PORE STRUCTURE AND THERMAL CONDUCTIVITY OF BURNT CLAY BRICKS

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Abstract:
Commonly manufactured burnt clay bricks were analysed from the aspect of the relationships between their microstructure and dry thermal conductivity. On the base of the analysis a simple microstructural model of thermal conductivity was proposed. The proposed model was compared with the microstructural model developed for the calcium silicate hydrates based composite materials.

Keywords:
Thermal conductivity, clay brick, porosity, fractal dimension

INTRODUCTION

Most of the building materials are composites and their thermal parameters represent the effect resulting from the properties of their particular phases and components. Usually the composite consists of the bonding matrix, aggregate and pore space. The thermal conductivity of the dry porous material is given by the properties of the solid phase as a whole and by the pore volume. The known relationships among the solid phase properties pore structure parameters and material thermal parameters enable to model thermal properties of the porous materials only from the knowledge of properties of the solid phase and the pore space.

In the previous work [6] the relationship between the thermal conductivity and pore structure parameters for dry CSH-based mortars, plasters and insulation boards was analysed. It was found out that in the first approximation the thermal conductivity of tested materials was proportional inversely to the second power of their total porosity. It was also shown that the thermal conductivity of the tested materials could be modeled by serial configuration of the aggregate with bulk paste and interfacial transition zone conductivities, weighted by the power function of their volume fractions. The exponents of the power function were determined using the particular components fractal dimensions.

With the aim to verify this approach on a different building material the relationship between the thermal conductivity and pore structure parameters was analysed for burnt clay bricks.

Burnt clay bricks are common building material manufactured from the clay-sand mixture (the portion of the sand can be from 30 to 50%). The burning takes place at temperatures 900 - 1000°C. Their microstructure is dependent of the particle size distribution, mineralogical and chemical composition, type of burning additives and the way of burning [2,3].

THEORY

Macroscopic thermal conductivity of composite material can be expressed using the thermal conductivities of particular components. For the continuous high conductivity components fractions with the discrete low continuity components the macroscopic thermal conductivity can be modeled by the summation of particular components:

$$\lambda = \sum_i \lambda_i \cdot (\Phi_i - \Phi_{i,crit})^{n_i} \tag{1}$$

Where λ_i is thermal conductivity of component,
Φ_i is component volume fraction,
$\Phi_{i,crit}$ is the critical volume needed for a connected network to be formed through the material,
$n_i = 1 + FD$,
FD is the fractal dimension of the component or pore volume fraction [5].
In case of parallel configuration of the components $n_i = 1$.

In case of discrete high conductivity components in the continuous low conductivity or pore volume fractions the following relation can be applied:

$$\lambda = \frac{1}{\sum_i \frac{(\Phi_i - \Phi_{i,crit})^{n_i}}{\lambda_i}} \tag{2}$$

Where n_i =1for serial configuration of the components, $n_i > 1$ in case of dispersion of the low conductivity component.

In the previous work [6] the following empirical relation between thermal conductivity and total porosity was found out for CHS based materials:

$$\lambda = \frac{1}{\frac{\Phi^2}{0.064}} \tag{3}$$

It was also shown that the thermal conductivity of the tested materials could be modeled by serial configuration of the aggregate with bulk paste and interfacial transition zone conductivities by the following relation:

$$\lambda = \frac{1}{\frac{(\Phi_{aggregate} + \Phi_{paste} - \Phi_{pasteITZ})^{n1}}{\lambda_{aggregate}} + \frac{(\Phi + \Phi_{pasteITZ})^{n2}}{\lambda_{ITZ}}} \tag{4}$$

Where λ_{ITZ} is thermal conductivity of interfacial zone + porosity.
The porosity and solid phases fractal dimensions were estimated as FD ≈ 1.0.

EXPERIMENTAL

The pore structure parameters and dry thermal conductivity were determined for four types of burnt clay bricks.

The pore size distribution, the open porosity and the specific surface area of pores were studied using the mercury intrusion porosimetry (MIP): the high-pressure porosimeter mod. 2000 and macro-porosimeter mod. 120 (both Carlo Erba, Milan). This system enables determination of micropores with the radius from 3.7 up to 7500 nm and of larger pores with a radius up to 0.06mm. The porosimetry measurement was carried out by the fraction of broken dried (up to 105°C) samples. Specific surface area of pores was determined using the cylindrical model. The open porosity was also determined from the suction test.

The thermal conductivity was measured by transient pulse method using the commercial device ISOMET 2104 with the surface probe API 210412. The used surface probe is suitable for thermal conductivities in the range from 0.3 to 2 W/m·K. The measurement is based on the analysis of the temperature response of the practically semi-infinite body to the heat flow impulse. The heat flow is generated by electrical heating using a resistor heater having a direct thermal contact with the surface of the sample.

The samples were conditioned under laboratory conditions: 28°C and 36% relative humidity and they can be practically considered as dry.

RESULTS AND DISCUSSION

The total porosity, specific surface area and pore radius median values, determined by MIP are presented in Tab. 1. The values of open porosity, determined from suction test, bulk and true density and the measured values of thermal conductivity are in Tab. 2. Because for the clay bricks the values of open porosity and total porosity are practically identical [3], the values of open porosity were used in the following analysis of the relationships between the thermal conductivity and microstructure.

In Fig. 1 the relationship between the total porosity and thermal conductivity of tested bricks is compared with the previous measurements of CHS materials and the empirical relation (3). As can be seen from the figure the dependence thermal conductivity/porosity dependence of bricks can be in the first approximation expressed by empirical relation (3) similarly like in case of CHS materials.

The clay bricks structure is characterised by configuration of discrete solid components in continuous low thermal conductivity phases. Therefore it was expected that the model of thermal conductivity could be based on relation (2). Analogously to the relation (4) for CHS based materials the thermal conductivity of dry clay bricks was expressed using the model of the serial configuration of solid and low thermal conductivity phases:

$$\lambda = \frac{1}{\frac{(\Phi_{solid} - \Phi_{ITZsolid})^{n1}}{\lambda_{solid}} + \frac{(\Phi + \Phi_{ITZsolid})^{n2}}{\lambda_{ITZ}}} \tag{5}$$

Table 1. Pore structure parameters of the bricks (MIP)[Bagel 2001]

Material	Total porosity	Specific surface area [m^2/g]	Pore radius median [nm]
Brick D	0.3	-	-
Brick L	0.28	2.39	559.1
Brick P	0.50	8.07	535.1
Brick S	0.43	1.44	542.9

Table 2. Open porosity (suction test), true density and dry thermal conductivity of the bricks

Material	Bulk density [kg/m^3]	Open porosity [-]	True density [kg/m^3]	Thermal conductivity λ [W/m·K]	λ standard deviation [W/m·K]
Brick D	1724	0.3	2460	0.656	±0.018
Brick L	1710	0.33	2550	0.625	±0.033
Brick P	1377	0.42	2370	0.397	±0.015
Brick S	1426	0.44	2590	0.456	±0.014

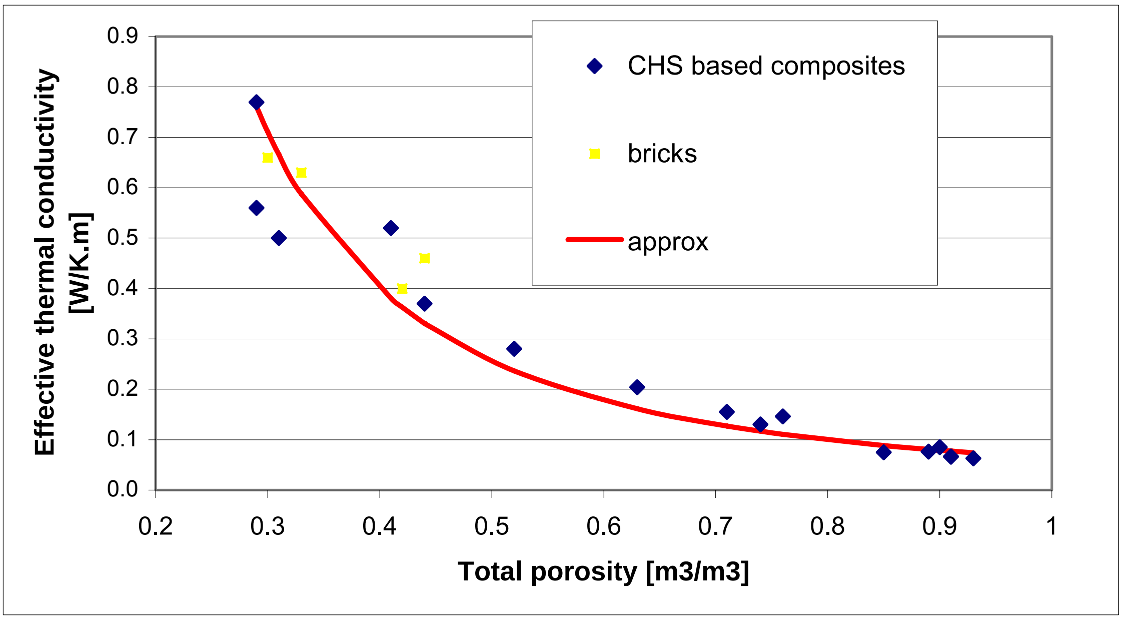

Fig. 1 Thermal conductivities of clay bricks and CHS based materials vs. total porosity. Comparison of the measured values and empirical approximation (1)

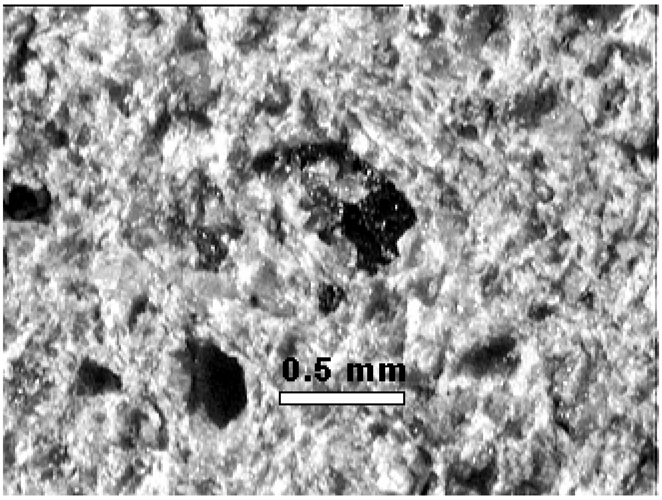

Fig. 1 Optical microscopy of brick L

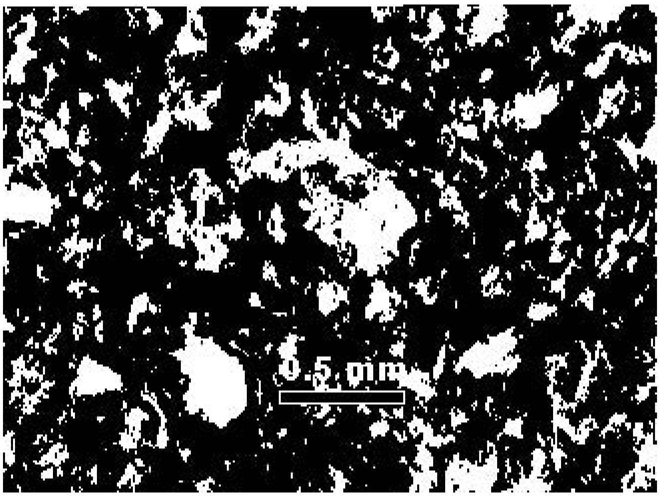

Fig. 3 Binary image of microscopy – brick L

The fractal dimensions were determined from SEM pictures (Fig. 2, 3) of the considered materials by a box counting method [8]. The fractal dimensions and corresponding exponents of the bricks components are in Tab. 3. The considered thermal conductivity of the clay brick body with density equal to ca 2500 kg/m^3 (Tab. 2) was about 1.5 W/m·K [7]. As the thermal conductivity of interfacial zone (including its porosity) the value 0.064 W/m·K, corresponding to the value measured for the pure CHS – xonotlite [4], was considered. It was also supposed that the interfacial zone volume fraction represented 10% of the total porosity in average.

The comparison of the measured thermal conductivities/total porosity relation for clay bricks and CHS based materials with the relation (5) is shown in Fig. 4. As can be seen from the Fig. 5, the measured values of clay bricks are in a satisfactore agreement with the relation (5). It was also found out that the value 0.064 W/m·K could qualify the thermal conductivity of the pore space + interfacial zone fraction also in case of burnt clay bricks.

With the aim to evaluate the sensitivity of the relation (5) to the used material parameters, the influence of the values of thermal conductivity of clay brick body and pore space + interfacial zone fraction was analysed. The changes of the thermal conductivity of clay brick body within the interval ± 30% of the original value had negligible influence on the resultant thermal conductivity/porosity relation for the considered porosities. On the other hand the changes of the thermal conductivity of pore space + interfacial zone fraction had noticable influence. In Fig. 5 the effect of the thermal conductivity of pore space + interfacial zone fraction changes within the interval of ± 9% of the original value is presented.

Table 3 Fractal dimensions and corresponding exponents of tested bricks

Component	Fractal dimension	Exponent
Solid phase	FD = 0.0	$n_1 = 1$
Porosity	FD = 1.7	$n_2 = 2.7$

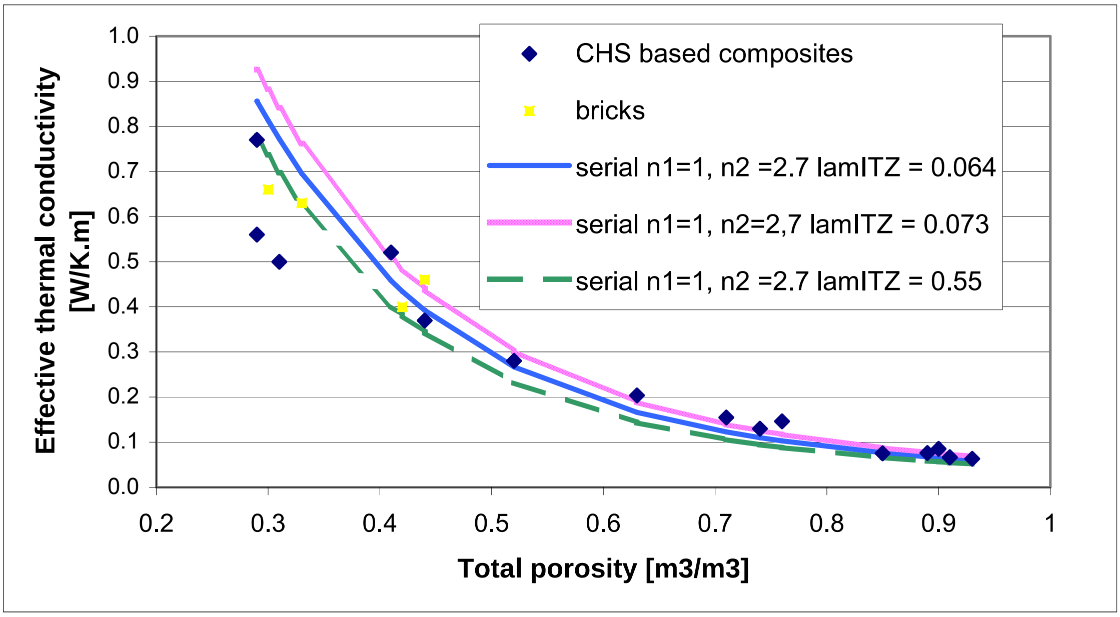

Fig. 4 Thermal conductivities of clay bricks and CHS based materials vs. total porosity. Comparison of the measured values and relation (4)

CONCLUSIONS

The relation between microstructure and effective thermal conductivity was investigated for four types of burnt clay bricks.

The effective thermal conductivity of dry clay bricks can be similarly, like thermal conductivity of CHS based mortars, plasters and insulation boards, modelled by serial configuration of solid and porous - low thermal conductivity - phases.

In the model the degree of the dispersion of low thermal conductivity phase is expressed by a power low. The exponent contains the pore space fractal dimension.

The fractal dimension can be determined with the use of image analysis.

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