Geotechnical Properties of BP-1 Lunar Regolith Simulant

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NASA worker performing soil penetration testing in the BP-1 Lunar Regolith Testbed located in the KSC Swamp Works Facility.

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BACKGROUND

BP-1 Lunar Regolith Simulant was discovered during NASA's 2009 Desert RATS field test campaign near Flagstaff. It originates from the Black Point basalt flow, and consists of silt-sized washing paste from a rock quarry located in San Francisco Volcanic Field in northern Arizona.

Understanding soil properties of lunar regolith is essential in the design and construction of prospective facilities such as landing pads and lunar bases using excavators and additive manufacturing.

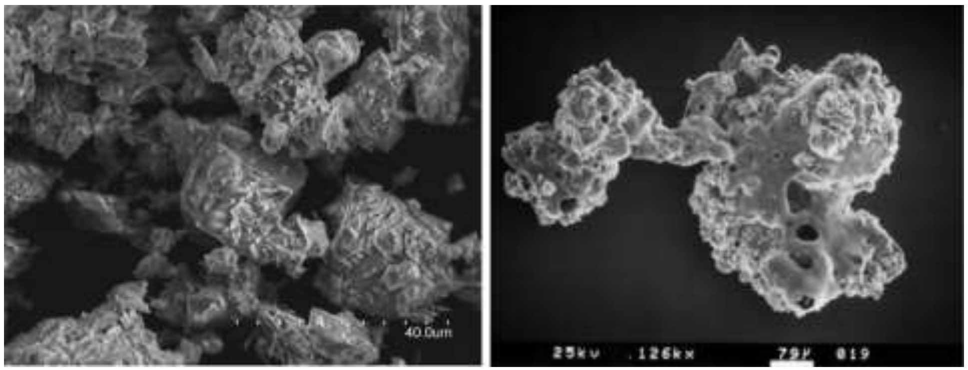
2020 Lunabotics Engineering Competition

https://www.nasa.gov/offices/education/centers/kennedy/technology/nasarmc.html

Since 2010, over 100 tons of BP-1 lunar simulant has been used by University Teams competing in annual Lunabotics and Robotic Mining Competitions.

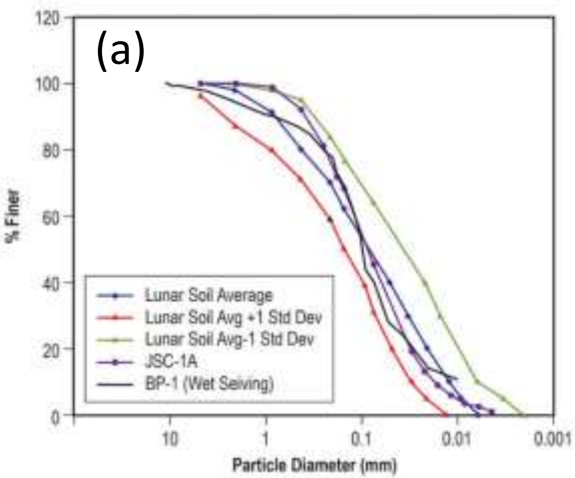
https://www.facebook.com/Lunabotics.Competition/

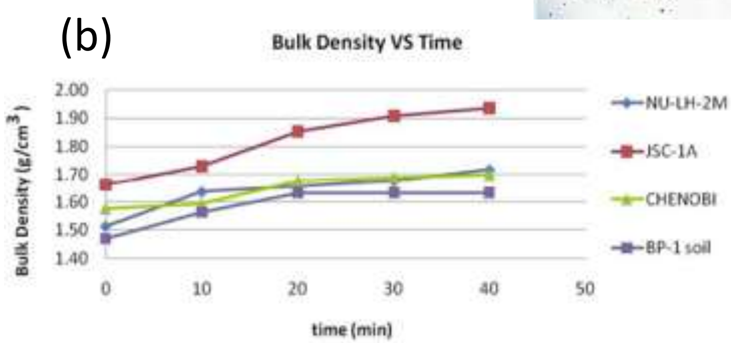
BP-1 vs Lunar Regolith and Other Simulants



SEM images of BP-1 particles (left) and Apollo lunar regolith (right).
(Suescun-Florez et al., J. Aerospace Eng., Sept. 2015, Vol. 28, Issue 5)

Granular size distribution indicates that BP-1 falls within the one standard deviation range of the lunar regolith particle distribution. BP-1 is classified as silty sand.





(a) Comparison of particle size distributions of BP-1 to Apollo lunar soil sample averages and the lunar soil simulant JSC-1A. (b) Bulk density of lunar simulants as a function of compaction time on a shaker table.
(Rahmatian and Metzger, Earth & Space 2010)

BP-1: Composition

Black Point Basalt is alkaline and typical of continental basalts.
It has a high ratio of iron to magnesium relative to most basalts.

<u>Elemental Composition</u>:

SiO_2	47.2%
Al_2O_2	16.7%
CaO	9.2%
MgO	6.5%
FeO	6.2%
Fe_2O_3	5.9%

<u>Mineralogy</u>:

Labradorite	60.7%
Augite	23.7%
Olivine	6.2%
Magnetite	3%
Calcite	2.7%
Hematite	2%

<u>Ref</u>: Stoeser, Wilson, Rickman. NASA/TM-2010-215444

BP-1: Mechanical Properties

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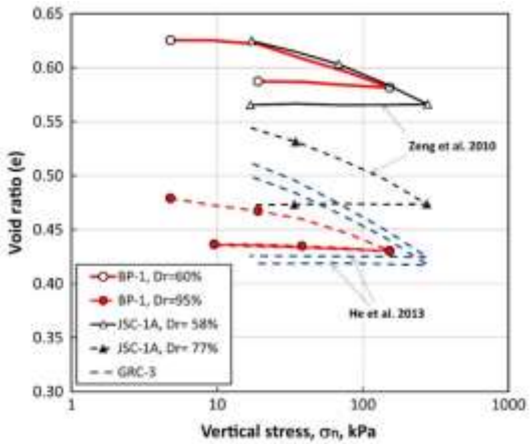


In general, BP-1 and JSC-1A simulants behave quite similarly under loose and dense conditions. BP-1 and GRC-3 show similar trends when samples are densely prepared. The compressibility index (Cc) of dry BP-1 varied from 0.0418 to 0.0174 for loose and dense samples. The recompression index (Cr) falls in the range of 0.0066 and 0.00415 for loose and dense conditions, respectively. The stiffness of BP-1 increases slightly with increase in relative density. Compressibility and recompression index of BP-1 are also comparable to those reported by Zeng et al (2010) for JSC-1A, who reported values of Cc and Cr of 0.068 and 0.001, respectively.

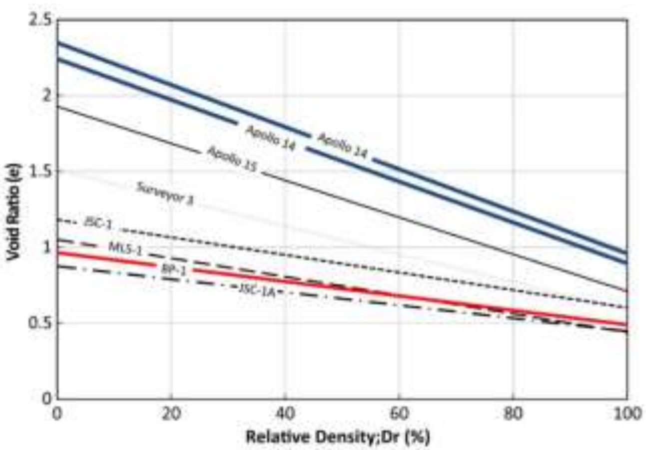
(Suescun-Florez et al., J. Aerospace Eng., Sept. 2015, Vol. 28, Issue 5)

Maximum and Minimum Densities of BP-1, Lunar Regolith, and Other Lunar Simulants

Soil	G_s	ρ_{min} (g/cm^3)	ρ_{max} (g/cm^3)
BP-1	2.81	1.43	1.86
GRC-3	2.63	1.52	1.94
JSC-1	2.90	1.33	1.80
JSC-1A	2.88	1.57	2.03
MLS-1	3.20	1.56	2.20
Lunar regolith	2.90-3.24	0.87–1.36	1.51–1.93

Shear Strength Parameters of Lunar Regolith and Other Simulants (from Suescun-Florez)

Soil	ϕ (degrees)	C (kPa)
BP-1	39–51	0–2.0
GRC-3	37.8–47.8	—
JSC-1	45	1.00
JSC-1A	43.6–44.4	3.9–14.4
	37–48	2.0–5.0
	46–57	—
Lunar regolith	25–50	0.26–1.80

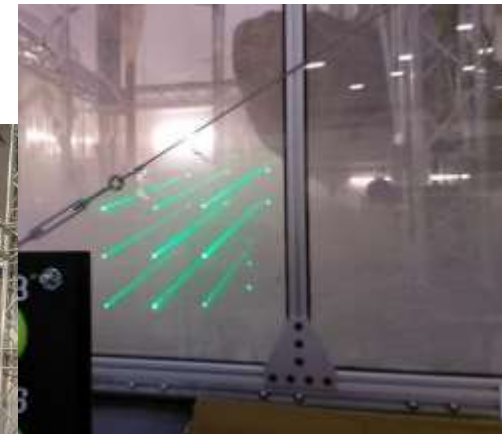


Comparison of relative density versus void ratio for lunar simulants and samples.
(Suescun-Florez et al., J. Aerospace Eng., Sept. 2015, Vol. 28, Issue 5)

The maximum and minimum void ratios are 0.965 and 0.49, respectively. On average, BP-1 is somewhat lighter than the GRC-3, JSC-1A, and MLS-1 simulants, but heavier than those of JSC-1 and lunar regolith. All simulants exhibit a lower void ratio versus relative density trend than lunar regolith, possibly due to the role of water erosion in smoothing terrestrial soil substances used to make simulants. (Suescun-Florez et al., J. Aerospace Eng., Sept. 2015, Vol. 28, Issue 5)

Uses of the BP-1 Lunar Regolith Testbed Facility

Telerobotic Perception Sensor Testing



BP-1 Lunar Regolith Testbed at NASA KSC Swamp Works

Evaluating Geotechnical Tools

Lunar ISRU Field Testing

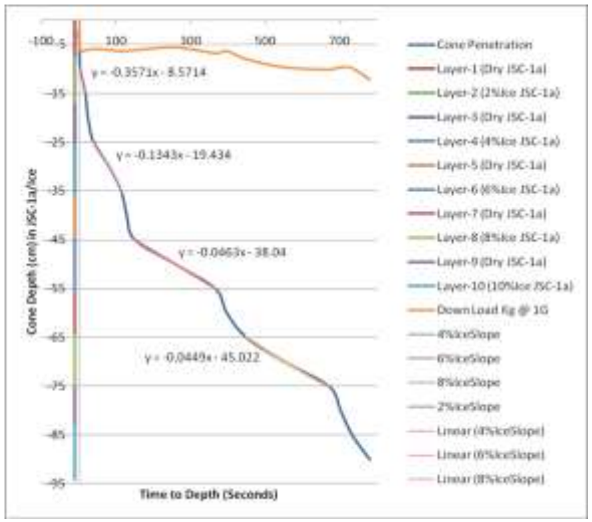
Evaluating Excavator Technologies

Evaluating Spacesuits for Work Tasks

Icy Regolith Testing

Percussive Cone Penetrometer

Honeybee Robotics and NASA Kennedy Space Center have demonstrated that percussive penetration is a suitable method to insert instruments into a mixture of regolith and water ice in which the concentration of water varies.



Results for JSC-1a show that the rate of penetration (distance divided by time) for dry frozen regolith at the same compaction is much easier to penetrate than wet frozen regolith, and that frozen regolith at lower ice content is easier to penetrate than regolith at higher ice contents.

Ref: NASA/TM—2011-216302, (2011) "Low Force Icy Regolith Penetration Technology," Metzger, Galloway, Mantovani, Zacny, and Craft.

Cone Penetrometer Testing in a Vacuum Cryostat Chamber

The GMRO Lab at NASA Kennedy Space Center performs cone penetrometer testing of regolith simulants cooled by a LN2 heat exchanger under vacuum conditions in a cryostat chamber in the KSC Cryogenics Testlab.

Questions?