Development of New Lunar Simulant from Terrestrial Soil

- A Comparative Study

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Abstract— **The need for terrestrial soil and crushed rocky soil for making simulants, especially Lunar and Highlands regolith (Apollo-16 sample) simulants has resulted in research activities with new simulants. As it is difficult to simulate all the characteristics of the lunar samples, researchers try to match the properties as much as possible. This paper outlines the research activities carried out on the native soil samples collected from Sittampundi complex of Namakkal district, Tamil Nadu, India. The sample was analysed for mineralogical characteristics by X-Ray diffraction method and for geotechnical characteristics such as grain size distribution, specific gravity, shear strength parameters (cohesion and angle of internal friction), minimum and maximum dry densities in accordance with relevant Indian Standards. The results obtained were compared with those of the existing lunar simulants, Lunar samples and with a newly developed Indian simulant.**

Keywords- ***Indian soil simulant,Geotechnical properties, Lunar stimulants***

I. INTRODUCTION

Simulants are prepared with the purpose of simulating one or more physical and/or chemical properties of a lunar rock or soil. Terrestrial materials, specifically chosen to simulate the lunar soil, need to be processed in order to replicate the critical physical and chemical parameters of the regolith; they may also have added synthetic materials such as glasses, metals, and minerals to provide some of the unique qualities of lunar regolith.(Chunmei He, 2010). There are more than 30 simulants that have been produced till date - by various countries for various purposes produced from various natural and man-made materials such as crushed volcanic tuffs with abundant glass to anorthosite with added fayalitic, to synthetic agglutinates, to synthetic nanophase metallic iron. (Carrier et. al.,1991). Accurately produced lunar regolith properties(higher fidelity simulants) are required, especially for conducting various tests.

They are essential for the system requirements for lunar exploration and in support of future human activities on the Moon.

Such studies include material – Handling, Construction, Excavation,Transportation

The simulants are also appropriate for research on: Dust control, Spacesuit durability and Agriculture.

II. OBJECTIVES

The following objectives were identified.

1. Identification of potential location for collecting soil sample for development of lunar soil simulants.
2. Review of the properties of lunar soil and understanding the conditions under which these properties were determined.
3. Review of the properties of existing lunar soil simulants and understanding the purpose and intent of creation and use.
4. Characterisation of geotechnical properties of a new lunar regolith mare simulant.
5. Comparison of these properties with the lunar regolith and other existing lunar soil simulants.

III. LITERATURE REVIEW

Numerous experimental studies have been conducted to understand the properties of lunar samples. In this section, properties of lunar soils characterized by previous researchers have been reviewed very thoroughly

Carrier et al. (1991) found that the ranges of geotechnical properties of lunar materials are less than those that occur in surficial materials on Earth. This is due to the three factors. First, no chemical weathering, running water, wind, and glaciations exist on the Moon. These processes tend to yield well-sorted sediments with uniform grain sizes. The primary lunar soil forming process meteoroid impact produces a heterogeneous and well-graded soil. The second factor is the lack of water, clay minerals and organic materials, which produce unusual or “problem” soils on Earth. Third, the variety of minerals in lunar soil is much less than found on Earth. Therefore, the geotechnical properties of lunar soil tend to fall in a relatively narrow range.

Aarthy et al. (2009) conducted spectral studies of anorthosite on rock sample located in Sittampundi complex, Namakkal district of Tamilnadu. This study is an attempt to understand the lunar highland surface. The massive anorthosite sample spectra have the highest spectral reflectance of lunar high land. Results indicate that Sittampundi rock sample have highest reflectance similar to that of lunar highland due to the presence of anorthosite.

Carrier et al. (1991) conducted a complete review of the particle size distribution of nearly 350 lunar samples obtained. These samples were taken in the vicinity of six landing sites on the Moon: Apollo 11, 12, 14, 15, 17, and Luna 24. On average, it contains approximately 2% coarse sand (2.0 to 4.75 mm), 14% medium sand (0.425 to 2.0 mm), 33% fine sand (0.074 to 0.425 mm), and 51% silt. The majority of the lunar soil particles fall in a fairly narrow range of particle distribution. This is due to the meteorite impact, which is the primary lunar soil formation process. In general, the lunar soil is a well graded (or poorly sorted) silty sand to sandy silt, with approximately half the soil particle by weight irresolvable with the unaided eye (SW-SM to ML in the Unified Soil Classification System).

The lunar particle size distribution data is primarily determined by means of sieving, generally effective for particle sizes greater than about 10 µm. A few investigators have also used sedimentation columns, Coulter electronic counters, computer-coupled television optical microscopes, and scanning electron microscopes for finer size fractions. Various sieving techniques have been employed by different investigators: dry; dry with brushing; dry with sonic sifter; wet with vibration; wet (methanol) with sonic sifter; wet (acetone) with vibration.

Carrier et al. (1991) recommends a value of 3.1 for general scientific and engineering analysis. The lunar soil exhibits sub-granular porosity which exists as voids enclosed within the interior of the lunar soil particles. During the specific gravity test, the soil particles are immersed in a fluid to measure the volume that it replaces. Various fluids can be used, including water, air, or helium. The fluid can fill into the intergranular and intragranular voids, but not the sub granular voids.

The specific gravity ranges from 2.8 to 3.25 (Chunmei He (2010) (Water Pycnometry/Helium pycnometry/Nitrogen Pycnometry are adopted.)

IV. METHODOLOGY

A. Collection of Sample

Sittampundi samples have good reflectance of anorthosite material (Aarthy et al., 2009). Hence the soil samples were collected from the native soils of Sittampundi and the geotechnical properties were characterized.

B. Mineral Characterisation

Mineralogical characteristics of the material were determined with the help of X-ray Diffraction, so as to understand the mineralogical parameters in the native sample.

C. Geotechnical Characterisation

- Particle size distribution

The particle size distribution of a material is the most important parameter in determining its geotechnical properties. The particle size distribution of lunar regolith has a significant variation with depth and from location to location (Carrier et al., 1991, Carrier, 2003). Based on all the available data on particle size distribution of lunar regolith, the first step is to investigate whether the particle size distribution of new lunar soil simulant matches with that of lunar regolith. The tests to determine the particle size distribution of new simulant are as per IS 2720(Part 4)-1985 (Reaffirmd 2006), ´´Method of test for Soils-Grain Size analysis´´.

- Specific gravity

Specific gravity of a soil is defined as the ratio of the mass density of solid particles to the mass density of pure water at 4°C. Values for lunar soils range from 2.3 to 3.2 and a value of 3.1 is recommended for general scientific and engineering analysis of lunar soils (Carrier et al., 1991). The specific gravity of new simulant is determined as per IS 2720(Part 3/Sec 1)-1980 (Reaffirmed 2002), ´´Method of test for Soil- Determination of Specific Gravity´´.

- Shear strength Parameters

Shear strength parameters - cohesion and angle of internal friction are determined using Mohr-Coulomb failure criterion. Direct shear test is conducted to determine shear strength parameters. The shear strength parameters are determined as per IS 2720(Part 13) -1986 (Reaffirmed 2002), ´´Method of test for Soil-Direct shear test´´.

- Minimum and maximum densities

The state of density of a dry soil is typically measured in terms of maximum and minimum densities. Minimum and maximum dry density are determined in accordance with IS 2720 (Part 14)-1983 (Reaffirmed 2006), ´´Method of test for Soil-Determination of density index of cohesion less soils´´.

- Comparison with existing simulants

A comprehensive study is carried out on the geotechnical properties of lunar regolith and comparisons made with existing lunar simulants including MLS-1, JSC-1, JSC-1A, GRC-1, GRC-3, NU-LHT-2M. These are compared with new lunar simulants in order to establish benchmark properties.

V. RESULTS AND CONCLUSIONS

- Mineralogical characterisation of soil simulant

The sample was collected from Namakkal District, Tamilnadu in India and the soil sample was tested meticulously.

Major mineral compounds present in sample (from XRD) (Table 2)

Table 2 Composition from XRD

Peak No	d-Value	Intensity (cps)	Mineral
1	3.1685	2800	Apuanite
2	3.1597	1580	Komarovite
3	3.3214	487	Ferroaluminoceladonite
4	3.3141	440	Wollastonite -1A

- Geotechnical Characteristics

The geotechnical characteristics of the material were determined as per Indian Standards. The properties for the natural soil sample collected and properties for various particle size ranges were determined

A. Grain size analysis

Comparison of Grain size distribution, specific gravity,cohesion and internal friction angle and the densities for various existing simulants is shown in Fig.1. to Fig.8 respectively.

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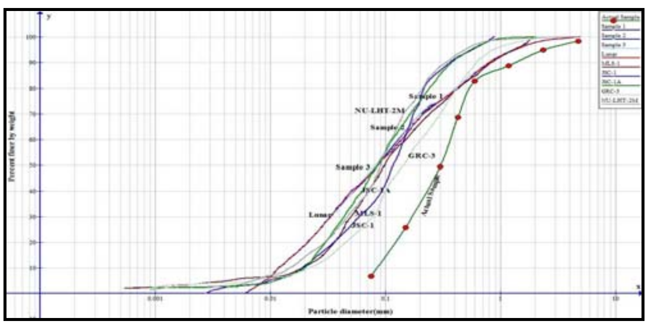

Fig.1 Grain size distribution of various simulants

B. Specific Gravity

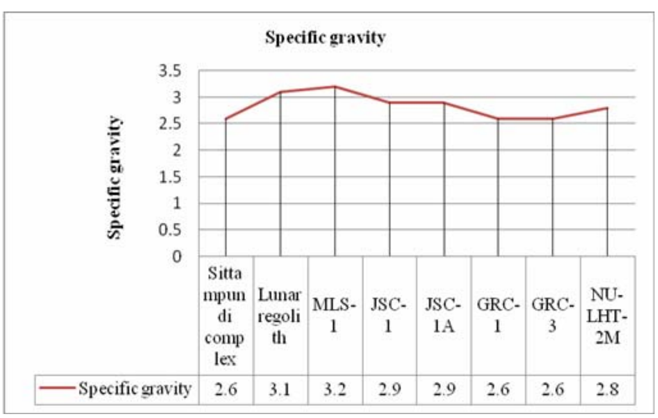

Fig.2 Specific Gravity of various Simulants

C. Cohesion

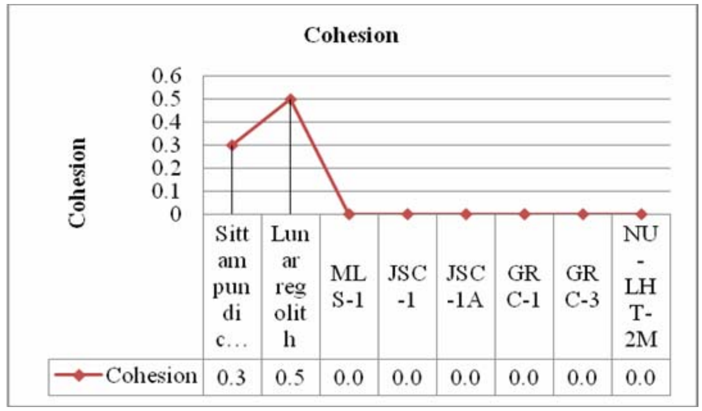

Fig.3 Cohesion value of various Simulants

D. Angle of internal friction

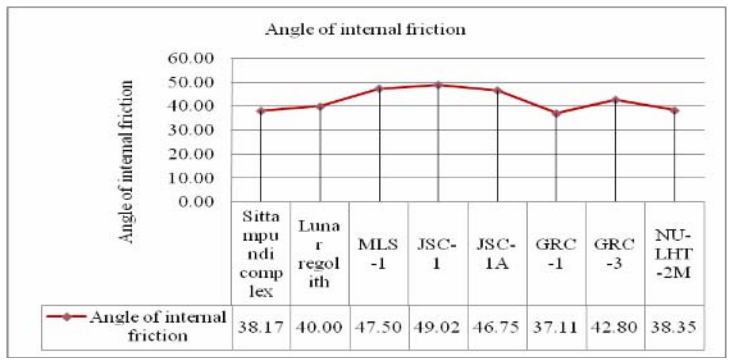

Fig.4 Angle of internal friction of various Simulants

E. Minimum dry density

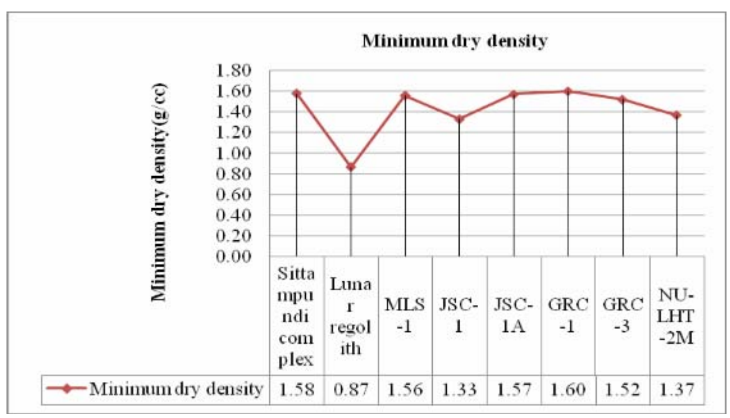

Fig.5 Minimum dry density of various Simulants

F. Maximum dry density

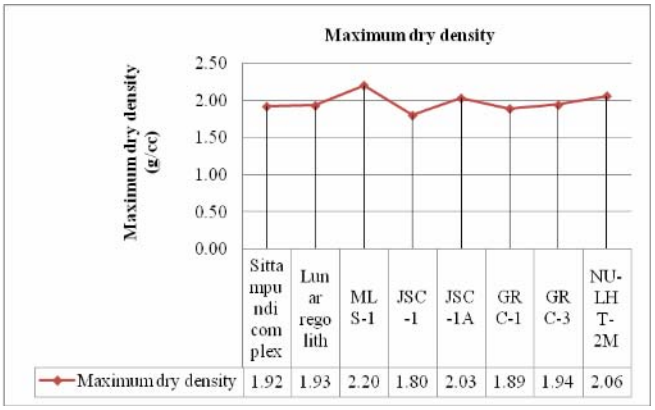

Fig.6 Maximum Dry Density Of Various Simulants

Thus Various Results Obtained Are Illustrated - Which show the comparison with the Properties of various Simulants Considered.

Fig.7 Soil Sample Of Sittampundi Complex Of Namakkal District, Tamilnadu , India

G. Direct Shear Test – Fig.8

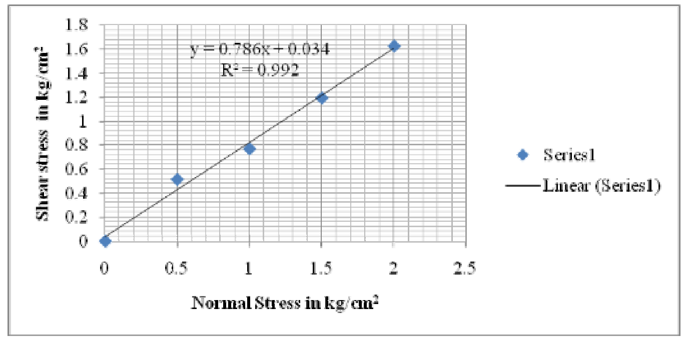

Fig.8 Shear Stress (kg/cm^2)(Y) Vs. Normal Stress(X) (kg/cm^2)

- Geotechnical Properties Of Sittampundi Sample

Table 7 Geotechnical Properties Of Sittampundi Sample

Geotechnical	Test Methods	Result
Specific Gravity	IS: 2720 (Part 3/Sec 1) – 1980	2.6
Cohesion	IS: 2720 (Part 4) – 1985	38.17 Degrees
Angle Of Internal Friction	IS: 2720 (Part 4) – 1985	0.034 kg/cm^2
Minimum Dry Density	IS: 2720 (Part 14) – 1983	1.58 g/cc
Maximum Dry Density	IS: 2720 (Part 14) – 1983	1.92 g/cc
Coefficient Of Uniformity	IS: 2720 (Part 4): 1985 (Reaffirmed 2006)	4.33
Coefficient Of Curvature	IS: 2720 (Part 4): 1985 (Reaffirmed 2006)	0.95
Water Content	IS: 2720 (Part II) – 1973.	0.68%

- CONCLUSIONS

The particle size distribution of the new simulant matched with lunar mare soil by adding known percentages of different particle sizes, found from grain size analysis curve for lunar soil. Also existing simulants falls between +1 standard deviation and -1 standard deviation of typical lunar soils.(Carrier,1970,1973,1991, Costes and Mitchell, 1970, Costes et.al. 1970a, 1970b) In most particle size ranges, it is close to the average of lunar soils.

The value of cohesion for the new simulant varies from 0.7kPa to 1 kPa which is slightly higher than that of cohesion of lunar regolith. Cohesion for lunar regolith varies from 0 to 1 kPa. The peak angle of internal friction of new simulant varies from 36.61° to 45.14° which is close to the average of lunar soil. Recommended value for lunar sample is 41° - 51°. Existing simulants such as MLS-1,JSC-1, JSC-1A, GRC-1, GRC-3, NU-LHT-2M. varies from 37.11° to 49.02°(David Mc.Kay et al. 1994, David A.Kring 2006, Duke et.al 1970a, 1970b, Heywood 1971, Scott R.F. 1975, Scott et. al 1970).

Minimum dry density for new simulant ranges from 1.11 g/cc to 1.17 g/cc which is slightly more than that of lunar regolith which has a minimum density of 0.87 g/cc. Existing simulant varies such as MLS-1, JSC-1, JSC-1A, GRC-1, GRC-3, NU-LHT-2M. from 1.33 g/cc to 1.6 g/cc.

Maximum dry density of the new simulant ranges from 1.62 to 1.92 g/cc. Lunar regolith consists of maximum dry density of 1.93 g/cc. Existing simulant MLS-1, JSC-1, JSC-1A, GRC-1, GRC-3, NU-LHT-2M. varies from 1.8 g/cc – 2.2 g/cc.

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