The use of Solar Heating and Heat Cured Polymers for Lunar Surface Stabilization

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Dust and surface stabilization

- Dust ejecta during lunar launch/landing can affect visibility, erode nearby coated surfaces and get into mechanical assemblies of in-place infrastructure
- Dust mitigation will be necessary for certain areas of the lunar habitat
- Surface stabilization can be used for roads, launch pads and other dust free areas

Surveyor

- Apollo 12 LM landed 163m from the Surveyor 3 craft
- NASA-SP-284: Analysis of Surveyor 3 material and photographs returned by Apollo 12 – found "sandblasting" with shadows showing that the blast came from the LM

Overview

- Compare and test potential stabilization methods
  - Polymer palliatives
  - Solar
  - Microwave
- Evaluation Criteria
  - Mass
  - Power
  - Ease of use
  - Time
- Physical and engineering properties

Polymer Palliatives

- Technology successfully used in military applications for helicopter pads and roads
- Polymer is sprayed with water as the solvent
- Technology required very little development

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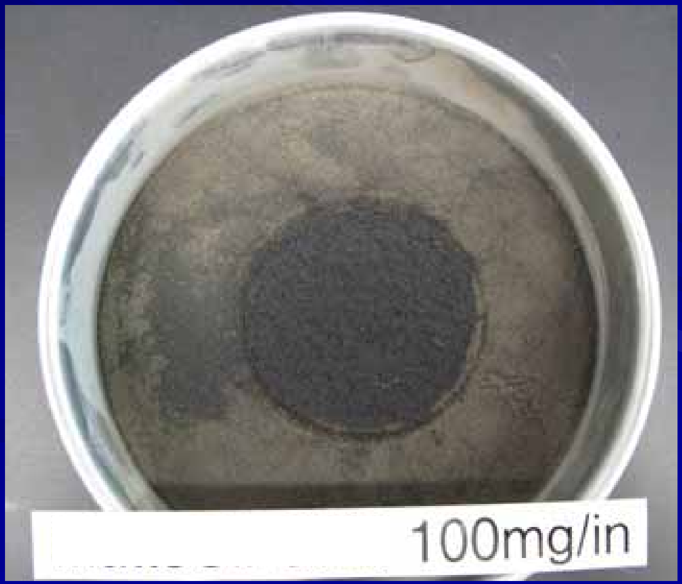
Polymer Palliatives

- Advantages
  - Ease of use: heat, UV or ambient curing
  - Many commercially available products (solvent free solids or liquids) with different desirable properties: High temperature resistance, abrasion resistance, flexibility
- Disadvantages
  - Mass
  - Consumable

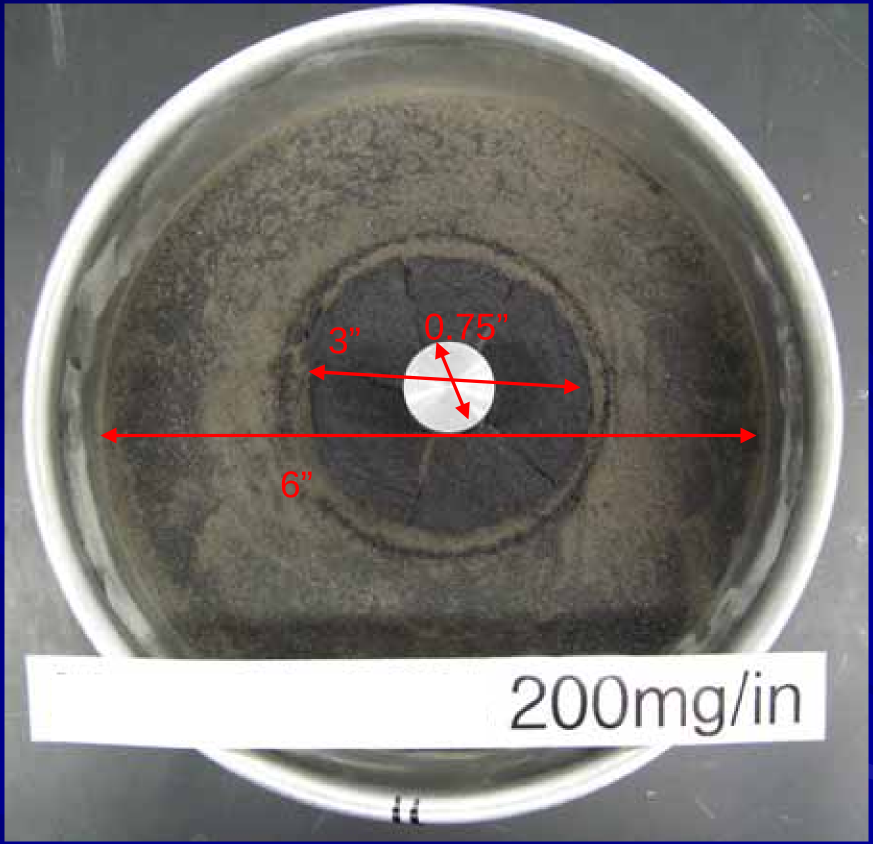
Polymer Palliatives

- Evaluated 4 commercially available powders and 1 developed at KSC
  - Abrasion, UV resistance, high temperature resistance
- Demonstrated stabilization in the lab and in the field using our solar concentrator
- Investigated different spreading ratios, mixing ratios and application methods
- Polymers do not begin thermal degradation until 260 – 290 C
- Coverage rates ranged from 0.08 to 0.31 kg/m2

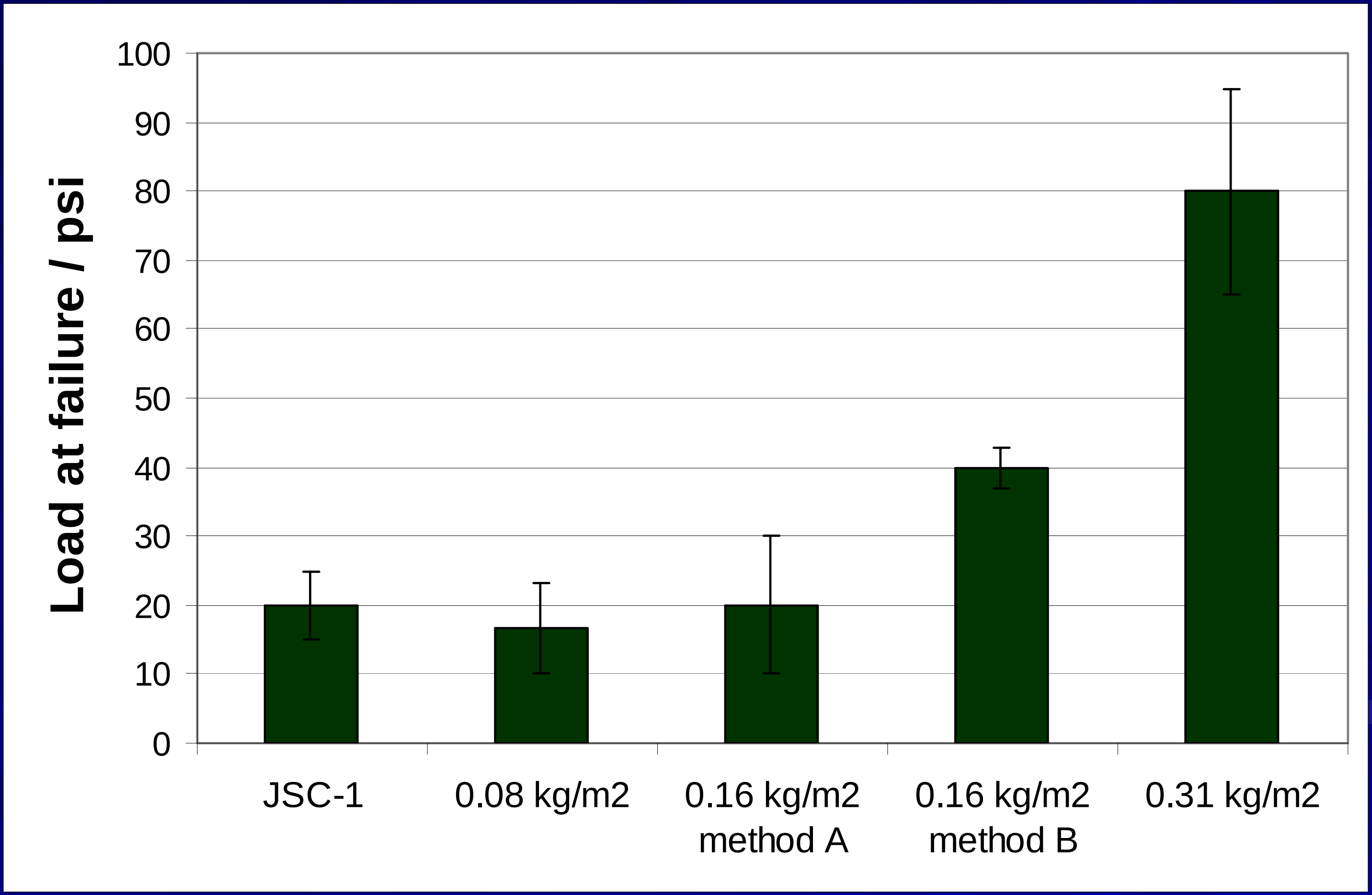


Load Bearing Strength

- Loads applied on different surface treatments were measured
- JSC-1A lunar simulant placed in a 6" diameter dish
- Surface treatment placed in center 3" diameter area
- Load is applied with a 0.75" diameter piston



Polymers: Load Bearing Strength

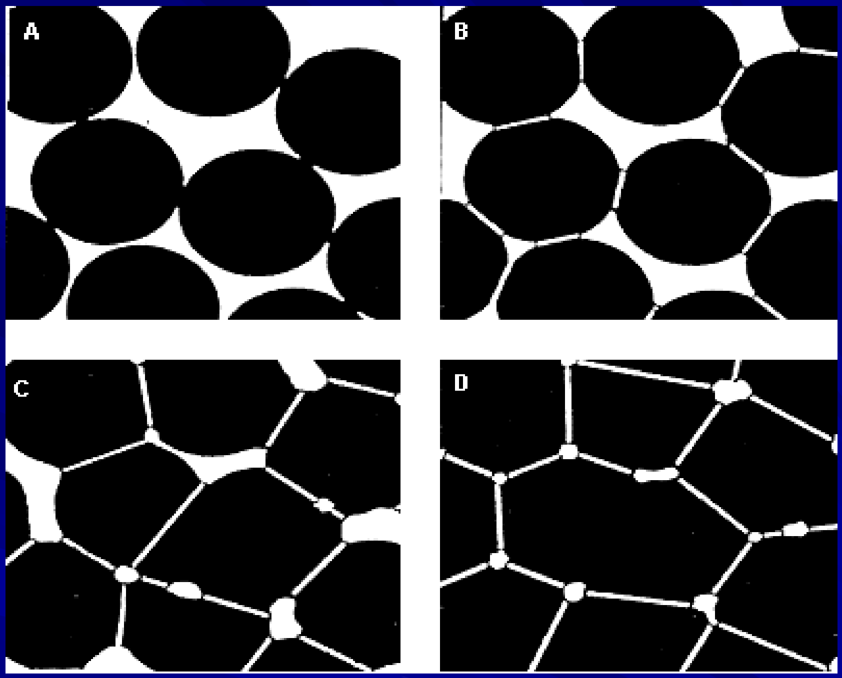


Polymers: Future Work

- Continue to work on spread rates and application methods
- Apply to larger areas
- Investigate thermal cycling and application under vacuum

Sintering

- Sintering is a method for making solid objects from a powder by heating the material (below its melting point) until its particles adhere to each other
- Particle size, density and packing of regolith are ideal for sintering
- Use *in situ* materials; need heat source



A. Loose powder (start of bond growth).
B. Initial stage (the pore volume shrinks).
C. Intermediate stage (grain boundaries form at the contacts).
D. Final stage (pores become smoother).

How long does it take?
100 m^2 area to a depth of 2.5 cm

Heating Method	Efficiency	Time in Days
1 m^2 solar concentrator	100%	27
1 kW microwave	100%	35

- 2.5 m^3 of regolith requires 3×10^9 J to heat 1000K assuming a regolith density of 1.5g/cm^3; regolith heat capacity of 0.8 J/(g K)
- Assumes all energy is converted to heat
  - It will take longer: losses in solar concentrator, electrical to microwave conversion, coupling to regolith etc…

Microwave sintering

- Technology has been proposed for sintering a surface (Taylor et. al.)
- Most materials absorb microwave energy to some degree, especially at higher temperatures
- Lunar regolith is a great microwave absorber

Microwave Sintering

- Advantages:
  - Much more efficient than electrical heating
  - Moderate Mass
  - Inexpensive technology
  - Heats the bulk of material
- Disadvantages
  - Power consumption (1 – 10 kW?)
  - Magnetron requires cooling
  - Thermal runaway can lead to inconsistent results
  - Energy might penetrate deeper than needed

Solar Concentrator

- Sunlight gives 1.3 kW/m^2 of energy
- Solar heating used for cooking, water purification and other uses

Solar Concentrator

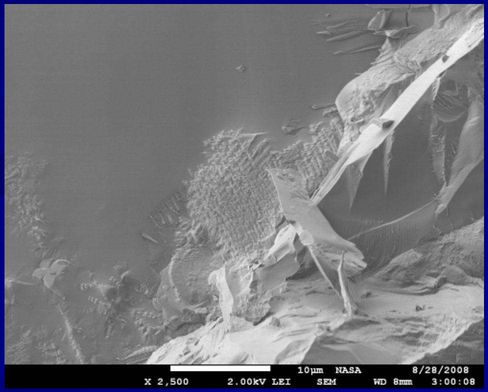
- Advantages
  - No power
  - Lightweight
  - Inexpensive
- Disadvantages
  - Direct heating only heats the surface
  - Uneven heating can cause problems
  - Must follow the sun

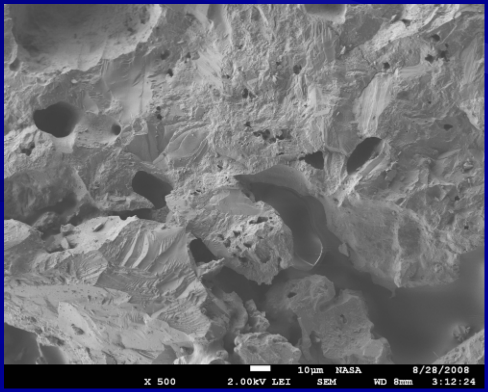
Solar Concentrator

- Rastering across a surface can produce cracking in between passes
- Staying on a sample can lead to both sintering and melting

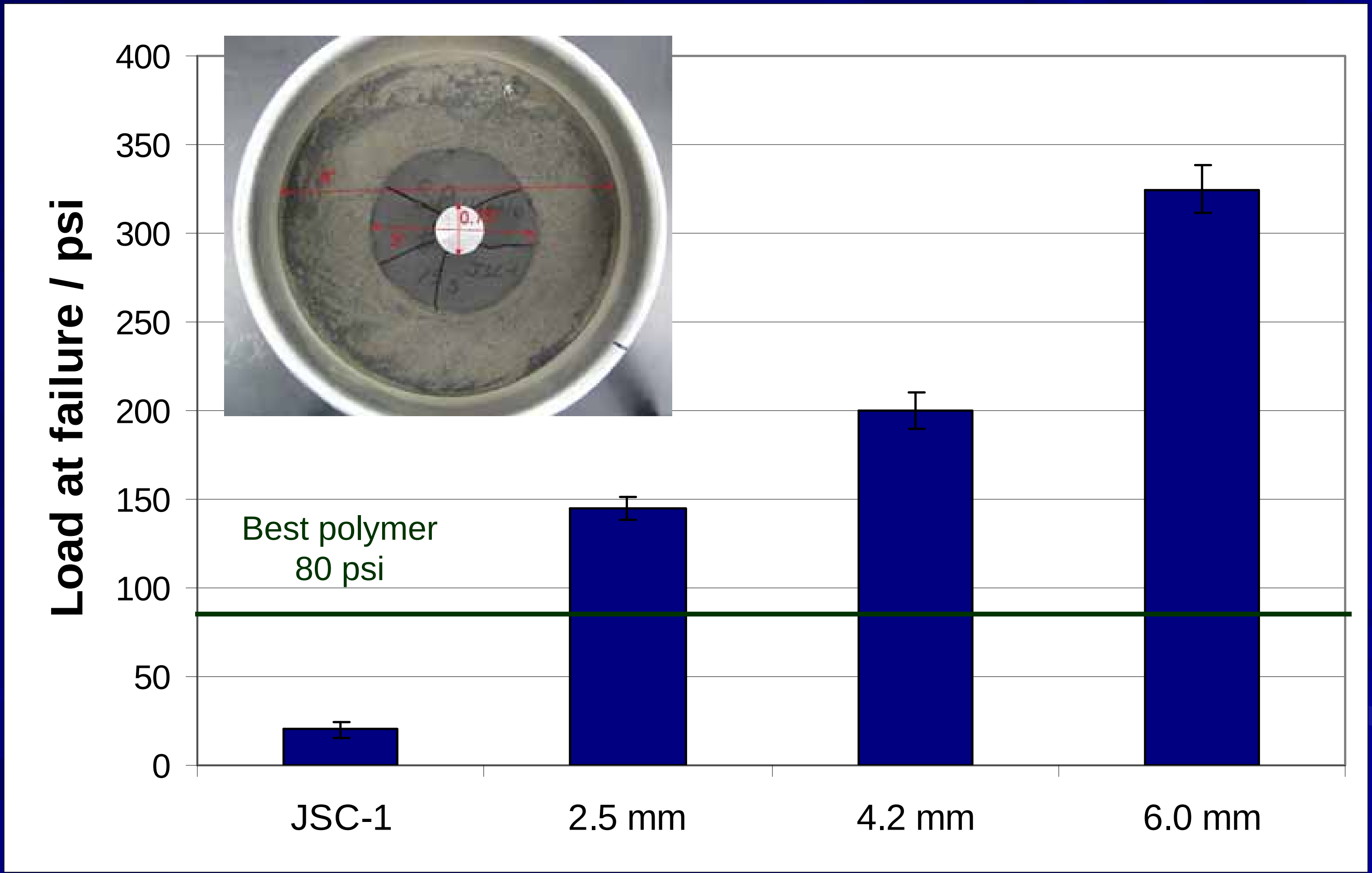
Solar Concentrator

- You need good control to sinter, without melting
- Melted areas can be brittle; sintered areas might not have abrasion resistance

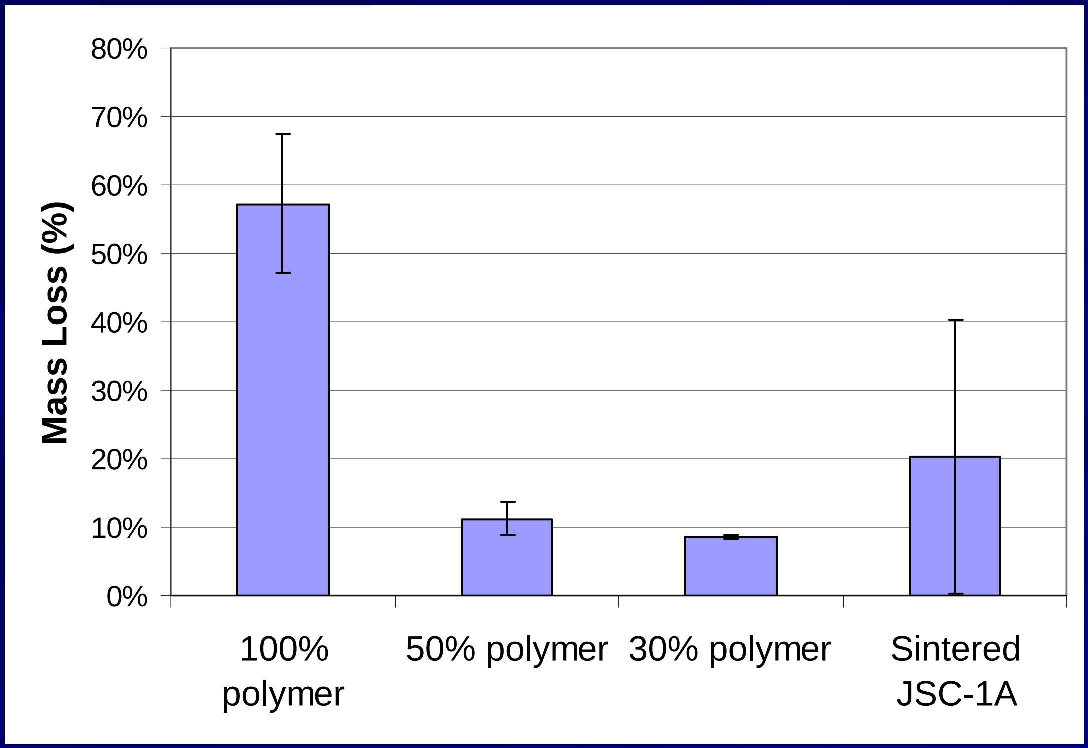




Sintered: Load Bearing Strength



Abrasive Blast Testing



- Test adapted from ASTM C704: Standard Test Method for Abrasion Resistance of Refractory Materials at Room Temperature

Future Work

- Perform load testing on solar sintered samples, as was done for lab samples
- Abrasion testing (abrasive blast) to compare polymer, sintered, and melted specimens
- Thermal cycle testing
- Optimize…