COMBUSTION OF LUNAR REGOLITH/ MAGNESIUM MIXTURES

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In-Situ Production of Construction Materials

- Construction materials are needed for landing/ launching pads, thermal wadis, and other structures.
- External heating of regolith
  - Needs lots of energy
- Energetic additives to regolith enable self-sustained combustion
  - Low energy needed

Self-propagating High-temperature Synthesis (SHS)
Also called Combustion Synthesis

- Upon ignition of a mixture, exothermic reactions cause self-sustained propagation of the combustion wave.
- Advantages
  - Low energy for ignition
  - High temperatures generated by the reaction heat release.
- Used for synthesis of numerous ceramics and other compounds

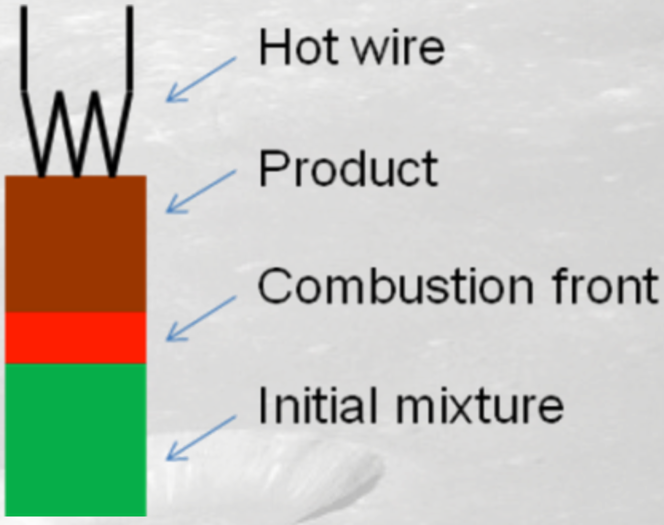


Image: White, Alvarez, and Shafirovich.

Combustion in Regolith-based Mixtures

- Martirosyan and Luss (2006):
  - JSC-1A + Ti + B — JSC-1: <60%
- Faierson et al. (2010)
  - JSC-1A + Al — JSC-1A: <67%
  - Heating wire throughout the mixture
- Corrias et al. (2012)
  - JSC-1A + $FeTiO_3$ + Al — JSC-1A: <30%
- Our approach
  - JSC-1A + Mg — JSC-1A: >74%

Prior Research

- SHS of mixtures of JSC-1A lunar regolith simulant with magnesium
- Thermodynamic calculations of the adiabatic flame temperatures and combustion products.
  - For Mg, the temperatures are higher than for Al
  - Maximum adiabatic temperature: 1417 °C at 26 wt % Mg

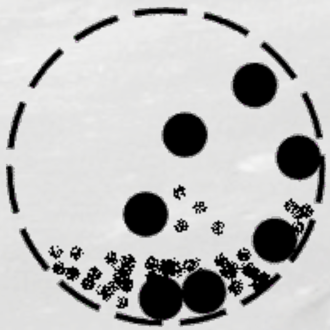
Combustion at 26 wt % Mg

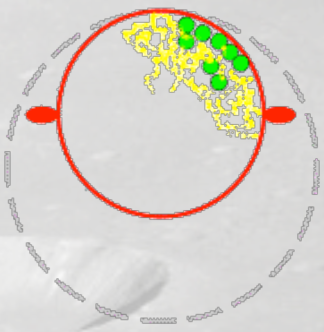
Spin Combustion

- Observed at 23 wt% Mg
- This is the first observation of spin combustion with two counterpropagating hot spots in solid-solid mixtures.

Minimization of Magnesium Content

- High-energy ball milling in a planetary mill significantly decreased the particle size.
- Minimum Mg concentration decreased to 13 wt %





Technique	Roller Ball Mill	Planetary Ball Mill
Volume Mean Diameter (μm)	46	5.6
Volume Median Diameter (μm)	40	3.4
Lowest Mg content (wt %)	24 wt %	13 wt %

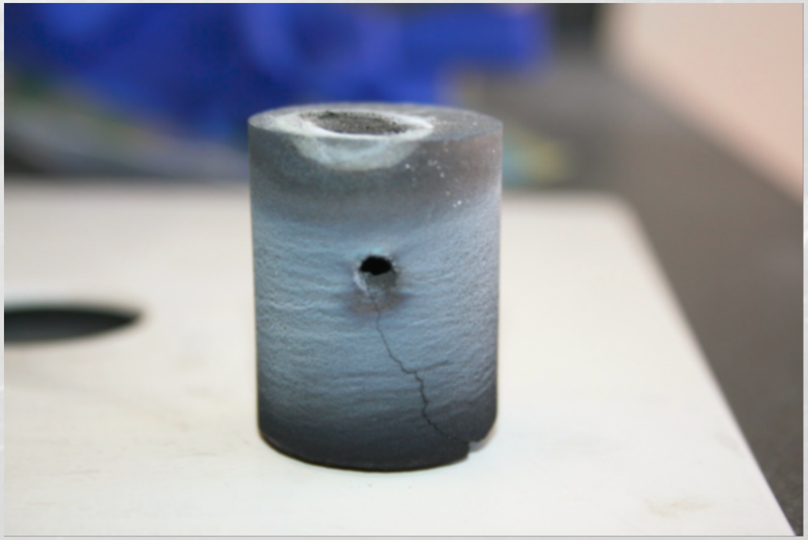
cSETR

UTEP

Combustion at 26 wt % Mg
(after high energy milling)

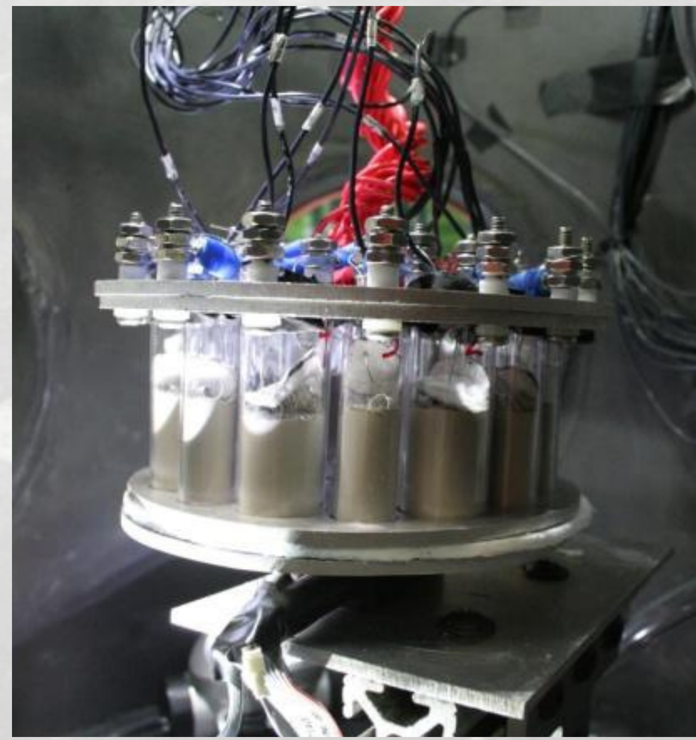
Temperature Measurements

- Type K thermocouples were placed inside the pellets, perpendicularly to the pellet axis.
- For 25.4 mm diameter pellets, the maximum temperature was 1313°C – 1316 °C.



Microgravity Experiments

- “Space Miners” Team was selected by NASA
- Microgravity rig developed



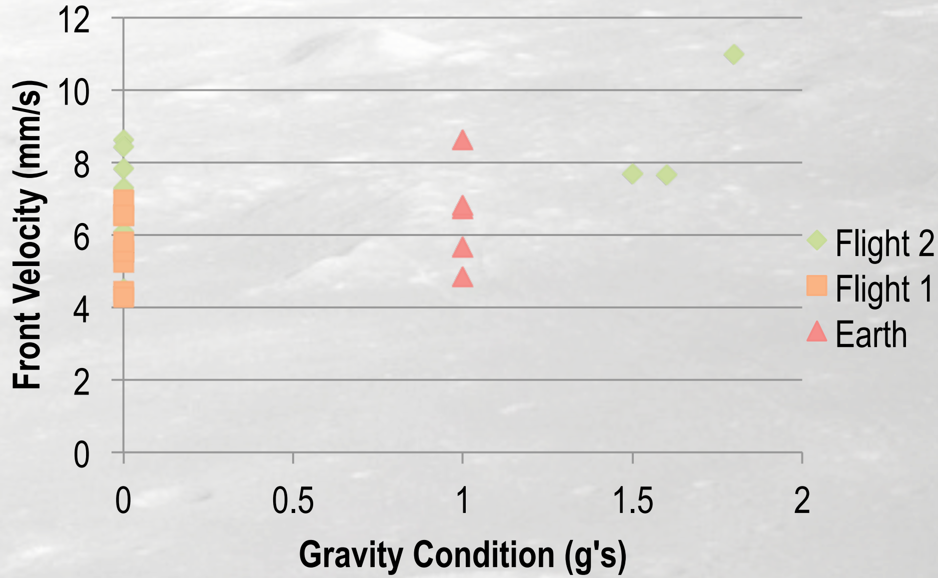
Microgravity Experiments

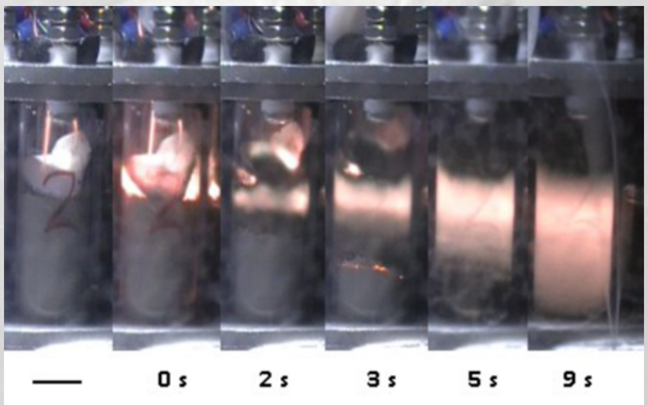
- Parabolic flights conducted at Ellington Field through NASA Educational Reduced Gravity Program in June 2011

Micrograms Experiments

Velocity Measurements

- The combustion front propagation velocity was determined using video record.
- Different gravity conditions
  - Zero gravity (0g)
  - Terrestrial gravity (1g)
  - Increased gravity (1.6-1.8g)





New Microgravity Experiments (June 2012)

- Microgravity experiments (parabolic flights) scheduled for next week.
  - Pellet samples
  - Temperature measurements.

Current Research

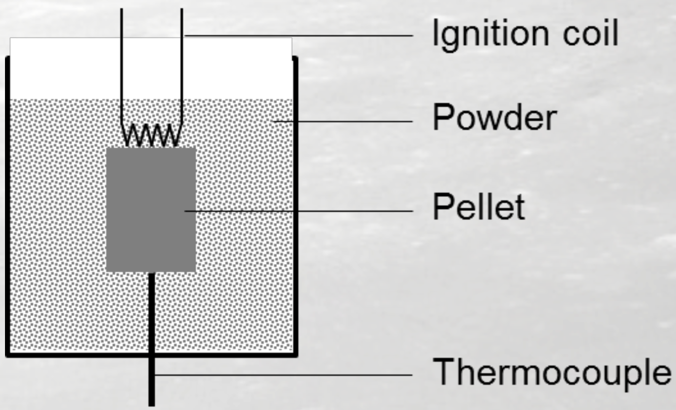
- In prior experiments, the strength of the combustion products is not sufficient for using them as construction materials.
- Determine conditions for fabricating **stronger** products.
- Investigate the influence of heat transfer from the mixture to the surroundings during combustion and subsequent cooling.

Sample Preparation

- The powder mixtures were compacted into pellets (25.4 mm dia.).
  - 74% JSC-1A (PBM)
  - 26% Mg
- Channel drilled for thermocouple
- 3 mm thick ceramic fiber insulator.

Experimental Procedure

- Pellets submerged in silica
- Thermocouple inserted to measure the temperature during combustion and cooling
- The pellet was ignited by a Nichrome wire connected to a DC power supply.

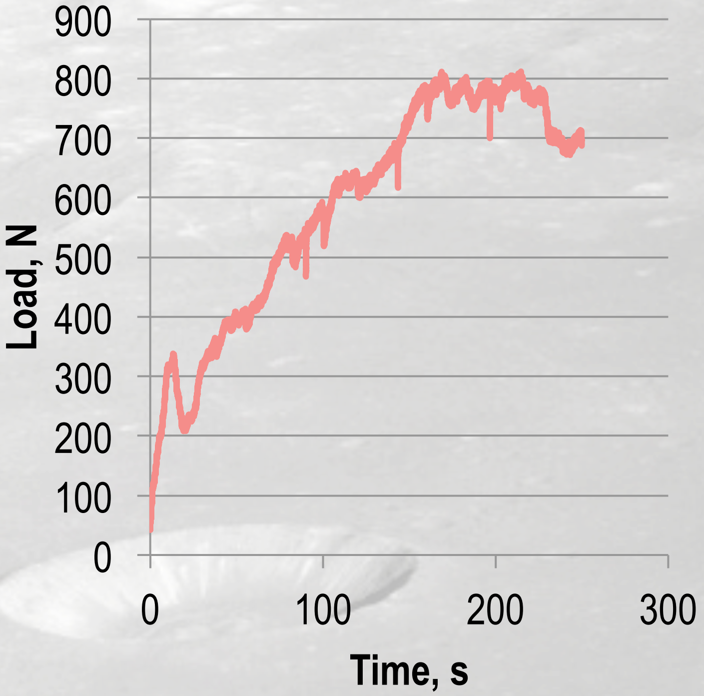


Results

- With silica, strength of the combustion products dramatically increased.
- The obtained materials could not be broken by hands; they could only be cut by a saw.

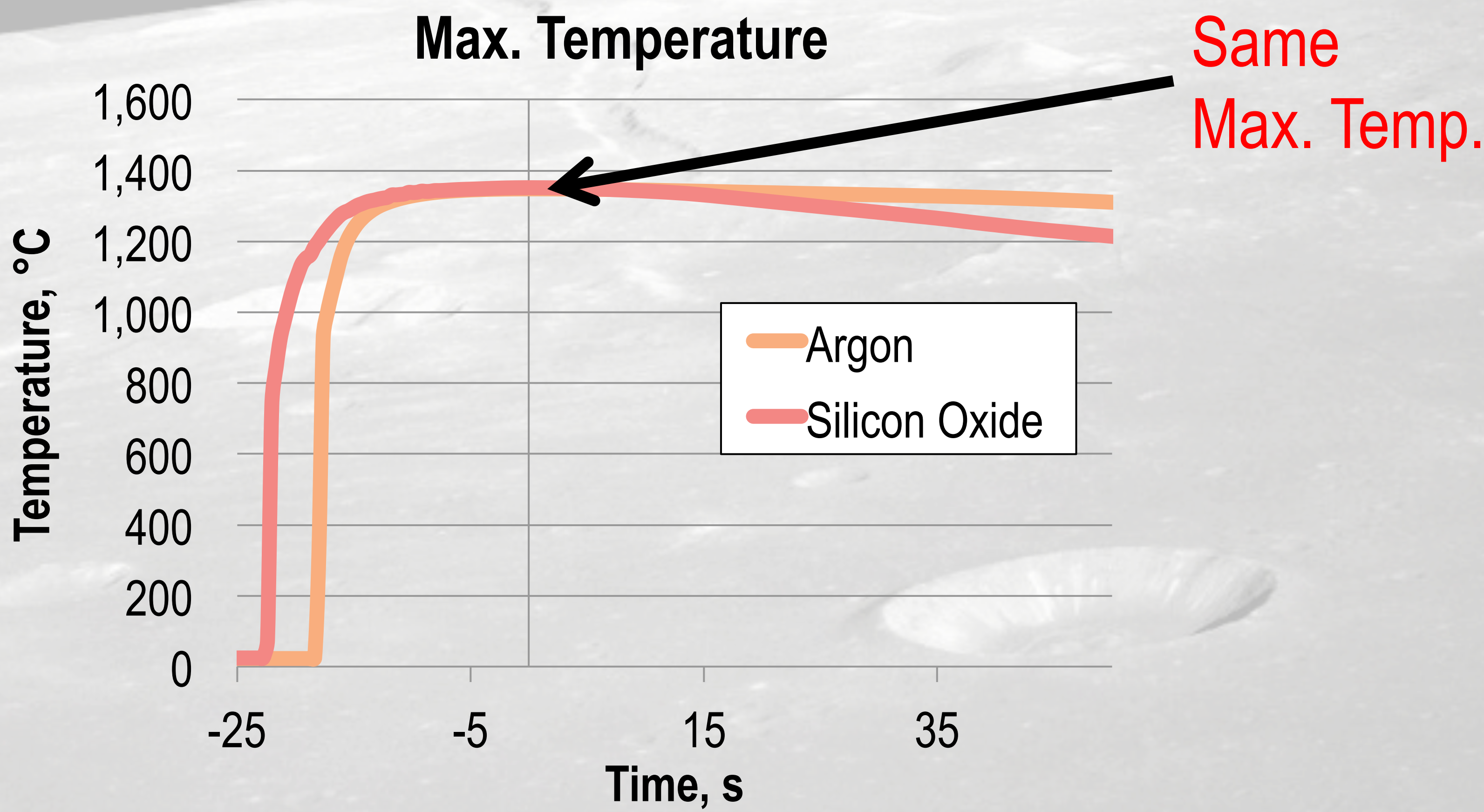
Compression Test

- Compression test in silica sample was conducted.
  - Sample length: 22.8 mm
  - Displacement rate: 1 mm/s
- Max. load carried by the sample was 800 N
  - 1.6 MPa

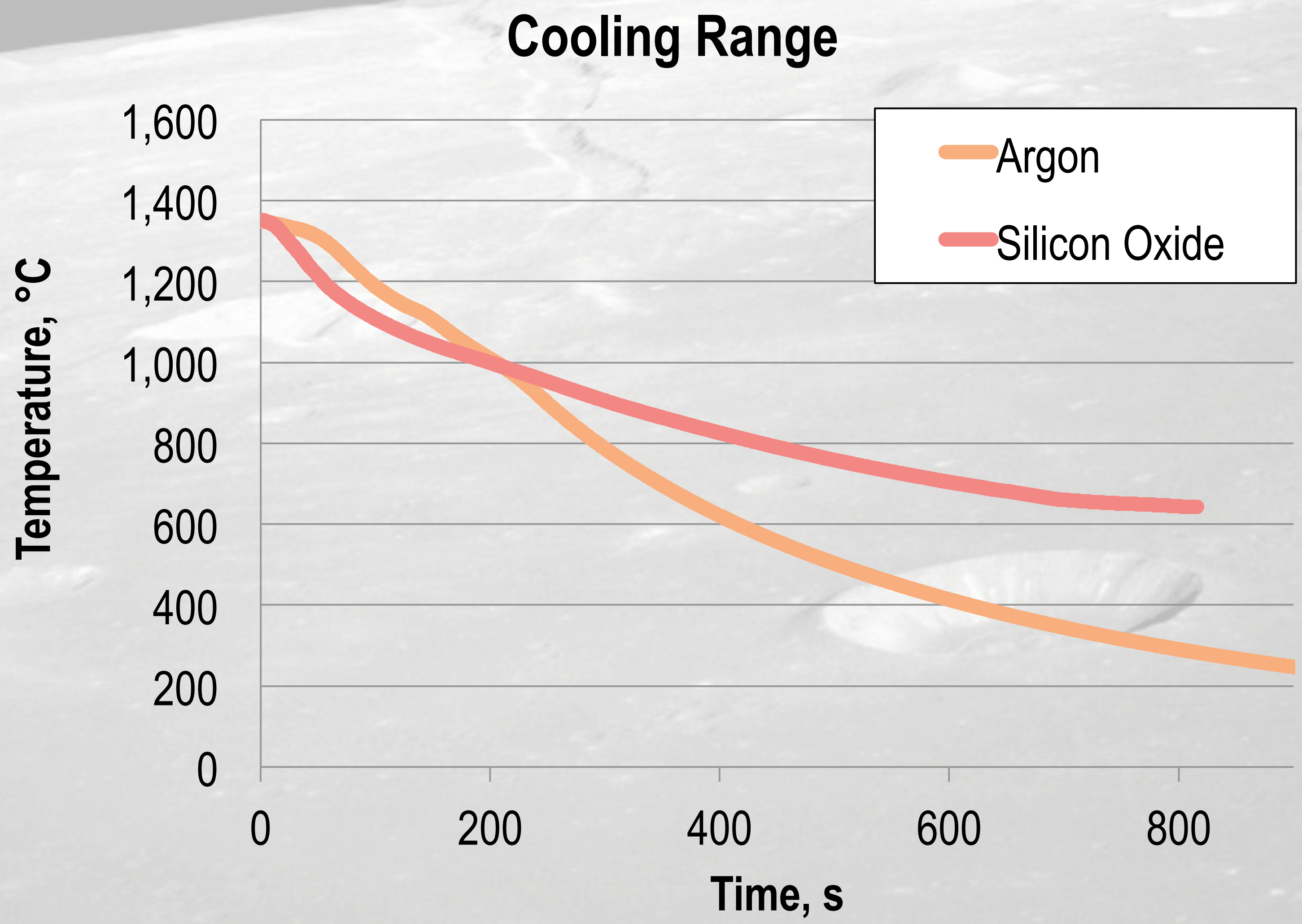


Sample obtained from argon environment was not tested due to its brittleness while preparing for test.

Temperature of JSC-1A/Mg combustion



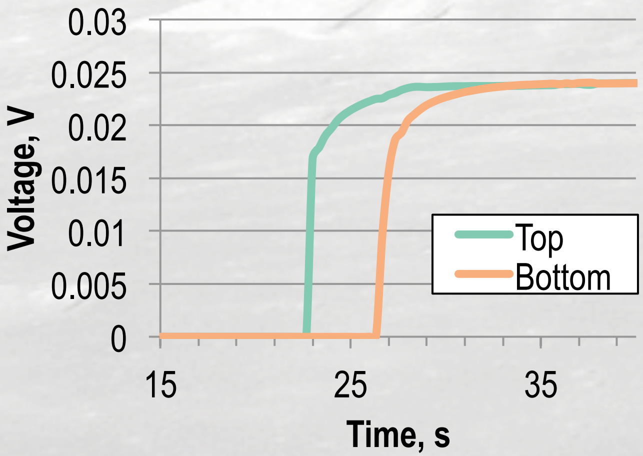
Temperature of JSC-1A/Mg combustion



Environment Comparison

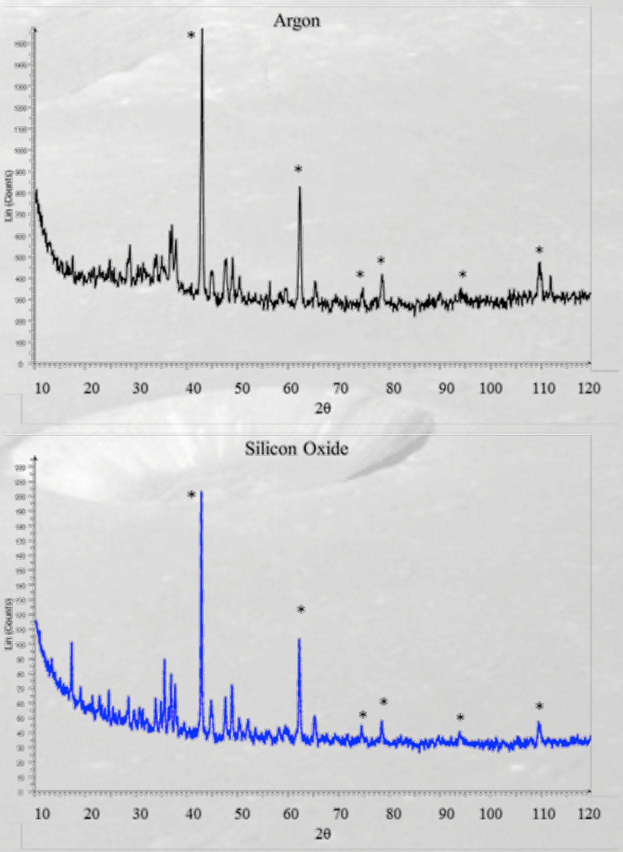
Propagation Velocity from Temperature Measurements

- Two Type-C thermocouples placed within a 15 mm distance.



Environment	Velocity (mm/s)
Argon	4.1
Silicon Oxide	4.5

XRD Analysis



Conclusions

- Spin combustion with two counterpropagating hot spots observed near the limit of combustibility.
- High energy ball milling of JSC-1A decreased the minimum concentration of Mg to 13 wt %.
- Microgravity experiments provided additional insight.
- Submerging the pellets in silica during combustion significantly increases the strength of the products, which may be associated with different cooling rates.

Future Work

- Test different surroundings to produce stronger materials.
- SHS Compaction
  - Press while products still hot
  - Decreases porosity and increases density of products

SHS Compaction

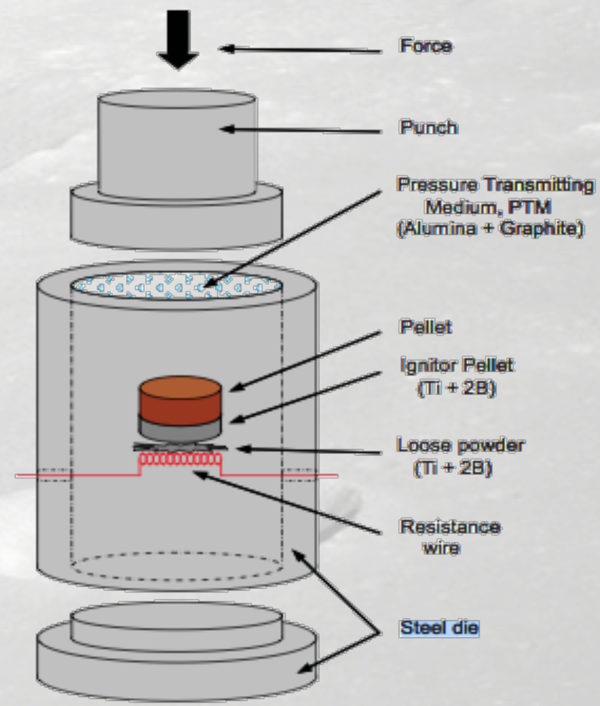


Image: Martínez Pacheco, Maria

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