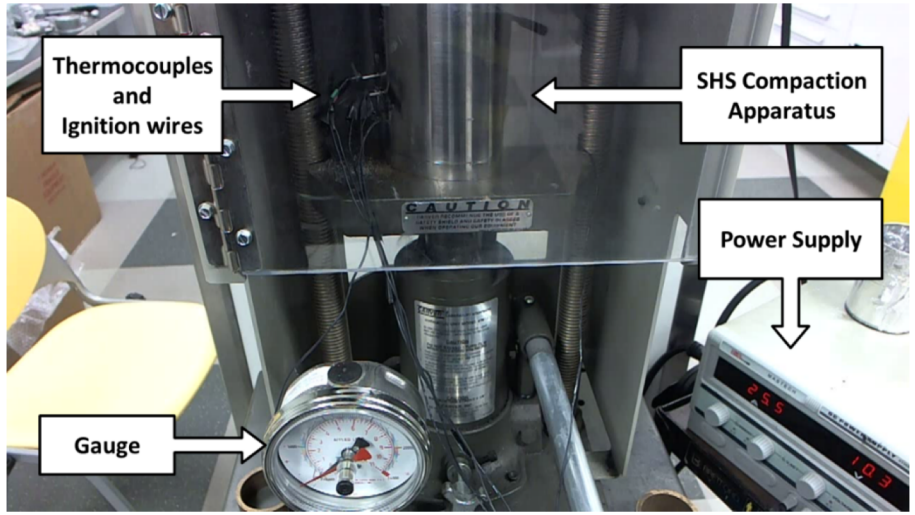
Combustion of Regolith with Magnesium

- Milling regolith
- Mixing with Mg
- Compacting to a pellet
- Igniting the pellet

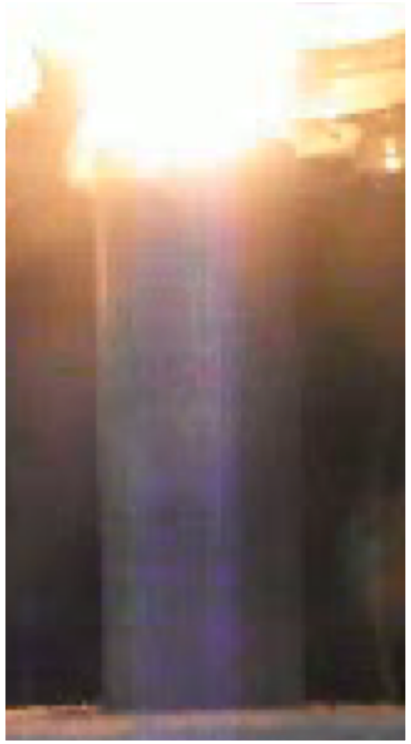




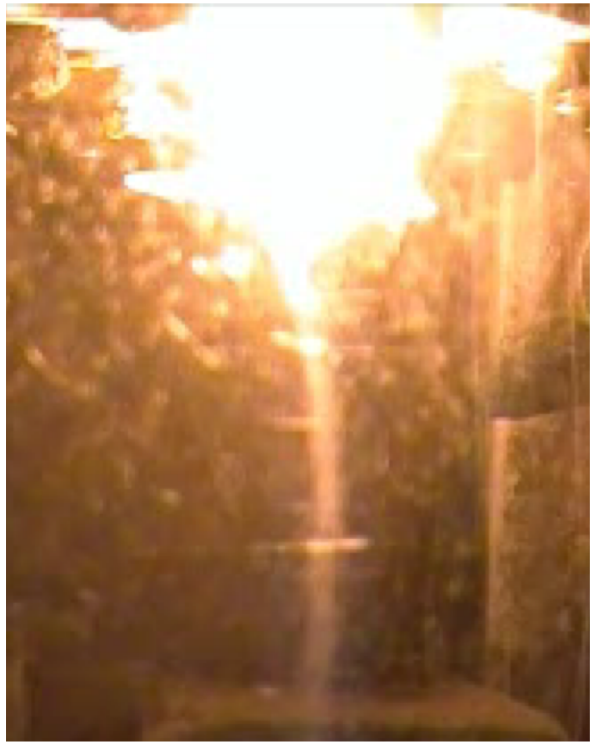




How Does It Burn?



JSC-1A/Mg (23 wt% Mg)
Coarser regolith



JSC-1A/Mg (26 wt% Mg)

Mojave Mars/Mg (30 wt% Mg)

JSC-Mars-1A/Mg (30 wt% Mg)

10 wt% Mg was needed for a self-sustained combustion of JSC-1A

How Does the Product Look?

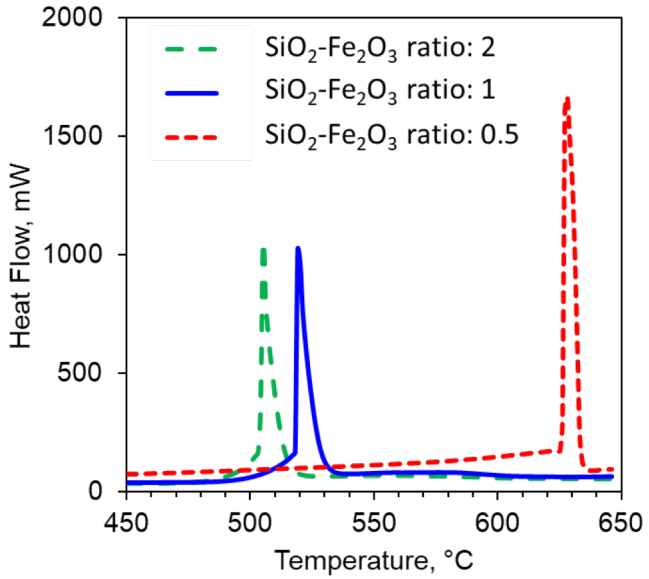
What Did React with Mg?

Compound	Concentration, wt%		
	JSC-1A [6]	JSC-Mars-1A [7]	Mars Mojave [7]
SiO_2	**45.7**	**43.48**	**49.4**
Al_2O_3	16.2	22.09	17.1
Fe_2O_3	**12.4**	**16.08**	**10.87**
CaO	10.0	6.05	10.45
MgO	8.7	4.22	6.08
Na_2O	3.2	2.34	3.28
TiO_2	1.9	3.62	1.09

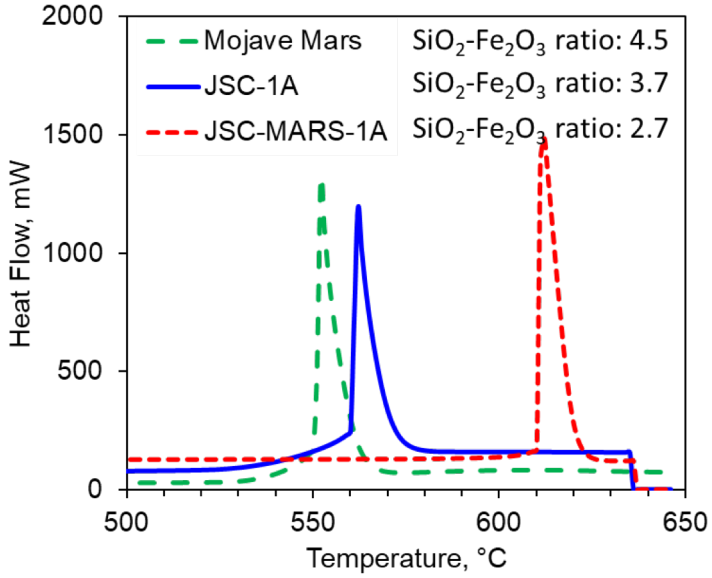
$SiO_2 + 2\ Mg \rightarrow 2\ MgO + Si$

$Fe_2O_3 + 3Mg \rightarrow 3MgO + 2Fe$

JSC-Mars-1A has the highest content of Fe_2O_3. It burns more vigorously.



Differential scanning calorimetry
Mg – SiO_2 – Fe_2O_3 mixtures



Differential scanning calorimetry
Mg – Regolith simulant mixtures

The higher SiO_2-Fe_2O_3 ratio, the lower the peak temperature. SiO_2 facilitates the ignition.

Conclusions on Regolith–Mg Combustion

- Mixtures of lunar and Martian regolith simulants with Mg exhibit a self-sustained combustion, leading to formation of ceramic materials.
- Without preheating, 10 wt% Mg was needed for a self-sustained combustion of JSC-1A.
- The reaction mechanisms in these mixtures involve thermite reactions of Mg with iron oxide and silica.
  - Iron oxide ensures intensive combustion.
  - Silica facilitates the ignition.

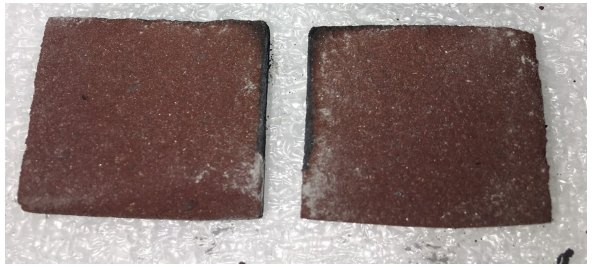
Regolith Tiles for Launch/Landing Pads

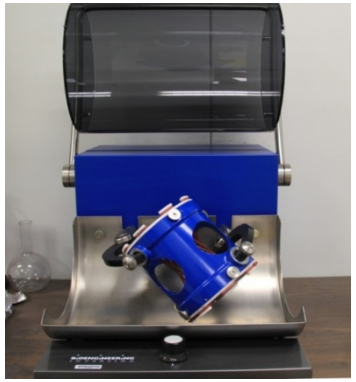
- Kennedy Space Center makes regolith tiles.
- The tiles can be laid down and interlocked, but this is not reliable.
- Solution: Place a reactive mixture between the tiles and ignite it to weld the tiles.
  - Thermites?
  - Intermetallics?

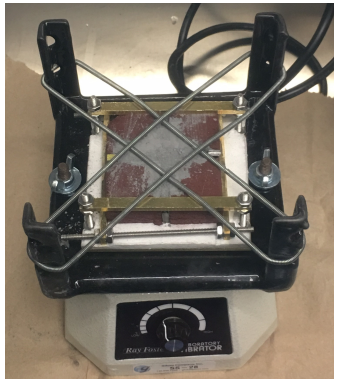
Assembling a launch/landing pad.
Credit: PISCES

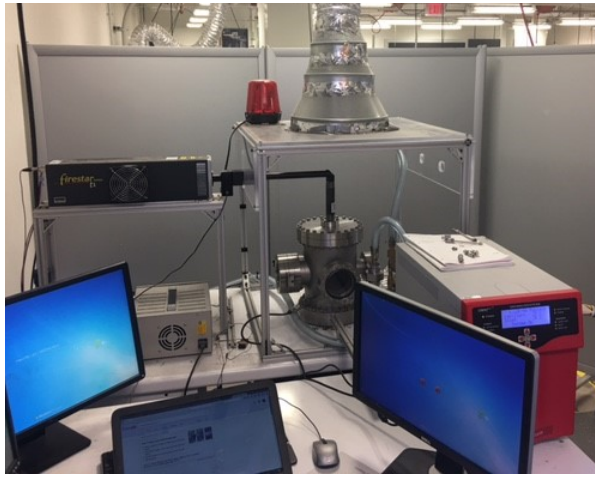
Al-Ni Combustion for Joining Regolith Tiles

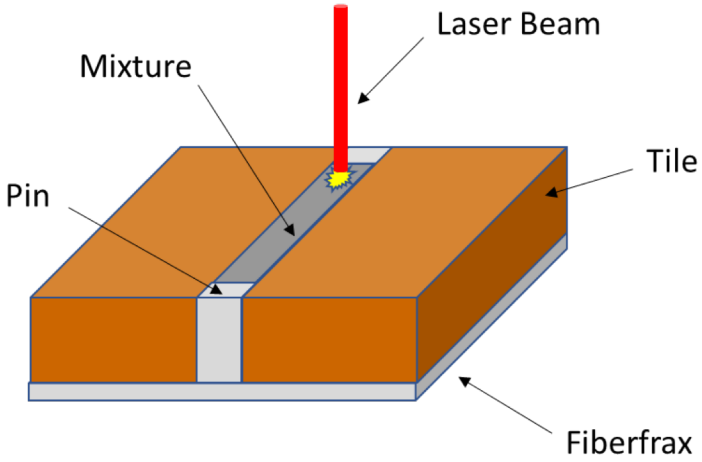
- Cutting tiles
- Mixing Al and Ni
- Installation in a holder and shaking
- Installation in a vacuum chamber
- Making 10 mbar Ar environment
- Igniting the mixture







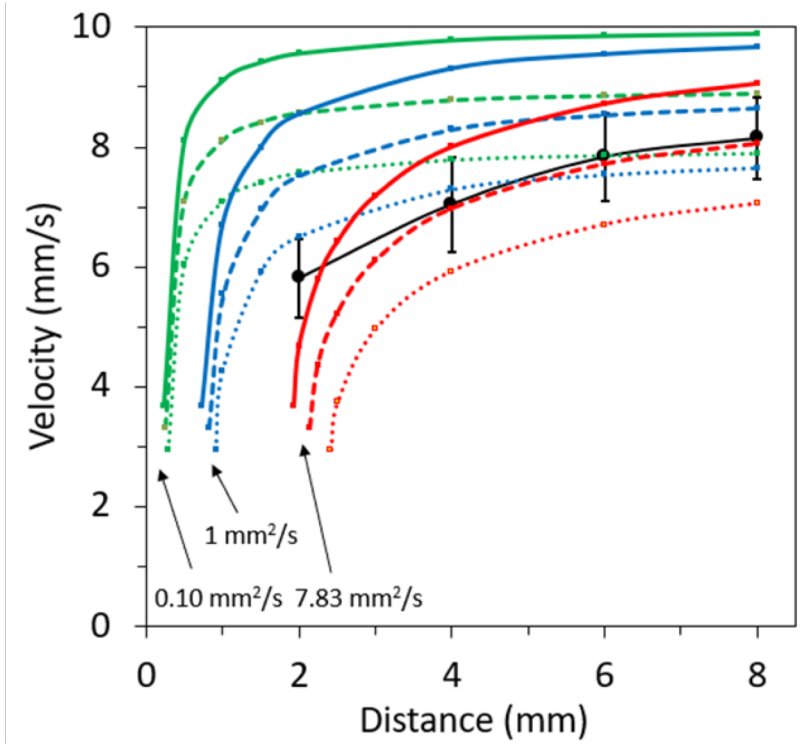




How Does It Burn?

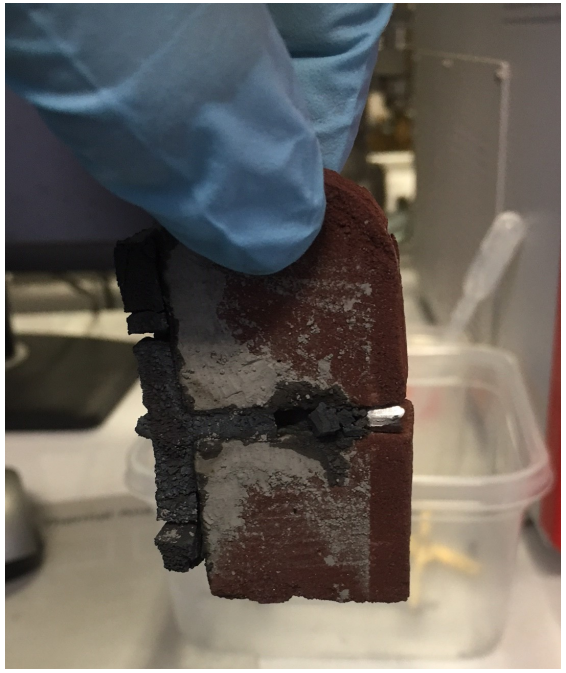
Combustion Front Velocity *versus* Distance

- Modelling
- Properties determined
  - Density
  - Specific heat
  - Thermal diffusivity
  - Thermal conductivity
- Reasonable correlation
- Small quenching distance



The combustion front velocity vs. the distance between the tiles. Calculations at different values of the adiabatic combustion front velocity (8, 9, and 10 mm/s) and different thermal diffusivities. Black: Experimental values

Joining?



Joining is occurring but is not consistent.

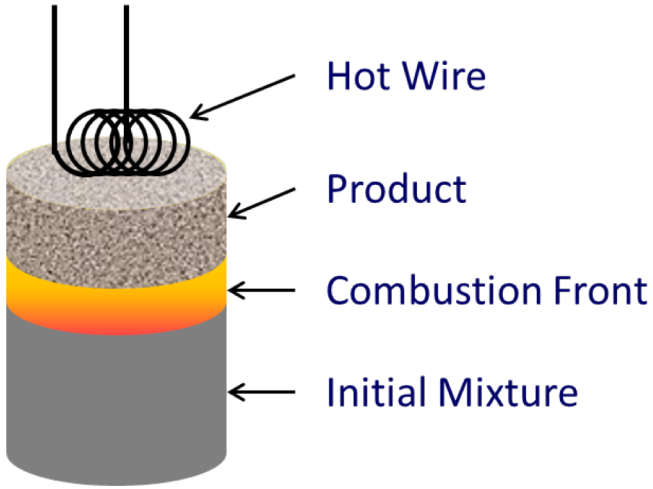
Conclusions on Combustion Joining of Tiles

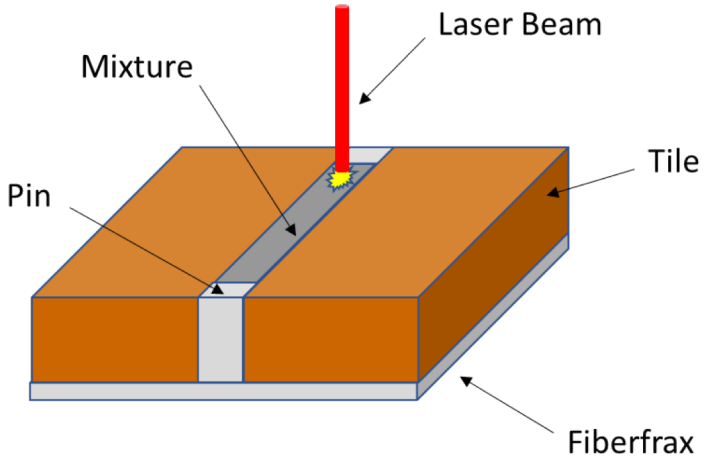
- Experiments on combustion of Al/Ni mixture in 2–8 mm gap between two JSC-1A tiles have been conducted in Ar at 10 mbar.
- Stable propagation of the combustion front was observed.
- The quenching distance is low (< 2 mm in the experiments).
  - A small amount of the reactive mixture would be required for joining regolith tiles on the Moon.
- Joining of the tiles was achieved in some experiments.
  - A better mixture is needed to increase the temperature.
  - A better holder is needed to fix the thermal expansion problem.

Concluding Remarks

- When energy is limited, a self-propagating exothermic reaction (combustion synthesis) is a promising solution.

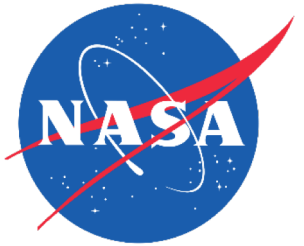
- It can:
  - make useful materials
  - join parts
  - generate heat

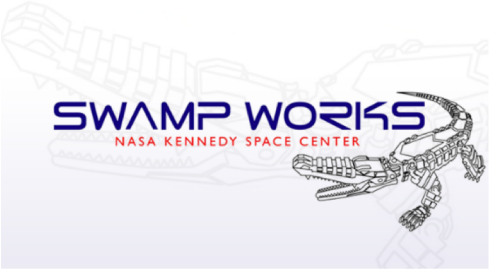




Acknowledgments

- NASA
  - Minority University Research Education Project
  - Dr. James Mantovani of Kennedy Space Center
- Students
  - Francisco Alvarez
  - Sergio Cordova
  - Armando Delgado
  - Robert Ferguson
  - Ashvin Kumar Narayana Swamy
  - Christopher White





Thank you!