INFLUÊNCIA DA QUALIDADE DO FILLER NA CONDUTIVIDADE TÉRMICA DO CONCRETO

INFLUENCE OF FILLER QUALITY ON CONCRETE THERMAL CONDUCTIVITY

ВЛИЯНИЕ КАЧЕСТВА ЗАПОЛНИТЕЛЯ НА ТЕПЛОПРОВОДНОСТЬ БЕТОНА

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RESUMO

Estudos sobre o efeito da composição de grãos na condutividade térmica de concreto leve, demonstraram que a composição mineral do material de enchimento (agregados) reflete substancialmente a condutividade térmica e a densidade do concreto. Os grãos do componente têm um efeito ligeiramente mais alto na condutividade térmica do que o próprio material. A prova dessa posição é que a condutividade térmica de materiais a granel é sempre um pouco menor que dos materiais celulares da mesma densidade média. Em um corpo poroso absolutamente seco, a transferência de calor pode ocorrer não apenas através da condutividade térmica através do esqueleto sólido do corpo e localizado nos poros do ar, mas também por convecção e radiação entre as paredes dos poros. Com um diâmetro de poro inferior a 1 mm, a transferência de calor por convecção é praticamente zero, e o coeficiente de condutividade por calor radiante pode ser desprezado apenas quando o diâmetro de poro é inferior a 0,5 mm. Portanto, com a mesma porosidade, o coeficiente de condutividade térmica será maior, maiores serão os poros do material. Portanto, a criação de uma estrutura finamente porosa de concreto leve e o uso de agregados finamente porosos contribuem para a produção de concreto com condutividade térmica reduzida. A prova pode ser o resultado de experimentos e as curvas apresentadas. Um aumento no tamanho dos poros na superfície dos grãos dos agregados leva a um aumento nos vazios intergranulares das misturas. Como resultado dos estudos mineralógico-petrográficos de agregados porosos artificiais, foi estabelecido que as fases de aluminossilicato com uma estrutura desordenada - argila amorfizada com queima e vidros ácidos - predominam na argila expandida, agloporita e perlita expandida. A escória é caracterizada por uma predominância de fases cristalinas - silicatos com baixo teor de cálcio básico do que aluminossilicatos de cálcio e magnésio. A fase vítrea está presente apenas na forma de impureza de 15 - 20%. Ao analisar os dados experimentais, concluiu-se que a condutividade térmica da argila expandida aumenta com o aumento da densidade. No entanto, na mesma densidade, argila expandida de diferentes lotes da mesma planta e especialmente de plantas diferentes diferem nos valores do coeficiente de condutividade térmica.

Palavras-chave: *density, porosity, slag concrete, thermal conductivity coefficient, crystalline phase.*

ABSTRACT

Studies on the effect of grain composition on the thermal conductivity of lightweight concrete, it was shown that the mineral composition of filler (aggregates) substantially reflects the thermal conductivity and density of concrete. The grains of the component have a slightly higher effect on the thermal conductivity than the material itself. The proof of this position is that the thermal conductivity of bulk materials is always slightly lower than cellular materials of the same average density. In an absolutely dry porous body, heat transfer can occur not only through thermal conductivity but also through the solid skeleton of the body, located in the air pores, but also by convection and radiation between the pore walls. With a pore diameter of less than 1 mm, convective heat transfer is practically zero, and the coefficient of radiant heat conductivity can be neglected only when the pore diameter is less than 0.5 mm. Therefore, with the same porosity, the thermal conductivity coefficient will be the greater, the larger the pores of the material. Therefore, the creation of a finely porous structure of lightweight concrete and the use of finely porous aggregates contributes to the production of concrete with reduced thermal conductivity. The proof can be the results of experiments and the curves

presented. An increase in the pore size on the surface of the grains of the aggregates leads to an increase in intergranular voids of the mixtures. As a result of mineralogical-petrographic studies of artificial porous aggregates, it was established that aluminosilicate phases with a disordered structure — clay amorphized with firing and acidic glasses — predominate in expanded clay, agloporite, and expanded perlite. Slag is characterized by a predominance of crystalline phases - low-basic calcium silicates than calcium and magnesium aluminosilicates. The glassy phase is present only in the form of an impurity of 15 - 20%. When analyzing the experimental data, we came to the conclusion that the thermal conductivity of expanded clay increases with increasing density. However, at the same density, expanded clay of different batches of the same plant and especially of different plants, differ in the values of the coefficient of thermal conductivity.

Keywords: *density, porosity, slag concrete, thermal conductivity coefficient, crystalline phase.*

АБСТРАКТ

Исследования влияние зернового состава на теплопроводность легкого бетона показали, что минеральный состав заполнителей, существенно отражает теплопроводностью и плотности бетона. Зерна составляющего оказывает несколько большее влияние на теплопроводность, чем самого материала. Доказательством этого положения служит то, что коэффициенты теплопроводности сыпучих материалов всегда несколько ниже, чем ячеистых материалов той же средней плотности. В абсолютно сухом пористом теле, передача тепла может происходить не только теплопроводностью через твердый скелет тела и находящийся в порах воздуха, но и путем конвекции и излучения между стенками пора. При диаметре поры меньше 1 мм конвективный теплообмен практически равен нулю, а коэффициентом лучистой теплопроводности можно пренебречь лишь в случае, когда диаметр поры менее 0,5 мм. Следовательно, при одинаковой пористости величина коэффициента теплопроводности будет тем больше, чем крупнее поры материала. Поэтому создание мелкопористой структуры легкого бетона и применение мелкопористых заполнителей способствует получению бетона пониженной теплопроводности. Доказательством могут служить результаты экспериментов и представленные кривые. Увеличение размера пор на поверхности зерен заполнителей приводит к увеличению межзерновых пустотностей смесей. В результате минералого-петрографических исследований искусственных пористых заполнителей установлено, что в составе керамзита, аглопорита и вспученного перлита преобладают алюмосиликатные фазы с неупорядоченным строением - аморфизированное обжигом глинистое вещество и кислые стекла. Для шлака характерно преобладание кристаллических фаз - низкоосновных силикатов кальция, чем алюмосиликатов кальция и магния. Стекловидная фаза присутствует лишь в виде примеси 15 - 20%. При анализе экспериментальных данных пришли к выводу, что коэффициент теплопроводности керамзита повышается с увеличением его плотности. Однако при одной и той же плотности керамзиты разных партий одного завода и особенно разных заводов отличаются значениями коэффициента теплопроводности.

Ключевые слова: *плотность, пористость, шлакобетон, коэффициент теплопроводности, кристаллическая фаза.*

1. INTRODUCTION

The lighter the concrete, the usually less thermal conductivity, since a decrease in concrete density is associated with an increase in porosity. Noting the presence of a certain general relationship between the density and thermal conductivity of concrete, it is necessary to keep in mind the possible significant deviations from this dependence. In blast-furnace slag containing a large number of different impurities, it is possible that there is such a frequent violation of the crystal lattices formed in the mineral slag when their thermal conductivity becomes close to the thermal conductivity of the glasses, in addition, the fact that the slag especially acidic, there is

always a certain amount of glass enveloping the crystals. In addition, the introduction of granular slag into concrete instead of porous slag led to an increase in the thermal conductivity of concrete, while increasing its average density (Petrov, 2009; GOST 9758 – 2012, 2012; CN&R 23-02-2003 and 2004).

The thermal conductivity of concrete is determined by the type of aggregate used. The production of porous aggregates for lightweight concrete was made by the use of lightweight concrete wall panels of exterior walls in the construction of heat-insulating lightweight concrete for various purposes.

Factors can be divided into groups according to the degree of their influence on the thermal

conductivity of slag concrete, with decreasing significance: the first group is the porosity of concrete and aggregate, particle size distribution and phase composition of the aggregate; the second group - the type and consumption of cement; the third group is mixing water consumption; the fourth group - conditions for hardening concrete. According to leading experts, the factors of the fourth group have a slight effect on the thermal conductivity of lightweight concrete (CN&R 23-02-2003, 2004; Dvorkin, 2013; Bazhenov, 2013).

With an increase in the glass phase content, the thermal conductivity of the slag decreases. So, as an increase in the glass phase by 10-20% reduces the coefficient of thermal conductivity of the backfill from slag pumice by 8-12%. According to (GOST 32496-2013, 2013; Zotkin, 2014; Nesvetaev, 2012), at the same density and grain composition, the thermal conductivity coefficient of the backfill from completely crystallized slag is 16–20% higher than that of vitrified slag. The predominant influence on the coefficient of thermal conductivity of slag is provided by the isotropic glass. A small amount of denitrified glass enhances the effect of isotropic glass, and its content of more than 25% causes a weakening of the effect of the glass phase on the thermal conductivity of slag (STO 08.23.02-2009, 2009).

According to (Maksimov, 2004; Gorin, 2010), the thermal conductivity coefficients of concrete with a density of 1250 kg/m³ on blast furnace slag and a density of 800 kg/m³ on expanded clay gravel are the same.

According to (GOST 10832-2009, 2009; Gorin, 2011), the improved thermophysical properties of expanded clay of one plant are due to the fact that it contains only 10 - 15% of crystalline quartz compared to 30 - 40% in comparison with expanded clay of another plant, in addition, depending on the type of expanded clay, the thermal conductivity of concrete is its identical density can vary by 0.06 - 0.12 W/(m·°C).

2. MATERIALS AND METHODS

2.1 Effect of porous filler on the properties of lightweight concrete

A highly active component of the crystalline phase is residual quartz. The quartz content in the solid phase of the high-strength aggregate

(filler) varies from 20 to 26%. The grain size of quartz varies on average from 2-3 to 120-200 mcm. Usually, the surface of quartz grains is fused and corroded by feldspar melt. In the presence of active feldspar melt and sufficient firing temperature, the thickness of the margin of fusion of the grains of residual quartz is 2–5 mcm. Grains smaller than 2 mcm, as a rule, pass into the melt. It has been established that quartz grains and the vitreous component experience uniform tension in all directions: radial tensions in the entire region are tensile; the tangential tensions in the glass phase at the boundary with quartz grain are compressive. Special individual studies and processing of the results using equations characterizing the stress state and radial deformations determined the magnitude and distribution of tensions in the quartz component and the surrounding glass phase (Petrov, 2009; Rogovoi, 2016). As they move away from quartz, they decrease, pass through zero, and become tensile at the boundary of the region. The resulting micro tensions are directly proportional to the content of residual quartz. These tensions are proportional to the total surface of all quartz grains per unit volume of the rock and are manifested to the greatest extent when the radius of the quartz grains is three times the thickness of the dissolved layer. Therefore, the most dangerous place is the interphase boundary of contact of quartz grains with the glass phase.

As a result of studies of porous aggregates of various plants, it was found that the average pore diameter of slag is higher, in addition, the average porosity is lower, and the content of the glassy component is much lower than that of expanded clay. Meanwhile, as follows from Figure 1, the thermal conductivity of slag and expanded clay with a density of 900 and 600 kg/m³, respectively, is the same.

The solid phase may be in a crystalline or glassy state. The thermal conductivity of glasses is a function of their chemical compound; the limits of its change are small. The minimum and maximum values of the thermal conductivity coefficient of the studied glasses are between 0.7 and 1.3 W/(m·°C).

The highest thermal conductivity has transparent quartz glass - 1.3 W/(m·°C). Various oxides introduced into the glass change the thermal conductivity of the glasses. Other conditions being the same, refractory materials have higher thermal conductivity. The bigger the content of MgO, SiO₂, Al₂O₃ constituents with high thermal conductivity, and the higher the

firing temperature, which contributes to an increase in the content of crystalline substance.

2.2 Thermal conductivity of lightweight concrete

Studies of establishing the dependence of the density of lightweight concrete on the thermal conductivity for concrete with a density of 1300 kg/m³ and a lower coefficient of thermal conductivity have slag concrete (Figure 1).

Thermal conductivity is the most important essential property of lightweight concrete, the lighter the concrete, the lower its thermal conductivity, since a decrease in concrete density is associated with an increase in porosity, i.e., involving air in the concrete volume, which is a good heat insulator in small pores (Figure-2).

From this, we see that the thermal conductivity of concrete is significantly affected by the mineralogical composition of the aggregate. Thus, quartz has the highest thermal conductivity, limestone, and dolomite - medium, trachyte, and basalt - the lowest, which also depends on the directions of the heat flux with respect to the orientation of the crystals. Since the thermal conductivity of water is greater higher than the thermal conductivity of air, the degree of saturation of concrete with water is of great importance. For example, an increase in the level of humidity in lightweight concrete leads to an almost twofold increase in thermal conductivity.

The thermal conductivity coefficients of crystals and glasses with the same chemical composition differ very significantly. As compiled from the data, the thermal conductivity coefficients of the crystals of the main compounds, which are usually part of building materials, are several times higher than the same value for glasses of the same chemical compound (Table 1).

There is a relationship between density and thermal conductivity, but there may be deviations from this dependence. For example, those amorphous materials are less thermally conductive than crystalline. Therefore, from the point of view of thermal insulation requirements, aggregates are preferable, in which there is more glass, for example, slag pumice.

Table 2 shows data on the dependence of the coefficient of thermal conductivity of air in closed pores on the pore diameter at 0 °C.

The thermal conductivity of the material in pores up to 1 mm in size varies little, and in

pores, with a diameter of more than 1 mm, it increases sharply. Therefore, with the same porosity, the thermal conductivity coefficient will be the greater higher, the larger the pores of the material. Therefore, the creation of a finely porous structure of lightweight concrete and the use of finely porous aggregates contribute to the production of concrete with reduced thermal conductivity (Mikulsky, 2007).

In addition, the thermal conductivity of lightweight concrete is affected by the particle size distribution of the aggregate, because the nature of the porosity and pore size depends on it.

It was found that the thermal conductivity coefficients of concrete with a density of 1450 kg/m³ with aggregate made of slag and the same concrete in which fine sand (fractions below 1.2 mm) is replaced by quartz sand are within respectively 0.42-0.56 and 0.57-0.72 W/(m·°C) (Figure 3).

Sodium - calcium glass (69% - SiO₂, 15% - Na₂O, 16% - CaO) in the form of a tile 2 cm thick, heated to 900 °C, partially crystallized and cooled to 50 °C, has a thermal conductivity 40% higher than the original (Bazhenov, 2002). The thermal conductivity of dump blast furnace slag with a crystalline phase content of 85-90% and 3-5% at an equal density in a piece is respectively 1.23 and 0.87 W/(m·°C) (Bobrov, 2003).

The effect of the amount of glass phase on the thermal conductivity of the slag filling of fractions of 0-10 mm was determined (Figure 4). Significant changes in thermal conductivity are observed when the glass phase content is less than 35 - 40%.

It was found that the optimal combination of heat-shielding and physical-mechanical indicators of slag concrete is determined by the content of 50-60% glass phase and 40-50% of the crystalline phase in the slag since this depends on the type of slag used (Bazhenov, 2004).

The dependence of the thermal conductivity of the slag on the glass phase content in it is extreme, i.e., the slag has a low thermal conductivity with a low content of crystals and with a sufficiently high, which implies that in order to reduce the thermal conductivity of the slag, it is not necessary to strive to increase the glass phase content in it or to maintain its amount in a narrow range. Unwanted combinations of pore diameter and degree of crystallized slag should only be avoided (Eremkin, 2000).

When studying the effect of slag quality on

concrete properties, a tendency was found to decrease the thermal conductivity coefficient with an increase in the content of the vitreous phase in the slag (Figure 5).

The separation of the slag into vitreous (less than 20% of crystals) and crystalline (more than 35% of crystals) is conventionally accepted (20 - 35% of crystals is glass crystalline) 0.190 W/(m·°C). The content of the crystalline phase in the slag is 50 -70%.

The use in the concrete of two types of crushed stone from slowly and quickly cooled slag (hence, with different glass phase contents) does not significantly affect the value of the thermal conductivity coefficient. And when granular slag is replaced with slag sand in concrete, the value of thermal conductivity even decreases slightly. The introduction of granular slag into concrete instead of porous slag led to an increase in the thermal conductivity of concrete by 14%, while its density increased by 13.2%.

Structural and heat-insulating concrete was studied at various plants. The thermal conductivity coefficient of concrete in one plant is 14% higher than concrete in another plant, with concrete density increased by 7%. At the same time, slag at one plant is characterized by a glass phase content of 60 - 85% than at another plant 45 - 70%.

Therefore, under other unchanged conditions, the thermal conductivity of the material is determined not only by the amount of glass phase, which was ascertained by the researchers but also by other parameters of the phase structure of the material.

The researchers found that to reduce thermal conductivity, not only the total amount of glass contained in the aggregate but also its distribution is significant.

The most advantageous from this point of view is the case when the vitreous membranes cover the walls of pores and capillaries with at least a thin layer since, in this case, the heat transfer by radiation will decrease. It is also important essential that the pore walls have not only a porous but also a porous structure, i.e., so that crystalline inclusions would be separated from each other by at least thin glassy layers. Then there will be no "cold bridges" - the most intense direct heat transfer paths through adjacent crystals.

According to (GOST 25820-2014, 2014), the size of the material's crystals is assigned an important role in influencing the thermal

conductivity. With a decrease in the crystal size, the thermal conductivity of the slag decreases. In addition, the thermal conductivity of the material is significantly affected by its mineralogical composition.

This is explained by the low, close to glass thermal conductivity of crystallized slag. In blast-furnace slag's containing a large number of various impurities, it is possible that there is such a frequent violation of the crystal lattices of minerals formed in the slag when their thermal conductivity becomes close to the thermal conductivity of the glasses. In addition, the decrease in the thermal conductivity of the slag is also influenced by the fact that in the slag, especially acidic, there is always a certain amount of glass enveloping the crystals. The enveloping component has a slightly greater higher effect on thermal conductivity than the enveloped. The proof of this position is that the thermal conductivity of bulk materials is always somewhat lower than cellular materials of the same density.

With increasing porosity of a material, the effect of its phase composition on thermal conductivity decreases, and the influence of porosity increases. If within the limits of the density of slag concrete 1300 - 1600 kg/m³, which corresponds to the range of the total concrete porosity of 0.4 - 0.5, the value of the glassy structure of the aggregate is most affected, and then the influence of concrete porosity prevails in the region of lower density values.

In an absolutely dry porous, heat transfer can occur not only through thermal conductivity through the solid skeleton of the body and the air in the pores, but also by convection and radiation between the walls of the pore. With a pore diameter of less than 5 mm in a temperature difference of 10 °C, convective heat transfer is practically zero, and the coefficient of radiant heat conductivity can be neglected only when the pore diameter is less than 0.5 mm.

Figure 6 shows the curves, from which it follows that for a material with the same density, the dependence of the coefficient of thermal conductivity on porosity is higher for fired bricks, characterized by rough porosity due to the introduction of large significant burnable additives than for finely divided masses in which pores smaller and formed due to the introduction of a large amount of water.

So, with an increase in the density of concrete, for example, from 314 to 415 kg/m³, the value of

the coefficient of thermal conductivity does not change, provided that the average diameter of the cell decreases from 1.86 to 0.81 mm.

According to the author (GOST 27005 – 2014, 2014), an increase in the pore size on the surface of the aggregate grains leads to an increase in the intergranular voidness of the mixtures, which causes an additional consumption of the binder. A decrease in the density of aggregates with increasing pore size leads to an increase in the density of concrete, and, consequently, its coefficient of thermal conductivity.

The nature of porosity also affects thermal conductivity. Closed porosity not only reduces the thermal conductivity of the air trapped in it but also prevents water absorption.

The thermal conductivity of lightweight concrete is significantly affected by the particle size distribution of aggregates since it determines the structure of concrete and the nature of porosity.

On the question of the rational grain composition of slag concrete from the point of view of obtaining concrete with minimal thermal conductivity, there are various views (Davidyuk, 2010; Orentlicher, 2010). Special individual studies to determine the influence of the particle size distribution of slag concrete aggregates showed that with the addition of slag sand with a bulk density of more than 1000 kg/m³, the thermal conductivity of concrete increases in proportion to the amount of sand introduced into concrete (Figure 7), which is caused by an increase in concrete density.

Therefore, obtaining concrete of a cohesive structure is advisable only in the presence of fine aggregate with a density not exceeding that of slag.

The thermal conductivity of concrete on slag increases by 10%, with an increase to 0.45 of the fraction of fine aggregate in the total volume of aggregates of slag concrete. With a further increase in the sand content in concrete, its thermal conductivity does not change.

Studies of concretes based on expanded clay gravel have shown that the coefficient of thermal conductivity of expanded clay concrete can fluctuate over a fairly reasonably wide range (up to 30%) depending on the selected structure at the same density. The decisive factor in the structure formation of lightweight concrete, according to the authors, is the content of fine aggregate in concrete.

The experts came to the same conclusion in the study of slag concrete (Alekseev, 2010; Surkov, 2009). For slag concrete, the linear relationship between density and thermal conductivity is not fair. With a decrease in the size of the slag fraction, the average pore size decreases and, consequently, the proportion of large pores in concrete. Since the thermal conductivity of air in pores with a diameter of more than 1 mm (up to 3 mm) is 15-20% higher than in pores with a diameter of up to 1 mm, the presence of large pores will be less effective obstacle to heat transfer in concrete than small pores of the same volume.

The thermal conductivity coefficient is also affected by the size of the contact areas between the individual particles of the material: the larger these sites are, the higher the thermal conductivity of the material will be. For example, an increase in grain size from 5 to 30 mm increases the thermal conductivity of slag filling by 36% at the same density.

An increase in the fraction of the fine fraction in the concrete of the composite structure contributes to an increase in the interface between the cement stone and the aggregate; thermal resistances arise on the interface, which will increase in proportion to the increase in the interface. Therefore, slag concrete on aggregate with a lower average fineness has a thermal conductivity coefficient lower than concrete on a larger aggregate (Figure 8).

The optimal value of the fraction of fine aggregate for obtaining concrete of the lowest density is 0.25, the lowest coefficient of thermal conductivity is 0.50. With an increase in the fraction of fine aggregate from 0.25 to 0.50, the coefficient of thermal conductivity of slag concrete decreases by 10-12%, with an increase in the density of concrete by 5-6%.

The conducted studies suggest that the use of slag sand as fine aggregate for structural and heat-insulating concrete with optimal composition selection should not lead to an increase in the thermal conductivity, despite a significant increase in density. This is due to the increased, against slag crushed stone, the glass content in the slag sand, the phenomenon is explained by the fact that, firstly, with an increase in the cooling rate of the slag melt, the glass content in the composition of the slag material increases. Thus, the part of the sand resulting from granulation upon direct contact of the slag melt with a large amount of water is more glass-containing than the slag crushed stone formed at

a relatively low cooling rate of the melt with a lack of water.

Secondly, when crushing a slag block, glass-containing inclusions are subject to greater more considerable grinding, which, when sifted, are also released into slag sand.

According to (Fedoseev, 2010) the lowest thermal conductivity is characterized by lightweight concrete with aggregate containing 20% of grains of 1.2–5 mm fraction and 80% of grains of 5–20 mm while maintaining the strength of concrete.

In mortars and concrete, cement particles surround the aggregate, so the thermal conductivity of cement stone has a significant effect on the thermal conductivity of concrete.

Concrete of the same composition, in different Portland cements, has different thermal conductivity coefficients. Thus, the thermal conductivity on slag cement was 30% lower than when using conventional Portland cement (Figure 9).

This is due to the fact that cement has a different amount of fiberglass slag. In addition, the increase in the number of crystals can lead to an increase by an average of 10% in the thermal conductivity of cement stone, the same density with an increase in the type of cement.

Studies of the effect of cement on the thermal conductivity of heavy concrete revealed that with an increase in the amount of cement, an increase in thermal conductivity is initially observed, which is a consequence of filling air voids. Then, having reached a certain limit (about 500 kg/m³), a decrease in thermal conductivity occurred, since concrete aggregates have higher thermal conductivity than cement stone.

3. RESULTS AND DISCUSSION

The aggregate has a noticeable effect on the structure formation of lightweight concrete after hardening of the concrete mix. He creates a rigid frame, strengthening the structure at the first stage of its formation; its presence significantly affects the hardening conditions of cement stone. In concrete, the interaction of cement and water and its hardening occur in thin layers between the grains of the aggregate with full interaction with it.

The thermal conductivity coefficients of the grains of porous aggregates depend on their type, density, and pore structure. The conducted studies suggest that the use of slag sand as fine

aggregate for structural and heat-insulating concrete with optimal composition selection should not lead to an increase in the thermal conductivity, despite a significant increase in density.

Increasing the thermal resistance of the walls of the solid base by reducing their cross-section, the deterioration of the contacts between the walls of the skeleton also significantly improve its thermal conductivity. The most important goal of thermal insulation of building structures is to reduce energy consumption for heating a building. In construction, thermal insulation reduces the thickness of building envelopes.

4. CONCLUSIONS

The thermal conductivity of porous aggregates, like other porous bodies, is affected by the quantity and quality (size) of air pores and humidity. The phase composition of the material has a noticeable effect. An anomaly in the coefficient of thermal conductivity is associated with the presence of a vitreous phase. The larger the glass, the lower the thermal conductivity coefficient for the aggregate of the same density. In order to stimulate the production of aggregates with the best thermal insulation properties for concrete claddings, it is proposed to standardize the content of slag glass (for example, for high-quality slag pumice stone 60-80%).

Therefore, with other conditions unchanged, the thermal conductivity of the material is determined not only by the amount of glass phase but also by other parameters of the phase structure of the material. For example, it was found that to reduce thermal conductivity, not only the total amount of glass contained in the aggregate is significant, but also its distribution. The most advantageous from this point of view is the case when the vitreous membranes cover the walls of pores and capillaries with at least a thin layer since, in this case, the heat transfer by radiation will decrease. It is also important that the pore walls not only have a porous and porphyritic structure so that crystalline inclusions are separated from each other by at least thin glassy layers. The thermal conductivity coefficients of crystals and glasses with the same chemical composition differ very significantly.

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Figure 1. The dependence between thermal conductivity and density

Figure 2. The dependence of the thermal conductivity (heat conduction) of concrete on their density (according to CN&R P-3-79).

1 - agloporiton concrete and concrete on fuel (boiler) slag; 2 - expanded clay concrete on expanded clay sand; 3 - concrete on blast furnace granulated slag; 4 - slag concrete.

Figure 3. The thermal conductivity (heat conduction) of concrete with different fine aggregate

Figure 4. The effect of the glass phase content on the thermal conductivity (heat conduction) of the slag fraction 0-10 mm

Figure 5. The dependence of the thermal conductivity (heat conduction) of concrete on its density and quality of slag pumice

Figure 6. The dependence of the coefficient of thermal conductivity (heat conduction) on porosity for materials of cellular structure.
1 - burnt brick; 2 - heat-insulating masses

Figure 7. Dependence of the thermal conductivity (heat conduction) of slag concrete on the particle size distribution of aggregates

Figure 8. The dependence of the density and thermal conductivity (heat conduction) coefficient of structural and heat-insulating slag concrete on the fraction of the fine fraction

Figure 9. The dependence of thermal conductivity (heat conduction) of concrete
1 - on portland cement; 2- on slag cement

Table 1. The thermal conductivity of compounds at 0 °C

Condition	Compound	Coefficient of thermal conductivity, $W/(m \cdot ^\circ C)$
Crystalline	SiO ₂	9.3
	MgO	38.8
	Al ₂ O ₃	9.1
	CaO	7.98
Vitreous (glassy)	SiO ₂	1.49
	MgO	1.2
	Al ₂ O ₃	0.55
	CaO	0.72

Table 2. The dependence of the coefficient of thermal conductivity of air in closed pores on the pore diameter at 0 °C

Thermal conductivity, $W/(m \cdot ^\circ C)$	Pore diameter, mm					
	Without pore	0.1	0.5	1	2	5
Absolute	0.02	0.022	0.023	0.03	0.03	0.04
Relative	0.92	1.02	1.12	1.14	1.34	1.90