CONSTRUCTION MATERIALS FOR PLANETARY OUTPOSTS: A REVIEW. V. Aulesa and I. Casanova*, Institut d'Estudis Espacials, Universitat Politècnica de Catalunya. Gran Capita 2-4, 08034 Barcelona, Spain (* correspondence author's e-mail address: casanova@etseccpb.upc.es).

Introduction: Various approaches to establish permanent outposts on the Moon and Mars are being considered by major space agencies and construction companies from different countries. Construction materials for such applications must be produced from indigenous sources and able to protect crew members and equipment against the effects of vacuum, radiation, meteoroid bombardment, temperature extremes and, in the case of Mars, dust storms. Proposed materials for planetary outpost construction include concrete (cement or sulfur-based), sintered regolith, cast basalt ceramics, ice and metals. Construction of even simple infrastructures on planetary surfaces can greatly help not only to optimize operations and research activities, but also the development of new missions through in-situ resource utilization.

Materials: Concrete is a versatile, widely-used construction material that consists of a binder element and aggregates (generally crushed rocks) in order to provide mechanical strength. Two different kinds of concrete materials have been proposed for planetary construction [1, and references therein].On one hand, conventional concrete (composed of cement, water and aggregates) requires high-T processing (ca. 1800 C) of available silicate-rich regolith materials (either lunar or martian) in order to produce the cementitious components. Other than the need for high temperatures, the main problem that presents the manufacture of conventional hydraulic cement from planetary materials is the relatively low Ca contents of lunar and martian surface rocks (about 65 % CaO is required). The other type of concrete uses molten sulfur (instead of cement+water) as a binder [2] and, in principle, extraction of this element from the regoliths is more straightforward than in the case of hydraulic cement. Also, temperatures required for sulfur melting and workability of sulfur concrete do not exceed 150 C. However, it is unclear yet whether sulfur contents (mainly in the form of FeS on the Moon and/or possibly sulfosalts on Mars) are high enough to make exploitation feasible without significant environmental damage.

Sintered regolith, a fine-grained mixture of rock and glass, has been proposed as a lunar construction material for thermal and dust control, as well as for radiation protection [3].

Cast basalt has a long tradition in Europe in the manufacture of tiles, pipes, sewage and industrial pipe inlays [4]. The process of casting itself is similar to metal casting, although differences exist due to the lower density and higher viscosity of basaltic melt. The high durability and extremely low abrasive wear make cast-basalt tiles a suitable material for communication paths on planetary surfaces.

Bricks and ceramics for planetary applications have been produced through hybrid microwave sintering of lunar simulants [5], yielding materials that meet the specifications for construction of some of the infrastructures listed below.

Ice constructions may seem exotic for planetary applications, but the availability, ease and little processing required [6] makes it an attractive possibility for specific purposes, especially at or near the Martian polar areas.

Finally, metallic materials (e.g. Fe and Ti from lunar ilmenite) are also available at planetary surfaces, but the difficulty of extraction and elaboration makes them only suitable for very specific needs.

Applications: Careful selection and optimization of the production methods and utilization of the materials described above are heavily constrained by the specific applications they are designed for. Two different kinds of short-term uses of construction materials in planetary outposts have been proposed [7]. First, such materials will have to provide shelter for crews and equipment against radiation, micrometeorite bombardment, thermal cycles and extremes and, for Mars, dust storms. Second, suitable materials will have to meet the specific requirements of compressive and flexural strength, durability and low porosity for the construction of supporting infrastructures such as pavements, landing/liftoff platforms (LLP), reservoirs and, eventually, habitats. Pavements and LLPs are of critical importance in order to minimize the harmful effects of dust levitation on machinery and pressurization systems. It must also be taken into account that the preservation of the pristinity of the planetary environment is a priority for lunar and martian outpost development.

Discussion: As mentioned above, different kinds of materials may be suitable for diverse applications in the construction and development of lunar and martian outposts. In this work, and for practical purposes, rather than identifying and describing the specific properties of each of the possibilities, we will discuss which of the components are unsuitable for the proposed applications in the aim to provide reference information for future feasibility studies.

Radiation protection requires essentially the interposition of mass between the source and the protected area. Other factors have to be considered as well, e.g. the possibility that the materials became activated by particle fluxes and become themselves a source of secondary radiation, as is the case of many metals. The radiation shielding capability of sulfur concrete is not well known, and further theoretical and experimental studies are required. Sintered regolith and cast basalts can be considered to have radiation absorption properties similar to those of planetary regoliths, implying that structures made of these materials for radiation protection should be on the order of 1.0-1.5 m. in thickness [7].

Protection from micrometeorite bombardment is a minor problem, since a few mm of any of the materials listed above would provide an adequate shelter against microimpacts. Thermal protection from low and high-T extremes as well as temperature cycles requires special consideration as a function of the material, planet and proposed location (latitude) of the service infrastructure. Good thermal insulators are required and, consequently, metallic components are unsuitable for that purpose.

A special shelter requirement in Mars arises from periodic dust storms, that can seriously affect instrumentation designed for long-term service (e.g. seismometers, atmospheric measurements). In the initial stages, small shelters can be brought together from Earth but the high cost of transportation (especially to Mars) makes this solution unfeasible for continuing exploration strategies. Protection from dust storms requires basically providing a physical barrier, with a good durability in front of abrasion from transported particles and high-velocity wind loads.

Planetary surfaces are dusty environments, and special care must be taken in the minimization of the effects of dust on machinery and life support systems. This problem is especially acute on the lunar surface, where the absence of an atmosphere and electrostatic charging of very fine-grained materials cause levitation and high residence times. In this sense, providing a rigid substrate for the motion of robotic equipment is an important issue. Given that even small communication paths require relatively large amounts of material for their construction, special priority must be given to the availability of raw materials and minimization of required processing. Among the materials listed above, manufacture of bricks is possibly the best short-term alternative to serve this purpose (always from a strict in-situ resource utilization point of view). If sulfur ores are identified, sulfur concrete could also be a suitable material for this application; however, utilization of this material is heavily constrained by the relatively high temperatures to which LLPs become exposed.

A very specific problem is that of reservoirs for life support systems and materials (e.g. oxygen-production plants) and supplies. In general, total impermeability (for liquids and gases) will be required for these application. The only material that meets this specification is metal, but the difficulty of its implementation on planetary surfaces from local resources has already been discussed.

Finally, in the longer-term, habitats will have to be built for extended stays. None of the materials presented in this paper is, for now, suitable for the construction of such structures although they can certainly serve to provide anchoring systems, footings and floating foundations.

Conclusions: Planetary regolith resources can be exploited in-situ for the production of materials suitable for the needs of most shelter and supporting infrastructures during the early developmental stages of planetary outposts on the Moon and Mars. However, it is clear that none of the possibilities explored to date meets all the specifications of the required applications. Then, selection criteria have to be carefully chosen considering protection needs, availability of raw materials, amount of processing required and response under specific environmental conditions on each planetary surface. It thus becomes evident that, especially at early stages, spacecrafts and transportation modules will have to be designed for temporary service on the surface as well.

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