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# STRUCTURAL HEAT-INSULATING CONCRETES WITH GLASSY POROUS AGGREGATES FOR EFFICIENT FILLER STRUCTURES

Criteria of estimation of heat and hygrophysical efficiency are offered for efficient filler structures. Efficiency of light structural heat-insulating concretes on the base of glassy porous aggregates is shown.

**Keywords:** efficient filler structure, glassy porous aggregates, light structural heat-insulating concretes, heat conductivity.

## Introduction

In Russian Federation the problem of housing is pressing social problem. It is known that available housing of Russia is 2,9 milliard sq. m, or about 20 sq. m per head, whereas this indicator is 74 sq. m in Norvey, 70 sq. m in USA, 50 sq. m in Germany, 43 sq. m in France, 28 sq. m in Czech Republic, 27 sq. m in China. In Russia there are about 92 million sq. m (3.17 %) of dangerous and ramshackle structures. About 300 million sq. m (10.3 %) may turn into this state in the 15 years ahead [1]. In recent years about 35 million sq. m of dwelling per year has been brought into service. In doing so about 70 % of Russians have need for housing improvement. It is obvious that in situation like this problem of sharp increase in housing construction volume is pressing, which is confirmed by acceptance the national project “Accessible and comfortable dwelling – to citizens of Russia”. Adopted concept of gradual transition to increase in the number of low-storey building means that in the years ahead it is necessary to make the best use of possibilities of the present housing construction to construct social dwelling. The base of industrial house building (420 factories with 50 million sq. m in area) is used at 20 % [1]. Development of efficient filler structures for large-panel house building can make a contribution to development of this sector of social dwelling construction.

Researches and monitoring of operated filler structures reveal the necessity of changes in heat engineering requirements to filler structures. New approach to the problems of standardization and calculation of thermalphysic parameters of filler structures is suggested. According to A. G. Perekhozhentsev, the condition of comfort should be in the first place when designing the building, the condition of reliability and longevity should take the second place, energy saving should take only the second place. In this connection Code of Practice have been refined subject to standartization and calculation of heat and porous isolation of multilayer filler structures [2]. Consequently, the problem of increase in thermal resistance of filler structures (i. e. decrease in material heat conductivity coefficients) is urgent problem as increase in thermal resistance of building envelopes of 10 % on a national scale may lead to reduction in costs for heating at several millions tons of equivalent fuel. According to [3], costs for heating in Russia are 360 millions tons of equivalent fuel, or about 30 % of yearly energy resources consumption. More than 12 years ago costs for heating were 240 millions tons of equivalent fuel, or about 20 % of yearly energy resources consumption. The problem of heat protection of building and structures is pressing nowadays in Russian Federation.

The problem of rate setting of heat inertia of energy efficient envelopes at the level of wood is burning, because “application of sandwich panels for external walls in block of flats with central heating is inadmissible in Russia” [4]. The authors offer to standardize heat inertia of such structures at the level of wood. At $R_0 = 2.6$ index of ruggedness is about 11 in this case. We remark that A. N. Borschevsky pointed to necessity of ruggedness of filler structure at the level as low as 7.

It makes sense to formulate the concept “efficient filler structure”. This is the structure providing required thermal resistance and having ruggedness sufficient for variations in temperature in the range of rated ones. Selection of materials for efficient filler structure at the stage of principle design decision making is based on the results of solution of equations including indexes of heat and hygrophysical efficiency of materials:

$$\begin{gathered} 0.27\delta\sqrt{\frac{C_0+0.0419W_{\text{Б}}}{(1+KTK_W W_{\text{Б}})\cdot KTK_{\text{Б}}}}>4, \\ \frac{\delta_i}{(1+KTK_{W,i}W_i)\cdot KTK_i\cdot\rho_i}>[R_i],\quad , \\ R_0<xK_{\varphi\text{У}}+(\delta-x)K_{\varphi\text{Б}} \end{gathered} \tag{1}$$

where $x$ is the thickness of heat insulation material, m; $\delta_i$ is the thickness of $i$ layer of material of multilayer filler structure, m; $\delta$ is the total thickness of multilayer filler structure set by actual number of forms or shuttering, m; $K_{\varphi,\,\text{У}}$, $K_{\varphi,\,\text{Б}}$ are coefficients of hygrophysical efficiency of heat insulation material; $[R]_i$ is the heat resistance of of $i$

layer of material in filler structure required for given climatic area; $C_0$ is the specific heat capacity of concrete, kJ/kg °C (0,8—0,88); $KTK_i$ is the integral coefficient of heat engineering efficiency of *i* material determining dependence of coefficient of dry material thermal conductivity on its density; $KTK_{Wi}$ is the coefficient of heat engineering quality of *i* material taking into account rise in coefficient of thermal conductivity under increase in material humidity at 1 % subject to average density of material; $W_i$ is the humidity of *i* material depending on mode of operation, %.

When solving the problem formalized in (1) optimization on economic parameters is possible. Solution of the second equation (1) regarding $KTK_i$ allows to determine the requirements for maximal value depending on the required value of thermal resistance, i. e., of the climatic conditions. Solution of the first equation allows to determine more accurately the application of concretes subject to structure ruggedness, i. e., provision of comfort temperature in the amplitude of temperature fluctuations. The result of solution of two equations allows to evaluate specific conditions, some of the factors (thermal resistance or ruggedness of material) are conditioning in this design which permits to make decision on optimization of design parameters, for example, on change in the ratio of layer thicknesses, replacement of the heater by more (less) effective, etc. The third equation enables to make a final decision on application of one or other material subject to ensuring the protection of filler structure from moisture accumulation. Thus, the key characteristics of heat and hygrophysical efficiency of materials are coefficients of heat and hygrophysical efficiency. Classification of certain light concretes by the coefficient of thermotechnical efficiency based on statistical analysis of changes of this magnitude for different concretes is presented in the Table 1.

Table 1

Classification of concrete efficiency by *KTK*

| Efficiency | *KTK* | Materials |
|---|---|---|
| Highly efficient | < 0,00021 | Perlite concrete, foam concrete, autoclave porous concrete, concrete on foamed gravel (ВВГ), concrete on foam glass granulated material (ПСГ) |
| Middle-efficient | < 0,00029 | Vermiculite concrete,<br>cellular polystyrene concrete |
| Low-efficient | > 0,00029 | Expanded-clay concrete, schungite concrete, aggloporous concrete, polystyrene concrete |

The figure shows the dependence $KTK_w$ on the average density and type of concrete. It follows from the data obtained that concretes with glassy porous aggregates have less value of this ratio in comparison with the majority of traditional concrete. For example, for the concrete with ПСГ $KTK_w$ does not exceed 0.04 (4 % increase in the thermal conductivity coefficient per 1 % increase in humidity), whereas for expanded-clay concrete this value varies from 0,048 to 0,062. This means that at equal operating humidity of concrete (e.g., 8 %) increase in thermal conductivity coefficient in reference to dry state of concrete with ПСГ is 32 %, with 38—50 % for expanded-clay concrete. The effectiveness of concrete with ПСГ is obvious. Concretes on the glassy porous aggregates in their properties are not inferior to the best analogues [5], and the raw materials base for production of the aggregates is practically unlimited, their production can be organized at the plants of expanded clay gravel.

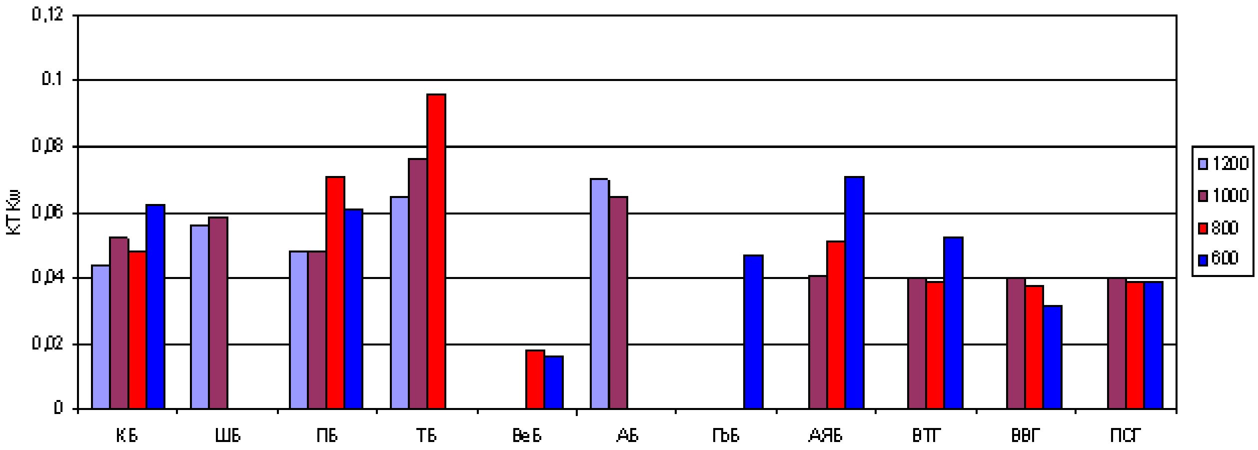

**Fig.** Dependence of *КТК*$_w$ on type and average density of concrete:
*КБ* — expanded-clay concrete; *ШБ* — schungite-concrete; *ПБ* — perlite concrete;
*ТБ* — foam concrete; *ВеБ* — vermiculite concrete; *АБ* — aggloporous concrete;
*ПоБ* — cellular polystyrene concrete; *АЯБ* — gasosilicate; *ВТГ* — concrete on foamed tuff argillaceous gravel (ВТГ); *ВВГ* — concrete on ВВГ; *ПСГ* — concrete on ПСГ

The comfort of dwellings depends on both temperature and humidity conditions. To provide comfort humidity conditions it is necessary to provide easy removal of excess steam from the filler structure, i. e. total resistance to vapor permeability should be limited, too.

In Scandinavian countries and in Belarusian Republic external walls made of steam-cured concrete with density of 500—600 kg/cubic m and thickness of 0.4—0.45 m. Such filler structure is characterized by the index of ruggedness 6—6.8, resistance to vapor permeability 1.7—2.6. Brick wall 0.51—0.64 m thick which reveal good properties as filler structure in many regions has the index of ruggedness 6.7—8.4 and resistance to vapor permeability 4.6—5.8. Table 2 contains comparison characteristics of filler structures with the use of certain materials for filler structures. If external wall made of wood is considered as an ideal one for provision of design comfort for residents it is necessary to set forth the requirements on rate setting of filler structure resistance to vapor permeability at the level of wooden wall, i. e. approximately 5. Such condition is formulated in paragraph 13.8 of Building Code (СП) 23-101-2004.

Table 2

Characteristics of building envelops made of conventional wall materials

| Wall material | Thickness, m | $R_0$, sq. m $^{o}$C/W | $R_\mu$, sq. m h Pa/mg | $D$ | $K_\varphi$ |
|---|---|---|---|---|---|
| Wood | 0.28—0.4 | 1.6—2.4 | 3.8—5.3 | 6.2—8.1 | 1.7 |
| Autoclave gas concrete | 0.4—0.45 | 1.6—2.4 | 1.7—2.6 | 6—6.8 | 3.85 |
| Ceramic cavitated brick | 0.51—0.64 | 0.9—1.2 | 3.6—4.6 | 7.6—10.2 | 1.1 |
| Efficient structure criteria | | | <5 | >4 | >$R_0$ |

Accordingly, we formulate the principle of the selection of materials for efficient structure in the first stages of implementation of design decisions on moisture protection criteria as follows: a comfortable humidity conditions should be provided in the premise, i. e., the following condition should be met:

$$\frac{\delta_Б}{\mu_Б}+\frac{\delta_У}{\mu_У}<5, \tag{2}$$

where $\delta_Б$ is the thickness of concrete layer from internal surface up to possible condensation plane. In accordance with Building Code (СНиП) 23–02–2003, p. 9.1 “…plane of possible condensation in multilayer structure correspond with external surface of the heater”, therefore thickness of concrete internal layer is taken as $\delta_Б$; $\delta_У$ is the heater thickness; $\mu_Б$, $\mu_У$ is the vapor permeabilty coefficient of concrete and heater, respectively.

It follows from (2) that

$$\mu_Б>\frac{\delta_Б}{5-\dfrac{\delta_У}{\mu_У}}. \tag{3}$$

As it has been already noted to compare the effectiveness of materials in terms of protection from moisture under water vapor migration in the design it is appropriate to introduce the coefficient of moisture protection (hygrophysical) effectiveness of the material which is numerically equal to

$$K_\varphi=\frac{5\mu}{\lambda}, \tag{4}$$

where $\mu$ is the vapor permeability coefficient, mg/m·h·Pa; $\lambda$ is the thermal conductivity coefficient, W/m·$^{o}$C.

Since the thermal resistance of a single-layer structure (without considering heat transfer of surfaces) is $R_o=\delta/\lambda_o$, resistance to vapor permeability $R_o=\delta/\mu$, we obtain $\delta = 5\mu$, taking the condition of Building Acts (СП) 23-101-2004, paragraph 13.8 ($R < 5$), whence it follows (4), i. e. value of the coefficient of hygrophysical efficiency of the material is numerically equal to the value of thermal resistance of the layer of material at which the resistance to its vapor permeabilty will not exceed 5. The proposed coefficients of heat and hygrophysical efficiency of materials permit to select efficient materials for filler structure taking into account the region of construction before making principled constructive decisions.

Since light structural heat insulating concretes with porous aggregates are effective materials for efficient filler structure, it is advisable to reveal main factors influencing the coefficients of heat and hygrophysical efficiency of concretes for purposeful management of their values using prescription- technology regulation. To evaluate coefficients of thermal conductivity of concrete in dry state as a two-component system “matrix — aggregate” it is expedient to use a model similar to model of Hirsch for determining the modulus of elasticity of concrete using the structure parameters, i. e, the modules of the matrix and the aggregate. To estimate the thermal conductivity in this case, we use the dependence

$$\lambda_{Б} = \frac{2}{\left(\frac{1}{\lambda_З V_З + \lambda_{ЦК} V_{ЦК}} + \frac{V_З}{\lambda_З} + \frac{V_{ЦК}}{\lambda_{ЦК}}\right)}. \tag{5}$$

Table 3 shows the calculated and experimental values of thermal conductivity of light-insulating constructional concretes. The values are defined at the coefficient of thermal conductivity of porous aggregate (ПСГ) 0.16 at the density of the piece 700 kg / cubic m (average apparent density is 350 kg/cubic m) and the coefficient of thermal conductivity of cement paste with the value of water-cement correlation 0.7 in the range from 0.28 to 0.41 (according to V. G Dovzhik, the coefficient of thermal conductivity of cement stone with water-cement correlation 0.7 is 0.325).

Data of other researchers are also used. Analysis (5) shows that reduction in one parameter (coefficient of thermal conductivity of cement stone, coefficient of thermal conductivity of the aggregate, volume concentration of cement stone) by 10 % reduces the thermal conductivity of concrete, respectively, by 2.1; 8.1, 1.9 %.

Thus, the key factor in reduction in the thermal conductivity of the light concrete is reduction in the thermal conductivity of the porous aggregate. In this regard, the use of glassy aggregates provides compelling advantages over the conventional roasting aggregates. Coefficient of thermal conductivity of ПСГ with equal density is 25—30 % lower in comparison with expanded clay gravel. According to (5) reduction in the thermal conductivity of aggregate by 25 % provides reduction in the thermal conductivity of concrete by 19—21 %. Using glassy porous aggregate reduction in the coefficient of thermal conductivity of concrete in the dry state reaches 18.5 % with reference to expanded-clay concrete of equal density.

Table 3

Calculated and true values of thermal conductivity coefficient of concrete on ПСГ

| Average density of concrete, kg/cubic m | $V_3$ | Thermal conductivity coefficient, W/m°C | | | | | |
|---|---|---|---|---|---|---|---|
| | | of cement stone (filler) | of concrete | | | | |
| | | | true value | calculated by the formula* | | | |
| | | | | of Odelevsky | of Harmathy | of Raleigh | (5) |
| 800 | 0.82 | 0.28 (0.16) | 0.19 | 0.189<br>–0.5 | 0.074<br>–61.0 | 0.179<br>-5.8 | 0.177<br>-6.8 |
| | | 0.41 | | | 0.091<br>-52.1 | 0.197<br>3.7 | 0.192<br>1.1 |
| 900 | 0.78 | 0.28 (0.16) | 0.22 | 0.215<br>-2.3 | 0.091<br>-58.6 | 0.183<br>-16.8 | 0.181<br>-17.7 |
| | | 0.41 | | | 0.112<br>-49.1 | 0.206<br>-6.4 | 0.199<br>-9.5 |
| 625[1] | 0.82 | 0.41 (0.089) | 0.122 | 0.144<br>18.0 | 0.074<br>-39.3 | 0.134<br>9.8 | 0.121<br>-0.8 |
| 550 | 0.84 | 0.41 (0.078) | 0.104 | 0.125<br>20.5 | 0.063<br>-39.4 | 0.119<br>14.4 | 0.106<br>1.9 |
| 600[2] | 0.82 | 0.41 (0.125) | 0.16 | 0.138<br>-13.9 | 0.083<br>-48.1 | 0.166<br>3.8 | 0.158<br>-1.3 |
| 500[3] | 0.82 | 0.41 (0.085) | 0.126 | 0.113<br>-10.3 | 0.073<br>-42.0 | 0.13<br>3.2 | 0.117<br>-7.1 |

**Notes on the table:** *relative error in the numerator, %;
1 – by V. P. Petrov; 2 — by E. V. Maltsev, etc.; 3 — by D. R. Sadykov, etc.

Basic properties of glassy porous aggregates (ПСГ, ВВГ, ВТГ) are presented in the Table 4. The compositions of light concrete of average density equal to 600—900 kg/cubic m on glassy porous aggregates (kg/cubic m) are following: Ц = 200—290; fine filler with fraction 0—5 mm is roasting and crushed glassy sand, areas of thermal power plants, natural porous sands, etc. — 150—230; large glassy filler of fraction 5—10 and 10—20 mm — 170—310. In some compositions air additive was introduced providing up to 10—12 % of solution component vaporization when reducing the consumption of fine filler.

Depending on climatic conditions, i. e., on required thermal resistance, thermal homogeneity of the panel, applied heater, concrete, total thickness of the panel and the thickness of individual layers, different designs of НСП are available. Table 5 presents data on the thermal resistance of НСП of total thickness of 400 mm with the use of concrete in the vitreous filler, heaters with a coefficient of thermal conductivity 0.047— 0.052 W / m °C (ПХВ — 1; mats made of fiberglass URSA).

Table 4

Basic properties of glassy porous fillers

| Basic properties | The filler | | |
|---|---|---|---|
| | ПСГ | ВВГ | ВТГ |
| Apparent density, kg/cubic m | 170—300 | 350—450 | 300—450 |
| Durability under squeezing in the squeezing, MPa | 0.3—1.7 | 1.4—2.4 | 1.2—2.8 |
| True density, kg/ cubic m | 2.34 | 2.35 | 2.34—2.56 |
| Water absorption, % by mass | 60—19 | 12—16.5 | 8—14 |
| Coefficient of softening | 0.87—0.89 | 0.78—0.84 | 0.8 |
| Intergranular voidage, % | 37—39 | 37—40 | 39—48 |
| Frost resistance, cycles, not less than | 15 | 15 | 50 |
| Coefficient of the form | 1 | 1.6—2 | 1.4—1.8 |
| Silicate and ferriferous decomposition resistance of ПСГ, loss, % | In the limit of requirements of State Standard ГОСТ 9757-86 | | |
| Glass phase content, % | 97.4—97.6 | 91.6—95.5 | 96.3—98.0 |
| Hydraulic activity, g/l | 9.4—9.6 | 13—14.8 | |

It follows from the data in Table 5 that one and three-layer НСП with a total thickness of 400 mm having thermal resistance from 1.54 to 4.79 sq. m °C / W can be obtained with the use of lightweight concrete on the glassy aggregates provided operation B, i. e. for the regions with the value of degree-days of heating period prior to 9685 (the required thermal resistance: Magadan — 4.47 sq. m °C / W (8785 degree-days); Moscow — 3.31 sq. m °C / W (5453 degree-days), Rostov-on-Don — 2.81 sq. m °C / W (4042 degree-days) when the estimated internal temperature of 22 °C.) The surface density of such structures is approximately 208—380 kg/sq. m.

Table 5

Calculated values of thermal resistance of НСП

| $\rho$, кг/м$^3$ | Thickness of concrete layers, m<br>surface density, kg/sq. m | $R_0$, sq. m °C/W, at coefficient of thermal homogenity | | | | Ruggedness, $D_Б + D_У$ | $K_\varphi$ |
|---|---|---|---|---|---|---|---|
| | | 0,7 | 0,8 | 0,9 | 1,0 | | |
| 600 | $\frac{0.4}{296}$ | | | | 2.06–2.26 | 6.74–7.48 | 3.75–2.81 |
| | $\frac{0.28}{252}$ | 2.7–2.98 | 3.07–3.38 | 3.43–3.78 | | 5.58–6.09 | 5.28–10.58 |
| | $\frac{0.21}{208}$ | 3.42–3.76 | 4.09–4.28 | 4.43–4.79 | | 4.91–5.29 | 6.17–14.56 |

End of the Table 5

| $\rho$, кг/м$^3$ | Thickness of concrete layers, m / surface density, kg/sq. m | $R_0$, sq. m °C/W, at coefficient of thermal homogenity | | | | Ruggedness, $D_Б + D_У$ | $K_\varphi$ |
|---|---|---|---|---|---|---|---|
| | | 0,7 | 0,8 | 0,9 | 1,0 | | |
| 700 | $\frac{0.4}{336}$ | | | | 1.76–2.06 | 6.68–7.35 | 2.93–2.18 |
| | $\frac{0.28}{280}$ | 2.56–2.88 | 2.9–3.27 | 3.24–3.65 | | 5.53–6.03 | 4.69–10.03 |
| | $\frac{0.21}{229}$ | 3.3–3.69 | 3.75–4.19 | 4.2–4.69 | | 4.86–5.24 | 5.17–13.95 |
| 800 | $\frac{0.4}{380}$ | | | | 1.54–1.82 | 6.61–7.23 | 2.12–1.56 |
| | $\frac{0.28}{310}$ | 2.45–2.76 | 2.78–3.13 | 3.1–3.51 | | 5.48–5.92 | 4.14–9.44 |
| | $\frac{0.21}{252}$ | 3.22–3.6 | 3.66–4.09 | 4.1–4.58 | | 4.83–5.16 | 5.02–13.4 |

## Conclusion

The main effect of the use of porous glassy aggregates is the expansion of the resource base, as stocks of clays allowing to obtain expanded gravel of mark 400 are very limited, whereas the raw material base for the production of porous glassy aggregates is much broader. We can say that the main effect of production and use of glassy porous aggregates and concretes based on them is the provision of technical possibility to produce effective materials without increase in costs.

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