ENGINEERED LIVING BUILDING MATERIAL (LBM) FORMED BY BINDER JETTING UNDER MARTIAN TEMPERATURE AND AIR PRESSURE. Ning Liu[1] and Jishen Qiu[1], [1]Dept. of Civil and Environmental Engineering, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China, nliuak@connect.ust.hk

Introduction: Two recent trends have greatly raised the public's interest in establishing settlements in frontiers like Moon and Mars. For future Lunar or Martian settlements, many concept construction technologies have been studied. All the extra-terrestrial construction (ETC) technologies, despite their difference in feedstock processing and target material, essentially involve the same route of energy conversion, i.e., (i) generating electric power on site, (ii) converting the power it into heat (because no fossil fuel available for heating) , (iii) using the heat to melt solid feedstock, and (iv) using the liquid binder to bond the aggregates on site, forming a loading-bearing composite material. Before this study, ceramic, alloy, and cement processed from Lunar/Martian regolith had been proposed as concrete binders for constructions in situ. Such material processing requires high energy input, often involving heavy power generators (e.g., nuclear reactors) and heaters (e.g., laser) to melt the minerals at hundreds to thousands of degrees Celsius. It will still take weeks to months to build a full-size structure based on best energy generator with the highest specific power that can be shipped to site.

Hydrogel-based concrete (HBC) is a new type of composite material used in construction. It is formed in two steps: first, by mixing flowable hydrosol with inert aggregates; second, by curing the fresh mixture for sol-to-gel transition, dehydration, and composite hardening. Previous studies have shown that "Mars HBC" can be formed with minimal shipped ingredients and energy consumption, with 20-kg polymer powders contributing to 1 m^3 HBC with a compressive strength of 5 MPa (Figure 1.a) [1-2]. This type of HBC is structurally adequate for multi-story buildings under Martian gravity (Figure 1.b). Compared to current ETC, HBC can be generated at a much higher rate by warming water up to only 50 Celsius degrees.

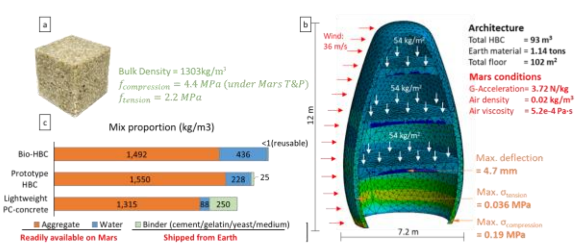

Figure 1. a) Prototype (gelatin) HBC; b) FEM simulation of HBC Mars base.

Bio-HBC: Engineered Living Building Material: Living Building Material (LBM) represents either synthesize building blocks of the material or form the material itself. In LBM, the microbial cells are genetically engineered for synthesizing functional building blocks, thus the material can possess unique attributes that are only seen in living organisms, e.g., self-repair, stimuli-responsiveness, environmental adaptivity. In order to make HBC renewable and have expandable functionality to cope with possible extreme environments, so that it can be used for a longer period of time on resource-scarce Mars, we used genetically modified yeast strains (*Saccharomyces cerevisiae*) to synthesize hydrogel to make bio-HBC (Figure 2.a). These modified yeast cells can produce recombinant SpyTag/SpyCatcher pairs and collagens which are super strong adhesive proteins, resulting in hydrogels with strong cohesive properties [3].

As Figure 2.b shown, our findings reveal that the addition of a small portion of engineered yeast can yield bricks with higher mechanical properties when cured under harsh environments. Previous studies show that HBC cured under harsh environments has worse mechanical properties than that dehydrated under room environment, because the ice crystal forms HBC with high porous microstructure. In bio-HBC, the yeast cells can reposition the growth of ice crystals to prevent the formation of porous joint structures during freezing. Notably, collagen shares a comparable tri-helix protein structure with gelatin and can promote adhesion through specific binding sites on the protein that interact with other molecules, such as integrins on cell surfaces or extracellular matrix components.

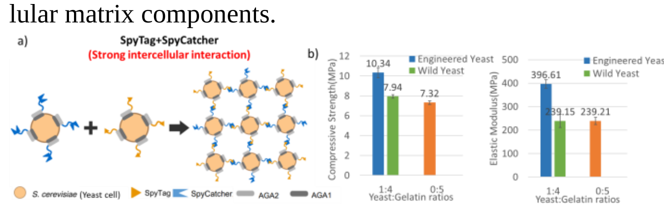

Figure 2 a). Intercellular adhesion proteins such as SpyTag and SpyCatcher assemble individual cells into gel networks; (b) Uniaxial compression results of bio-HBC, showing improved mechanical properties compared to traditional HBC."

Binder Jetting of bio-HBC in Vacuum Condition: Binder Jetting of HBC is a potential method for automatic construction via binder jetting additive manufacturing methods. Binder jetting is a low-energy-consuming inkjet-based additive manufacturing process that selectively ejects binder droplets on a powder bed layer by layer to produce three-dimensional objects. As Figure 3 shows, understanding and characterizing the binder-powder interaction is critical for determining binder powder compatibility and developing suitable printing process parameters based on sessile drop tests. The powder granules created by binder sessile drops can be used to study the size and morphology of the primitives created by inkjet drops in binder jetting [4]. Here, we used bio-hydrosol (wt.%=0.2) as a binder and silica sand (0.5mm-1.2mm) as a powder bed. The hydrosol will not crosslink until it is frozen.

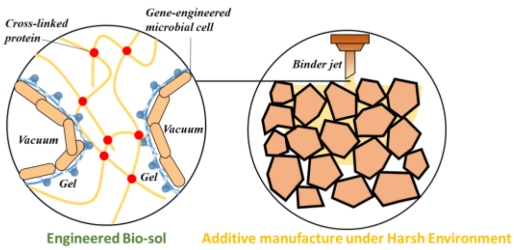

Figure 3 Schematic of binder jetting process using engineered bio-sol.

The rheology properties and related printing behaviors of HBCs are hard to predict under extreme environmental conditions like Mars. Assuming the fresh hydrosol is prepared in an indoor environment and exposed to outdoor Mars environment for printing, the system will depressurize quickly while temperature decreases slowly because of low thermal conductivity in thin air. The change of air pressure will affect the short printing process, including the mechanical properties and printing accuracy of HBC green parts. The mechanical properties of HBC products are highly dependent on curing air pressure. Therefore, controlling depressurization well is important for successful binder jetting under extreme conditions.

As shown in Figure 4a, we built an environmental chamber that can provide a wide range of temperature (-50℃~80℃) and air pressure (0-1 atm) to mimic the extreme environment of Mars (-50℃, 0.6% atm). If the environmental pressure is lower than the saturation line, depressurization will cause the sol to flash boil and cool down quickly [5]. For successful injecting, the binder must stay at the liquid phase without flash boiling during depressurization. The setups shown in Figure 4b were built and set inside the chamber for testing in-situ droplet penetration process and related parameters, including saturation level, penetration depth, and width, under extreme environments. The penetration depth can be further characterized by Washburn theories, which are related to the viscosity of liquid, contact angle, and surface tension [6]. The Washburn capillary rise setup in Figure 4c is used to modify and verify the theoretical equations, and experimental results fit the theoretical prediction well, as shown in Figure 5.

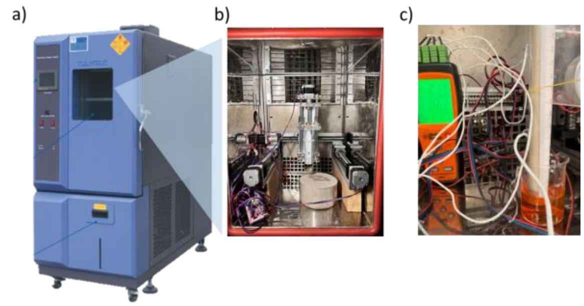

Figure 4: Experimental Setups for In-Situ Testing of Hydrogel-Based Concrete under Martian Conditions. (a) Environmental chamber for simulating Mars-like temperature and air pressure; (b) Droplet penetration testing of hydrosol; (c) Washburn capillary rise setup; (d) HBC setting test.

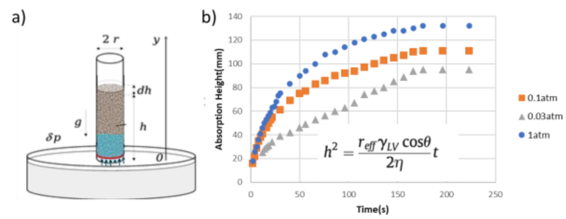

Figure 5: a) The Washburn capillary rise setup, where a powder is packed inside a capillary tube. b) The relationship between capillary rise height and time follows the Washburn equations.

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