Three-Dimensional (3D) Additive Construction: Printing with Regolith

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Three dimensional (3D) printing is a new and booming topic in many realms of research and engineering technology. When it comes to space science and aerospace engineering, it can be useful in numerous ways. As humans travel deeper into space and farther from Earth, sending large quantities of needed supplies from Earth for a mission becomes astronomically expensive and less plausible. In order to reach further to new places, In Situ Resource Utilization (ISRU), a project that pushes for technologies to use materials already present in the destination's environment, is necessary. By using materials already available in space such as regolith from the Moon, Mars, or an asteroid's surface, fewer materials need to be brought into space on a launched vehicle. This allows a vehicle to be filled with more necessary supplies for a deep space mission that may not be found in space, like food and fuel. This project's main objective was to develop a 3D printer that uses regolith to "print" large structures, such as a dome, to be used as a heat shield upon a vehicle's reentry into the atmosphere or even a habitat. 3D printing is a growing technology that uses many different methods to mix, heat, and mold a material into a specific shape. In order to heat the regolith enough to stick together into a solid shape, it must be sintered at each layer of material that is laid. Sintering is a process that heats and compresses a powdered material until it fuses into a solid, which requires a lot of energy input. As an alternative, a polymer can be mixed with the regolith before or as it is sent to the 3D printer head to be placed in the specific shape. The addition of the polymer, which melts and binds at much lower temperatures than sintering temperatures, greatly decreases the required heating temperature and energy input. The main task of the project was to identify a functional material for the printer. The first step was to find a miscible polymer/solvent solution. This solution was added to the regolith and the solvent was evaporated essentially leaving polymer-coated regolith particles. This material would be sent through the printer head and heated layer by layer to melt the polymer and bind the regolith. This method was one of many in a large goal to utilize materials in space with a custom-made 3D printer that builds dome-shaped habitats and other essential equipment for future deep space missions.

As this project was a new project still partially in a brainstorming stage, the experimentation with a polymer/regolith mixture as the printing material was the first "quick win" effort. This would be the first attempted method to successfully use regolith as a material in a 3D printer. My responsibilities were to find a suitable polymer/solvent mixture to add to the regolith that would leave an even mixture of polymer and regolith. Research was performed to select certain polymers and solvents that were likely to be soluble. The suitable solutions were then added at low concentration to the regolith, and the solvent was evaporated through rotary evaporation in a Rotavapor ®. This left the dried regolith/polymer combination. Different combinations of polymer/solvent solutions, different concentrations of polymer, and different polymer to regolith weight fractions altered the resulting material. Some conditions left clumps of hardened regolith in the midst of loose regolith without polymer, where as some resulted in a completely hardened structure that held the regolith in a tight structure that remained stuck in the flask. None of these results were particularly desirable. The regolith was most likely too fine of a particle to be coated evenly by a polymer molecule. The polymer molecules tangled together in a matrix that held both polymer and regolith in a solid form. This is desirable only after the material has been placed in its desired shape. For this reason, the addition of the polymer/solvent solution directly after each layer of regolith was placed in a certain shape was discussed. This could be done with a double printer head, one containing the regolith, one containing the polymer/solvent mixture. For the purposes of a quick win, however, the idea of simply using a powder mixture of polymer and regolith was employed. The ratio of polymer to regolith was a lot larger when the solvent was not used, but the material was much easier to use in a printer head. Different ratios of polymer/regolith were used and heated in puck shapes in an oven at slightly varying temperatures for varying amounts of time. The final chosen ratio was 25% polystyrene polymer to 75% regolith simulant. A 30g brick of this powder was completely melted and hardened in an oven at 250°C in about 30-45 minutes, meaning about 1-1.5min/g. In addition to the polystyrene powder used in the mixture, powder was made from Sonny's restaurant Styrofoam containers that were used as a sustainability effort. The containers were washed and dissolved in toluene. The toluene was evaporated off while the polystyrene was heated in an oven. The leftover polystyrene was ground into a powder. This was a side effort to prove that Sonny's food containers could be recycled and used in many other ways. A large stock of the polystyrene/regolith powder was made for trial runs with the 3D printer. If the mixture melts well, the printer will be able to make a one foot diameter dome for a quick win effort. For future goals, the solvent method may be revisited with a more sophisticated printer design. This early stage research will continue even after my summer internship has ended, but I believe I made a large contribution to finding the best way to carry out a 3D printing procedure using a polystyrene/regolith mixture.

This project gave me many opportunities to take the initiative and create my own project structure. I had a lot more freedom and responsibility, which was more difficult at times, but it was a great learning opportunity. I had less direction, but I was able to consult with my mentor about once a week to discuss obstacles and options for continuing to move forward. Overall it was a great opportunity to learn about a new area of research with polymer binding and 3D printing processes.