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Building on Mars with human blood and urine

Aled D. Roberts

Researchers look to the human body as a feasible resource for construction materials beyond Earth.

Mars has no significant geomagnetic field to deflect harmful solar flares or cosmic rays. For NASA to have any sustained human presence there, it will need to protect inhabitants from deadly radiation exposure. The most sought after real estate is likely to be subterranean caves, which provide a natural buffer against the harsh conditions. But if Mars's explorers land in spots far from such rocky hollows, their protection will need to come from habitats with meter-thick walls and ceilings that reduce radiation exposure to tolerable levels. (See the Quick Study by Larry Townsend, *PHYSICS TODAY*, March 2020, page 66.)

Obtaining bulk material for that purpose is a challenge. With no infrastructure or economy on the red planet, it won't be as simple as popping down to a local builders' supply store for a few bags of cement or pile of bricks. Everything used on Mars will have to be either shipped from Earth or produced locally.

It currently costs about \$5000 to ship a single brick's worth of material (2.27 kg) into low Earth orbit and significantly more to transport and land it safely on Mars's surface. Given that many tons of material will be needed to build even a minimal habitat to protect humans from deadly radiation, the only feasible option is to use resources available on-site—a concept known as *in situ* resource utilization.

Living off the land

The geological and atmospheric conditions on Mars have eroded much of its surface into an extremely fine dust known as regolith. To resist erosion from Martian dust storms, regolith will need to be consolidated into a sturdy material for use in construction and radiation shielding. Researchers have proposed several technologies to stabilize the regolith into monolithic materials, but most have serious limitations.

One proposed method is to melt the regolith and cast it into blocks or deposit it through a 3D-printer nozzle. Although the method would produce a strong and stable material, it would also require tremendous quantities of energy. That in turn would necessitate bringing substantially more energy-generation equipment, such as solar panels, on a mission to Mars. And the additional mass would largely offset the benefit of *in situ* resource utilization in the first place.

Another option is to produce a Martian equivalent of terrestrial concrete. Rovers have identified deposits of gypsum, basanite, and carbonate minerals, which could be mined, purified, and processed into cement and combined with regolith to produce concrete. (See "Martian concrete could be tough stuff," *PHYSICS TODAY* online, 10 November 2022.) That method

would constrain the placement of habitats in regions with such mineral deposits, and the need for heavy mining equipment would add to the mission's cost and complexity.

Synthetic polymers produced from constituents of the Martian atmosphere—carbon dioxide, mainly—could serve as binders and turn loose regolith into a solid composite. But that technology is still in its infancy and would likely consume large quantities of energy and another scarce Martian resource—water. Even so, if successfully developed, the production of plastics from thin air would be a useful technology and worth pursuing for benefits on Earth as well as in space.

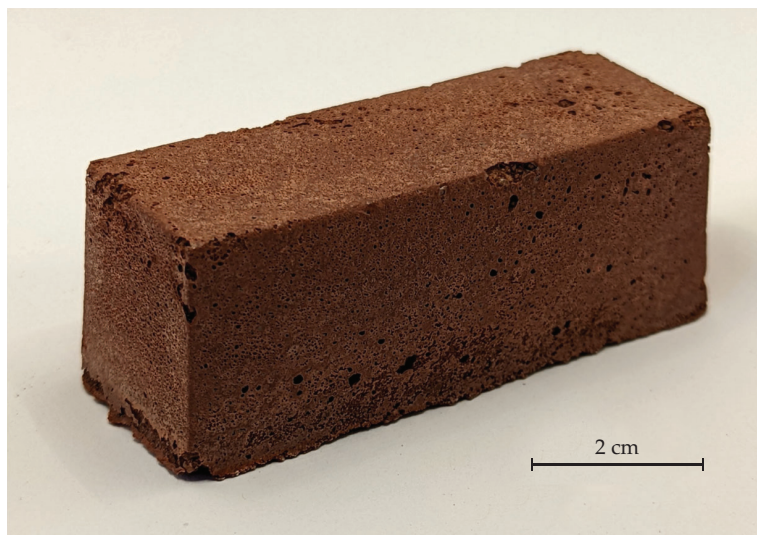
Polymeric binders can also be produced through biotechnological routes. Historically, proteins and carbohydrates served as adhesives and binders before the development of synthetic alternatives—an improvement that saved many horses a one-way trip to the glue factory. In recent times engineers have not only elucidated the structure–function relationships of proteins and other biopolymers but also developed toolkits to produce tailored proteins synthetically. Some have even suggested that bioreactors could be taken to Mars to produce biopolymers from engineered microorganisms, such as photosynthetic algae, that could be sustained by CO₂, nitrogen, water, sunlight, and trace minerals on Mars.

Although such biotechnological methods could significantly reduce launch mass, and thus mission cost, downsides abound: a low yield of bioreactors—typically less than 10 grams per liter per day—along with a lot of waste and water usage. The mass and volume of the bioreactors and the need for spare parts and backup systems for redundancy would also be a significant contribution to a launch's mass and cost, despite the prospect of long-term benefits.

Is the answer inside us?

Aside from regolith, atmospheric gases, and an extremely limited amount of water, one resource that we know will be available on a crewed mission to Mars is the crew themselves. Surprisingly, the concept of humans as an *in situ* resource has gone largely unnoticed by the scientific community. To redress the oversight, my colleagues and I at the University of Manchester decided to investigate.

We were developing new glues based on synthetic spider silk that adheres to glass. As a control experiment to establish a baseline stickiness, we decided to test a protein known as bovine serum albumin (BSA). The main protein in cow blood plasma, BSA is commonly used by biologists and biochemists in control experiments. To our surprise, BSA was able to stick



HUMAN BEINGS naturally produce serum albumin and urea. The first can be extracted from their blood plasma, and the second from their urine, sweat, and tears. Combined with Martian regolith, those ingredients can make a biocomposite material termed AstroCrete—pictured as a 3D-printed structure (**left**) and a brick (**right**)—that's stronger than terrestrial concrete.

glasses together extremely well—much better than our carefully engineered spider silk proteins and comparable to commercially made adhesives.

That finding got us digging around in the scientific literature. Recent research studies had little to say. The sticky properties of BSA appeared to have been overlooked despite the protein's common use. A deeper search, however, revealed that animal blood had been used historically as an adhesive and binder and could even produce some remarkably beautiful materials, such as Bois Durci—a substitute for wood, leather, bone, metal, and hard plastic.

If BSA can bond glass together so well, we reasoned, shouldn't it also be able to adhere particles of sand, since glass and sand are both made of silicon dioxide? A quick experiment with some waste sand from the lab confirmed the suspicion. And if regolith on the Moon and Mars is also mainly silicon dioxide, shouldn't its powdery particles be able to stick together too? Transporting cows to Mars would hardly be practical. But humans will necessarily be aboard any crewed mission, so why not instead use the human equivalent, human serum albumin? The protein is abundant in human blood plasma at a concentration of up to 50 g/L in healthy adults. And it can be extracted safely without removing the precious red and white blood cells from the body.

A few tests confirmed the proof of principle: The protein from human blood can transform lunar or Martian regolith into a concrete-like biocomposite material. We then set out to find out how and why it does so. After probing the bonding mechanism with some spectroscopy, we determined that the protein unfolds from a tightly bound globular state into an extended state where it interacts strongly with adjacent proteins and surfaces. Curiously, that's also how spider silk behaves.

To test our hypothesized mechanism, we added a substance known as urea to the formulation. Because urea is commonly used in biochemistry labs to unfold and destabilize proteins, we expected that the strength of our materials would drop with its inclusion. To our surprise, however, adding the urea actually makes the materials up to three times as strong. Conve-

niently, urea is the second main component of human urine, after water. We already know that astronauts will have to extract and recycle water from their urine on any space habitat—indeed, it's a common practice on the International Space Station—so they would have a ready supply of urea on any mission.

Tests done on the resulting biocomposite material, which we named AstroCrete and made from simulated Mars dust, yielded compressive strengths as high as 11.9 MPa. And when the experiments were performed on AstroCrete made from simulated Moon dust, the materials were even stronger—up to 39.7 MPa. By comparison, ordinary concrete typically has a compressive strength of 20–41 MPa. Considering that gravity on Mars and the Moon is low—just 38% and 16.6%, respectively, of that on Earth's surface—the AstroCrete is strong enough for most practical applications. It's certainly strong enough to serve as a radiation-shielding material.

According to our calculations, for a mission to Mars, a total of 550 kg of high-strength AstroCrete could be produced over 72 weeks with a six-person crew. That's too little to make the required quantity of radiation-shielding material to construct a Martian habitat. But if it's used as a mortar for sandbags or heat-fused regolith bricks like the one shown in the figure, calculations suggest that it's plausible for each crew member to produce enough additional habitat construction materials to support an additional future crew member. That would allow potentially rapid growth of an early Martian colony.

Additional resources

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