PORE STRUCTURE AND THERMAL CONDUCTIVITY OF POROUS INORGANIC BUILDING MATERIALS

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Abstract

Commonly manufactured mortars and plasters were analysed from the aspect of the relationships between their composition, pore structure and dry thermal conductivity. The thermal conductivity of the materials was analysed considering different models of the configuration of particular phases and components. Dry thermal conductivity of plasters and mortars is given by the thermal conductivity of used aggregate, binder, fillers and porosity. In case of not satisfactory information on the material composition and properties the simple microstructural model of thermal conductivity enables to estimate the thermal conductivity from the total porosity.

Key words: porous materials, thermal conductivity, material composition

1 Introduction

Thermal conductivity of dry material is a basic material parameter for evaluation of the moisture dependent thermal conductivity of the porus building materials. In the proces of design and development of new material or in case of the necessity to estimate its dry conductivity it is usual to model the thermal conductivity by the application of adequate microstructural model. The determination of the dry thermal conductivity by such a model is usually accompanied by the problem of the lack of information on the thermal conductivity of particular components. In such a situation usually the data from another sources are used. However such data have high variability resulting from the material properties variability as well as the variability of the used measurement methods. In order to analyse the reliability of microstructure based thermal conductivity models the dry thermal conductivities of 16 various mortars and plasters were measured. Besides the thermal conductivity also the pore structure and composition of each of the analysed materials was determined in order to prove the possibility of an application of a general thermal conductivity model for the chosen material group. From the apect of their chemical properties the plasters and mortars are calcium silicate hydrates (CSH) based composite materials.

2 Experimental

The macroscopic parameters of the analysed composite materials represent the effects resulting from properties of their particular phases and their components. The components of the solid phase can be differentiated according to their function in a material. Generally the solid phase of the analysed materials consists of the bonding matrix, the reinforcement, the aggregate or the lightweight filler.

The thermal conductivity of the analysed mortars and plasters was measured by the guarded hot plate method [3]. The dry bulk density of the materials was in the range of 200 - 1725 kg.m^{-3}. The measured samples were of the dimensions 0.50x0.50x0.04/0.08 m. The mean sample temperature was ca 19°C and temperature difference during the measurements were ca 6 K. The samples were conditioned under laboratory conditions at the 19°C temperature and the 45% relative humidity and they can be considered as practically dry. The volume fractions of particular components for each material (Bagel 2002) together with the corresponding results of the thermal conductivity measurements are in Table. 1.

Table 1. Compositions volume fractions and dry thermal conductivities of particular materials

Material	Aggregate	Binder	Lightweight Filler	Porosity	Thermal conductivity [W/m.K]
PM02	0.41	0.19		0.41	0.52
PM04	0.41	0.15		0.44	0.37
KM	0.43	0.17		0.4	0.50
ZM	0.43	0.28		0.29	0.77
EP-T	0.08	0.18	0.82	0.74	0.13
EPS-T	0.039	0.11	0.57	0.28	0.075
710	0.39	0.33		0.29	0.56
720	0.11	0.26		0.63	0.204
EP-B	0.095	0.2	0.80	0.70	0.155
EPS-B	0.004	0.07	0.73	0.16	0.076
Sanova	0.1	0.14		0.76	0.146
MSS20	0.3	0.18		0.52	0.28
1100		0.09		0.91	0.066
1100M		0.09		0.91	0.067
200		0.07		0.93	0.063
250		0.10		0.90	0.085

3 Analysis of the measured results

In principle the microstructure based thermal conductivity models assume that the thermal conductivity is correlating with the thermal conductivities and the volume portions of particular phases. The possible thermal conductivities of the particular components of mortars and plasters are in Table 2. It results from the table that the thermal conductivity of aggregate is significantly higher in comparison with the other components.

Table 2. Considered thermal conductivities of the mortars and plasters components [2], [5], [7], [8]

Material	Thermal conductivity [W/m.K]
Cement paste	0.66 – 1.2
Gypsum	0.66
Quartz	2.90 – 5.18
Limestone	3.15 - 3.23
Calcium silicate hydrate	1.00

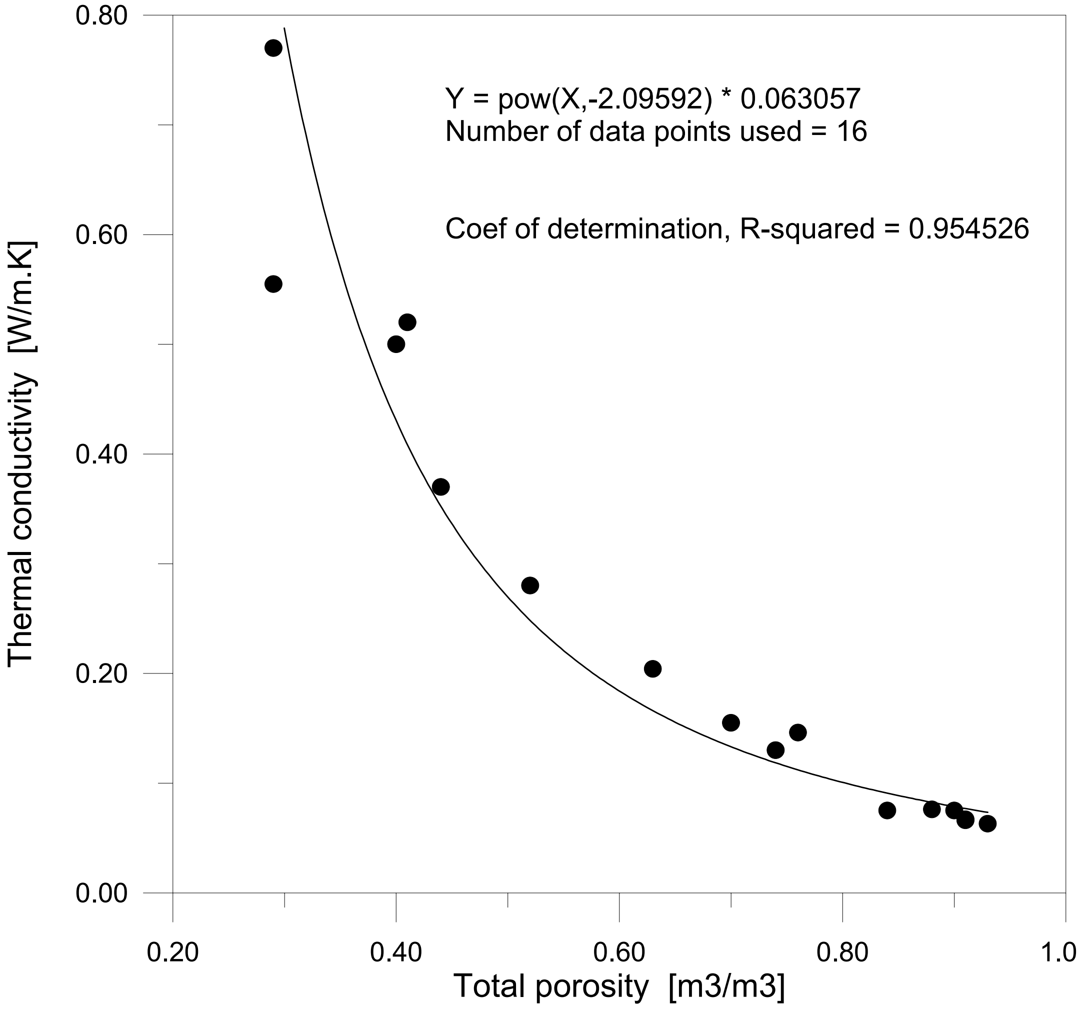

Figure 1. Dry thermal conductivity of mortars and plasters vs. total porosity

The correlations between the measured thermal conductivities and the volume portions of the particular components as well as of the mortars/plasters porosities were analysed. The best correlation was found out between the thermal conductivity and the total porosity (Fig. 1). The analysed mortars and plasters thermal conductivity dependence on the total porosity can be expressed by the following relation:

$$\lambda_s = \frac{1}{\frac{\Phi^2}{0.063}} \tag{1}$$

where Φ is the total porosity [-].

4 Discussion

The model of the thermal conductivity of mortars solid phase assumes that it consists of a continuous binder phase in which a discontinuous aggregate is dispersed (Fig. 2). It supposes two parallel heat flow paths, one through the connecting binder layers and the other through a path consisting of aggregate and cement paste in series [2], [5]. Considering the thermal conductivity of aggregate 3.0 W/m.K and the thermal conductivity of cement paste 0.7 W/m.K this model gives the thermal conductivity in the range from 1.0 to 1.5 W/m.K for the compact solid phase of plasters. From the comparison of the evaluated thermal conductivities of the compact solid phase, the volume portion of solid phase and measured values of themal conductivities (Tab. 1) it follows that solid phase cannot be considered as a continuous path for heat flow for the analysed materials.

Drying shrinkage is an inherent property of all CSH-based materials. The pure hardened CSH paste undergoes very high drying shrinkage, whereas the reinforced material shows significantly less shrinkage due to the restraint provided by aggregate (or fibre) reinforcement [4]. Preliminary test results on the behaviours of capillary pores have shown that the pore volume exhibits size and shape changes with change in relative humidity and frequently the pores expand rather than shrink upon drying. What apparently happens may be explained by the fact that non-shrinking reinforcement may form a high resistance to shrinkage and as a result the shrinkage force generated by the CSH paste opens up the pores. The shrinkage induced pores opening disconnects the originally compact binder and the pores create the disconnected solid phase the thermal conductivity of which can be modelled by the serial composition of the solid and air layers [4]. Simultaneously the disconnected solid phase is parallel with the air volume represented by the total porosity. The resulting thermal conductivity of the mortars and plasters can be expressed as the serial configuration of the compact (aggregate + bulk paste) and porous interfacial zone (disconnected paste + pores) by the relation:

$$\lambda_s = \frac{1}{\frac{\Phi_{aggregate}}{\lambda_{aggregate}} + \frac{(1 - p_{IZ}) \cdot \Phi_{paste}}{\lambda_{paste}} + \frac{\Phi^2}{\lambda_{IZ}}} \tag{2}$$

where: $\Phi_{\mathrm{aggregate}}$ and Φ_{paste} are volume portions of aggregate and paste respectively, p_{IZ} is volume portion of disconnected paste on total volume of paste, $\lambda_{aggregate}$, λ_{paste} , λ_{IZ} are thermal conductivities aggregate, the bulk paste and porous interfacial zone (pores + disconnected paste) respectively [W. m^{-1}.K^{-1}]. The second power of the total

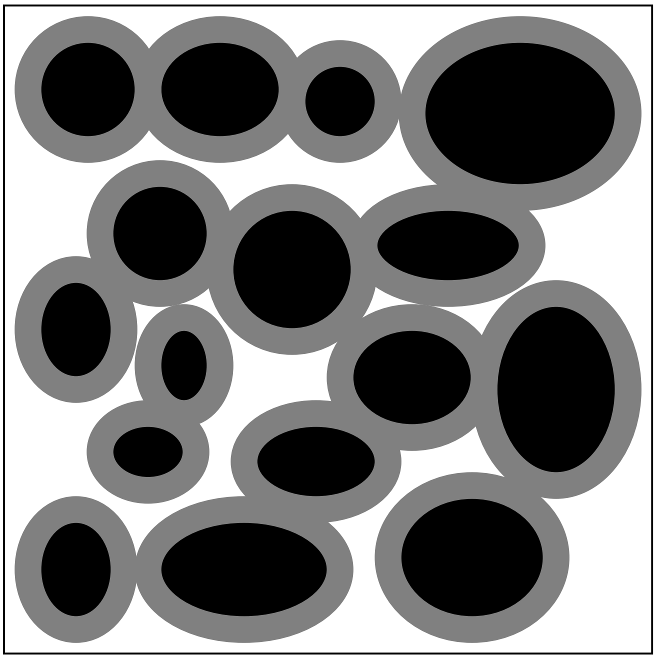

Figure 2. Two-dimensional schema of interfacial zone in mortar.

porosity in relation (2) expresses the randomness of the disconnected solid phase continuity.

As the thermal conductivity of bulk paste and mainly aggregate in the relation (2) are signicantly higher than the thermal conductivity of the disconnected interfacial zone the relation (2) has practically the form of the approximation (1) obtained from measurements. The thermal conductivity of the porous interfacial zone 0.063 W/m.K in the relation (1) corresponds to the values measured for the pure disconnected CSH [4]. As follows from the analysis of the relation (2), the simplified form (1) is suitable mainly for the more porous materials.

There is a lot of models for the evaluation of the resulting thermal conductivity of porous composite materials [2]. The most of them are based on the combination of parallel and serial configuration of particular phases and components. The problem or empiric factor of each model is the determination of the adequate portion of the serial components. Simultaneously the aggregate thermal conductivity is significantly variable and it increases the uncertainty of the model used.

The model formulated by the relation (2) tries to prevent this uncertainties. It estimates the resulting composite thermal conductivity from one relatively easily measurable parameter – the total porosity. From Fig. 1 the relationship (2) has the best fit in the porosity range from 0.4 do 0.65. The local worse coincidence between the measured and estimated values can be explained by the actual variability of the thermal conductivity value of solid phase.

5 Conclusion

The thermal conductivity of dry CSH-based materials is characterized by the decomposition of their solid matrix due to shrinkage induced microcracking occurrence.

The thermal conductivity of such materials can be modelled by the serial composition of the compact solid components (aggregate + bulk paste) and the porous interfacial zone (pores + paste disconnected by the microcracks).

The thermal conductivity of all analysed mortars and plasters is proportional inversely to the second power of their total porosity. The comparison of the measured and calculated results indicates the effect of possible uncertainty of the calculation inputs and the best coincidence of the results is in the porosity interval of 0,4 –0,6.

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References

[1] Bagel L. 2002. *Structural parameters of plasters.* Internal report. Institut of Construction and Architecture, SAS, Bratislava. (in Slovak)

[2] Khan M.I., 2002. Factors affecting the thermal properties of concrete and applicability of its prediction models. *Building and Environment.* **37,** pp. 604-614.

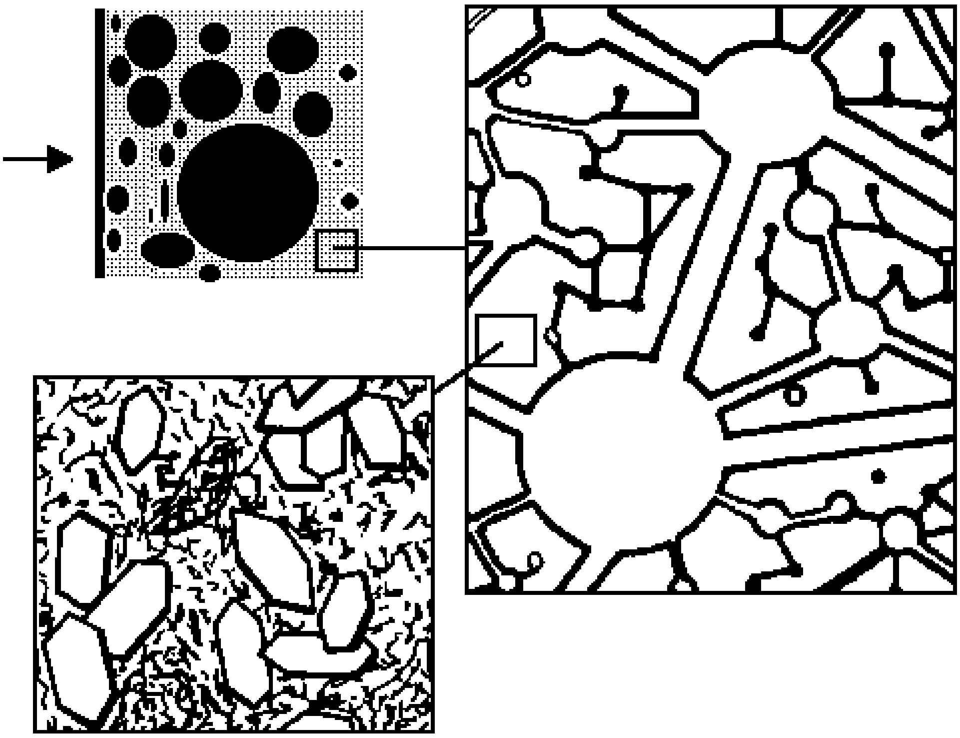
[3] Klarsfeld S, 1984. Guarded Hot Plate Method for Thermal Conductivity Measuremenent, in *Compendium of Thermophysical Property Measurement Methods, Vol.1 Survey of Measurement Techniques*, (Eds: Maglic K D, Cezairliyan A, Peletsky V E, New York, London: Plenum Press 1984) pp. 169-230.

[4] Koronthalyova O., Matiasovsky P.: Thermal conductivity of fibre reinforced calcium silicate hydrate-based materials. Submitted to *Journal of Thermal Envelope and Building Science*.

[5] Marshall A. L. 1972. The thermal properties of concrete. *Building Science* **7,** pp. 167-174.

[7] Xu Y., Chung D.D.L.: Effect of sand addition on the specific heat and thermal conductivity of cement. *Cement and Concrete Research **30***, pp. 59-61.

[8] Missenard A.: Conductivité thermique des solides, liquides, gaz et de leurs mélanges, (Paris: Editions Eyrolles 1965).



Schematic description of mortar microstructure distinguishing aggragate, binder, pores and CSH