DEVELOPMENT OF CERAMIC BLOCKS FOR MASONRY CONSTRUCTIONS WITH THERMAL INSULATION FILLING ON THE BASIS OF EASILY RENEWABLE RAW MATERIALS AND BY-PRODUCTS

Jiri Zach¹; Jiri Brozovsky²; Jitka Hrouova³; Martin Sedlmajer⁴

¹ PhD, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, zach.j@fceu.vutbr.cz
² PhD, Assoc. Professor, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, brozovsky.j@fceu.vutbr.cz
³ Ing. Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, hrouoda.j@fceu.vutbr.cz
⁴ PhD, Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, sedlmajer.m@fceu.vutbr.cz

At present the requirements for building materials have been growing in the sphere of their thermal-insulation and acoustic properties. In case of ceramic blocks the ways to further improvement of its insulation properties are quite limited. It is reduction of ribbon thickness or increase of width of masonry construction. Use of insulation filling integrated in ceramics block cavities is an alternative technology of production of insulation masonry blocks of high insulation properties. In these cases the ceramic frame ensures the mechanical stability of the block and integrated insulation layer in smaller or bigger part (depending on its part) the thermal properties and eventually also the acoustic and insulation ones. The paper describes possibilities of use of raw materials alternative sources (natural fibres from agriculture, selected fabric waste, ...) as integrated insulation layers in modern ceramic blocks of high performance properties.

Keywords: masonry, ceramics block, thermal insulation, thermal insulating properties, acoustic insulation properties

INTRODUCTION

Higher and higher thermal and technical requirements that have recently been addressed to the building structures are reflected in the requirements for thermal-technical properties of building materials and elements of which the above-mentioned structures are built. The trend of the last few years lies in development of such building elements intended for siding structures that they themselves (without using any additional thermal insulation) meet the requirements which are placed on thermal-insulating capacity of the building structure.

In the area of ceramic fittings there are generally three ways to improve their thermal insulation ability:

1.  reducing the thermal conductivity of a ceramic cullet,
2. suitable relieving of the shaped piece by using air cavities - design of the optimal geometry of the shaped piece’s internal arrangement,

3. relieving the shaped piece’s cavities by using the integrated thermal insulation with low thermal conductivity value.

Reducing the thermal conductivity of the ceramic cullet is tied to quality of input raw-material and possibility of its lightness. Reducing density of the ceramic cullet leads to decrease in its thermal conductivity. Unfortunately, the process of relieving the ceramic cullet also leads to a reduction in its mechanical properties and some increase in sensitivity during the process of drying. Therefore, most manufacturers of ceramics begin to look for other ways to increase the thermal resistance of their products (see below).

The process of lightening the ceramic shaped pieces by air cavities has till the present times been regarded as the most effective way of increasing their thermal-technical parameters. Effectiveness of the relieving process depends both on the ratio of volume of air cavities vs. volume of the ceramic skeleton as well as the shape of cavities, their arrangement, thickness of inner and siding walls of the shaped piece and also the size of cavities.

In the recent years, there has been an effort to integrate the structure of ceramic shaped piece together with insulating materials with low thermal conductivity value. When increasing the size of air cavities, we can experience some reduction in their thermal insulation properties. If we want to increase the value of thermal conductivity of the ceramic shaped piece, we must increase the amount of air cavities compared to the total volume of the ceramic skeleton of the shaped piece. If we want to maintain good thermal insulation properties of air in the cavities, we must use only the cavities of small dimensions for the relieving process, whereas we have to reduce the thickness of the shaped piece’s wall. This reduction in wall thickness, as well as the cullet relieving process, is dependent on quality of ceramic raw-material. Such reduction leads to a reduction in load capacity of the shaped piece and technological problems in the process of creating and drying the shaped piece.

The way to eliminate these problems consists in creating larger cavities in the skeleton of the ceramic shaped piece, e.g. the cavities that shall be filled with thermal insulating material with low thermal conductivity value. This material must be easily applicable to the shaped piece, it should have a certain minimum strength to ensure spatial rigidity of the resulting shaped piece. This material should not significantly increase the final price of the shaped piece.

**STRUCTURAL DESIGN OF THE SHAPED PIECE WITH INTEGRATED THERMAL INSULATION**

When designing the shape and internal arrangement of the shaped pieces, it is necessary to consider possible ways of integrating insulators into the cavities, which is also related to types of insulators which can be applied to the shaped pieces’ cavities. In general terms, it can be said that most common ceramic shaped pieces (for outer walls) have cavities with thickness of about 6-15 mm. With increasing thickness of the cavities, there is also the increase of thermal conductivity of air in cavities. On the other hand, the degree of relieving of the shaped pieces by the cavities is rising up.

From the perspective of technology related to filling the shaped piece cavities with an insulator, there are currently two basic directions:

a) filling the cavities with lump insulators which are applied in the cavities in compressed
state,
b) filling the cavities with insulators in cellular or liquid state.

ad a) As for the first example, there can be lump technical insulations used, those which are at least partially compressible. It is mostly about mineral wool, but you can also use foam polystyrene. The advantage of this method of integration of the insulation filling to the shaped piece consists in relatively low work difficulty, easy applicability, absence of special equipment for processing and hardening of the insulator, absence of wet processes. The main disadvantage is the need of large-scale cavities creation, because the lump insulators cannot be applied to the thin cavities having size of millimetres units.

ad b) As for the second example, these are the insulators in cellular state, e.g. mixtures of both fillers and binders that are applied to the shaped piece’s cavities and then after compaction they are left to mellow and harden. Furthermore, these are also cellular insulators (e.g. polystyrene) which are applied to the cavities and left there to expand. These are also liquid / foam insulators which are injected into the cavities where they are left to expand and harden (e.g. PUR or PIR foam). The advantage of this technology is that it is possible to fill up even the more complicated cavities of shaped pieces of smaller dimensions. The disadvantage is conversely higher technological and time-consuming difficulty, need for hardening the insulator and quite often worse thermal insulation properties. The exception is the application of PIR and PUR foams. However, the problem of these cases lies in their high cost which ultimately causes an enormous increase in prices of the end product.

During the research works, there were designed two basic geometric arrangements of the shaped pieces of various thickness and number of cavities:

a) Option 1: The shaped piece with thickness of 500 mm which has 9 rows of cavities for the whole width of shaped piece with the thickness of 40 and 50 mm.
b) Option 2: The shaped piece with thickness of 500 mm which has 9 rows of cavities of various width, with the thickness of 40 and 50 mm.

Figure 1: Diagram of geometric arrangement of the shaped piece No. 1
SELECTED INSULATION MATERIALS ON EASY RENEWABLE AND BY-
PRODUCT ROW-SOURCE BASE

As for the design of ceramic shaped piece with integrated filler, there were selected
alternative heat insulators based on easily recoverable raw materials and secondary materials.
It was about new thermal insulating materials whose development was conducted in
cooperation with the Brno University of Technology. Specifically, there were two types of
insulators based on natural fibres originating from agriculture and two insulators based on
waste textile fibres (modified fibres of sorted textile predominantly formed of cotton, e.g. the
textile which is obtained from collection boxes for waste textiles). All insulators are
manufactured by the technology of bonding by bi-component fibres at elevated temperatures.
It is about fibrous mats with longitudinal fibres orientation. Specifically, it was about the
following insulators:

a) Insulation No. 1: thermal insulation of hemp fibres containing shive material of up to 30
% and having a density of about 100 kg m$^{-3}$,
b) Insulation No. 2: thermal insulation of linen fibres containing shive material of up to
40% and having a density of about 100 kg m$^{-3}$,
c) Insulation No. 3: thermal insulation of textile fibres having a density of about 40 kg m$^{-3}$,
d) Insulation No. 4: thermal insulation of textile fibres having a density of about 60 kg m$^{-3}$.

Share of bi-component connective fibres ranged from 10 to 20 %.

The thermal insulations were used for determination of basic physical and mechanical
properties. These were:

- determination of thickness according to EN 823,
- determination of density according to EN 1602,
- determination of thermal conductivity according to EN 12667 (in dry state with mean
temperature 10°C),
- determination of tension at 10% deformation according to EN 826,
- determination of water vapor transmission properties according to EN 12086.

The measurement results are shown in the following table:
Table 1: Overview of physical and mechanical properties measured on samples of thermal insulations

<table>
<thead>
<tr>
<th>Insulation n.</th>
<th>Thickness [mm]</th>
<th>Density [kg.m⁻³]</th>
<th>Thermal conductivity [W.m⁻¹.K⁻¹]</th>
<th>Factor of diffusion resistance [-]</th>
<th>Tension at 10% deformation [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>105</td>
<td>0.0392</td>
<td>1.6</td>
<td>26.7</td>
</tr>
<tr>
<td>2</td>
<td>67</td>
<td>106</td>
<td>0.0437</td>
<td>1.6</td>
<td>16.8</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>38</td>
<td>0.0364</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>61</td>
<td>0.0348</td>
<td>1.3</td>
<td>3.5</td>
</tr>
</tbody>
</table>

As evident from the results listed in Table 1, all insulators show very good thermal insulation properties. Better properties are achieved by insulators based on textile fibres whose thermal conductivity value is fully comparable with thermal conductivity of conventional mineral-fibrous insulators in the construction market. Materials based on natural fibres originating from agriculture (tow and hemp) show better mechanical properties. When comparing the flax and hemp insulation, the hemp insulator shows better properties, which is due to higher purity of hemp fibres and also due to their different lengths. In the case of hemp insulation, there was better orientation of fibres perpendicular to the direction of heat flow, during the production. In terms of achieved mechanical properties, the better mechanical properties of hemp insulation are further caused by a higher proportion of binding fibres (compared with linen isolation).

**CALCULATION OF THERMAL INSULATION PROPERTIES OF SHAPED PIECES WITH INTEGRATED THERMAL INSULATION LAYER**

Calculations of thermal insulation properties were carried out on the models of ceramic shaped pieces of 1 and 2, prepared on the basis of geometric configuration - see figures 1 and 2 above. The calculations were carried out according to EN 1745 using the method of finite elements. During the calculation, the models of shaped pieces were accompanied by marginal conditions typical for the territory of Central Europe (external temperature: -15 °C; internal temperature +21 °C). As for the calculation, there were chosen - from the viewpoint of material properties - the values of thermal conductivity of insulators listed in Table 1 and then also the values of the thermal conductivity coefficient of the ceramic cullet \( \lambda_{10} \), dry: 0.275; 0.300, 0.325 a 0.350 W.m⁻¹.K⁻¹. These values were chosen as the reference values, based on a survey in the area of typical values of thermal conductivity coefficient in thermal-insulating ceramic shaped pieces of the leading manufacturers in the EU area. The calculations were performed for ceramic shaped pieces in dry state. The calculated values are given in Tables 2 and 3 below.
Table 2: Overview of the calculated values of thermal resistance $R$ for burnt masonry elements - Model 1

<table>
<thead>
<tr>
<th>Thermal conductivity of ceramics, clinker [W.m$^{-1}$.K$^{-1}$]</th>
<th>Thermal resistance [m$^2$.K.W$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>insulation 1</td>
</tr>
<tr>
<td>0.275</td>
<td>6.9121</td>
</tr>
<tr>
<td>0.300</td>
<td>6.6656</td>
</tr>
<tr>
<td>0.325</td>
<td>6.4357</td>
</tr>
<tr>
<td>0.350</td>
<td>6.2248</td>
</tr>
</tbody>
</table>

Table 3: Overview of the calculated values of thermal resistance $R$ for burnt masonry elements - Model 2

<table>
<thead>
<tr>
<th>Thermal conductivity of ceramics, clinker [W.m$^{-1}$.K$^{-1}$]</th>
<th>Thermal resistance [m$^2$.K.W$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>insulation 1</td>
</tr>
<tr>
<td>0.275</td>
<td>5.9775</td>
</tr>
<tr>
<td>0.300</td>
<td>5.7208</td>
</tr>
<tr>
<td>0.325</td>
<td>5.4879</td>
</tr>
<tr>
<td>0.350</td>
<td>5.2757</td>
</tr>
</tbody>
</table>

Graph 1: Dependence of the thermal resistance of insulating shaped pieces $R$ on thermal conductivity of the integrated thermal insulation - Model 1
The obtained results show that in the case of model 2 the thermal-insulating properties of the shaped piece are more affected by the properties of brick shard. Generally, better properties were obtained in the case of insulator based on textile fibres. However, the shaped piece with insulator based on flax showed thermal resistance values higher than 5 m².K.W⁻¹.

CONCLUSION
When designing the ceramic shaped pieces with integrated thermal insulation filler, it was found that the alternative insulating materials based on easily renewable and secondary raw materials can be used as filling for large-sized cavities of the shaped pieces. The alternative insulation materials show comparable thermal insulation properties as the conventional insulators (for example mineral wool or expanded polystyrol). Their use also leads to savings in drawing of non-renewable raw materials or non-easily-renewable raw materials. In the case of waste textile fibres, it is about an effective recycling of problematic municipal waste whose large part is disposed of by burning, which has a negative impact in terms of greenhouse gas emissions.

In general, it was found that when choosing appropriate geometry of the shaped pieces and relieving the ceramic cullet, we can reach the thermal resistance (in dry state) of 7.4 m².K.W⁻¹ in the shaped piece with the thickness of 500 mm, which corresponds to an equivalent value of the thermal conductivity of 0.068 W.m⁻¹.K⁻¹.

ACKNOWLEDGEMENTS
This paper was elaborated with the financial support of the project MPO FR-TI3/231.

REFERENCES


