Lunar Soil Simulant in Japan 2018. N. Uyama[1], H. Kanamori[1] and S. Aoki[1], [1]Shimizu Corporation, Japan (3-4-17 Etchujima, Koto-ku, Tokyo, 135-8530, JAPAN, {uyama, kanamori, saoki}@shimz.co.jp).

Introduction: Simulating the lunar soil is of great importance to examine the feasibility of artificial systems which shoud function properly on the moon, and to investigate the possibility of In-Situ Resource Utilization (ISRU). The surface of the moon is covered by sand, called regolith, of which the majority of particle size lies below 10 [mm]. We, Shimizu Corporation, collaborated with NASDA (currently JAXA) and succeeded in manufacturing regolith simulant, named FJS-1 [1], whose characteristics such as particle size distribution, chemical composition, etc, are close to the samples returned in Apollo 11, 12 and 14 missions. The amount of FJS-1 is however running out of stock due to the increasing demands from space research and development community. We therefore decided to manufacture a new lunar soil simulant and to deliver to the space community.

In this paper, we first introduce the previously manufactured regolith simulants, their basic properties, and applications to research. Then, we report the current status of a new regolith simulant.

Regolith Simulant "FJS-1": FJS-1 is the first-manufactured and current standard of Japanese regolith simulant [1], and has been widely used in Japanese space research and development community. The following are the characteristics of FJS-1.

The particle size distribution of FJS-1 lies below 2 [mm], and the meadian particle size (50% weight past through sieves) is between 70 and 75 [μm].

The chemical composition of FJS-1 is shown in Table 1 with values compared to the Apollo samples. The basic composition is close to the Apollo samples. On the other hand, FJS-1 contains more Fe_2O_3 and Alkarine components such as Na_2O, which Apollo samples do not contain or less contain.

Regolith Simulants of Different Regions on the Moon: In order to answer the demand for simulating the soil more accurately, we experimentally manufactured three types of simulants [2]:

a) Agglutinate
b) Simulant in lunar mare region
c) Simulant in highland region

Agglutinate is a compound of crushed and/or melted surface materials which was produced due to meteoroid impacts. Since some location on the moon is mostly covered by agglutinate, simulating such soil is also important to know its characteristics. Figure 1 is the SEM images of FJS-1 and experimentally generated agglutinate. As shown in the picture, generated agglutinate became spherical shape and needs more improvement in generation process.

Table 1. Comarison of chemical compositions of Apollo 11, 12 and 14 samples and simulant FJS-1 [wt%]

Element	Lunar Sample			Lunar Soil Simulant
	Apollo 11	Apollo 12	Apollo 14	FJS-1
SiO_2	42.20	46.3	48.10	49.14
TiO_2	7.80	3	1.70	1.91
Al_2O_3	13.60	12.9	17.40	16.23
Cr_2O_3	0.30	0.34	0.23	0.00
FeO	15.30	15.1	10.40	8.30
Fe_2O_3	0.00	0	0.00	4.77
MnO	0.20	0.22	0.14	0.19
MgO	7.80	9.3	9.40	3.84
CaO	11.90	10.7	10.70	9.13
Na_2O	0.47	0.54	0.70	2.75
K_2O	0.16	0.31	0.55	1.01
P_2O_5	0.05	0.4	0.51	0.44
S	0.12	-	-	0.00
H_2O	0	0	0	0.43

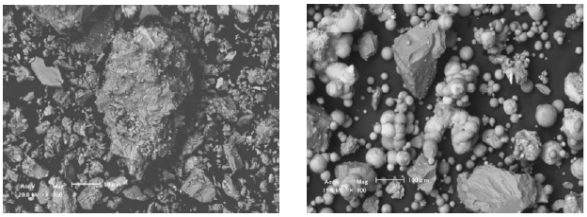

Figure 1. SEM images of FJS-1 (Left) and experimentally generated agglutinate (Right)

In addition, we experimentally manufactured other types of simulants representing the lunar mare region, named "Oshima", and the highland region, named "Kohyama". As shown in Table 2, the simulant in the lunar mare region contains more glasses, while the one in the highland region contains more Plagioclase.

Table 2. Major Chemical Composition (wt%) compared to Apollo samples A-16 and A-12.

	A-16	NU-LHT (NASA)	Kohyama	A-12	JSC-1A (NASA)	Oshima
SiO_2	45.00	46.6	47.49	46.30	46.8	44.4
TiO_2	0.54	0.115	0.14	3.00	2.44	5.54
Al_2O_3	27.30	21.55	22.59	12.90	13.9	12.6
FeO	5.10	*5.08	*8.53	15.10	*12.1	*16.1
MnO	0.30	0.09	0.17	0.22	0.21	0.36
MgO	5.70	9.5	10.24	9.30	5.6	7.0
CaO	15.70	12.6	8.02	10.70	10.5	9.7
Na_2O	0.46	0.965	1.65	0.54	3.89	2.09

*A-16 and A-12 are representing highland and sea regions, respectively.

Applications of FJS-1: FJS-1 has been widely used in a variety of research such as ISRU and terramechanics. For instance, FJS-1 was used to investigate the possibility of oxygen production on the moon. Shimizu Corporation, American startup Carbotek Development Laboratories, and NASA examined the oxygen production using FJS-1 by hydrogen reduction. Assuming the use of a fluid bed as a hydrogen reduction reactor, we conducted parabolic flights using the test airplane KC-135 of NASA to examine the behavior of soil (FJS-1) and hydrogen gas (in this case, Helium) under the lunar gravitational field, as shown in Figure 2.

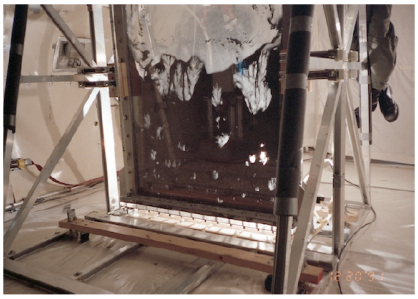

Figure 2. Fluid bed observation under 1/6G using NASA's KC-135 airplane.

Another use of FJS-1 is to examine the interaction between the soil and mechanical elements, whose filed of research is called terramechanics. NASDA (currently JAXA) and Shimizu Corp investigated the driving performance of a wheel simulating the low gravity (Figure 3).

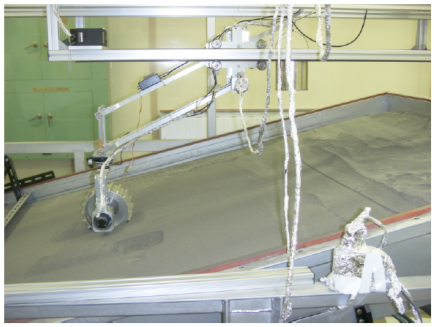

Figure 3. Low-gravity wheel testbed (copyright JAXA)

Preparation for the Delivery of New Simulant: Since 1995 when the FJS-1 was first developed, it has been used in various studies relating to lunar surface activities, as described above. The FJS-1 has been reproduced several times up to this point, but it is almost out of stock again now. This material was produced basically by crushing basaltic lava obtained from Mt. Fuji area, and well simulates bulk mechanical properties and approximates chemical and mineralogical composition of Apollo samples in lunar mare region. However, it contains very small amount of glasses, which may affect the chemical behaviors in ISRU processes.

Under these circumstances, we have decided to develop new lunar mare simulants, and already started site investigation of raw materials (Figure 4-5). There are two major candidates as raw materials for the new simulant. One is the basaltic lava in Mt. Fuji area, which is the same as the source of the FJS-1, and the other is the basaltic lava distributed in Izu-Oshima Island. A good point of the Izu-Oshima basalt is that it contains glassy materials.

Figure 4. Stock yard of basaltic lava in Mt. Fuji area

Figure 5. Stock yard of basaltic lava in Izu-Oshima

After conducting several analyses and mechanical tests on these materials, we will select the best production procedure, and will start delivery of the simulant by the end of this year.

Conclusions: This paper presented the Japanese standard lunar soil simulant FJS-1 made in Japan,

simulants of the lunar mare region and the highland region, and the current status of a new lunar soil simulant to be delivered near future. We plan to start manufacturing a new simulant this year, and the new simulant will be delivered hopefully by the end of this year.

References:

[1] H. Kanamori, et al., (1998), ASCE, Space 98, 462-468. [2] S. Aoki, et al., (2009), JSASS, The 53rd Space Sciences and Technology Conference, 1C11 (printed in Japanese).