

# Mechanical Property of Gravel Produced from Lunar Soil Simulant by Rapid Sintering Using Single-mode Microwave

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## Introduction

Gravel is an important material for making road, foundation, improved ground, composite material and so on, not only here on the Earth but also on the moon. In order to obtain the gravel with stable quality and quantity on the moon, we have proposed to make gravel from lunar regolith by rapid microwave sintering.

Our previous study showed that the gravel could be produced by heating a lump of lunar soil simulant by microwaves using a single-mode microwave resonator and semiconductor microwave generator [1].

As a follow-up report, changes in temperature and mechanical strength of the gravel produced in various sintering conditions were compared and discussed.

## Production of gravel

Microwave sintering was conducted by semiconductor microwave generators equipped with a single-mode (TM<sub>010</sub> mode) microwave resonator [2]. Two frequencies, ie. 2.45GHz and 915MHz were selected in this experiment. Simulant (FJS-1) was added to quartz tube in between quartz wool and quartz sand. The quartz tube was inserted at the center of TM<sub>010</sub> mode microwave resonator (Fig.1, Fig.2). Microwaves were irradiated to the simulant by 20 – 100 W and 5 – 25 min in air. The impedance matching was adjusted by inputting resonance frequency to obtain maximum microwave propagation to the irradiated material.

The gravel sintered in a muffle furnace was also produced as control specimen.

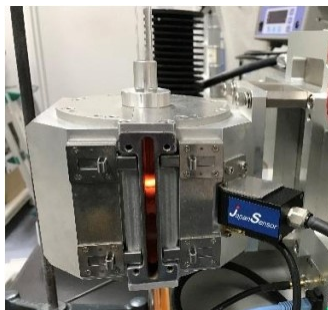


Fig. 1 Microwave apparatus equipped with single-mode (TM<sub>010</sub> mode) microwave resonator and semiconductor microwave generator

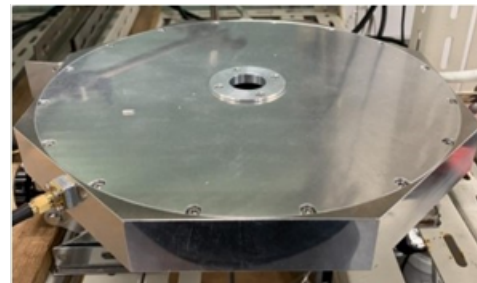


Fig.2 Microwave resonator for 915MHz TM<sub>010</sub> mode

## Measurement

**Temperature:** Temperature changes at the center and the surface of the specimen during microwave heating were measured. A fiber optic thermometer was used for the center while a pyrometer was used for the surface of the specimen.

**Mechanical Strength:** Point load strength of the sintered specimen was measured to evaluate a property of gravel as construction material. Fig. 3 shows an apparatus of the point load test.



Fig.3 Point load test apparatus

## Results

**Temperature and resonant frequency:** Fig.4 shows a sample of the changes in the temperature of specimen and in resonant frequency during microwave heating. The resonant frequency began to reduce about 2 minutes after the start of heating, and this

tendency was shown in most of the test cases. This should be due to increase in conductivity of lunar simulant under microwaves.

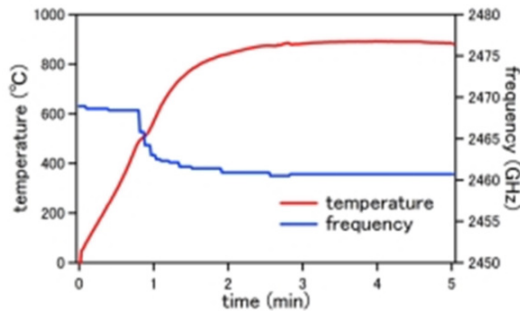


Fig.4 Changes in temperature of specimen and resonant frequency (2.45GHz, 60W)

**Mechanical Strength:** Relationships between the Point load strength of the specimen produced in various conditions and the maximum sintering temperature were shown in Fig. 5.

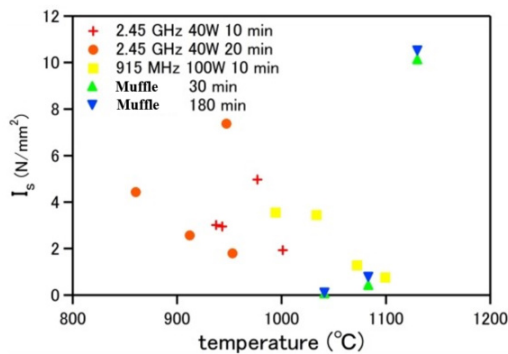


Fig.5 Point load strength ( $I_s$ ) of sintered material

The gravel produced by microwave sintering tends to show higher strength than the gravel produced by muffle furnace, even though the central temperature of microwave sintered material was lower than that of the muffle sintered material.

## Conclusion

The gravel produced from lunar regolith could be a useful material for pavement, composites, cultivation, and so on. We have proposed a production method of gravel, in which a lump of regolith is heated by microwaves using a single-mode microwave resonator and semiconductor microwave generator without any addition of microwave susceptor.

Mechanical strengths and temperature changes of the material sintered by various conditions were com-

pared, and finally the effectiveness of microwave sintering was confirmed.

## References

- [1] Kanamori, et al.; Production of gravel from lunar soil simulant by rapid microwave sintering, 9<sup>th</sup> Joint meeting of Space Resources Roundtable and Planetary & Terrestrial Mining Science Symposium, June, 2018.
- [2] Masateru Nishioka, Masato Miyakawa, Haruki Kataoka, Hidekazu Koda, Koichi Sato and Toshishige M. Suzuki, *Nanoscale*, 2011, 3, 2621-2626.