Modifications of lightweight concrete for use in housing construction

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Abstract: The article analyzes the types, methods and characteristics of lightweight concrete modification in order to improve their strength and other characteristics. To substantiate the relevance of the study, the specificity and importance of the use of lightweight concrete in housing construction was determined, the evolution of the use of lightweight concrete in the construction of buildings and structures for various purposes was studied, the main types and characteristic features of lightweight concrete types depending on their composition, specifics of the technology for their production, usage and subsequent operation of structures and elements were examined. The classification of lightweight concrete structure modifiers is developed; their influence on the properties of concrete mixtures is studied.

1. Introduction

Currently, the use of lightweight concrete in the construction of both low-rise and high-rise buildings is becoming increasingly significant. Lightweight concrete is used as an independent structural material for the construction of load-bearing structures of houses and as heat-insulating materials. It is almost impossible to overestimate their importance for modern construction; therefore, for the development of house building, economical lightweight concrete with improved characteristics based on various modifications is needed.

The use of lightweight concrete on porous aggregates as a structural material has been known since ancient times. In particular, in the territory of modern Armenia, ancient structures have survived to the present day, during the construction of their arches and walls lightweight lime-based concrete was used.

It is known that in Italy in the V century hydraulic structures were built on the basis of lightweight concrete by adding crushed and lumpy light aggregate of volcanic origin (tuff or pumice) or artificially prepared (brick) to lime. For example, Pliny proposed mixing 1 part of lime, 2 parts of pozzolan and 1 part of crushed tuff. And such a recipe for several centuries was the only one in the construction of hydraulic structures, since one of the important properties of concrete is the ability to harden not only in air but also under water.

The use of low thermal conductivity of lightweight concrete began much later; approximately in the XIX century, not only monolithic structures, but also individual artificial stones began to be made from them. Initially, lime was used as a binder, but with the development of the chemical industry, it began to be replaced with Portland cement, which made it possible to increase the strength characteristics and hardening speed.
The development of the fuel and metallurgical industries gave impetus to the use of various types of slag as porous aggregates for lightweight concrete. In addition, a serious impetus to the development of construction from lightweight concrete structures was given by the production of concrete mixtures using machines with the subsequent molding of artificial concrete stone.

At the end of the XIX century, Professor H. A. Zhitkevich recommended the use of brick gravel, coke, and slag from boiler furnaces and blast furnaces as porous aggregates for concrete. He also recommended the composition of lightweight concrete and defined the values of their thermal conductivity coefficients. In 1912, Professor H. A. Belelubetskiy proposed walls 45 cm thick made of brick and slag concrete stones. Engineers S. L. Prokhorov and M. N. Smirnov proposed the production of multi-hollow slag concrete stones, which, after they were improved in 1926, were called “peasant” stones. They also began to produce slag concrete stones using a wooden hand machine, which was improved by S. A. Torletsy in 1924.

The beginning of the trends of lightweight cellular concrete modifying based on the introduction in their composition of the porous filler can be attributed to the 1930s. The founder of this direction of concreting development is considered to be B. G. Skramtaev, whose ideas were supported and developed by Professor N. A. Popov, who experimentally proved the effectiveness of this direction. In addition, V.G. Dovzhik, I.N. Akhverdov, A.I. Vaganov, N.P. Bleshchik and others made an invaluable contribution to the development of lightweight concrete technology [1–6].

2. The main types of lightweight concrete used in modern housing construction

Lightweight concretes belong to the group of lightweight materials and are called porous concretes. They are classified quite extensively on the basis of various parameters, while it is necessary to take into account the impossibility of compiling the final version of the classification due to the appearance of new types of porous concrete, for which there is still no clear manufacturing technology, which allows them to be produced only in limited quantities.

Particularly, in accordance with the established ideas and existing practice, porous concrete can be of the following types:

– traditionally, it is recognized that lightweight concrete is concrete based on binding and porous aggregates; the porosity of the material is mainly due to the porous structure of the aggregate grains;
– large-porous (sandless) concrete on porous or dense aggregates is concrete based on a binder and porous or dense (ordinary) aggregate, while the porosity of the material is largely due to pores in the spaces between grains as a result of the low content of small fractions of aggregate;
– porous lightweight concrete is concrete based on binder and porous aggregates, the porosity of which is ensured by both the porous structure of the aggregate grains and the pores in the cementing binding aggregate, formed by introducing foam into the mixture or expanding the mixture with gas-forming additives, or introducing additives involving air into the mixture;
– cellular concrete is concrete made of a ductile fine-grained mixture in which pores are formed as a result of introducing foam into the mixture or swelling of the mixture with the addition of blowing agents [2].

The main types of concrete macrostructure are presented in figure 1.

![Figure 1](image_url)

**Figure 1.** The main types of concrete macrostructure: 1– dense, 2 – dense with porous aggregate, 3 – cellular, 4 – granular, R1 and R2 – strength of concrete components, Rb – average structure strength.
For clarity, the classification of lightweight concrete by type of binder and by type of large porous aggregate is shown in figure 2.

![Classification of Lightweight Concrete](image)

**Figure 2.** Classification of lightweight concrete by type of binder and by type of large porous aggregate.

For porous lightweight concrete, instead of the structure it is allowed to indicate the type of blowing agent in the name of concrete. Depending on which large porous aggregate is used, the following types of lightweight concrete are defined:
- expanded clay concrete (concrete on expanded clay gravel);
- schungizite concrete (concrete on schungizite gravel);
- agloporite concrete (concrete on agloporite crushed stone);
- slag pumice concrete (concrete on slag pumice crushed stone and gravel);
- perlite concrete (concrete on expanded perlite crushed stone, etc.);

From the point of view of application, lightweight concrete based on porous aggregates should be classified as:
- structural, used for the construction of load-bearing walls, so they are subject to increased requirements for strength and resistance to low temperatures;
- thermal insulating, used as an insulator, as well as for the construction of structures, which are subject to increased requirements for thermal insulation;
- structural and thermal insulating intended for the construction of load-bearing walls, ceilings, interior partitions, fences, therefore, they are subject to serious requirements for both strength and thermal insulation.

The pores in lightweight concrete can be filled with either gas or air, so they are respectively called aerated concrete or foam concrete. The classification of blowing agents can be represented in the form of a scheme shown in figure 3.
The process of concrete porization is carried out by introducing into the composition of the previously prepared foam (sandless mixtures) or gas-forming (sand mixtures) or air-entraining additives (mixtures with sand and without sand).

It should be noted that as a result of the analysis of the initial components in the production of light concrete, binders with various hardening methods (air, hydraulic, autoclave) are used, the choice of which is determined by the required concrete grade.

3. Study of possible modifications of lightweight concrete

Modification of the structure of lightweight concrete has now acquired significant proportions due to the need to increase strength and other technical and operational parameters, including reducing costs for production and sale.

Particularly, in comparison with ordinary equal-strength heavy concretes, modified light concretes on average have the following characteristics

- the density is reduced by 20–50%, it can significantly reduce not only the mass of the structures themselves, but the total load of the building or structure on the foundation, as well as reduce the consumption of concrete and reinforcement;
- reduction of levels (upper and lower) of the area of micro crack formation boundary to 25%, which increases the efficiency of prestressing of reinforcement in structures and the ultimate tensile strength of concrete;
- increase the coefficient of dynamic hardening and ultimate deformability in shock loading up to 25%, i.e. increased resilience, which is especially important to ensure the safety of pile heads and the durability of foundation grouts;
- increasing frost resistance by 2–3 grades and water resistance by 1–3 grades, which entails the possibility of increasing the durability and reliability of structures in particular, and buildings in general, improving operational properties;
- a decrease in the thermal conductivity coefficient by more than 3 times, due to which an increase in the heat efficiency of building envelopes and buildings as a whole is achieved;
– increased resistance to fire and ultra-high temperatures by an average of 0.4 hours, which seriously increases the fire resistance of structures in bearing capacity, positively affecting the fire safety of the building [3].

The process of modifying construction materials is carried out to improve their operation properties due to the introduction into their structure of special function additives. In concretes, modifying additives are used, which operating principle is to change the structure through chemical, physical or physical-chemical interaction [4, 8].

For clarity, the classification of modifiers is shown in figure 4. Structural additives contribute to increasing the strength properties of composite materials in concrete, both light and heavy, by reducing strains that can develop under the influence of stresses that arise during operation.

![Modifiers of lightweight concrete classification.](image)

The most used in the production of lightweight concrete are hydraulic binders based on Portland cement clinker, in particular, Portland cement, quick-hardening cement, slag Portland cement, quick-hardening slag Portland cement [4].

The choice of cement brand is necessary based on the conditions of hardening of concrete. In particular, for the production of structural thermal-insulating concrete with heat-moisture steaming, it is necessary to use cements M400 and higher, the cement consumption in the end is up to 380 kg, which entails a significant increase in the cost of the structures under construction. The problem arises of the need to save raw materials, the solution of which is possible by reducing the binder in combination with a decrease in the density of lightweight concrete.

It is possible to solve the above problem when using Portland cement for the production of lightweight concrete, to which slags and ashes are added as having lower thermal conductivity due to the amorphous glassy structure. As a result, an artificial stone made from slag Portland cement will have improved thermotechnical properties; in addition, resistance will increase in aggressive environments.

As analysis has shown, it will reduce cement consumption by about 20–30% due to the binder vibratory grinding. Additional cement vibratory grinding with a wet (with water) or dry method, as well as with additives that contribute to a decrease in the water-holding capacity of cement and water demand, respectively, will significantly improve the uniformity and workability, and hence the formability of the concrete mixture.
The use of plasticizers in the composition of concrete mixture allows for temporary liquefaction of the mixture, but without the need to increase the consumption of binder and water. It has been experimentally determined that when adding to the mixture up to 3% of the cement mass of superplasticizers in equal plastic mixtures, water consumption decreases to 30%, and cement consumption – up to 20%.

As a result of adding various hydrophobizing silicone additives in liquid form and a number of other chemical additives to the concrete mixture, its plasticizing properties increase and, as a result, not only water demand is reduced by 12%, but also cement consumption is reduced by 5-7%, there is increase in homogeneity, average density, etc. Additives of this property make it possible to modify the structure of a lightweight concrete mixture, which, together with hydrophobization, entails a decrease in capillary suction and water absorption, leading to an increase in frost resistance and durability. The disadvantage of using the above additives is an increase in the hardening time of the concrete mixture [6].

A modification of lightweight concrete is polystyrene concrete, which includes porous polystyrene granules, water, as well as an air-entraining additive as a porous aggregate. The use of this aggregate makes it possible to obtain concrete with an extremely low density in combination with resistance to decay, hydrophobicity, the highest indices of load-bearing characteristics, thermal insulation, fire protection, sound insulation, frost resistance and periods of freezing and thawing, which positively affects the operation life. This type of concrete is characterized by good strength, but at the same time ease of processing.

Lightweight self-compacting concrete is another modification of concrete mixes, and especially of heavy self-compacting concrete. They are made using polyacrylate esters and polycarboxylates, do not require forced compaction during installation without compromising the quality of concrete structures. A feature of lightweight self-compacting concrete is the use of volcanic tuff as a filler (sand with a fraction of 0–5 mm, crushed stone with a fraction of 5-10 mm) with the addition of dense sand, because otherwise, the concrete mixture cannot provide the rheological stability of the concrete mixture, i.e. delamination effect due to the ascent of individual expanded clay grains [7].

To increase the frost resistance of lightweight concrete, it is possible to introduce silicon-organic surface-active additives into the lightweight concrete mixture that affect the reduction of capillary porosity of concrete due to the different water requirements of the applied porous aggregates.

4. Conclusions

As practice shows, the use of lightweight concrete in housing construction allows saving not only time, but a significant amount of money. In addition, being a heat-efficient material, they provide an opportunity to save on heat supply.

The indisputable advantage of such concretes is their fire safety, since, for example, foam concrete with a thickness of 150 mm protects against fire for four hours. Even with a smaller thickness, the material will not burn, split, or emit toxic gases.

Despite the indisputable advantages, lightweight concretes also have drawbacks: abrasion, water absorption, etc., the reduction of their negative impact is possible due to the use of improved concrete based on the use of modifying additives, provided that the requirements for the manufacturing technology, transportation, laying and aging are adhered to.

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