JASMAC
Conference of the Japan Society of Microgravity Appllication

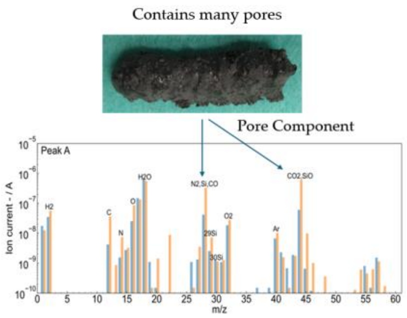
PS23

レゴリスシミュラントの溶融凝固過程で発生する気泡成分の推定

Estimation of the Composition of Pores Generated During the Melting and Solidification Process of Regolith Simulant

的場創 [1*], 若井悠貴 [1], 門井洸衛 [1], 大西正悟 [2], 南尚吾 [2], 鈴木進補 [1]
So MATOBA[1], Yuki WAKAI[1], Koei KADOI[1], Shogo ONISHI[2], Shogo MINAMI[2], and Shinsuke SUZUKI[1]
[1] 早稲田大学，Waseda University,
[2] 株式会社 Space Quarters, Space Quarters Inc.
* Correspondence: matobaso29843939@ruri.waseda.jp

Abstract: Lunar surface development requires in-situ resource utilization (ISRU) which involves manufacturing using the regolith. The regolith is melted and solidified to fabricate components. However, numerous pores generates inside the solidified material, and their formation mechanism remains unclear. Therefore, this study aims to clarify the composition of pores generated during the melting of regolith simulants. In this study, regolith simulant named FJS-1 was melted by an electron beam irradiation. The solidified material was then drilled using a diamond-coated drill. The ion current of the pore components contained within the solid was measured using a quadrupole mass spectrometer, resulting in the mass spectrum shown in the figure. The presence of fragment peaks for each atom was confirmed to narrow down the substances present. The solidified material appeared to be black color and glossy surface. In addition, some powder particles adhered to the surface of the solidified material like sintering. The glossy surface portions were considered to be vitrified. The pore components were identified as N_2, SiO_2, Si, CO, CO_2, or a mixture of them.



Keywords: Lunar surface development, ISRU, Regolith, Regolith Simulant, Melted and Solidified, Pore quadrupole mass spectrometer, Pore component

1. Introduction

Lunar surface development is currently underway. In-situ utilization of lunar materials is essential for efficient lunar surface development[1)]. One lunar material attracting attention is lunar regolith. Half of regolith simulant consists of SiO_2[2)] which is a raw material of glass. Previous study revealed that many pores in the molten and solidified regolith simulant, which mimics the composition of lunar regolith. Similarly, approximately 50 vol. % pores generate in 1/6G experiments, which suggest that pores may also form in the lunar environment[3)]. To suppress or control the porosity, clarifying the mechanisms of pore generation is crucial. Therefore, this study aims to clarify the composition of pores generated during melting regolith simulants. In this experiment, a regolith simulant is heated with an electron beam to obtain a solidified material. Then, the pore composition was analyzed using quadrupole mass spectrometer (Q-mass) analysis.

2. Experimental Procedures

A regolith simulant named FJS-1(Shimizu Corp.) was used as a raw material. The median particle size of the FJS-1 was 75 μm. The regolith simulant was filled in a sample container made of Al_2O_3 under air condition. The sample container was then set into an electron beam equipment (EBM-6LB-2VR-C3030, Mitsubishi Electric Corp.) and then evacuated to below 10^{-1} Pa. The electron beam was irradiated to the regolith simulant to melt.

The solidified material of the FJS-1 was drilled using a diamond-coated drill with a diameter of 3 mm. Then, the gas components released from the pore located inside the solidified material were measured by Q-mass analysis (M-401QA-MUSY, -1900 V, Canon Anelva Corp.) under vacuum pressure (5×10^{-5} Pa). Finally, the ion current value for each m/z ratio from 1 to 100 was summarized as a gas mass spectrum. The background was the value averaged over 10 s from the base before and after the peak.

3. Results

Figure 1 shows a photograph of the solidified material obtained by heat input using an electron beam. The dimensions were approximately 42 mm in length in the scanning direction, 10 mm in width, and 14 mm in depth. The solidified material appeared with black color and glossy surface. Some sintered material and powder particles adhered to the surface of the solidified material. The bottom of the solidified material was flat shape.

Figure 2 shows a gas mass spectrum obtained by Q-mass analysis when the pore inside the solidified material opened. The horizontal axis represents the m/z ratio which indicates the ratio of mass to ion charge. The vertical axis represents the amount of gas detected as ion current. The bars with blue and orange color represent the ion current values at the background and peak, respectively. The results show that the m/z ratios at which a large difference occurred between the background and peak values were at m/z = 28 and 44. The atoms or molecules corresponding to 28 are Si, CO, and N_2. The molecules corresponding to 44 are CO_2 and SiO.

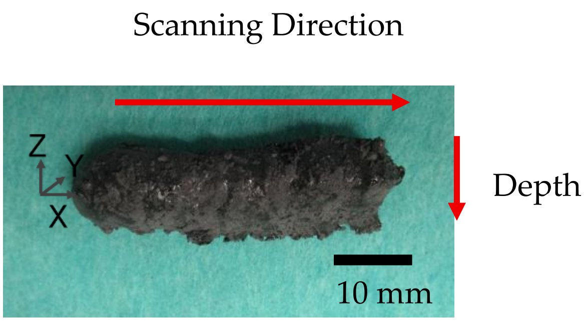


Figure 1. Regolith simulant solidified by electron beam heating.

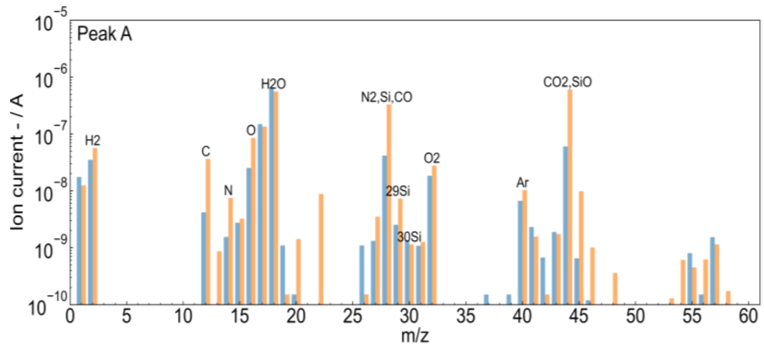


Figure 2. Relationship between the m/z ratio and ion current value during pore release caused by drilling. The blue and orange bars represent the background and the actual measured values, respectively. The labels above the bars indicate the molecules and atoms corresponding to each m/z ratio.

4. Discussion

In the Q-mass equipment, the released gas from the solidified material was irradiated by the electron beam and ionized. During the ionizing process, some molecules within the gas component randomly separate into atoms. These atoms are detected as fragment peaks[4], which can distinguish the gas components in detail. For instance, the fragment peaks of the candidate gas components (N_2, Si, CO) corresponding to m/z = 28 are (N, Si, C, O), respectively. When checking the mass spectrum in **Figure 2** for m/z=14, which corresponds to N, a fragment peak was present. The same procedure was applied to other candidate gas components at m/z =28, fragment peaks were also present for Si, C, and O. Next, the fragment peaks of the potential gas components (CO_2, SiO) corresponding to m/z=44 are (C, O, Si), respectively. Considering the above fragment peaks, it was determined that N_2, Si, CO, CO_2, and SiO could all be present.

5. Conclusion

In this study, the regolith simulant FJS-1 was melted using an electron beam, and the gas pore contained in the solidified material was analyzed using a Q-mass spectrometer. The results revealed that the gas pore was composed of N_2, SiO_2, Si, CO, CO_2, or a mixture of these.

Acknowledgment

We would like to thank Kimura Foundry Co., Ltd. for their financial support.

Conflicts of Interest

The authors declare no conflict of interest.

References

1) J. C. Ginés-Palomares, M. Fateri, E. Kalhöfer, T. Schubert, L. Meyer, N. Kolsch, M. Brandić Lipińska, R. Davenport, B. Imhof, R. Waclavicek, M. Sperl, A. Makaya and J. Günster: Laser melting manufacturing of large elements of lunar regolith simulant for paving on the Moon. Sci. Rep., 13 (2023) 15593, DOI: https://doi.org/10.1038/s41598-023-42008-1.
2) Shimizu Corporation: Lunar Soil Simulant — Specification Sheet. Shimizu Corporation, Tokyo (2025).
3) B. Reitz, C. Lotz, N. Gerdes, S. Linke, E. Olsen, K. Pflieger, S. Sohrt, M. Ernst, P. Taschner, J. Neumann, E. Stoll and L. Overmeyer: Additive Manufacturing Under Lunar Gravity and Microgravity. Microgravity Sci. Technol., **33** (2021) 25, DOI: https://doi.org/10.1007/s12217-021-09878-4.
4) T. Kamashima and T. Morikiyo: Preliminary experiments for the quantitative analysis of multi-component gases by a quadrupole mass spectrometer. Japan. Mag. Mineral. Petrol. Sci., **32** (2003) 1–11, DOI: https://doi.org/10.2465/gkk.32.1.