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Modelling of Cooling Rate of Clays: An Example of Indirect Evaluation of Heat Capacity and Storage

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Abstract: We investigated how compacted samples of Ca-bentonite and kaolin cool down when exposed to room air after oven drying to understand whether we can constrain their thermal conductivity and heat capacity. We evaluated the effect of porosity on the cooling rate and used a simple numerical model of heat transfer to obtain the sought-after parameters. Our laboratory results show that both soils exhibit sudden cooling behavior, which can play a crucial role in identifying thermal conductivity and other thermal parameters of soil samples. Our approach provided reasonable values for both thermal conductivity and heat capacity. The latter, however, exhibits much larger sensitivity to porosity and can therefore be constrained better. Further experiments are required to establish a standardized procedure and evaluate the response of different materials. Nevertheless, our approach could prove useful for empirically calibrating thermal parameters in advanced constitutive models.

Keywords: ***Clay, Cooling rate, InfraRed thermography, Heat capacity.***

Introduction

Thermal conductivity plays a crucial role in many engineering applications involving thermo-hydro-mechanically coupled processes. Well-constrained, experimentally determined values are thus preferable to literature values.

Among their diverse applications, clay materials, such as bentonites, are proposed for use as buffer and backfill in high-level radioactive waste disposal (Baryla et al., 2019; Ren et al., 2022; Svoboda et al., 2023). Due to the expanded timescale of clay barriers, their design relies on mathematical models validated with laboratory data. Thus, direct acquisition of the thermal variables, which are of primary importance in this task, may be challenging and may be influenced by various factors, including soil properties and boundary conditions (water content, humidity, and temperature). Thermal conductivity and volumetric heat capacity are among the fundamental parameters to describe the evolution of temperature and stored heat in FEM models.

In this perspective, the combined use of InfraRed Thermography (useful to identify preferential flow and porosity) with laboratory tests (carried out using high-resolution soil surface thermal imaging obtained using a portable infrared camera) may be precious (Loche et al., 2021; 2022).

We will focus our attention on back analyzing the results by imposing the conditions observed in the experiments, without trying to replicate and simulate the exact behavior seen in the test. The back analyses will show whether using literature values is consistent and useful, especially for the Ca-bentonite chosen as a material in a barrier for radioactive waste disposal.

Methodology

For this experimental campaign, we used bentonite from the Czech Republic and kaolin from Malaysia. Sample preparation was done using 50 mm cylindrical molds with 14 g of dry soil powder. The samples were compacted with various loads using a hydraulic press (Figure 1). After preparation, the samples were placed on a tray and heated to 105 °C for 24 hours. Subsequently, they were left to cool down to room temperature while being monitored using infrared thermography. The thermograms were captured with a FLIR C2 camera mounted perpendicularly over the sample tray. The samples were imaged for 80 minutes, with snapshots taken every 5 minutes. Finally, the cooling behavior inferred from the thermograms was fed into GeoStudio's Temp/W and Air/W packages to simulate a uniaxial heat conduction test.

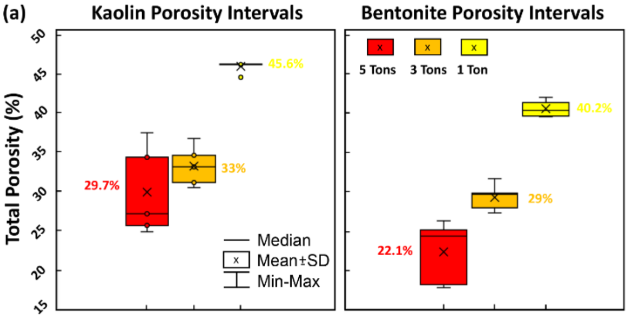

Figure 1, Box plot of porosity distribution for kaolin (left) and bentonite (right) samples after compaction.

Results and conclusion

The modelled curves (Figure 2) are close to each other, which is a point of discussion and may state that this experimental method is not very sensitive to changes in properties in the same material (i.e., it would not be possible to distinguish different porosities if unknown by analyzing the whole curve), but a difference is marked by looking at the first minute. Or, rather, the error prevails in the second part of the cooling.

With the observed cooling as a boundary condition, considering convection negligible, and assuming negligible changes in thermal conductivity during the cooling phase, the cooling process of bentonite and kaolin was simulated. The simulation produced a reasonable cooling trend in both materials. However, at any time during cooling, the bentonite samples exhibited slightly higher temperatures compared to the kaolin samples (Figure 2).

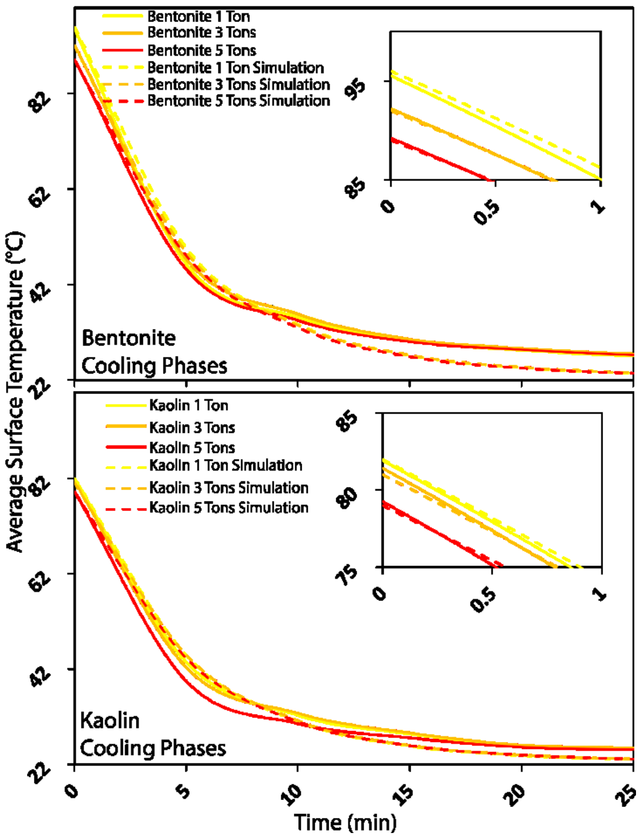

Figure 2, Predictions of the cooling tests for compacted Bentonite and Kaolin under constant volume conditions at three differing initial compaction levels of 1, 3, and 5 tons.

The results may change drastically as a function of the water content, possibly affecting the resolution of the modelling part. However, in this simple setting (in dry conditions), sophisticated laboratory equipment is not required. However, an adequate upscaling from the laboratory conditions in the laboratory to those in the field (mock-up with mixture or pellets) should also be considered.

References

Baryla, P., Bernachy-Barbe, F., Bosch, J. A., Bornert, M., Darnet, L., Djeran-Maigre, I., Gatabin, C., Hemmen, H., Karnland, O., Kröhn, K. P., Lassin, A., Massmann, J., Martin, C., Musso, T., Pintado, X., Schädle, P., Sellin, P., Shafizadeh, A., Sillen, X., and Weber, H. (2019). Bentonite mechanical evolution experimental work for the support of model development and validation (Deliverable 4.1 of EU EURATOM project BEACON—Bentonite Mechanical Evolution). BEACON Project. https://www.beacon-h2020.eu/wp-content/uploads/2019/11/Beacon_WP4_Deliverable41_final.pdf

Loche, M., Scaringi, G., Blahůt, J., Francioni, M., Casagli, N., and Hartvich, F. (2021). An infrared thermography approach to evaluate the strength of a rock cliff. Remote Sensing, 13(6), 1265. https://doi.org/10.3390/rs13071265

Loche, M., Scaringi, G., Blahůt, J., and Hartvich, F. (2022). Investigating the potential of infrared thermography to inform on physical and mechanical properties of soils for geotechnical engineering. Remote Sensing, 14(16), 4067. https://doi.org/10.3390/rs14164067

Ren, G.-L., Chung, C.-C., Tsai, C.-E., Wang, Y.-T., and Lin, C.-W. (2022). Experimental study on the thermal conductivity of compacted SPV200 bentonite. Minerals, 12(7), 932. https://doi.org/10.3390/min12080932

Svoboda, J., Mašín, D., Najser, J., Vašíček, R., Ondráčková, L., Pruška, J., Šťastná, A., Mach, P., and Bílek, V. (2023). BCV bentonite hydromechanical behaviour and modelling. Acta Geotechnica, 18(8), 3193–3211. https://doi.org/10.1007/s11440-022-01689-0