FABRICATION AND CHARACTERIZATION OF A LUNAR SIMULANT-BASED SINTERED CONSTRUCTION MATERIAL. Eric Z. Tucker[1], Samantha A. Johnson[1], Joseph N. Zalameda[1], and Joel A. Alexa[2], [1]NASA Langley Research Center, Hampton, Virginia 23681, USA, E-mail: E-mail: Eric.Z.Tucker@nasa.gov, [2]Analytical Mechanics Associates Inc, Hampton, VA 23666, USA.

Introduction: In-situ resource utilization (ISRU) is critical to enable future efforts to have a long-term human presence on the Moon as well as Mars [1,2]. ISRU technologies are being developed for radiation protection, dust mitigation, thermal insulation, and other applications [2,3]. One such ISRU technology for creating construction materials out of lunar and Martian regolith is sintering, which is a thermal-based construction process that bonds finely grained material together at temperatures below the melting point [1–3]. However, the conditions employed during the sintering, such as temperature, atmospheric composition, duration of the process, and pressure, can have a significant impact on the quality and strength of the resulting materials. In parallel, the development of methods for characterizing the quality, porosity, density, and other properties of these materials is critical.

X-ray computed tomography (X-ray CT) can image large changes in density within a material, such as the presence of pores throughout an otherwise uniform medium, with relatively high spatial resolution [4]. Similarly, Terahertz time-domain spectroscopic (THz-TDS) imaging is sensitive to density variations within samples, but is restricted to non-conducting materials [5–7]. Specifically, previous work has shown that the refractive index (n_{eff}) values obtained through the analysis of THz-TDS images increases with increasing density within plastic samples [6]. Even further, this work showed that it is possible to create a calibration curve for a given material from samples of different, but known density, which can enable one to directly convert n_{eff} to density for samples having the same composition, but unknown density.

Here, we report on the fabrication of a lunar simulant-based sintered construction material using vacuum hot pressed (VHP) sintering, then show X-ray CT and THz-TDS imaging results of the sample, which show spatial variations in the material. This has important implications for efforts to improve these types of lunar construction material processes and verify the quality of these materials in terms of consolidation. To the best of our knowledge, there is no previous work utilizing VHP sintering to make lunar simulant-based construction materials or exploring the feasibility of THz imaging to spatially map the density variation through a lunar simulant-based construction material.

Experimental Methodology: The sample was made in a VHP chamber with temperature and loading capability up to 1200 °C and 190 tons [8]. 52 grams of LHS-1 lunar simulant (Exolith Labs) was loaded into a Molybdenum tooling with liner, which was used to define the shape of the sintered simulant[a]. This fixture was placed in the chamber and subjected to a vacuum pressure of <5.0 x 10^{-5} torr. Then, the temperature was increased to 200 °C and held for 30 min to outgas any volatiles and high vapor pressure constituents. Next, the chamber temperature was increased to ~950 °C and the sample was put under a load of 15 ksi (47 tons) for 1 hr. This resulted in a relatively brittle material due to suspected lower than optimal temperatures for sintering. Nonetheless an adequate sample was produced regarding the exploration of methods to characterize consolidation and density variation in lunar simulant-based materials.

X-ray CT measurements were performed using a model HMXST225 Micro-CT system (X-Tek LLC) at 70 kV and 15 µA. Voxel sizes were roughly 50 µm. THz-TDS imaging measurements were performed using a T-ray 5210 THz imaging system (Luna Innovation/Picometrix), which is a time-domain, pulsed THz imaging system. This system irradiates a sample with radiation mostly between 0.05-4 THz [5]. The instrument operates in reflection mode where in this case the sample was placed on a relatively flat, smooth aluminum plate to reflect radiation that propagates through and around the sample back to the detector. A 73 x 52 mm area was measured with a step size of 0.2 mm.

Results and Discussion: Fig. 1 shows one slice from an X-ray CT 3-dimensional (3D) data volume. Here, the slice shown is from the approximate middle of the sample. Relatively large, distinct variations in contrast are clearly shown where the brighter features are on the order of 0.3-1 mm in diameter. Similar features were observed in other image slices at different depths within the sample. The data shows that X-ray CT is able to capture local variations in these types of lunar construction materials, although does not appear to capture any long range, subtle variation.

Fig. 2 shows a graph of THz time domain spectra from a selection of measurements taken across the sintered lunar simulant-based sample. The two peaks at

[a] Specific vendor and manufacturer names are explicitly mentioned only to accurately describe the test hardware. The use of vendor and manufacturer names does not imply an endorsement by the U.S. Government nor does it imply that the specified equipment is the best available

roughly 110 and 150 ps correspond to the reflection of the pulses from the surface of the sample and surrounding metal plate, respectively. A much weaker set of peaks at around 200 ps with a broader distribution is attributed to pulses transmitted through the sample and reflected from the metal plate back to the detector.

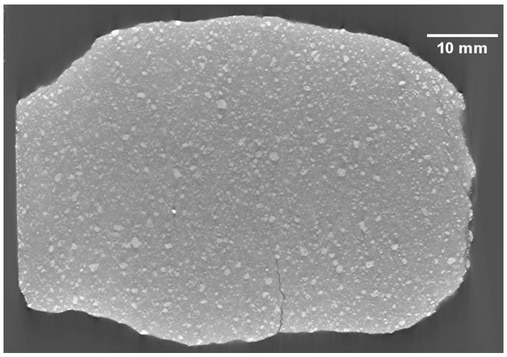

Fig. 1. X-ray CT image slice from the 3D volumetric data set of the sintered sample at a depth of approximately halfway through the sample.

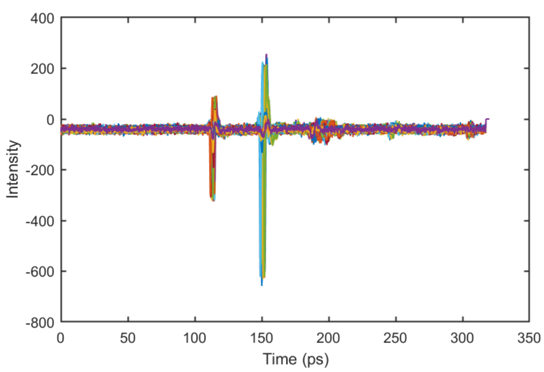

Fig. 2. Graph of THz time domain spectra from a selection of measurements taken across the sintered lunar simulant-based sample. Different color plots show spectra from different positions across the sample and around the sides of the sample on the metal plate.

Analyzing the time-of-flight (TOF) signals from these different reflections allowed for the thickness and effective refractive index (n_{eff}) to be extracted from this data set spatially across the sample, similar to other work [6]. For a heterogenous, 3D material the n_{eff} is an averaged parameter of the refractive index along the propagation path through the specimen and over the bandwidth of the instrument. Fig. 3 is a surface plot of n_{eff} across the sample where this value varies spatially across the sample and is higher towards the middle. A higher n_{eff} is expected to correlate with a higher density and consolidation of the material. This matches other observations about the sample, especially that the edges of the sample were far more brittle and contained more cracking by eye compared to the center.

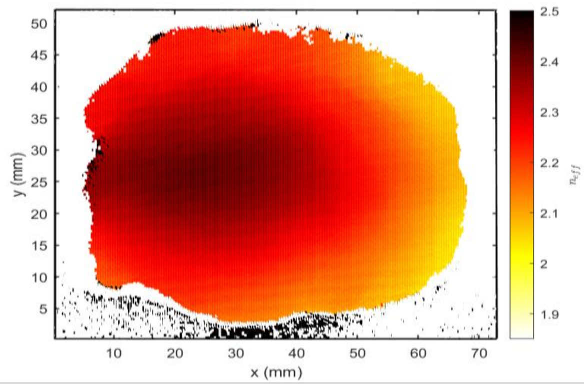

Fig. 3. Surface plot of the effective refractive index (n_{eff}) across the sample calculated from the THz time domain data. Darker red in the colormap represents higher values of n_{eff} while lighter yellow regions correspond to lower values of n_{eff}.

Conclusion: In this work we fabricated a consolidated sample of LHS-1 lunar simulant using VHP sintering and showed that X-ray CT and THz-TDS imaging can provide information on spatial variations within the sample, but at different spatial scales. Further work could be done to calibrate the n_{eff} from samples of known density to obtain actual density values for unknown samples, which has been demonstrated for other materials. Also, these and other characterization results of the sintered lunar simulant sample show a lack of uniform consolidation throughout the material, so future work can be done to optimize the VHP process to produce samples with more uniform consolidation and improved structural integrity.

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