Development and Mechanical properties of the first Thailand lunar simulant (TLS-01) †

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Abstract: Lunar regolith simulants are an essential material that must replicate the crucial character of the actual lunar regolith in various major aspects, including both physical and chemical properties. For sustained research development progress, it is essential for Thailand to develop a lunar simulant that is widely available and cheap to produce while representing the crucial characteristics of lunar regolith. In this paper, the first Thailand Lunar Simulant (TLS-01) will be presented with its mechanical properties as the main topic. Their mechanical properties were tested by the Multi-stage direct shear testing method (KU-MDS shear testing method) and demonstrate that their results are within the range with other lunar regolith simulants and the actual lunar regolith collected from Apollo missions. The origin source of the TLS-01 was chosen based on the similarity in geochemical properties of the previous survey of basaltic rock in Thailand and lunar regolith from Apollo missions. Thus, TLS-01 demonstrated suitable mechanical and chemical properties to be the first lunar regolith simulant for Thailand and Southeast Asia.

Keywords: Lunar regolith simulant; Mechanical properties; Direct shear testing

1. Introduction

In the 21st century, the possibility of humans to establish colonies on extra-terrestrial planets is becoming a reality. The emerging interest in the upcoming colonization on the moon has led to exponentially increasing work in research and engineering [1]. With the limited resources of the actual lunar regolith, it is crucial to develop a lunar simulant to study and design the suitable tool that can work on the surface of the moon, such as ISRU processes, actual lunar regolith is needed in amounts much larger than is available. Thus, the lunar regolith simulant was invented to replicate most of the relevant properties of real lunar regolith by using material on Earth [2]. [3] has ranked each property's importance to producing lunar regolith simulants. According to the ranking, the physical properties, which includes the mechanical properties, is one of the top-ranking properties. It is crucial that a lunar regolith simulant must resemble that of real lunar regolith, in order to increase the accuracy of the result in further utilizations, especially ones that place an emphasis on the physical properties.

2. Samples Collection

Raw material of TLS-01 is basaltic rock and collected from abandoned quarry beside Khereethan Dam, Chanthaburi province (Figure 1). The chemical composition of basalt is quite suitable to represent the actual lunar regolith, based on literature published [4]. A representative sample was collected with carefulness by denying the vein-existing, secondary deposition layers and weathering samples from the collection to make it represent their true properties. X-ray fluorescence method is performed to double check their geochemical properties. For major oxides, SiO_2 content is 44.60 wt%. The alkali oxides ($Na_2O + K_2O$), MgO and Al_2O_3 content are 6.43 wt%, 12.26 wt% and 15.04 wt%, respectively. The CaO, TiO_2 and FeO_{Total} content are 9.57 wt%, 2.68 wt% and 7.92 wt% respectively.

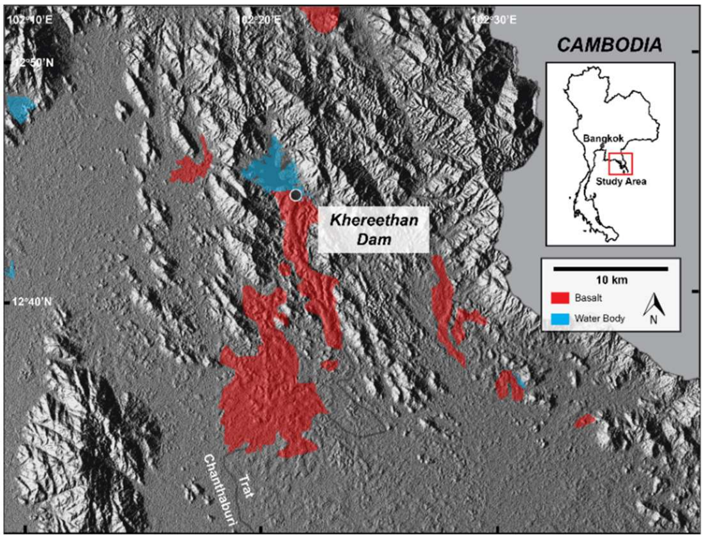


Figure 1. Location map of TLS-01 collection site near Khereethan Dam and Chanthaburi-Trat Cenozoic basalt boundaries.

3. Processing Method

Lunar simulant is characterized as a granular or powder material. The size of these powders usually range from coarse scale <0.1 mm to powder-like scale of < 0.074mm [5]. These powder-like bulk may present a challenge to rovers or infrastructure establishments on lunar colonies such as dry quicksand [6] or traversability performance of the rover which depends on the materials constituting the terrain [7]. The interactions between the wheels and the ground determine the friction-slip characteristics, which is one of an important parameter in evaluating rover performance [8].

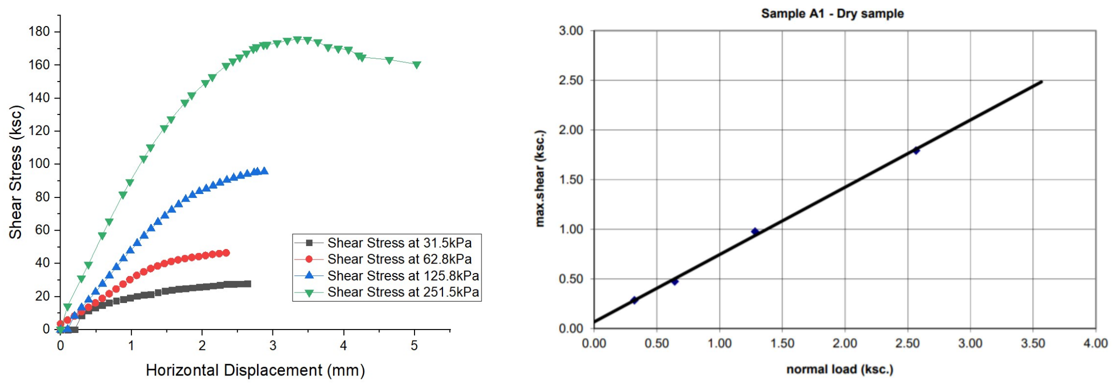
Sample rocks were processed using a Los Angeles Abrasion Machine to grind and reduce the size of sample into a mixture of gravel and powder. The sample was then sorted into different particle sizes using the dry-sieving method, isolating the sample portion finer than 15 millimeters for utilization in order to replicate genuine lunar regolith [9]. In addition, TLS-01 was air dried for 1 month to provide fully dried soils to replicate the atmosphere of the lunar surface.

4. Direct Shear Testing

Direct shear tests were prepared and performed using the Multi-Stage Direct Shear Test (KU-MDS Shear Test) method [10]. The simulant sample was prepared according to ASTMD3080 standard and filled in a box-shaped 62.370 cm^2. Direct shear tests were performed with five different vertical confinement levels (0.321, 0.641, 1.283, and 2.565 ksc). To eliminate the influence of shear rate on shear strength, all tests were performed at a constant shear rate of 0.05 mm/min. The shear rate was considerably slower than the test performed by [11], thus minimizing the error from the shear rate.

5. Result

The results of direct shear stress and horizontal shear displacement and shear stress vs. normal stress curves of TLS-01, previous simulants, and Apollo data were plotted and are shown in figure 2 [12]–[14]. The cohesion value and friction angle of the actual lunar regolith samples from Apollo 11,12 and 14 are in the range of 0.003 to 0.021 ksc and 30-50 degree [12] while the TLS-01 cohesion value and friction angle is 0.066 ksc and 33.92 degree which consider to be fit in the acceptable range of Apollo mission. When compared to other lunar regolith simulants, TLS-01 fits relatively well. For example, TLS-01 has similar values to FJS-1 [13] and JSC-1 [14], which have a cohesion value of 0.0168 ksc and 0.083 ksc and friction angle of 39.4 and 45 degree [11], respectively.



(**a**) (**b**)

Figure 2. Shear Stress with respect to horizontal displacement (a) and shear strength properties (b) of TLS-01.

6. Discussion

While TLS-01 shows promising physical characteristics according to the friction angle and cohesion value, it must be noted that both these values are slightly smaller than the previously published lunar simulant. This slight deficiency in friction angle might be a result of the unique production method of TLS-01, which utilized Los Angeles Abrasion Machine for grinding instead of the conventional method of using a jaw crusher and hammer mill. Since the Los Angeles Abrasion Machine uses a combination of actions including abrasion or attrition impact from the steel sphere to grind rock in a rotating steel drum, it is possible that these actions resulted in a different particle shape (ie, rounded shape) and thus lowered the friction angle value [15], [16].

7. Conclusion

The TLS-01 lunar regolith simulant has suitable mechanical properties that resemble actual lunar regolith (from Apollo missions), which were validated using the direct shear testing method. With its mechanical properties, TLS-01 can be defined as a Mare lunar regolith simulant.

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