

Proposal for a Testing Standard for Planetary Construction Technologies with ISRU

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A fundamental part of ISRU construction research is to establish a useful metric to compare and evaluate the different technologies from the available sources, addressing the differences in the data presented across the selected publications. Earth-based testing with In Situ materials can be conducted in two possible ways: with original materials sourced from the Moon and Mars surface or through simulants fabricated from soil analysis. The only tests we have been able to perform on original material is on lunar regolith, mainly from the 360kg of lunar regolith and rocks brought back from the Apollo missions, but recently also from the Chang'e 5 lander. As for Mars, there is currently a Martian sample return mission planned for 2026, but at the moment the only manufacturing experiments have been performed on simulants.

Analyzing the current literature, it is possible to find a common problem that affects this kind of research: different tests performed on simulants and samples across the decades cannot be easily compared. Different research groups with different equipment and different methodology to analysis have produced a great deal but inconsistent amount of data and results.

This paper proposes a testing standard for Planetary Construction technologies with ISRU.

I. Nomenclature

<i>ISRU</i>	=	In Situ Resources Utilization
<i>CEN</i>	=	Construction Environment
<i>CEL</i>	=	Construction Element
<i>AM</i>	=	Additive Manufacturing
<i>NASA</i>	=	National Air and Space Administrations
<i>TLR</i>	=	Technology Readiness Level
<i>DMMM</i>	=	Department of Mechanics, Mathematics and Management
<i>SICSA</i>	=	Sasakawa International Center for Space Architecture

II. Introduction

Establishing a sustained human presence on the Lunar or Martian surface depends on our capacity to leverage local resources effectively. Although there is an upward trajectory in the development of advanced carriers that can transport more payloads to the Moon and Mars, either through larger payload volume or increased frequency, harnessing local resources instead of transporting materials from Earth presents a more efficient and cost-effective solution for maintaining human presence. This becomes particularly crucial in the context of extracting and utilizing materials for planetary construction.

Over the past decades, the additive manufacturing industry has grown steadily. This progress allows for innovative construction techniques using additive manufacturing technologies in tandem with In-Situ Resource Utilization (ISRU). Concurrently, significant advancements have been made in material science. Simulants that closely mimic Lunar and Martian regolith, based on our current knowledge, have been employed to advance experiments testing these technologies and techniques. Many experiments have been conducted to examine various aspects of this issue, ranging from

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construction techniques to material behavior under diverse conditions. Although these experiments could theoretically and practically share overlapping objectives, they are typically conducted for a specific set of goals, leading to different experimental conditions. This variability makes comparability of collected and reported data for scientific analysis challenging as it hinders the establishment of a benchmark that could serve as a foundation and a reference point for producing comprehensive and reliable results.

This paper proposes a fundamental testing standard for planetary construction technologies and materials using ISRU. This proposal holds importance on multiple levels:

- It establishes a basic benchmark against which experiments can be conducted and compared, thereby eliminating numerous variables that could obscure specific findings.
- It serves as a stepping-stone that can be further developed as more data is gathered and additional conditions are required.
- Given the diversity in potential experimental objectives, this metric is adaptable. The proposed standard can distinguish between basic experiments conducted to test technologies where vacuum or microgravity conditions may not be crucial for the objectives of the studies, and those where such conditions are necessary.

III. Relevant Research and Technologies

Experiments conducted for research and testing in planetary additive construction using In-Situ resources generally fall under two broad categories of objectives:

- 1) Technological Testing
- 2) Materials and Additives Testing

While experiments typically align with a broader objective, they also contain specific sub-objectives that can alter the parameters and variables of the experiments. The experimental focus may center on controlling for certain variables, while considering others as unnecessary or irrelevant. Listed below are some inputs and parameters that could influence the results and findings:

- 1) Inputs/Parameters Associated with Category 1 (Technological Testing) Experiments
 - Type of technology employed.
 - Technical specifications of the utilized technology, such as power, wattage, operating temperature, etc.
 - Exposure to the elements and operating conditions, including controlled vs. uncontrolled environments, temperate vs. extreme environments, pressurized vs. non-pressurized conditions, and the presence of microgravity or a vacuum.
- 2) Inputs/Parameters Associated with Category 2 (Materials and Additives Testing) Experiments
 - Type of material used, be it original regolith or simulants.
 - Additives to materials, including their type and percentage composition.
 - Requirements for pre-processing and/or post-processing of the material used, if any.

Given the above, the challenge of comparing any two experiments becomes apparent. This necessitates a proper classification of variables to uphold the rigor of the experiments in terms of comparability with other experiments and ensure the relevance of their outcomes within the broader framework of planetary construction research.

A. ISRU Construction Technologies

Numerous manufacturing technologies for In-Situ Resource Utilization (ISRU) construction show promising results for construction using Martian and Lunar regolith. Each technology employs different processes to produce construction materials and mass for infrastructure and habitats. Not only do these technologies offer unique opportunities and limitations, but the characteristics of their outputs also vary, affecting their feasibility in the context of Martian and Lunar environments. Additive, Subtractive, and Formative technologies have all been considered for construction on the Moon and Mars. Their success is largely contingent upon their ability to utilize in-situ regolith, which is abundant on both celestial bodies. However, the list of processes below, which involve the use of sintered or melted regolith, have proven particularly cost-effective and robust [1]:

1. Radiance Furnace Sintering

Radiance Furnace Sintering is a thermal process designed to bind particles into a solid without completely melting the material [1].

2. Microwave Sintering

As an alternative to radiance furnace sintering, Microwave Sintering is another thermal process that utilizes electromagnetic waves with frequencies between 300 MHz and 300 GHz. Materials interact with these frequencies and absorb heat based on their dielectric properties [1].

3. Cast Regolith

In this process, regolith is heated until the particles fully melt, surpassing the liquidus temperature. This procedure produces dense materials that exhibit strong resistance to abrasion [1].

4. Direct Sintering

Direct Sintering is a variation of radiant and microwave sintering in that the material is sintered in place [2].

5. Additive Manufacturing (AM) for construction

Often referred to as additive construction, this extrusion-based method uses a mobility system—such as a gantry, robotic arm, or crane—to position a nozzle that extrudes a bead of cementitious material in successive layers, following a specified path [3].

6. Regolith Fiber

This relatively new process bears similarities to the glass production technique on Earth. Fibers are produced by heating and melting the regolith to a specific viscosity before reaching the liquidus point of the material. The molten mass is then extruded through an orifice plate and wound onto a drum where it is stored until used [4].

7. CNC Machining

CNC (Computer Numerical Control) machining is a type of subtractive manufacturing where objects are created by progressively removing material from a solid block or sheet. This process is controlled by a computer and makes use of CAD (Computer-Aided Design) and CAM (Computer-Aided Manufacturing) to create and instruct the CNC machine, respectively. The major processes in CNC machining include turning, drilling, and milling, all aimed at removing material in accordance to a 3D model [5] [6] [7].

8. Laser Cutting

Laser cutting is a subtractive manufacturing technology that uses a high-power laser beam to cut or engrave materials. The process works by directing the laser beam at the material, which then either melts, burns, vaporizes, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Laser cutting is typically used for cutting sheet metal but can also be used for cutting materials like plastics, wood, and ceramics. It's particularly known for its high precision and accuracy, making it a common choice for detailed work. The laser cutting process is controlled by a computer program, often in conjunction with CAD software for designing the end product [8] [5] [6].

9. Electric Discharge Machining

Electric Discharge Machining (EDM), also known as spark machining, is a subtractive manufacturing technique that uses electrical discharges or sparks to remove material from a workpiece. This process takes place in a dielectric liquid and involves no direct contact between tool and workpiece, thus eliminating mechanical stress. EDM is especially effective for hard materials and complex shapes and requires the material being machined to be electrically conductive. It's frequently used in industries requiring high dimensional accuracy, such as mold-making [9].

10. Others

As research progresses, new technologies, materials, and additives are developed. Although most of the current capabilities fall within the aforementioned categories, a flexible research framework should accommodate future implementations.

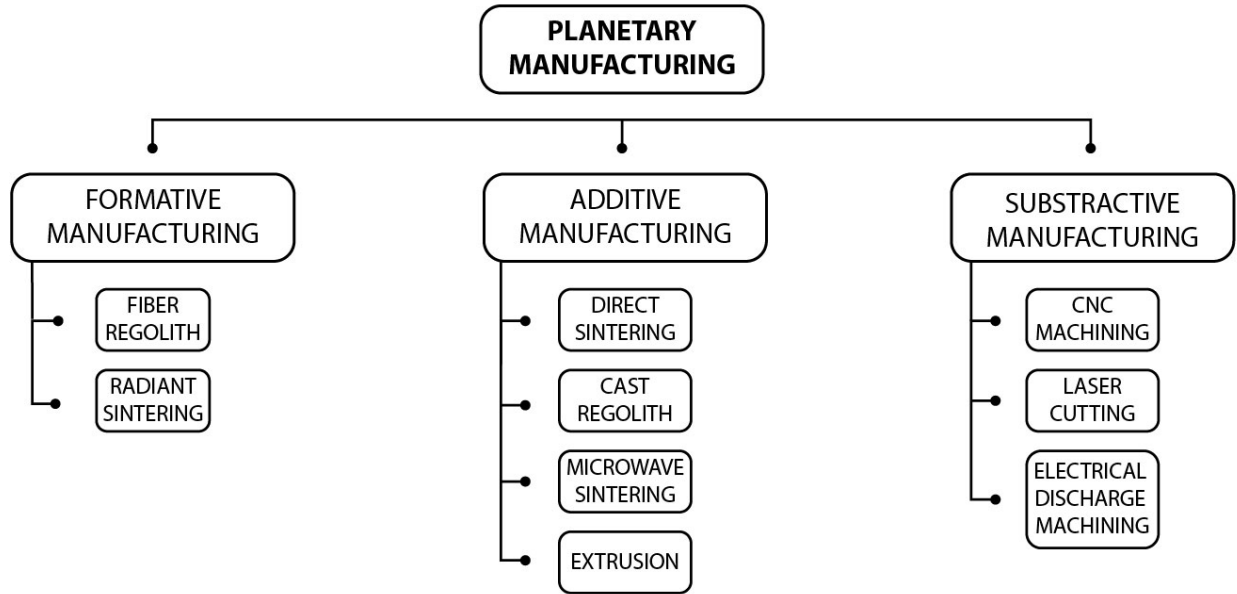


Fig. 1 Construction Technologies Classification

B. In Situ Materials and Simulants

As outlined in section III, materials research plays a pivotal role in the advancement of extraterrestrial construction. Typically, the scarcity of regolith samples - such as Lunar regolith - or the absence of retrieved samples altogether, as in the case with Martian Regolith, makes the utilization of this limited material for testing and experimentation impractical. Consequently, leading space agencies, private corporations, and research institutions have turned to rely on local material simulants. These simulants aim to replicate the real samples, embodying the geotechnical, mechanical, and chemical properties of the regolith based on data obtained from studies carried out on retrieved samples, or from information collected and analyzed using planetary rovers and transmitted back to Earth.

1. In Situ Original Regolith

On Earth, "in-situ" typically refers to using materials from local sources for cement-based concrete, including sand, gravel, Portland cement, water, and wet and dry additives [1]. On the Moon and Mars, "in-situ" pertains to inorganic materials extracted from the planetary surface to serve as the basis for cementitious materials used for construction, as well as binders extracted from the same materials [3]. Regarding lunar regolith, the Apollo missions retrieved 382kg of lunar regolith and rocks [1], and more recently, the Chang'e lander procured additional regolith [10]. As for Mars, no original samples exist yet, however a return mission is planned for 2026. Due to the limited supply of original regolith, the strategy has been to analyze the original material and create simulants rather than expend it in experiments.

2. Regolith Simulants

Regolith simulants are regolith-like materials, often of basaltic composition, produced after extensive analysis of original material retrieved from the lunar surface or data collected from rovers traversing the Martian surface and

analyzing soil samples. Simulants are typically created by combining, melting, cooling, and crushing oxide or carbonate reagent powders in various proportions [1].

Like on Earth, the composition of the original regolith varies with the region it's extracted from. Regolith across the Lunar and Martian surfaces could contain varying amounts of different components and elements and may vary in terms of physical mechanical, and chemical properties and behavior. Hence, different types of regolith simulants would need to be produced to match the original regolith from various regions of the Lunar and Martian surface to test planetary construction in different Lunar or Martian areas. Regolith simulants that closely resemble the original regolith in terms of mineralogy, chemical, engineering, and physical properties are deemed high-fidelity regolith simulants [11].

Today, a range of high-fidelity Lunar, Martian, and asteroid regolith simulants of varying compositions tailored to different applications and research needs are available on the market. The selection of the simulant depends on the objectives of the testing being conducted (Fig. 4 and Fig. 5).

Owing to the lack of Martian regolith retrieved to date, the composition of Martian regolith simulants has primarily been determined by data and soil analysis conducted onboard NASA rovers, such as Curiosity from 2012 [12]. The simulant's composition is a general representation of standard Martian Regolith usable for various purposes.

The varying compositions of simulants representative of the same environment add an additional layer of complexity to establishing a testing standard. Properties such as particle size distribution and geometry, density, porosity, viscosity, permittivity, and even dielectric properties [13] of the simulants not only impact the behavior and performance of the simulant itself but also may influence the technology selection [14].

For instance, simulants with different particle size distributions compared to actual regolith may produce weaker material that may not provide adequate support, necessitating reconsideration of temperature, cooling rate, and layer thickness for sintering [15][16]. Factors like the chemical composition of the simulants, cost, and ease of processing are also crucial when comparing different simulants and the technologies used for testing.

The most significant differences between most simulants and real regolith are not necessarily related to composition, but rather to particle distribution and density. One of the most significant distinctions in geological composition is due to the absence of sodic plagioclase, resulting from the scarcity of anorthite deposits on Earth. In the simulants, phenomena such as the activation of regolith grains by solar wind and cosmic particles, which are not replicable on Earth, are not present. This particle activation creates strong adhesion, on top of a magnetic charge of nanophase iron, a feature that is also impossible to find in simulants [17].

For high Technology Readiness Level (TRL) applications, the use of simulants with and without agglutinates should be considered, as well as the use of real lunar soil. Sample 70050, taken from the Apollo 17 landing site, lacks the detailed provenance characteristics that would make it suitable for scientific studies, rendering it primarily suitable for engineering tests [18].

C. Testing environment

The existing research framework on extraterrestrial construction technologies is exceptionally diverse. Each unique development is shaped by a specific research objective and constrained by the resources at hand. Consequently, scientists and researchers often have to prioritize certain conditions for performing tests. The NASA-STD-1008 outlines ideal conditions for hardware testing in a planetary environment. It provides detailed instructions for testing equipment under conditions that replicate those of a planetary setting. These instructions encompass [19]:

- Moisture Levels
- Pressure
- Particle Distribution
- Temperature

Adhering to these guidelines necessitates a rigorous procedure supported by various technologies aimed at recreating

the characteristics of the planetary environment. The objective of any technological testing in a simulated or relative environment should be to demonstrate the technology's viability in performing its intended function in the environment for which it is designed. For example, machinery intended for construction includes intricate mechanical elements, requires substantial energy consumption, and incorporates moving parts that can easily be damaged in a dusty planetary environment [20]. One of the challenges of space hardware testing is the cost of maintaining a scientifically relevant testing environment. The extraterrestrial conditions of space and planetary surfaces are particularly challenging to replicate on Earth [21]. Space hardware testing demands complex equipment and rigorous testing procedures.

IV. The Construction Testing Framework

Section III explored the fundamental aspects of interplanetary construction technology research, briefly detailing how experiments are conducted to test regolith simulants and various technologies. This section, Section IV, aims to establish a reliable approach to standardize these experiments. The goal is to minimize the number of variables while maintaining flexibility to accommodate different objectives. The Construction Testing Framework proposed in this paper consists of two primary components: the Construction Testing Element (CEL) and the Construction Testing Environment (CEN). The initial point of comparison between various construction technologies is the process. For successful construction on another planet using In-Situ Resource Utilization (ISRU), we need to ensure a high degree of reliability and repeatability in the process, coupled with a comparable output for testing and evaluation. As outlined at the beginning of this section, the intent of the Standard framework is to establish a benchmark for ISRU construction techniques. Each benchmark is defined by a standardized testing element, which enables the comparison of proposed technologies. This standard is considered applicable for construction technologies tested in a laboratory environment. Given that diverse research teams, institutions, and private companies are expected to conduct ISRU research using their own technological means and resources, it is crucial to provide a standard that facilitates easier integration of these construction technologies into future exploration frameworks.

A. The Construction Element (CEL)

A comparison of different construction technologies should ideally be based on the product of the construction process, which is the primary reason for conducting the research. Therefore, it is essential to standardize the construction element.

The Construction Element (CEL) refers to the building block that results from the transformation process of the regolith. Even though the technologies considered vary widely, as do the outcomes and the mechanical properties of the blocks, it remains important to standardize the testing element's form factor to validate the technology's versatility and its suitability to construct different infrastructural elements (or habitats).

The chosen building block is a cylinder measuring 150mm x 150mm with a height of 250mm (Fig. 2). This shape has been selected for its compatibility with Molding, Casting, Additive Manufacturing, and Machining processes, as well as its suitability for most laboratory mechanical testing equipment [22].

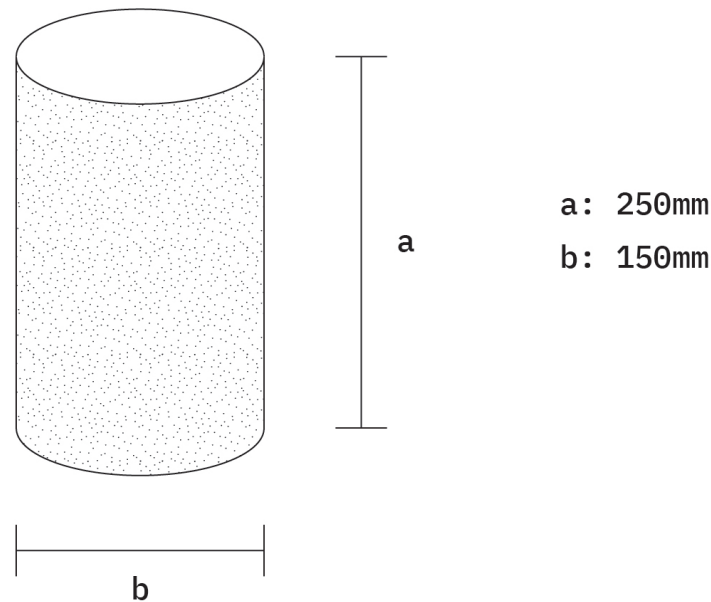


Fig. 2 The Construction Element

B. The Construction Testing Environment (CEN)

The Construction Testing Environment (CEN) pertains to the environmental exposure, or the absence thereof, and the operational conditions of the hardware and the simulants. It can be subdivided into three levels.

As we incorporate increasingly accurate simulations of the environments, the testing becomes more complex and resource-intensive. The complexity and fidelity level of the testing environment can be adapted according to the development status of the technology being tested (Fig. 3). This adaptability ensures that testing is preparatory to validating the specific technology being tested.

- **CEN LEVEL I**

CEN Level I involves conducting basic testing related to the input material and the construction technique. Therefore, the CEN Level I environment is a controlled environment that doesn't necessarily simulate microgravity or vacuum conditions. In other words, it's a standard, preferably indoor, basic controlled environment, where fundamental questions related to construction material and technology can be addressed. It is intended to provide an overarching analysis that can produce findings at a macro scale, such as the suitability of a material for a specific technique or the behavior of the output material based on the parameters/settings of the construction technique.

- **CEN LEVEL II**

CEN Level II testing involves the examination of technology and material within a controlled vacuum environment. CEN Level II environment is intended to provide a secondary level of testing following Level I. It delves deeper into the macro questions addressed by CEN Level I by turning them into micro questions, which would have more to do with the behavior of the input and output material and the construction technique in an environment that represents the Lunar and Martian surfaces.

- **CEN LEVEL III**

CEN Level III testing involves examining processes in microgravity and/or testing in the actual environments of the Moon and Mars. CEN Level III experiments are considered high-fidelity as they primarily aim to validate the findings of CEN Level I and Level II experiments.

TLR	Testing Conditions	Machinery	Material
3-5	Open Air	Regolith Pool	Basaltic dust / Regolith simulant
5-7	Vacuum	Vacuum Chamber	Regolith Simulant
7-9	Thermal Vacuum	Thermal Vacuum Chamber	Regolith Simulant/ Dust sample

Fig. 3 Testing Environment Compared to Development Level

V. Element Testing Framework

The produced element will be further tested by different means to produce a valid data base for technology comparison. The proposed testing standard operates at different scales to provide a complete analysis of the constructed element (CEL). The testing categories include:

- Microstructure Morphology
- Rheology of Regolith Mix
- Material Testing
- Element Testing

The Element Testing Framework is derived from the Construction testing of concrete elements on Earth, which has a long track history record [22]. The element is observed and tested at both micro and macro levels to evaluate the composition of the paste and the distribution of the particles, as well as to conduct mechanical testing on the element.

The element testing aims to define parameters that are useful to determine the mechanical properties of the Regolith mix:

- Young's Modulus
- Yield Stress
- Ultimate Strength
- Ultimate Strain

To define these properties, the following tests will be performed:

- Compressive Strength Test
- Flexural Strength Test
- Bond Strength Test
- Direct Tensile Test
- Splitting Strength Test

These tests are to be performed in the rigor of a lab environment, but there is no restriction on the machinery to be used in the tests. In addition to the mechanical testing, a micro-scale analysis on the regolith mix is performed in a lab environment through rheology of the concrete paste. This step is performed when the regolith mix is in its liquid state and is used to describe different characteristics compared to the mechanical testing [23]:

- Stability
- Compact-ability
- Flow-ability

VI. Conclusion

The purpose of this paper is to establish a foundational standard for testing planetary construction technologies that involve the use of local basaltic materials. These guidelines are derived from the well-established standard of Earth's concrete testing and incorporate elements of extraterrestrial environmental condition simulation that have been refined through decades of space hardware development and testing. For now, this proposal serves as a set of initial guidelines, recognizing that it is still far from defining a comprehensive standard. We anticipate these guidelines will evolve and mature, alongside advancements in the field of space construction technologies. Our hope is that this proposal will encourage discussion, refinement, and further collaboration among scientists, researchers, and engineers in the field, ultimately contributing to the long-term goal of establishing sustainable human settlements beyond Earth.

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Simulants database[24]:

Acronym	Name	Body	Country
C2	C2 Carbonaceous Chondrite Simulant	Asteroid	United States
CI	CI Carbonaceous Chondrite Simulant	Asteroid	United States
CM	CM Carbonaceous Chondrite Simulant	Asteroid	United States
CR	CR Carbonaceous Chondrite Simulant	Asteroid	United States
HCCL-1	Hydrated Carbonaceous Chondrite Lithologies	Asteroid	Canada
IRS-1	Itokawa Regolith Simulant	Asteroid	China
MPACS	Mechanical Porous Ambient Comet Simulant	Comet	United States
SSC-1	Surrey Space Centre	Generic	United Kingdom
SSC-2	Surrey Space Centre	Generic	United Kingdom
	UF Acid-Alkaline-Salt Basalt Analog Soils	Mars	United States
	Salten Skov 1	Mars	Denmark
CSM-MGS-1	CSM Mars Global Simulant	Mars	United States
CSM-MGS-1C	CSM Mars Clay ISRU	Mars	United States
CSM-MGS-1S	CSM Mars Sulfate ISRU	Mars	United States
ES-X	ES-X Mars Simulants	Mars	Europe
JEZ-1	Jezero Delta Simulant	Mars	United States
JMSS-1	Jining Mars Soil Simulant	Mars	China
JSC Mars-1/1A	Johnson Space Center	Mars	United States
JSC-RN	JSC-Rocknest	Mars	United States
KMS-1	Korean Mars Simulant	Mars	Korea
MGS-1	Mars Global Simulant	Mars	United States
MGS-1C	Clay ISRU	Mars	United States
MGS-1S	Sulfate ISRU	Mars	United States
MMS	Mojave Mars Simulant	Mars	United States
MMS-1	The Martian Garden	Mars	United States
MMS-2	Mojave Mars Simulant	Mars	United States
NEU Mars-1	Northeastern University Martian soil simulant	Mars	China
OUCM-1	Open University Contemporary Mars	Mars	United Kingdom
OUCM-2	Open University Contemporary Mars	Mars	United Kingdom
OUEB-1	Open University Early Basaltic	Mars	United Kingdom
OUEB-2	Open University Early Basaltic	Mars	United Kingdom
OUHR-1	Open University Haematite-rich	Mars	United Kingdom
OUHR-2	Open University Haematite-rich	Mars	United Kingdom
OUSR-1	Open University Sulfur-rich	Mars	United Kingdom
OUSR-2	Open University Sulfur-rich	Mars	United Kingdom
P-MRS	Phyllosilicatic Mars Regolith Simulant	Mars	Germany
S-MRS	Sulfatic Mars Regolith Simulant	Mars	Germany
UC Mars1	University of Canterbury	Mars	Australia
Y-Mars	Yellowknife	Mars	United States
	Oshima Simulant	Moon	Japan
	Maryland-Sanders Lunar Simulant	Moon	United States
	Kohyama Simulant	Moon	Japan
ALRS-1	Australian Lunar Regolith Simulant	Moon	Australia
ALS	Arizona Lunar Simulant	Moon	United States
BHLD20	Beijing Highlands Lunar Dust	Moon	China
BP-1	Black Point	Moon	United States
CAS-1	Chinese Academy of Sciences	Moon	China
CHENOBI	CHENOBI	Moon	Canada
CLDS-i	China Lunar Dust Simulant	Moon	China
CLRS-1/2	Chinese Lunar Regolith Simulant	Moon	China
CMU-1	Carnegie Mellon University	Moon	United States

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CSM-CL	Colorado School of Mines Colorado Lava	Moon	United States
CSM-LHT-1	CSM Lunar Highlands Type	Moon	United States
CSM-LMT-1	CSM Lunar Mare Type	Moon	United States
CUG-1A	China University of Geosciences	Moon	China
CUMT-1	China University of Mining and Technology Number One	Moon	China
DNA-1	De NoArtri	Moon	Italy
EAC-1	European Astronaut Centre	Moon	Europe
FJS-1/2/3	Fuji Japanese Simulant	Moon	Japan
GRC-1/3	Glenn Research Center	Moon	United States
GSC-1	Goddard Space Center	Moon	United States
JLU-U	JLU-H Highland Simulant	Moon	China
JSC-1	Johnson Space Center	Moon	United States
KLS-1	Korea Lunar Simulant	Moon	Korea
KOHL-1/KAUMLS	Korean Lunar Simulants	Moon	Korea
LCATS-1	Lunar Caves Analog Test Sites	Moon	United States
LHS-1	Lunar Highlands Simulant	Moon	United States
LMS-1	Lunar Mare Simulant	Moon	United States
LSS	Apollo Lunar Soil Simulant	Moon	United States
MKS-1	MKS-1 Lunar Simulant	Moon	Japan
MLS-1/1P	Minnesota Lunar Simulant	Moon	United States
MLS-2	Minnesota Lunar Simulant	Moon	United States
Mooncastle	Mooncastle	Moon	United States
NAO-1	National Astronomical Observatories	Moon	China
NEU-1	Northeastern University Lunar Simulant	Moon	China
NU-LHT	NASA/USGS Lunar Highlands Type	Moon	United States
OB-1	Olivine Bytownite	Moon	Canada
OPRFLCROSS1	Off Planet Research LCROSS Simulant	Moon	United States
OPRH2N/H2W/H3N/H3W	Off Planet Research Highlands Simulant	Moon	United States
OPRL2N/L2W	Off Planet Research Mare Simulant	Moon	United States
TJ-1/2	Tongji University	Moon	China
TLS-01	Thailand Lunar Simulant	Moon	Thailand
TUBS-M	TU Braunschweig Base Simulant Mare	Moon	Germany
TUBS-T	TU Braunschweig Base Simulant Terrae	Moon	Germany
UoM-B	University of Manchester – Black	Moon	United Kingdom
UoM-W	University of Manchester – White	Moon	United Kingdom
	Carbonaceous Chondrite Based Simulant of Phobos	Phobos	United States
PCA-1	Phobos Captured Asteroid	Phobos	United States
PGI-1	Phobos Giant Impact	Phobos	United States
UTPS-IB	University of Tokyo Phobos Simulant, Impact-based	Phobos	Japan
UTPS-TB	University of Tokyo Phobos Simulant, Tagish Lake-based	Phobos	Japan

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