Development of Landing Pads Using Regolith Blocks for Lunar Base Construction

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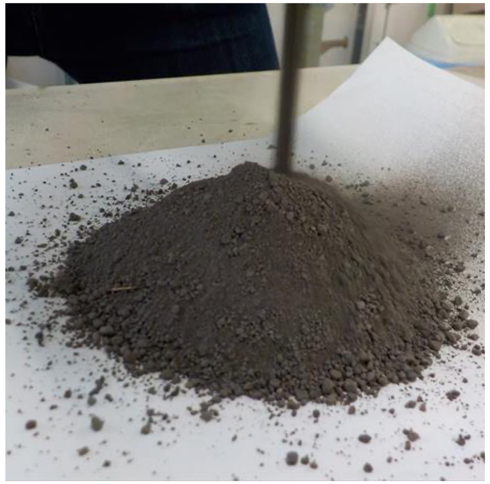
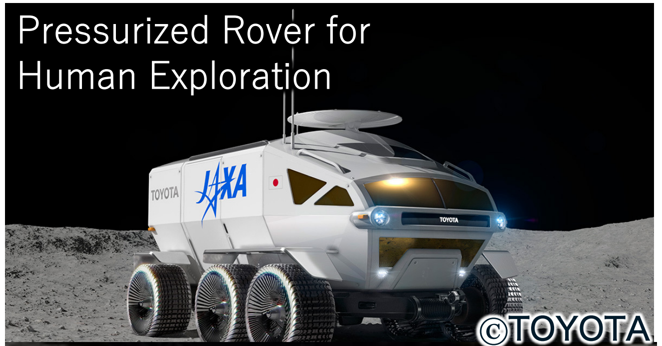



Background

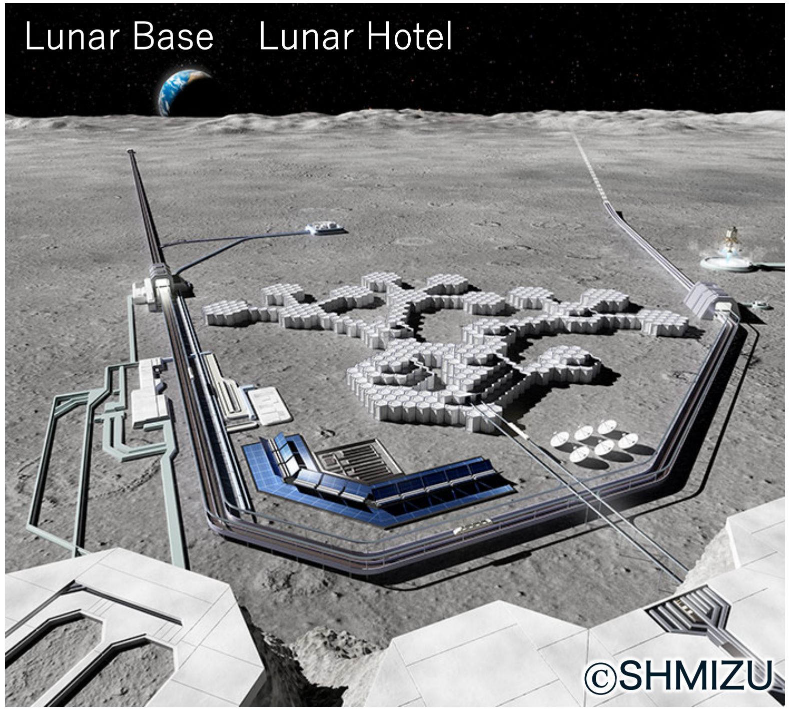
- Lunar development is accelerating with programs such as NASA’s Artemis initiative.

The 2020s

The 2030s



The 2040s



Lunar exploration, resource mining, habitation and tourism, and the construction of deep space exploration facilities are underway.
Research and development of a transit station for Mars missions has also begun.

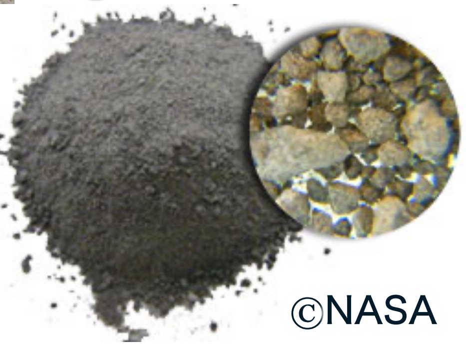
Effective Use of Lunar Soil and Existing Technologies

■ Construction materials are essential for lunar development.

・Transportation cost to the Moon: Extremely high

・Local procurement and on-site production of building materials are indispensable

Lunar Sand： Regolith



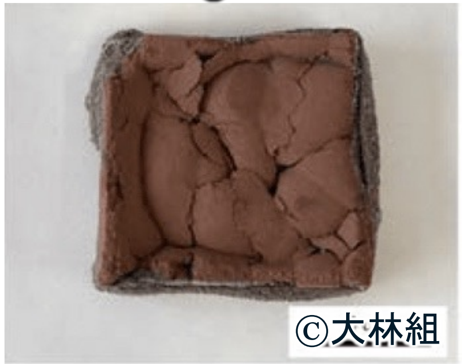
□ Lunar Regolith

・Technologies exist to solidify regolith for use as a construction material

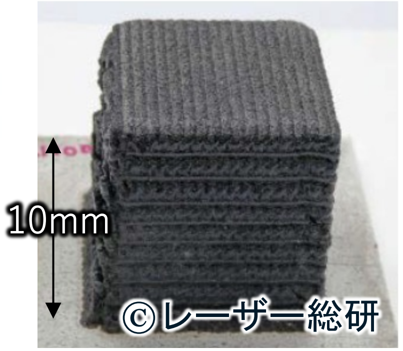
・Existing methods: heating, sintering, or melting of regolith

・ Achievable compressive strength: 10 to 50 N/mm²

Sintered Regolith



Molten Regolith



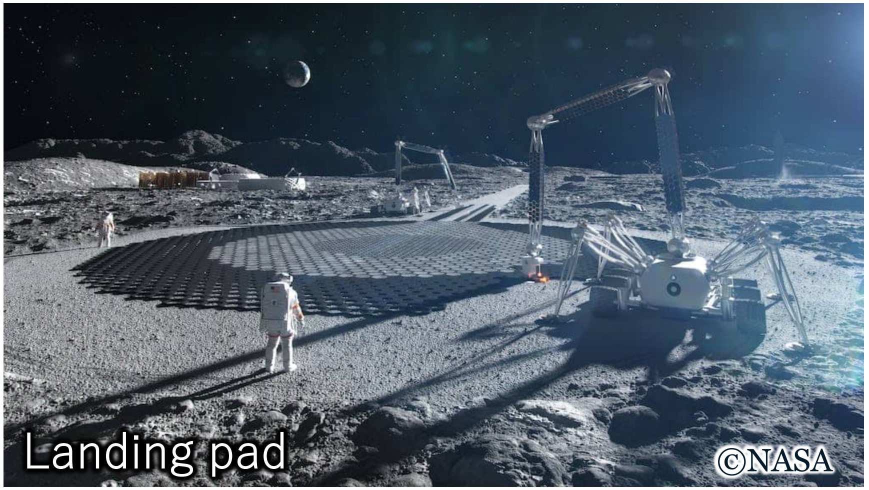
However, existing techniques require around six hours to produce a small solidified block, involve huge energy consumption and special equipment, making them impractical.
Without rational, local production methods, lunar development faces serious constraints.

Required Strength for Lunar Construction Materials

What strength is required for lunar construction materials?

- Current regolith-based solidified materials can exceed 30 N/mm^2
- Standard concrete on Earth is around 18 N/mm^2
- Assuming 1/6 gravity on the Moon, 3 N/mm^2 may be sufficient ?

Heavy Structures in Lunar Development



Lunar landing and takeoff vehicle (Starship): design mass up to 150 tons

→ Required compressive strength for the landing pad: 1.4~4.1 N/mm²
(considering safety factors, surface area, etc.)

↑ Depends on the safety factor

Lunar module (Moon Village): approx. 21 tons

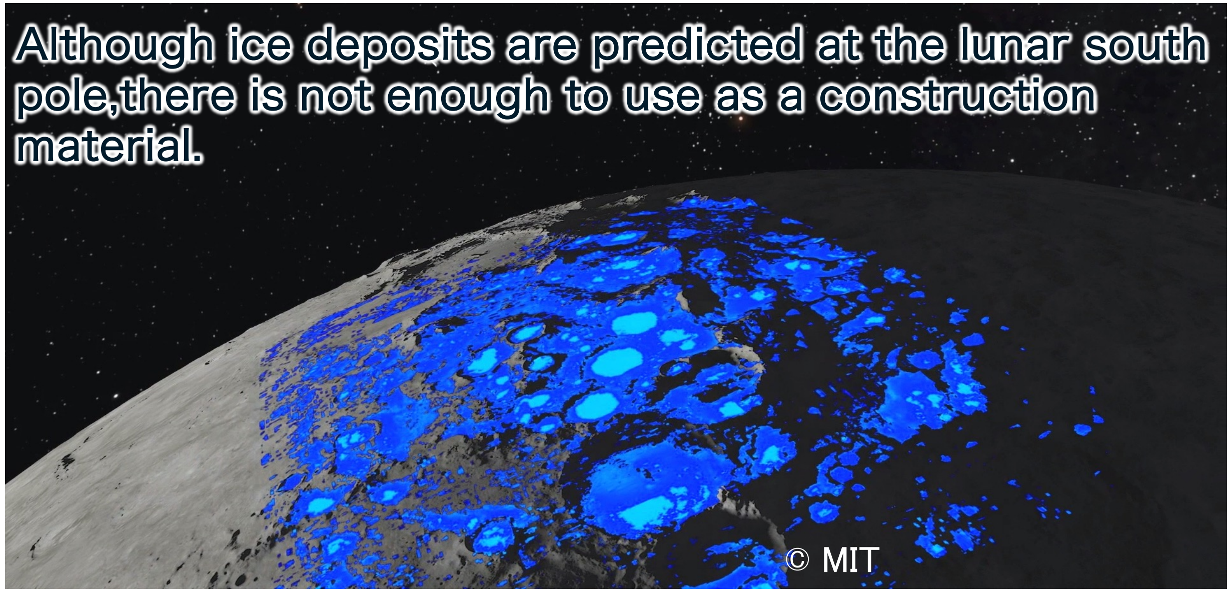
→ Required compressive strength for foundation blocks: 1 N/mm²

▶ Due to the Moon's low gravity, low seismic activity, and smaller structures, the required compressive strength is extremely low.

Development of Regolith Solidified Blocks

Development Concept

Regolith is used without water.

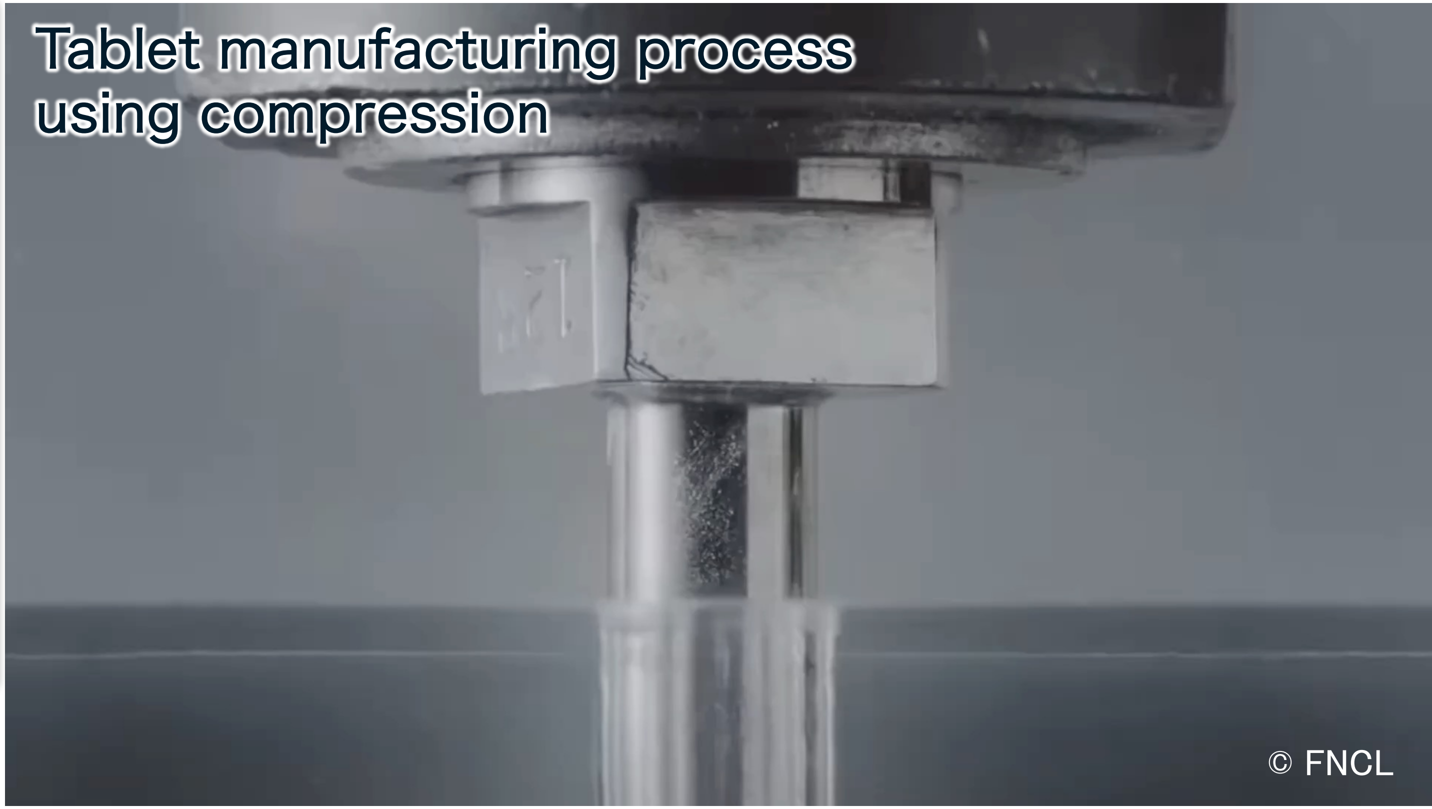


Lunar base construction requires materials that can be manufactured easily at low strength.
→ But how to solidify without water or high heat?

Regolith behaves like powder →
Do solidification techniques exist in other fields?

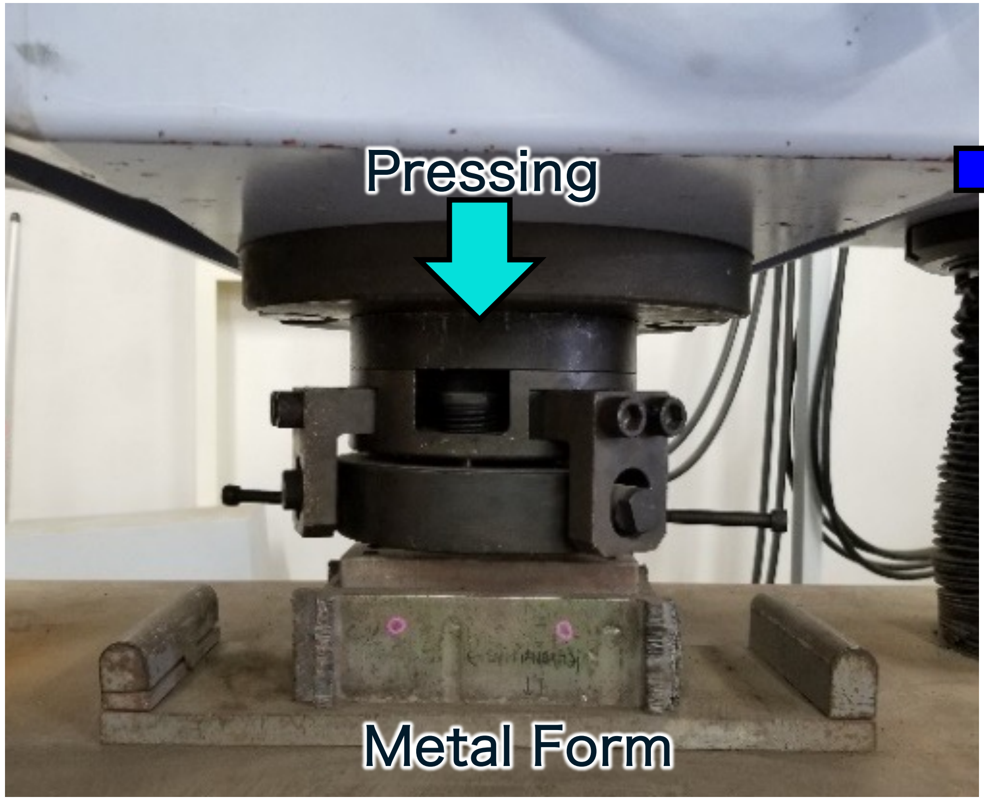
Breakthrough: Pressure-Based Solidification in Pharmaceuticals

In the pharmaceutical industry, tablets must be solidified **without using water** (since they dissolve in water).



Initial Trials

■Press-based block forming



Regolith was placed into metal molds and pressed

Despite no water, regolith was successfully solidified into blocks

Even soil mechanics experts were surprised

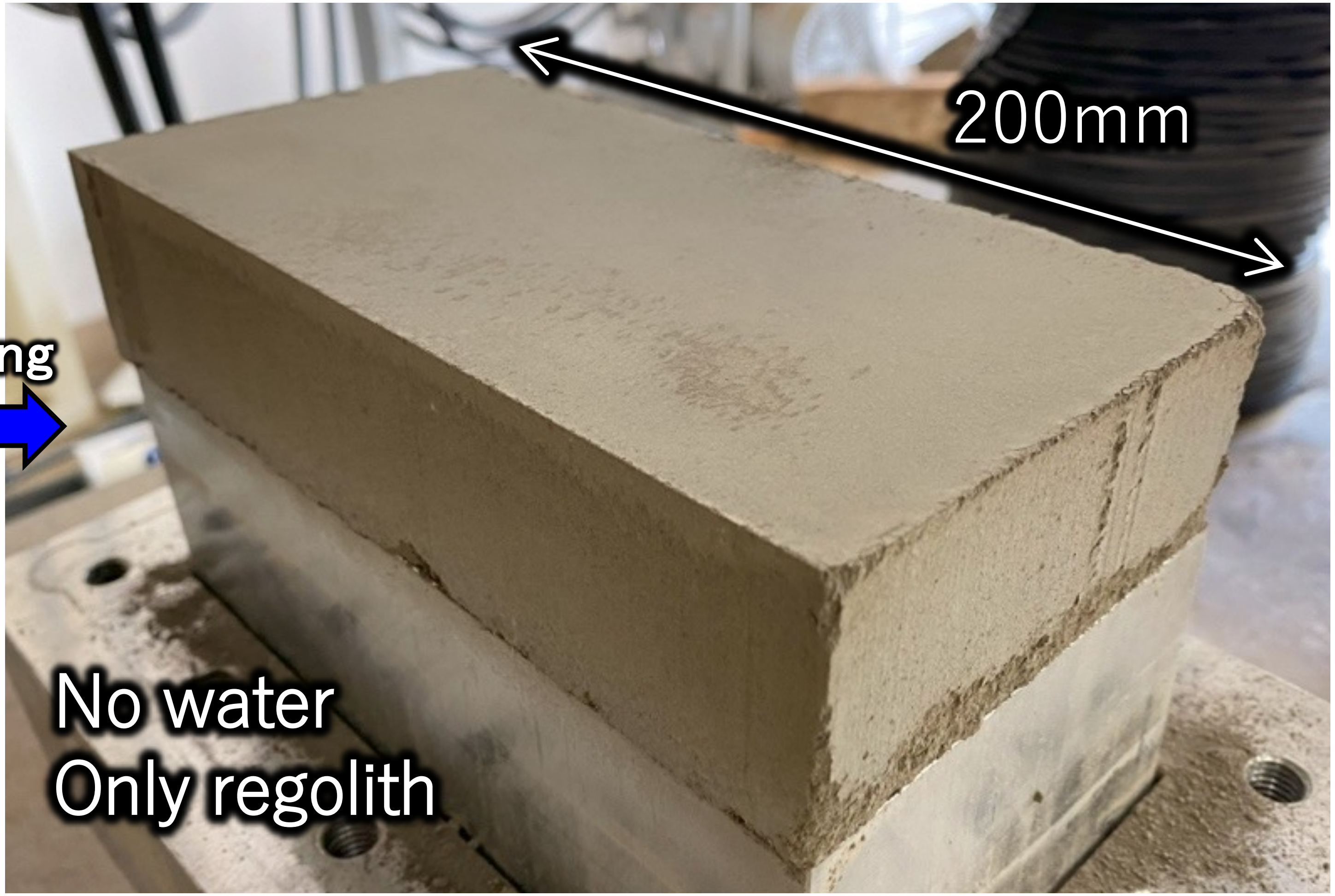
However, ・・

Blocks crumbled easily during demolding and transport
→ Compression alone was insufficient

Discovery of Vibratory Compaction Solidification

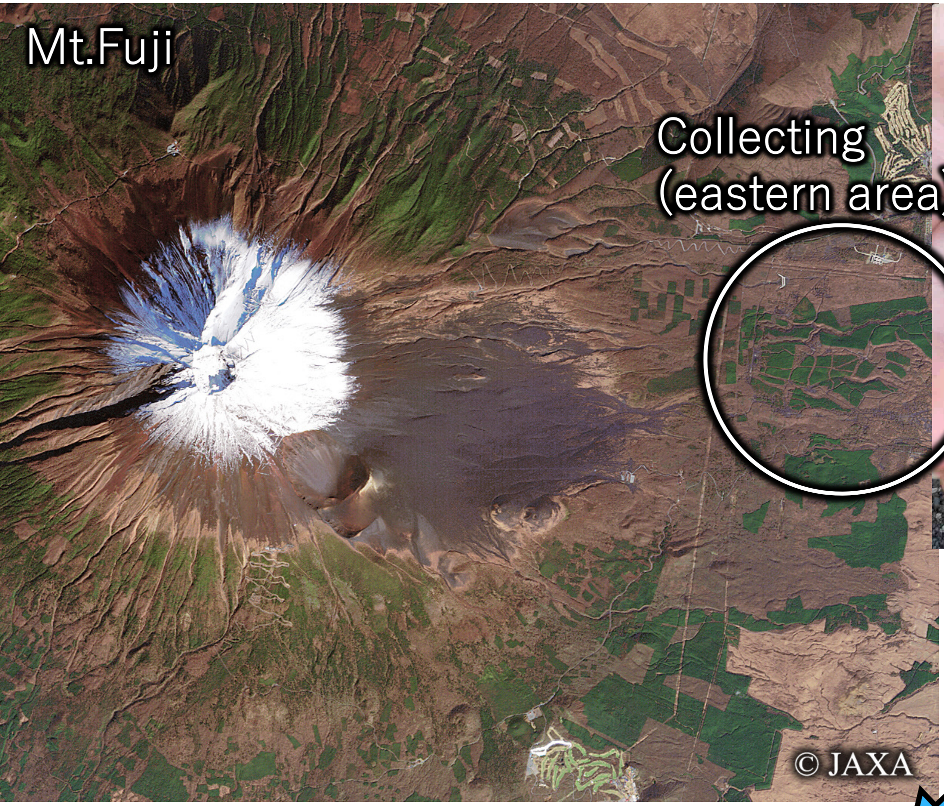
Vibration applied before pressing

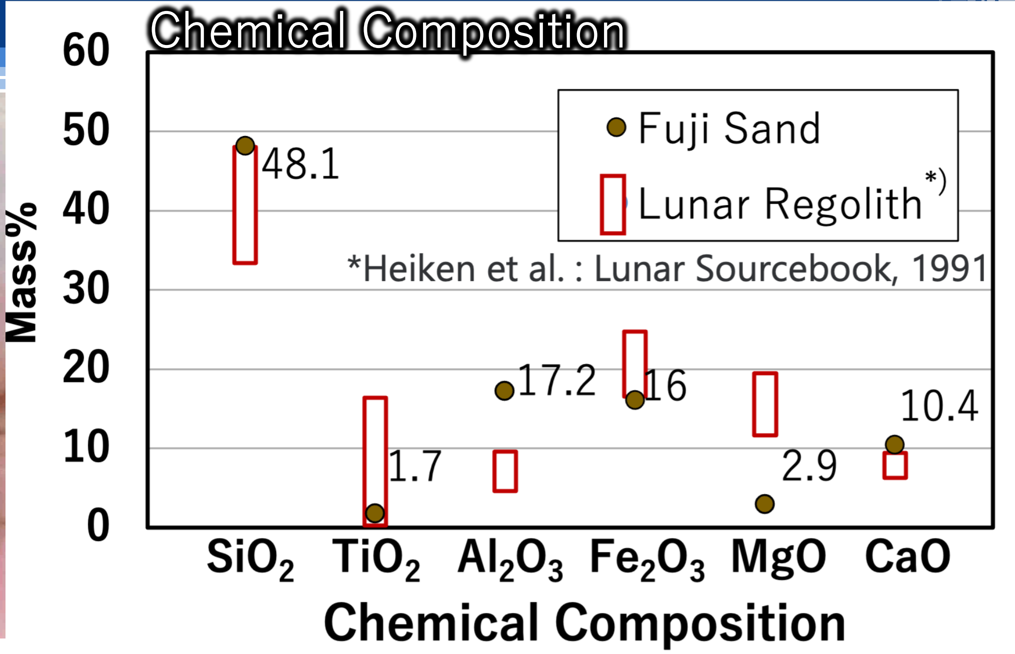
+Pressing

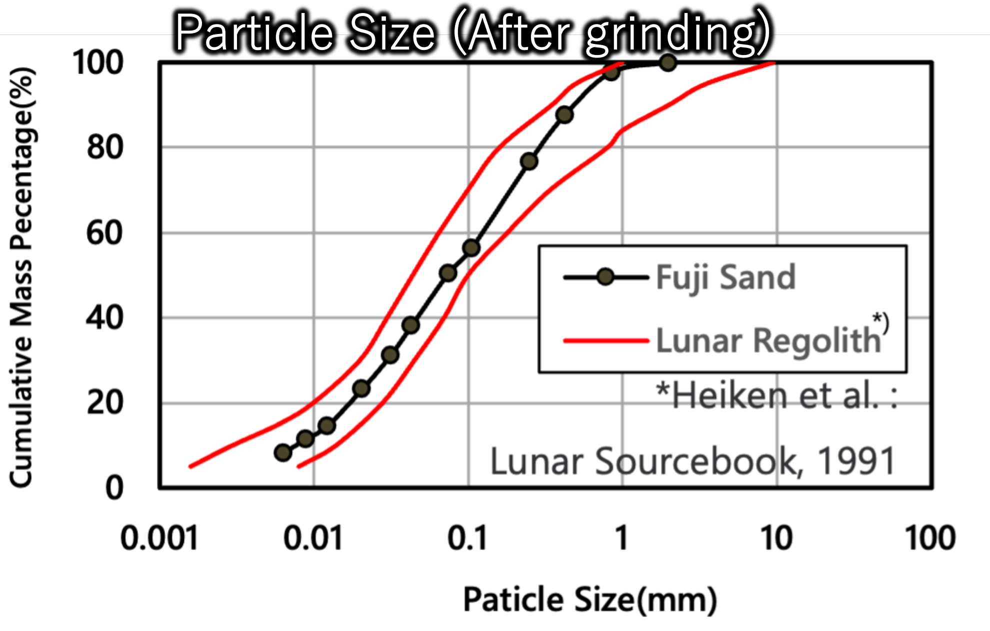


Successfully produced a large regolith blocks

Overview of the Regolith Simulant

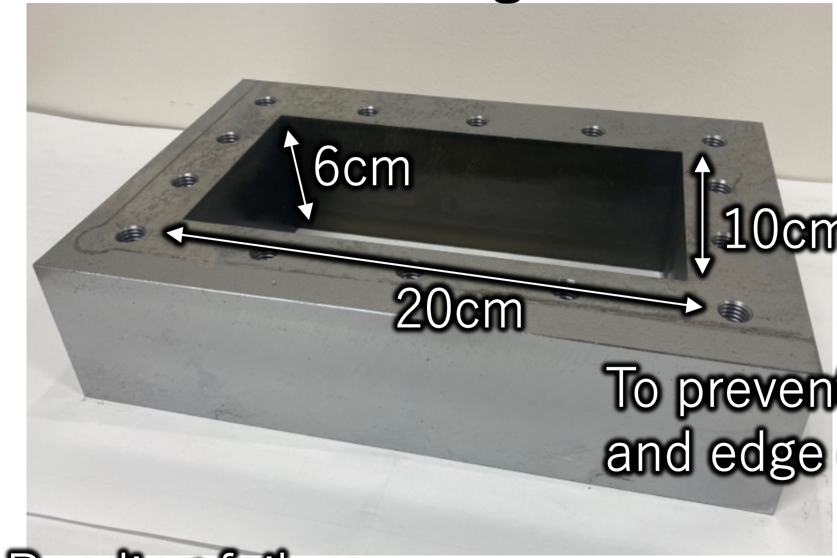






Minor modification of mold frame

～2023
Rectangle



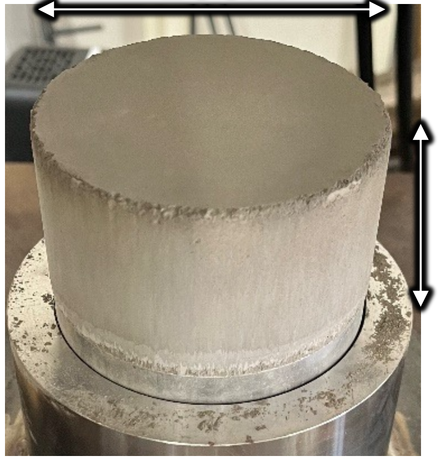
To prevent bending failure
and edge chipping

Bending failure

Edge chipping

2024 New
Cylinder

10cm



Future?

Method for prototyping a landing pad

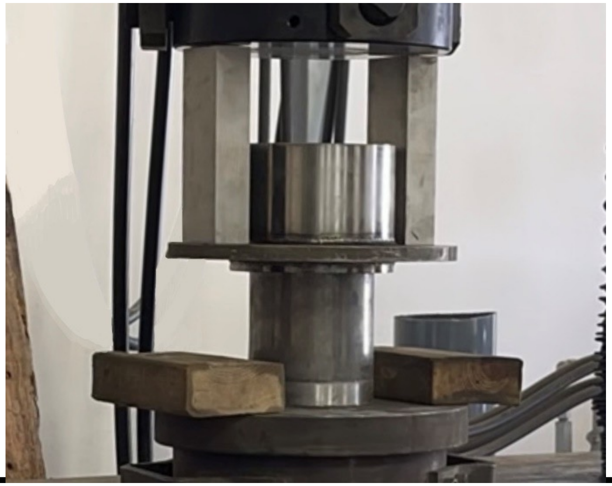
Pour simulant into the mold

Apply vibration

Place the compression lid

Compression(600kN=75N/mm^2)

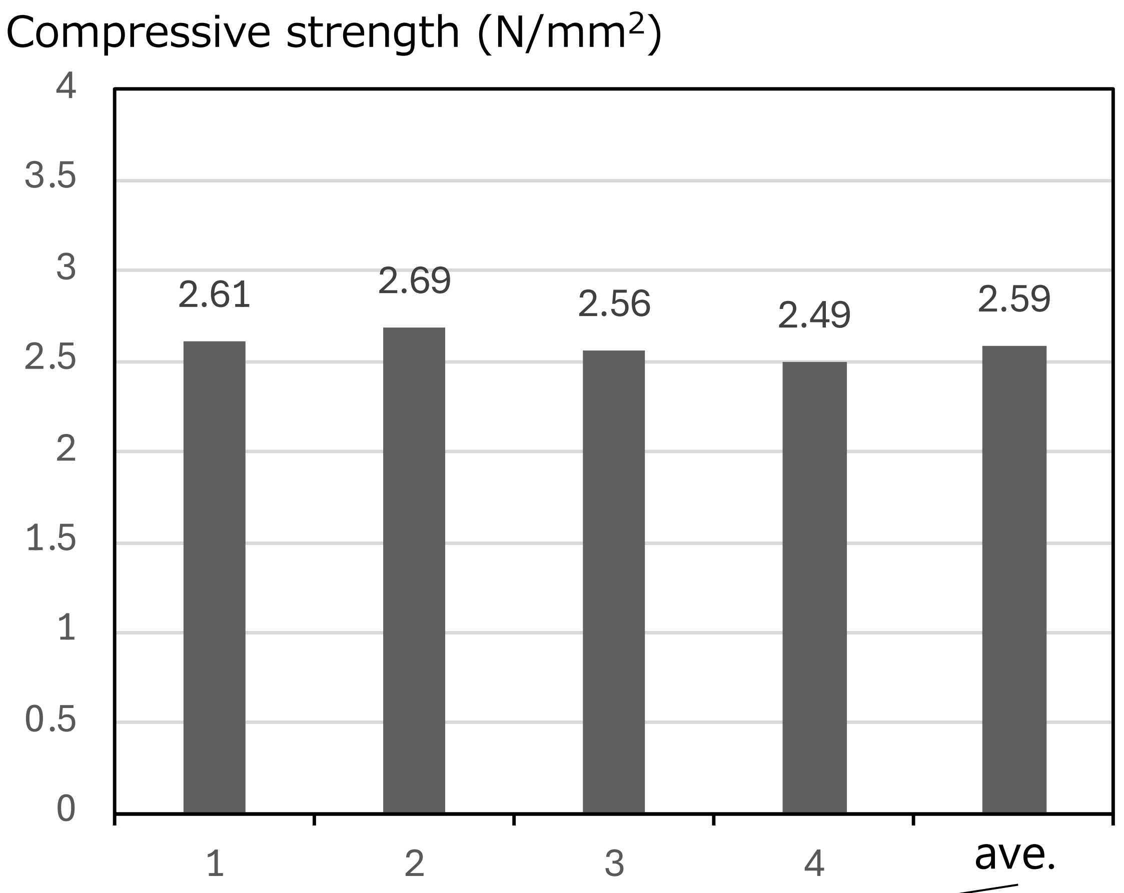
Demolding



Finished appearance

Compressive strength test (Japan Industrial Standard)

■Compressive strength test results of the landing pad



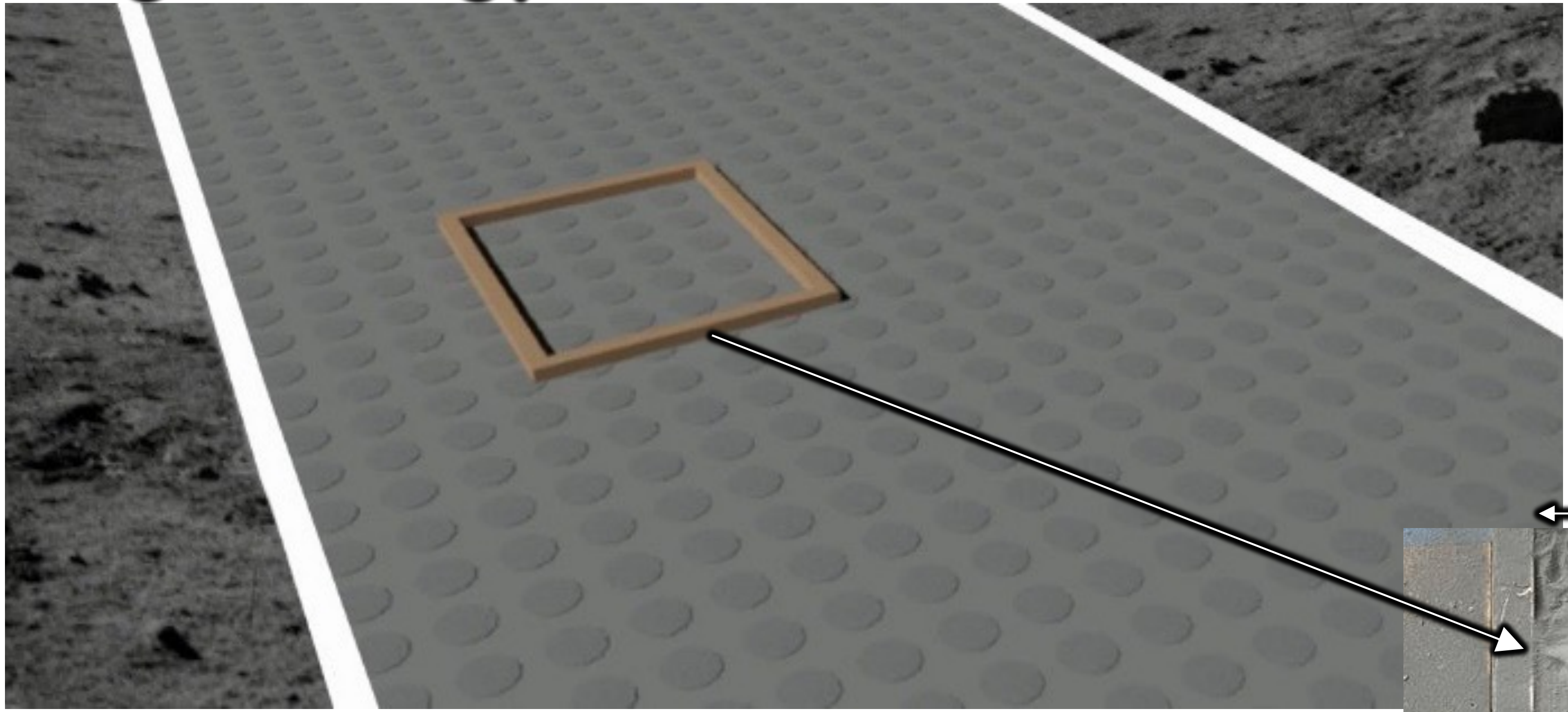
Landing pad specimens before compressive test

After testing

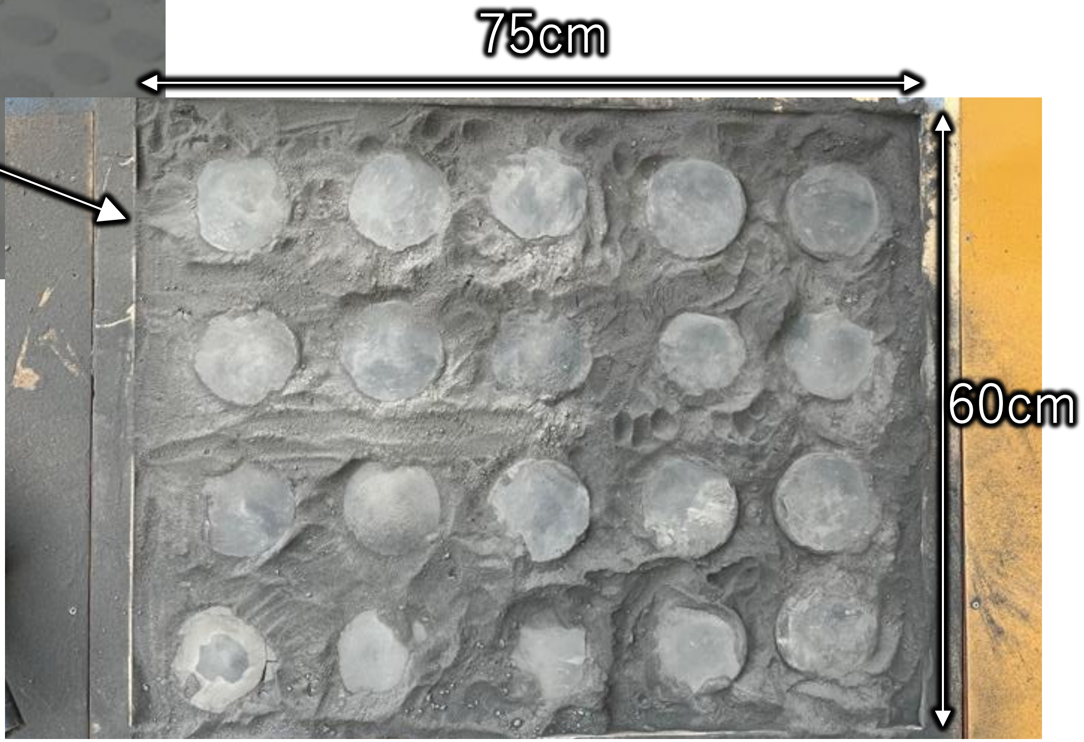
▶ave.:2.6(N/mm²) > Required compressive strength for the landing pad：1.4 (N/mm²)

Trial construction of the landing pad

Image of landing pads and lunar roads



A trial construction was conducted for part of the target area.

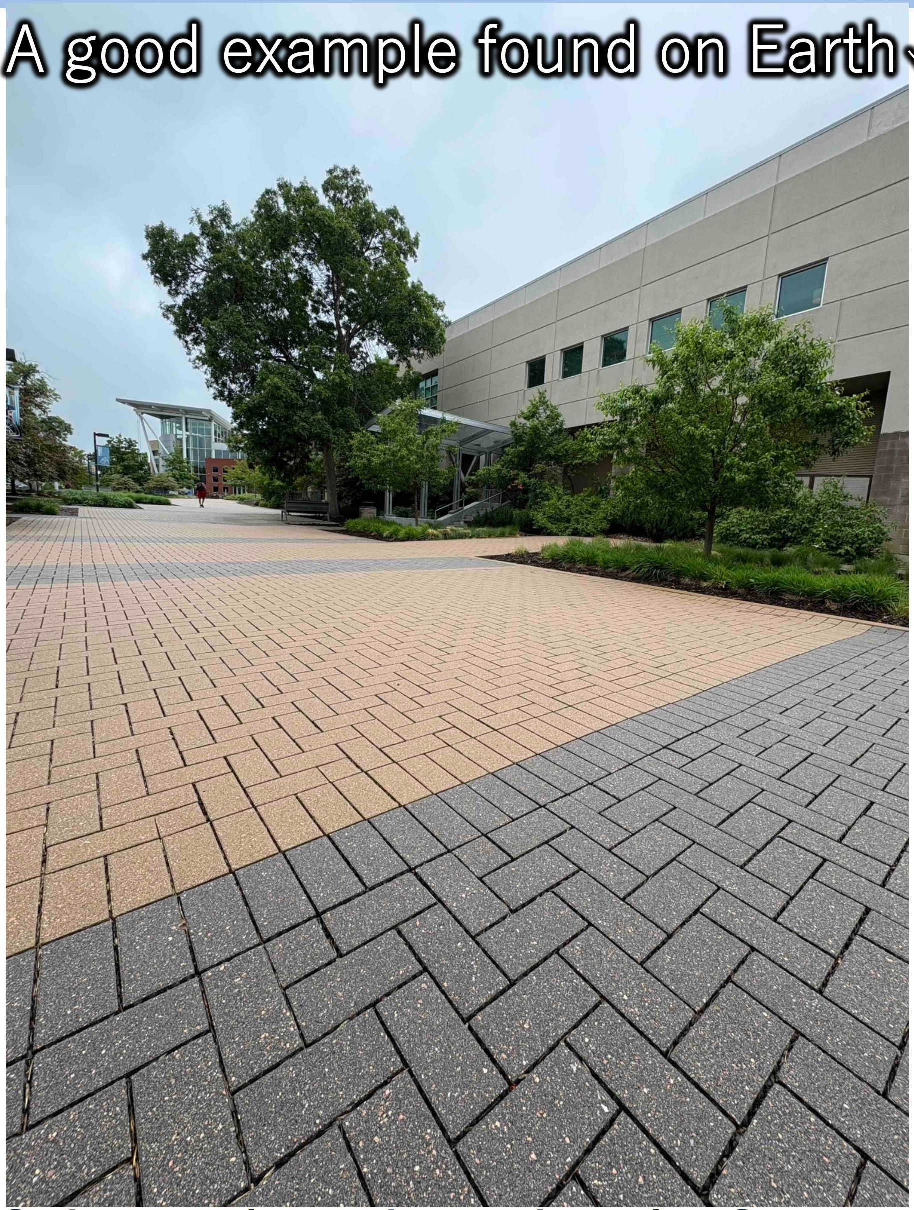


Trial construction of the landing pad

It is necessary to consider the balance between the effort required to manufacture the blocks and the effort needed to fill the gaps with regolith.

A common types of paving blocks on earth

A good example found on Earth



What would be a good example on the Moon?

A photo of the Colorado School of Mines campus

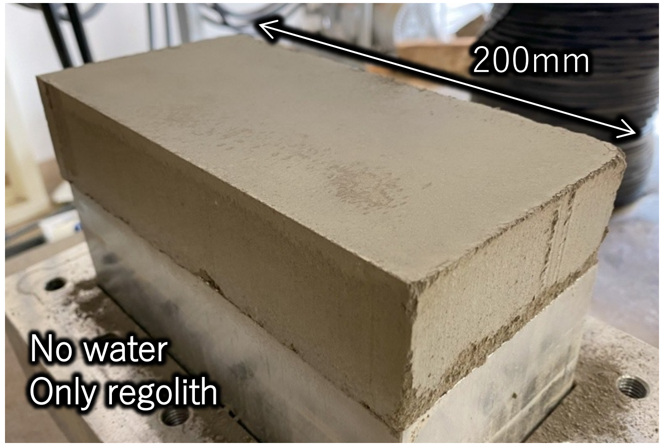
The landing pad after experimental construction

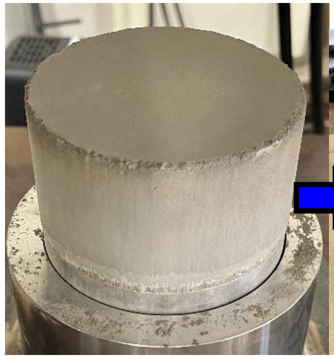
Summary

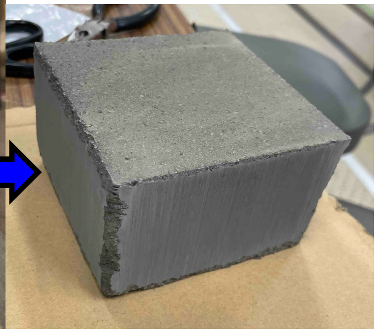
■ Successfully solidified lunar regolith into blocks using vibratory compaction

■ Conducted a partial trial construction of a landing pad

■ Future tasks:
・Optimization of block shapes
・Optimization of manufacturing methods
・Development of block production equipment
・Study of automated construction methods







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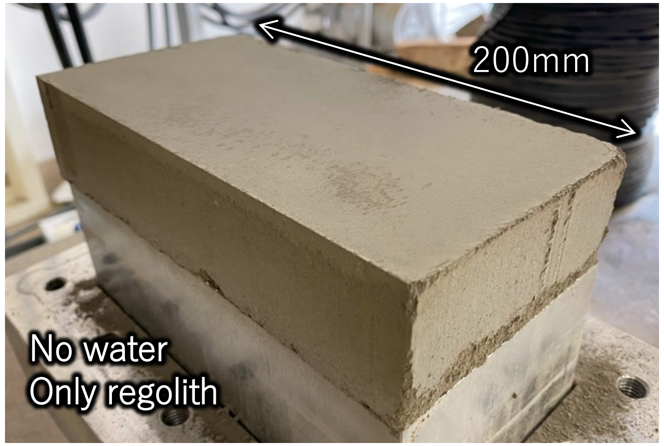
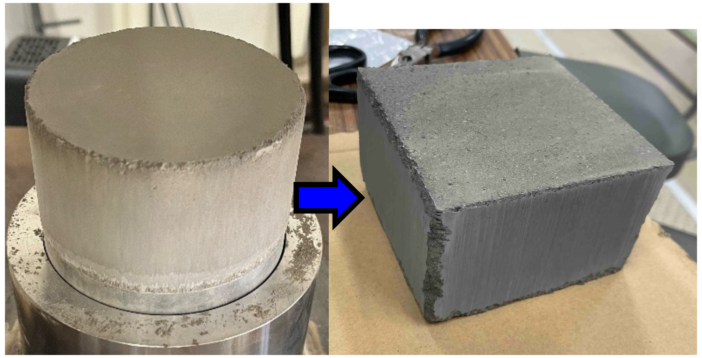




Thank you for your attention!!

フライトモデルの試作

自動製造装置

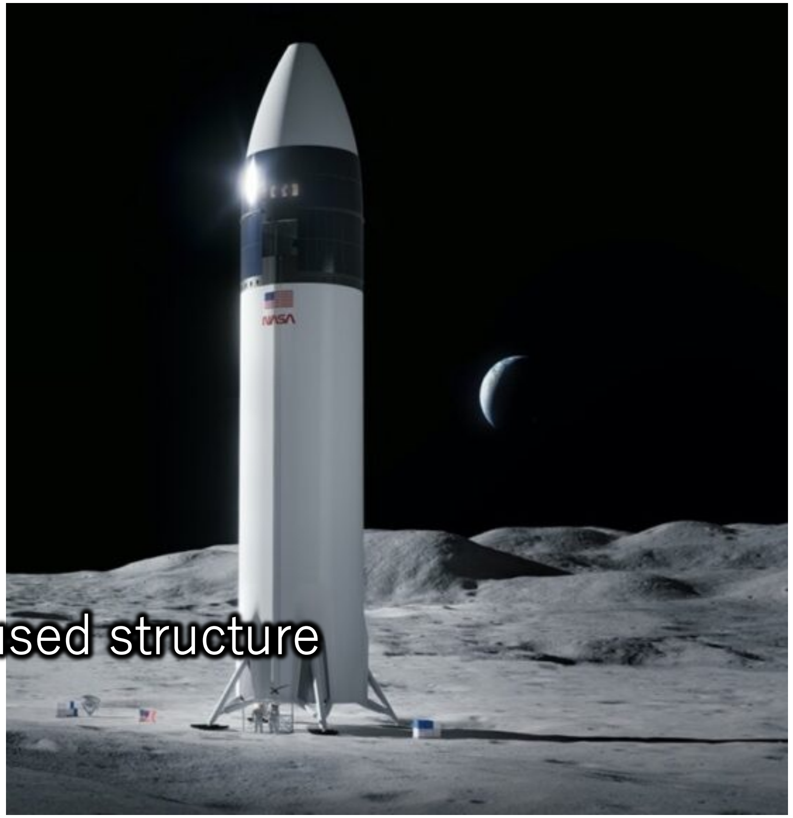
振動加圧固化

脱型

自動ブロック製造機をロケット搭載し，月面での実証実験へ

■着陸パッドにおけるスターシップの着陸を想定

・スターシップの重量，離着陸の衝撃，着陸脚の本数，構造物の安全率などを想定して着陸パッドの必要圧縮強度を計算



スターシップの重量：ドライマス+離着陸推進剤=100~150トン

$$W = m \times g_{moon} = 1.5\times10^5 kg \times 1.62 m/s^2 \approx 2.43\times10^5 N$$

離着陸の衝撃荷重として2~3倍を想定

Safety factor for landing impact

$$P_d = 2\sim3\times W = 4.9\times10^5 N \sim 7.3\times10^5 N$$

スターシップの着陸脚を4本，1本の接地面を4m²と仮定(狭め)

着陸パッドに生じる最大応力 : $\sigma_{pad} = \frac{7.3\times10^5 N}{4\times4m^2} = 4.56\times10^4 N/m^2 = 0.46 N/mm^2$

Safety factor for permanently used structure

継続的に使用する構造物として安全率を3とした

着陸パッドに必要な圧縮強度 : $\sigma_{padc} = 0.46 N/mm^2 \times 3 = \mathbf{1.38 N/mm^2}$

設計安全率を2~3とした場合(着陸機の姿勢等により局所荷重が生じるなど)

$$\sigma'_{padc} = 1.38 N/mm^2 \times 2\sim3 = 2.76 N/mm^2 \sim 4.14 N/mm^2$$

Safety factor under localized loading due to lander attitude or orientation