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DEVELOPMENT AND MECHANICAL PROPERTIES OF
STRUCTURAL MATERIALS FROM LUNAR SIMULANT

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Abstract

Development of versatile engineering materials from locally available materials in space is an important step toward testablishment of outposts such as on the Moon and Mars. H e r e development of the technologies for manufacture of structural and construction materials on the Moon, utilizing local lunar soil (regolith), without the use of water, is an important element for habitats and explorations in space. It is also vital that the mechanical behavior such as strength and flexural properties, fracture toughness, ductility and deformation characteristics are defined toward establishment of the ranges of engineering applications of the materials developed.

The objectives here include two areas: (1) thermal "liquefaction" of lunar simulant (at about 1100°C) with different additives (fibers, powders, etc.),^{1,2} and (2) development and use of a new triaxial test device in which lunar simulants are first compacted under cycles of loading, and then tested with different vacuums and initial confining or insitu stress. The second area has been described in previous progress reports and publications^{3,4}; since the presently available device allows vacuum levels up to only 10⁻⁴ torr, it is recommended that a vacuum pump that can allow higher levels of vacuum is acquired.

Introduction and Results to Date

The development of new construction materials through liquefaction of lunar simulants with various admixtures (powders and fibers), and determination of mechanical properties using various laboratory testing devices to perform bending and flexure, cylindrical triaxial, and three-dimensional multiaxial tests are the main objectives in this progress report.

The lunar simulant used, called Arizona Lunar Simulant, has been developed locally from a basaltic rock found near Hanford, WA. This material has a mineralogical composition similar to that of the lunar mare soil. The rock is ground so that its grain size distribution falls well within that of the distribution envelopes for the samples of the lunar regolith brought to earth by Apollo missions, Fig. 1.

In order to achieve various engineering properties such as flexure, compressive, tensile and fracture strengths, deformation characteristics, and ductility, the lunar simulant is combined with various powders and fibers. These include steel, stainless steel, aluminum, and fiberglass. The simulant itself, and with various percentages of powders or fibers, is liquefied in a furnace with a temperature capacity of 1700°C. The material is placed and compacted in molds made of

graphite and titanium so that appropriately sized specimens for various tests can be obtained (see Table 1). Diagrams of these samples with loading conditions are shown in Figure 2.

In the thermal liquefaction, the simulant melts at about 1100°C and forms a matrix that can be made into various specimen sizes and shapes. The resulting intermediate ceramic, formed solely by the simulant, is relatively brittle. With addition of a powder or fiber, the liquefaction may involve melting of the admixture at a lower or higher temperature than that for the soil simulant. Thus the powder/fiber melts before the heated soil particles or vice versa, resulting in a "ceramic composite." Such composites can possess a wide range of the aforementioned mechanical properties.

An objective of the research is to perform a parametric study in which the ratio of simulant to powder/fiber is varied, together with different levels of temperature and cycles of temperature, the latter is expected to add "prestressing" due to residual expansion of the powder/fiber. It has been noted that such powders and fibers can be manufactured from the lunar regolith. Table 2 shows details of the initial batch of samples made for beam bending tests.

Specimens of the material combinations thus developed will be tested for bending, fracture, ductility, and stress-strain-strength properties using laboratory testing methods as described previously. This is a vital step toward potential engineering applications of the materials developed, because based on the parameters and constants determined, the ranges and type of application of the materials developed in space construction can be established.

The current research so far has included: 1. Acquisition of the furnace, 2. development of a beam bending device as per the ASTM standard, 3. production of a number of beam specimens with varying admixture content (Table 2), and 4. testing of a number of beam specimens for their load-displacement behavior. Typical test results are shown in Figure 3. It can be seen that the addition of fibers contributes greatly to the load-carrying capacity and ductility of the material.

Development of cylindrical and multiaxial specimens will be the subjects of future research. The latter will be tested in unique three-dimensional devices (Figure 4) that allow application of three independent principal stresses, different paths of loading, and static and cyclic loading. Future work will also involve use of the Arizona simulant and the simulant developed at the University of Minnesota to include determination of the effect of agglutinates in this type of research. Agglutinate is a small glass-welded aggregate of rock, mineral, and glass fragments formed during micrometeorite impacts into the regolith. Also considered will be acquisition and use of a pump with higher vacuum levels and testing of specimens under higher levels of vacuum, about 10^{-12} torr. This will also be used to continue the study using the new vacuum triaxial device.

The final objective of the research is to develop a methodology by which structural materials can be produced on the Moon using locally available and derived (fibers, powders, etc.)

materials, formed into useful shapes by thermal solar energy and compaction. In addition to the development of materials, attention must be given to the determination of the mechanical properties necessary to structural design so that the material can be used in a wide range of engineering applications such as roads, foundations, blocks, walls, floors, buildings, support systems, and shields. The research results are expected to represent a significant contribution towards construction of facilities on the Moon.

References

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Table 1. Various specimens

SHAPE	SIZE	TEST	STATUS
Rectangular	1.0 x 2.5 x 25 cm.	Bending	Current
Cylindrical	5.5 cm.diam. x 15 cm.ht.	Triaxial	Future
Cubical	10 cm. x 10 cm. x 10 cm.	Multiaxial	Future

Table 2. Beam samples prepared to date

1. Lunar Simulant Only

<u>Sample</u>	<u>p. gm/cc</u>
1 -	2.43
2 -	2.44

<u>2. Fibers</u>	<u>% By Weight</u>	<u>% Volume</u>	<u>Matrix p. gm/cc</u>
Steel	15.0	4.65	2.17
Steel	30.0	10.95	2.26
Stainless	7.5	2.32	2.39
Stainless	15.0	4.54	2.20
AL	7.5	7.27	2.61
AL	15.0	--	--
AL shavs	10.0	--	--

- 20 samples have been made so far.
- Each of these is cut into 1-3 beams for testing.
- All batches were heated at the same cycle. Heat of 1100C was held for 1 hour, then cooled over an eight hour period.
- AL = Aluminum

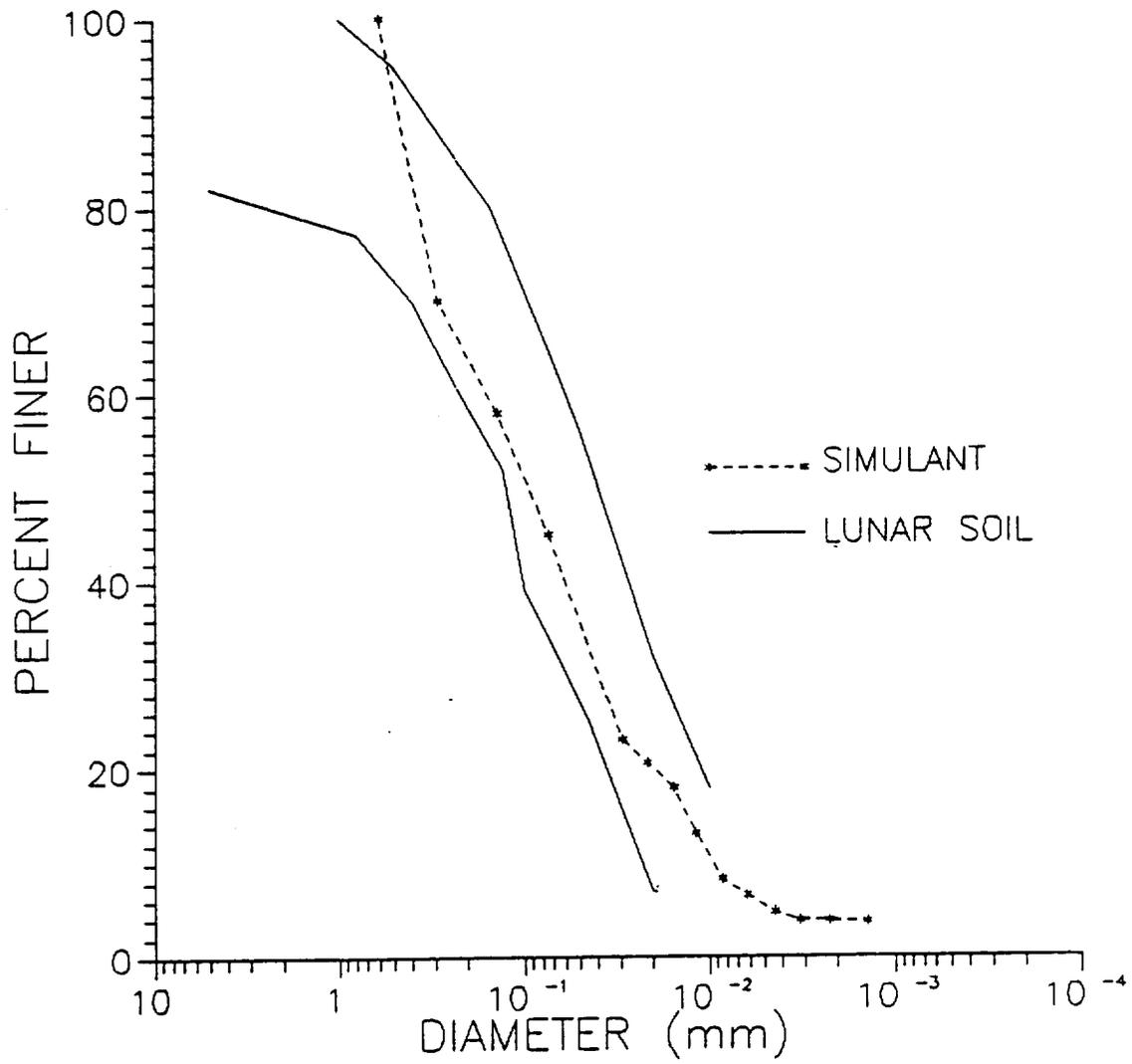
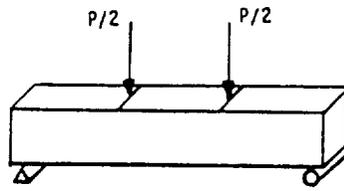
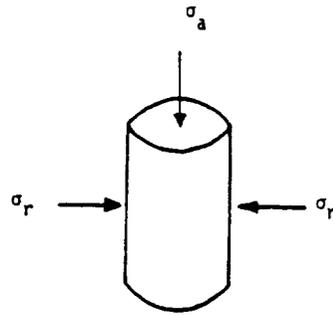


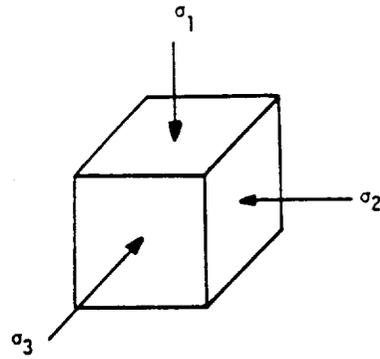
Figure 1. Grain size distribution of actual lunar soil and simulant



a) Beam bending.



b) Cylindrical triaxial.



c) Multiaxial.

Figure 2. Specimens for bending, cylindrical, and cubical tests

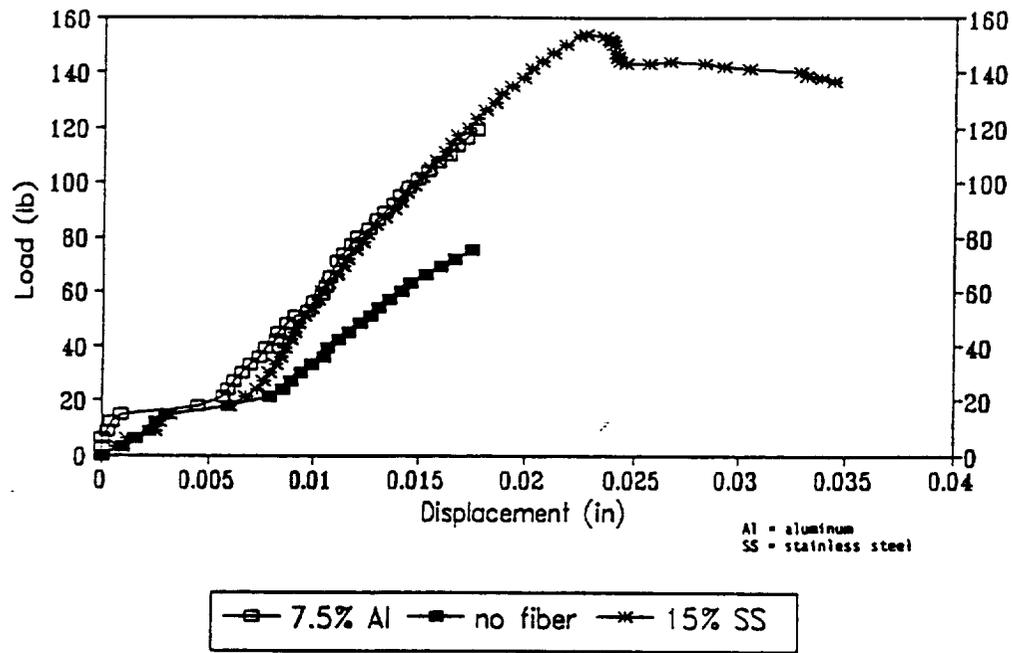


Figure 3. Load-displacement curves for typical simulant-fiber beams

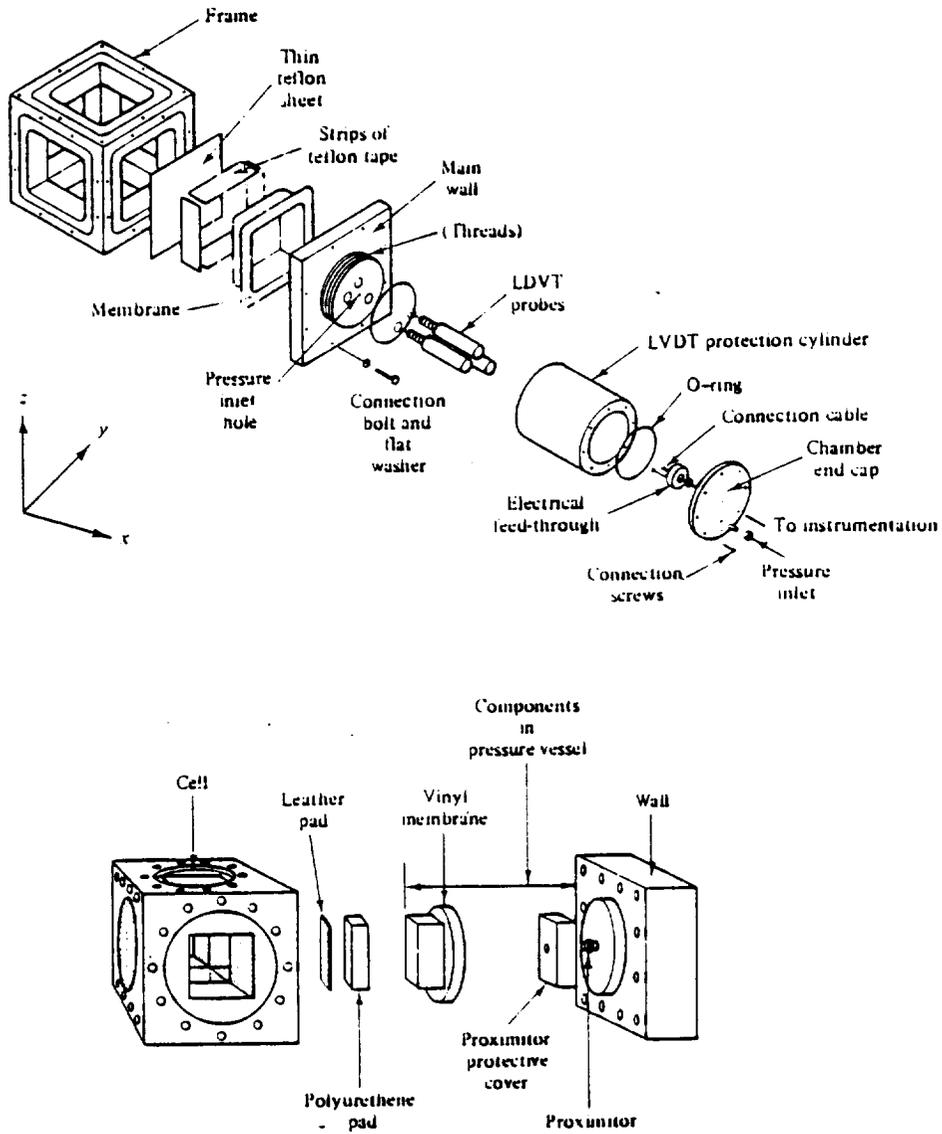


Figure 4. Multi-axial test devices