A Home Away from Home

Neil Savage

Scientists explore ways to use Martian soil to build habitats on the red planet.

Someday, many people hope, humans will travel to Mars. The U.S. National Aeronautics & Space Administration (NASA) has plans for a mission to the planet in the 2030s, and entrepreneur Elon Musk says his SpaceX company can do it by 2024. If people succeed in setting up an outpost on Mars, they’ll need to build someplace for astronauts to live, sleep, and work.

But hauling building materials across 225 million km of space—the average distance between Earth and Mars—would be a nightmare. It costs about $4,000 to launch a kilogram of material to low Earth orbit, and many times that amount to send it to Mars, so trying to ship tons of concrete would be financially ruinous and logistically very difficult, says Robert P. Mueller, senior technologist for advanced products development at the Swamp Works, an innovation laboratory he cofounded at NASA’s Kennedy Space Center.

Any new inhabitants of the red planet will have to do what colonists have always done: Use the materials they have at hand to build shelters. On Mars, that material is regolith, a dusty, pulverized rock layer deposited throughout the solar system over billions of years by asteroid collisions. “It’s a ready-made construction material—crushed rock—sitting on the surface of the planet,” Mueller says. “All we have to do is develop the technology to use that aggregate that already exists and somehow bind that aggregate together.” That’s the goal of teams trying a variety of approaches to turn the stuff into a substance suitable for three-dimensional (3-D) printing.

This manufacturing technique, which creates objects by depositing material layer upon layer, would allow NASA to send robots ahead of any colonists to prebuild habitats. Three-dimensional printing can also create structures with shapes and thinness that might not be possible with standard concrete pouring techniques. Part of the challenge is developing a building material that is amenable to 3-D printing—in terms of consistency and hardening time—and creates stable structures.

A handful of researchers have already shown that they can probably turn the red dirt of Mars into sturdy construction materials. Some have been spurred by NASA’s 3D-Printed Habitat Challenge, which Mueller helped to launch. The challenge offers $2.5 million in prizes to encourage industry and academic scientists to explore ways to build on Mars. The first phase sought new architectural concepts that take advantage of 3-D printing, and the second phase delivered prizes in August to five teams who printed beams and other shapes out of a regolith simulant. A third phase just began.

This 2015 combined image from the Mast Camera on NASA’s Curiosity Mars rover shows the landscape of Mars, including the regolith that covers the red planet’s surface. The image has been color balanced to resemble what the landscape would look like under daylight conditions on Earth. Credit: NASA.

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There’s still a long way to go, but building homes out of Martian soil may not be the stuff of science fiction forever.

### THE RIGHT STUFF

On Earth, builders work mostly with concrete. This material typically consists of crushed rock or sand mixed with Portland cement and water. The cement, made from limestone and clay heated together, reacts with the water to form a paste that binds the rocks and gets stronger as it cures.

Researchers think regolith on Mars could serve as a replacement for concrete components. The Mars rovers have used gas chromatography, mass spectrometry, and laser spectrometry to determine the composition of Martian soil. Mars regolith is mostly silicon dioxide and ferric oxide, with a fair amount of aluminum oxide, calcium oxide, and sulfur oxide. The composition varies from place to place on the planet’s surface because of variability in asteroid collisions and the weathering by wind and water, in ancient oceans and in some modern water flows. But no spacecraft has returned to Earth with actual samples of the material.

So scientists at NASA’s Johnson Space Center have used the rover data to develop JSC Mars-1a simulant, a mixture of Earth minerals designed to match the composition and particle size of Mars’s soil. Scientists have used this regolith stand-in for tests of new building materials.

JSC Mars-1a is made from basalt gathered from a volcano in Hawaii. Meanwhile, Mueller uses another regolith simulant called BP-1. This material is made from a different crushed basalt from the Black Point Lava Flow north of Flagstaff, Ariz. “There are a variety of simulants out there, but they’re all based on basalt,” he says. Depending on what researchers are doing, they choose the simulant based on its mineralogical properties, its distribution of particle sizes, or its other qualities.

Yu Qiao, a professor of structural engineering at the University of California, San Diego, says JSC Mars-1a is very close replica of Martian soil. The simulant is 43.48% silicon dioxide and 16.08% iron oxide by weight, compared to average values measured on Mars of 45.41% silicon dioxide and 16.73% iron oxide. Qiao wants to see if he can come up with an even better replica based on newer measurements gathered by Mars rovers, which have turned up perchlorates in the soil. He wants to see if the perchlorates change the behavior of the materials he is testing. “Not only are we considering the soil itself, but also we need to consider impurities,” he says.

### SULFUR STRENGTH

On Earth, concrete cures and strengthens thanks to the chemistry of cement, which consists of limestone and water. However, most limestone on Earth was formed by sea creatures, which Mars never had. Martian soil has the calcium and carbon found in limestone, but the elements are scattered around the planet. Mars has water but it’s not plentiful. “It’s going to be a long time before we can produce cement on another planet,” says Gianluca Cusatis, a professor of civil and environmental engineering at Northwestern University.

But Mars does have a lot of sulfur in its soil, and molten sulfur has been used to bind some concrete on Earth. To test the possibility of using it to make Martian concrete, Lin Wan-Wendner, while a Ph.D. student in Cusatis’s lab, melted sulfur and mixed it with JSC Mars-1a in a ratio of 1:3, the same recipe used for sulfur concrete on Earth. She then subjected the concrete to standard tests of its strength under compression, bending, and splitting.

Using Earth sand, that recipe produces compression strength of about 30 megapascals, similar to that of cement-based concrete. But the simulated Martian concrete was much weaker, which may have been because the material was more porous than the Earth version, Cusatis says. More porous concrete is usually a result of larger particles in the sand.

When Wan-Wendner, now a researcher at the University of Natural Resources & Life Sciences, Vienna, and colleagues tried a sulfur-to-sand mix of 1:1, and compressed the mixture to break down grains and drive out air bubbles, the resulting concrete had a strength of 60 MPa, twice as strong as standard concrete. Sulfur-based concrete also hardens.
quickly, in the time it takes for the mixture to cool. Regular concrete takes 28 days to completely cure and gain its full strength. The quick setting may be an advantage for 3-D printing, Cusatis says, because it means each layer of the material will almost immediately be strong enough to hold the layer printed on top of it.

Cusatis could not explain the extra strength of the Martian concrete, so he tried varying the size of soil grains to see if that made a difference. It did, but not enough to account for the doubling in strength. He thinks the sulfur may be reacting with metals in the regolith, particularly the iron oxide that gives Martian soil its characteristic red-orange color, to form chemical bonds within the material.

There are some drawbacks to the Martian sulfur concrete, however. Like standard concrete, it has poor tensile strength and cracks easily under a load. On Earth, builders solve this problem by reinforcing structural concrete with steel rebar, but it is not clear what kind of rebar could be built on Mars. And one reason sulfur isn’t widely used on Earth as a binder is that it is not heat resistant. If a building caught on fire, the sulfur could melt and the concrete would fall apart. Perhaps, Cusatis suggests, the sulfur concrete could act as a core material providing strength, encased in something fireproof.

There’s one other problem for using it in building materials: “Sulfur smells bad. You certainly don’t want to have the sulfur smell in your house,” Cusatis says. It might be necessary to coat the concrete with something just to contain the smell.

In Mueller’s lab at NASA, researchers are testing polymers as a binder for the regolith. It should be possible to manufacture polymers, such as high-density polyethylene, on Mars using carbon dioxide from the atmosphere and hydrogen from water in the soil, Mueller says. With a 3-D printer, his lab built a dome 1 m in diameter out of their simulated Mars concrete, to show what they hope to do on a larger scale.

Of course, 3-D printing with concrete is challenging, says Mueller. The deposited material has to be thick enough to hold its shape during the printing process but thin enough that it doesn’t clog the machine or dry so fast that it cracks. “The trick is getting a material that has the right consistency so that it can be extruded and it can cure,” he says.

Mueller would like eventually to skip the polymer binder and instead harden the soil by sintering it—that is, heating and compressing it until it becomes solid. That should be possible using a laser beam, a solar concentrator, or a microwave system. But until researchers develop that technology, they’re using the polymer binder to test their 3-D-printing ideas.

Another proposal for Martian building materials eliminates a binder altogether. UCSD’s Qiao discovered that he could turn a regolith simulant into bricks by simply compressing the material rapidly. The soil is full of iron oxide and oxyhydroxide particles about 25–45 μm across. “If you compress the soil grains at high enough pressure, you are going to cleave those iron oxide nanoparticles,” Qiao says.

The breakage gives the nanoparticles clean, flat surfaces. Under further pressure, they rotate so that the tiny, freshly cleaved facets press against each other and form a bond. Qiao believes the nanoparticles bind to each other through a mix of van der Waals forces and atomic bonds, though he hasn’t tested that assumption. What’s more, the binding happens in just about a millisecond under 400 MPa of pressure. That is about the same amount of pressure produced by dropping a hammer on the soil, Qiao says. And that is essentially what his team did.

There is another type of soil common on Mars, a sedimentary, claylike material formed in ancient oceans. It has the same chemical composition as other regolith, but weathering by water long ago means it has a fine-grained structure with no nanoparticles and an electrostatic surface charge. Qiao found that compacting layers of a replica of this dry Mars clay under high pressure also created a solid material. The layers of the clay become naturally aligned under pressure so that electrostatic forces held them together. But rather than striking the material rapidly, the researchers slowly squeezed the clay layers together. The two soils produce “similar strong solids,” Qiao says.

There’s still a long way to go, however, from scientists playing in simulated Martian dirt to erecting habitable buildings on another planet. The third phase of the NASA 3D-Printed Habitat Challenge, which will require contestants
to 3-D print a scale model of a proposed habitat, was announced this month. Mueller hopes this will continue to advance the field. Still, at this point the work is aimed at proving the technology is viable rather than planning for a specific mission, Mueller says. Cusatis agrees: “I’m pretty sure there is a lot of work to do before being able to build a structure on Mars.”

AUTHOR INFORMATION

Author Contributions

Neil Savage is a freelance contributor to Chemical & Engineering News, the weekly newsmagazine of the American Chemical Society.