SECTION 2. ARCHITECTURE, CONSTRUCTION

DOI: 10.46299/ISG.2024.MONO.TECH.3.2.1

2.1 Improving the performance of non-autoclaved foam concrete for use in road construction

The process of producing non-autoclaved cellular concrete has come a long way in the course of experimental research, which has helped to achieve the desired parameters of the material's physical and mechanical characteristics. Modern foam concrete can be used both for the manufacture of concrete structures directly at the construction site and for the production of prefabricated elements at landfills and moulding shops, and reinforced concrete product plants [8-13].

The physical and mechanical properties of cellular concrete have clear interrelationships [14-15]. For example, the thermal conductivity coefficient in the dry state depends mainly on the value of the average density, the type of binder, curing conditions, and other factors. The porosity of a material with a cellular structure consists of microporosity and macroporosity. The nature of the porosity of cellular concrete is determined by the spatial arrangement of pores, the distribution of pores by size, the maximum and average pore size, their shape, and the thickness of the interporous partitions [16-17]. Unlike autoclaved foam concrete, non-autoclaved foam concrete has a closed-porous structure, so it is characterised by lower water absorption [18-19].

The quality of foam concrete largely depends not only on the type and consumption of the starting materials, but also on the method of mixing them. To accelerate the hardening of foam concrete, electric heating, fast-setting cements or chemical accelerators can be used [20-21].

It has been established that among the various factors influencing the properties of foamed concrete, the chemical nature of the foaming agents plays a pivotal role [22]. The extensive range of synthetic foaming agents permits their application in foamed concrete technology alongside traditional agents such as resin and others. They are characterized by relatively low cost, storage capability at temperatures ranging from -

5°C to +40°C, and other favorable attributes. Classification based on chemical composition, surface tension, and hydrogen ion concentration has facilitated the scientific substantiation of the relationship between SAS and their stability in foam-mineral systems, contingent upon the chemical composition of the components [23-24].

In order to improve the technology of non-autoclaved building materials, a type of foam concrete "non-autoclaved cellular concrete" was developed, which was obtained by introducing modifying additives into the mixture, allowing to obtain a material structure with evenly distributed air pores by one-stage mixing. This results in a reduction in process moisture content not exceeding 10% and a 1.5-2.0-fold reduction in shrinkage deformations [25-26].

The structure of the inter-pore partitions has a significant impact on frost resistance. The strength of foam concrete of the design class is determined by the strength of the inter-pore walls. The ratio of voids to interstitial walls determines the average density and strength of the finished material. The greater the number of voids and the thinner the pore walls, the lower the density and, consequently, the strength of the material. However, the size, shape, and uniformity of the voids also have a significant impact on the strength of the finished material [27-28].

In the production of non-autoclaved foam concrete in turbulent plants, as well as in plants for the separate preparation of components equipped with a foam generator, three types of pores are observed. The first type is represented by spherical voids of regular shape with dimensions from 0.1 to 2 mm, the so-called "useful voids", which should be the majority. It is these pores that determine the average density, thermal conductivity and strength of the finished material.

The second type includes chaotically located capillary pores of different diameters and lengths, the so-called "harmful voids of the first kind", which significantly increase the water permeability of cement stone, reduce its frost resistance and the strength of the bearing inter-pore partitions. In addition, a significant number of capillary pores move water to neighbouring blocks located above due to the capillary effect.

The third type includes very small pores, the so-called "harmful voids of the second kind", which are characterized mainly by an irregular shape and are located in the interpore walls of the main "useful" voids. They do not play a significant role in reducing the thermal conductivity of the material and reducing its density, but significantly reduce the strength of the material.

Thus, the strength of foam concrete is primarily determined by the strength of the inter-pore partitions. There are several ways to increase the concrete's grade strength. An increase in the proportion of cement results in foam concrete with increased strength. However, this increases its cost, which is economically unprofitable [29-30].

Increased strength is also achieved by reducing the water-cement ratio (W/C). At a W/C of 0.5-0.6, the strength of the finished foam concrete decreases sharply. The dependence of the physical and mechanical properties of the material on the W/C is explained by a significant increase in the volume of capillary pores ("harmful pores of the first type"). Capillary pores significantly weaken the interstitial walls of foam concrete. The higher the water content in the foam concrete solution, the greater the number of capillary pores formed, and the lower the strength and frost resistance of the resulting foam concrete.

Another effective way to increase the strength of the finished foam concrete is to use coarse sand with a reduced modulus. To create a strong inter-pore frame, it is necessary to use sand and its sieving (or other aggregate), the main size of which does not exceed 0.35-0.8 mm. Otherwise, the inert aggregate in the material of the inter-pore walls will turn into an inclusion surrounded by pores, playing no role in increasing the strength of the finished foam concrete material.

The development of technological methods for improving the properties of cellular concrete mixtures based on an in-depth study of the strength properties of qualitative and quantitative parameters of traditional raw materials was covered by the authors in [31, 32]. The results of studies conducted in this area show that optimizing the following factors, such as the chemical and mineralogical composition of aggregates and binders, their dispersion, temperature of the concrete mixture and the environment, create opportunities to increase the compressive strength to 30%.

Research in Ukraine and abroad has shown that non-autoclaved cellular concrete with a density of 400-800 kg/m^3 is characterized by slightly lower compressive strength than autoclaved concrete. Modified non-autoclaved foam concrete, consisting of 5-7% microsilica, is characterized by a strength class equal to that of autoclaved cellular foam concrete. However, its cost due to the high cost of ultrafine microsilica makes it impossible to widely use such foam concrete [33-34].

Thus, the authors of [35-36] proposed to increase the resistance of cellular concrete in humid and slightly aggressive environments by volumetric hydrophobization using bitumen and synthetic resins. At the same time, the effect of additives does not affect the strength properties of cellular concrete, but leads to a significant reduction in shrinkage deformations, thermal conductivity and increased frost resistance, i.e., improved material performance. Chemical additives make it possible to produce non-autoclaved quick-setting fly ash concrete of reduced density.

However, all of the above areas do not solve the main problem of qualitatively improving the properties of cellular concrete: increasing the crack resistance and dramatically increasing the tensile strength, which are the main qualities that make it possible to use this material in road structures.

According to [37-38], a significant increase in tensile strength can be obtained by dispersed reinforcement of cellular concrete with various types of fibers. Dispersed reinforcement of foam concrete allows [39-40] to improve the viscosity and ease of laying mixtures; control the rate of plastic strength gain; improve the capillary-porous structure; reduce their density and thermal conductivity.

A number of experimental and theoretical studies have been devoted to establishing the feasibility of using synthetic fibers as dispersed reinforcement for concrete. In works [41-42], it was found that with dispersed reinforcement of cellular concrete with glass fiber that is resistant to alkaline environments, the compressive strength increases by 30-60%, the tensile strength in flexion increases by two times, and the impact strength increases by 1.5-2 times. Dispersed reinforcement of cellular concrete with asbestos fibers [43] in the amount of 3-5 % by weight increases the tensile strength by 30-50 %, the compressive strength by 20-40 %.

In research related to the strengthening of materials based on mineral binders, two main areas can be distinguished. First, to solve this problem, it is proposed to use special additives that organize the cement stone hardening processes and improve its physical and mechanical properties. According to [44], the use of fibrous crystals of calcium hydrosilicate provides a 2-4-fold increase in flexural strength in concrete. The directed crystallization of neoplasms leads to dispersed self-reinforcement of cement stone due to the formation of oriented crystal hydrates in its volume, which can significantly improve the quality of concrete.

The second direction recommends the use of reinforcing fibers that differ in composition from the matrix material and can perceive higher stresses in the foam concrete body compared to the matrix during the operation of the material [45-46].

The methods of using dispersed reinforcement in cellular concrete provide for the possibility of obtaining a directed and chaotic orientation of fibers in the volume of foam concrete. Dispersed reinforcement can be created by one of the types of fibers - chrysotile asbestos, cellulose, glass, steel, polyethylene, polypropylene, polyamide, or a mixture of different fibers (of different lengths or nature of material).

Studies have established [47-48] that the effectiveness of dispersed concrete reinforcement depends primarily on the ratio of the strength and deformation characteristics of the reinforcing fibers (fiber) and the concrete matrix. If the elastic modulus of the fiber is significantly (3-10 times) higher than the elastic modulus of concrete, then an increase in mechanical strength, crack resistance, and other performance properties of dispersed-reinforced concrete should be expected. If the elastic modulus of the fiber is close to the elastic modulus of concrete or slightly lower, then there will be an increase in the tensile strength of the material while reducing the structural qualities.

Another factor affecting the efficiency of fiber use in concrete materials is the ultimate tensile strength. In [49-50], it is recommended to use fiber, the maximum deformability of which is greater than the maximum deformability of concrete, for dispersed concrete reinforcement. At the same time, with a sufficient amount of volumetric reinforcement with dispersed reinforcement, concrete cracking under the action of maximum loads will show that the moment of failure is approaching. Structures made of such materials become operationally safe, since even with a complete loss of the bearing capacity of the matrix, the fracture does not occur instantaneously, as is the case with brittle materials, but slowly, viscously [51-52].

According to the authors of [53], the propagation rate and size of cracks in concrete are determined by its structural characteristics, which are formed by the properties and structure of the source materials, as well as by technological methods that ensure their interaction and continuity. In concrete, along with a strong brittle base, there must be elastic-viscous inclusions that can dampen the crack growth energy, which leads to material failure. Synthetic dispersed reinforcement is an elastic-viscous component with a margin of plasticity that delays the moment of material fracture [54], and also positively affects the features of structure formation in the process of manufacturing dispersed reinforced foam mixtures using a one-stage technology and their structure formation during the curing period [55-56].

Assessment of the effect of dispersed reinforcement with synthetic fibers on the deformational properties of concrete in [57-58] found that the introduction of polyamide fibers randomly placed in concrete forms a structure whose bending behavior becomes formally similar to that of reinforced concrete. When loading concrete specimens dispersed-reinforced with polyamide fibers, unlike traditional foam concrete, which collapse brittle, three main characteristic stages of change in the stress-strain state were observed.

The first stage is the elastic behavior of the material until cracks form in the stretched zone of the concrete, when the tension is less than the tensile strength of the concrete matrix and the tensile forces are perceived by the dispersed reinforcement and the matrix together. The second stage includes the work of gradual crack accumulation in the stretched zone of fiber foam concrete. The consolidation of primary cracks into a main crack begins at a load 1.6-2.0 times greater than the load for the first crack. The third stage is characterized by intensive opening of the main crack due to the stresses in the dispersed reinforcement reaching its yield strength, and ends with the loss of the bearing capacity of the specimen, but does not lead to fragmentation of the compressed zone of the specimens and their separation into separate parts. The value of the destructive load is 2.5-3.0 times higher than the load corresponding to the first crack.

With dispersed fiber reinforcement of concrete, their maximum tensile strength increases by 9-15% [59], and the increase in flexural strength, depending on technological and formulation features, can reach 550%.

The introduction of dispersed reinforcement contributes to the formation of optimal porosity in concrete, increases the strength and stability of the cellular concrete structure during the initial period of hardening. A significant part of the tensile stresses that occur during the curing process is also absorbed by synthetic reinforcement. In addition, dispersed reinforcement blocks the initial cracks in the deformed material [60], reducing the likelihood of their development into a destructive effect and shifting the realization of this possibility to the region of higher deformations.

Since both the strength and deformation qualities of cellular concrete (ceteris paribus) are determined by the value of their average density, it becomes necessary to determine the rational areas of reinforcement of structural foam concrete. A number of experimental studies have been devoted to determining the optimal degree of saturation of cellular foam concrete with dispersed reinforcement [61-62]. However, these works are mainly devoted to heat-insulating cellular concrete.

The authors in their research [63] found that the use of synthetic fibers is most appropriate in cellular concrete with a density of at least 900 kg/m^3. In this case, qualitative changes in the pore structure of the matrix and a significant increase in frost resistance are observed.

The effectiveness of dispersed polyamide fiber reinforcement in compression of concrete with an average density of 500 to 800 kg/m^3 tends to increase, since the concrete matrix has low strength characteristics. As the strength characteristics of the concrete matrix increase and the strength characteristics of the concrete matrix increase and the grafting strength between the components increases, the effectiveness of dispersed reinforcement also increases.

Despite the fact that the use of fibers in structural foam concrete with an average density of 900 to 1200 kg/m^3 does not significantly increase the strength characteristics of the material, the efficiency of dispersed tensile reinforcement, as established in [64], reaches 2.5-3.5 times.

Taking into account the numerous advantages of non-autoclaved foam concrete, as well as the prospects for its use for building elements designed to withstand bending loads, large-scale construction using this material is currently not observed. The limited use of non-autoclaved foam concrete is due to the lack of a complete set of regulatory and technical documentation and the lack of research that would ensure the design and construction of buildings and structures, including roads, that meet modern requirements.