Study of thermal conductivity design for thermal loaded geomaterials.

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EXTENDED ABSTRACT

Soil thermal conductivity plays preponderant role in many geoengineering projects involving thermal effects, such as high voltage underground power cables, oil and gas pipelines, nuclear waste disposal facilities, ground heat energy storage and heat exchanger piles. A thorough understanding of thermal conductivity is necessary in heat transfer modelling. Depending upon the application and desired purpose of such projects, materials with either high or low thermal conductivity are used. Materials with high thermal conductivity are desirable in cases such as high voltage underground power cables to dissipate the generated heat rapidly to the surrounding soil. On the other hand, ground heat energy storage needs materials with low thermal conductivity and high heat capacity to hinder the heat energy loss.

In this study, high conductive backfill materials for underground power cables were analysed based on existing knowledge of heat transfer mechanism in granular media and models of soil thermal conductivity in both dry and wet conditions (Yun and Santamarina, 2007, Cortes and Santamarina, 2009). Several researchers have developed theoretical, empirical and semi-empirical models to estimate the thermal conductivity of natural soils and crushed rock materials based on various factors such as particle shape and size, particle distribution, mineral composition, dry density, and water content (Farouki, 1986). However, majority of the models are not capable of estimating thermal conductivity of highly conductive artificial geomaterials, and fail to consider the interconnectivity and quality of high thermal contacts of high thermal conductivity mineral phases present in such geomaterials.

The experimental program covered the study of several mix proportion of granular soil, binder, additives and water to achieve the desired properties. The selection of materials was based on the fact that higher thermal conductivity can be achieved with bigger and round shaped particles, minerals with higher thermal conductivity and lower porosity (Yun and Santamarina, 2007). Minimum porosity can be attained for mass fraction of fine particles (FR_{mass} 30-40%) and larger size ratio $FR_d = D_{large}/D_{small}$ (Guyon, 1987, Santamarina, 2001). Previous studies show that fuller curve gradation also produces higher mixture density and lower porosity (Fuller & Thompson, 1907). Consequently, heat transfer and thermal conductivity of the media are improved significantly. To attain particle sizes lower than 63µm in the fuller curve gradation, sodium bentonite with desired proportion was added. The thermal conductivities of all the mixes were measured with a thermal needle probe.

Figure 1 shows experimental results of thermal conductivity as function of dry density for studied four mixes. The experimental results were also compared to the Johansen (1975) model, Côté and Konrad (2005) model and Lu (2006) model at dry state. As expected, the main heat transfer via thermal conductivity is carried by the particles, the density and the particle or mineral thermal conductivity. As example, tests with mixed Siliciumcarbide particles could increase the conductivity by around 30% for material of same density.

As shown in figure 1, all three semi-empirical models underestimated the measured thermal conductivity values for all studied design mixes. This is due to the fact that these models are primarily based on dry density (or porosity) of media and lack considerations for mineral thermal conductivity, volumetric fraction of solid and pore in dry state among others. Hence, the authors focus upon the development of a new prediction model, which is formulated from existing theoretical as well as empirical models incorporating key factors such as dry density, soil structure and mineral thermal conductivity, to predict the dry thermal conductivity of highly conductive backfill soils. The proposed model was further validated against experimental results on several backfill soils with high conductivity. Reasonable agreement between the predicted and measured thermal conductivities was obtained.

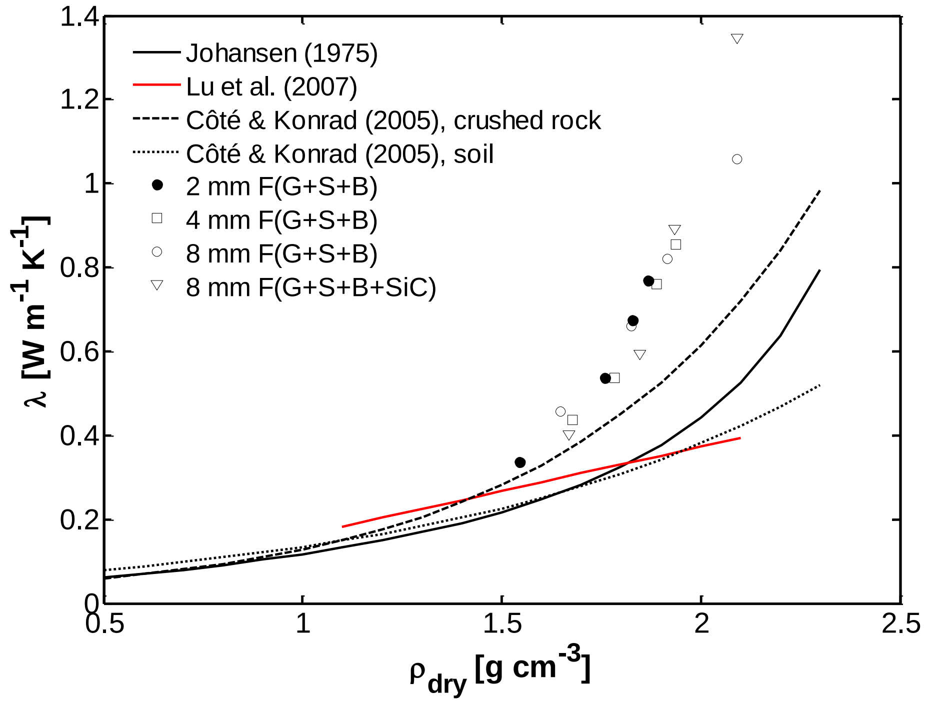

Figure 1. Thermal conductivity λ as a function of dry density ρ_{dry} for the studied four mixes.

Keywords: thermal conductivity; high conductive backfill materials; fuller curve.

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