Study of the efficiency of epoxy coating protection of concrete surfaces from sulfuric acid corrosion

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Abstract. The application of epoxy coatings to concrete is a method of its protection against sulfuric acid corrosion. The problem of ensuring the efficiency of the coating protection conditioned by many factors is considered herein. Penetration of acidic substances through local defects on the coating surface, which causes its swelling and a sharp increase in the corrosion rate, is one of the main factors. Results of the studies of the samples exposed to 5% solution of sulfuric acid and to the environment of a sewer system with a high content of hydrogen sulfide in the air are described. It is established that the modification of concrete with additives and the increase of its physical and mechanical properties prevent the stability of the “concrete–epoxy coating” system from increasing. To ensure the reliable operation of reinforced concrete structures in an acidic environment, it is advisable to periodically monitor the condition of coatings in order to identify and to timely eliminate local corrosion.

1. Introduction
The analysis of emergency situations in water discharge networks shows that sewer tunnels, collectors and structures of inspection shafts become inoperable before their service life expires. The study of operational resources of distribution systems of water discharge networks indicates that up to 80-90% of accidents are caused by corrosion processes. Chemical reactions occurring in a free space of a sewage network form an environment which is aggressive to its structures [1, 2]. The restoration of the performance of collectors for extending their trouble-free service life is a costly and difficult task. Modern cement-based concrete of different grades used for repair works gives the possibility to solve it at different technical and economic efficiency levels [3-5]. However, it should be understood that acid corrosion is inevitable for them, because cement-based concrete is alkaline in its nature and may be damaged by the acid environment.

2. Problem Statement
Ways to protect concrete from acid aggression (in particular, in sewage collectors) include the application of corrosion-resistant coatings based on epoxy resins [6, 7]. However, despite the fact that those coatings are resistant to sulfuric acid, their use in the protection of concrete is
often ineffective. For example, R. Bielecki and G. Schremmer [8] describe a case of damage caused to a 4-kilometer section of a sewage collector in Hamburg 2 years after its commissioning. Such damage was caused to the internal C30-C40 concrete surface sealed with epoxy resin, and resulted in the swelling of the coating and the subsequent destruction of concrete. The same damage caused to coatings of concrete samples tested in a hydrogen sulfide environment of collectors has also been repeatedly recorded by N.K. Rozenthal [9]. The destruction of such coatings is supposedly associated with diffusion processes: osmosis and penetration of hydrogen sulfide or acid under the coatings [10, 11]. These mass transfer and corrosion processes are highly dependent on the properties of the concrete and the adhesion of the coating with the substrate. In our opinion, it is advisable to develop the effective combination of epoxy coatings within the single "concrete – epoxy coating" system.

3. Results and Discussion

Laboratory studies were conducted in two stages. In the first stage, the stability of concrete of different grades exposed to a 5% sulfuric acid solution was investigated [12]. There were made 8 series of samples: two formulations based on different cement grades (Portland cement and slag Portland cement), which had different content of chemical (superplasticizers, hydrophobizers, anti-clogging additives) and mineral (micro silica) additives and different physical and mechanical properties (durability from 25 to 80 MPa, water absorption from 3 to 8 %, water resistance W4-W12 and above). After exposing 40x40x160 mm test beams to a sulfuric acid solution within 28 days, the surface of all those samples was damaged to a significant extent, their weight loss exceeded 10% and their durability loss exceeded 20%. This led to the conclusion that the resistance of conventional concrete grades to sulfuric acid is low, regardless of the type and content of modifying additives.

At the second stage, the sulfuric acid resistant epoxy coating “PenetronPenePoxy 2K” consisting of two components was applied in one layer to the samples (2, 4, 6, 8, 10, 12, 14, 16) for the purpose of evaluation of the performance of the “concrete – coating” system. The coating was 1-2 mm thick. The resistance of the coating to acids was tested by immersion of test beams made of the epoxy coating material in acid solution for 1 year. No signs of corrosion were found on the samples after their exposure and examination; their mass increased by 1% and their tensile and compressive strength did not change.

The joint performance of the coating and the concrete was evaluated by visual inspection of the samples after their exposure to a 5% solution of sulfuric acid for 60 and 120 days. After 60 days of the exposure, the epoxy coating of all samples (except for the 10th sample) had minor surface damages (figure 1).

Figure 1. The appearance of the samples with the epoxy coating exposed to acid within 60 days.
Such damages were local; the concrete was damaged at points of penetration of sulfuric acid through the coating (figure 2).

![Figure 2. Spot corrosion of concrete under the epoxy coating.](image)

120 days later, the areas of the damaged coating began to significantly grow (Figure 3). The largest destructed areas were observed on the sample No.14, which had the lowest water-to-cement ratio (0.27) and the highest binder consumption (600 kg/m³). No destruction of the coating was observed on the sample No.10 during the entire study period. Based on the similarity of compositions of the sample No.10 and the sample No.8 and compositions of the sample No.10 and the sample No.12, it was concluded that the mechanism of destruction of the coating largely depends on local surface microdefects through which acid penetrates and which result in the further expansion of the concrete and swelling of the coating. It should be noted that the increased water resistance of the concrete did not result in slowing down the rate of corrosion of the “concrete - epoxy coating” system. This made it possible to conclude that the use of modified concrete of different grades having low water absorption and high water resistance values is ineffective for such systems and can lead to the opposite effect: more rapid destruction of the coating and concrete.

In order to confirm the results of the laboratory tests, field studies were conducted: concrete samples were immersed into a collector and held there within 140 days in the summer period. In order to accelerate the study, the collector shaft, in which the concentration of H2S exceeded 30-50 times its threshold limit value, was selected. After exposing the samples in such a way, all of them were severely damaged; however, their surface was damaged only partially. No corrosion processes were observed in dry areas of the samples. Such results are influenced by the considerable complexity of conducting studies in collector shafts, which are usually examined twice a year, and for that reason studies in such shafts cannot be monitored. Therefore, the use of quantitative analysis involving measurements of changes in mass and strength was impractical. The results were analyzed visually (in particular, on the basis of changed cross sections of the samples in certain places). The previously obtained data showing a lack of significant effectiveness of the increased strength and water resistance of the concrete were confirmed. Cross sections of all samples in certain places decreased by 10-15 mm during such a short period of time. The application of coatings to the samples substantially protected them from corrosion, but, as in the case of exposure to 5 % acid solution, local damages to the coatings were observed (Figure 4).
4. Conclusion
The results obtained suggest that the "concrete - epoxy coating" system studied has a much larger service life in the corrosive acid environment than concrete. To enable it work effectively, first of all there should be no defects on the coating surface through which aggressive substances penetrate to the concrete surface. Those defects can be partly eliminated by the careful application of a multilayer coating. However, this will greatly increase the cost of anti-corrosion protection of concrete. Moreover, during the operation of sewer networks their deformation is inevitable, and such deformation can be accompanied by the formation of cracks on the surfaces of the coatings. The modification of concrete with additives and the increase of its physical and mechanical properties prevent the stability of the system from being increased.
and may aggravate it. It is advisable to periodically monitor the condition of coatings in order to identify and to timely eliminate local corrosion.

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