SURFACE CLEANLINESS IN LUNAR REGOLITH MECHANICS

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An understanding of the mechanical properties of lunar regolith is necessary to perform the geotechnical design of a lunar base. This design may include foundation systems, regolith shielding, mining excavations, erosion of launch pad areas, and soil anchors for communications towers. Particle angularity, size distribution, porosity and other common geotechnical engineering parameters control the mechanical properties of all granular materials. Another important parameter affecting the mechanical properties of lunar regolith is surface cleanliness. The latter is a measure of the quantity of gas molecules adsorbed to a material surface. In order to assess the effects of surface cleanliness on the mechanical properties of lunar regolith and simulants, the thermodynamics of adsorption, physical chemistry of surfaces, and mechanics of granular materials must be taken into consideration. The dependence of surface cleanliness on various environmental factors was investigated. An analysis of the effects of surface cleanliness on the mechanical property of shear strength was conducted. Results of this analysis compare closely with data from previous tests on simulants and actual regolith samples. The role of surface cleanliness in the geotechnical design of a lunar base is discussed.

Surface cleanliness is a parameter defined as the inverse of adsorbate thickness. Thus, a high degree of surface cleanliness indicates a thin layer of adsorbate. The adsorbed gas molecules govern the spacing between grains of soil and weaken interparticle forces, which contribute to soil shear strength. Therefore, shear strength is directly related to surface cleanliness. Since adsorbate thickness is governed by temperature, pressure, and atmospheric composition, surface cleanliness can be used to describe and quantify the effects of various environmental conditions on regolith mechanical properties. At terrestrial atmospheric pressure, the adsorbate layer is several molecules thick, surface cleanliness is low, and interparticle forces insignificantly affect soil shear strength. On the Moon, regolith is characterized by high surface cleanliness and, consequently, greater shear strength prevails.

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A model was developed to estimate surface cleanliness and its effects on lunar regolith shear strength under any set of environmental conditions. Model development consisted of the assessment of intermolecular potential energy between a regolith particle and a gas molecule, estimation of adsorbate thickness based on the potential energy method, approximation of interparticle force between adjacent regolith particles, and establishment of the relationship between interparticle force and bulk lunar regolith shear strength. The effect of electrostatic charge, particle spacing, and adsorbate pressurization were accounted for in the calculation of surface cleanliness. Effects of sample gradation, void ratio, average yield stress, and particle deformation were incorporated into the analysis of regolith shear strength.

The model was examined using previous laboratory data from desorption and shear strength studies. Estimates of nitrogen desorbate quantity compare closely with measured values, whereas estimates of water vapor desorbate quantity exhibited higher deviation from measured values due to the probable alteration of intragranular pore space. Changes in lunar regolith and simulant shear strength based on the model correlate well with direct shear and rotating drum test data considering the inherent variability of the laboratory data.

Results of the model indicate that soil shear strength increases with high temperature and decreased pressure. Interparticle forces are greater within a medium of lunar regolith as opposed to common terrestrial soils due to the high polarizability of metal constituents including titanium and iron. A significant portion of lunar regolith shear strength arises from high surface cleanliness. This shear strength varies slightly from lunar day to lunar night due to diurnal temperature extremes on the Moon. Changes in lunar atmospheric composition, which have been measured over the course of a lunar day, may be explained by the adsorption of gases on the lunar regolith. Inert gases such as nitrogen and argon maintain the cleanliness of lunar regolith samples returned to Earth. However, even slight exposure to humid terrestrial air significantly alters the mechanical properties of these samples. Shear strength testing in preparation for a lunar base should be conducted in situ or by replicating lunar regolith surface cleanliness in laboratory. Application of the model allows for the achievement of this surface cleanliness by application of higher temperature at obtainable vacuum levels.

The effects of lunar environmental conditions on lunar regolith mechanical properties were studied. A model was developed that consists of a method for determining surface cleanliness and the shear strength induced by it. Previous laboratory data correlate well with estimates based on the model. A significant portion of lunar regolith shear strength is caused by high surface cleanliness. Thus, surface cleanliness is a factor which must be considered in the geotechnical investigation of a lunar base.