Experimental and numerical study on the performance of various filled hollow bricks

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Abstract

Here presented work describes a development of the brick fillings, focused on optimisation of thermal performance of hollow bricks. Therefore, various mixtures of aerogel-based brick filling were developed. Thermal properties of unfilled and filled hollow brick (standard and aerogel-based fillings) were investigated. The thermal conductivity of clay and different fillings were measured in two-plates-apparatus with guarded hot plate. Based on measured results, numerical simulation was performed in order to determine thermal conductivity of the hollow brick filled with various fillings. Importance of this study is developed brick with aerogel-based filling with performance beyond state of the art. The brick filled with developed aerogel-based filling is able to achieve a thermal conductivity lower than 0.060 W/(m·K).

Keywords: aerogel-based brick filling materials, thermal conductivity, numerical studies, performance evaluation.

1. Introduction

Development of brick masonry units is mainly conducted for the purpose of achieving better thermal insulation properties. In last thirty years new raw materials are used for optimisation of performance. Moreover, masonry units became larger and perforated. Hollow bricks have either larger perforation structure filled with thermal insulation materials or dense unfilled perforated web. One further way for brick optimisation would be aerogel-based filling for hollow bricks.

Aerogel is highly porous material with thermal conductivity between 0.015 and 0.020 W/(m·K). For this reason, aerogel is combined with other materials in order to reduce thermal conductivity of such hybrid materials. Some aerogel-based products are already commercialised, e.g. insulation blankets or thermal insulation plasters. Development of aerogel-based brick filling can be based on studies of insulation plasters (e.g. [1], [2], [3]) because of their similar material performance.

2. Hollow brick with advanced geometry

Brick geometry of developed hollow brick (see Figure 1, left) was chosen in order to gain optimal combination of thermal conductivity and load-bearing capacity (combination of inclined and orthogonal web). For this reason, large sized holes and medium thick web were chosen. Moreover, larger holes are suitable for filling with pasty aerogel-based substance.

The determination of thermal conductivity for clay of the brick was performed in two-plates-apparatus with guarded hot plate according to [4]. The samples (Figure 1, right) were cut, polished and dried at 105°C before testing. Individual samples were approximately 5 mm thick. Measurement of thermal conductivity was carried out with two layers of clay, in order to fulfil the requirements of used device to sample thickness (10-40 mm). Results of the measurement are shown in Table 1.

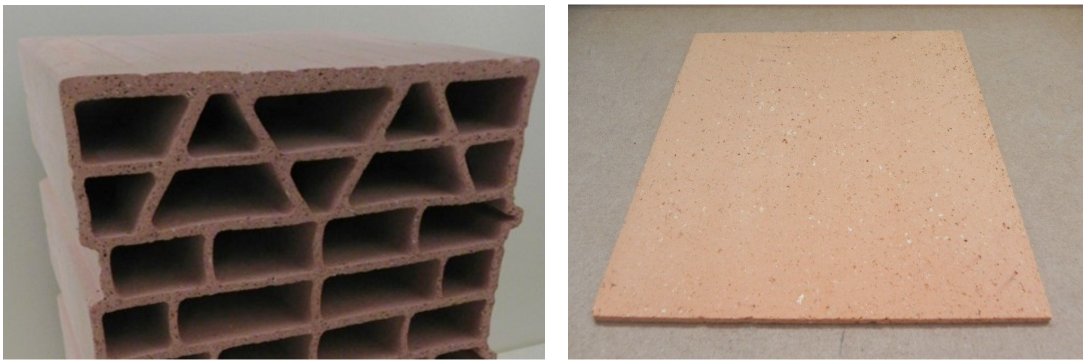

Figure 1: Section of hollow brick (left) and sample for testing of thermal conductivity on clay (right)

Sample	Density ρ [kg/m³]	Thickness d [mm]	Thermal conductivity λ [W/(m·K)]
Clay of brick	1376.7	10.7	< 0.20

Table 1: Results of thermal conductivity measurement (clay).

Based on experimental investigation of thermal conductivity on clay, a 2D numerical simulation was performed in order to determine thermal conductivity of the hollow brick without filling. The numerical simulation and the calculation of the characteristic values of the heat transfer were carried out according to [5], using the software BISCO from Physibel. The boundary conditions listed in Table 2 were used for the numeric simulation of thermal transmission coefficient (U-value) of the brick. The simulation calculation shows that developed brick without filling has a thermal conductivity of about 0.150 W/(m·K). This value lies in lower range of thermal conductivity for hollow brick.

Brick	Thermal conductivity λ (measured)	[W/(m·K)]	0.20
	Emissivity	--	0.9
Air	Thermal conductivity	[W/(m·K)]	0.025
Temperature	Mean temperature T_m	[°C]	10
	Difference ΔT between outer layers)	[K]	20
Ambient air, outside	Heat transmission coefficient h_e	[W/(m²·K)]	0
Ambient air, inside	Heat transmission coefficient h_i	[W/(m²·K)]	20

Table 2: Boundary conditions used for 2D numerical simulation.

3. Brick filled with mineral wool

Thermal insulation bricks are generally filled with mineral wool, perlite, polystyrene or wood wool. We chose mineral wool as a standard filling for developed bricks. For the numerical simulation of hollow brick filled with mineral wool, a thermal conductivity of the filling was measured.

The determination of thermal conductivity of mineral wool filling was performed according to [6]. Dry (dried at 105°C), loose mineral wool was filled to 50 mm high purpose-built frame (Figure 2) for measurement of thermal conductivity. In this way, the density of sample corresponds to the density of mineral wool filling in the brick. The measured thermal conductivity (Table 3) for mineral wool filling is in agreement with the values given in [7].

Figure 2: Mineral wool filling

Sample	Density ρ [kg/m³]	Thickness d [mm]	Thermal conductivity λ [W/(m·K)]
Mineral wool filling	100.3	50.0	< 0.040

Table 3: Results of thermal conductivity measurement (mineral wool filling).

Thermal conductivity of filled hollow brick was determined numerically using measured values of thermal conductivity for brick components - clay and mineral wool. Emissivity of mineral wool filling was set in simulation to 0.9. All other boundary conditions were kept constant as in simulation of unfilled hollow brick.

Material	Heat transfer coefficient *-dry state-* U [W/(m²·K)]	Thermal resistance R [m²·K /W]	Thermal conductivity $\lambda_{10,dry}$ [W/(m·K)]
Brick filled with mineral wool	0.180	5.386	< 0.07

Table 4: Results of 2D numerical simulation on brick filled with mineral wool.

Table 4 shows the results of the 2D calculation of thermal conductivity on brick filled with mineral wool. Thermal conductivity of developed brick filled with mineral wool is slightly lower than for insulation bricks available on market (thermal conductivity between λ = 0.07 W/(m·K) and λ = 0.10 W/(m·K)). It can be concluded that optimisation limit has been reached for calculated filling.

The 2D temperature distribution for unfilled brick and brick filled with mineral wool is given in Figure 3.

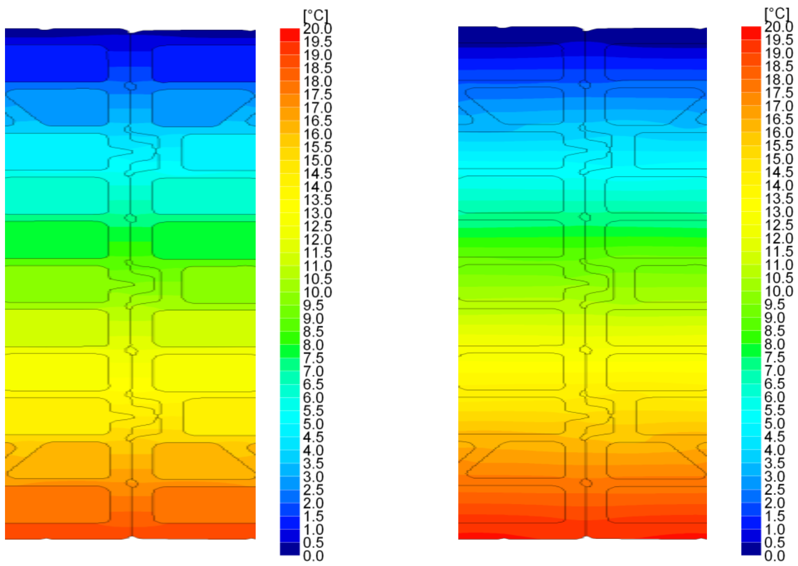

Figure 3: Sections of 2D temperature distribution for unfilled brick (left) and brick filled with mineral wool (right)

4. Parametric studies

Furthermore, 2D numerical parametric studies were performed for developed brick geometry in order to study thermal performance of filled bricks. The numerical simulations were carried out according to [5]. In the parametric studies, two variables were varied – thermal conductivity of clay and thermal conductivity of filling. All other boundary conditions were kept constant as in simulation of brick filled with mineral wool.

<table>
<tr><th>Thermal conductivity - Filling of brick [W/(m·K)]</th><th>0.04</th><th>0.035</th><th>0.03</th><th>0.025</th><th>0.022</th><th>0.02</th><th>Air</th></tr>
<tr><td>Thermal conductivity - Clay of brick [W/(m·K)]

0.3</td><td colspan="3">0.073 - 0.084
(state of the art)</td><td colspan="3">0.063 - 0.068</td><td>0.177</td></tr>
<tr><td>0.25</td><td colspan="2">0.072 - 0.077
(state of the art)</td><td colspan="4">0.056 - 0.067</td><td>0.167</td></tr>
<tr><td>0.2</td><td>0.070
(state of the art)</td><td colspan="5">0.050 - 0.065</td><td>0.150</td></tr>
</table>

Table 5: Results of parametric study on hollow brick for varied thermal conductivity of clay and filling.

The results (thermal conductivity of hollow brick) of the 2D numerical parametric studies are given in Table 5. The calculated values are grouped in two categories relating to thermal conductivity: state of the art and beyond state of the art. It can be concluded that a filling with thermal conductivity from 0.04 W/(m·K) can reduce thermal conductivity of hollow brick by 50 % compared to unfilled brick. In case of better insulating filling (0.02 W/(m·K) < λ < 0.04 W/(m·K)), further reduction of thermal conductivity by max. 0.02 W/(m·K) is possible.

5. Aerogel based filling materials

In order to develop a brick beyond state of the art (λ < 0.07 W/(m·K)), new aerogel-based filling was developed. In this study, aerogel particles produced from Enersens Company [8] were used. Except optimised thermal properties, two additional requirements were set for new filling material: material should have short hardening time and be strong enough to have good flank cohesion with the brick body.

Four mixtures of filling with different percentage of aerogel were produced. For each mixture (see Figure 4) a thermal conductivity was measured. Measurements were performed on dry samples according to [6]. Results are shown in Table 6. Measured thermal conductivity varies between 0.023 and 0.031 W/(m·K). Expectedly, thermal conductivity of aerogel-based filling was lower with higher percentage of aerogel in mixture. It can be seen that highest drop of thermal conductivity was measured for sample no. 3. In that case, additional 8% of aerogel in mixture resulted in 0.004 W/(m·K) lower thermal conductivity than for sample no. 2.

Figure 4: Typical sample of aerogel-based filling

Material	Sample No.	Procentage of aerogel	Thermal conductivity (dry) λ [W/(m·K)]
Aerogel based filling	1	X %	0.031
	2	X+5 %	0.031
	3	X+13 %	0.027
	4	X+23 %	0.023

Table 6: Results of thermal conductivity measurement (aerogel based filling materials).

6. Conclusion

In here presented work, thermal conductivity of developed hollow brick with various fillings was experimentally and numerically determined with the objective to study a thermal performance. Importance of this study is developed brick with aerogel-based filling with performance beyond state of the art. For this reason, four mixtures of aerogel-based brick filling are developed and here presented. Their thermal conductivity varies between 0.023 and 0.031 W/(m·K). According to 2D simulations, it can be concluded that the brick filled with developed aerogel-based filling achieves a thermal conductivity from about 0.055 W/(m·K).

7. Acknowledgements

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8. References

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