Microwave Permittivity and Permeability Measurements on Lunar Simulants.

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Introduction: Advanced lunar simulants need to be developed in preparation for the future colonization of the Moon. It will be cost effective to use lunar soil as raw material for forming structures needed for a lunar home base. One approach is to use microwaves to perform in-situ processing of the lunar soil. It has been demonstrated that the lunar soil is an excellent absorber of microwaves and there is speculation that the cause of this absorption is associated with the nanophase iron content in the regolith [1].

To evaluate the various approaches for using lunar soil, studies must be performed with simulants that accurately represent the unique physical features of the lunar soil. One of these unique features is the presence of nanophase iron that was produced by the bombardment of micrometerites over eons of time [2]. Several approaches are now being investigated to produce simulants containing nanophase iron. In this investigation, we have measured the dielectric and magnetic properties of simulants being developed by three companies Orbitec (Or), Plasma Processes (PP), and Zybek (Zy) and compared their resulting behavior to earlier measurements of representative mare and highland lunar soil samples [3]. These measurements will be useful in supporting the development of new simulants having the correct composition to adequately simulate the lunar regolith.

Microwave Measurements: We have measured the room temperature permittivity and permeability of 14 simulant samples. A list of the simulant samples, as well as the previously measured lunar samples, is given in Table I. Samples that do not contain nanophase iron (nFe) are indicated in the table. The mare-like simulants were Orbitec #1 and #4, Plasma Processes #1, #2, #4, and #5, and all Zybek samples. The highland-like simulants were Orbitec #2 and #3, and Plasma Processes #3, #6 and #7. The measurements were performed over the frequency range 1.8 – 3.5 GHz with the same microwave facility used earlier in our lunar soil study [3]. All the simulant samples were initially heated to 150 C for 3 hours to eliminate any water. The resonant frequency and quality factor of the rectangular cavity's TE_{101} – TE_{106} modes, with and without the sample inserted, were used to determine the permittivity and permeability from a cavity perturbation approach [4].

Table I. Lunar simulant and lunar soil samples.

Company	Samples	Density (g/cc)
(Or) #1	JSC1A-AGGL	1.39
#2	CHENOBI-AGGL	1.30
#3	NU-LHT-2M-AGGL	1.40
#4	JSC-1A-AGGL-DUST	0.60
(PP) #1	JSC-1A (no nFe)	1.65
#2	S09_23	1.31
#3	NU-LHT-2M (no nFe)	1.42
#4	V2-10-146-180-750 UM	1.22
#5	V2-10-146-106-180 UM	1.20
#6	S11-3	0.77
#7	V2-11-109/110	1.42
(Zy) #1	Synth. Basalt 4% Ti (no nFe)	0.71
#2	Synth. Basalt 12% Ti (no nFe)	0.77
#3	Synth. Basalt 16% Ti (no nFe)	0.62
Lunar #1	Mare #75081,14	1.72
#2	Highland #64501,12	1.46
#3	Mare #10084,27	1.70
#4	Highland #14163,179	1.55

All the simulants had larger absorption associated with their dielectric properties than with their magnetic properties, i.e., ε_r'' was larger than μ_r'' in all cases. This behavior was also found for the lunar soil samples at room temperature and suggests that nanophase iron is not a major contributor to the absorption. There still is a need to perform these permittivity and permeability measurements at higher temperatures to determine if the magnetic components (specifically, nanophase iron) are ultimately responsible for the excellent microwave heating.

The ε_r'' determined for all but two of the mare-like simulants had values ranging from $(3.5-32)x10^{-3}$ that were significantly smaller than obtained for the mare lunar soil samples. The exceptions were the Orbitec #1 sample that agreed with the lunar soil sample's values of $(40-47)x10^{-3}$ and the Plasma Processes #1 sample that had higher values of $(55-73)x10^{-3}$. The ε_r'' measured for all the highland-

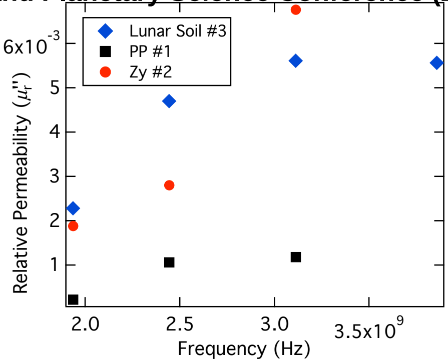

Fig. 1. Imaginary relative permeability vs frequency for mare-like Zybek #2 and Plasma Processes #1 samples and the mare lunar soil #3 sample.

like simulants that ranged from $(11-22)x10^{-3}$ was higher than found for the highland lunar soil samples.

The magnitude of the magnetic absorption μ_r'' of all the simulants was in the same range as found for the lunar soil samples. However, the frequency dependence of the magnetic absorption for almost all the measured simulants was different from the monotonically increasing frequency behavior found for the lunar samples. The only simulants that did have the same type of frequency dependence were the Zybek mare-like samples and the Plasma Processes #1 mare-like sample. Figure 1 shows the frequency dependence of two mare-like simulants (Zybek #2 and Plasma Processes #1) compared to the lunar soil #3 mare sample.

The measured dielectric constant, ε_r', of the simulants had values that were lower than found for similar lunar soil samples. This difference is due to the fact that the densities of the measured simulants were lower than the lunar soil samples tested. Figure 2 is a plot of all the simulant and lunar soil samples average dielectric constant over the measured frequency range against their corresponding density. The solid curve is the best fit expression $\varepsilon_r' = 2.15^{\rho}$. This fit coefficient is

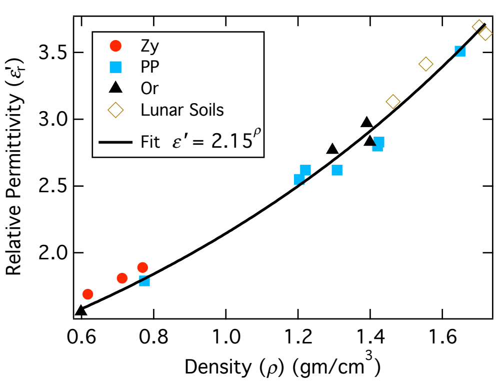

Fig. 2. Universal behavior of real relative permittivity versus density.

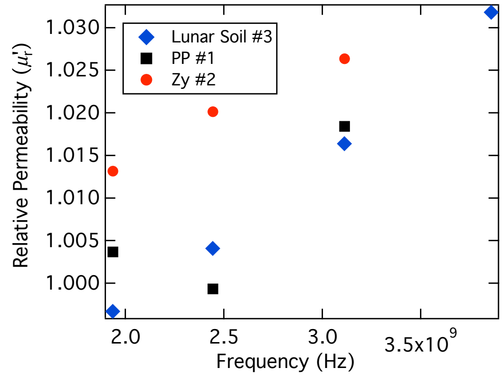

Fig. 3. Real relative permeability vs frequency for mare-like Zybek #2 and Plasma Processes #1 samples and the mare lunar soil #3 sample.

slightly higher than found in earlier analyses [5] of lunar soil samples that gave 1.93 for the coefficient.

All of the mare-like simulants showed μ_r' values very close to the mare lunar soil samples and all of the highland-like simulants also showed μ_r' values similar to the highland lunar soil #2 sample. The highland lunar soil #4 sample showed anomalously large monotonically decreasing behavior with frequency. All but one of the measured magnetic constant, μ_r', of the simulants had a monotonically increasing behavior with frequency similar to what was found for the lunar samples (except highland lunar soil sample #4). The only deviation from this increasing monotonic trend was for the Plasma Processes #1 mare-like JSC-1A sample. Figure 3 shows the frequency dependence of two mare-like simulants (Zybek #2 and Plasma Processes #1) compared to the lunar soil #3 sample.

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