Moon-to-Mars Planetary Autonomous Construction Technology

# MMPACT Material Screening

National Aeronautics and Space Administration
www.nasa.gov

## Reduced-Cost Construction on the Moon and Mars

MMPACT's goal is to use regolith, available all over the Moon and Mars, in the construction of local infrastructure. Taking advantage of resources at the destination of a space mission is referred to as an **In-Situ Resource Utilization** (ISRU) and has the potential to save on mission costs. The tradeoff here is that material properties of regolith-based constructions are limited, unless additional materials are added. Additionally, targeted minerals in regolith can be sorted or concentrated in order to change the final properties.

## MMPACT Major Milestones

2020: MMPACT project chartered
2020: YET2 Planetary Construction Materials Study
2021-2023: Down-select for landing pad application
2022: Advanced Concepts Office Study
2022: SBIR III award to ICON for development of VMX technology

## Landing Pad Down-select

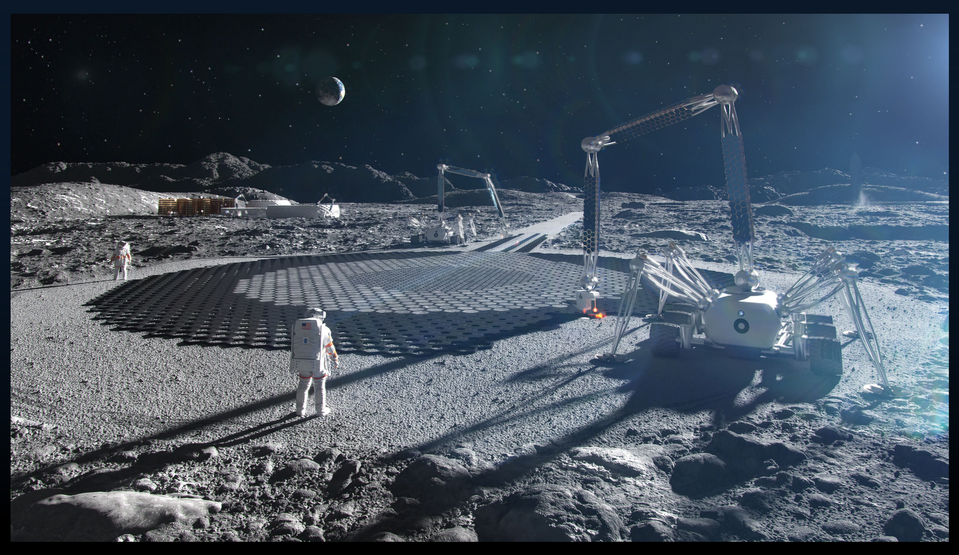
Testing of technologies mature enough to achieve:

- $10^{-3}$ torr vacuum during fabrication or environmental enclosure CONOP
- Multi-layered (min. 2) specimens
- Incorporation of new high-glass simulant
- Sizing to meet test standards

Materials tested:

1. Calcium Sulfo-Aluminate binder-based mortar (CSA)
2. Vitreous Material Transformation glassy ceramic (VMX)
3. Molten Extrusion glassy ceramic (ME)

Down-select testing was performed between 2022 and 2023.
Only VMX and CSA completed a full-suite of the required test matrix. ME submitted specimens for compression and ablation. Due to unsuccessful technology demonstrations for the necessary envirionmental enclosure, CSA mortar was not considered successful for the down-select test campaign, leaving VMX as the best candidate. In addition to down-select results, VMX showed overall better maturity, versatility and extensibility out of all candidate technologies.

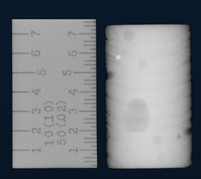


## Down-select Test Matrix

| Test Name | Material | Standard # | Standard Name | Test Enviro. | Test Qty. | Specimen Configuration[1] |
|---|---|---|---|---|---|---|
| Compression | Mortar | ASTM C0109 | Standard Test Method for Compressive Strength of Hydraulic Cement Mortars | STP | 3 | Cube |
| | Ceramic | ASTM C1424 | Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature | STP | 3 | Cylinder |
| Compression at Cold Temperature | Mortar | ASTM C0109 | Standard Test Method for Compressive Strength of Hydraulic Cement Mortars | -192°C | 3 | Cube |
| | Ceramic | ASTM C1424 | Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature | -192°C | 3 | Cylinder |
| Compression at Hot Temperature | Mortar | ASTM C0109 | Standard Test Method for Compressive Strength of Hydraulic Cement Mortars | 57°C | 3 | Cube |
| | Ceramic | ASTM C1424 | Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature | 57°C | 3 | Cylinder |
| Compression After Thermal Cycling Under Vacuum[2] | Mortar | ASTM C0109 | Standard Test Method for Compressive Strength of Hydraulic Cement Mortars | STP | 3 | Cube |
| | Ceramic | ASTM C1424 | Standard Test Method for Monotonic Compressive Strength of Advanced Ceramics at Ambient Temperature | STP | 3 | Cylinder |
| Layer to Layer Adhesion | Mortar | ASTM C297 | Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions | STP | 3 | Cylinder |
| | Ceramic | | | STP | 3 | |
| 4 Point Bend Flexural Test | Mortar | ASTM C78 | Standard Test Method for Flexural Strength of Concrete | STP | 3 | Rectangle |
| | Ceramic | ASTM C1499 | Standard Test Method for Monotonic Equibiaxial Flexural Strength of Advanced Ceramics at Ambient Temperature | STP | 3 | Disk |
| Ablation[3] | Mortar | EM40-OWI-013 | EM40 Non-Metallics & Advanced Manufacturing Division Plasma Torch Test Facility Operation Procedure | TBD | 6 | Cylinder |
| | Ceramic | | | | 6 | |
| Coefficient of Thermal Expansion | All | ASTM E228 | Standard Test Method for Linear Thermal Expansion of Solid Materials with a Push-rod Dilatometer | One cycle[4] | 3 | Rectangle |

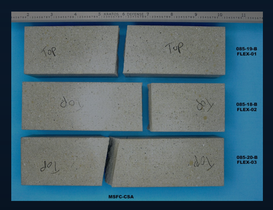
## Examples of down-select specimens:

(CT image courtesy of EM21; x-ray and digital pictures, Kratos-Southern Research Engineering)



*VMX compression specimen, X-ray image from KSRE*

*Post-test VMX ablation specimen, CT image from EM21*



*Post-test 4 Point Bend CSA specimens*

*Post-test CSA tension specimens*


*Molten extrusion compression specimens*

## Toolbox Development

- Development of processes and CONOPs
- Applications: landing pad repair or augmentation, roads, habitats
- Variety of materials: ceramics, mortars, alloys, sealants, polymer matrix composites, additives and more

| Material | Process | Development & Test Responsibility |
|---|---|---|
| Laser Vitreous Material Transformation (VMX) | Thermal | ICON |
| Molten Regolith Extrusion | Extrusion | ICON |
| Microwave Multi-Mode Sintered Regolith | Thermal | MSFC/Holly Shulman |
| Calcium Sulfo-Aluminate (CSA) Binder/Lunar Regolith Concrete | Extrusion | MSFC |
| $Na_2SiO_3$/NaOH (Geopolymer) Binder/Lunar Regolith Concrete | Extrusion | MSFC/PSU |
| Sulfur Binder / Lunar Regolith Concrete | Extrusion | MSFC/LSU |
| AT2LAS Polymer Binder / Lunar Regolith Composite | Extrusion | MSFC/AAT |
| Molten Regolith Tile Formation | Extrusion | MSFC/Astroport |
| Microwave Near Field Coupler Sintered Regolith | Thermal | MSFC/Radiance |
| Magnesium Oxysulfate (MgO) Binder/Lunar Regolith Concrete | Extrusion | MSFC |
| Sulfur / Nickel (S/NI) Binder / Lunar Regolith Concrete | Extrusion | MSFC |
| Aluminum/Graphite (Low Thermal Expansion) | Extrusion | MSFC |

## Examples of MMPACT material and technology development:

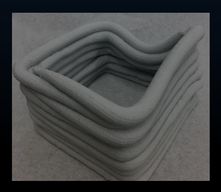
*Compression test cubes of regolith simulant-loaded epoxy*

*CSA mortar/epoxy "Grout" sample beam cured in $10^{-3}$ torr*

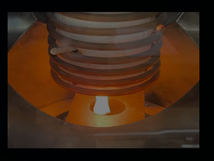
*Kappler-developed environmental enclosure at ~0.7 atm internal pressure*

*Geopolymer concrete specimens*

*Microwave multimode fabrication setup*



*Magnesium Oxysulfate concrete print*



*Astroport molten extrusion tile setup*

**Regolith-based construction materials can be used for a number of applications, such as:**

1. **Landing pads + blast shields**
2. **Roads**
3. **Habitats**

Upcoming Work

- Refinement of VMX material properties
- Lunar Landing pad design optimization
- Systems and materials testing in combined vacuum + temperature testing in a "dirty" chamber (V20)

Poster prepared by Chelsea Pickett (EM42)