Microwave Magnetic Properties of Dust and Its Implication for Geophysics and Cohesion.

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Introduction: This paper introduces simulated experiments conducted to investigate two major issues related to luna soil behaviors. The first one is related to the electromagnetic properties of lunar soils at microwave frequency (dielectric permittivity, magnetic permeability and electrical conductivity) which aims to identify specific problem that might arise when applying electromagnetic wave based geophysics tools such as Ground Penetration Radar (GPR) for lunar subsurface survey. The second issue investigated is the orginal of cohesion in lunar soils. A hypothesis is proposed on the origin of cohesion in lunar soils. Method to validate this hypothesis is provided.

Background: Electromagnetic wave based technology such as ground penetration radar provides efficient tool for subsurface investigations. This technology is based on the propagation and reflections of electromagnetic wave due to the electromagnetic properties of a material. When apply electromagnetic wave technology on the earth, the most important component that need special attention is water. This is due to its large dielectric constant and high electrical conductivity. The amount of water has important effects on the speed, dispersion and attenuation of of electromagnetic wave propagating into the ground. The magnetic permeability of geomaterials are typically assumed to be around one for GPR applications as most earth materials are diamagnetism or parmagnetism.

The travel speed of an electromagnetic wave in a material, V, is related to its relative dielectric permittivity, ε_r, and relative magnetic permeability, μ_r by Eq. (1):

$$V = \frac{c}{\sqrt{\varepsilon_r \mu_r}} \qquad (1)$$

where c is the speed of light.

Compare with the earth, lunar soil is absent of water. On the other hand, it features gluttinitic glass structure with nanophase metallic Fe grains [1]. FeO on average accounts for around 15% of the total weights [2]. As ferromagnetic materials, FeO shows distinctive large ferromagnetic behaviors. The influence of FeO nanoparticles on the electromantic properties of lunar soils thus need to be investigated to properly interpret radar signals.

Method: Measurement of electromagnetic properties was conducted using Time Domain Reflectometry (TDR), which is a guided electromagnetic wave technology[3]. A schematic test set up is shown in Fig. 1a. TDR utilizes the propagation of electromagnetic wave to measure material properties. It works by generating a small-magnitude electromagnetic field excitation and measures the material response. By using a fast rising pulse of a few picoseconds by the current electronics, TDR measures the broad frequency band material responses from a few megahertz to gigahertz. The information commonly used from a TDR signal is the reflection points, which are related to the speed of electromagnetic wave in the soil and are subsequently used for determining the apparent dielectric constant K_a; and the long term signal level, which is related to the energy attenuation and subsequently used to determine the electrical conductivity EC_b (Fig. 1b). Both quantities can be easily obtained from a TDR sig-

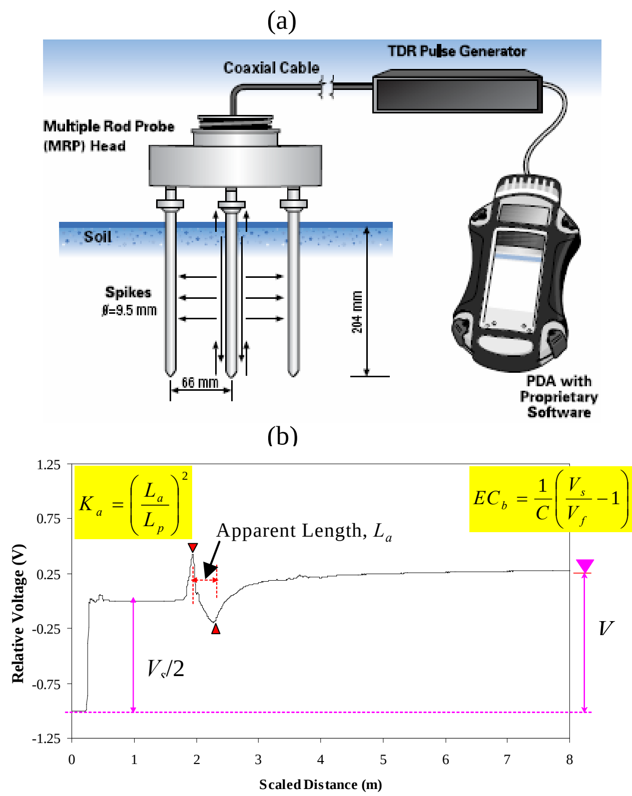

Fig. 1 a): Schematic plot of TDR measurement system; b): Typical TDR signal and information utilized

nal[4].

The measured apparent dielectric constant (refered as dielectric constant in the following context for simplicity) is related to the electromagnetic properties by Eq. (2):

$$K_a = \left(\frac{c}{V}\right)^2 = \varepsilon_r \mu_r \quad (2)$$

In this experimental program, tests were conducted in a cylinder mold with known volume. TDR test was first conducted on pure fine sand. FeO powder is weighted and mixed with sand at mass ratio of 5%, 10%, 15%, 30%. Mixtures were placed into the mold and TDR tests were taken, from which the dielectric constant and electrical conductivity were determined. Based on the amount of mixture placed, the density and percentage of different phases were also determined. An example of measured signal is shown in Fig. 2. The sharp rising at the end of probe indicates there is no appreciable dispersion occurs for the simulated lunar soil mixture. Although FeO is conductive, the electrical conductivity of whole mixture is low. This might be due to the fact that they have not formed a percolation channels to allow current to be conducted across the sample.

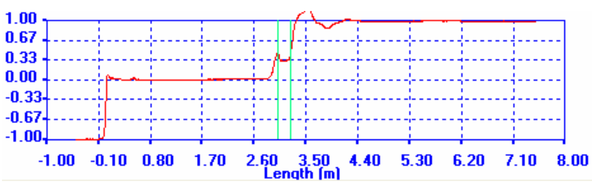

Fig. 2 Example of TDR measured signal of sand FeO powder mixture

Analyses: The dielectric constant measured by TDR is the bulk value of the mixture. It is related to the volumetric components by the following relationship:

$$K_a^n = n_{air} \cdot K_{a,air}^n + n_{sand} \cdot K_{a,sand}^n + n_{FeO} \cdot K_{a,FeO}^n \quad (3)$$

where n_{air}, n_{sand}, n_{FeO} are volume of air, sand and FeO respectively. K_a with appropriate subscript stands for their respective dielectric constant. n is an index related to particle orientation, n has a value of 0.5 when particles are randomly oriented.

Substittue Eq. (2) into Eq. (1), there is:

$$\sqrt{K_a} = n_{air}\sqrt{\varepsilon_{r,air}\mu_{r,air}} \cdot + n_{sand} \cdot \sqrt{\varepsilon_{r,sand}\mu_{r,sand}} + n_{FeO} \cdot \sqrt{\varepsilon_{r,FeO}\mu_{r,FeO}} \quad (4)$$

where ε_r and μ_r with respective footnote stands for the relative dielectric permittivity and relative magnetic permeability respectively.

The relative dielectric permittivity of air is close to 1. That of sand particles can be obtained from literature value. The relative magnetic permeability for both air and sand are around 1. By matching the measured data with that predicted by Eq. (4), the term $\varepsilon_{r,FeO}\mu_{r,FeO}$ is estimated to be around 116.1. As the dielectric constant of FeO is approximately constant at microwave frequency (around 16.6), the relative magnetic permeability is estimated to be around 7 at equivalent TDR frequency (low gigahertz range).

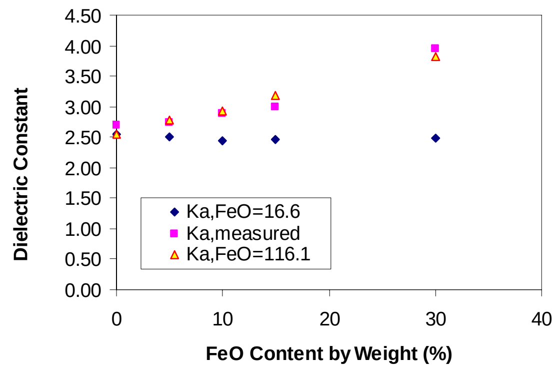

Fig. 3 Comparison of measured dielectric constant and those predicted from mixing formula

Discussions: the following conclusions were drawn based on this investigation:

A detailed analyses indicated that the magnetic permeability for FeO at TDR frequency range is around 7.

The following propose a hypothesis to describe the origination of cohesion in lunar soil. The Moon, similar as the Earth, is a huge magnet. Ferromagnetic material Fe-particle in lunar soils tends to be magnetized under the magnetic field of Moon. They act as small magnets, which tend to attract with each other. The closer the distance, the larger the attraction forces. A method to differentiate their contribution to cohesion from other sources such as molecular attractions is if mixing them randomly, the cohesion will disappear due to disturbance of the alignments of these "small magnets". The cohesion will increase, however, as Fe grains are re-magnetized at their new locations.

References: [1] Liu, Y, Thompson J.R., Taylor L.A., and Park J. (2006) Lunar and Planetary Science XXXVII. [2] Duke M.B., Woo C.C., Bird M.L., Seller G.A. and Finkelman R.B. (1970) Science, Vol. 167, No. 3918, pp648-650. [3] Topp et al. (1980) Water Res. Res. [4] Yu and Drnevich (2004), JGGE, pp1-13.