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Development of Masonry Blocks with Thermal Insulation

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Abstract

The requirements of today's society in the area of properties of building materials are increasing all the time. From point of view of masonry construction it means first thermal and acoustic insulation properties. In the case of improvement of thermal technical properties of masonry construction is possible to use external thermal insulation systems or build in thermal insulation layer directly into construction. Integration of thermal insulating material into cavities of blocks is an alternative production technology of thermal insulating ceramic blocks. Mechanical stability of the block provide the ceramics body. Thermal insulation material in block cavities provides mainly thermal and acoustic insulating properties of masonry blocks (construction). This paper describes the possibility of using a wide range of insulation materials (alternative natural insulation, conventional insulation materials) as an integrated insulation layer in modern ceramic blocks with good thermal insulation properties.

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Introduction

At present, higher thermal technical requirements are always stated for building constructions which closely relate to the thermal technical requirements of building materials and the elements they consist of. The objective of ceramics blocks for peripheral masonry is to develop elements with strong thermal insulating properties which fully replace the use of additional thermal insulating system. To improve the thermal insulating properties of the ceramic blocks, there are several options that can resolve this issue:

- decrease in the thermal conductivity for ceramic clinker,
- the proposal for the optimal internal geometric arrangement of the block,
- the application of thermal insulation material with the low thermal conductivity into the hollows of the block.

Reduction of the thermal conductivity of the ceramic clinker (body) related to the quality of input raw material and the possibility of lightening. By decreasing the density which leads to a positive decrease in the thermal conductivity, there is worsening of the mechanical properties and an increase in sensitivity during drying. For these reasons, other alternatives are sought to increase thermal resistance for ceramic shaped units.

Until recently, the lightening of ceramics blocks using air hollows was regarded as the most effective method of increasing thermal technical properties of ceramic blocks. The efficiency of this lightening depends on the ratio of the volume of the air hollows (gaps) and the volume of the ceramic body, as well as on the form and size of the hollows, their arrangement and the thickness of the internal and peripheral walls (size of ceramics blocks).

The trend in recent years has been to integrate insulating materials with low thermal conductivity into the hollows of the ceramic block. This means using insulating material of an ecological character or material consisting of industrial waste raw material sources. The intention is the easy application of insulating material with minimum strength into the shaped piece due to ensuring the spatial rigidity of the resulting shaped unit.

The paper looks at the hygrothermal behavior of untraditional thermal insulating materials integrated into the hollows of ceramic masonry blocks for peripheral masonry.

Integration of Thermal Insulation Materials in Masonry Bricks

The integration of suitable thermal insulating materials into hollows of ceramic blocks represents a very progressive method which can significantly decrease thermal conductivity in the hollows of ceramic blocks and fully eliminate convection inside the blocks.

Insulating materials for filling the hollows of ceramic block must:

- have a very low value of the thermal conductivity (lower then thermal conductivity of air gaps in block),
- must be easily applied into the hollows of the shaped units.

In general, two types of insulators are used:

a) piece insulations which, after pressing, are inserted into the hollows of the shaped pieces and with consequent relaxation are fixed inside the hollows (these insulators can only be inserted into large sized hollows),
b) particular insulations which can be filled into hollows and consequently fixed by sealing, thermal fixation, etc.

Thermal Insulation Materials Based on Natural and Textile Waste Fibers

During the research and the development of insulating materials on the basis of alternative raw material resources, insulating materials on the basis of textile fibres, were selected as suitable materials for filling the hollows of masonry blocks. Insulating materials based on natural fibers (technical hemp, flax) are represented at 48% by natural fibres, 10% bio-component binder fibres from polyester and 42% shive (waste from natural fibers processing). Insulating materials from textile fibres were produced from de-fiberized textile consisting of a minimum of 95% cotton. Textile fibers were thermally bound using bi-component fibres consisting of a core with high-temperature polyester and a coat from low-temperature polyester. Content of input raw textile fibres was 85% and content of bi-component fibres was 15%.

During the development of insulating materials on the basis of alternative raw material sources which has been conducted at the Faculty of Civil Engineering of Brno University of Technology for several years now, optimal sets of testing samples were selected for application into the hollows of ceramic shaped units. These were the testing sets (Figure 1):

- Set A) Thermal insulating material on the basis of hemp fibers,
- Set B) Thermal insulating material on the basis of flax fibers,
- Set C) Thermal insulating material on the basis of textile fibers.

Figure 1. *Example of testing samples*

The key properties were determined on the prepared testing samples of individual testing sets of insulating materials on the basis of natural and textile fibres:

- determination of the thickness according to EN 823 (measurement was taken at the nominal load of 50 Pa),
- determination of linear dimensions according to EN 12085,
- determination of density according to EN 1602, determination of the thermal conductivity in a steady status according to ČSN 727012, EN 12667, ISO 8301 (measurement was taken at a medium temperature of +10 °C and thermal gradient 10 K on dried testing samples).
- determination of mechanical properties (tensile strength, stress at 10% deformation) according to EN 1607 and EN 826,
- determination of sound absorption coefficient according to ISO 10534-1, and the measured values were evaluated according to EN ISO 11654.

The results of these physically, thermal insulating, mechanical and acoustic properties are shown in Table 1.

Table 1. *List of average values of key properties at individual testing sets*

Set of samples	A	B	C
Thickness [mm]	67.0	77.4	77.1
Density [kg.m^{-3}]	56.8	32.1	41.4
Thermal conductivity, dry [W.m^{-1}.K^{-1}]	0.0399	0.0431	0.0355
Stress at 10% of deformation [kPa]	6.94	0.38	0.69
Tensile strength[kPa]	21.75	7.75	13.20
Weight value of sound absorption coefficient [-]	0.55	0.40	0.90

It is evident from the measured values that the testing samples on the basis of hemp and textile fibers report very good thermal insulation properties. The very high value of the sound absorption of textile fibers which may positively improve the value of air sound transmission loss of the resulting partitioning construction can also be mentioned.

Moreover, the testing samples were the subject of the determination of thermal insulating properties. In particular, this concerned the determination of:

- dependence of the thermal conductivity on temperature,
- dependence of the thermal conductivity on moisture content.

Thermal insulating properties are defined by the thermal conductivity λ [$W.m^{-1}.K^{-1}$]. The measurement was taken using the stationary plate method according to ISO 8301 standard on the Lambda 2300 device.

The measurement of the dependence of the thermal conductivity coefficient on temperature was taken at laboratory humidity at medium temperatures
-10 °C, 0 °C, +10 °C, +20 °C, +30 °C and +40 °C. Thermal gradient of was for all measurements 10 K. The results are shown in Table 2.

Table 2. *List of average values of the thermal conductivity of individual testing sets depending on the temperature*

Set of samples	**Thermal conductivity λ [$W.m^{-1}.K^{-1}$]**					
	-10 °C	**0 °C**	**10 °C**	**20 °C**	**30 °C**	**40 °C**
A	0.0371	0.0376	0.0395	0.0405	0.0417	0.0422
B	0.040	0.0413	0.0425	0.0456	0.0496	0.0511
C	0.033	0.0345	0.0365	0.0388	0.0396	0.0404

Experimental determination of the dependences of the thermal conductivity on humidity was carried out at a medium temperature of 23 °C on fully dry samples and on samples conditioned in the environment and relative humidity of 33 %, 55 % and 80 %. The results of this measurement are shown in Table 3.

Table 3. *List of average values of the thermal conductivity of individual testing sets depending on the relative humidity of the environment*

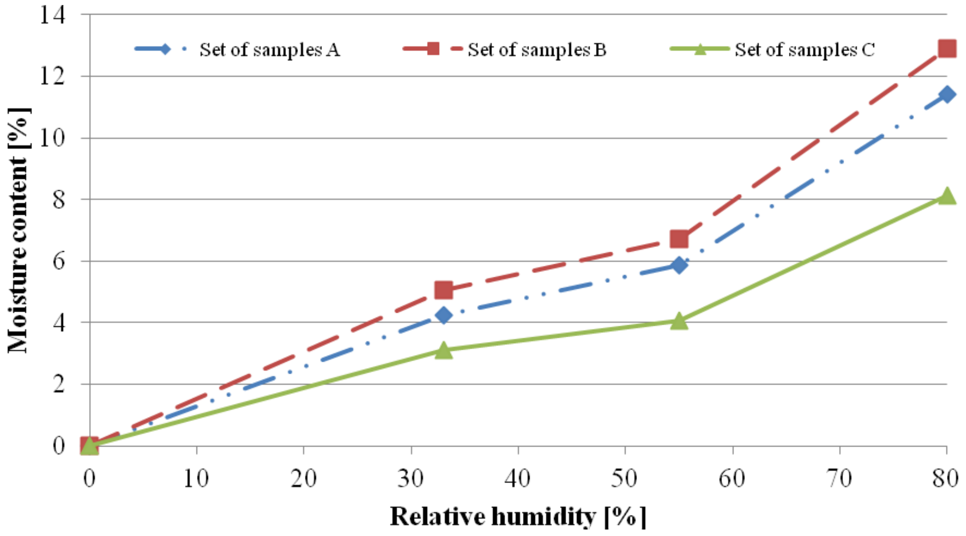
Thermal conductivity λ [$W.m^{-1}.K^{-1}$]				
Set of samples	**RH 0%**	**RH 33%**	**RH 55%**	**RH 80%**
A	0.0399	0.0408	0.0421	0.0456
B	0.0431	0.0437	0.0442	0.0537
C	0.0355	0.0357	0.0369	0.0469

In the next step, the sorption properties for testing samples were determined. The sorption properties of the material were stated together with the determination of the dependence of thermal insulating properties on humidity on the basis of the change of weight of the investigated samples in individual environments (0 %, 33 %, 55 % and 80 % relative humidity). The results are shown in Table 4 and Figure 2.

Table 4. *List of average values of material moisture of individual testing sets depending on the relative humidity of the environment*

Thermal conductivity λ [W.m^{-1}.K^{-1}]				
Set of samples	**RH 0%**	**RH 33%**	**RH 55%**	**RH 80%**
A	0	4.24	5.85	11.41
B	0	5.04	6.73	12.90
C	0	3.11	4.06	8.13

Figure 2. *Dependence of the moisture content of testing samples on the relative humidity of environments at the temperature of 23 °C*

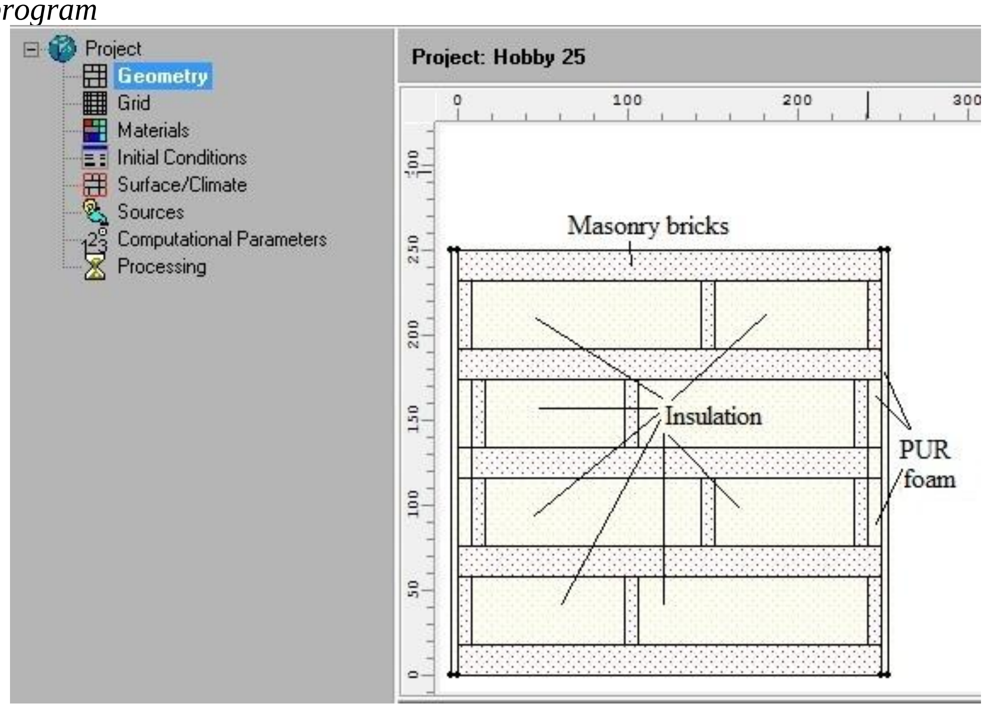


The results of the experimental measurements served as the source materials for the simulation of design simulations during the development of new ceramic shaped pieces with integrated insulating materials on the basis of waste textile fibers.

The Development of New Non-Traditional Masonry Blocks

For the design simulations in the WUFI 2D design program, a masonry block was selected with the thickness of 250 mm with 8 big hollows which were filled with developed insulating materials on the basis of waste textile fibers. For this paper, the hygrothermal behavior of the shaped unit was simulated with the developed insulations with a comparison of the moisture content. The measured data was entered into the material database of the design program.

Figure 3. *Display of the drawing of a shaped unit in the WUFI 2D design program*



First of all, the geometry was modeled in basic form, see Fig 3. Then the parameters of model grid were set (frequency of odes in which individual properties will be monitored). In the following step, suitable materials were taken from the material database. The ceramic clinker was identified as Solid Brick (with density 1744 kg.m^{-3} and thermal conductivity 0,544 W.m^{-1}.K^{-1}) and the hollows were filled as mentioned above, with the developed textile insulation (properties you can see above). Individual shaped units were bound using PUR foam (thermal conductivity 0,029 W.m^{-1}.K^{-1}).

Input and climatic conditions were stated for the following procedure. Hygrothermal behavior was monitored for the area of Vienna. The area of the shaped unit facing the exterior was designed for the north area. On the part of the interior, the procedure according to EN 13788 was used where Humidity Class 2 was proposed.

Assumed characteristics for the exterior (red brick):

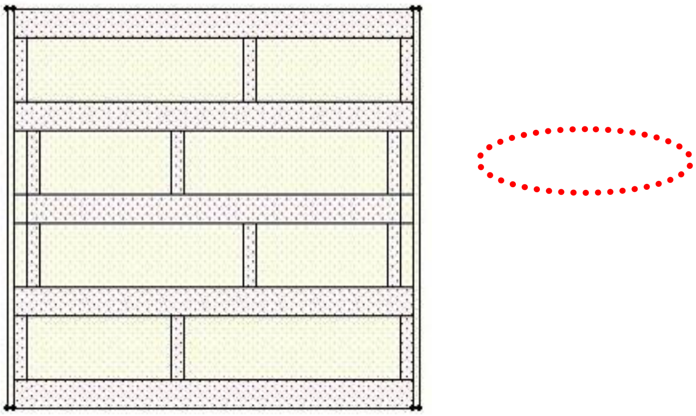
- Heat transfer Coefficient: 25 W.m^{-2}.K^{-1},
- Short-Wave Radiation Absorptivity: 0.68,
- Long-Wave Radiation Emissivity: 0.9.

Proposed characteristics for the interior:

- Heat transfer Coefficient: 8 W.m^{-2}.K^{-1}.

The hygrothermal behavior of the masonry was monitored from 1. 10. 2011 to 1. 10. 2012, and real data measured in the area of Vienna was used. Moreover, within the simulation, from the viewpoint of moisture, the insulating filler space (red dotted area), see Fig. 4.

Figure 4. *Monitored area from a moisture viewpoint for experimental masonry block filled with insulation in the WUFI® design program*



There is a graphic evaluation of the moisture courses in individual insulation materials in the marked area, in the following diagrams Fig. 5, 6, 7.

Figure 5. *Course of material moisture in textile insulation in the monitored period from 1. 10. 2010 to 1. 10. 2012*

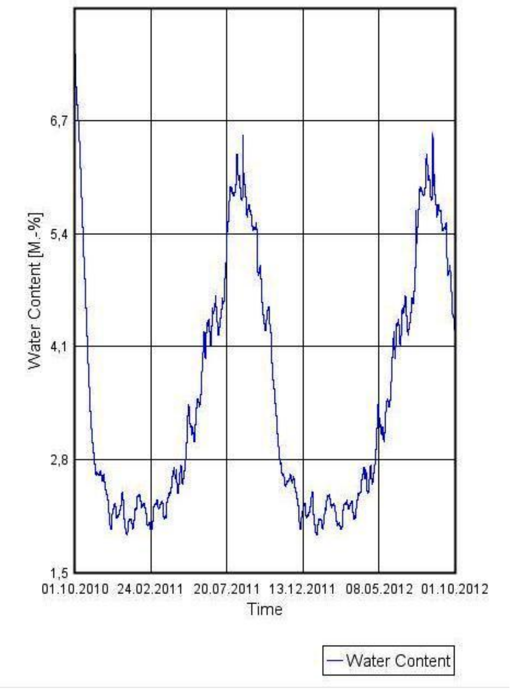


Figure 6. *Course of material moisture in hemp insulation in the monitored period from 1. 10. 2010 to 1. 10. 2012*

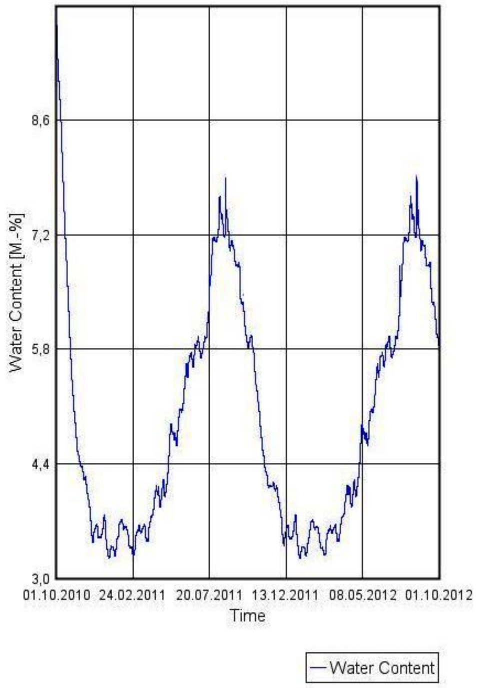
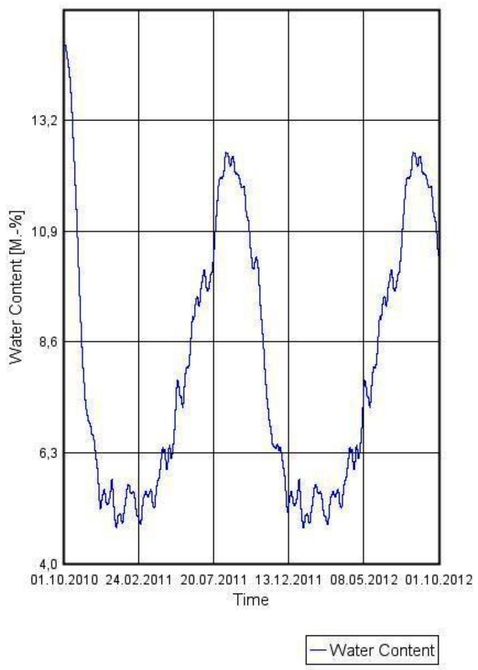


Figure 7. *Course of material moisture in flax insulation in the monitored period from 1. 10. 2010 to 1. 10. 2012*



Conclusion

The development of insulating materials from alternative raw material sources contributed by several possible materials (mainly insulation on the basis of fibers from waste textile and technical hemp) for their application as insulation recommended for applications into the hollows of the ceramic blocks. These materials reported excellent properties during the determination of thermal insulating properties and acoustic properties and represent suitable alternative materials for standard insulating materials currently used, which in most cases are expanded polystyrene, mineral wool, etc.

For the selection of suitable insulating materials into the hollows of the blocks, three sets of testing samples were tested for which experimental measurements of basic physical, thermal insulating, acoustic and mechanical properties were taken. On the basis of these measurements, the best insulating material for integration into the air holes of ceramic blocks is the insulation based on waste textile fibers. Despite this fact, from the viewpoint of the verification of their thermal insulating behavior of ceramics blocks using numerical simulations, all three types of insulating materials were tested. For the design simulations of hygrothermal behaviour of developed block, the WUFI 2D design program was selected. On the basis of the results of these simulations, it can be stated that the insulation material on the basis of textile fibres represents a good alternative to currently used fillers on the basis of mineral wool. However, textile insulations represent a more ecological variation when using waste fibres.

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