Microwave Structure Construction Capability Year One Accomplishments

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The Microwave Structure Construction Capability (MSCC) element, part of the Moon to Mars Planetary Autonomous Construction Project (MMPACT) was initiated in 2020. MSCC is responsible for creating horizontal and vertical infrastructure on the moon using microwave energy. Microwave energy was selected since is the only method to volumetrically heat the regolith. All other sintering/melting methods rely on thermal conduction through the very low conductivity surface, resulting in an inefficient process. Advances were achieved in materials characterization and understanding, microwave sintering in vacuum, and microwave design and analyses.

Two dielectric property testing systems have been developed at Radiance Technologies and JPL. These will examine dielectric properties at cryogenic temperatures and over a broad frequency range. Permittivity and permeability testing at -60˚C in vacuum from 0.05 to 3GHz has been generated at JPL. Additional modifications will be made to go to -190˚C (LN_2). Radiance Technologies created a test system to measure dielectric properties at greater than 10 GHz and initiated work on developing a vacuum capable, portable test system to measure dielectric properties of Apollo regolith and simulants from 100 MHz to 18 GHz. These tests are to identify optimal heating frequencies and protocols.

During microwave sintering at about 1100˚C, volatiles were creating difficulty in achieving a reasonably dense specimen. Due to processing in vacuum and the nature of the lunar regolith, some volatiles and porosity are expected. However, the Earth produced simulants have non-lunar materials in them that create volatiles that aren't representative of lunar regolith. Therefore, a five month effort was conducted to establish a heat treat method to remove these non-lunar materials. Tests were conducted using TGA mass spectrometry, heating in vacuum and conducting mass spectrometry, dielectric and DTA, Raman, BET, particle size analysis, morphological analysis, carbon and sulfur chemical content determination and microscopy. The process has been scaled-up to 6 kg batch size and undergoing evaluation. A 36 kg batch size is the target for JSC-1A and other limited availability simulants. These calcining protocols will be standard for NASA and beyond.

MSCC has also created scalable processes for fabricating synthetic lunar materials. Processes to fabricate Anorthite (plagioclase $CaAl_2Si_2O_8$), Diopside (pyroxene $CaMgSi_2O_6$), and Enstatite (pyroxene $Mg_2Si_2O_6$) have been generated. These materials will enable generation of microwave sintering models to bound various composition ranges anticipated on the Moon, therefore mitigating the need for a precise simulant with respect to location on the Moon.

Successful microwave sintering in air using a horn applicator was demonstrated. All previous microwave vacuum sintering in the literature was at small scale and in a contained enclosure thus taking advantage of reflections. This is the first to use a lunar like microwave applicator to sinter ceramic in a bed as it would be done on the Moon. Small scale and inert sintering was conducted to assist in developing protocols with quicker turnaround times than larger scale testing. Testing has anchored thermal analysis predicting heat flow in vacuum during microwave sintering. Thermal conductivity testing was also initiated.

Microwave coupling to the regolith has been modeled by multiple organizations and with different software packages. At least six horn designs and applicator configurations for both magnetron and solid state sources are being examined. Optimal simulant container designs for microwave have also been generated. The power and electronics design for the solid state microwave system has been initiated. Concept designs for a lander based microwave sintering have been evaluated.