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Original scientific paper

MODIFIED EXPANDED CLAY LIGHTWEIGHT CONCRETES FOR THIN-WALLED REINFORCED CONCRETE FLOATING STRUCTURES

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Abstract: Reinforced concrete floating structures have much more durable metal structures and do not require frequent repairs. Heavy and lightweight shipbuilding concrete is used for these structures. Floating structures are operated in difficult climatic conditions. Properties of modified expanded clay concrete for thin-walled reinforced floating structures were investigated. The experiment was carried out according to the 3-factor optimal plan. Concretes with the strength of up to 43 Mpa, with water resistance up to W12 and the average density of up to 1750 kg/m^3 were obtained. Due to the use of expanded clay lightweight concrete, the carrying capacity of a ship, in particular, the floating dock, is increasing, and the comfort of people and technological equipment is increasing. Regulations for the technology of manufacturing modified shipbuilding expanded clay lightweight concrete for the construction of thin-walled floating structures and floating docks were developed and approved. The results of the research were used in the development of the national standard of Ukraine "Shipbuilding Concrete".

Keywords: expanded clay; floating structures; lightweight concrete; plasticizer; silica fume; water resistance

1 INTRODUCTION

Reinforced concrete has been used to build ships for more than a hundred years. Nowadays, parking floating structures are mainly built from reinforced concrete: docks, wharves, pontoons, houses, hotels and oil platforms. Floating structures are operated in difficult climatic conditions. They are exposed to water, freezing and thawing, sulfate corrosion, and dynamic impacts. Concrete floating structures are much more durable then metal structures and do not require frequent repairs [1].

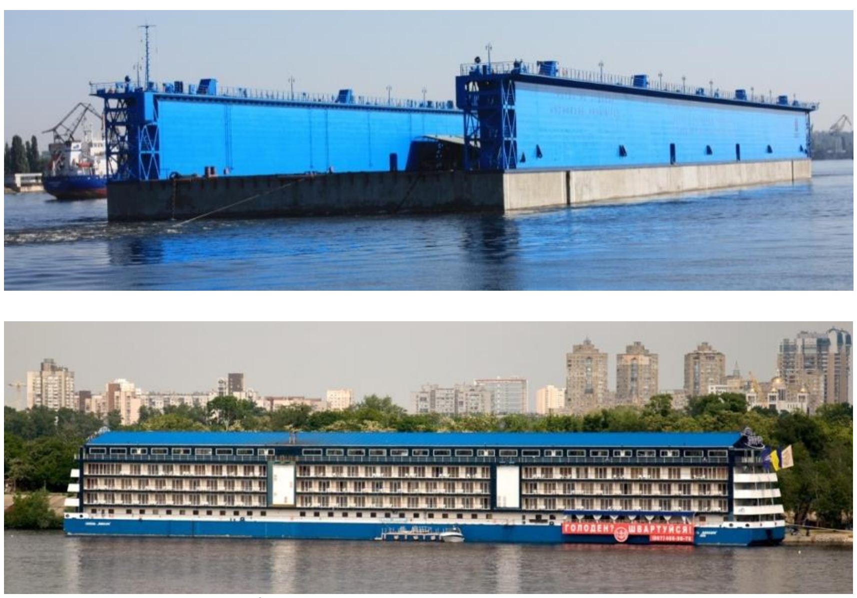

Figure 1 Floating dock and hotel with reinforced concrete pontoons. These structures were built at Kherson state plant "Palada".

Heavy and lightweight shipbuilding concrete is used for reinforced concrete floating structures. The main type of lightweight ship-building concrete is high-strength expanded clay concrete. Through the use of expanded clay weight construction is reduced. Reducing the weight of structures increases the carrying capacity of the floating structure. Morover, the use of lightweight concrete improves the working conditions of equipment and people on a reinforced concrete vessel. In particular, light concrete class LC-60 constructed "Heidun" floating oil platform. This platform operates in the Norwegian sector of the North Sea [2]. Concrete with porous aggregates has shown excellent durability in the harsh operating conditions in waters with sulfates and chlorides. Also, concrete with porous aggregates has a high frost resistance [3]. The first arctic floating structure made of concrete with porous aggregates is the caisson Tarsiut Island in the Beaufort Sea (Canada). It was built for extraction of sand in 1982 and is still in operation [4]. Positive experience was gained in the construction of lightweight aggregate concrete floating docks in Ukraine at the reinforced concrete shipbuilding Kherson state plant "Palada" (Kherson) [5]. Fig. 1 shows a floating dock and hotel with reinforced concrete pontoons. These structures were built at Kherson state plant "Palada".

Different types of modifiers are used to improve the durability of shipbuilding concretes. Most often, plasticizers, colmatizing additives and active fillers are used. Silica fume is one of the most commonly used modifiers of shipbuilding concretes. It is also important than the silica fume is produced in Ukraine. Accordingly, the study of the properties and durability of modified expanded clay lightweight concrete for thin-walled reinforced concrete floating structures is relevant.

2 MATERIALS AND METHODS

Studies of the shipbuilding expanded clay concrete properties were conducted using the methods of planning the experiment [6]. The experiment was carried out according to the 3-factor 15-point optimal plan.

The following materials were used: sulfate-resistant Portland cement M400, expanded clay gravel fractions 5-10 mm, quartz sand with fineness modulus 2.7, additive superplasticizer S-3 and silica fume. The following factors had varied compositions: x_1 – sulphate-resistant Portland cement, from 500 to 600 kg/m^3; x_2 – silica fume, from 0 to 50 kg/m^3; x_3 – additive S-3, from 0.5 to 1 % of cement weight. All expanded clay lightweight concrete mixes have mobility equal 3 ± 1 cm.

3 RESULTS AND DISCUSSION

As noted above, all the mixtures had an equal mobility of 4 to 6 cm. Therefore, *W/C* ratio of mixtures depended on the composition of expanded clay concrete. According to data obtained at 15 experimental points, an experimental statistical model of the influence of composition factors on the *W/C* was constructed:

$$W/C = 0.318 - 0.025x_1 + 0.012x_2 - 0.032x_3 + 0.022x_1^2 + 0.021x_2^2 + 0.009x_3^2 + 0.007x_1x_3 \quad (1)$$

According to the model (1), a diagram in the form of a cube was constructed, which is shown in Fig. 2. The analysis of the diagram shows that an increase in the amount of Portland cement and the addition of S-3 reduces the *W/C* mixture. With the introduction of silica fume in an amount of up to 30 kg/m^3, the concrete mixture *W/C* varies insignificantly. Increasing the amount of silica fume to 50 kg/m^3 necessitates an increase in the *W/C* or an increase in the amount of the additive S-3 to stabilize the mobility of the mixture.

Fig. 3 shows a diagram that shows the effect of the composition on the compression strength of concrete. This diagram is constructed from a similar (1) experimental-statistical model. The analysis of the diagram shows that the compressive strength of concrete is in the range of 32 to 43 MPa. By increasing the amount of Portland cement expanded clay lightweight concrete strength increases. Addition of 30-35 kg/m^3 of silica fume increase the compressive strength of concrete at average of 2 MPa. This effect is not significant, but the main goal was the addition of silica fume increase water resistance and durability of concrete. With the increasing amount of additive S-3 to 0.8-1 % by reducing the mixture W/C concrete compressive strength is increased by 2-2.5 MPa.

Importantly, expanded clay lightweight concrete has high tensile strength compared with the heavy concrete compressive strength equal. The tested concretes had tensile strength at flexure in the range from 5.6 to 7.0 MPa. This expanded clay lightweight concrete is effective for thin-walled structures.

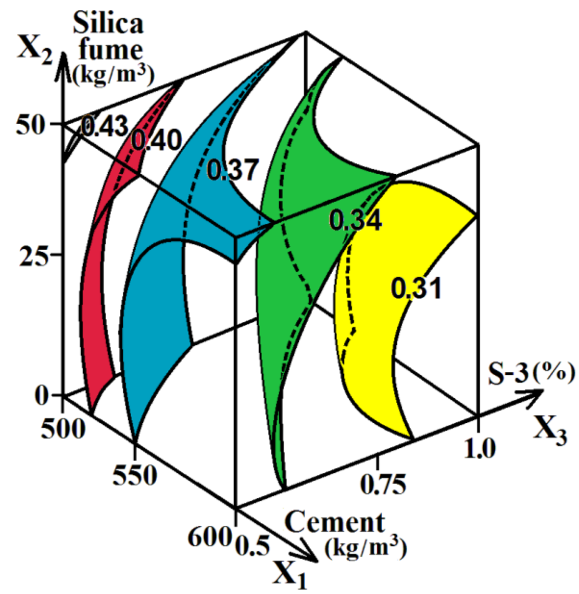

Figure 2 Effect expanded clay concrete composition on the *W/C* mixture.

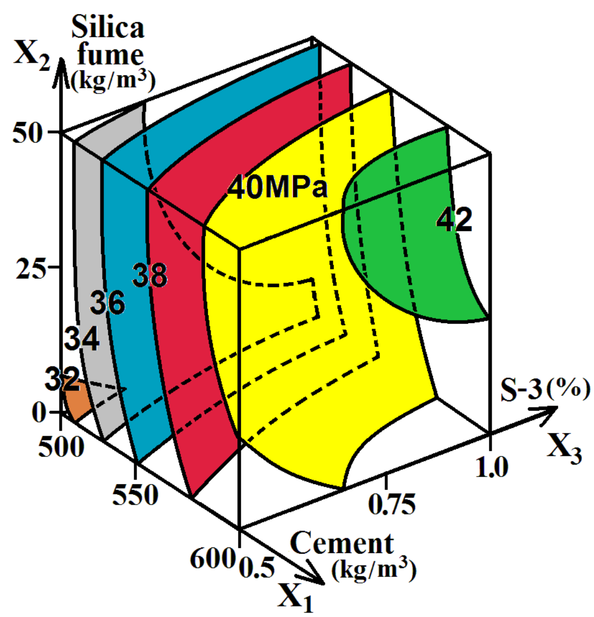

Figure 3 Effect of composition on the compression strength of expanded clay concrete.

Moreover, the water resistance of concrete was investigated. This quality score is very important for concrete floating structures. Water resistance determines the durability of reinforced concrete structures in water. The diagram in Fig. 4 shows the effect of composition factors on the water resistance of concrete.

As it can be seen from the diagram, the amount of Portland cement most significantly affects the level of water resistance concrete. In addition, 30-35 kg/m^3 silica fume concrete increases the water resistance of more than 2 atmospheres. By increasing the amount of superplasticizer S-3 from 0.5 to 0.9 %, the resistance of concrete increases by almost 2 atmospheres. Maximum water resistance was W12. This level of water resistance ensures the durability of concrete.

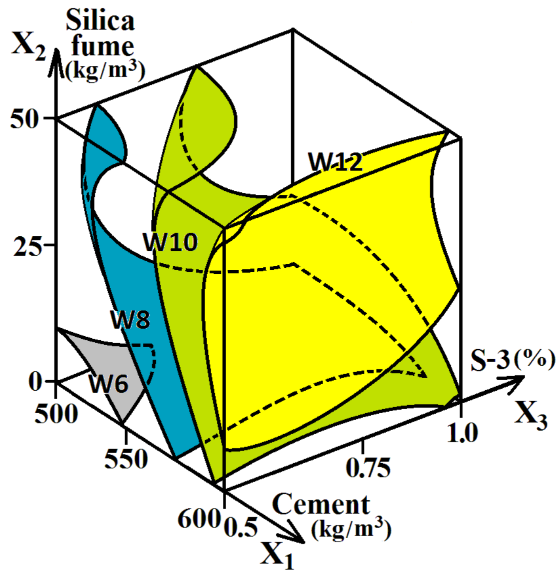

Figure 4 Effect of composition on the water resistance of expanded clay concrete.

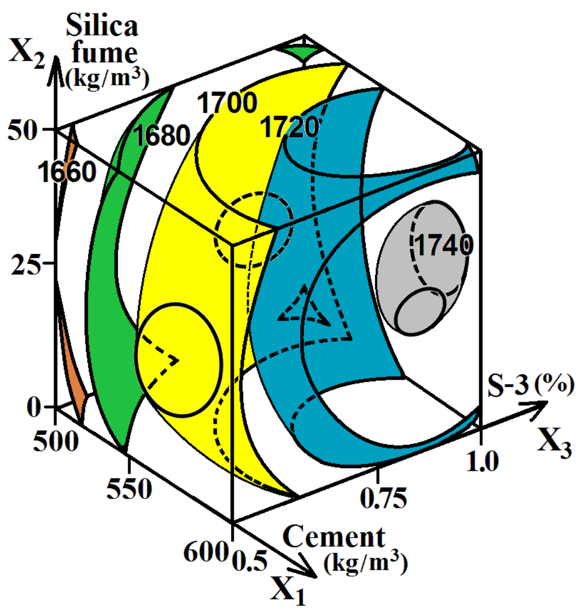

Figure 5 Effect of composition on the average density of expanded clay concrete.

Due to the use of lightweight concrete, the weight of the structures is reduced. This increases the carrying capacity of reinforced concrete floating structures, including floating docks. Fig. 5 is a diagram which shows the effect of the composition on the average density of the concrete in a dry state. As can be seen in the diagram, the density of expanded clay concrete in a dry state was from 1640 to 1750 kg/m^3. The amount of cement and superplasticizer S-3 most significantly affects the density of concrete. Also, the density increases with the addition of silica fume in an amount of 30-35 kg/m^3. It can be concluded that denser concrete had higher strength. After saturation with water, the average density was from 1750 to 1900 kg/m^3. This density corresponds to industrial shipbuilding standards. It was also found that modified shipbuilding concretes had frost resistance of F500 or more.

Therefore, modified expanded clay lightweight concrete complies with Maritime Register and can be used for the thin-walled floating structures. Optimal compositions of shipbuilding expanded clay lightweight concrete have been selected [7]. Technological methods of the production and the use of expanded clay lightweight concrete were developed for thin-walled floating hydraulic engineering structures. The regulations for the technology of manufacturing modified shipbuilding expanded clay lightweight concrete for the construction of thin-walled floating structures and floating docks were developed and approved at State shipbuilding plant "Pallada". Moreover, the results of the research were used in the development of the national standard of Ukraine "Shipbuilding Concrete".

4 CONCLUSION

The compressive strength of shipbuilding expanded clay lightweight concrete is in the range of 32 to 43 MPa. The tensile strength of concrete was in the range of 5.6 to 7.0 MPa. The water resistance of the modified concrete was in the range of W6 to W12, and the average density was from 1640 to 1750 kg/m3. Therefore, modified expanded clay lightweight concrete complies with Maritime Register and can be used for the construction of floating docks, hotels, houses, marinas, oil platforms and other floating structures. The replacement of heavy shipbuilding concrete with expanded clay lightweight concrete increases load-carrying capacity of a ship, in particular a floating dock, and increases people's comfort and technological equipment. In addition, lightweight shipbuilding concrete has high durability.

Note: This investigation was presented at the International Conference MATRIB 2017 (29. 6. - 2. 7. 2017, Vela Luka, Croatia).

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