Current Science Reports

Extra-terrestrial Concrete

For building on Mars

Space organisations across the world aim to settle humans on Mars by 2050. For human habitation on Mars, buildings are necessary. But taking cement and other materials to Mars will prove to be expensive.

Can we create the necessary building materials on Mars? But there is no liquid water there. So can we design a material that does not require water?

K. Snehal, MNNIT, Allahabad and Piyush Chaunsali, IIT Madras collaborated with a researcher based in the United Kingdom to find a solution to the problem. They leveraged on the abundance of sulphur on Mars. Sulphur can act as a binding agent at high temperatures.

To test their idea, they used a commercially available Martian top soil simulant and sulphur powder. Martian soil is mainly composed of silica, aluminium, and iron, and sulphur can act as a binder.

A combination of 70% Martian topsoil and 30% sulphur provided a maximum compressive strength of more than 25 megapascals – sufficient to meet building requirements on Mars.

But would the mechanical and structural characteristics of the extraterrestrial concrete withstand the surface temperature conditions on Mars?

The researchers tested the concrete at 0°C, 40°C, and 50°C for one week and then for one month. The concrete could maintain a comprehensive strength of 25 megapascals at 40°C and 50°C for one month.

Interestingly, the strength of the concrete increased to 35 megapascals after 28 days at 0 degrees. This was due to the closing of the pores in the concrete as a result of freezing.

Testing the mineral phase composition of the concrete, the researchers found that it varied at different temperatures. For example, octasulphur, a form of sulphur where eight atoms of sulphur join to form a molecule, which was not present in the initial Martian concrete mixture, increased to 13–20% when exposed to 40°C and 50°C. Five per cent anorthite, a rock forming mineral composed of calcium aluminosilicate, increased to 20% at 0°C and disappeared at 40°C and 50°C. The olivine phase of magnesium iron silicate disappeared under all exposed temperature conditions.

The researchers did not find any major defects in the internal structure of the extraterrestrial concrete at higher temperatures, though the morphology became porous at 40°C and 50°C due to changes in the sulphur phase in the concrete matrix.

The team is still exploring additives to control the hardening rate of the Martian topsoil-based concrete. They also have to test the concrete's durability, and resistance to radiation.

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Rock Varnish

Nature's shield

In the cold desert of Ladakh, there are dark-stained rocks that look varnished. The sun shines on these rocks during the day and dew trickles down on them at night. But this does not explain the varnished appearance of the rocks.

Now, researchers from the Birbal Sahni Institute of Palaeosciences, Lucknow, in collaboration with the CSIR-Indian Institute of Toxicology Research, Lucknow have come up with a plausible explanation.

They collected samples of rock varnish for lab analysis to probe into the formation of the varnish.

First, they analysed the surface morphology and chemical composition of the varnish layer. Microbial fingerprinting using organic biomarkers and isotopic analyses in conjunction with electron microscopy revealed the presence of organic metabolites such as fatty acids, alkyl benzenes, oxime, amide, and fatty acids. This, the scientists say, could be a result of mineral–microbial interactions.

Next, the researchers used isotope-ratio mass spectroscopy to identify the source and variation of isotopes in the organic metabolites. The surface of the rocks presented an ideal environment for microbial development. Since the rock is rich in manganese, one prevailing hypothesis is that the varnish is left behind by microbial communities that use manganese as a defence against the desert sun.

To confirm the role of microbial life in varnish formation, the researchers analysed the hydrophobicity of the varnish layer. They compared the surface wettability on the rock samples with what could be observed on a hydrophobic material such as a raincoat. Both surfaces displayed comparable responses to water.

Contact angle studies showed that the varnish layer changes from hydrophilic in host rock to hydrophobic in varnish. The varnish layer acts as both host and barrier, protecting the microbial populations from harmful environmental influences, particularly UV irradiations and weathering.

During his voyages on the HMS Beagle, Darwin described the dark colour of the rock varnish as 'glittering in the sunlight'. The study by Indian researchers now throws light on the glitter and provides insights into life in extreme environments.

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Recombinant Protein

To treat cancer

The human paired box gene 4 protein or PAX4, is reported to suppress tumours. If the gene coding for this protein could be introduced into bacterial cells, the bacteria could produce adequate amounts of the human paired box protein.

The recombinant proteins thus produced, such as recombinant insulin, are already being used as therapeutic agents. But PAX4 recombinant proteins have not been produced yet.

Producing pure and bioactive recombinant proteins is challenging. However, recently, a team from IIT Guwahati reported success in their efforts to produce the recombinant human paired box gene 4 protein.

They downloaded the human paired box gene 4 gene's code from the publicly available molecular database of the National Centre for Biotechnology

Information, and optimised the gene to enhance the traits of the gene sequence to fit in a bacterial genome. As per the optimised code, the gene was synthesized by GenScript, a company that provides custom gene synthesis services.

The gene was inserted into *E. coli* cells using a carrier DNA molecule, plasmid pUC57. The researchers then cultured the *E. coli* cells and purified recombinant proteins from the culture using the BioRad purification system.

An investigation of the bioactivity of the protein on cell migration, cell proliferation and cell cycle showed that purified recombinant paired box gene 4 fusion proteins can indeed function as tumour suppressors.

So the recombinant human paired box gene 4 protein can now be used in clinical trials for treating cancer. But first, we need to study its functions. And, perhaps, further modifications may be required to make the industrial production of this protein possible, say the researchers.

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Mesquite Leaf Extract

For treating leishmaniasis

Leishmaniasis, caused by *Leishmania*, a protozoan parasite, is transmitted via the bites of infected female sand flies. Visceral leishmaniasis, the most severe form of the disease, affects internal organs and can be life-threatening. The chemotherapy used for managing the disease has severe side effects. There is a need for alternatives.

Investigating the leaf extract of the mesquite plant, *Prosopis juliflora*, researchers from the National Centre for Cell Science, Pune and the Savitribai Phule Pune University, found that it had medicinal properties, including anticancer properties, promoting apoptosis or apoptosis-like mechanisms. They asked themselves: can we use the cytotoxic effects of the plant extract to treat leishmaniasis?

The researchers continued their investigations on the *Prosopis juliflora* leaf extract. For their experiments, they used the *Leishmania donovani* parasite strain.

They first tested the extract on *Leishmania donovani* promastigotes, the form of the parasite with a tail that enters via sand fly bites. The extract had a concentration-dependent anti-promastigote activity. About 50% of the parasites were killed at an extract concentration of 6.5 milligrams per millilitre.

Image: Thamizhpparithi Maari

The life cycle of *Leishmania* parasites has another form, amastigote, the tailless form the parasite takes when engulfed by macrophages. Does the mesquite extract work on amastigotes?

To analyse the anti-amastigote activity of the extract, the researchers used it on parasite-infected mouse macrophage cell lines. They found that the leaf extract reduced the replication of amastigotes within the macrophage cell lines.

Further *in-vivo* studies are, of course, required to confirm the efficacy and safety of the *Prosopis juliflora* leaf extract. There is also a need to identify the active ingredient in the leaf extract.

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Treating Monkeypox

Searching for drugs

Monkeypox is like smallpox, but with milder symptoms and lower death rates. Besides monkeys, the causative virus infects other animals, including humans. Though human infections have been reported from Africa since the 1970s, the world woke up to the threat only last year. Several cases have been reported from different parts of the world since then and a number of confirmed deaths prompted the WHO to flag monkeypox as a global issue.

But no specific drug is available so far for treating monkeypox. So researchers from the National Institute of Pharmaceutical Education and Research, Hyderabad decided to take up the challenge.

From existing research, they knew that it is the E8 protein on the surface membrane of the virus which helps it enter host cells. If any existing drug can target the E8 protein, we could find an immediate treatment for monkeypox, they reasoned. And they started searching for the best available drugs for monkeypox, using the available tool kits.

There was no 3D structure of the E8 protein in any database. So they downloaded the amino acid sequence of the protein from the Uniprot database. From the protein sequence, they could predict the 3D structure of the E8 protein using the Swiss-model server and the homology model. Based on the predicted model, they prepared a protein structure for reliable docking studies, using the protein preparation wizard of the Schrodinger-suite 2022.

Then the team started screening a library of natural products available in the Drug Bank, a library of approved drugs. They focused on drugs isolated from bacteria and fungi, since such drugs can be easily produced by culturing the organisms.

The top ten per cent of molecules identified from the virtual screening of the drug molecules were used for simulating molecular docking with the E8 protein. Using binding affinities and protein-ligand interactions, the researchers identified the best drug molecules: Gabosine D, a natural product found in Streptomyces bacteria, and Edoxudine, a deoxythymidine analogue, used to treat herpetic keratitis.

Now these two potential drugs for monkeypox need further validation using *in vitro* and *in vivo* studies.

Wet lab researchers, are you listening?

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Graphene from Coconut Husk

For supercapacitor applications

Graphene is used for high performance energy storage applications. But it is expensive. So Nanda Gopal Sahoo and colleagues from Kumaun University started looking for raw waste materials to synthesise graphene for supercapacitor applications.

Coconut husk is an abundantly available waste product. So the researchers decided to make reduced graphene oxide from coconut husk to use as a supercapacitor electrode.

They processed coconut husk using pyrolysis to develop graphene oxide sheets. With the sheets, they fabricated electrodes.

To test the electrode, they prepared a sulphuric acid-based electrolyte and a polymer gel electrolyte. With these electrodes and electrolytes, the researchers then fabricated two supercapacitor cells. They measured and compared the electrochemical parameters of the devices. Both devices showed good electrochemical properties.

The sulphuric acid-based device had lower equivalent resistance, higher specific capacitance and higher energy density and had better performance. The polymer-gel-based device, on the other hand, had higher input to output ratio and was stable for several cycles.

'The fine pore structure of the polymer-gel enhanced ion transportation and charge transfer and, hence, its stability,' explains Nanda Gopal Sahoo.

'As a biodegradable material, coconut husk graphene is eco friendly and hence easily disposable,' says Gaurav Tatrari, Kumaun University.

Researchers can now explore the possibility of improving the performance of supercapacitors made using the abundantly available, cost-effective material.

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Sulphur Trioxide Sensor

Improving selectivity

Sulphur trioxide, released from power plants, industries, automobiles and even gas stoves, is toxic and can cause problems in the eyes, skin and respiratory system.

Solid state sensors are effective at detecting the gas at room temperature and in low concentrations. Among the different sensor materials, metal-oxide materials are user-friendly for sensor fabrication because they can easily be fabricated and designed. They also have better chemical stability. Moreover, the morphology can be easily tuned through doping – a property that can be used for improving their gas detecting performance.

So, researchers from the Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore and the Swami Ramanand Teerth Marathwada University, Nanded collaborated with colleagues in the UK, Poland and Romania to improve the sensing properties of aluminium oxide.

Aluminium oxide is a comparatively cheaper metal oxide and has been used for moisture and concentration-sensitive sensing. It is also used as adsorbent, coating, catalyst, or catalyst support material.

These applications are dependent on the surface area of aluminium oxide. Thus altering the surface area and morphology could improve the performance of aluminium oxide.

The team decided to use a nickel-doped aluminium oxide nanomaterial. Nickel has low-humidity and its catalytic nature makes it appropriate for use in sensors. It shows affinity for oxygen and thus enhances the adsorption of oxygen species.

High doping with nickel ions makes the size of aluminium oxide powder uniform, improving sensor response.

The researchers prepared aluminium oxide nanoparticles and nickel-doped aluminium oxide nanoparticles using microwave-irradiation to ensure that the nanoparticles were of uniform size and were evenly distributed.

Transmission electron microscopy showed that the nickel atoms were evenly distributed throughout the matrix, forming a homogeneous nickel-aluminium oxide alloy. Using scanning electron microscopy, the researchers found that the nickel atoms created a rough surface on the sensor, which increased the surface area available for gas adsorption.

X-ray photoelectron spectroscopy showed that the nickel atoms had perfectly fused with the aluminium atoms, forming a strong chemical bond – a useful property for improved sulphur trioxide sensing.

X-ray diffraction analysis revealed a phase change in the nickel-doped alumina nanoparticles, from cubic to orthorhombic, and a decrease in crystallite size. This allows small gas molecules to be detected.

The researchers evaluated the response of the nickel-doped sensor to different concentrations of sulphur trioxide gas at various temperatures. Nickel-doped alumina nanoflakes showed efficient and fast responses to all tested concentrations of sulphur trioxide gas, and an increased response at higher temperatures.

The team then tested the stability of the nickel-doped sensor over a period of five weeks. The nickel-doped sensor had a high response even after 5 weeks, retaining 97 per cent of the original sensing property.

Based on the resistance modulation and adsorption kinetics of oxygen species on the sensor surface, the researchers demonstrated that the sensor could selectively detect sulphur trioxide even in the presence of other gases such as formaldehyde and sulphur dioxide and oxides of nitrogen.

Economical, sensitive, selective and stable, nickel-doped alumina nanoflakes offer reliable and fast detection of sulphur trioxide gas. Could the sensor be used for real-time monitoring of sulphur trioxide levels and to ensure industrial safety?

Only the future can tell.

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Piezoelectric Devices

Using chicken bone extract

Piezoelectric materials generate electricity when subjected to mechanical stress. Quartz, barium titanate, and lead zirconate titanate are conventional piezoelectric materials found in various piezoelectric devices such as quartz watches, sensors, and actuators. However, about a decade ago, it was found that hydroxyapatite in bone powder also has piezoelectric properties.

Since India produces nearly three billion broiler chickens per year to meet the protein needs of its citizens, and the chicken bones go to waste, we have abundant and cheap resources to make piezoelectricity.

Usually, piezoelectric devices are made by compacting powder inside a die or by extrusion – processes that are cumbersome and time-consuming.

Researchers from IIT Kharagpur collaborated with researchers from the Defence Materials and Stores Research and Development Establishment to come up with an easier method: 3D printing.

They prepared a chicken bone extract by grinding chicken bones into a fine powder, separated bioceramics

from the bone matrix and made a slurry that can be used in 3D printing.

'Using 3D printers, we can fabricate piezoelectric devices/components in a more controlled manner,' says Chandra Sekhar Tiwary, IIT Kharagpur.

Using three-dimensional objects from a digital file, the 3D printers added the chicken bone extract, layer by layer, until the object was completely created.

The researchers found that the piezoelectric properties of the chicken bone extract were improved by increasing the concentration of the extract and by optimsing the process parameters.

They characterised the device and determined its piezoelectric properties. The device showed a piezoelectric coefficient comparable to that of the other commonly used piezoelectric materials.

Since the raw material used is chicken bones which would otherwise be wasted, and since 3D-printing technology is becoming easier to use, perhaps we can think of carpets that generate electricity when people walk on them and other similar uses.

The researchers, however, are more excited about the potential use of the chicken bone extract and 3D printing in designing biomedical sensors and actuators as well as implants in orthopaedics and dentistry.

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Pune Slum Potential

In-situ redevelopment

Pune is a prime location for institutional and educational activity. A city with pleasant climate and beautiful surroundings. And so, over time, many have migrated to Pune. Many of the migrants belong to low income groups. So slums have sprouted to house them. Slums have high population density, growing faster than the city's rate of population growth. Thus, from about 4% in 1951, by 2021, slums started housing 44% of Pune's population.

Some slums are next to railway tracks and water bodies, posing a risk to the slum dwellers. If this trend continues, public services and infrastructure will be overburdened.

Redevelopment, where houses are built at the existing location, without disrupting lives and social networks, is a possible humane solution. But is it really possible to convert existing slums into proper residential areas?

Nitin Mundhe, Sir Parashurambhau College, Pune and Ravindra Jaybhaye, Savitribai Phule Pune University analysed the suitability of current slum lands in Pune for redevelopment.

They collected geographical data about the slums and procured Landsat 8 satellite infrared camera images for land use data. ASTER remote sensing data provided a slope profile of the Pune area. To obtain other details such as the locations of railway, road and drainage networks, the researchers used Survey of India topographic maps. With the help of data from Resourcesat-2, the Indian remote sensing satellite, and Google Earth images, they counted 477 slums within the Pune Municipal Corporation limits. About half are declared slums by the government, and the others are either undeclared or unnotified.

Slum redevelopment is easier if the slum is situated in lower to middle income areas with low slopes, and easy access to reliable transport networks. Using the Rajiv Awas Yojana guidelines, the researchers evaluated various criteria and, using analytic hierarchy and expert rankings, they classified the slums' suitability for redevelopment.

As per the analysis, higher priority was given to land ownership and land value, on the one hand, and slum dwelling unit and population densities, on the other. Comparatively lower priority was given to slope, transport networks and land use.

The researchers found that nearly a fifth of the slums are highly suitable for redevelopment at the existing location. And another three-fifths of the slum areas are moderately suitable for on-site redevelopment. These are in open areas, have gentle slopes, and are close to transport networks.

The rest of the slums in Pune can only be renovated. Redevelopment is not easy because they are on public land with strong transport links.

Government schemes such as the Prime Minister's Awas Yojana can be used by real estate agencies to build houses for social and public welfare. However, redevelopment plans need to be implemented to avoid further haphazard development.

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Reports by **Manish Kumar Tekam, A. Karthic, Amit Kumar, M. S. Induja, Atig Udham** and **Sileesh Mullasseri**

scienceandmediaworkshops@gmail.com