RESEARCH ARTICLE
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Study of Biostability of Concretes

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The problem of corrosion destruction of building structures, despite the existing scientific and engineering achievements in this area, does not lose its relevance. The purpose of the study is to determine the degree of impact of various types of microorganisms on the physical and mechanical properties of concrete. We carry out the assessment of the possibility of concrete to serve as a substrate for various types of biodestructors by determining the moisture absorption and pH of the extract of the concrete samples. As a result, we experimentally determine the mechanism of action of various microorganisms on concrete. Also we define the taxonomic composition of the most aggressive microorganisms for concrete. During the study we assess the effect of biofouling on the physical and mechanical properties of concrete. The results of the study serve as a basis for the selection of the most effective corrosion protection methods for concrete structures operated in biologically aggressive environments.

Key words: concrete, destruction, microorganisms, water absorption, corrosion

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НАУЧНАЯ СТАТЬЯ
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Исследование биостойкости бетонов

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Проблема коррозионной деструкции строительных конструкций, несмотря на существующие научные и инженерные достижения в этой области, не теряет своей актуальности. Целью исследования являлось определение степени воздействия различных видов микроорганизмов на физико-механические свойства бетона. Оценка возможности бетона служить субстратом для различных видов биодеструкторов проводилась с помощью определения влагопоглощения и pH вытяжки из проб образцов бетона. В результате был экспериментально установлен механизм воздействия различных микроорганизмов на бетон. Определен таксономический состав наиболее агрессивных к бетону микроорганизмов. Проведена оценка влияния биообрастания на физико-механические свойства бетона. Результаты исследования служат основой для подбора наиболее эффективных методов антикоррозионной защиты бетонных конструкций, эксплуатирующихся в биологически агрессивных средах.

Ключевые слова: бетон, деструкция, микроорганизмы, водопоглощение, коррозия

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INTRODUCTION

Concretes are prone to deterioration and premature ageing in corrosive environments. In the most cases of corrosion detection in concrete structures the several types of corrosion damage are observed together at the same time during the survey phase. According to classification by V.M. Moskvin, corrosion of the first and second type, or biological and chemical corrosion (Fig. 1, 2) are combined [1, 2]. These types of corrosion damage are characterised by the complexity and high cost of repair measures because they require the use of spot repair technology, especially in vertical compressed and horizontal bent structures [1-3].

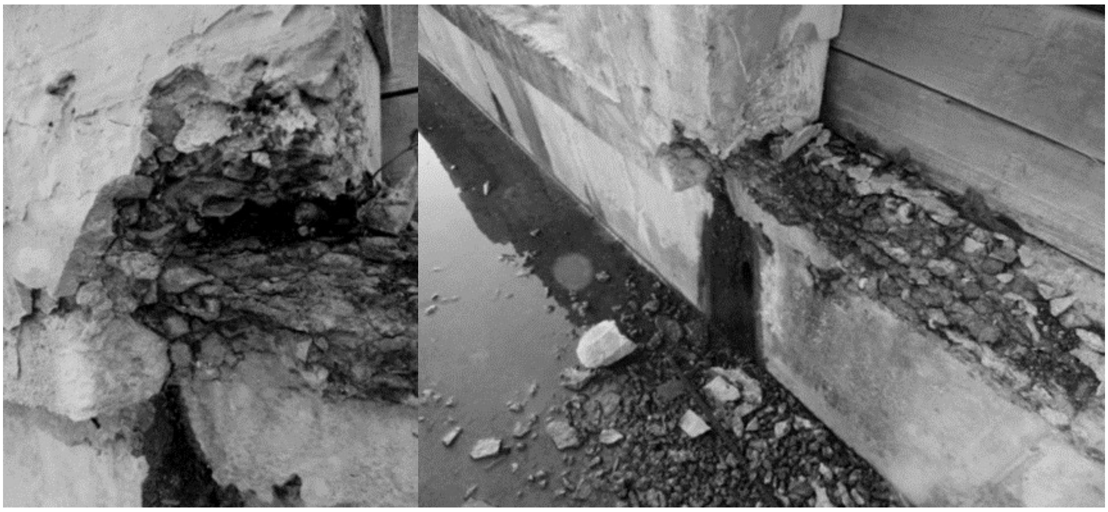

Fig. 1. Corrosion destruction of the reinforced concrete wall

Biological corrosion is still the one of the most poorly studied type of concrete corrosion. Therefore, nowadays the study of corrosive processes developing in concrete under the influence of various microorganisms is relevant. There are three types of biological corrosion of concrete: bacterial, algal and fungal one [4].

Studies of corrosion destruction of concrete are caused by the necessity of increasing the durability and reliability of concrete and reinforced concrete structures; the development of measures to prevent accidents; significant material losses due to corrosion degradation of concrete; the problem of environmental pollution by corrosion products and metabolites of biodegraders [5, 6].

Biological corrosion of concrete is a multifactorial process; its kinetics depends on the species diversity of biodegraders, a number of abiotic factors and the properties of the concrete itself. Successful research of biological corrosion of concrete is possible only through a thorough study of the physical and chemical processes developing in concrete as a result of damaging by microorganisms.

EXPERIMENTAL PART

The study of biological destruction of concrete was carried out in accordance with the requirements of State standards. The method consists in correlation of parameters characterizing the biostability of concrete specimens subjected to biofouling with the values of indicators characteristic of control concrete specimens [7].

In accordance with the requirements of State standards, the experimental samples were pretreated with a nutrient solution promoting the growth of algae, bacteria, and fungi. The mechanisms of all types of biological corrosion of concrete are reduced to the physical and chemical processes occuring as a result of release of acidic products of metabolism of microorganisms. Therefore, to study the mechanisms of various types of biocorrosion of concrete, the following methods were chosen: determination of moisture absorption of concrete by mass and volume, registration of changes in the pH of aqueous concrete by potentiometric method using a pH-meter/ionometer Anion-4100. To define the taxonomic composition of biodamage, scrapes were taken from the surface of concrete samples. Electron microscopy was performed by using a Meiji Techno microscope (Japan).

Concrete samples, some of which had no visually detectable biological contamination, were examined for bioresistance. Electron microscopy detected biodegradation of all samples (Fig. 2).

The samples subjected to algal corrosion showed a greenish plaque with grayish inclusions. The method of electron microscopy recorded large accumulations of algae on the surface of the concrete (Fig. 2, a, d). The taxonomic composition of the biota, namely algae of Gloeocapsa, Chlorococcum, and Chlorella, was established by using identifiers [8-10]. Algae produce oxygen as a coproduct of photosynthesis. Algae blue-green color is due to the presence of chlorophyll and phycocyanin, so they are sometimes called blue-green algae [11].

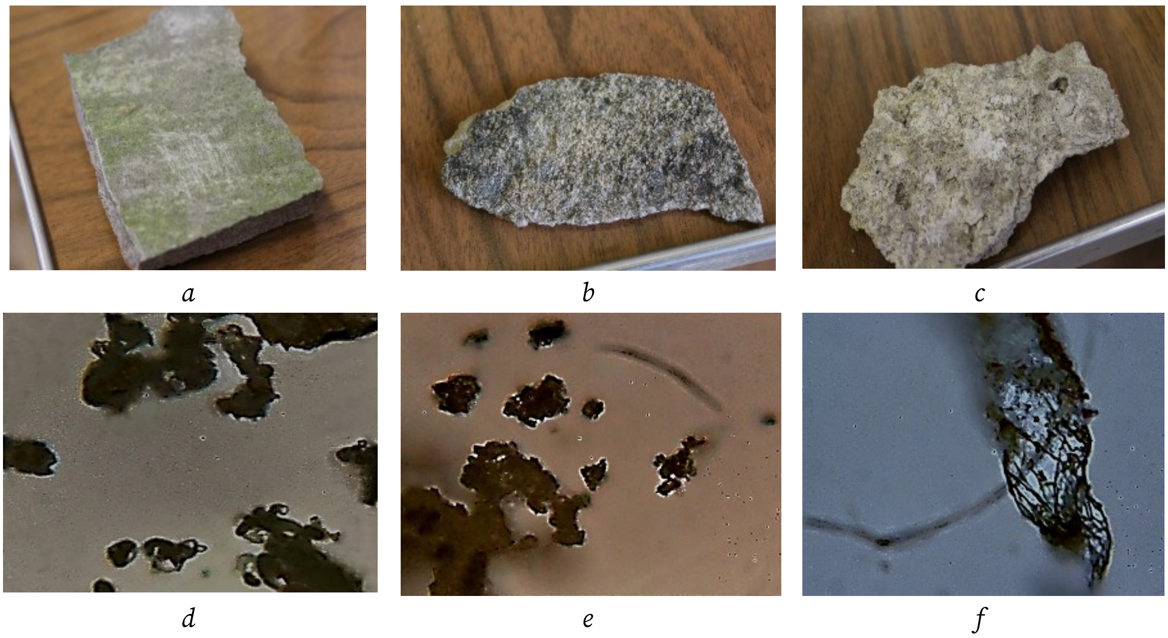

Fig. 2. The surface of a concrete sample: *a, d* - algal corrosion,
b, e - bacterial corrosion; c, f – fungal corrosion;
d, e, f – at 300x magnification

The surface of the concrete samples subjected to bacterial corrosion was severely damaged (Fig. 2, *b, e*). The rodlike bacteria were identified by light microscopy and using identifiers [8-10]. During the experiment, it was fixed that the most common causative agents of bacterial corrosion of concrete are Bacillus bacteria.

The presence of fungal corrosion severely damages the surface of the concrete samples and caused the whitish-gray plaque with black inclusions in the penetrations (Fig. 2, *c, f*). The taxonomic composition of micromycetes showed the presence of fungi of the genera Mucor, Penicillium, and Aspergillus in the samples. Fungi are heterotrophic and have no chlorophyll, so they depend on available organic matter. They attach to the surface of the substrate and usually look like fluffy gray, green, black or brown patches.

According to experiments, the most aggressive biodegraders of concrete are fungi and bacteria.

Meanwhile, clusters of both bacteria and fungi were found on some samples. This fact indirectly correlates with the hypothesis of biocenoses forming by microorganisms. As a rule, the first to appear in these communities are chemolithotrophic bacteria, which are able to obtain adenosine triphosphoric acid by using the energy released during oxidation-reduction reactions of an inorganic substrate - concrete. The clusters of organic matter formed as a result of the vital activity of chemolithotrophic bacteria serve as a substrate for the vital activity of fungi [12].

The rate of biofilm formation can vary. According to references, biofilm can form in minutes when a substrate comes into contact with water containing various metabolites [12].

In order to define the degree of impact of different types of microorganisms on concrete, a number of studies were conducted to assess the water absorption of concrete samples by mass.

Assessment of water absorption of concrete by mass, %, is calculated according to the formula

$$W_m = \frac{m_d - m_{ws}}{md} \cdot 100, \tag{1}$$

where W_m - sample water absorption by mass, %; m_d - mass of dried sample, g; m_{ws} - mass of water-saturated sample, g.

The water absorption of concrete control samples by mass was 11.41%, for samples subjected to algal corrosion - 13.66%, for samples damaged by bacterial and fungal corrosion - 16.71% and 19.84%, respectively. Therefore, the bacterial and fungal corrosion leads to a significant increasing of water absorption by mass.

By Fig. 3, samples affected by fungal and bacterial corrosion were saturated with water at the first 24 hours, while the control samples and the samples with algal corrosion reached a constant weight only on the second or third day of storage of samples in water. The curve of change in the rate of water absorption by mass of samples subjected to algal corrosion practically repeated the curve describing this process for the control series of samples. The processes described in Fig. 3 may be a consequence of different porosity and density of the samples. The greater volume and pore size of samples subjected to fungal and bacterial attack is direct evidence of the greater aggressiveness of fungi and bacteria to concrete than algae [13].

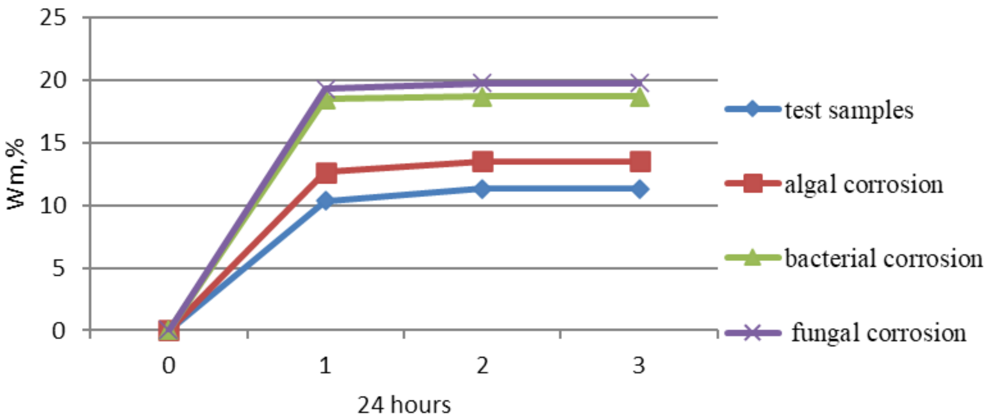

Fig. 3. Water saturation curves

The number of experiments was conducted to assess the water absorption of samples by volume.

Water absorption of concrete samples by volume was calculated according to the formula

$$W_o = \frac{W_m \cdot \rho_o}{\rho w_в}, \quad (2)$$

where W_o is the water absorption of the sample by volume, %; W_m is the water absorption of the sample by mass, %; ρo is the density of dry concrete, kg/m^3; ρ_w is the density of water, assumed to be 1 g/cm^3.

The samples subjected to algal corrosion showed no significant changes in water absorption by volume in compare with the control sample series. Bacterial and fungal corrosion was accompanied by a significant increase of water absorption of the concrete samples by volume.

The increased volumetric water absorption of concrete samples subjected to bacteria and fungi confirms the high degree of aggressiveness of these bioagents. As a result, increased porosity and decreased density of concrete leads to a reduction of strength.

Experimentally obtained pH values of the aqueous extracts of the samples made it possible to determine the degree of corrosion activity of various biodegraders (bacteria, fungi, algae). For the control samples pH was 8, for algal corrosion - 8.1, for bacterial corrosion - 7.7 and for fungal corrosion - 7.2. Decreasing of pH of the aqueous extract of concrete samples indicates that bacteria and fungi, compared to algae, are more aggressive towards concrete due to their metabolites, which are mainly represented by organic acids (oxalic acid, citric acid, succinic acid, etc.). Organic acids act as catalysts for the corrosion damage of concrete.

RESULTS

The following conclusions were obtained:

1) Fungi and bacteria are the most corrosive biodegraders of concrete.

2) The main cause of damage to concrete in biodegradation is the effect of microbial metabolites, which are a mixture of organic acids.

3) Effects on concrete by algae, bacteria and fungi are accompanied by an increase in porosity and a reduction in density, which leads to a significant deterioration of the physical and mechanical properties of concrete.

4) Concrete can be protected against bio-damage by treating the material surface in a suitable period of time with various anti-microbial compounds and by producing low-porosity concretes.

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