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Manufacture of polymeric concrete on the Moon

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ABSTRACT

The present study concerns a development of lunar concrete using a thermoplastic polymer in constructing outpost on the Moon, assuming that a given quantity of polymer has to import from the Earth. A mixture of 10% polymer and 90% lunar soil by mass was cast in a 50 mm cubic mold, followed by being preheated in the vacuum chamber at < 0.1 Torr to mimic the highest temperature on the equator, and then further heat was provided to the mix with a heat plate at 230 C. Substantially, the strength of the lunar concrete was gained about 12.6–12.9 MPa within 5 h, as being strong enough to construct an infrastructure on the Moon, encompassing habitat, landing/launching pad and facilities. Considering the maximum payload in a lander, about 100 t of lunar concrete could be produced by a single landing on the Moon.

1. Introduction

To extend duration of visit to the Moon, energy production/provision, transmission to communicate with the Earth and daily necessities for crews' living must be accompanied which would be allocated to payload of a lander in a large portion. As for energy on the Moon, solar power is quite probable to produce electricity [1]. Additionally, environmental conditions on the Moon could be useful such as high or low temperature and low gravitational force. Thus outposts are of necessarily concern to provide housing to crews, a landing/launching platform and lunar observatory. Lunar concrete, therefore, must be potentially developed in near future as construction material, mainly consisting of lunar soil and rocks; utilization of in-situ resource may reduce, in fact, import from the Earth to lower the cost of construction.

Notwithstanding, there was little achievement on technology of lunar concrete. For example, a hydraulic binder was previously developed by a modification in terms of sintering lunar rocks (i.e. in fact, lunar simulant) to produce lunar concrete [2], but this one requires water to gain strength. More currently, sulfur and aluminum concrete has been investigated in the majority of previous studies [3,4]. Heating to oxides refined or extracted from lunar soil, for example, sulfur or aluminum can be liquefied to bind lunar soil in the matrix consisting of these oxides and lunar soil. For the sulfur and aluminum concrete, the compressive strength was more or less gained, accounting for 34.0 and 13.8 MPa, respectively, which seems high enough to construct a structure on the Moon. However, these concrete require to have preliminarily produced sulfur and aluminum on the Moon, or to import them from the Earth. The process of producing sulfur and aluminum from lunar soil and regolith includes excavation, refining and chemical treatment. In fact, a plant or factory for this production should be constructed.

In the present study, polymeric lunar concrete was developed in a lunar-mimic environment, covering the variation in the daily temperature up to 123 °C in a vacuum chamber. To hypothetically minimize the payload to a lander on the Moon, only the minimum thermoplastic polymer was mixed with lunar soil, accounting for 10% by weight of the concrete. Then, the strength of the lunar concrete and pore distribution were examined immediately after manufacture in the atmospheric environment.

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2. Production of lunar concrete

A lunar concrete was developed in this study using a thermoplastic polymer (polyethylene) in the mixture. To produce lunar concrete, artificial lunar soil (i.e. lunar simulant) was preliminarily produced by grinding basalt, a chemically similar rock to the lunar soil, which was subsequently further ground to meet the fineness <75 μm. The specific gravity of the lunar simulant accounted for 2.63, and the oxide composition of the lunar simulant is given in Table 1, together with lunar soil excavated in the Apollo programme, Lunar soil 14163 [5]. Then, the lunar simulant and polyethylene-based thermoplastic powder were cast in a 50 mm cubic mold after the drying process to remove water in an oven at 50 °C for 24 h, as seen in Fig. 1. Prior to dry mixing of the lunar simulant and polymer, the size of the polymeric powder was also refined by sieving to meet the fineness of the lunar simulant, being lower than 75 μm. Then, the polymeric lunar concrete mix consisted of 90% lunar simulant and 10% polymer by mass. To mimic an exposure to the Moon, the specimen was placed in a vacuum chamber where the air was evacuated by a pump to reach <0.1 Torr and the temperature was set at 20 and 123 °C, to take the daily variation in the temperature on the Moon into account. In fact, the daily lowest temperature of the Moon was not considered. Once the temperature and vacuum condition were set, the polymer was forced to melt down to bind the lunar simulant by heating with a heat plate attached tight on the top of the specimen after preheating at 20 and 123 °C for 2 h to mimic the lunar condition. The duration of heating with the heat plate was up to 5 h when the specimen was subjected to preheating at 123 °C in the vacuum chamber, while the specimen subjected to an exposure to an ambient temperature (20 °C) was heated for up to 24 h. The temperature of the heat plate was kept 230 °C to conduct heat energy throughout the mix, while the temperature of the chamber was controlled by radiators sealed behind the walls of chamber. Then, the hardening depth, compressive strength and pore structure of the lunar concrete were measured to assess its applicability for constructing a structure on the Moon.

The pore structure of lunar concrete was examined by the mercury intrusion porosimetry. The specimen was crushed to obtain a fragment, which was then dried to remove potential water in an oven at 50 °C for 24 h. The sample was initially evacuated to about 50 μm mercury (Hg) and the low pressure was generated up to 0.21 MPa by nitrogen gas, and then the pressure was gradually increased to 117.21×10^3 MPa at the rate of 9.1×10^3 kPa/s. The pressure was converted to the equivalent pore diameter using the Washburn equation as given in Eq. (1). Then the pore volume distribution at a given pore diameter was achieved. The pore volume was adjusted to the percentage of the volume of sample:

$$d=\frac{-4\gamma\ \cos\ \theta}{P} \tag{1}$$

where

d:	Pore diameter, m
γ:	Surface tension, N
θ:	Contact angle, deg
P:	Pressure, MPa

3. Strength development of lunar concrete

After the completion of heating, degree of solidification of the polymeric lunar concrete was determined by measuring the hardened depth, followed by the compressive strength and pore structure. As seen in Fig. 2, hardening of the lunar concrete is dependent on the exposure condition, in terms of the temperature of the vacuum chamber. The lunar concrete produced at a lower temperature (20 °C) in the vacuum

Table 1
Oxide composition of lunar simulant and lunar soil excavated from the Apollo programme (Lunar soil 14163) (%).

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O
Artificial lunar soil	54.6	0.7	16.7	5.7	–	0.2	2.3	5.4	2.3	3.4
Apollo program	47.3	1.6	17.8	–	10.5	0.1	9.6	11.4	0.7	0.6

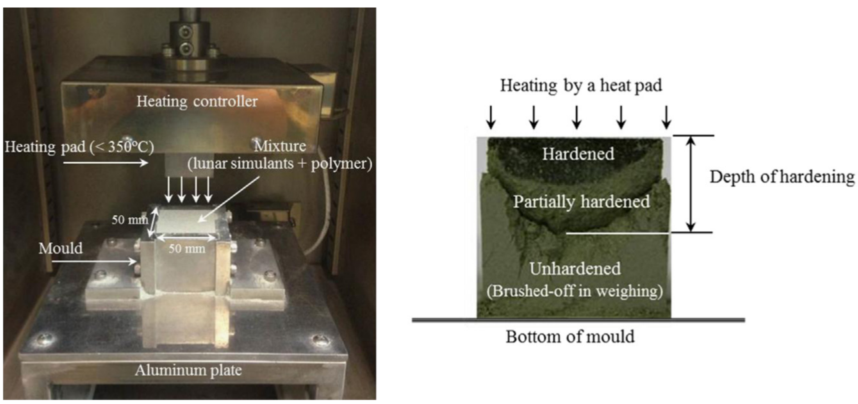

Fig. 1. Experimental setup for producing lunar concrete containing thermoplastic polymer and measurement of hardened depth for the lunar concrete.