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Research Paper

Experimental study on thermophysical properties of clay after high temperature

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HIGHLIGHTS

- The effect of high temperature on the thermophysical properties of clay is studied.
- Thermal conductivity and specific heat decrease exponentially as temperatures rise.
- Thermal diffusivity exhibits a certain degree of volatility with temperature.
- Thermal conductivity of clay exhibits excellent linearity with mass loss.

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ABSTRACT

Thermophysical properties are among the most basic properties of soil and play a key role in the efficient utilization of energy and heat insulation performance. Though several researchers have studied the influence of temperature on thermophysical properties, the scope of the temperature is usually below 100 °C, and the relationship between thermophysical properties and mass loss caused by high temperature has not been investigated in detail. In this paper, the effect of high temperatures (up to 800 °C) upon the thermophysical properties of clay is investigated and the relationship between thermal parameters and mass loss is researched via laboratory test. The test results indicate that thermal conductivity and specific heat decrease exponentially as temperatures rise, and thermal diffusivity that fluctuates between 0.3 mm^2/s and 1.2 mm^2/s exhibits a certain degree of volatility with temperature. When the temperature rises, the water dissipates, the clay splits, and the organics carbonize and sublimate. All of these physical-chemical changes make the water content decrease and porosity increase, eventually altering the thermal parameters of clay. Furthermore, thermal conductivity displays a good linearity with mass loss and a negative exponent with porosity. The results obtained in this paper will be good for predicting the thermophysical properties of clay when exposed to high temperature.

1. Introduction

Thermophysical properties of soil are among the most basic properties and exhibit great significance to many thermal ground structures. Clay represents an excellent thermodynamic material and exhibits various functions, such as seepage control, pollution prevention, heat insulation and radiation protection. Clay is the principal medium for geothermal energy piles and underground power cables, and its thermophysical properties directly determine the efficiency of energy utilization [1–3]. Landfills often use clay as a liner, but the temperature field can significantly influence the performance of the liner system. Thus, gas migration and mechanical behaviors of municipal solid waste (MSW), as well as thermal conductivity, are important parameters for determining the appropriate temperature field in the landfill [4,5]. Clay is also used for a cushion in nuclear waste disposal, and the thermophysical properties directly determine the radiant heat dissipation [6–8]. In addition, when the temperature rises sharply in the tunnel fire, it leads to significant changes in the thermophysical properties of the clay, which affects the tunnel heat dissipation or preservation [9,10]. Furthermore, higher requirements for thermal performance of building materials are currently necessitated. For example, when fired clay bricks experience high temperatures, the clay's thermal conductivity is an important criterion for energy conservation, as it influences the structural heat loss [11]. Therefore, it is necessary

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to study the relationship between the thermophysical properties of clay and high temperatures in order to improve the utilization efficiency and heat insulation performance of the thermal engineering.

As Table 1 shows, most previous studies have only investigated the influence of water content, porosity, and dry density on the thermophysical properties of clay at room temperature [12,15,16,19]. Though several studies examined the influence of temperature on thermophysical properties, the range of temperatures is usually low, and they have not investigated the relationship between thermophysical properties and mass loss caused by high temperatures in detail [13,14,17,18]. Thus, knowledge of the thermophysical properties of clay under high temperatures is insufficient. Based on the previous research results, this paper has explored the influence of high temperatures on the thermophysical properties of clay (up to 800 °C) and investigated the relationship between thermal parameters and mass loss, as well as those factors affecting thermal parameters. The findings presented in this paper are valuable for determining the thermophysical properties of clay when exposed to high temperatures.

2. Experimental studies

2.1. Preparation of specimens

Clay for this experiment was obtained from Xuzhou of Jiangsu province, China. Firstly, the clay was filtered through a 0.075 mm sieve, and its composition was determined by X-ray diffraction

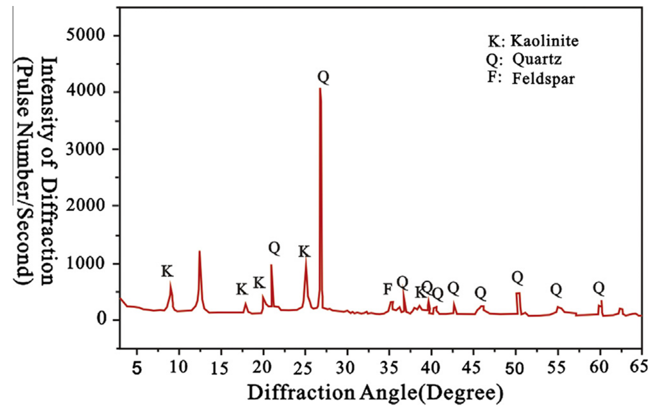

Fig. 1. X-ray diffraction (XRD) pattern of clay [20].

(XRD). The test results of the clay are shown in Fig. 1, and its main components are kaolinite and quartz.

Next, the clay was formed into a cylindrical shape with a hammer. The weight of the hammer is 1 kg, and its drop height is 29 cm. The number of frontal and reverse strikes is 100 times and 50 times, respectively. Lastly, the clay specimens were placed inside for 5 days to dry naturally and then sealed with sealing bags. The physical properties of the clay are listed in Table 2, and its density is 2.11 g/cm^3. The clay was identified as low liquid limit soil according to the plastic diagram.

Table 1
Previous studies of thermophysical properties.

Authors	Objects	Thermal parameters	Factors	Achievements
Su et al. [12]	Soil	The thermal conductivity specific heat	Water content porosity	The thermal conductivity of soil has logarithmic relationship with the increase of moisture content and pore-solid ratio; the specific heat increases linearly with moisture content
Zhang et al. [13]	Sand, clay, rock	The thermal conductivity	Sizes saturation temperature (<50 °C)	The thermal conductivities of samples with different geometric sizes are similar; the values of β (the thermal variance coefficient) of geotechnical materials are small, mostly with magnitude 10^{-3}, and the curves of thermal conductivity and temperature are approximately linear under different saturation
Liu et al. [14]	Silty clay loam, fine sand	The thermal conductivity	Water content temperatures (5–88 °C)	The thermal conductivity under 88 °C is 3 or 4 times as high as that under 5 °C; the critical water content, which depends on texture, exists as thermal conductivity changes with the water content
Zhang et al. [15]	Soil	The thermal conductivity volume specific heat thermal diffusivity	Dry density water content soluble salt	The thermal conductivity of soil increases linearly with increasing water content and dry density; the thermal diffusivity and volume specific heat also increase with increasing water content and dry density; the thermal parameters are found to be correlated positively to the S_iO_2 content in soil and the concentrated N_aCl increases the thermal conductivity of soil
Dondi et al. [16]	Clay bricks	The thermal conductivity	Composition features	The simple linear binary correlations and the multivariate analyses highlight the role played by some mineralogical components; the role of open porosity in improving the thermal performances of bricks is predominant
Duarte et al. [17]	Sandy-clay (SC), clayed-sand (CL)	The thermal conductivity specific heat	Water content saturation temperature (<65 °C)	The thermal conductivity and specific heat are not constant for a given soil, the thermal conductivity varies exponentially with gravimetric water content and degree of saturation whereas specific heat varies linearly with gravimetric water content and temperature
Abuel-Naga et al. [18]	Clay	The thermal conductivity	Porosity temperature (<90 °C)	The thermal conductivity increases as the soil porosity decreases and also increases as the soil temperature increases; the thermal conductivity of saturated soils is more sensitive to porosity change than temperature change
Alrtimi et al. [19]	Sandy soil	The thermal conductivity	Porosity saturation	The performance of most of the selected models also increases as the soil approaches a two phase state, where conduction plays the dominant role in controlling heat transfer; the variation of the thermal conductivity against the volumetric water content and porosity can be closely expressed as a logarithmic function