On the *In Situ* Utilization of Sulfur-Based Concrete on the Lunar Surface

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ABSTRACT

Long term human exploration, habitation, and colonization of interplanetary bodies will require the development of economical and robust engineering and construction techniques in order to create sustainable habitats and protection for human explorers. In this paper, the authors examine the factors related to in situ resource utilization and construction techniques that may be explored for long term habitat construction and support in space.

(Keywords: in situ resource utilization, ISRU, space exploration, space colonization, space construction Lunar exploration, extraterrestrial resource exploitation, lunar concrete).

INTRODUCTION

Earthly construction techniques face various difficulties presented by the distinctive lunar topography and may be difficult to implement. One overwhelming issue is the creation of appropriate development materials. Materials must offer comparative quality, strength, and other building properties to help human residence as on Earth.

Composition of ejecta and lunar lava tube regolith is a well-established variable determinant of structural stability. Lunar lava tubes are tunnels that are believed to be formed from fast-moving lava flows. Ejecta are the remnants of meteor impact, volcanic/stellar explosion. Because, the surface of the moon is very harsh, *in situ* resources play a key part in measures to be taken in emergency situations.

The main three issues that astronauts face while on the moon's surface are: falling micrometeorites, exposure to extreme temperatures, and fatal levels of radiation. The concept of “lunar concrete” was first introduced after the identification of intact lava tubes with high loading capacity [1].

Micrometeorites are small and incredibly quick falling pieces of space debris that can cause various impacts on astronauts and equipment, depending on the size of the micrometeorite and the speed at which its travelling. On Earth, most micrometeorites do not reach Earth's surface because as they are subject to vaporization by profound amounts of heat produced by the friction of passing through earth's atmosphere [2]. In deep space however, there are no atmospheric shields to protect a spacecraft or a spacewalker in the case of falling micrometeorites.

Likewise, exposure to extreme temperatures is another consideration on human missions and for human habitation on the lunar surface. Unlike Earth, daytime temperatures vary widely from night temperatures on the Moon.

Another major issue is the exposure of astronauts to fatal levels of radiation while on the Moon's surface, which may come in various ways such as: solar flares which are constituted similarly to the solar wind, but the individual particles hold higher energies, galactic cosmic rays which are composed of very high energy particles, mostly protons and electrons. Considerations must also be taken into account for the atmosphere and magnetic field which the moon lacks, compared to the Earth’s surfaces.

Here, we describe the utilization of using “lunar concrete” in a similar way to how cement is utilized on Earth. We describe its ability to:

(i) maintain its shape and structural properties,

(ii) offer protection from micrometeorites, extreme temperatures, and radiation, and

(iii) act as a reliable building tool for human space missions and future habitation.

Structural Properties and *in situ* Shielding Abilities

Not at all like under Earth-bound situations, pressure driven cement including concrete, granular and water may not be appropriate under lunar conditions. The essential reason for this is that the moon does not contain substantial presence of water. Given innovation to date, transportation of this fluid from Earth is additionally not financially attainable.

Arrangement of lunar magma tube regolith is additionally a variable determinant of auxiliary steadiness. In the wake of distinguishing unblemished magma tubes, the idea of "lunar cement" is acquainted with increment stacking limit. As such, its utilization for radiation protecting and temperature change is conceivable.

Cast regolith would be fundamentally the same as Earthly cast basalt where the regolith is softened and let to cool to shape a crystalline structure. The compressive and tractable structure parts are reinforced accordingly.

Sulfur-based cement is proposed to substitute pressure driven based cement for lunar development. Advantages of sulfur-based lunar cement consist of factors including its quality, sturdiness and astounding protecting properties [3].

Additionally, financial considerations for development and transport expenses are eliminated when considering *in situ* utilization of this material. Sulfur-based solid examples were made to ponder the possibility of utilizing lunar regolith and folios. The most significant factor in utilizing sulfur cement contrasted with earthbound pressure driven cement is that it does not require the loading of water for compounding.

Compositional Properties and Building Capacity of Lunar Cement

Previous tests demonstrate that this sort of cement can increase full quality in a moderately brief timeframe and requires less warmth to produce [2]. Because cements of all kinds are fragile, Omar proposed the employment of metal filaments in the framework to increment elasticity and diminish weakness. The finding presumes that the 25.4mm fiberglass filaments of 0.25% and 0.50% weight diminished compressive quality by 27% and rigidity by 20%.

Most of the mineral found on the moon are made out of silicates. Creation of lunar basalts is roughly half pyroxenes, 25% plagioclase and 10% olivine by volume. With the synthetic synthesis as a primary concern, the creator must consider the heaps for structure. In essential auxiliary mechanics, a fashioner must consider the dead burden, which is principally from the heaviness of the development material brought about by gravity. Interior pressurization and the measure of protecting must likewise be considered as this may build the dead burden. Live loads brought about by moving or vibrating articles, for example, ventilation apparatus must be additionally incorporated into the transportation and construction plan.

Constructional Considerations for Protective Effectiveness

A Factor of Safety (like in Earthly structure construction regulations) must be incorporated for incidental effect loads from potential micrometeorites, conceivable seismic movement, outrageous Sun-oriented maximums, and so forth. This worth should be evaluated through experimentation. As it would be a challenging test to perform such analyses on the moon, researchers and specialists should lead these tests under comparable condition which may inevitably have a higher probability of error.

Late experimentation by Toutanji *et. al.* investigated supplanting the coupling blend of cement with sulfur and JSC-1 lunar simulant [4]. The lunar simulant was created by Johnson Space Center in Houston, TX, as a total expansion in lieu of the proposed lunar regolith. The examination concluded that the sulfur-based cement is possible under lab condition reenacting lunar conditions. Thus, sulfur-based cement is able to maintain its shape, no matter of the issues faced by the harsh conditions of the moon, such as falling micrometeorites, exposure to extreme and rapid temperature changes, and likewise, since the moon lacks an atmosphere and magnetic field, exposure to fatal levels of radiation, must be taken into account.

In order to be used on the Moon's surface the sulfur-based cement must withstand average daytime temperatures of about 224.6 degrees Fahrenheit and 107 degrees Celsius, and night average temperatures of -243.4 degrees Fahrenheit and -153 degrees Celsius, respectively. As the experimentation has proved that the sulfur-based concrete is able to withstand such temperatures, thus it remains a reliable tool that may be used on lunar craters.

Further Considerations

Support of magma tubes and ejecta by sulfur-based solid utilizing lunar regolith is a practical arrangement. Contrasted with pressure driven bond cement utilized on earth, it presents comparative quality and strength as showed in tests. Because of the obscure idea of the lunar surface, these properties may change and hence it is hard to assess the exhibition of such a material on the lunar surface. Regardless of the development material being possibly achievable, the whole application procedure of sulfur-based solids should be investigated. The way toward framing, steel fortification establishment, pour and relieving under lunar conditions has not been investigated and should be explored with further inquiries.

We have previously described a classification system to detect Martian levees using polarimetric Synthetic Aperture Radar (polSAR) data analysis, which could additionally be an integral method to enhance the evaluation of sulfur-based concrete construction material [5]. Using this data can also facilitate targeted landing at sites where habitation and missions can bring about greater success, when assessing lunar geomorphological parameters.

It is significant to consider sulfur-based concrete may be a reliable tool to be used on the moon's surface, and thus must be overlooked and examined more closely, in order to ensure its capacity.

Since, the conditions on the Moon's surface are very harsh, and there are many issues that the use of the sulfur-based concrete may face, such as falling micrometeorites, exposure to extreme and rapidly changing temperatures, as well as exposure to fatal levels of radiation, the experimentation conducted has proved that the sulfur-based concrete has the capacity to maintain its shape, and thus it is a reliable tool to be used on the moon's surface. Thus, we are to conclude that the sulfur-based concrete must be overlooked and clearly examined as to be able to maintain its shape and condition while facing the harsh conditions of the moon, in order to ensure it being a reliable tool to use on the moon's surface.

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