Enhancement of insulating properties of brick clay by renewable agricultural wastes

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Abstract

The use of agricultural wastes (byproducts) in various segments of brick and tile industry is increasing continuously. These additives, which are previously mixed into the raw or compound clay, start to ignite during the firing process, providing extra thermal energy inside the product and decreasing the required external energy need. Besides this effect, the combustion of additives increases the porosity of the final product resulting in enhanced thermal insulation properties. In this paper the effect of some common agricultural wastes (sawdust, rice-peel and seed-shell) on the thermal properties of brick clay products was investigated. The brick samples were prepared from the mixture of the yellow and gray clay in the ratio of 4:1, water content was between 15.57-16.67 wt.% and the pore-forming additives in concentrations 0, 4 and 7 wt.%. To measure the steady state thermal conductivity of the clay mixtures, samples with dimensions of 300×300×50 mm were prepared. Drying and firing were performed using the industrial partner's standard procedures. Precise thermal conductivity data was measured, using a RAPID-K type static thermal conductivity instrument. The results showed that increasing the quantity of agricultural byproducts in the clay mixture significantly decreases the thermal conductivity of the final products, while only a minor reduction in the mechanical strength was observed. It was found that the most efficient byproduct additive was the sunflower seed-shell. With the addition of only 7 wt.% seed-shell to the basic clay the thermal conductivity decreased from 0,27 W/m·K to 0,17 W/m·K (i.e. ~36%).

Keywords: brick clay, thermal conductivity, pore-forming additives, agricultural waste

I. Introduction

The usage of renewable agricultural byproducts and waste materials in fired clay products as performance enhancing additives is continuously growing [1−3]. During the firing process the additives, mixed to the brick clay, are producing extra thermal energy due to combustion and effectively decreases the total energy need of the furnace used in the production. Besides of saving energy, the burning of the organic additives (also the gasification process) will form pores in the brick body, and thus causes a decrease in the product's thermal conductivity [4]. In early experiments and recipes, wood based additives like sawdust and wood chips were used, but more recently polymers and agricultural waste materials/byproducts, such as rice-peel or seed-shell, are also introduced as additives in the brick and tile industry. Because of that it is important to compare contribution of these additives to the quality of the final product, specially to their mechanical and thermal insulating properties.

In this paper a series of experiments was carried out to measure the effect of the specific type and the mixing ratio of the different additive materials (agricultural by-products) on the thermal conductivity of standard brick clay products. The clay samples were prepared using the same technology as in industrial processes, with different concentrations of the waste materials in the clay (i.e. 0, 4 and 7 wt.% of sawdust, rice-peel and seed-shell).

II. Sample preparation

A basic clay mixture was prepared from two type of raw materials (the yellow and gray clays), taken from different areas of the industrial partner's mine. In addition, three different types of pore-forming materials

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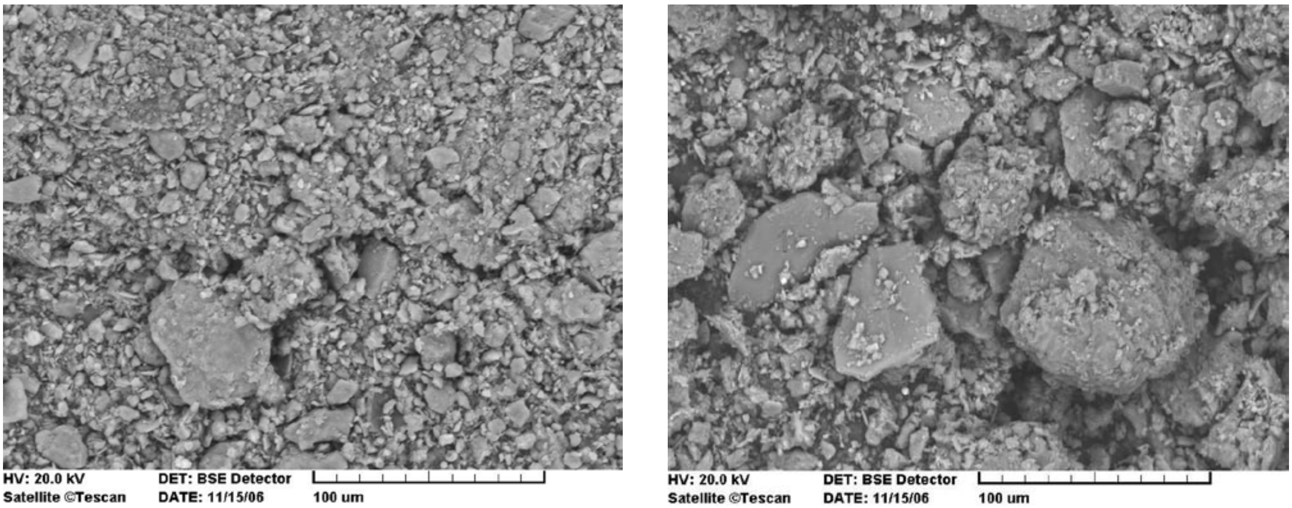
(sawdust, rice-peel and seed-shell) were added to the raw clay mixtures during the preparation of the brick samples.

The phase composition of the yellow and gray clays, were determined by using X-ray diffraction apparatus (XRD, Bruker D8). The results are shown in Table 1. During the first stage of sample preparation, the clays were milled and homogenized in a pan-mill. Scanning electron microscopy (SEM, AMRAY 1830 I with PV 9800 EDAX microprobe) was used to investigate the resulting microstructure of the raw materials. The SEM micrograph of the yellow clay (Fig. 1a) shows that structure is not really a homogeneous and consists mostly of particles smaller than 20 µm with some larger ones that approach 50 µm in size. The gray clay has higher inhomogeneity (Fig. 1b) where a large portion of particles are larger than 20 µm.

The pore-forming additives of interest (sawdust, rice-peel and seed-shell) are produced in abundance in every year by the agricultural industry, ensuring a sufficiently large reservoir for industrial applications like brick production. To eliminate the problems caused by the varying quality of organic products, care was taken to control the humidity and the particle size of all agricultural wastes, by drying and sieving.



a) b)

Figure 1. Microstructure of: a) yellow and b) gray clay (SEM image, 1000x magnification, bar=100 µm)

Table 1. Phase composition of the yellow and gray clays and the mixed compound

Phases	Yellow Clay [wt.%]	Gray Clay [wt.%]	Mixture 4:1 [wt%]
Quartz	75.9	73.5	75.4
Montmorillonite	1.2	-	1.0
Illite	3.3	1.4	2.9
Clinochlore	8.3	11.9	9.0
Muscovite	4.0	5.1	4.2
Gypsum	2.9	7.6	3.8
Vermiculite	4.4	0.5	3.6

Table 2. Compositions used for preparation of the different samples

Sample notation	Yellow Clay [wt%]	Gray Clay [wt%]	Pore-forming additives	
			Type	Portion [wt%]
RS	80	20	-	-
F4	80	20	Sawdust	4
F7	80	20	Sawdust	7
R4	80	20	Rice-peel	4
R7	80	20	Rice-peel	7
N4	80	20	Seed-shell	4
N7	80	20	Seed-shell	7

The brick samples were prepared from the mixture of the yellow and gray clay in the ratio of 4:1 (the phase composition of the mixture is shown in Table 1). The water content of the mixture was kept between 15.57−16.67 wt.%. The pore-forming additives were added to form compositions with 0, 4 and 7 wt.% of organic compound. The sample notation and their compositions are given in Table 2. Standard test specimens, with dimensions of 300×300×50 mm, were produced by shaping the mixtures in a special "molding" box. The prepared clay samples were first dried under laboratory conditions with free air drying for 72 hours, taking special care to ensure the crack free surfaces. After that the samples were fired in a laboratory muffle furnace (Hoker 2/3 1200) following industry practice at temperature of 900°C, using a predetermined temperature program (i.e. heating rate of ~100°C/h, dwelling time of 2h and cooling rate of ~70°C/h). The careful drying and strenuously controlled firing process enabled production of crack free brick samples with smooth and plain surfaces.

III. Measurement of thermal conductivity

Thermal conductivity was measured by a low temperature RAPID-K type heat conductivity measuring system (Fig. 2) designed for accurate steady state experiments. A brick sample was positioned between two plates (heat buffers), which temperatures were precisely controlled by an automatic regulator system. This system uses parallel thermocouples and regulates both sides independently. The measured temperatures at both sides were adjusted by electric heating elements and water cooling. Since two heated plates had different temperatures a controlled heat exchange process started between the buffer plates and through the brick sample with a set and well defined temperature gradient. At the bottom plate a heat flux detector was implemented to gather quantitative data about the quantity of transferred heat. The one-dimensional nature of the heat transfer was ensured by the application of effective insulation. Since the walls had the same thermal gradient as the sample material, the one-dimensional solution of the thermal conductivity differential equations can be used. At first, a measurement with the well known standard sample was carried out, to calibrate the thermal resistance of the heat flux meter and its dependence on temperature. As the detector's thermal resistance was determined the characteristic instrumental coefficient (k) was calculated, and the measurements with the real brick samples were started.

To measure the actual temperatures and the heat flux, fast response K-type thermocouples and a multi channel digital data acquisition system was used. The thermocouples were positioned at both (parallel and opposite) sides of the sample. The heat flux was measured with the internal, previously calibrated detector on the bottom buffer plate. The measurements started when both plates were adjusted at a lower temperature. The separately control units for the heat buffers (controlling the electrical heating and continuous cooling) ensured that soon after a sort time period both plates reached the desired temperatures as smoothly as possible and have them stabilized to a constant. The heat flux registered during the warm up period can not be used for calculation, because the large oscillations caused by the temperature control units of both plates may change even the sign of the heat flux. A typical temperature and heat flux plot vs. experiment time is shown in the Fig. 3. As can be seen, after about 40–50 minutes the measurement reached the steady state (i.e. all values became flat on the main plot). This is the measuring period when the heat flux can be read from the detector's voltage data and use to determine the sample's thermal conductivity with great accuracy. Fig. 4 shows a detailed plot of the temperature changes and the corresponding voltage values for heat flux at the end of the measurement. From the plot it is clear that in the final state there is only a slight change of the measured values (i.e in the range of 0.01mV or 0.1°C). This effect was eliminated by using the mean values for the last (10–20 minutes) stable timeframe in the calculations. Now, the thermal resistivity (R) of the "unknown" material can be calculated by inserting the

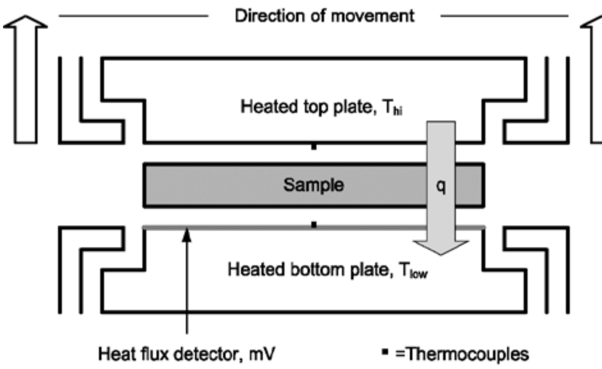


Figure 2. Schematic view of the heat conductivity measuring system

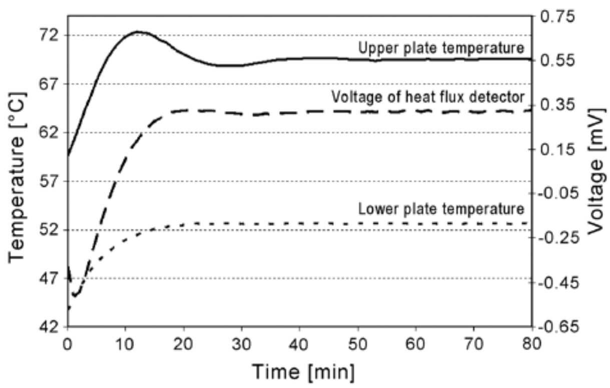


Figure 3. Typical plot from the measurement

determined characteristic instrumental conversion coefficient (k) into the following equation:

$$R=\Delta T/(U\cdot k) \tag{1}$$

where ΔT is the temperature difference between the two opposite walls of the sample (or plates) and U is the measured heat flux. Knowing the mean thickness of a sample (Δx), its thermal conductivity (λ) can be calculated using the following equation:

$$\lambda= \Delta x/R \tag{2}$$

All measurements were carried out using the average temperature of 61°C and with a fixed thermal gradient of ΔT =12°C, to ensure the comparability of the results.

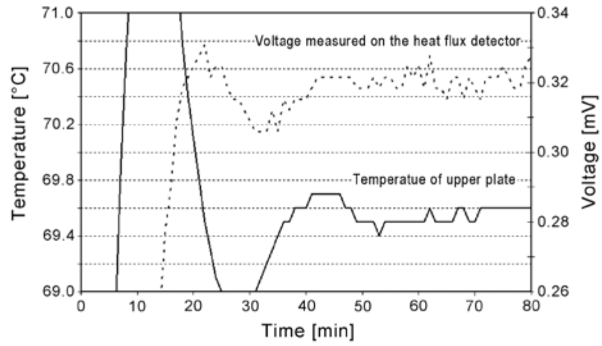


Figure 4. Detailed view of voltage and temperature change at steady state

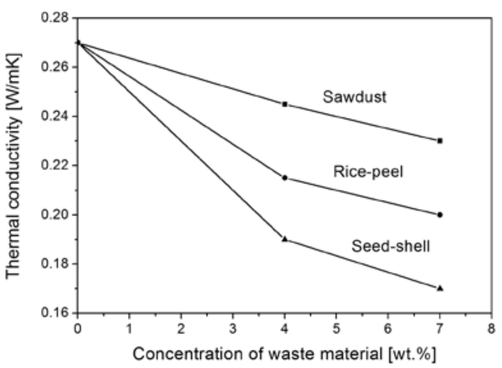


Figure 5. Thermal conductivity of the brick clay samples with different pore-forming additives

IV. Results and discussion

The thermal conductivity measurement was performed for all the previously prepared brick samples. Fig. 5 presents the results and shows that the thermal conductivity significantly decreases with the addition of increasing amounts of the agriculture byproducts. The brick sample without any additives (RS) has a thermal conductivity of λ=0.27 W/m·K, which decreases for 10–31% and even 16–37%, with the addition of 4 or 7 wt.% agricultural waste compounds, respectively. The increased porosity of the brick samples with the additives (which burned out during thermal treatment and left new pores in structure) is most probably the main reason for their improved thermal insulating properties.

The measurements also show that the seed-shell additive has the largest effect on the insulating properties of the brick clay (leading to a decrease of thermal conductivity for 37% - in sample N7). At the same concentration, the rice-peel (sample R7) and sawdust (sample F7) decrease thermal conductivity only for 26% and 16%, respectively. The different thermal conductivities of the samples N4/N7, R4/R7 and F4/F7 are most probably caused by the difference in the additive's agglomeration capabilities, packing, density, water uptake and swelling, which strongly affects the pore volume, size and size distribution in the final products. The quantification of these relations needs further studies.

It is also important to mention that in this low concentration range (up to 7 wt.%) these additives did not decrease the mechanical properties below the levels required by standards [5,6].

V. Conclusions

Brick samples were prepared by mixing of the yellow and gray clay with different pore-forming additives (sawdust, rice-peel and seed-shell) in portions of 0, 4 and 7 wt.%., using industry standard procedures. The usage of renewable agricultural, industrial and organic wastes as pore-forming additives, not only provide extra heat during the firing process (due to their combustion) but also leads to better thermal properties of brick products. It was found that the highest decrease in thermal conductivity was obtained with the addition of the sunflower seed-shell. Thus, the addition of 7 wt.% seed-shell to the basic clay mixture decreased the thermal conductivity of the brick sample product from 0.27 W/m·K to 0.17 W/m·K (i.e. ~36%). In this low concentration range (up to 7 wt.%) these additives do not decrease the mechanical properties below the levels required by standards for construction materials.

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