UNIQUE PROPERTIES OF LUNAR SOIL FOR IN-SITU RESOURCE UTILIZATION ON THE MOON.

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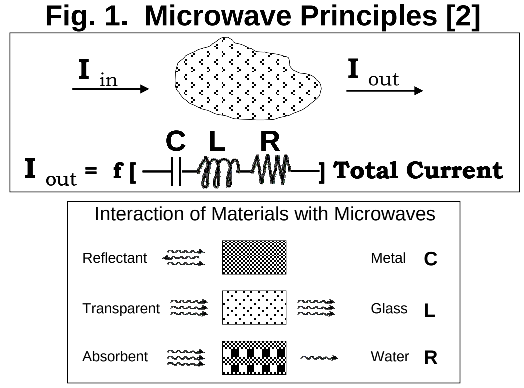
Introduction: Moon is an enormous Earth-orbiting space station, a natural satellite outside of Earth's gravity well, with raw materials that can be put to practical use as humanity expands outward into the solar system. The establishment of a base of operations on the Moon in preparation for and implementation of further exploration of the Solar System looms large upon the horizon. Paramount in these endeavors is the need to learn to "live off the land" on the Moon. This will involve the "In-Situ Resource Utilization" (ISRU) of the materials on the lunar surface for a plethora of uses. Such studies for lunar ISRU will include: facilities construction, regolith digging and moving, trafficability (e.g., roads, landing pads), microwave processing, conventional heat sintering, oxygen production, dust abatement, mineral beneficiation, solar-wind gas release, cement manufacture, radiation protection, et cetera. The surface mobility (rovers), scientific instrument, and EVA (extra vehicular activity) communities also must address the nature of the lunar materials as well. The various engineering and material science studies that are necessary for these endeavors will mostly address the lunar regolith (crushed rock) and soil (<1 cm of regolith) for their starting materials on the Moon. It is to the unique properties of the lunar soil that this presentation is directed, particularly as regards the areas of "dust mitigation" and the techniques of "microwave sintering/melting of lunar soil," both subject to recent activity by our Tennessee group [1,2].

Uniqueness of Lunar Soil: The chemical and physical properties of the fine fraction of lunar soil are at the root of the unusual properties of the dust that contribute to its deleterious effects – its liability." Dust-sized particles (<50 µm) of the lunar soil consists of 50-80 % impact-generated glass, not what one would anticipate from comminuted rock [3]. It is micrometeorite impacting kinetics that generates melting of small portions of the soil that quenches to the glass that binds aggregates of soil particles together to form the ubiquitous agglutinates. The glass in the agglutinates and the fine vapor-deposited patinas on most soil grains contain a myriad of nanophase-sized metallic Fe^0 particles, on the order of 3-30 nm. These Fe^0 particles form as a result of the micrometeoritic bombardment and formation of the lunar soil [3]. Realizing that almost 50% of a typical lunar soil is <50 µm and contains the majority of this nanophase Fe^0 , it is this fine fraction of the soil, the dust, that imparts unique properties to the soil that make it an excellent feedstock for numerous ISRU purposes. Armed with a sufficiently detailed knowledge of these fine particles, it should be possible to address and remedy the problems as the ever-present deleterious dust, as well as investigate the soil as feedstock for ISRU manufacture, such as produced by microwave sintering / melting.

DUST Abatement: All activities on the Moon will involve guarding against, as well as utilizing, the ever-present, clinging, penetrating, abrasive, resource-rich, fine-grained lunar dust. The properties of the fine portion of the lunar soil (<50 µm), its dust, must be adequately addressed before any sustained presence on the Moon can be fully realized; these include: 1) ***abrasiveness,*** with regards to friction-bearing surfaces; 2) ***pervasive nature*** as coatings, on seals, gaskets, optical lens, windows, etc., 3) ***gravitational settling*** on all thermal and optical surfaces, such as solar cells; and 4) ***physiological effects*** on the tissue in human lungs [1].

The presence of this nanophase Fe^0 in agglutinates and on the surfaces of most soil particles [3], particularly of the fine dust-sized particles,

Fig. 1. Microwave Principles [2]



LOSS TAN δ = Sum of Losses from All Mechanisms during Microwave Heating.

imparts a magnetic susceptibility to the particles such that virtually the entire <20 μm portion of the soil has a high ferromagnetic magnetic susceptibility that it can react to a simple strong magnet [1].

MICROWAVE Principles and Processing: There exists a group of persons that take great pleasure in placing strange things in microwave ovens (e.g., bars of soap, CDs, even poodles). But their remains a lack of appreciation for the *principles* of microwave energy. The microwave part of the electromagnetic spectrum corresponds to frequencies between 300 MHz and 300 GHz [2]. Based on their microwave interaction, most materials can be classified into three categories- opaque, transparent, and absorbers. Bulk metals are opaque to microwave and are good reflectors (Fig. 1). Most other materials are either transparent or absorb microwaves at ambient temperatures, depending on the frequency of the microwave radiation and their dielectric constraints. As many have experienced, solid, non-porous metal readily reflects and effectively 'shorts out' the microwaves. However, that same metal when in minute grain size can become an effective conductor separated by dielectric (e.g., np-Fe0 + glass) and absorb microwaves at room temperature and rapidly generate heat. Specific frequencies 'couple' with conductors of sufficiently small size – i.e., np-Fe^0 - such that they cause substantial heating. ***The power of the microwave energy becomes ever-more concentrated into a smaller volume as temperature increases.*** With this net effect, it is imperative that the frequency of radiation and the electric-field intensity be properly balanced such that the heating does not go into a "run away mode", which is not easily controlled.

Microwave Products: The unique properties of lunar regolith make for the extreme coupling of the soil to microwave radiation [2] The microwaves couple strongly with the Fe^0 to such a degree that a sample of Apollo soil placed in an ordinary 2.45 MHz kitchen microwave will literally begin to melt before your tea-water boils. Further considerations of the properties of the fine soil are the basis for the microwave sintering/melting, hot-pressing, and extrusion of the soil to form various construction materials, in order to realize some of the "assets", particularly with the dusty portion of the soil. Other products that microwave processing can result in are only restricted to the depth of ones imagination – **from** microwave-formed *roads* (Fig. 2) **to** large-smooth *parabolic antennas* **to** fabrication of structural products **to** *recovering large masses of hydrogen* from the lunar soil, et cetera. All these products involve the microwave heating of the fine fraction of the lunar soil, whereby the minute, yet separated, native Fe grains readily couple with the 2.45 GHz microwaves in a simple Sears microwave oven. The position of much of the Fe^0 on the surfaces of grains, imparts the unique ability for local high-temperature domains at grain boundaries, such that the sintering actually involves the production of melt at the interfaces. Microwaved, pre-compacted, as well as, hot-pressed forms are relatively easy to produce.

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Fig. 2. Lunar Road-Paving Wagon [2]