

## Suitability of Martian Regolith as Material for Future Dwellings--An Investigation by Middle School Students in Collaboration with MIT and JEOL, USA

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Presented here in poster format is the preliminary result of a continuing investigation conducted by nine middle school students into the mechanical properties of simulated Martian regolith and its suitability as a construction material for proposed 3D-printed Martian dwellings. These investigations have been an integral part of research being conducted at MIT's Laboratory for Atomistic and Molecular Mechanics (LAMM) [1] and in the Laboratory for Infrastructure Sciences and Sustainability (LISS) [2].

In 2015 NASA began issuing challenges for the development of innovative technologies that would support human colonization of Mars by 2050. Students began with concepts and images developed at MIT as part of the initial Habitat Challenge [3]. From there, the team, including middle and high school students, MIT researchers, and grad students, hypothesized that the most efficient and sustainable means of structural development would be to use the indigenous materials: silicon-rich basaltic regolith, the thin gaseous carbon dioxide atmosphere, and the water ice discovered by the Curiosity rover. In addition, we assume NASA's Challenge to chemically convert CO<sub>2</sub> to simple sugars [4] and possibly starches will be successful and provide an additional structural constituent.

Our research focused on evaluating the structural capacity of a Martian regolith analog [5] and its ability to withstand compression and impact forces. For this work we evaluated three fractions of milled sorted Mojave Martian Simulant (MMS-1)—Superfine (<0.5mm), Fine (0.5-1.27mm), Coarse (1.27mm-3.17mm) and Unsorted (<3.17mm); each with differing total surface area available for binding and adhesion. For this investigation commercially available casein-based "milk glue" and saccharide-based flour-water paste were evaluated. Water was used as a control. In addition, samples of the Fine fraction were vitrified with the assistance of the Department of Energy's Pacific Northwest National Laboratory (PNNL).

Each regolith sample was mixed with an equal volume of binding agent, formed in a 6 cm circular mold, pressed to a thickness of approximately 1 cm, and allowed to air dry for seven to 14 days. Afterward, each sample was centered on a frame that supported the outside edge. A 6 cm spherical weight was dropped from increasing heights to determine the force needed to catastrophically fracture the regolith.

The milk glue mixture exhibited the greatest fracture resistance. Samples were subsequently tested with a reduced the ratio of regolith to glue from 1:1 to 1:0.66 and 1:0.5. Both exhibited substantially greater strength, similar to the grain size related findings of Kupwade-Patil et al [2].

Based on our observations, we believe Martian regolith may become a viable construction material but additional work will be necessary to produce a binding material that will be suitable for building sound, impact-resistant dwellings. In addition to reinforcing concepts developed during research, this activity dramatically demonstrates the links among public school learning, academic research, and the private sector that supports them [6].

References:

[1] SD Palkovic et al., *Construction and Building Materials* **115** (2016), p. 13.  
 [2] K Kupwade-Patil et al., *J. Mater. Civ. Eng.* **30(8)** (2018), p. 04018190.  
 [3] <http://news.mit.edu/2017/mars-city-living-designing-for-the-red-planet-1031>  
 [4] [https://www.nasa.gov/solve/CO2\\_Conversion\\_Challenge](https://www.nasa.gov/solve/CO2_Conversion_Challenge)  
 [5] GH Peters et al., *Icarus* **197** (2008), p. 470.  
 [6] The authors thank the Laboratory for Atomistic and Molecular Mechanics, and the Laboratory for Infrastructure Science and Sustainability at MIT, Bradley Johnson, Connor Appel, and Michael Schweiger at the Pacific Northwest National Laboratory, and the educational outreach of JEOL, USA.




**Suitability of Martian Regolith as Material for Future Dwellings**



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**Rising to the Challenge**



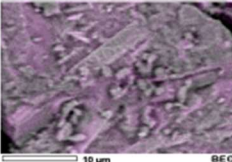
In 2016 NASA issued an unrestricted multi-year challenge to design and prototype a 3D-printed habitat for Mars. Domes, eggs, honey combs, cylinders, and spheres were proposed. MIT won 1<sup>st</sup> place with a bio-inspired forest design. We propose to investigate suitability of the indigenously available materials to support the construction of this venture.

**Martian Surface Simulants**



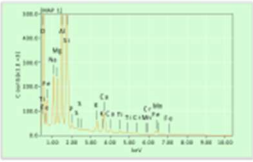
Much of the Martian surface is covered with eroded basaltic material that has been lithologically and chemically characterized by NASA. In addition, NASA has identified terrestrial locations that have similar characteristics and can yield appropriate analogs that can be investigated. This material is available and known as Mojave Martian Simulant.

**Chemical Composition**



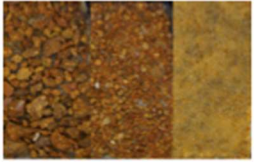
An energy dispersive spectrograph X-Ray map of simulant indicates a relatively low amount of Calcium (purple), the material in cement that is responsible for the formation of concrete. The Calcium map is superimposed on a 2500x SEM image of super fine sifted simulant. Microscopy is provided of JEOL.

**Quantitative Assessment**




Shown above is an EDS X-ray analysis of the chemical composition of a point on the Mars simulant map. The Calcium peaks (Ca) at 3.6 and 4.0 keV indicate relatively small amounts of CaO. JEOL's assessment is that CaO constitutes about 5.3% of the total mass of the sample. The implication is that cementation is unlikely and that a binder or adhesive will be needed.

**Mortar from Sorted Fractions**



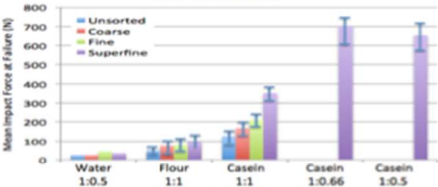
To assess the suitability of martian soil for dwellings, the regolith was mechanically sifted and sorted by grain size then mixed with equal amounts of water and/or binder to form mortar. Screening yielded with samples of coarse (1.27-3.17mm), fine (0.50-1.27mm) and super fine (<0.50mm) sand. Additional samples of unsorted material (<3.17mm) were evaluated.

**Impact Resistance Testing**



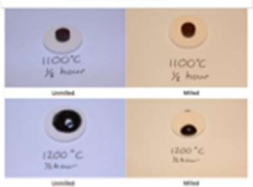
Two binding materials—casein based milk glue and flour-water paste—were mixed with sorted and unsorted regolith and formed into 6 cm discs. Discs were air dried for 7 to 14 days, mounted on a frame and impact-tested by dropping a spherical weight to determine the force needed to cause failure.

**Binder Effectiveness**



The strength of the material is related to size of the particles being bound and the relative proportion of the binder to the substrate. After completing the first casein tests, the amount of binder was reduced yielding greater impact resistance. Further reduction yielded less strength indicating an optimal non-linear relationship.

**Heat Treatment**



Verification may offer a way of transforming loose aggregate into a strong structural material. Samples prepared at PNNL indicate 1200 degrees C and fine milling may be needed.

**Conclusions and Future Investigation**

Based on our preliminary activity, we feel that the Martian soil is a plausible building material because:

- Fine grain material is plentiful on the planet
- It adsorbs water and can be shaped by extrusion
- With a suitable binder, it can be formed into a good structural material that can withstand external impact
- A suitable organic binder needs to be developed

**Future Investigations**

- Development of a suitable binder
- Design of construction equipment
- Stability in a thinner CO<sub>2</sub> atmosphere
- Structural integrity in an unsupported structure (i.e. dome, pyramid, etc.)

