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STABLENESS OF NEW CONCRETE ON THE QUARTZ BOND IN WATER AND SULPHATE ENVIRONMENTS

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ABSTRACT

This paper presents the results of an experimental investigation in which the effect of water and saturated sodium sulphate solution on the strength of Silica-Concrete (SC) under their constant or cyclical action was carried out. It was found that SC has achieved high-quality performance and high durability in these media. The results indicate that SC can be used in place of the traditional concretes in sulphate environments of the wide concentrations range up to saturated solutions. *Copyright © 1996 Elsevier Science Ltd*

Introduction

Many industries face the acute problem of ensuring the durability of building and protective constructions which may be subjected to the action of various aggressive agents, for example, water and salt solutions. In such cases construction elements are manufactured, as a rule, with the use of corrosion-resistant metals, polymeric materials and concretes. A promising chemically resistant non-metallic material is concrete based on the quartz bond, named silica-concrete (SC).

The scientific principles of fossilization by quartz of various concrete-like compositions containing fine and coarse aggregates as well as water were formulated in 1962 (1). It was postulated that a quartz bond could be obtained in a system containing vitreous silica and high-dispersed quartz. The basic notions accounting for this process are as follows. During hydrobarothermal treatment under stable temperature the vitreous silica dissolved in water. The solution is supersaturated by silica relative to quartz. Then the "superfluous" SiO_2 is deposited from the supersaturated water solution in the form of secondary quartz. It is crystallized on particles of the initial high-dispersed quartz as a substrate. The dissolution of a new portion of glass is taking place. The process is successively repeated till the vitreous silica is completely dissolved and crystallized on quartz microparticles as seeds outside the volume it occupied before. The crystallization products on the seed push the solution into the porous space created by the dissolving glass grains as well as into the additional free volume that appears due to the localizing the utilized solution, monolithic crystalline agglomerates are formed in separate micropores and in the interporic space out of the particles of seed quartz, surrounded by shells of new quartz formations.

As demonstrated by subsequent investigations, colorless laminar crystals of sodium hydrosilicates and scales of anhydrous sodium silicates are found among the other new formations of the cementitious agent (2). In the contact zone of the cementitious agent with grains of ordinary sand and with the coarse aggregate regenerating rims are formed binding all the components together. The material obtained, (SC), has a conglomerate structure and is characterized by the presence of elongated, predominantly closed pores 0.01 - 1.5 mm in size.

SC can have the compressive strength up to 100 MPa and very small water uptake (not more 2-3%). Taking into account the peculiar composition and structure of the cementitious agent in SC, this material can be presumed to possess high corrosion-resistance in the water and sulphate media.

The present paper considers certain aspects of SC durability under constant and cyclical action of the water and saturated solution of sodium sulphate.

Experimental

Materials. The following materials were used in preparing SC:

High silica glass. It contained 90% of SiO2 and 10% of Na_2O. The glass was crushed on a hammer crusher, screened on sieves, and the 0.315-1.2 mm fraction was separated and utilized.

Aggregates. The coarse aggregate was crushed quartzite rock with grain size of 5 - 20 mm.

Natural quartz sand with finess module of 1.55 was used as the fine aggregate and for a preparation of high-dispersed quartz seed of SC. In order to obtain high-dispersed quartz seed the dried natural sand was ground in a ball mill to the specific surface of 430 m^2/kg (after Blaine).

Water. Common tap water was used.

Aggressive media. Water and a saturated solution of sodium sulphate at 18% concentration were used as aggressive media.

Silica-Concrete Composition. SC mixture concluded (by weight parts): high-dispersed quartz seed - 0.9, ordinary natural sand - 0.9, crushed quartzite aggregate (5-20 mm) - 4.3, high silica glass - 1.0 and water - 0.44 (3). The compressive strength of SC for this composition is 65 MPa.

Preparation of Specimens. The 10 × 10 × 10 cm specimens served to determine the resistance of SC to water and to the saturated sulphate solution under constant and cyclical action of these aggressive agents. Test specimens were prepared according to the following scheme. At first a concrete mixture was prepared. High silica glass, high-dispersed quartz sand, ordinary sand and the coarse required quantity aggregate were premixed in a laboratory fixed-drum concrete mixer for 2 min. Then the of water was added to the mixture, and the mixing went on for another 2 min. Specimens of required sizes were shaped in steel molds vibrating on a standard vibrotable for 1.5-2 min. The interval between the formation of a specimen and the start of its curing did not exceed 6h. The molds with specimens were placed into a laboratory autoclave (about 1 m in diameter and about 1.5 m long), in which temperature and pressure were created by supplying saturated steam at 187°C. Test samples were cured under the conditions where steam pressure was raised to 1.2 MPa (temperature of 187°C) for 3.5 h, isothermal exposure at 1.2 MPa took 21 h and steam pressure was lowered to atmospheric pressure for 3.5 h.

Testing of Specimens. In order to determine SC durability in water and in the sodium sulphate solution under constant conditions all the specimens were stored in containers with water and 18% Na_2SO_4. After 30, 90, 180, 365 and 730 days they were taken out of the containers, inspected, weighed and tested for compressive strength.

Before the start of the cyclical tests the specimens were placed for 96h in the water and 18% sulphate solution. Part of them were tested to determine the initial compressive strength in the water or sulphate saturated state. The remaining specimens were placed for 4 hours into the conventional oven with temperature of 105 - 110°C (for water saturated specimens) or with temperature of 133 - 138°C (for sodium sulphate saturated specimens). [The boiling temperature for 18% Na_2SO_4 is 133 °C]. Then the specimens are cooled in the oven up to the "room" temperature. After cooling they were submerged for 4h into water or sulphate solution at 20 ± 2°C. The drying - cooling - impregnation cycles were then repeated. After a certain number of cycles the specimens were kept in water or sulphate solution for 96h, inspected, weighed and tested for compressive strength. The tests were conducted after 10, 25, 50, 100 and 125 cycles.

Results and Discussion

Fig. 1 presents changes in strength of SC after specimens were kept in water and in the sulphate solution.

It can be seen that their compressive strength fell sharply (by almost 75%) after 180 days in water (curve 1). By that time the material was impregnated to the depth of 40 - 45 mm, the specimens' mass was stabilized. By the 730th day SC was completely impregnated by water. But after 180 days strength was practically unchanged. The specimens had no visible distinctions from their initial exterior: clear-cut ribs and corners were preserved, no damage could be seen.

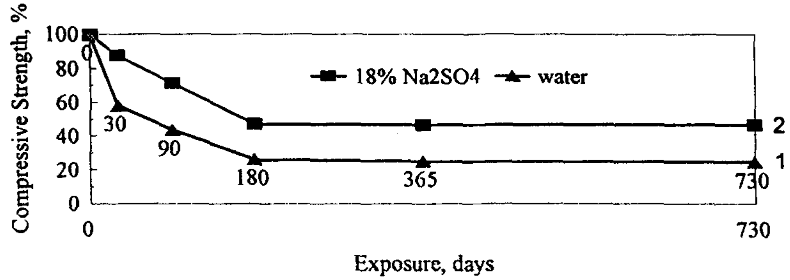

FIG. 1.
Compressive Strength of SC in Sulphate and Water Environment

After constant immersion in sodium sulphate solution for 180 days SC compressive strength fell by 53% (curve 2) with a parallel increase in mass by 3.9%. The depth of solution penetration was 15 mm. By the 730th day the specimens' strength showed little change, and their impregnation depth did not exceed 35 - 40 mm. The mass grew by 4.25%. The exterior of the specimens did not change during the tests.

Results of the cyclical tests of SC samples in water and sodium sulphate solution are shown in Fig. 2.

The compressive strength of SC fell most drastically in the first 50 cycles in the both cases. For the strength reduction by 45%. In tests with the sulphate solution the impregnation depth was 20 mm and strength fell by 22%. The next 50 test cycles resulted in an additional decrease in strength by 8 - 10%. Subsequent tests did not bring about any significant changes in strength, and by the time they ended (after 125 cycles) strength equaled 29.6 MPa and 45.5 MPa for water and for the sulphate solution respectively. Water completely impregnated the specimens after 100 cycles, whereas impregnation by the Na_2SO_4 solution reached the level of 40 - 45 mm after 100 cycles and did not change any more.

Considering the mechanism of the action of water and of a saturated sodium sulphate solution under constant and cyclical test conditions, it should first of all be stated that there is no chemical interaction between these liquid media and SC components, including the cementitious material as the silica bond. Mainly two physical factors seem the influence to the material under the conditions of constant tests, namely penetration of the external liquid medium and its "softening" by water. They result in strength decrease, the dynamics and scale of which depend on the speed and depth of impregnation. The latter are in their turn functions of the density and viscosity of the impregnating medium. In both water and sulphate media SC "softening" ends almost for 180 days. The water penetrates in material faster and deeper than the sulphate solution, which is more viscous. Correspondingly, the strength of specimens kept in water also decreased faster and to a greater degree than of those kept in a sodium sulphate solution. After 180 days reduction of SC compressive strength was not registered in either medium till the termination of the tests (up to 730 days), in despite of deeper impregnation of the material. The well crystallized quartz bond apparently preserves the integrity and mechanical properties of the material.

During cyclical tests the following physical processes take place in SC. At the initial stage of each cycle the material is impregnated by the liquid. At the second stage, in drying, the moisture is vaporized and the material undergoes thermal expansion. Besides, when a

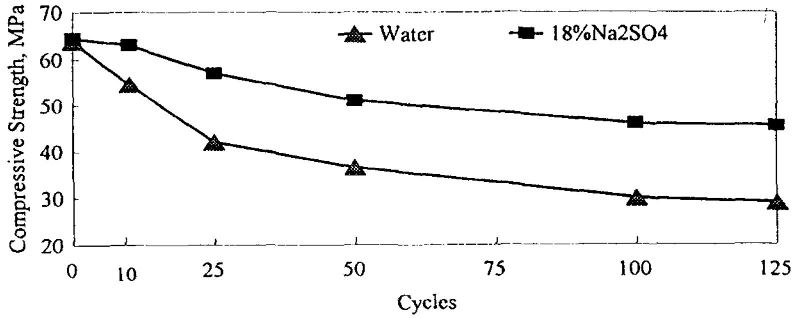

FIG. 2.
Compressive Strength of SC after Cyclical Tests

saturated sulphate solution is applied the sodium sulphate can be crystallized within the pores into the decahydrate form with the emergence of crystallization pressure and corresponding internal stresses. The material is contracted when cooled to the ambient temperature. Multiple repetition of these processes loosens SC structure and can eventually decrease its strength.

During the first 100 cycles with the use of the sulphate solution SC strength, as in the constant tests, decreased more slowly and by a smaller figure than with the use of water. It was the result of the role that the thickness of the impregnated layer played. This layer is formed at the stage of immersion in a liquid medium for the cyclical tests: the thinner the layer, the slower and smaller the decrease in strength is noted. It should be remembered that the depth of SC impregnation by a sulphate solution with its higher viscosity is smaller than by water. The stability of the impregnated layer depth after 100 test cycles helped to stop the decrease in SC strength.

After 125 cycles the compressive strength of the specimens was the same as after 100 cycles. The difference in the thickness of the moist layer and in the strength of the specimens tested under the sulphate solution and under water was preserved.

Conclusions

The following conclusions can be drawn from the present study:

1. No chemical interaction takes place between SC components, water and the saturated sodium sulphate solution under constant and cyclical action by these liquid media.
2. Liquid penetration into SC and its "softening" can be referred to physical processes whose action consists in compressive strength being lowered to a certain limit. The dynamics of strength reduction and its scale is influenced by the density and viscosity of the impregnating media.
4. SC is more durable in a sulphate medium than in water.
5. SC will resist well to liquid sulphate environment of wide range of concentrations, where the conventional concrete, based on the Portland cement or sulphate resistant cement, can not resist at all.

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