Water demand management in the production of non-autoclaved foam concrete

Evgeny Vishtorsky, Sergey Bogomolov, Aleksandr Smirnov, Gavakhirat Mutalibova

1 Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Department of Agricultural Construction and Real Estate Expertise, 127434, Moscow, Russian Federation

Abstract. The article deals with the issues of regulation of water consumption of foam concrete mixtures. Theoretical substantiation of the possibility of using various mineral and chemical additives in the production of non-autoclaved foam concrete is carried out. An experimental study of the flowability of non-autoclave foam concrete from mixtures of reduced water content is carried out. It is established that in a water-solid ratio equal to 0.38 the additive "Hemix Art-2" in the amount of 1.1% of cement mass increases the fluidity of foam concrete mixture by 89%. It is obvious that with the use of the additive "Hemix Art-2" reduces the size of the bubbles of the involved air, which gives high plasticity of the foam concrete mixture.

1 Introduction

To increase the strength of foamed concrete, the water-solid ratio is reduced by using plasticisers. Besides, fine-distillation mineral modifiers (microsilica, ash, metakaolin) are used, binder activity is increased, dispersed-fibre additives, setting accelerators are used. Affecting the surface phenomena and microstructure of the mixture, additives allow to control the properties of the concrete mixture and contribute to obtaining its optimal structure [1 - 3]. To reduce shrinkage, binder consumption is reduced and the amount of aggregate is increased.

The water requirement and setting and curing rate of foam concrete depends directly on the dispersibility of Portland cement and fillers [4]. Now commodity cements are produced with specific surface area of 250-350 m²/kg, which results in low setting and hardening rates. Cement grinding fineness should be within the range of 400-500 m²/kg. The cement particle size should not exceed 50 microns. There is also an opinion that for foamed concrete it is most effective to use LWC (low water consumption binder) - finely ground cement with the addition of superplasticiser. The water consumption of foam concrete mixtures is also influenced by the material composition of cement [2].

In addition to the use of highly dispersed cements for the production of foam concrete, there is a proposal to use "extra-class" binders. To such binders it is proposed to include hydraulic binders based on alumina cement, which allow to obtain the yield strength of foam concrete in 4-6 hours when hardening in natural conditions. This is the so-called...
"aluminosulfate-slag" cement. Some researchers [3] believe that cements should be purely clinker - "plasterless", so-called FHB (fast hardening clinker binder), not containing calcium hydrosulfoaluminates. From the analysis of technical literature, it follows that alumina, gypsum-free and highly dispersed grinding cements cannot be recommended for widespread production of foamed concrete for economic reasons (high cost of production of such cements, small volume of its consumption, transport costs, etc.). It is also obvious that it is impossible to recommend one standard type of cement with a certain mineralogical composition, dispersity, setting and curing time for foam concrete production.

The most common aggregate is sand. An important indicator is the particle size distribution, which is assigned according to the average density of foam concrete. The maximum coarse particles should be no more than half the thickness of the interstitial partitions. The selection of a rational ratio between aggregate and binder also has a significant influence on the characteristics of aerated concrete.

The introduction of fly ash from power plants into foamed concrete affects primarily the change in water demand and mobility of the concrete mixture. The effect of fly ash on the water content of the foam concrete mixture is determined by its dispersity, shape and character of the particle surface, as well as mineral-phase composition. When fly ash from a thermal power plant is introduced into foam concrete, consisting of spherical particles with a smooth glazed surface texture, the mobility of the concrete mixture increases due to the reduction of internal friction of the concrete mixture. It is worth noting that the more dispersed the ash is, and as a consequence, the more glazed spherical particles it contains, the greater the plasticising effect of the ash on the foam concrete mix [4-6].

When fly ash, which contains a large number of large aggregate particles with irregular shape, is added, the amount of water in the concrete mix increases. This phenomenon can be explained by the fact that such particles have high water absorption. Grinding of such fly ash particles leads to decrease in porosity and consequently to decrease in water absorption of fly ash [5].

The water uptake of fly ash generally increases with increasing content of unburned fuel residues, which are able to absorb water to a large extent. The unburned fuel is usually predominant in the coarse fraction of ash, the sieving of which results in lower water content. The use of fly ash in foamed concrete results in an increase in the water content of concrete mixes. This phenomenon is due to the fact that even high-quality fly ash has a significant water content (about 46%) compared to the aggregate (sand) (12%). The use of plasticising additives [6] helps to reduce the water content of concrete mixtures using fly ash from thermal power plant.

Reduction of water consumption of concrete mixes by replacing part of cement, which in some cases acts as an aggregate with fly ash from thermal power plant and is determined by the reduction of water-binding ratio (binder: cement + ash). The actual value of water-cement ratio increases. This phenomenon is due to the fact that fly ash reacts directly with water and as a consequence, a large amount of water per unit mass of cement. The higher the water content of fly ash, the more the water-cement ratio increases [7].

Increased value of water cement ratio in concrete containing fly ash deteriorates the structure of concrete, especially at early age. The formation of 0.5-2 μm thick water films around the fly ash particles increases the capillary porosity of concrete, which negatively affects the strength, frost resistance and other main construction and technical properties of concrete. Capillary pores, which are formed by capillary evaporating water, have a favourable effect on the absorption and migration of moisture, which freezes in them from -5 to -9°C. The negative effect of increasing the water-cement ratio is compensated by the increased hydration of cement in the presence of ash, as a result of which the pores are intensively filled with cement hydration products. The increase in cement hydration can be attributed to the fine powder effect, the essence of which is that the ash particles expand the
free space in which cement hydration products are deposited. In addition, ash, by binding calcium hydroxide released during cement hardening into insoluble compounds, reduces its concentration in the aqueous solution of hardening cement mass and thus accelerates the hydrolysis of calcium silicates contained in clinker. Thus, the utilisation of cement in foamed concrete increases in the presence of ash.

The interaction of ash with calcium hydroxide leads to overgrowth of aqueous films around the ash particles with pozzolanic reaction products resulting in reduction of capillary porosity. The more active the ash, the faster this process takes place. Over time, strong bonds are formed between the ash particles and the surrounding concrete stone, the structure of concrete with fly ash is compacted, this leads to an improvement in the physical and mechanical properties of foamed concrete. It is worth noting that neither the involvement of fly ash in the pozzolanic reaction nor more active hydration of cement in the presence of fly ash can overcome the unfavourable effects of increasing water-cement ratio. Even at late age, the capillary porosity in cement-ash compositions is higher than in compositions without fly ash, which entails lower physical and mechanical properties of non-autoclaved foamed concrete with fly ash additives. In order to increase the pore structure properties of foamed concrete with fly ash, it is necessary to introduce additives that will reduce the water consumption of the concrete mixture.

One of the most effective mineral additives is microsilica - a waste product of production of silicon-containing alloys: ferrosilicon, crystalline silicon and others. In the process of production ultra-fine silica particles are formed (0.1...0.5 microns) with the content of 85...98% in the product SiO₂. However, fine powder has a high water consumption (normal density of 40...140%), which requires a significant increase in water consumption in the concrete mixture: in equipotent mixtures for each kilogram of microsilica introduced into the mixture water consumption increases by 1 litre. This is why microsilica is used together with a superplasticiser, which significantly reduces water consumption. At the same time, especially fine mineral additives increase the effectiveness of superplasticisers. The part of the superplasticiser that is adsorbed on the surface of the solid fraction of the concrete mixture has an active effect on the mobility of the concrete mixture, significantly affecting surface interactions and the lubrication effect. The part of superplasticiser that is in aqueous solution in the pores of the system is more passive and only increases the consumption of superplasticiser. Therefore, the introduction of fine fillers reduces the volume of large water pores, increases the specific surface area of the solid phase and thus increases the active part of the superplasticiser and its effect on the system as a whole [8].

The positive influence of plasticising additives is known, which increase the strength characteristics of concrete when the water content in concrete mixtures is reduced. Even when introduced into the mortar mix in small quantities, these additives have a significant effect on the processes of cement hydration, which affects the properties of foamed concrete mixes and foamed concrete.

Introduction of plasticisers into the mortar mixture contributes to the change of water of solvate shells of particles of newly formed cement. At adsorption of surfactants on the surface of solid phase the volume of water in solvate shells decreases, and the volume of free water increases. This leads to an improvement in the rheology of the mixture, but slows down the hardening of cement [9]. In foamed concrete production technology, the use of plasticisers is limited due to their negative effect on foam durability.

When water interacts with cement, its grains partially stick together, forming flocules and not having time to react with water. Flocules of cement grains accelerate sedimentation, i.e., the disperse system becomes aggregate and sedimentation-unstable. Plasticiser additives are cement deflocculants, i.e., they break cement aggregates into smaller components, thus increasing the efficiency of cement utilisation and the stability of the dispersed system itself.
2 Research results

An important factor in obtaining non-autoclaved foam concrete from mixtures of reduced water content is the use of water-reducing additives in its composition. It is known that water-reducing additives increase strength characteristics of concrete when water content in concrete mixtures is reduced. Even when introduced into the mortar mixture in small quantities, these additives have a significant effect on the processes of cement hydration, which also affects the properties of foam concrete mixtures and foamed concrete. Compositions of porous cement stone per 1 m³ are given in Table 1.

<table>
<thead>
<tr>
<th>Composition group</th>
<th>Composition no.</th>
<th>Water-solid ratio (W/S)</th>
<th>Fluidity, cm</th>
<th>Density kg/m³</th>
<th>Strength at 28 days, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.42</td>
<td>19.5</td>
<td>11</td>
<td>686</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.65% Hemix Art-2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>0.5% UP-2 + 1% CN</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>0.05% Sika + 1% CN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.42</td>
<td>14.5</td>
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<td>15.5</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>0.38</td>
<td>16.5</td>
<td>12.2</td>
<td></td>
</tr>
</tbody>
</table>

In composition No.2 of group A and B, there is no curing accelerator, because the content of water-reducing admixture "Hemix Art-2" has no negative effect on setting time and formation of porous structure.

Figures 1 - 3 show the flowability of foam concrete mixtures with the use of water-reducing additives of different chemical action at W/S from 0.42 to 0.38.

**Fig. 1.** Flowability of foam concrete mixtures of group A at W/S equal to 0.42
The introduction of water-reducing additives into the mortar mixture favours the change of water in the solvate shells of the particles of newly formed cement. When the surfactant adsorbs on the surface of the solid phase, the volume of water in the solvate shells decreases and the volume of free water increases. This leads to an improvement in the rheology of the mixture, but slows down the hardening of the cement.

At a water-solid ratio equal to 0.42 (Fig. 1) with the use of the water-reducing additive "Hemix Art-2" in the amount of 0.65% of cement weight, the flowability of the foam concrete mixture increased by 32%, the composition with the additive "Sika Mix Plus" in the amount of 0.05% of cement weight - by 27%. The composition with the additive "Fort UP-2" in the amount of 0.5% of cement mass practically did not affect the flowability of the mixture in comparison with the control composition.

With reducing the water-solid ratio to 0.4 (Fig. 2) and increasing the consumption of the additive "Hemix Art-2" up to 0.85% of cement weight, the fluidity of the mixture increased by 52%, the composition with the additive "Sika Mix Plus" by 23%. The composition with the additive "Fort UP-2" in the amount of 0.6% increased the fluidity of the mixture by 13%.

At water-solid ratio equal to 0.38 (Fig. 3) the additive "Hemix Art-2" in the amount of 1.1% of cement weight increases the flowability of foam concrete mixture by 89%. It is obvious that with the use of the additive "Hemix Art-2" reduces the size of the bubbles of the involved air, which gives high plasticity of the foam concrete mixture. With the use of additives "Sika Mix Plus" and "Fort UP-2", the flowability of the obtained mixtures is increased by 26% in comparison with the control composition.
References


