New methods for the transport and management of lunar regolith

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Overview

In the field of space exploration, it is essential to assemble and transport particles for various applications, for example transporting lunar and Martian soil (typically regolith), for mining, to study geological aspects and establish habitats on the Moon or Mars. The ability to synthesize complex materials directly in space or build specific structures on the surface of other planets is one the main challenges to be addressed in such a context. In this regard, the utilization of lunar regolith is being explored with regard to several potential applications, e.g., as feedstock for 3D printing and even as a solid-support substrate for plant growth, a source for extraction of essential plant-growth nutrients, a substrate for microbial populations in the degradation of wastes, a source of O_2 and H_2, which may be used to manufacture water [1-3]. However, the lunar and Martian soils are difficult to handle, because they are made of abrasive and reactive materials. Regardless of its intended use, the use of lunar regolith is hindered by its intrinsic nature, which makes its management (transfer from the surface of the Moon inside 'containers' or transport inside 'pipes') relatively difficult. Lunar regolith is characterized by very strong electrostatic effects and internal friction, which strongly limit its 'flowability'.

Case Experience

The author is collaborating with the European Space Agency (ESA) in the framework of an OSIP project entitled "Vibrations as a novel tool for particle self-assembly and regolith vibro-fluidization in space environments". OSIP is the Open Space Innovation Platform that the European Space Agency ESA launched in 2019 to better serve the emerging needs of the modern space sector. With this project, novel particle-control strategies based on "vibrations" are being explored at the University of Strathclyde. In microgravity, vibrations can be used as an alternate means to control the dynamics of solid particles dispersed in a liquid forcing them to self-organize and form specific three-dimensional complex structures (which can be used as backbones for special alloys or other materials) [4]. In the presence of a gravitational field such as that on the surface of Moon, there is potential to use vibrations to force regolith (which is characterized by strong internal inter-particle friction) to behave as a 'fluid' [5] thereby making its transportation and utilization in the context of several applications much easier. Researchers at the University of Strathclyde are combining theoretical, numerical and experimental work to study in detail the ability of vibrations with different amplitudes, frequency and direction to induce "liquefaction" of regolith-type particles (simulants) for different levels of gravity. The behaviour of lunar regolith is being assessed considering various geometries or configurations, i.e. pipes (with square or circular cross section and different constant transverse size) under different inclinations and "hoppers" (ducts with converging walls) with various sizes of the outlet sections.

Opportunity for Research and Innovation

Moon is the closest available target for the definition and testing of new technologies that make use of locally available (extra-terrestrial) resources for the production of consumables for life support systems, propellant, and/or feedstock for 3D printing. Lunar regolith is the most abundant material on the Moon and it could be used for the development of manned installations and many other applications. Most of its surface is covered with this substance, namely, a mixture of fine dust and rocky debris produced by meteor impacts, which displays many similarities with analogous materials available on asteroids and other rocky planets. There is therefore strong interest in this material and its potential exploitation for the colonization of Moon and the definition of new technologies for the exploration and exploitation of even more distant sites. In such a context, the present project targets the elaboration of a new regolith control strategy relying on the combined use of different mechanical stimuli.

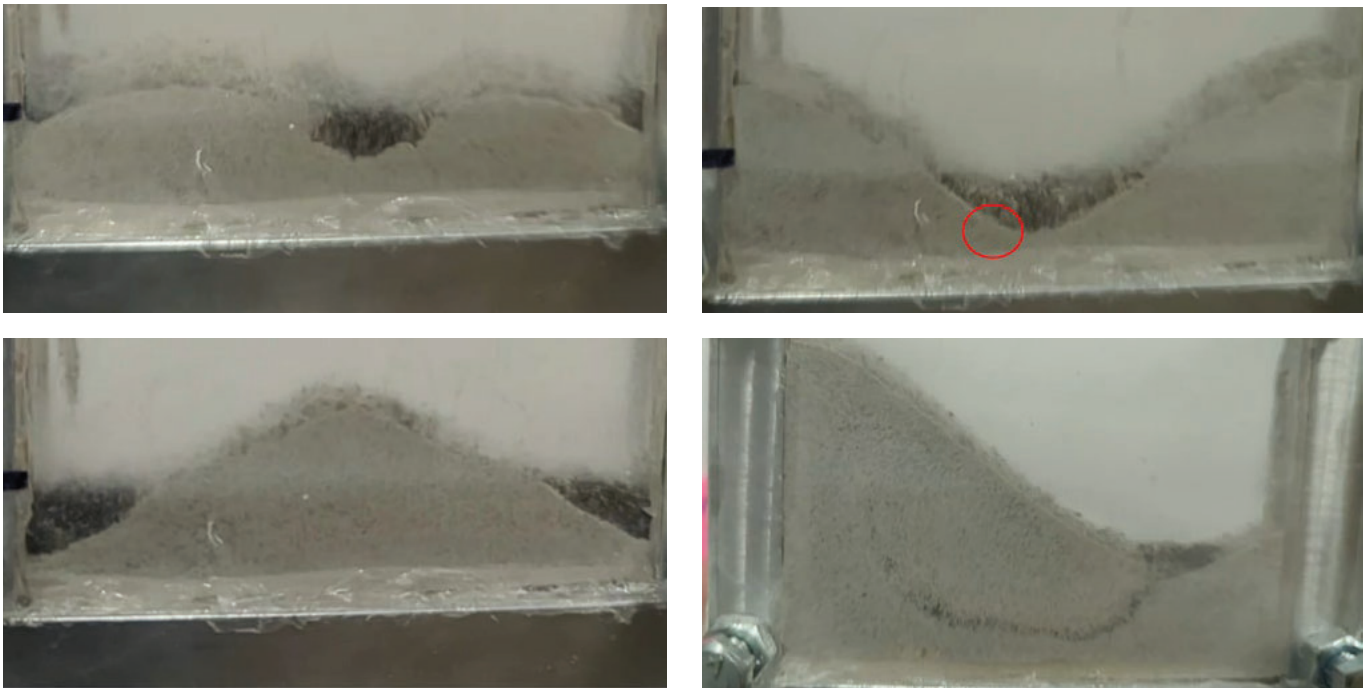

Figure: Snapshots of various convective states enabled in a layer of lunar regolith (simulant) with initial constant depth when it is subjected to vertical vibrations (Note: black particles with larger size tend to separate from particles having a smaller size and accumulate in the regions where the thickness of the material becomes smaller as a result of the liquefaction process).

References

1. Cesaretti G., Dini E., De Kestelier X., Colla V., Pambaguian L., (2014), Building components for an outpost on the Lunar soil by means of a novel 3D printing technology, Acta Astronautica, 93, 430-450.
2. Corrias, G., Licheri, R., Orrù, R., & Cao, G. (2012). Optimization of the self-propagating high-temperature process for the fabrication in situ of lunar construction materials. Chemical Engineering Journal, 193–194, 410–421
3. Ming D.W. and Henninger D.L., (1994), Use of lunar regolith as a substrate for plant growth, Advances in Space Research, 14(11), 435-443.
4. Santhosh B.M. and Lappa M., (2023), “On the relationship between solid particle attractors and thermal inhomogeneities in vibrationally-driven fluid-particle systems”, Physics of Fluids, 35(10), 103316 (26 pages), DOI: 10.1063/5.0170162
5. Watson P., Bonnieu S. V. and Lappa M., (2023), “Fluidization and Transport of Vibrated Granular Matter: A Review of Landmark and Recent Contributions”, Fluid Dynamics & Materials Processing, 20(1): 1-29, DOI:10.32604/fdmp.2023.029280