

INCREASING THE DURABILITY OF EXPANDED CLAY LIGHTWEIGHT CONCRETES FOR THIN-WALLED HYDRAULIC ENGINEERING STRUCTURES

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INTRODUCTION

Thin-walled construction is used in many types of hydraulic engineering structures (floating structures, channel walls, quay walls, pumping stations etc.). Heavy concretes were mainly used for such structures previously. Since recent times, lightweight aggregate concrete has been used for thin-walled structures. Modified expanded clay lightweight concrete has a relatively low bulk density with high strength and durability [1]. It can be used for thin-walled hydraulic engineering structures, such as floating docks, houses and hotels.

In the course of the study the influence of the expanded clay lightweight concrete composition on its properties has been found. First stage of the study investigated the lightweight concrete processed by the hydrophobized gravel. Second stage studied the concretes with the use of silica fume. High-quality concrete has been obtained.

1. PROBLEM FORMULATION

Expanded clay lightweight concrete is known to have strength higher than that of the expanded clay. Positive effect of porous fillers can be often explained by self-vacuating [2]. They act as "pumps" that take water from the cement paste. As a result of a porous filler action we obtain compacted cement paste. Moisture that has been accumulated in the filler grains is later yielded to the cement paste. This moisture from the filler improves the cement hydration process. The concrete using the porous filler is less prone to sedimentation than concrete based on granite crushed stone. This is conditioned to self-vacuating process as well. According to [3], self-vacuating process also increases the chemical resistance of concrete. For this reason, the recommendation for developing the facilities/structures in an aggressive environment is to use fillers with high capillary water absorption.

Also, concrete with porous aggregates has high frost resistance [1].

For example, many years of experience in the shipbuilding domain proved that expanded clay lightweight concrete is effective for thin-walled structures [4]. There is a positive experience in using the lightweight aggregate concrete for constructing the thin-walled structures of the floating docks at Pallada State Shipbuilding Plant in Kherson (Ukraine) [5].

However, concretes based on porous aggregates have high W/C. Therefore, a significant interest represents the study of porous gravel hydrophobic property to reduce W/C in the concrete mixture.

Fiber concretes are also widely used in thin-walled engineering structures. Therefore, there is an important study of the effectiveness of using the dispersed reinforcement in expanded clay concretes.

2. RESEARCH METHODOLOGY

Studies of the expanded clay lightweight concrete properties were conducted using the experimental design techniques [6]. The following materials were used: grade M400 sulphate-resistant portland cement, expanded clay gravel of the 5-10 mm fraction, quartz sand with 2.7 fineness modulus, S-3 superplasticizer, Penetron Admix bridging agent, 136-157M silicon-organic fluid, Baucon polypropylene fiber (18.7 μm diameter, and 12 mm fiber length), and silica fume.

At the first stage, 5-factor experiment was conducted in accordance with the 27-point optimal plan [7]. The following factors had variable compositions:

X_1 – portland cement, from 400 to 600 kg/m^3 ;

X_2 – concentration of the silicone-organic fluid in the emulsion during processing of gravel, from 0 to 1.6%;

X_3 – addition of Penetron Admix, 0 to 2% of the cement weight;

X_4 – S-3 superplasticizer, from 0.5 to 0.9% of the cement weight;

X_5 – fibers, from 0 to 1.2 kg/m³.

Hydrophobized gravel was obtained by dipping into the silicone-organic fluid emulsion. All concrete mixes had mobility equaling to 2 ± 0.5 cm.

At the second stage, 3-factor experiment was conducted in accordance with the 15-point optimal plan. The following factors had variable compositions:

X_1 – portland cement, from 500 to 600 kg/m³;

X_2 – silica fume, from 0 to 50 kg/m³;

X_3 – S-3 superplasticizer, from 0.5 to 1% of the cement weight.

All concrete mixes had mobility equaling to 3 ± 1 cm.

3. RESULTS AND DISCUSSION

As a result of the study, complex experimental and statistical models were obtained. The analysis of these models (the first stage of studies) shows that increasing the amount of portland cement and S-3 superplasticizer reduces the water content of the mixture. Introduction of Penetron Admix additive does not affect the W/C, and the use of fiber significantly increases the W/C. Hydrophobized gravel reduces the W/C in the concrete mixtures by 10-20% due to the reduction of water absorption by lightweight aggregate.

Introduction of Penetron Admix and fiber has little effect on the compressive strength of expanded clay lightweight concrete. Effect of an amount of the portland cement, S-3 superplasticizer and the concentration of the silicone-organic fluid in the processing gravel is shown in Figure 1.

The diagram shows that the highest strength will have that lightweight concrete, into which S-3 superplasticizer in the 0.7-0.8% concentration is added. Hydrophobized gravel, at the 0.7-0.8% concentration of the silicone-organic fluid, increases the strength of expanded clay lightweight concrete. Increasing the concentration of the silicone-organic fluid in excess of 0.8% will have a negative effect as the filler adhesion to the matrix will deteriorate.

Water resistance of the concrete is one of the main indicators of the quality of the thin-walled structures. It was found that introduction of the fibers would have a little effect on water resistance of the expanded clay lightweight concrete. Effectiveness of the introduction of Penetron Admix additives is large and it is approximately equal for all compositions. Introduction of 2% Penetron Admix improves the water resistance of concrete by around 2 atmospheres.

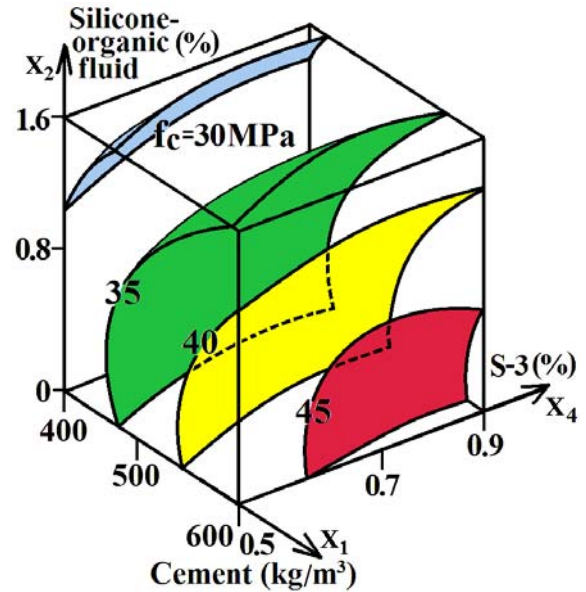


Figure 1. Effect of the amount of the portland cement, S-3 superplasticizer and the concentration of silicone-organic fluid on the strength of expanded clay lightweight concrete (the first stage of studies); $x_3=x_5=0$

Figure 2 diagram shows the influence of portland cement, S-3 superplasticizer and the concentration of the silicone-organic fluid used for processing of the gravel on the water resistance of concrete. When plotting the chart, we accepted that amount of Penetron Admix additives would be 2% of the cement weight ($x_3=1$).

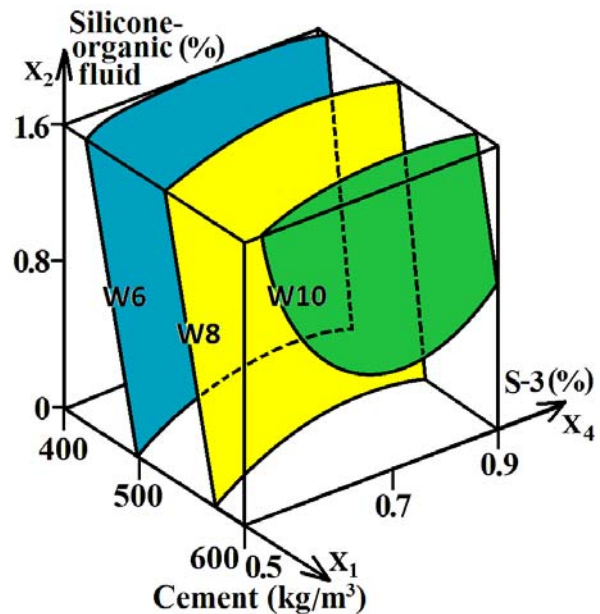


Figure 2. Effect of the amount of the portland cement, S-3 superplasticizer and the concentration of silicone-organic fluid on water resistance of expanded clay lightweight concrete (the first stage of studies); $x_3=1, x_5=0$

The diagram shows that if the volume weight of the portland cement is under 500 kg/m^3 , water resistance of the expanded clay lightweight concrete will be from W4 to W6. Compounds where amount of the portland cement is 500 kg/m^3 and concentration of the fluid used for obtaining the hydrophobized gravel is about 0.8%, will have water resistance from W6 to W8. When the amount of cement is 600 kg/m^3 , water resistance of the concrete is not less than W8. Compositions where the amount of S-3 superplasticizer is 0.7-0.9% of the weight will have maximum water resistance up to W10.

Frost resistance is an important quality indicator for the durability of thin-walled concrete structures. Research has shown that expanded clay lightweight concrete using at least 500 kg/m^3 of the portland cement will have frost resistance not worse than F450. Integral waterproofing increased frost resistance of the expanded clay lightweight concrete by 50-100 cycles, and introduction of the fibers increased it by 50 more cycles. Frost resistance of the fiber-modified expanded clay lightweight concrete reaches F600 degree.

Second stage investigated the influence of silica fume on the properties of expanded clay lightweight concrete. The use of silica fume is one of the promising areas for high-quality cement composite technology [8]. Silica fume reduces the volume changes in concrete, thereby reducing the number of micro-cracks [9]. This additive increases strength and water-resistance of concrete. However, the use of silica fume requires increasing the W/C ratio in the mixture. Because of this, silica fume is used effectively with the superplasticizer only [10].

The diagrams in the form of cubes were plotted in accordance with the experimental and statistical model of the second stage of studies. These charts (Figure 3) show the influence of factors on the strength of the lightweight concrete.

The diagram shows that strength of the expanded clay lightweight concrete rises with the increase of the amount of the portland cement. In case the amount of S-3 additive is increased to 0.8-1% and, thus, the W/C is decreased, the concrete compressive strength is increased by 2-2.5 MPa. Introduction of $30\text{-}35 \text{ kg/m}^3$ of silica fume increases the compressive strength of concrete to 2 MPa in average. This effect is not significant, but the main goal of the introduction of silica fume was to increase water resistance and durability of concrete. An important point is that expanded clay lightweight concrete has high tensile strength as well. So, this type of concrete is effective for thin-walled structures.

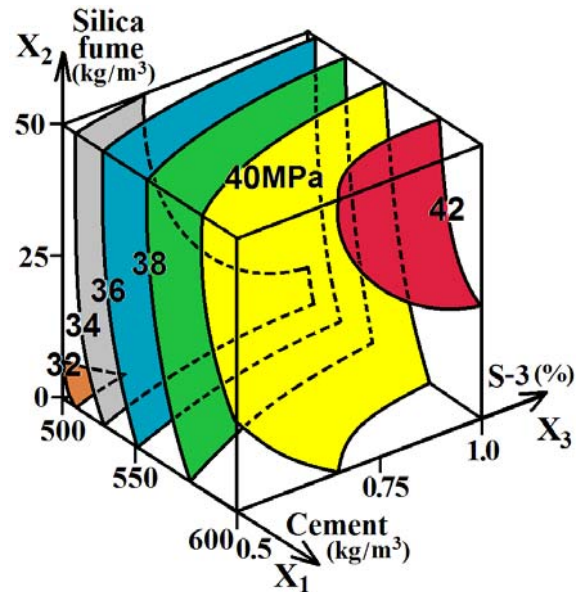


Figure 3. Effect of the amount of the portland cement, silica fume and S-3 superplasticizer on the strength of expanded clay lightweight concrete (the second stage of studies)

What has been also studied is water resistance of the expanded clay lightweight concrete. Figure 4 diagram shows the influence of the composition factors on water resistance of concrete with silica fume.

Figure 4 diagram shows that amount of the portland cement most significantly affects the concrete water resistance degree. Introduction of $30\text{-}35 \text{ kg/m}^3$ of silica fume to the concrete increases water resistance by more than 2 atmospheres. By increasing the amount of S-3 superplasticizer from 0.5 to 0.9%, the concrete resistance will increase almost by 2 atmospheres. Highest water resistance of the expanded clay lightweight concrete was larger than W12.

Due to the use of lightweight concrete, weight of the concrete engineering structures is reduced. Average density of the expanded clay lightweight concrete in a dry condition varies from 1600 to 1700 kg/m^3 . Average density of the concrete after water saturation falls within the range from 1750 to 1900 kg/m^3 . Such density of the concrete complies with the industry standard. Frost resistance of the modified expanded clay lightweight concrete with $30\text{-}35 \text{ kg/m}^3$ of silica fume is within the range from F500 to F600.

Therefore, modified expanded clay lightweight concrete can be used for the thin-walled engineering structures. Optimal compositions of shipbuilding expanded clay lightweight concrete have been selected. Technological methods of the production and use of expanded clay lightweight concrete were

developed for thin-walled floating hydraulic engineering structures. *Regulations on the Preparation of Modified Shipbuilding Technologies for the Fabrication of Thin-Walled Expanded Clay Lightweight Concrete Floating Structures and Floating Docks* were developed by and approved at Pallada State Shipbuilding Plant.

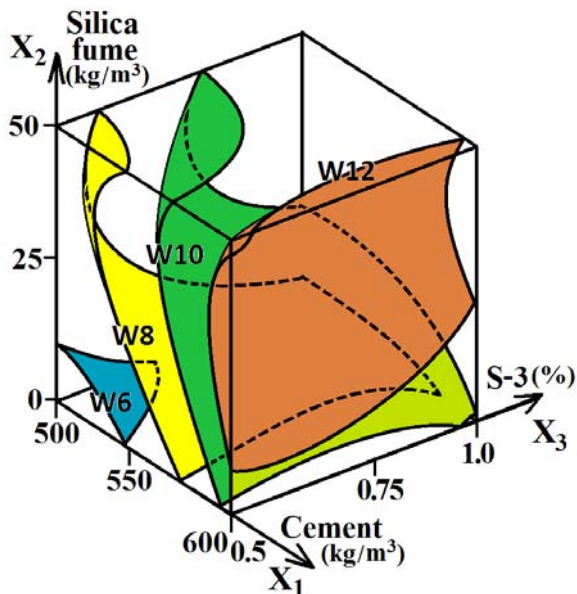


Figure 4. Effect of the amount of the portland cement, silica fume and S-3 superplasticizer on water resistance of the expanded clay lightweight concrete (the second stage of studies)

4. CONCLUSIONS

Compressive strength of the expanded clay lightweight concrete falls within the range of 30 to 43 MPa. Water resistance of the modified concrete was in the range from W6 to W12. Frost resistance of the modified expanded clay lightweight concrete was in the range from F500 to F600. Hence, the modified expanded clay lightweight concrete can be effectively used for construction of thin-walled hydraulic engineering structures (floating docks, hotels, houses, marinas, oil platforms, channel walls, quay walls, pumping stations and others). Optimal compositions of the shipbuilding expanded clay lightweight concrete have been selected. These compositions ensure high durability of the concrete. *Regulations on the Preparation of Modified Shipbuilding Technologies for the Fabrication of Thin-Walled Expanded Clay Lightweight Concrete Floating Structures and Floating Docks* have been developed and approved.

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