Development of a lunar soil simulator for Earth-based experiments

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Abstract. A simulator of lunar soil and lunar dust has been developed, designed for modeling various engineering processes in terrestrial conditions. The elemental and granulometric compositions of the simulator were studied using X-ray fluorescence analysis, scanning electron microscopy and laser light scattering. The resulting material will be used in the future to simulate thermophysical processes when creating lunar power generating plants. The finely dispersed component of the simulator based on basalt wool will be used to study the filtration of lunar dust.

Recently the issues of lunar exploration have been discussed more and more often in practical terms. Many countries, including Russia, have included in their space programs specific schedules of lunar launches and research directly on the Moon with human participation. The main difference from previous lunar expeditions will be the long stay of astronauts in the orbit of the Moon and its surface.

In this regard, the physical properties of the lunar soil are of considerable interest. Many studies have been devoted to this issue [1-3], however, the lack of data, which, among other things, are fragmentary, still makes the topic relevant not only for the study of the basic physical and mechanical properties of the lunar soil, but also for the creation of simulators (models) of the lunar soil and some of its components (in particular, lunar dust). This is necessary both for the development and testing of devices designed to work on the lunar surface, and for the design of various technological complexes created for the use of lunar resources.

As is known [2,4], the surface of the Moon is covered with regolith, a loose material obtained after repeated impacts of micro- and macrometeors into an initially solid surface, similar in composition to basalts available on Earth, and the elemental composition varies within 10% depending on the place of sampling. The granulometric composition is represented by particles from fractions of a micron to stones measuring centimeters or more. The median particle size (the average size dividing the size distribution into two equal parts by weight) varies from 40 to 130 microns with an average value of 70 microns [5]. At the disposal of the researchers are samples of lunar soil brought directly from the Moon by both Soviet automatic stations and American expeditions under the Apollo program. All samples are taken from different points on the surface, and their research continues, but their delivery to Earth is exceptionally expensive. For a number of cases, there is no need to deliver soil samples from the Moon and a simulator created on Earth that repeats both the elemental and granulometric composition is quite sufficient.

All the lunar soil simulators (LSS) described in the publications are developed on the basis of mechanical grinding of terrestrial rocks, usually of basalt composition. Since the regolith contains a significant amount of rock fragments, fragments of meteorites. breccias, etc., cemented with glass [1-3], then glass is added to the LSS as agglutinate.

It is difficult to achieve the necessary granulometric composition using one-stage technological process. So, it was decided to use a two-stage method for creating LSS.
At the first stage, three samples of fused basalt (lava taken after the 1976 eruption of the Tolbachik volcano in Kamchatka) were crushed separately with various measures to preserve the elemental composition. Those measures included the use of glass and stainless steel vessels to prevent contamination.

To obtain the crushed fraction of the components of the LSS, an electrohydraulic press with a force of 60 tons was used.

Pieces of fused basalt were placed in a metal cylindrical stainless steel cup with a diameter of 100 mm and a wall height of 100 mm. The bottom of the glass was a well-treated smooth surface. Then the piston of the press through a special mandrel, which also had a well-treated smooth end, crushed basalt.

The resulting basalt crumbs were sifted through a clean metal mesh with a cell (1 x 1) mm. The remaining unseeded larger fragments were subjected to secondary crushing. If it was necessary to obtain an even smaller component, the pressing operation could be repeated several times.

After the conversion of basalt (lava) into a finely dispersed form, the elemental composition of each of the three samples was studied by X-ray fluorescence analysis (XFA).

Measurements were carried out on the Clever B-23 installation [6]. This X-ray spectrometer is capable of detecting concentrations of elements from sodium Na to uranium U. To increase the sensitivity of the device to the determination of light elements, all measurements were carried out in a vacuum. The measurements were carried out in the mode of the diaphragm size of 4 mm, accelerating voltage of 40 kV, electronic current of 39 µA. The exposure time of the samples was 100 seconds.

The samples were placed in analytical tanks, the base of which was made of MYLAR polyester film (Chemplex Industries, USA), which practically does not cause parasitic radiation on the lines of elements within the sensitivity of the device. The XFA spectra of the studied samples are shown in Figure 1.

![Spectrogram of the elemental composition of a sample of crushed basalt, sample 1](image)

**Fig. 1.** Spectrogram of the elemental composition of a sample of crushed basalt, sample 1

| Tab. 1 - Content (%) of chemical elements in the studied samples |
|---------------------------------------------------------------|
| Element | Basalt, sample 1 | Basalt, sample 2 | Basalt, sample 3 |
| Mn      | 0.16             | 0.17             | 0.16             |
| Ca      | 13.10            | 11.87            | 13.95            |
| Si      | 57.50            | 56.18            | 55.40            |
| Al      | 14.24            | 16.82            | 16.75            |
| K       | 4.42             | 4.51             | 3.49             |
| Ti      | 1.38             | 1.53             | 1.13             |
| Fe      | 9.20             | 8.92             | 9.12             |
The elemental composition of the samples was measured at five points for each of the three samples, after which the obtained values were averaged. The results obtained are presented in Table 1. The measurements showed a good match in composition with the samples of the original lunar dust.

For the preparation of agglutinate, which had to be added to the crushed basalt base of LSS, basalt glass wool, widely used in the construction industry, was used. It is important to use just basalt wool, since admixtures of limestone and dolomite, uncharacteristic of lunar soil, are added to other types of construction glass wool.

After degreasing and drying, basalt glass wool was ground in a ball mill Pulverizette-5 (mod. 2008). Grinding was carried out in agate glasses with a volume of 50 ml with balls of zirconium dioxide with a diameter of 8 mm. The rotation speed of the ball mill was 180 revolutions per minute.

During the grinding process, three samples of the resulting product were taken for different grinding times – 15, 30 and 60 minutes. According to the results of a preliminary analysis of the dispersed composition of the resulting powder using an optical microscope, a finely dispersed fraction with a grinding time of 30 minutes was selected for addition to the LSS.

This glass powder was nebulized and the particle size distribution function was measured with a laser aerosol particle counter PKGTA 0,3-002. The results are shown in Fig. 2.

![Fig. 2. Histogram of the particles size distribution for nebulized crushed glass wool. The particle size in microns is deposited along the abscissa axis, and the number of particles in 0.1 liters is deposited along the ordinate axis.](image)

For additional control, the nebulized basalt powder was deposited on an analytical filter and examined by scanning electron microscopy (SEM). Because of very low electrical conductivity of the samples, a gold film was applied to the samples by magnetron sputtering in the installation of Complete Carbon & Sputter Coating Systems, SPI, USA. Micrographs of the samples were obtained in a VERSA 3D scanning electron microscope (Thermo Fisher Scientific, USA) at an accelerating voltage of 2 kV A in the secondary electron registration mode.

Both the results of measurements using an aerosol particle counter and the photos obtained by the SEM method (see Fig. 3, 4) correspond to the literature data on the dispersed composition of the submicron fraction of lunar dust [7], and also confirm the uniformity of the grinding of the source material.

The final stage of LSS production consisted in mixing the base (basalt crumbs) – and agglutinate (powder of crushed basalt wool) in a volume ratio of 1 to 1000.

The resulting LSS will later be used to measure thermal conductivity and other thermophysical characteristics, which is important for the creation of power generating plants. The highly crushed part, created on the basis of basalt wool, will be used to study the behavior of lunar dust.
Fig. 3. Particles of fine fraction of ground basalt fiberglass (grinding time 30 minutes) deposited on an analytical filter. An image from the screen of an electron microscope; magnification 400 x.

Fig. 4. Particles of fine fraction of ground basalt fiberglass (grinding time 30 minutes) deposited on an analytical filter. An image from the screen of an electron microscope; magnification 7500 x.

One of the most important ways of application for LSS is a filtration studies. A number of researchers report [3] that it is especially important to study and prevent the interaction of regolith components with various mechanisms and especially human lungs. As can be seen from the photograph (see Fig. 4), regolith particles have an irregular shape and have sharp edges, which is the reason for the increased abrasiveness and a significant negative effect on the respiratory system. Therefore, it is important to study the ways to reduce the amount of suspended particles in the air, or, in other words, to bring the concentration of particles by filtration to an acceptable level determined by medical standards, using reliable LSS.

Thus, the studies carried out made it possible to develop the simulator of lunar soil and lunar dust for research in the laboratory. The finely dispersed component of the simulator based on basalt wool will
make it possible to carry out research on the filtration of lunar dust. The obtained material will be set on basis for further modeling of thermophysical processes during the creation of lunar power plants.

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