Thermal characterization of natural clay using photothermal radiometry technique for thermal insulation applications

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Clay is a natural powder material that is constituted by granular mineral capable of becoming ceramic once it receives a heating treatment. It has been used as a building material in different communities in Mexico. Properties of clay mostly depend on the composition and minerals of the ground in the area where is recollected [1]. In this work, we study the thermal properties of natural clay ceramics to be used as thermal insulator material [2]. The clay from the Mexican village of Tlalpujahua, Michocán, México was chosen because in that area there is an abundant amount of clay, as well as their rich historical tradition making handcrafts and artistic figures. Under this motivation, determining the thermal properties of clay is of paramount importance [3]. These properties depend on the mineral composition and porosity caused during the thermal treatment [4]. In this study, clay was thermally treated at different temperatures (500, 750, 1000 °C) to obtain the thermal diffusivity using infrared photothermal radiometry.

The Photothermal Radiometry technique was used to determine the thermal properties of the samples in the forward emission configuration (see Fig. 1). A modulated laser at frequency was sent directly to the aluminum foil-clay. As a result of the laser heating, thermal waves were generated in the clay, which emits periodic radiation. The radiation emitted by the clay was collected by two parabolic mirrors and focused on an infrared detector (PVI-4 TE-6 VIGO System S.A.) The signal captured by the infrared sensor was sent to a lock-in amplifier (Stanford Research System SR830) and the amplitude and phase are recorded in function of frequency by the computer. The thermal-wave field at the back surface of the clay is given by [5]:

$$T(l_{AL}+l_C)=\frac{2\eta(1-R)I_0}{\sigma_{AL}k_{AL}+\sigma_C k_C}\left[\frac{e^{-\sigma_{AL}l_{AL}}e^{-\sigma_C l_C}}{1+g\left(e^{-2\sigma_C l_C}-e^{-2\sigma_{AL}l_{AL}}\right)-e^{-2\sigma_C l_C}e^{-2\sigma_{AL}l_{AL}}}\right], \quad \text{Eqn. 1}$$

where the clay´s thickness is l_C, thermal diffusivity is α_C, thermal conductivity is k_C and thermal effusivity is e_C. The aluminium foil thickness is l_{AL} with thermal diffusivity α_{AL}, thermal conductivity k_{AL} and effusivity e_{AL}. I_0 is the intensity of the incident light, η is the efficiency of the conversion from optical to thermal energy, R is the optical reflection coefficient at the wavelegth of the ligth source, and $g=\frac{e_{Al}-e_C}{e_{AL}+e_C}$. The thermal diffusion length of the clay is given by $\sigma_C=(1+i)/\mu_C$ with $\mu_C=\sqrt{\alpha_C/\pi f}$, in the same way $\sigma_{AL} = (1+i)/\mu_{AL}$ with $\mu_{AL} = \sqrt{\alpha_{AL}/\pi f}$ the thermal diffusion length of the aluminium.

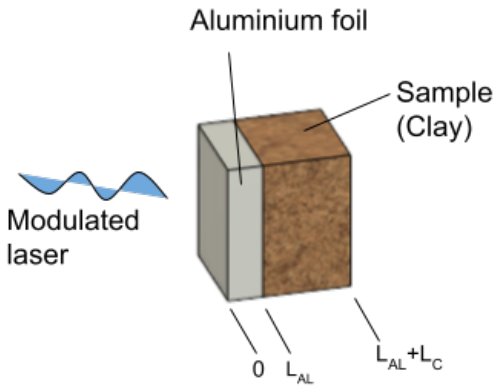

Fig. 1. Schematic of sample to be measured in the transmission configuration.

References

[1] T. Buchner et al. A multitechnique, quantitative characterization of the pore space of fired bricks made of five clayey raw materials used in European brick industry" Applied Clay Science 200 (2021) 105884. https://doi.org/10.1016/j.clay.2020.105884.

[2] D.V. Voronin et al. Clay composites for thermal energy storage: A review. Molecules 25.7 (2020) 1504. https://doi.org/10.3390/molecules25071504.

[3] P.-M. Nigay, et al. Structure and properties of clay ceramics for thermal energy storage.Journal of the American Ceramic Society 100.10 (2017) 4748-4759. https://doi.org/10.1111/jace.15014.

[4] M. Kubiś, et al. "On the anisotropy of thermal conductivity in ceramic bricks. Journal of Building Engineering 31 (2020): 101418. https://doi.org/10.1016/j.jobe.2020.101418.

[5] P. Martínez-Torres, A. Mandelis, J.J. Alvarado-Gil. Photothermal determination of thermal diffusivity and polymerization depth profiles of polymerized dental resins. Journal of Applied Physics 106.11 (2009) 114906. https://doi.org/10.1063/1.3266007.