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Thermal conductivity of traditional ceramics Part II: Influence of mineralogical composition

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Abstract

The thermal conductivity of traditional ceramic materials is known to be a function of their porosity or bulk density. However, the scatter in the thermal conductivity–bulk density data in certain studies, particularly when data from industrially processed brick are involved, suggests that thermal conductivity depends, apart from porosity, on other characteristics such as mineralogical composition, microstructure, humidity, and the presence of soluble salts.

A standard red-firing clay used in brick manufacture has been used in this study with a view to systematising the impact of the different variables that could influence thermal conductivity and mechanical strength. Part I of the study presented the results obtained when the dry bulk density of the pieces and their firing temperature were modified.

Part II examines the influence of the mineralogical composition of the starting raw materials mixture on the thermal conductivity and mechanical strength of clay brick products. The findings suggest that to manufacture traditional ceramics with high thermal insulation and appropriate mechanical properties, it is advisable to use illitic-kaolinitic clays. Large-sized potassium feldspar and quartz particles adversely affect fired mechanical strength. In addition, quartz has high thermal conductivity. The addition of carbonates or the use of calcareous clays has a positive effect on mechanical strength, because carbonate acts as a pore-forming agent and generates crystalline phases during firing that enhance mechanical strength.

Keywords: C. Thermal conductivity; D. Clays; D. Traditional ceramics

1. Introduction

The thermal conductivity of traditional ceramic materials is known to be a function of their porosity or bulk density [1–4]. However, the scatter in thermal conductivity–bulk density data in certain studies, particularly when data from industrially processed brick are involved, suggests that thermal conductivity depends, apart from porosity, on other characteristics such as mineralogical composition, microstructure, humidity and on the presence of soluble salts [5–9].

In the context of a systematic examination of the different variables that could influence thermal conductivity, a previous paper [10] presented the results obtained when dry bulk density and firing temperature were modified. That study showed that thermal conductivity does not solely depend on the total porosity of the fired pieces, but that microstructure and pore size distribution need to be considered, which depend on the degree of sintering.

This paper examines the influence of the mineralogical composition of the starting raw materials mixture on the thermal conductivity and mechanical strength of traditional ceramic materials. A standard red-firing clay for brick manufacture was used as starting material into which different raw materials were alternately incorporated to modify its mineralogical composition.

2. Experimental

A red-firing clay (IC) studied in a previous paper [10] was used as starting material. Clay IC mineralogical composition was modified by replacing 15% and 30% by weight of clay IC,

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Table 1
Chemical composition (wt%), true density, and average particle size of the raw materials used.

Oxide	IC	Q	PF	C	D	KC
SiO_2	58.5 ± 0.3	98.5 ± 0.4	68.3 ± 0.3	0.5 ± 0.1	0.05 ± 0.01	59.2 ± 0.3
Al_2O_3	20.2 ± 0.2	0.50 ± 0.03	17.2 ± 0.1	0.10 ± 0.03	<0.01 ± 0.01	26.5 ± 0.2
Fe_2O_3	7.14 ± 0.05	0.03 ± 0.01	0.10 ± 0.02	0.05 ± 0.01	<0.01 ± 0.01	1.20 ± 0.05
CaO	1.03 ± 0.04	0.33 ± 0.01	0.50 ± 0.02	55.3 ± 0.2	30.3 ± 0.1	0.65 ± 0.02
MgO	1.56 ± 0.09	0.02 ± 0.01	0.08 ± 0.01	0.10 ± 0.01	21.4 ± 0.1	0.25 ± 0.01
Na_2O	0.21 ± 0.03	0.01 ± 0.01	2.20 ± 0.10	<0.2 ± 0.2	–	0.05 ± 0.01
K_2O	4.35 ± 0.09	0.15 ± 0.01	11.0 ± 0.1	<0.04 ± 0.04	–	0.70 ± 0.02
L.O.I.(1025 °C)	6.09 ± 0.08	0.40 ± 0.03	0.50 ± 0.04	43.5 ± 0.1	45.8 ± 0.1	10.0 ± 0.1
True density (kg/m^3)	2680 ± 15	2650 ± 15	2500 ± 15	2720 ± 15	2850 ± 15	2650 ± 15
d_{50} (μm)	6.4 ± 0.1	40 ± 0.8	27 ± 0.5	14 ± 0.3	24 ± 0.5	4.3 ± 0.1

alternately, with each of the following raw materials: quartz (Q, Sibelco SE-6), potassium feldspar (PF, Incusa FK-100), calcite (C, Zaera Calaf C-40), dolomite (D, Quimialmel D-150) and a clay with a higher kaolinite content (KC, Imerys RC-593). Clay KC was included in order to establish the influence of the type of clay mineral. Table 1 shows the chemical composition, true density, and average particle size of the raw materials used.

In order to prepare the test pieces, clays IC and KC were dry milled in a hammer mill to a particle size fraction below 0.5 mm. Compositions of clay IC, in which 15% and 30% by weight of clay IC were alternately replaced with each raw material, were prepared in a lab mixer. The resulting powder was then moistened to 0.055 kg water/dry solid kg and test pieces were pressed at 25 MPa. These pieces were dried and then fired in an electric kiln at a heating rate of 5 °C/min to a peak temperature of 1000 °C, with a 60-min dwell at peak temperature. Cooling was performed by natural convection.

Dry and fired bulk density was determined by the mercury displacement method. The mechanical strength of the fired pieces was determined by three-point bending in a mechanical testing machine with bar-shaped test pieces, 80 mm long, 20 mm wide, and 6 mm thick.

The thermal conductivity measurement tests were conducted according to an adapted experimental procedure of international standards ISO 8301:1991: thermal insulation – determination of steady-state thermal resistance and related properties – heat flow meter apparatus, and ISO 8302:1991: thermal insulation – determination of steady-state thermal resistance and related properties – guarded hot plate apparatus.

Table 2
Characteristics of the test pieces.

Composition (wt%)	ρ_S (kg/m^3)	ρ_C (kg/m^3)	λ (W/(m K))	σ (MPa)
100% IC	1955 ± 2	1973 ± 3	0.56 ± 0.01	18.0 ± 0.4
85% IC + 15% Q	1974 ± 2	1942 ± 2	0.57 ± 0.01	11.1 ± 0.6
70% IC + 30% Q	1983 ± 4	1920 ± 2	0.58 ± 0.01	7.0 ± 0.2
85% IC + 15% PF	1978 ± 2	1938 ± 2	0.52 ± 0.01	12.2 ± 0.3
70% IC + 30% PF	1940 ± 2	1890 ± 1	0.50 ± 0.01	8.6 ± 0.5
85% IC + 15% C	1979 ± 2	1771 ± 2	0.51 ± 0.01	16.3 ± 0.4
70% IC + 30% C	1992 ± 2	1621 ± 4	0.46 ± 0.01	13.2 ± 0.3
85% IC + 15% D	2006 ± 2	1814 ± 3	0.52 ± 0.01	15.3 ± 0.3
70% IC + 30% D	2065 ± 3	1676 ± 3	0.49 ± 0.01	11.5 ± 0.2
85% IC + 15% KC	1974 ± 2	1982 ± 2	0.50 ± 0.01	19.9 ± 0.3
70% IC + 30% KC	1959 ± 3	1960 ± 2	0.47 ± 0.01	19.1 ± 0.3

Finally, the porous texture of the pieces was observed in a scanning electron microscope.

3. Results

3.1. Influence on bulk density

Table 2 details the raw materials contained in each composition, in addition to the dry bulk density (ρ_S), fired bulk density (ρ_C), thermal conductivity (λ), and mechanical strength (σ) of the test pieces.

The table shows that the introduction of the different raw materials in the compositions modifies dry and fired test piece properties. The differences in ρ_S are related to the particle size distribution of the different raw materials, as well as to differences in their true density (Table 1). The raw materials with the highest true density are dolomite (2.85 g/cm^3) and calcite (2.72 g/cm^3), correlating with the higher ρ_S values for the pieces containing these raw materials.

The bulk density values of the fired test pieces are plotted versus the clay IC content alternately replaced with each respective raw material in the starting composition in Fig. 1. The figure shows that ρ_C decreases in all the compositions with respect to clay IC, except in the kaolinitic clay-containing composition, which yields similar values. The differences observed between the test compositions may be attributed to

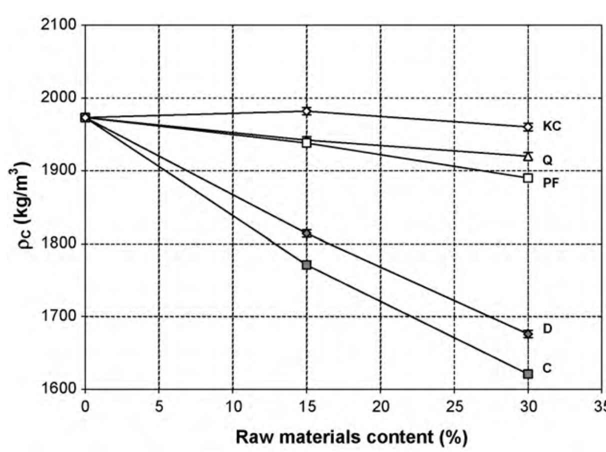

Fig. 1. Evolution of fired bulk density with the raw materials contained in the compositions.