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Modified concrete for producing pile foundations

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Keywords: modified concrete; additives; reinforced concrete pile foundations; resistance to corrosive environments; sulfate corrosion; water-tightness; concrete durability; ground water.

Abstract. There are considered the issues of structural modification of heavy concrete with oligomer-polymer additives. It has been established that crystallization of the cement stone proceeds at macro- and micro-levels. Macro-pores are filled with products of crystallization of cement particles grafted on the surface of polyvinyl chloride (PVC) macromolecules. The migration of PVC macromolecules and oligomers of the waste of coke-chemical production (WCP) into defective zones is due to the occurrence of internal stresses during hardening and volumetric compression which causes the closure of macro- and micro-pores, as well as cracks and capillaries. Thus, for the complex of physical and mechanical properties, resistance to sulfate corrosion and frost resistance the studied concrete based on structurally modified concrete can be used for producing pile foundations arranged in conditions of highly saline soils. The presented results of experimental studies indicate sufficient corrosion resistance of the concrete under study.

1. Introduction

The destruction of reinforced concrete structures depends on characteristics of the raw materials that form concrete. Therefore, concrete resistance to corrosion can be increased by reducing the ratio between water and cement, as well as the use of various modifiers [1–5]. In the field of developing and using modifiers there has been widely used the method of regulating the structure of concrete in order to increase its strength, cement hardening speed, increasing resistance to various aggressive media, etc.

Structural modification leads to increasing strength characteristics of concrete density, reducing water absorption and, as a consequence, chemical resistance of cement stone

There are a number of classification systems for cement and concrete modifiers. P.A. Rebinder [6] proposed to classify additives of surfactants according to the mechanism of their action. As it is known, all surfactants are divided into ionic and non-ionic compounds according to their ability to form ions in a viscous medium.

At present by the functionality of the modifier there are distinguished regulators of cement hardening speed, water repellent agents and plasticizers [7–9].

To obtain concrete with given structural and technological properties it is required to determine the functional area of modifiers and regularities of their impact on the parameters of cement systems at the stage of forming the cement stone structure. In this connection the development of the concrete composition, the study of the mechanism of the functional modifiers effect during hydration are of great importance.

Durability of concrete for foundations is mainly determined by the chemical composition of soils in the region of erection. Soil salinity is a characteristic feature of the regions with the arid climate, where the processes of evaporation of water prevail over the processes of infiltration.

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These regions include western regions of Kazakhstan (the Atyrau and Mangystau regions, especially the Caspian and Aral territories), where salinity reaches 100–150 mg/l. The maximum content of readily soluble salts in the Western region of Kazakhstan is 5–10 %, insoluble 65–70 % and carbonates up to 60 %.

Saline soils are found everywhere in Kazakhstan and occupy 65–70 % of its entire territory. Due to salinity of the soils of Central and Western Kazakhstan there is a need of increasing resistance of foundations to aggressive environments. In this regard pile foundations built in water-saturated, saline and problem ground conditions should be manufactured with high corrosion resistance, frost resistance and reliable experimental properties, taking into account characteristics of the water-aggressive operating environment [10–13].

Present day ideas of forming the structure of concrete and giving them the greatest resistance to aggressive media, as well as ways of increasing corrosion resistance of concrete were considered in [14–17].

The purpose of this work is obtaining structural modifiers of concrete that increase corrosion resistance of pile reinforced concrete foundations in conditions of saline soils.

There have been studied the mechanisms of cement stone structuring depending on the process of the structure formation, which takes place during cement hardening (forming the macro- and microstructure of concrete), the impact of structural modifiers on the concrete mixture and cured concrete properties.

The obtained materials are recommended for producing pile foundations and their operation in highly saline soils of Western and Central Kazakhstan [18–20].

2. Methods

It is well known that strength of concrete depends on various violations in the structure of cement stone that are due to the presence of pores and a defect that have arisen as a result of external force impacts. In this material internal stresses cause destructive processes of forming macro- and micro-cracks and ultra-pores. Due to defects in the crystalline structure of concrete when it is loaded there arise micro-cracks which formation is explained by the presence and movement of dislocations. When concrete is loaded, due to the difference in physical and mechanical properties, the size of the structural components and the presence of defects in the structure of the cement stone there arises the secondary stress field. The intensity of forming micro-cracks is greatly affected by the plasticity of the material in over-stressed micro-volumes.

One of the methods of protecting reinforced concrete structures from sulfate corrosion is strengthening the anticorrosive properties of concrete as a result of using special types of cement increasing the concrete density and introducing additives [21, 22].

At present corrosion resistance of concretes and structures in contact with a highly aggressive water-salt ground environment is provided by a combination of using special types of cement, volumetric water repellent agents, plasticizing additives and surfactants. At this the water-cement ratio decreases, the concrete density increases, while the deformation-strength properties, water resistance, sulfate resistance and resistance to cracking of reinforced concrete structures increase [23].

The present work deals with consideration of the issues related to the mechanisms of cement stone structuring depending on the structure formation that takes place during the cement hardening (forming the macro- and microstructure of concrete).

According to V.M. Moskvin, all three main types of corrosion are related to structuring during the concrete hardening, the concrete components dissolution, the exchange reactions between the components of the cement stone and the aggressive environment and developing internal stresses as a result of accumulation and crystallization of poorly soluble products with increasing the volume of the solid phase [24]. Destruction of concrete in the presence of all three types of corrosion is due to dissolution of hardened cement stone, mass-exchange processes between the cement stone and corrosive environment, the growth of crystals in the pores of concrete during avalanche development of cracks and capillaries during the cement stone hardening, as well as during operation with overlapping cyclic temperature and mechanical effects of the environment.

In this connection it is interesting to regulate the capillary-porous structure of the cement stone during hardening, and to reduce the level of macro-pore formation in the interphase layer of the cement-filler system and cement-reinforcement.

Experimental studies conducted in the laboratory of KSTU found that concrete with high ductility have improved resistance to multiple loads. Thus, resistance of concrete to dynamic loads is determined by the combination of elastic properties of the mortar and coarse aggregate.

So, increasing the mechanical strength of concrete is provided by modifiers that absorb the impact energy and optimize the structure of the cement stone.

3. Results and Discussion

In the work there is proposed a modification of the secondary structure of concrete by introducing oligomer-polymeric additives. The mechanism of structural modification is based on the theory of crystallization of organic polymers in the presence of fillers. It has been taken into account that crystallization of cement proceeds according to the similar mechanism of crystallization of organic polymers: nucleation, formation of a crystallizing systems gel, growing the degree of crystallization, solidification of a solid. Unlike crystallization of organic polymers, crystallization of cement proceeds with isolation of crystallization water from the volume of the cement stone, with formation of a large number of capillaries with the diameter of 2–20 nm that form micro-voids that reduce mechanical strength, frost resistance and aggressive resistance of concretes. By the method of mercury porosimetry it has been found that the volume of micro-pores in real concretes is up to 30 % of the total volume of concrete. According to S.V. Fedosov, the volume of micro- and macro-pores in concrete can be up to 40 %. According to Yu.M. Bazhenov, P.A. Rebinder, and others, formation of macro-pores with dimensions from several hundreds of microns to several mm is associated with the failure to comply with the technology of concrete production and cement properties, as well as the presence of large aggregates and fine fillers in the concrete composition with a high activity of their surface that participate in the forming the structure of cement stone and concrete.

In this regard the regulation of macro- and microstructure of concrete will produce concrete with high resistance to aggressive media, as well as with high strength properties.

Structural modification of concrete based on Portland cement has been performed by introducing structural modifiers into the composition of concrete at the stage of preparing a concrete mass. S.V. Fedosov and S.M. Bazanov [25] divide the process of hardening cement stone into three stages: the first stage is the beginning of hardening or nucleation, the second stage is coagulation or crystal growth and the third stage is formation of monolithic structure or achievement of operational strength. In our opinion, structural modifiers participate in the structure formation at all stages of macrostructure formation in concrete. At the second stages of forming the crystallization structure of the macromolecule of the organic silicon oligomer “Silor” SO, the PVC macromolecules with cement micro-particles are entrained into defective zones. This is due to the low molecular weight of the “Silor” SO and the low effective viscosity of the PVC + “Silor” SO coagulation system: $4–8 \cdot 10^{15}$ Pa·s (water+cement system $\eta = 10^{16}–10^{25}$ Pa·s.). The mobility of the “Silor” SO system manifests itself with the onset of internal hydrostatic pressure (P_{hst}) in the volume of the cement stone and increases with its increase (P_{hst} = 40–60 MPa). At the third stage, due to high internal stresses, the process of displacement of the structural modifier into macro- and micro-pores and capillaries continues. The process of migration of the structural modifier stops with the final filling of the defect volume with growing cement crystals which are formed by the general mechanism of crystallization of cement.

The regulation of macro and microstructure during formation of the concrete structure is performed by introducing into the composition powdered PVC with particle sizes of 100–150 μm and density of 0.5 g/cm^3 and industrial waste of coke-chemical production (WCP) with the density of 1.238–1.254 g/cm^3, the content of resinous substances 37.7–45.4 % and insoluble toluene 42.3–54.6 %, the ash content of which varies within the range of 0.5–4.3 %.

The samples for the study have been obtained by mixing grade 400 Portland cement of the Karaganda cement plant with the estimated amount of quartz sand within 10–15 min. in a ball mill. In the obtained mix there has been introduced 0.5–1.0 wt. % of powdered PVC and mixed within 10 minutes. At the same time there has been prepared the 60 % solution of WCP in water by mixing within 30 minutes at the rotor speed of 45–60 rpm. The sand-cement mix has been closed with water and at the same time there has been introduced the 60 % aqueous WCP solution in the amount of 3–5 mass % of the solid components. The composition was mixed within 20–25 minutes. The water-cement ratio was 0.2–0.3. Formulation of the compositions is shown in Table 1.

Table 1. Formulation of the concrete composition.

No	Concrete composition	Amount, mass %, W/C		
		I	II	III
1	G400 Portland cement	25	30	35
2	Sand	75	70	65
3	PVC	0.5	0.75	1.0
4	WCP	4.5	4.25	4.0
	Total	100	100	100
	W/C ratio	0.2 0.25 0.3	0.25 0.30 0.2	0.30 0.25 0.20

The kinetics of water absorption after aging the samples in the form of a cube of 100x100x100 mm is shown in Figure 1.

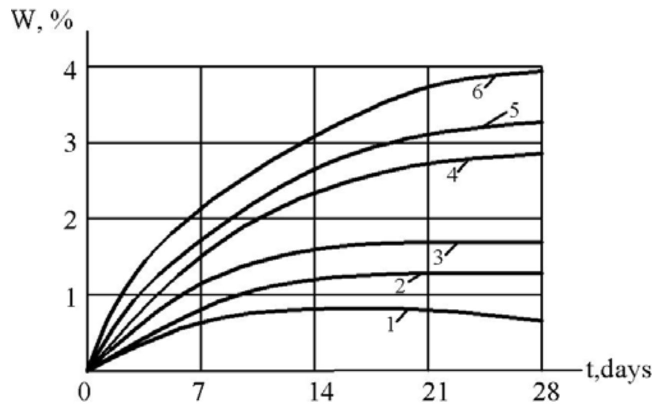

Figure 1. Kinetics of concrete water absorption:
1, 2, 3 – Polyvinylchloride (PVC) content 0.5; 0.75; 1.0 and waste of coke-chemical production 4.5; 4.25; 4.0, respectively: 4, 5, 6 – without additives; W/C – 0.2; 0.25; 0.3, respectively

As it can be seen from the presented data, the content of the complex additive leads to the 2.0–4.0 times reducing of water absorption which indicates decreasing porosity of the concrete. To determine the contribution to the .kinetics of water absorption, macro- and micro-pores there has been studied the structure of concrete on an optical electron microscope with resolution of x1000. The samples of the modified oligomer-polymeric additive did not contain macro-pores with sizes >200 µm as compared to the unmodified ones. The micro-pores of the modified concrete contained an oligomer additive. Macro-pores with sizes of 150–200 microns of concrete, as it has been supposed, at the stage of crystallization, are occupied by PVC macromolecules on which there are grafted Portland cement particles introduced with dry mixing of cement with PVC. After mixing with water, the cement particles grafted onto the PVC surface become new crystallization centers, and the crystal growth proceeds in the macro-pores volume. Migration of PVC macromolecules into macro-voids in the area of coverage of the filler (sand) contour is due to the difference in the PVC density and hardening concrete from the moment of coagulation to the formation of the crystallization structure. Apparently, the kinetics of crystallization of cement in the concrete mixture and in the macro-pores volume proceeds at different rates which explains the migration of WCP to the region of cracks and capillaries. The occupying of macro- and micro-pores of concrete by mobile molecules of the oligomer and polymer is also due to the development of internal stresses during formation of the crystallization structure of concrete. Unlike plasticizers and water repellents that envelop the aggregate particles and migrate to less crystallized regions, macromolecules of the oligomer and polymer under the impact of internal stresses participate in the structuring of the concrete. The processes of crystallization of cement particles grafted onto the surface of PVC macromolecules contribute to the formation of a micro-granular structure in defective areas of concrete. The mechanism of occupying defective zones by low-molecular products during crystallization (the doping effect) is known for crystallizing polymers. This indicates the formation of a fine-crystalline structure with optimal packing in the volume which causes increasing the deformation-strength characteristics of the material. Structural plasticization, i.e. occupation of the volume of submicrocracks by oligomers is also observed when both crystalline and amorphous oligomers are solidified. Thus, we assume that the crystal growth mechanism, both for organic and inorganic polymers, is similar. Migration to defective zones (pores, cracks, capillaries) of low-molecular and low-viscosity particles of WCP as a result of all-round compression during hardening of cement is confirmed by the parameters of the water absorption kinetics.

Figure 2 shows the results of testing concrete at the age of 28 days for compressive strength and frost resistance.

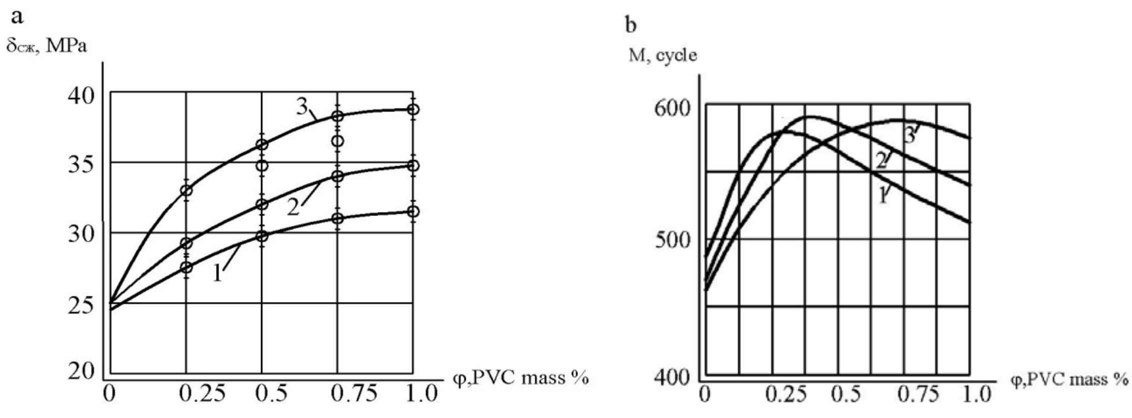

Figure 2. Concrete compression strength and frost resistance dependence on additives content: WCP content 1 – 3.0, mass %; 2 – 4.0 mass %; 3 – 5.0 mass %; formulation I, W/C = 0.25, to the effect of the 5 % water solution of sodium sulfate (Na_2SO_4).

The test results are shown in Table 2.

Table 2. Results of the studies.

Concrete	W/C	Concrete compression strength, t month		
		1 month	2 months	3 months.
I	0.2	27/25	27/18	25/12
II		31	30	29
III		35	35	32
I	0.25	27	22	20
II		31	27	23
III		35	30	26
I	0.3	27	20	18
II		31	25	19
III		35	27	21

Note. Denominator: indicators of concretes without additives.

The obtained results testify to the sufficient corrosion resistance of the studied concretes.

Thus, in the complex of physical and mechanical properties, resistance to sulfate corrosion and frost resistance, the studied concretes based on structurally modified concrete can be used for producing pile foundations arranged in conditions of highly saline soils.

4. Conclusions

1. The use of structural modifiers based on experimental data makes it possible to produce high quality concrete: strength higher by 20–30 %, corrosion resistance by 80–85 %.

2. The use of structural modifiers increases water-tightness to class W11–W12 and, as a result, reduces by 85–90 % capillary suction and water absorption which is caused by formation of the secondary crystallization structure of cement stone in defective areas of concrete;

3. Concretes modified with oligomer-polymeric additives exclude sulfate corrosion of concrete and anodic corrosion of metal reinforcement.

4. Adjusting the macro- and microstructure of concrete increases the structural uniformity of concrete which increases the speed of ultrasonic waves by an order of magnitude and in turn increases the continuity of the concrete.

5. Structural modification of concrete in the process of hydration of cement permits to increase the strength indicators of heavy concrete.

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Модифицированные бетоны для производства свайных фундаментов

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Ключевые слова: модифицированные бетоны; добавки; железобетонные свайные фундаменты; стойкость к воздействию агрессивных сред; сульфатная коррозия; водонепроницаемость; долговечность бетона; грунтовые воды.

Аннотация. В работе рассмотрены вопросы структурной модификации тяжелых бетонов олигомер-полимерными добавками. Установлено, что кристаллизация цементного камня протекает на макро – и микроуровнях. Макропоры заполняются продуктами кристаллизации частичек цемента, привитых на поверхности макромолекул поливинилхлорида (ПВХ). Миграция макромолекул ПВХ и олигомеров отходов коксохимической промышленности (ОКП) в дефектные зоны протекает за счет возникновения внутренних напряжений в процессе твердения и объемного сжатия, что обуславливает закрытие макро и микропор, а также трещин и капилляров. Таким образом, по комплексу физико-механических свойств, стойкости к сульфатной коррозии и морозостойкости исследуемые бетоны на основе структурно-модифицированного бетона могут быть использованы для производства свайных фундаментов устраиваемых в условиях сильно засоленных грунтов. Представленные результаты экспериментальных исследований свидетельствуют о достаточной коррозионной стойкости исследуемых бетонов.

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