Fabrication and Characterization of a Lunar Simulant-Based Sintered Construction Material

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INTRODUCTION

In-situ resource utilization (ISRU) methods for extracting resources out of regolith is critical for enabling a long-term human presence on the Moon as well as Mars [1,2]. ISRU methods are being developed for a wide range of different purposes, including extraction of water (and other materials), radiation protection, etc. [2,3]. Also, ISRU methods, including sintering, are being developed for the creation of construction materials for the building of infrastructure on these solid planetary bodies. Sintering is a thermal-based ISRU method where finely grained material, such as regolith, is bonded together at temperatures just below the melting point [1-3]. Developing these processes as well as capabilties to characterize the quality, density, and amount of defects in such materials produced from this processes is important. We report on the fabrication of a lunar simulant-based sintered material, which was done using vacuum hot press (VHP) sintering. Also, we explore some nondestructive evaluation (NDE) methods that are poentially applicable to these kinds of materails, including:

1. X-ray computed tomography (X-ray CT) [4]

2. Terahertz time-domain spectroscopic (THz-TDS) imaging [5-7]

This work has important implications for efforts to improve these types of lunar regolith-based construction material processes and identifying useful NDE methods for characterizing them.

EXPERIMENTAL METHODOLOGY

Vacuum Hot Press (VHP) Sintering Process:

The lunar simulant-based construction material used in this work was made using VHP sintering. The steps in this process are as follows:

1. Loaded 52 grams of LHS-1 lunar simulant into molybdenum tool/mold with liner.

2. Place this fixture into VHP chamber with capabilities of up to 1200 °C and 190 tons [8].

3. Chamber was pumped down to $<5x10^{-5}$ torr.

4. Temperature was increased to 200°C and held for 30 minutes to outgas volatiles.

5. Temperature was increased to ~950°C and the samples was put under a load of 47 tons for 1 hour.

6. Chamber was cooled to room temperature and sample was unloaded.

Nondestructive Evaluation Methods:

X-ray computed tompography (X-ray CT) measurements were performed using a model HMXST225 Micro-CT System (X-Tek LLC) at 70 kV and 15 µA. The voxel size was roughly 50 µm.

Terahertz time-domain spectroscopic (THz-TDS) imaging was done with using a T-ray 5210 THz imaging system (Luna Innovation/Picometrix), which is a time-domain, pulsed THz imaging system that we operated in reflection mode. The system irradiates the sample with radiation having the most intensity between 0.05-4 THz [5]. Past work has shown that THz-TDS imaging is sensitive to density changes in various materials, including plastic samples [6]. The actual quantity determined is effective refractive index (n_{eff}), which has been shown to coorelate to density and calibration curves can be made to relate n_{eff} to density.

RESULTS

Fig. 1 shows a height image of the lunar simulant-based sintered construction material collected using a 3D optical profilometer where the gray scale represents relative height across the surface of the sample. The diagonal line is an artifact of the stitching process that was used to merge two seperate images of the two halves of the samples together. Careful inspection of this image shows cracks, which are more prevalent towards the edges of the sample compared to the middle.

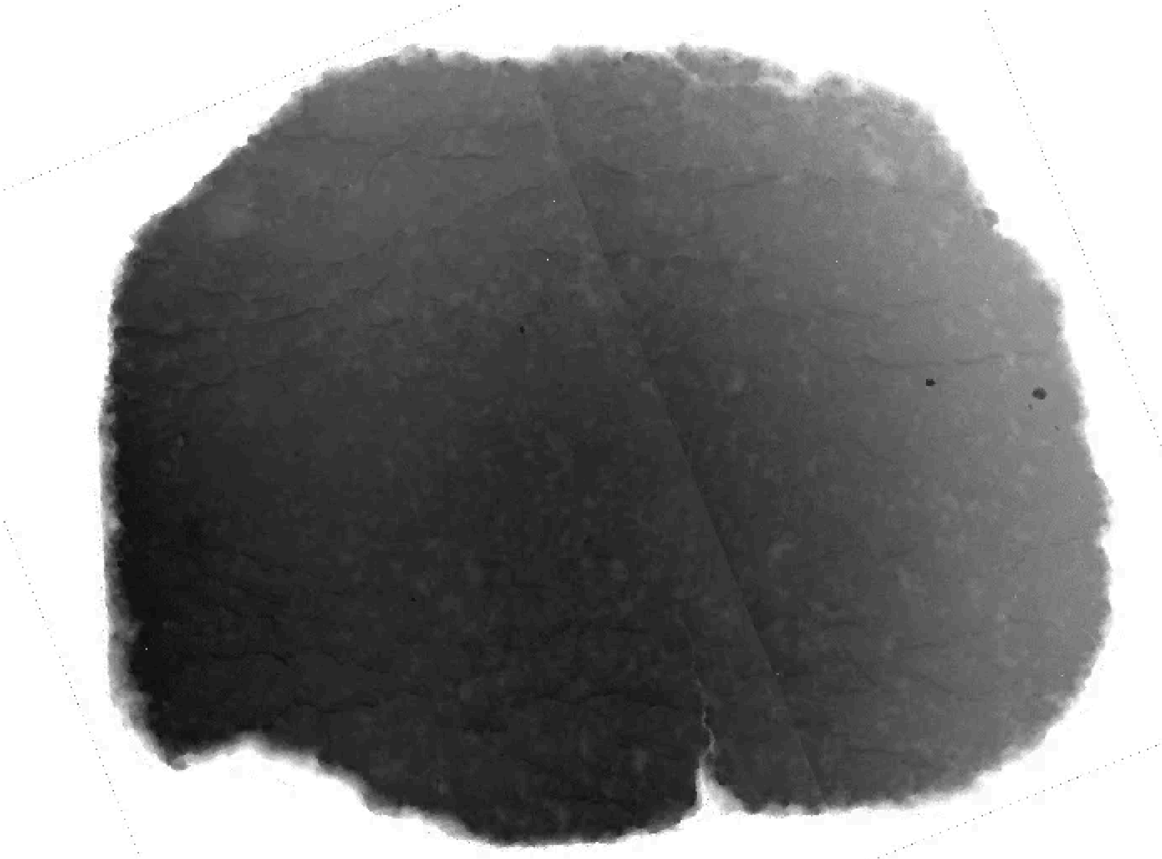

Fig. 1 3D optical profilometry image of the lunar simulant-based sintered construction material.

Fig. 2 shows one 2-dimensional (2D) X-ray computed tomography (X-ray CT) image slice from a 3-dimensional (3D) data volume collected of the sample. Distinct regions of abrupt constrast changes on the order of 0.3-1 mm in length are shown (also observed at other depths within the sample). Clearly, small scale variation in the materail is easily captured using this method, although it is not clear yet what these variations can be attributed to.

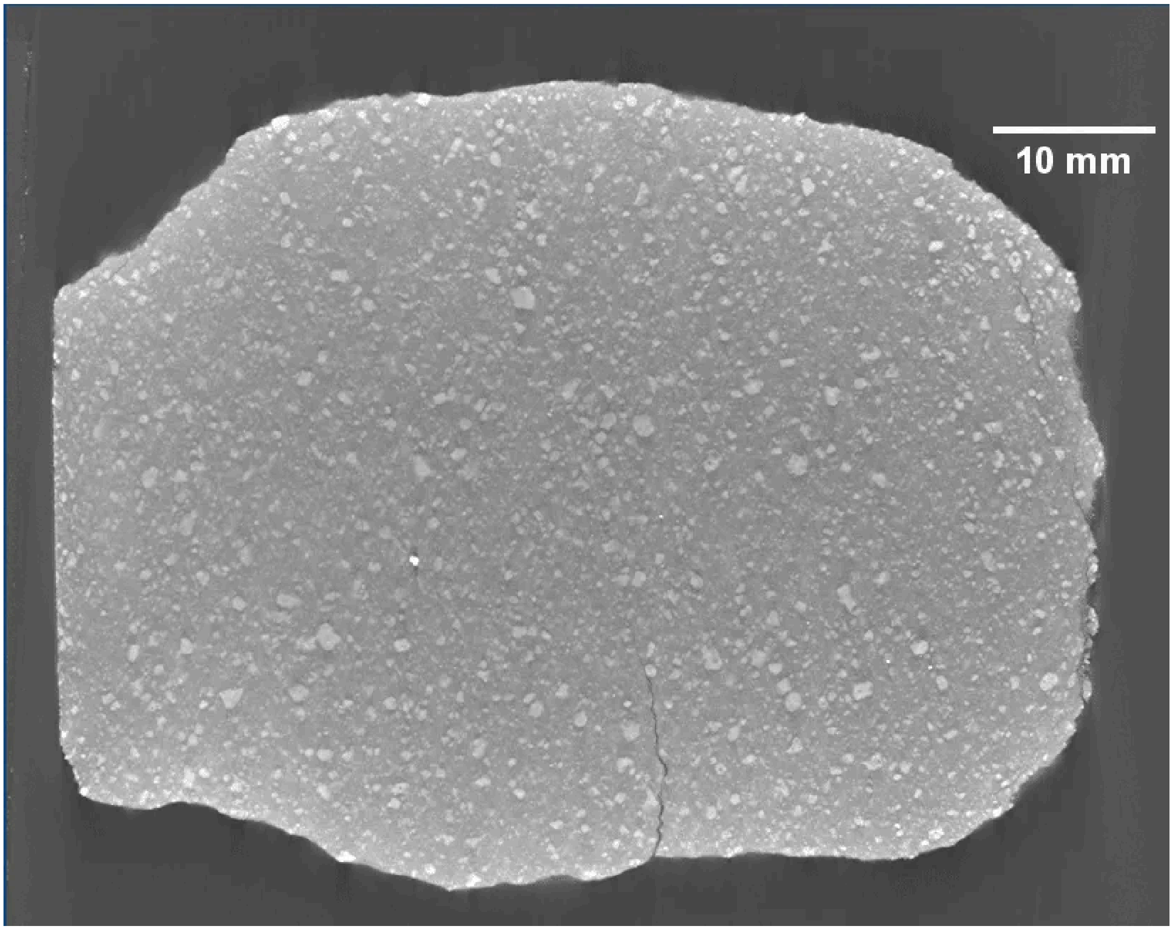

Fig. 2 X-ray CT image slice from 3D volumetric data set of the lunar simulant-based VHP sample.

Fig. 3 shows a graph of the THz-TDS data. Specifically, all of the time-domain data is shown across the whole sample. The two sharper bundle of peaks at 110 and 150 ps correspond to reflection from the sample surface and the metal reference away from the sample. A much weaker bundle of peaks at roughly 200 ps corresponds to THz radiaiton that is transmitted through the sample and reflected back to the detector.

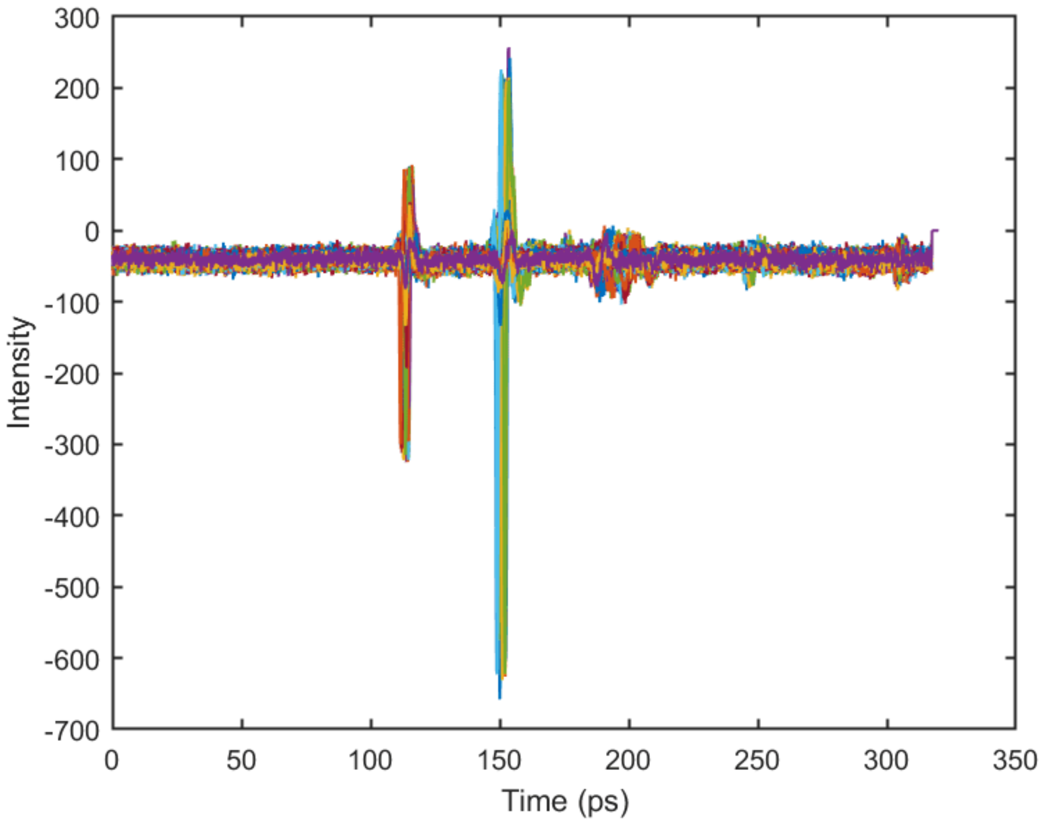

Fig. 3 Graph of time domain data from the THz-TDS measurements of the lunar simulant-based VHP sample.

Fig. 4 shows a surface plot of the effective refractive index (neff) across the sample calculated from the THz time domain data (Fig. 3). The n_{eff} is an averaged parameter of the refractive index along the propogation path through the specimen and over the frequency range of the instrument. Higher n_{eff} is attributed to higher density while lower n_{eff} is attributed to lower density and less consolidation in this context.

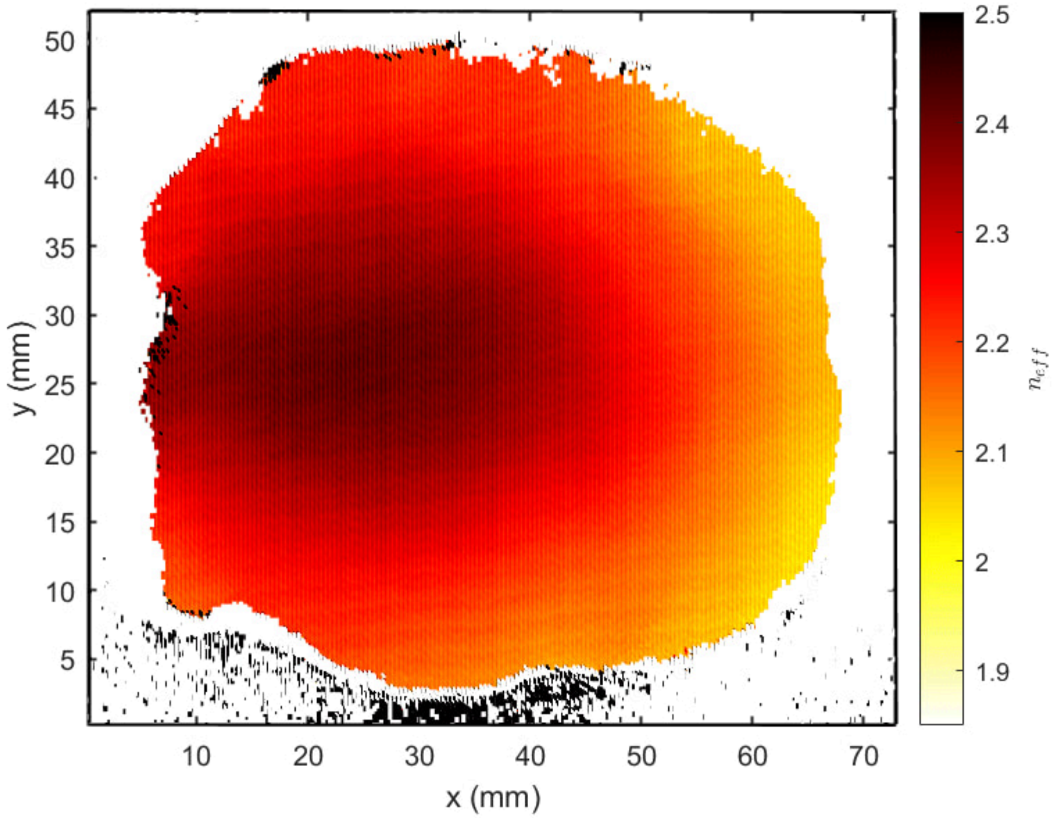

Fig. 4 Surface plot of effective refractive index (neff) acrross the lunar simulant-based VHP sample (calculated from Fig. 3)

CONCLUSION

In conclusion, we produced a lunar simulant-based construction material using vacuum hot press (VHP) sintering, which, to the best of our knowledge, has not be done before. Initial X-ray CT measurements showed short range changes in the material, although work is ongoing to understand the origins of these small scale changes. THz-TDS imaging of this sample was done, which allowed for us to generate a map of effective refractive index (n_{eff}) across the sample and this data showed longer range variation in the sample. We attribute changes in the n_{eff} across the sample to changes in density, which we are in the process of corroborating using other methods.

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AUTHOR INFORMATION

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TRANSCRIPT

ABSTRACT

Here, a lunar simulant-based construction material is fabricated by vacuum hot press sintering (VHP), then characterized by X-ray Computed Tomography (X-ray CT) and Terahertz time-domain spectroscopic (THz-TDS) imaging to assess spatial variations.

REFERENCES

[1] Y.C. Toklu, P. Akpinar (2022) Advances in Space Research, 70, 762–779.

[2] S. Lim, V.L. Prabhu, M. Anand, L.A. Taylor (2017) Advances in Space Research, 60, 1413–1429.

[3] E. Kyla, A. Christian, H. Kye, T. Joshua, R. Rodrigo (2021) in: Earth and Space 2021, 818–831.

[4] A. du Plessis, W.P. Boshoff (2019) Construction and Building Materials, 199, 637–651.

[5] J.M. Buckley, I. Duling (2023) E-Journal of Nondestructive Testing, 28.

[6] I. Catapano, S. Zappia, P. Iaccarino, R. Scapaticci, E. Di Maio, L. Crocco (2024) Scientific Reports, 14, 15560.

[7] D. Zimdars, J. Valdmanis, J.S. White, G. Stuk, S. Williamson, W.P. Winfree, E.I. Madaras (2005) in: AIP Conference Proceedings, American Institute of Physics, 570–577.

[8] R.K. Bird, J.A. Alexa, P.L. Messick, M.S. Domack, J.A. Wagner (2013) Investigation of Methods for Selectively Reinforcing Aluminum and Aluminum-Lithium Materials.