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A study on the thermal properties of near surface thin clay sand liners

M.A. Dafalla, Al-Mahbashi, A., Al-Shamrani, M.A. & A. Samman

Bushan Research Chair in Expansive Soils, Department of Civil Engineering, King Saud University, Riyadh, Saudi Arabia

ABSTRACT: The near surface clay sand liners are thin layers placed at grade level as cover layers or surface soil. These are artificial fill materials used for different purposes. The thermal properties of these layers are rarely considered, and the design focus is generally directed towards other goals. This study surveyed the thermal properties of clays and sands when combined to form a liner material. The gain and loss of heat and heat transfer properties were examined at ambient temperature for a semiarid region. A selected temperature gradient is used to investigate the size of gain and loss of heat and temperature variations in different clay sand mixtures. Day and night changes of the ground surface temperature are function of soil material type and placement conditions. Parks and green areas can benefit from this investigation. It helps in predicting the appropriate surface temperature within a particular time of the day. This research work investigated clay sand mixtures of 10%, 20% and 30% clay content when exposed to variable ambient temperatures.

1 INTRODUCTION

This study is initiated to answer a question of how much clay content is appropriate for use in the top fill layers in a green park. What difference in temperature variation if little or more clay content is used? Green areas used as parks can be conditioned to create the most comfortable weather if the design is optimized. This work deals with the thermal properties of the fill material used in backfilling and final layers in barriers or cover layers. The thermal conductivity is a term commonly used to define the ability of the material to transfer heat from a warmer part to a less warm part per unit time for unit area over a given temperature gradient. The unit of thermal conductivity is $Wm^{-1}K^{-1}$. The thermal properties for different types of soil materials quoted in the literature are broad. However, the flow of heat through soils is influenced by several factors and cannot be correctly predicted without considering all significant parameters. The flow of heat through a soil is affected by the moisture and air content as prime factors. The conductivity of solid particles is also dependent on the type and level of compaction. Air and water phases also show different conductivities depending on their states. Farouki (1986) stated that heat conduction is influenced by the soil composition, structure, density, porosity, geometry of the grain and pore or opening size. Tien et al. (2005) stated that basic three major parameters that affect the thermal conductivity of bentonite-sand mixtures

include the proportion of bentonite/sand, the dry density (or void ratio) of the bentonite, and the water content.

Some empirical models were established to predict the thermal conductivity measurements of soils based on the basic laws of thermodynamics (Campbell 1985, Tein et al. 2005). Due to the non-homogeneous nature of soils and complexity of fabric such models require many parameters to be used to achieve reliable prediction. Predictions were mainly based on adding up proportions of composite materials to achieve some good estimates.

This paper presents a simple approach of testing Al Qatif clay mixed with three different proportions of sand. Loss and gain temperature profiles are compared with loss and gain in temperature for a field section built for 20% clay content cover layer constructed at Al Jubail city east of Saudi Arabia. The study investigated the behaviour of laboratory-controlled heat transfer of specific clay sand mixtures. The outcome of laboratory tests is then compared to the behaviour of a selected mix constructed as thin liner on site.

2 MATERIALS AND METHODS

The clay used in this study was obtained from Al Qatif town located in the eastern province of Saudi

Arabia. Al Qatif clay is a highly plastic soil known of its high expansion and shrinkage properties and classified as CH in accordance with the unified soil classification system or ASTM D 2487. This section describes the materials and methods used for preparing compacted sand clay mixtures in laboratory and procedures used to construct a field section. Many studies were conducted on this specific type of clay during the last five years. This clay is suitable for use in clay sand liners for various environmental applications. Several research studies were performed to characterize and evaluate this type of clay (Mutaz et al. 2011, Elkadi et al. 2013, Dafalla et al. 2013).

The standard proctor maximum dry density of the clay was measured as 11.5 - 12 kN/m³ at an optimum moisture content of 30 - 32%. Consistency limits of Al Qatif clay showed liquid limit of 130 to 150 and plasticity index of 60 to 70. The sand material used is generally poorly graded sand with a coefficient of uniformity of 1.737 and coefficient of curvature of 1.078. The specific gravity of the sand used is 2.66. The maximum dry density of clay sand mixtures with clay content of 10%, 20% and 30% by dry weight of sand is reported in the range from 17.5 - 18 kN/m³ at an optimum moisture content of 13 - 15 %. The same material is used for a field section. The clay content selected for the field section liner is 20% clay by dry weight of sand.

3 EXPERIMENTAL AND FIELD SECTION TESTS

The laboratory investigation program included subjecting clay sand mixture samples to heat sources generated by an oven. The oven was set to provide a constant temperature. The clay sand mixture samples were cast in cylindrical moulds 75 mm diameter and 50 mm height. The main idea is to investigate the rate of gain and loss of heat for clay sand mixtures with 10%, 20% and 30% clay content. All soils were prepared at the maximum dry density and the optimum moisture content as obtained in a standard proctor test.

Variations in volumetric water content, temperature and electrical conductivity were recorded using 5TE Decagon sensors connected to Em50 data logger. The sensors were set to take records every 10 minutes intervals. To reduce the heat loss, 5 cm thick polystyrene was used to cover the cylindrical sample and allow heat gain and heat loss to occur through top or bottom direction (as shown in Figure 1). The oven was set to keep the temperature constant at 50 °C simulating or close to the highest temperature during summer times in Saudi Arabia. The soil samples were allowed to gain heat in the oven for a period of 24 hours.

The field section was constructed on site using 20% clay content layer made of clay sand mixture,

10 cm in thickness with a 20 cm top layer of silty sand material. The top layer is dominantly sand with silt content in the order of 5 to 10%. 5TE sensors were attached to mid depth of both layers and one more sensor installed to record the ambient temperature. The experiment is carried out during summer time where 8 degrees change in ambient temperature is recorded within 12 hours.

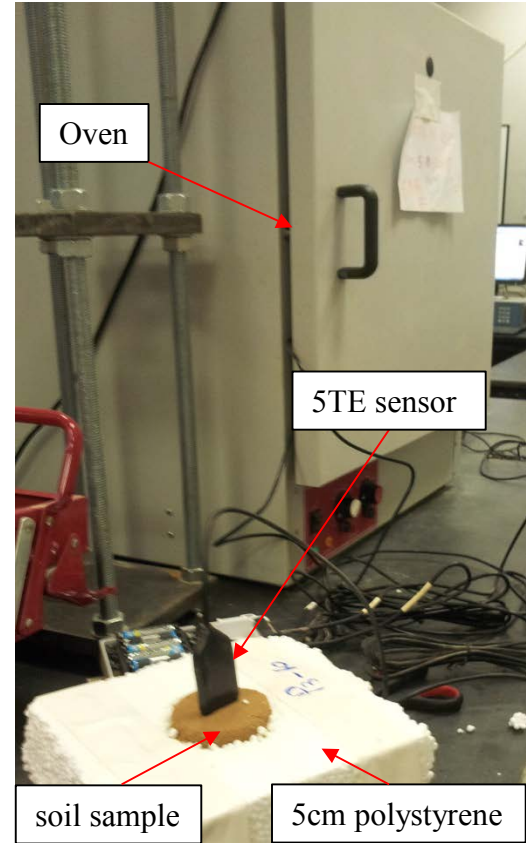


Figure 1. Setup of soil sample connected to transducer

4 TEST RESULTS AND DISCUSSION

Prediction models of the thermal conductivity of clay sand mixtures are mostly not reliable due to the factors discussed in the introduction. However, some models designed to give a better estimate can be used. For the material considered in this study, Campbell (1985) relationship between water content and thermal conductivity (k) of sand, silt loam, and forest litter following equation (McInnes 1981) is used.

$$K = A + B\theta v - (A - D)e^{-m}; m = (C\theta v)^E \quad (1)$$

where θv is the volumetric water content; A , B , C , D , and E are coefficients that are related to soil properties that were taken as:

$$A = 0.65 - 0.78\gamma_d + 0.60\gamma_d\gamma_d^2 \quad (2)$$

$$B = 1.06\gamma_d \quad (3)$$

$$C = 1 + 2.6/(mc^{0.5}) \quad (4)$$

$$D = 0.03 + 0.1\gamma_d^2 \quad (5)$$

$$E = 4 \quad (6)$$

where mc is the clay content. Substituting for γ_d a value of 1.75 Mg/m^3 the coefficients reduce to: $A=1.13$, $B=1.85$, $C=9.2$, 6.8 or 5.75 for 10%, 20% and 30% clay content, respectively. $D=0.336$ and $E=4$

Consider the field section condition, the thermal conductivity can be computed as:

$$K = 1.13 + 0.37 - (0.794) e^{-3.63} = 1.47 \text{ (for 20\% clay content)}$$

The value of the thermal conductivity for all the three investigated mixtures is close to or within 1.5 W/mK . The outcome of this prediction approach although comparable to the values given in Table 1 presented by Dafalla and Samman (2016) but does not clearly reflect the differences of thermal conductivity of the three tested mixtures.

Table 1. Typical thermal conductivity values for selected material

| Material | Thermal conductivity at 25 degrees in W/(m K) |
|--------------------|---|
| Sand, dry | 0.15 - 0.25 |
| Sand, moist | 0.25 - 2 |
| Sand, saturated | 2 - 4 |
| Clay, dry to moist | 0.15 - 1.8 |
| Clay, saturated | 0.6 - 2.5 |
| Air, atmosphere | 0.024 |

Instead of using variable predicted values the information collected for gain and loss of heat for clay sand mixtures subjected to $28 \text{ }^\circ\text{C}$ temperature gradient were considered. The results are presented in graphical forms for heating and cooling as shown in Figures 2 and 3. Figures 4 and 5 present the profile of volumetric water content and electrical conductivity, during heating from room temperature to $50 \text{ }^\circ\text{C}$. The temperature achieved within the middle of the sample is $46 \text{ }^\circ\text{C}$ when the rate of temperature change is getting steady and small. Time needed for heating and cooling for the three different mixtures is presented in Table 2.

It is clear from figure 3 and 4 that the electrical conductivity trend is similar to that of the volumetric water content. The drop of water content is caused by heating of the sample.

Table 2. Time needed for heating and cooling clay sand mixtures

| Clay % | Time needed for heating to 46 degrees | Time needed for cooling to 22 degrees |
|----------|---------------------------------------|---------------------------------------|
| 10% clay | 3.5 | 3 |
| 20% clay | 5 | 4 |
| 30% clay | 4 | 6 |

The lower clay content requires less time to heat up and cool than the clay rich mixture. For 20 and 30% clay content longer periods are needed for heat gain and heat loss. Adopting higher clay content will help in retaining heat for a longer period. In winter times green areas rich of clays will keep the heat for several hours and may provide comfortable sitting area in the evenings. The same material will retain cool temperature during day times in hot summer. This nature can be used as required to provide extended hours of comfortable times. The low clay content can be used in situations when quicker heating or cooling is required. From laboratory tests, we can observe variable heating rates. Primary heating rates, where temperature gradient is high are rapid and keep changing until a constant rate is achieved. It is proposed that similar testing to be carried out for different materials, so the design engineers can suggest appropriate mixtures for particular geographic zones and needs.

The rate for gain and loss of heat is found different for a field section of 20% clay of Al Qatif clay-sand mixture when compared to the silty sand layer without clay. The rate of change indicated slow increase and decrease in temperature when clay material is present. Adding more clay is likely associated with extra moisture which will help in reducing the rate of heat transfer. Figure 6 presents the effect of ambient temperature drop on silty sand and clayey sand layers in field.

The volumetric moisture content varied from 0.41 to 0.44 in the field while the value within the oven varied from 0.1 to 0.25 (m^3/m^3). Electrical conductivity and moisture content profiles indicated similar shapes.

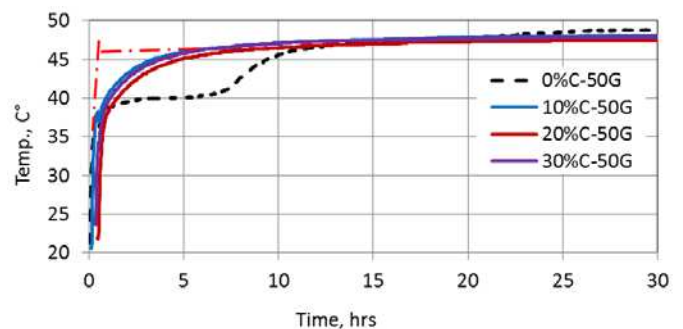


Figure 2. Gain of heat in an oven at $50 \text{ }^\circ\text{C}$

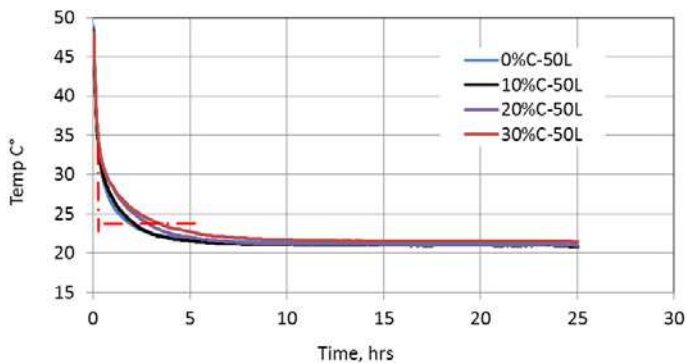


Figure 3. Loss of heat in an oven at 50 °C

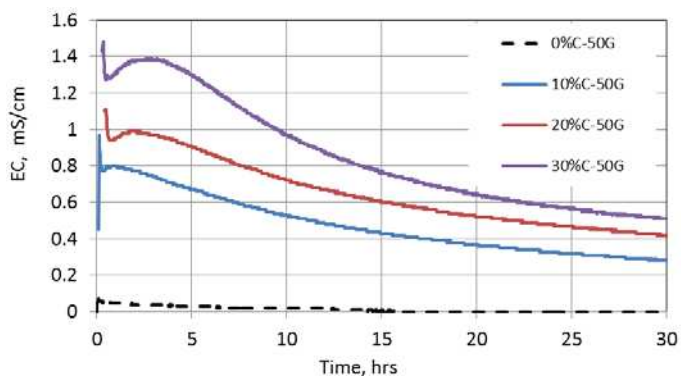


Figure 4. Electrical conductivity versus time during gain period in oven

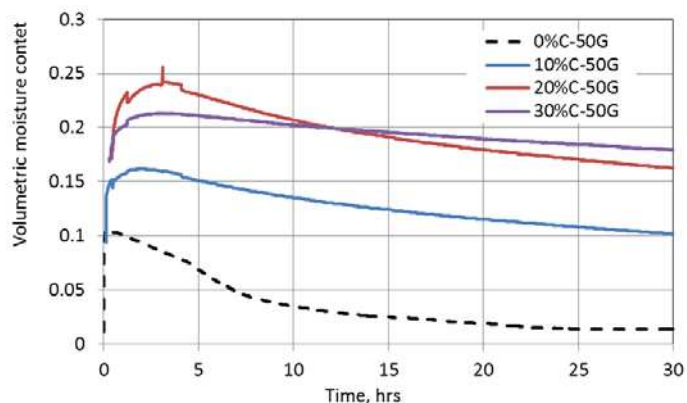


Figure 5. Volumetric moisture content versus time during gain period in oven

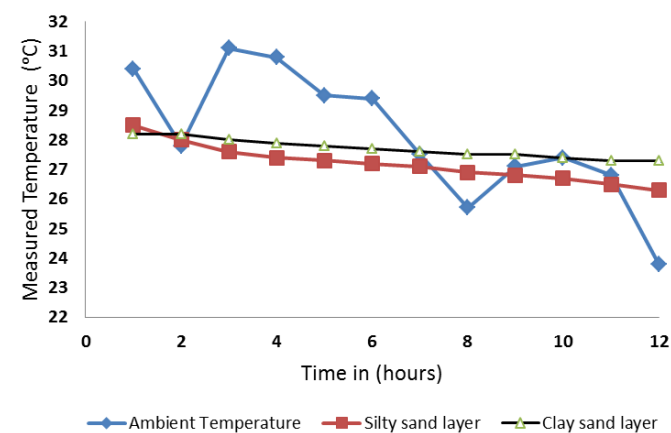


Figure 6. Effect of ambient temperature drop on silty sand and clayey sand layers in field

5 CONCLUSION

The thermal conductivity values predicted in models built for sand clay mixtures give rough estimates due to the many factors involved in heat transfer through clays. The lower clay content requires less time to heat up and cool than the clay rich mixtures. For 20 and 30% clay, longer periods are needed for heating up or cooling down. Designers can use this nature as required to provide extended hours of comfortable times. In winter times green areas rich of clays, 20% or over for this particular soil, will keep the heat for several hours and provide relatively warm evenings. In summer times, the mixture will retain cool temperature for some time during the day. It is more reliable to perform laboratory tests for materials intended as cover layers. Reliable information can be obtained if simple oven tests are conducted and the heating and cooling times can be established correctly. Variations in temperature in a field section indicated a linear reduction in temperature for none uniform changes in ambient temperature.

6 ACKNOWLEDGEMENTS

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