Development of Landing Pads Using Regolith Blocks for Lunar Base Construction. T. Nukushina[1], M. Nakamoto[1], J. Shimada[2], N. Fujioka[2], S. Okamoto[2], [1]Department of Civil Engineering and Architecture, National Institute of Technology, Tokuyama College (Gakuendai, Shunan, Yamaguchi 745-8585 JAPAN, nukushina@tokuyama.ac.jp), [2]Japan Aerospace Exploration Agency (JAXA), Tsukuba Space Center, Ibaraki, Japan.

Introduction: With the Artemis program, led by the United States, at its core, discussions on lunar exploration are actively taking place through collaborations among various national governments and space agencies. When constructing a habitable lunar outpost, it is expected that components and modules requiring high strength and airtightness will need to be transported from Earth. However, for the sustainable and long-term development of the outpost, it is essential to consider In-Situ Resource Utilization (ISRU), which enables the procurement of materials on the Moon and the local production of construction materials. This work is led by National Institute of Technology, Tokuyama College in cooperation with ISRU Research Team at Japan Aerospace Exploration Agency (JAXA).

Lunar regolith, the loose material covering the Moon's surface, is considered one of the most promising in-situ resources for construction. Utilizing regolith as a construction material could enable the large-scale, cost-effective production of building components on-site. However, the unique constraints of the lunar environment, vastly different from those on Earth, impose significant limitations on feasible material production methods.

Several solidification techniques have been investigated for utilizing regolith as a construction material. These include the addition of water or clay minerals [1,2], sintering [3], laser melting [4], and microwave processing [5]. Previous studies have demonstrated the formation of solidified regolith structures up to several tens of millimeters in size, with compressive strengths typically ranging from approximately 10 to 50 N/mm².

Nevertheless, current regolith solidification methods face several challenges. While water, which is used for solidification, is believed to exist in solid form in the lunar polar regions, the amount available in the early stages of development is unlikely to be sufficient for use as a construction material.

Additionally, if the required strength for lunar base structures is estimated based on the compressive strength of concrete on Earth (18–60 N/mm²), the lower gravity of the Moon suggests that the required strength would be significantly lower. A previous study conducted by the authors [6] analyzed this assumption, considering the Moon's low-gravity environment and the fact that initial lunar bases are expected to be low-rise structures. The results indicated that a compressive strength of just 1 N/mm² would be sufficient.

Determining the required compressive strength based on practical application scenarios allows for a broader selection of regolith solidification techniques, facilitating the economical and feasible construction of lunar bases.

Regolith Solidification by Vibratory Compaction Method: The authors have been conducting research on the use of vibratory compaction solidification technology to produce regolith blocks as construction materials using only lunar regolith [6] (Figure 1). Lunar regolith has been pulverized over millions of years due to continuous meteorite impacts. Therefore, to explore a method for solidifying fine powder without the use of water on Earth, the tablet manufacturing technology from the pharmaceutical industry was identified as a viable approach. By applying the principle of compressing powdered medicine into tablets and incorporating concrete vibration compaction technology, durable regolith blocks were successfully produced without the use of water.

Moving forward, the goal is to further optimize this block manufacturing technology, transport an automated production system to the Moon via rockets, and establish on-site mass production of regolith blocks. This paper focuses on the development of landing pads as a primary application of regolith blocks. A landing pad is a flat, well-prepared surface constructed on the lunar surface to enable spacecraft and landers to descend and land safely and stably. The proposed approach involves laying regolith blocks on the lunar surface to construct a paved landing area.

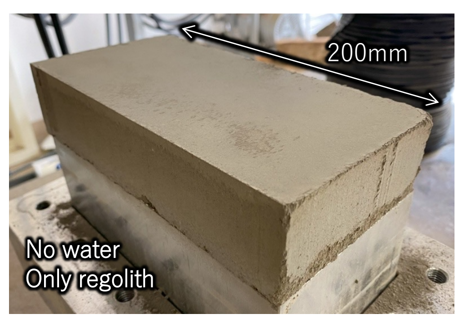

Fig.1. Regolith Blocks Manufactured by Vibratory Compaction

Manufacturing of Regolith Blocks for Lnading Pads: The mold dimensions for the blocks were set to a cylindrical shape with a diameter of 100 mm and a height of 60 mm. This shape was chosen to minimize the number of blocks required for the landing pad while preventing edge chipping. However, rectangular or hexagonal shapes are also being considered for future development.

The material used in this experiment was regolith simulant, which was made by crushing Fuji sand—a material with a composition similar to lunar regolith—into a particle size distribution equivalent to that of lunar regolith. As shown in Figure 2, the regolith simulant was placed into a metal mold, and a hand vibrator was applied to the mold for 20 seconds to compact the regolith. Afterward, a metal compression lid was placed on top of the regolith, and a pressure of 600 kN (75 N/mm²) was applied and maintained for 20 seconds before being released.

After compression, the regolith block was ejected from the mold, as shown in Figure 3, resulting in a block with a diameter of 100 mm and a height of 53 mm. Compression tests conducted on three similarly produced blocks showed an average compressive strength of 2.62 N/mm².

Using this method, 30 regolith blocks were produced, and a partial trial construction of a landing pad was conducted (Figure 4). In this trial, to reduce the number of blocks used, a spacing of 5 cm was left between the blocks, and regolith was filled into the gaps. As shown in Figure 4, a simulated landing pad measuring 60 × 75 cm was successfully constructed using 20 regolith blocks.

Summary and Future Prospects: A trial construction of a landing pad was conducted using mass-produced regolith blocks formed through the vibratory compaction method. Moving forward, efforts will focus on improving the shape, manufacturing process, and construction method of the blocks. Additionally, mid-scale landing pad trials and load-bearing tests for landers will be conducted to further evaluate feasibility. Furthermore, the applicability of regolith blocks will be explored for other lunar infrastructure, including pavement materials for lunar roads, protective walls, and structural foundations.

Fig.2. Regolith Placed in the Mold and the Compaction Process

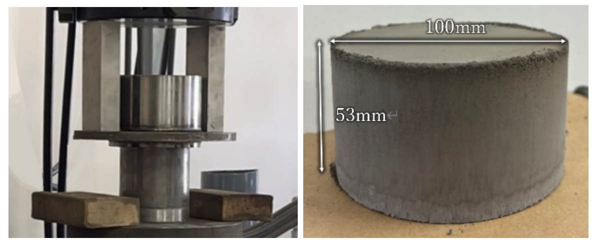

Fig.3. Demolding Process and Completed Regolith Block

Fig.4. Trial Construction of the Landing Pad

Fig.5. Appearance of the Trial-Constructed Landing Pad

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