Evaluation of heat storage and structural materials using resin-coated regolith

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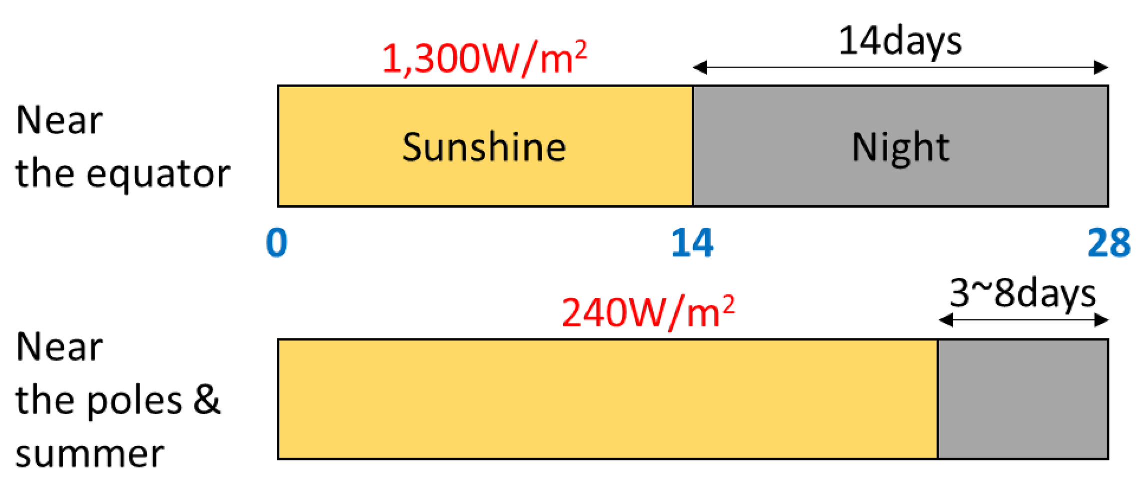
Background and Objective

Needs for heat storage materials using ISRU

- Possible energy sources for an overnight stay on the lunar surface could include reusable fuel cells or nuclear power.
- It is costly to transport large-scale power sources from Earth. It is also costly to lay cables from one power source to each location. We would like to build a heat storage material that stores heat during the day and releases it at night using regolith (ISRU).
- This will allow us to make effective use of energy through energy harvesting, and we can reduce the need for large-scale power sources, which is expected to lead to cost reductions.



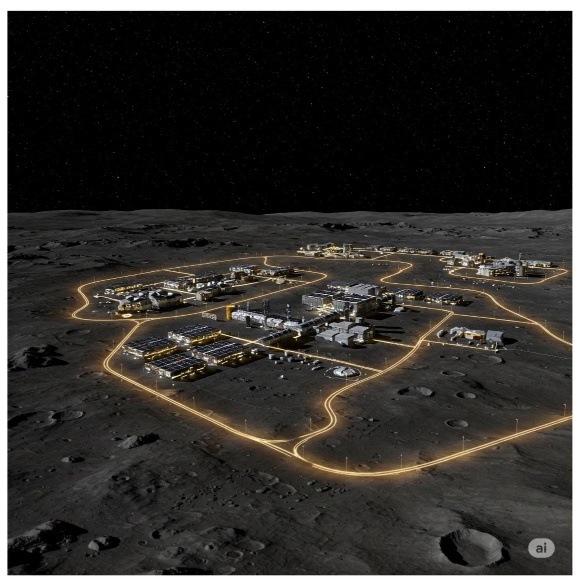


Image of a moon base with road lighting

Previous study and our plan using regolith as heat storage materials

- On the moon's environment, the contact thermal resistance between regolith particles is large, and the material acts almost like insulation. It is considered to melt the regolith using solar heat and turn it into glass.[1] The drawback is that this process requires a large mount of energy.
- We think that reduce the thermal contact resistance by coating the regolith with a thin layer of resin and then heating and molding it to bond the particles together. The advantages of this method are that it requires less energy for processing and only a small amount of resin.[2]

Objective of our study

Estimate thermal property and effective of resin coated regolith by simulation. Evaluate the physical property of the materials.

Simulation and Experiments method

Simulation method

- The thermal conductivity of the resin-coated regolith is calculated by steady-state thermal analysis. Using ANSYS, the particles are assumed to be spherical with a diameter of 70 µm as a regolith particle. A model with 20,000 elements is created, and the voids are set to a vacuum.
  The temperature difference is given as a boundary condition, and the heat flux at the boundary is calculated. The thermal conductivity is calculated using the Fourier's law.

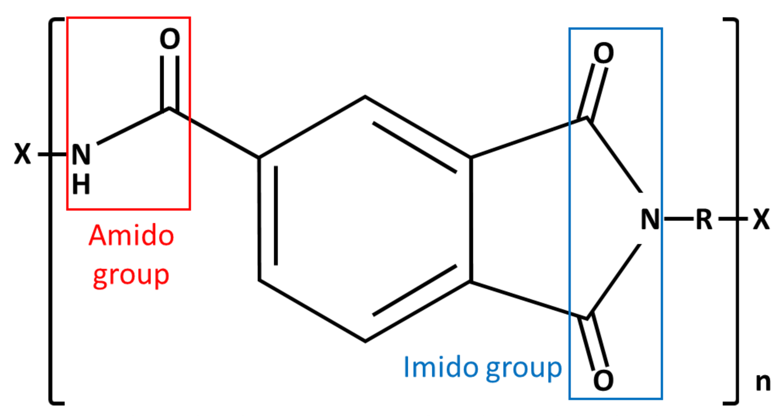
$$q = k\frac{\Delta T}{\Delta x}$$

Where q is thermal flux, k is thermal conductivity, ΔT is temperature change and Δx is cell size

- Non-steady state thermal analysis was carried out assuming the lunar surface. In 1m × 5m 2D model with 5,000 elements, the temperature change is calculated for the top 0.2m with resin-coated regolith material.

Experiments method

- Regolith simulant (FJS-1) was used as the regolith, and polyamide-imide (PAI) resin was mixed as the coating resin at a ratio of 2 and 3 wt% concerning the regolith. The regolith simulant was placed in a tray and heated in an oven at 100°C. After cooling to 90°C, the resin was mixed, and the mixture was mixed in an open-type planetary mixer for 3 minutes to perform resin coating.
- Granular; The material was removed from the mixer, spread on a tray, and heated in an oven at 270°C for 1 hour. After heating, the material was sieved through a 1mm mesh to separate the material that had mainly become lumps with a particle size of 1 mm or less from the mesh.
- Porous; It was screened with a 0.1mm mesh before coating. After mixing in a mixer, the mixture of 20mm and heated the above conditions.



Chemical structure of polyamide-imide

Dripping resin

Mixing

Estimated power consumption 6.7kWh/ton

Results and Discussions

Estimation of thermal property and effective of heat storage

- The resin coating regolith with porous structure reduced contact resistance and increased thermal conductivity. (Fig.1)

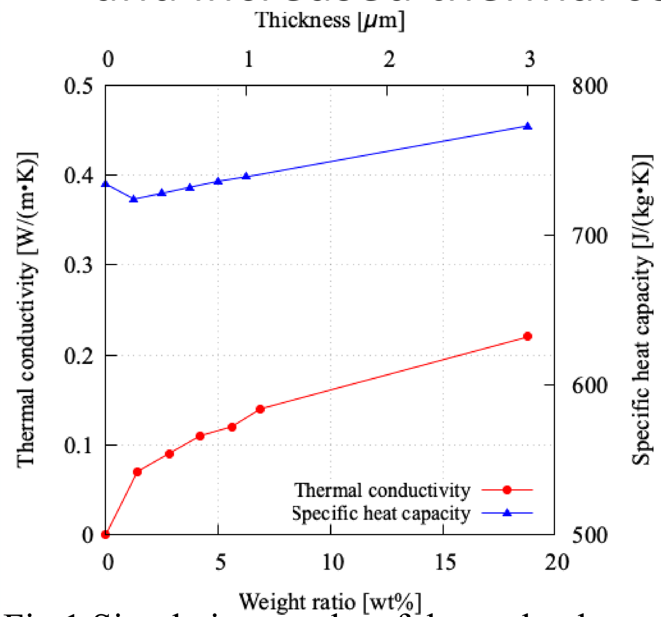
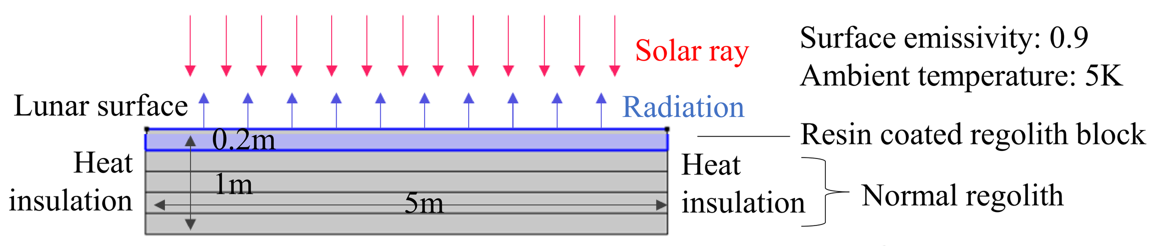


Fig.1 Simulation results of thermal value

- The heat can penetrate not only the surface but also the internal of the moon during the day. Ther energy gained by the two weeks overnight stay is about 40MJ/m² (=11kWh/m²). (Fig.2, 3)



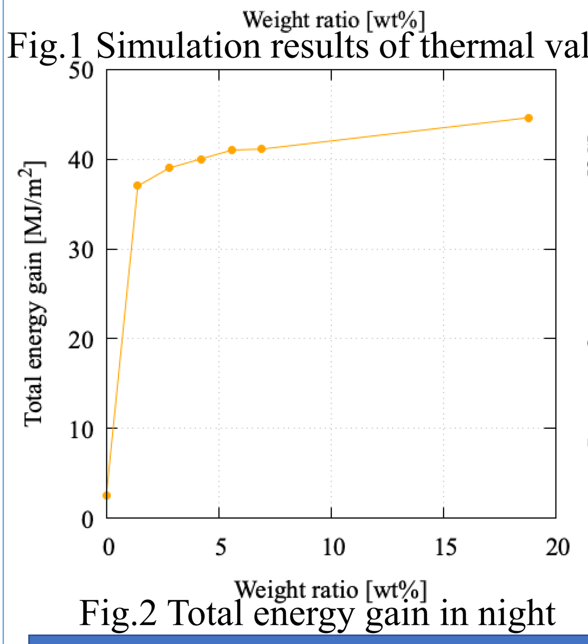


Fig.2 Total energy gain in night

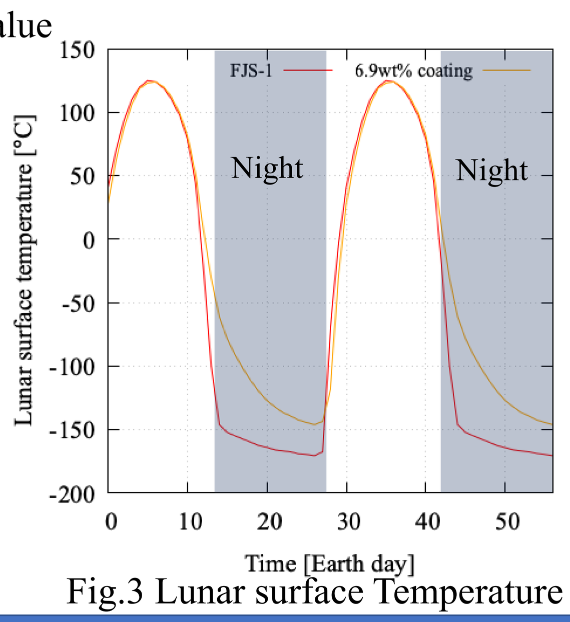
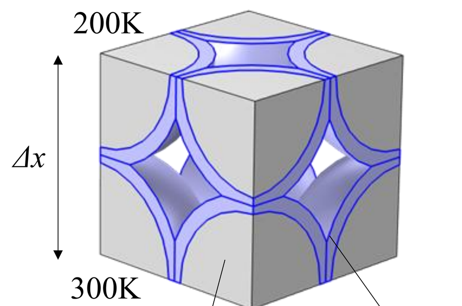


Fig.3 Lunar surface Temperature



Value @ RT	Regolith particle	PAI resin
Density [g/m³]	2.21	1.6
TC [W/(m･K)]	1.0	0.5
SPC [J/(kg･K)]	720	1000

A heat storage effect can be achieved by using a porous body that contains a small amount of resin by the thermal analysis simulation.

Evaluation of the physical property of the materials

- The thermal conductivity of the porous material was significantly improved compared to FJS-1 and granular in a vacuum condition. (Fig.4, 5)

Granular material

Porous material

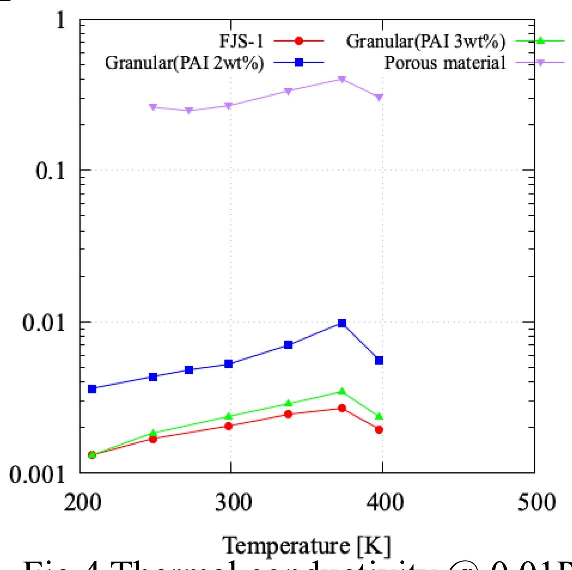


Fig.4 Thermal conductivity @ 0.01Pa

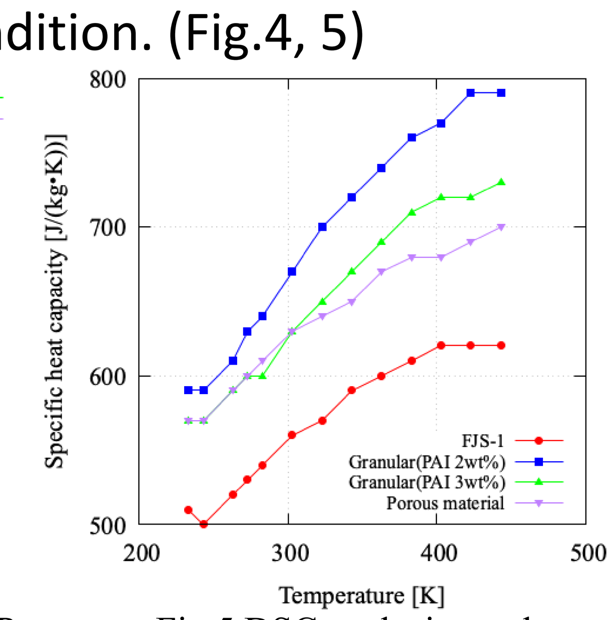
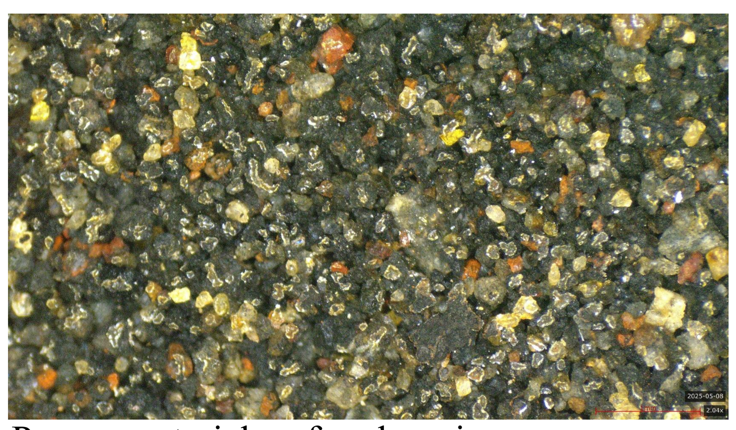
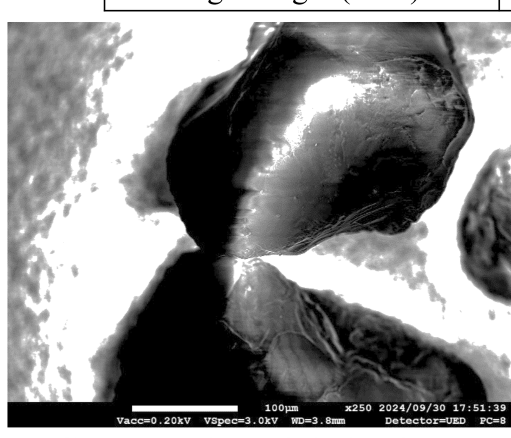


Fig.5 DSC analysis results

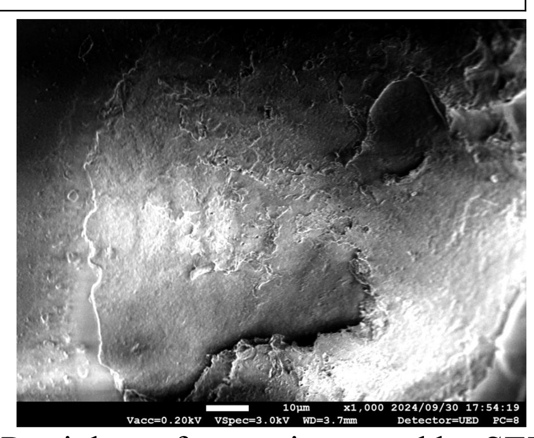
Reference value	Toyoura sand porous (0.1mm particle)
Compressive strength (MPa)	11
Bending strength (MPa)	6.5



Porous material surface by microscope



Connected particle by SEM



Particle surface resin coated by SEM

The method for coating regolith with resin has been established. It is confirmed that this actually improves thermal conductivity.

Conclusions

- We would find a heat storage effect of the regolith porous material with resin-coated in lunar surface by simple processing.
- It is necessary to consider structures and materials that can further increase thermal capacity and store heat efficiently.

[1] Wei Zheng and Guofu Qiao, Advances in Space Research, Volume 69, Issue 8 (2022).
[2] Roberto Torre, Aidan Cowley and Carlo Giovanni Ferrro, Discover Applied Sciences, Volume 6, Article number 88 (2024).

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