COMPARISON OF THE MECHANICAL PROPERTIES BETWEEN THE ASHES FROM THE KAMCHATKA PENINSULA AND LUNAR REGOLITH.

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Introduction: The lunar surface has been actively studied by various automatic space stations and manned missions, and at the moment a lot of material has been accumulated about the properties of the lunar regolith. However, for testing of various advanced scientific instruments for future missions, full-scale testing experiments are required. For this purpose, various soil analogues are being developed. The main purpose of this study is to examine the mechanical properties of several types of ashes from the Tolbachik, Gorely and Mutnovsky volcanoes, as well as the Khalaktyrsky beach and compare them with the lunar regolith. For this purpose, shear strength tests were performed for loose and dense compactions of material and then the angle of internal friction and cohesion were determined.

Description of the physical and mechanical properties of the lunar regolith: In terms of, particle size distribution, a typical lunar regolith is a poorly sorted sandy-silty soil with an admixture of rubble and boulders. The median particle size ranges from 0.04 to 0.130 mm with an average value of 0.07 mm [1].

Most of the lunar regolith samples are characterized by a predominance of a coarse-grained fraction from fresh crater ejections and a finely dispersed fraction of a mature regolith, which indicates insufficient sorting of the lunar regolith, in contrast to terrestrial loose soils [2].

The natural density of lunar regolith on the surface up to a depth of 15 cm, according to data from the Luna-16 and Luna-20 spacecraft missions, varies from 1.12 to 1.7 g cm^{-3} with an average value of about 1.5 g cm^{-3}. The average value of the density of the regolith on the surface, according to the data from the Apollo missions, is also 1.3 g cm^{-3}, but then sharply increases with depth with hyperbolic-like dependence. Deeper than 60 cm, the density of the regolith soil increases insignificantly, and at a depth of about 3 m it approaches 1.92 g cm^{-3} [3].

An assessment of the strength characteristics showed that on the surface the lunar soil in a loose state has insignificant cohesion and a small angle of internal friction. As the soil is compacted at a depth of up to 1.5 g cm^{-3}, the shear resistance increases both due to an increase in adhesion forces and due to an increase in the angle of internal friction. Scientists' assessment [4] of bore hole resilience against caving from Apollo-16 and Apollo-17 missions showed that the specific adhesion at landing sites is 1.1 - 1.8 kPa and a φ value of 46.5º.

Lunokhod-2 in Lemonnier crater near the eastern coast of the Sea of Clarity also measured the following parameters: specific cohesion - 0.40 kPa, angle of internal friction - 40 ° [2].
Experimental studies of the lunar soil delivered from the landing sites of the manned Apollo expeditions also showed a strong dependence of cohesion and the angle of internal friction on the density of the soil and, accordingly, on the depth of occurrence [5]. When the density changed from 0.99 to 1.87, the cohesion varied within 0.3–3.0 kPa and the angle of internal friction was 13–56º [5], [2].

Thus, the lunar regolith has a density range of 1.3 - 1.9 g cm^{-3}, the angle of internal friction, depending on the density, varies from 13 to 56º, and the cohesion is 0 to 3 kPa.

Used Methods: shear strength testing experiment based on the Mohr-Coulomb theory: the value of the shear stress (τ) will depend on the cohesion values (c), the internal friction angle (tgφ) and the applied normal stress (σ) [6].

The normal stress was set depending on the density of the samples in the range from 10 kPa to 50 kPa for loose and from 50 to 200 kPa for dense samples. The strength value was defined as the maximum shear stress at which the sample failed. The shear speed was 2 mm / min.

Results: Samples of Kamchatka ash are sandy soils with an admixture of dust and coarse-grained fractions, in different ratios, in more detail from the physical characteristics and granulometric composition are considered in [7]. There were 5 samples in total: Gorely volcano (lower part of the slope), Gorely vocano (upper part of the slope, 1390 m), Khalaktyrsky beach, Mutnovsky volcano, Tolbachik volcano. The last sample had fractions with a particle size too large for the testing equipment, thus it was sieved through a 2.5 mm sieve. The samples had a different range of density and, therefore, strength characteristics, as shown in table 1.

Table 1.
Comparison between the ashes of Kamchatka region and the lunar regolith

	Density g cm^{-3}	Internal friction angle,^{o}	Cohesion, кPa
Tolbachik	0.89 – 1.04	41.7 – 46.1	5.4 – 57.5
Mutnovsky	1.17 – 1.46	42 – 51.5	2.2 – 19.5
Gorely	1.17 – 1.44	29.7 – 36.1	2.8 – 20
Gorely (1390)	1.05 – 1.37	33.3 – 39.2	1.3 – 16.2
Khalaktyrsky beach	1.60 – 1.81	28.3 – 41.1	1.3 – 17.9
lunar regolitph	1.3 – 1.9	13 – 56	0.3 – 3

All samples have the values of the angle of internal friction comparable to those of the lunar soil; however, the specific cohesion of all samples is much higher than the cohesion of the regolith with a dense composition.

The density range for all samples also completely does not correspond to the lunar one, however, the samples of the Mutnovsky and Gorely volcanoes are similar in properties to the near-surface layer of the lunar regolith.

Conclusions: Consideration of Kamchatka ashes as potential analogues of the lunar soil showed that they will not be able to fully imitate the lunar soil.

Samples from the Mutnovsky and Gorely volcanoes can be used to simulate the upper layer (up to a depth of 15 cm) of regolith, with a minimum density.

Further research will be aimed at studying the properties of mixtures of various ashes, as well as crushed Tolbachik [7] in order to achieve a better balance between physical and mechanical properties. As the results of the granulometric composition show, its crushed part is very close to the Lunar regolith.

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