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Lunar regolith simulant preparation and its impact on static penetration resistance and DRD penetration.

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Abstract

To test lunar hardware, three regolith simulant preparation methods were tested and calibrated. Advantages and drawbacks of each are presented here. Static penetration tests demonstrated the efficiency of the methods to vary the penetration difficulty of a regolith simulant. Finally, DRD (dual reciprocating drilling, a novel drilling principle), was tested in a variety of relative density conditions using the preparation methods. Visual observations of the DRD tests lead to progression mechanisms propositions for each tested relative density level.

1. Introduction

Lunar regolith is found on the lunar surface at different relative densities (RD): very loose in the first few cm, it is highly compact beneath [3]. Granular material RD is a driver of its mechanical properties [4]. The difficulties encountered by the Apollo 15 astronauts with the Apollo Lunar Surface Drill are in part due to the high RD of the regolith they were drilling. To ensure proper performance of hardware during lunar exploration, it must be tested in simulants with controlled RD. To do so, preparation methods are proposed here.

2. Regolith preparation methods

Three methods are proposed and tested. The “pour method” consists in pouring the simulant from higher than 50 cm into its container. The container is vibrated while the simulant is poured into it for the “vibrate method”. The “raining method” consists in depositing layers of simulant thanks to a hopper at a given height h and speed v (sweeps per minute: swp).

2.1 Densities achieved

These methods were tested on two regolith simulants SSC-1 and SSC-2 [5]. The RDs achieved are reported in Table 1.

Table 1: Relative densities achieved.

Method	SSC-1	SSC-2
Pour	**7.4 %**	**-0.4 %**
Vibrate	**83 %**	**87 %**
Rain (h=3 cm v= 24 spm)	8.9 %	-4.4 %
Rain (h=23 cm v= 24 spm)	22 %	11 %
Rain (h=3 cm v= 72 spm)	21 %	9.3 %
Rain (h=23 cm v= 72 spm)	43 %	17 %

2.2 Advantages and drawbacks

The raining technique prepares simulants in a variety of RDs, depending on hopper speed and height. However, it is mandatory to control hopper speed and height, otherwise large dispersions should be expected. This makes it a time consuming method.

The pour and vibrate techniques allow to obtain only one RD each. However these two RDs are very different and represent two extreme conditions. These two methods present less dispersion compared to the raining one. However, very different pouring speeds or vibrations will have an effect on RD. In all cases, a modification of the prepared regolith simulant or of the preparation setup should be followed by achieved RD calibration.

3. Static penetration

To demonstrate the radical impact of the proposed preparation methods on regolith properties, the static force required to penetrate the simulants was recorded.

3.1 Setup

A 30° apex angle, 2.5 cm diameter cone (with backward pointing ridges) was pushed into SSC-1 and SSC-2 prepared with the pour and vibrate methods in a 25 cm diameter, 29 cm high cylinder. The cone is guided by a rail system. The force is controlled manually and measured by a scale. The depth is measured for each increment of force.

3.2 Results

Figure 1 presents the mean penetration curves recorded. The penetration depth reached with 100 N increases by: +169% (in SSC-1) and +107% (in SSC-2) when using the pour technique instead of the vibrate one; and by +71% (pour technique) and +31% (vibrate method) when changing from SSC-2 to SSC-1. The RD of a regolith has thus a higher impact on penetration forces than the nature of the regolith! Penetration tests on JSC-Mars1 have shown similar results [1].

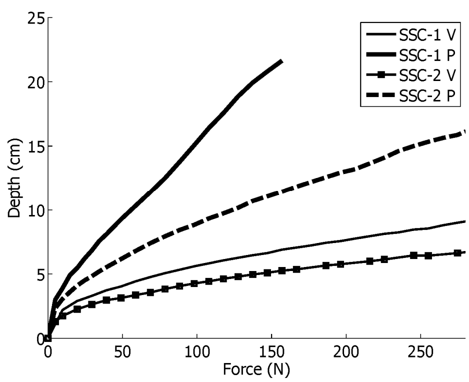

Figure 1: Mean penetration depth versus penetration force in poured (P) or vibrated (V) SSC-1 and SSC-2.

4. DRD tests

The vibrate and pour technique were used to prepare SSC-1 and SSC-2. The DRD test bench presented in [2] was used to drill into the regolith simulants.

4.1 DRD principle

Dual Reciprocating Drill (DRD) is inspired by the wood-wasp ovipositor which drills into wood to lays it eggs. Two drill bits, with backward pointing ridges, are reciprocated. The backwards movement of one generates a reaction on the drilled substrate and should help the penetration of the other.

4.2 Results

In most cases, the DRD penetrated all the poured regolith (30 cm) in less than 2 min, forming a crater around the drill. In vibrated regolith, DRD did not penetrate the full sample after 10 minutes. Regolith upheavals and regolith evacuation were observed.

In low RD regoliths, the crater formed suggests DRD progresses by locally compaction of the regolith. In high RD regoliths, the upheavals and regolith evacuation suggest DRD progresses by local shear.

5. Summary and Conclusions

Regolith RD must be taken into account when testing hardware. RD can impact by more than 100% the final depth of a lunar probe with a 100 N static force. RD even changes the progression principle of DRD. The preparation methods presented allow to control and drastically vary the RD of regolith simulants.

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