Investigation of thermal conductivity of non-autoclaved foam concrete based on microsilica

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Abstract. The article presents the results of a study of the thermal conductivity of non-autoclaved foam concrete based on microsilica, depending on its average density and humidity. It is established that the decrease of the average density of foam concrete from 800 to 400 kg/m³ leads to a decrease the thermal conductivity coefficient by 44.9%. The coefficients of thermal conductivity of the dry samples are about two times lower than the same samples at their natural humidity.

Thermal conductivity, that is the ability of the material to conduct heat from one surface to another, is one of the most important characteristics for heat-insulating and constructural-heat-insulating foam concretes.

Thermal conductivity is estimated by the coefficient of thermal conductivity \( \lambda \), the value of which depends on the average density of foam concrete, its structure (size and nature of pores) and its humidity.

Many researchers are engaged in the study of the thermal conductivity of cellular concrete \([1÷15]\). The value of the coefficient of thermal conductivity is known to be directly proportional to the average density of foam concrete that is the lower the grade of the average density of foam concrete is the lower the coefficient of thermal conductivity.

In addition to the average density of foam concrete the type of filler is affects on the coefficient of thermal conductivity. According to GOST 25485-89 “Cellular Concrete. Specifications” the coefficient of thermal
conductivity for foam concrete grades on the average density from D400 to D800 is from 0,1 to 0,21 W/(m·K) made on sand and from 0,09 to 0,18 W/(m·K) made on fly ash.

The water in the pores of foam concrete increases its thermal conductivity, because the thermal conductivity of water is 25 times greater than air ($\lambda_{\text{water}}=0.569$ W/(m·K), $\lambda_{\text{air}}=0.023$ W/(m·K)).

The coefficient of thermal conductivity of foam concrete of non-autoclaved hardening can be calculated to the formula V.P. Nekrasov:

$$\lambda = 1.16 \cdot \sqrt{0.0196 + 0.22 \cdot d^2 - 0.16}$$

where $d$ – is the relative density of the material, defined as the ratio of the average density of the material to the density of water equal to 1000 kg/m$^3$.

The exact value of $\lambda$ is determined experimentally using special devices, for example, using the device ITP-MG4 “Zond”.

The purpose of this work is to study the influence of the average density of non-autoclaved foam concrete based on microsilica [16, 17] and the percentage of humidity in it on the coefficient of thermal conductivity.

The following materials were used in the research:

- Portland cement CEM I 42,5 H (PC 500 D0) production of JSC “Angarskcement”;
- microsilica from dust collecting filters of the JSC “Kremniy” with the bulk density of 0,6 g/cm$^3$;
- a hyperplasticizer based on polycarboxylates “MC-Power-Flow-3100”;
- a synthetic foaming agent Penta Pav 430A.

The research method was as follows. The foam concrete mixes were prepared according to the classical technology: the mortar mix (Portland cement (PC)+microsilica (MC)+water with the addition of hyperplasticizer (HP) and the foam (water+foaming agent (FA) were separately prepared. Foam was introduced into the mortar mix in such quantity to get the foam concretes grades on average density of D400, D600, D800. The compositions of foam concrete mixes are given in Table 1.

**Table 1.** Compositions of foam concrete mixes.

| Grade of foam concrete on average density | Content, % of the mass of solids |
|-----------------------------------------|----------------------------------|
| D400                                    | PC 50    | MC 50   | Water 58 | HP 0,46 | FA 0,27 |
| D600                                    | PC 50    | MC 50   | Water 53 | HP 0,46 | FA 0,16 |
| D800                                    | PC 50    | MC 50   | Water 51 | HP 0,44 | FA 0,1  |

From foam concrete mixes of different average density were molded samples-cubes of size 100x100x100 mm. After 28 days of normal hardening on samples by the device ITP-MG4 “Zond” in according with GOST 30256-
“Building materials and products. Method of thermal conductivity determination by cylindrical probe” thermal conductivity coefficients were determined. Thermal conductivity was determined on samples of different average density and with different percentage of humidity.

The research results are presented in Table 2 and in Figures 1÷4.

Table 2. Dependence of the thermal conductivity coefficient of non-autoclaved foam concrete based on microsilica on the grade on average density and percentage of humidity.

| Grade of foam concrete on average density | Humidity, % | Thermal conductivity coefficient, W/(m·K) |
|------------------------------------------|-------------|------------------------------------------|
| D400                                     | 39,1        | 0,269                                    |
|                                          | 18,2        | 0,241                                    |
|                                          | 9,7         | 0,184                                    |
|                                          | 4,2         | 0,145                                    |
|                                          | 0           | 0,13                                     |
| D600                                     | 37,1        | 0,361                                    |
|                                          | 22,1        | 0,347                                    |
|                                          | 13,8        | 0,308                                    |
|                                          | 8,0         | 0,246                                    |
|                                          | 0           | 0,181                                    |
| D800                                     | 35,0        | 0,514                                    |
|                                          | 26,7        | 0,488                                    |
|                                          | 17,4        | 0,442                                    |
|                                          | 9,6         | 0,397                                    |
|                                          | 0           | 0,236                                    |

The results of the research presented in Table 2 show that the decrease in the average density of non-autoclaved foam concrete based on microsilica from 800 to 400 kg/m³ leads to a decrease in the thermal conductivity by 44.9 %. For foam concrete of the investigated grades (D400, D600, D800) the thermal conductivity coefficients of the samples dried to a constant mass are about two times lower than the thermal conductivity coefficients determined on the same samples at their natural humidity.
Figure 1. Dependence of thermal conductivity coefficient of non-autoclaved foam concrete based on microsilica on its average density.

The graph in Figure 1 shows that the change in the coefficient of thermal conductivity of non-autoclaved foam concrete based on microsilica depending on its average density has a linear character and is described by the equation:

\[
y = 0.0003 \cdot x + 0.0164
\]  
where \( x \) – the average density of non-autoclaved foam concrete based on microsilica, kg/m\(^3\).

Figure 2. Dependence of the thermal conductivity coefficient of foam concrete D400 on percentage of humidity.
The change in the coefficient of thermal conductivity of non-autoclaved foam concrete D400 depending on percentage of the humidity (Figure 2) described by the equation:

\[ y = -0.0001 \cdot x^2 + 0.0081 \cdot x + 0.1217 \]  \hspace{0.5cm} (3)

where \( x \) – percentage of the humidity of non-autoclaved foam concrete D400, %.

**Figure 3.** Dependence of the thermal conductivity coefficient of foam concrete D600 on percentage of humidity.

The change in the coefficient of thermal conductivity of non-autoclaved foam concrete D600 depending on percentage of the humidity (Figure 3) described by the equation:

\[ y = -0.0002 \cdot x^2 + 0.0115 \cdot x + 0.1768 \]  \hspace{0.5cm} (4)

where \( x \) – percentage of the humidity of non-autoclaved foam concrete D600, %.
The change in the coefficient of thermal conductivity of non-autoclaved foam concrete D800 depending on percentage of the humidity (Figure 4) described by the equation:

\[ y = -0.0002 \cdot x^2 + 0.0161 \cdot x + 0.2441 \]  

(5)

where \( x \) – percentage of the humidity of non-autoclaved foam concrete D800, %.

Calculated according to the formula of V.P. Nekrasov and experimentally established values of thermal conductivity coefficients of non-autoclaved foam concrete based on microsilica are given in table 3.

**Table 3.** Calculated and experimental values of thermal conductivity coefficients of non-autoclaved foam concrete based on microsilica depending on its average density.

| Average density of foam concrete in dry condition, g/sm | Calculated value of thermal conductivity coefficient, W/(m·K) | Experimentally established value of the thermal conductivity coefficient, W/(m·K) |
|--------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------------|
| 0.383                                                  | 0.104                                                         | 0.13                                                                             |
| 0.557                                                  | 0.184                                                         | 0.181                                                                           |
| 0.741                                                  | 0.275                                                         | 0.236                                                                           |

**Figure 4.** Dependence of thermal conductivity coefficient of foam concrete D800 on percentage of the humidity.
The results of the research presented in Table 3 show that for non-autoclaved foam concrete D400, the difference between the calculated and experimentally established values of the thermal conductivity coefficients is 25%, for foam concrete D800 – 14.2%. The minimum divergence was 1.6% for foam concrete D600.

Thus, it is experimentally established that:
- the decrease of the average density of non-autoclaved foam concrete based on microsilica from 800 to 400 kg/m³ leads to a decrease the thermal conductivity by 44.9%;
- thermal conductivity of foam concrete samples of natural humidity is about twice higher than dried samples;
- calculated and experimental values of thermal conductivity coefficients of non-autoclaved foam concrete based on microsilica differ significantly from each other: for the D400 the discrepancy is 25%, for the D600 – 1.6%, for the D800 – 14.2%.

According to the results of studies for non-autoclaved foam concretes based on microsilica, the dependences of the thermal conductivity coefficients on their average density and percentage of humidity were derived.

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