STRUCTURAL PARAMETER OF GAS CORROSION

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Resume. *This article describes the features of gas corrosion at the structural level, since this type of chemical corrosion is largely associated with protective (passivating steel fittings) the properties of cement stone. The safety of steel reinforcement is the most important aspect of the durability of concrete. The specifics of the corrosive effect of carbon dioxide, as the most common aggressive agent in gas corrosion, are also described. The work is devoted to the identification of the relationship of gas corrosion of concrete with the volume of its pores, as well as an indirect characteristic of the porosity of concrete - W / C, and the influence of the type of filler on the gas corrosion of concrete. A graph of the dependence of the depth of concrete carbonization on the structural parameter of gas corrosion is constructed.*

Keywords*: corrosion protection, carbon dioxide, aggressive effect of acid gases, carbonization depth, neutralization of concrete and depassivation of steel reinforcement, durability of concrete, degeneration of cement stone, structural parameters.*

Introduction

Of the total number of prefabricated reinforced concrete structures, about 25% are operated in aggressive gas environments. In turn, 25% of them are intended for use in a slightly aggressive gas-air environment, in which, as a rule, corrosion protection is not provided, that is, the structures must be designed so that their durability is ensured through their own resistance. [1]

It is important to study the features of gas corrosion at the structural level, since this type of chemical corrosion is largely associated with the protective (passivating steel reinforcement) properties of cement stone. The safety of steel reinforcement is the most important aspect of the durability of concrete. [2, 3]

1. Term "gas corrosion"

It should be noted that the term "gas corrosion" is somewhat conventional in relation to concrete. In essence, the elementary processes of corrosion of concrete in gaseous media do not differ from corrosion in liquids, i.e. chemical reactions between acid gases and cement stone minerals occur in moisture films. However, this type of corrosion also has specifics.

The nature of the gas-air environment in which it is operated has a great influence on the development of corrosion processes in reinforced concrete.

The most dangerous components of air (especially contaminated with impurities) for reinforced concrete are carbon dioxide, chlorine, sulfur dioxide, hydrogen chloride.

In relatively clean air, the main component influencing the composition of the liquid and solid phases of cement stone is carbon dioxide.

Acid gases are naturally aggressive to cement concrete, i.e. under certain conditions (humidity, temperature) they react with its components. However, the degree of aggressiveness (the nature and speed of concrete destruction they cause) can be different, depending on the type of gas, its concentration and air (or concrete) humidity.

The aggressive effect of acid gases on reinforced concrete structures of buildings and structures is manifested as follows: acid gases, penetrating into the pores of concrete, dissolve in the liquid phase, forming acids and, entering into chemical reactions with calcium oxide hydrate, silicates, aluminates and other cement stone compounds, neutralize it with the formation of appropriate calcium salts, silica gel, hydrates of aluminum and iron. The consequence of this is the gradual degeneration of the cement stone. [4, 5]

2. The specifics of the corrosive effect of carbon dioxide

It makes sense to describe in more detail the specifics of the corrosive effect of carbon dioxide, as the most common aggressive agent in gas corrosion. In addition, its effect is quite typical. [6]

The interaction of carbon dioxide with concrete can be considered as a heterogeneous physico-chemical process occurring between a gas and a porous body with the formation of a waste layer.

The following simpler processes can be distinguished here:

- diffusion of CO_2 in the pores and capillaries of concrete filled with air;
- dissolution of CO_2 in the liquid phase of concrete, formation of carbonic acid, its dissociation into hydrogen ions, bicarbonate and carbonate ions;
- diffusion of formed ions in the liquid phase;
- dissolution of $Ca(OH)_2$, its dissociation and diffusion of Ca^{2+} and OH^- ions ;
- chemical interaction of carbon dioxide with dissolved $Ca(OH)_2$ to form bicarbonate and calcium carbonate;
- crystallization of calcium carbonate.

In principle, the following types of limitation of the carbonation process are possible:

a) diffusion restriction in the gas phase will be observed if the physical and chemical processes in the moisture film on the surface of the pores proceed at a high rate, and the supply of carbon dioxide is limited;
b) kinetic limitation is possible in the case when the rate of carbon dioxide intake to the reacting surface of concrete pores will be significantly higher than the rate of absorption by concrete;
c) the mixed constraint is an intermediate case.

3. Neutralization of concrete with carbon dioxide

To date, a large number of papers on diffusion kinetics have been published. Neutralization of concrete with carbon dioxide is considered from the standpoint of the theory of heterogeneous chemical processes. [7, 8]

The obtained dependences, as a rule, were subjected to experimental verification, where deviations from theoretical concepts were observed only at the initial stage of testing, or occurred due to the ongoing carbonation of cement stone in a neutralized layer after depletion of the $Ca(OH)_2$ reserve due to the clinker fund of cement stone. However, despite some deviations, it can be assumed with a fairly high degree of accuracy that the depth of carbonation is proportional to the square root of the CO_2 concentration.

From the point of view of protective properties in relation to steel reinforcement, of all the changes that occur in concrete during carbonation, the most significant change is the pH of the liquid phase.

Numerous studies have shown that after several years of using concrete in air with a high content of carbon dioxide, the pH can reach 8.3...8.5.

It is well known that a decrease in the *pH* of the liquid phase of concrete causes the depassivation of steel reinforcement. Experiments have shown that in carbonized concrete, corrosion of steel reinforcement occurs with slight anodic braking. Increasing the resistance of concrete reduces the efficiency of corrosive vapors on the surface of steel.

The analysis of the combined effect of acid gases on concrete shows that in real operating conditions, carbon dioxide plays a leading role in neutralizing concrete, as it is more concentrated. The remaining gases only slightly accelerate or slow down this process. [7, 8]

4. The effect of the type of filler and the water-cement ratio on the gas corrosion of concrete

The influence of the type of cement on the development of gas corrosion of concrete has been sufficiently studied.

It is believed that with a decrease in the content of Portland cement clinker in cement, the gas corrosion of concrete accelerates.

Regarding the influence of the type of filler on the gas corrosion of concrete, the opinions of researchers are ambiguous.

It can be assumed that the advantages of concrete on porous aggregates, in terms of their corrosion resistance, are not always able to cover their disadvantages, in particular, such essential for gas corrosion as increased porosity and a reduced *pH* value. [9]

Concretes on limestone aggregates, having the advantages inherent in concretes on porous aggregates (finer porosity, self-healing ability, good quality of the contact zone), are practically free from their disadvantages (the *pH* of the liquid phase in them does not significantly decrease). One can expect good resistance of these concretes to the aggressive effects of acid gases.

The durability of concrete on limestone crushing waste is higher than the durability of concrete on granite, this is explained by the difference in the number and quality of pores of the contact zone in the compared concretes.

A lot of research has been devoted to identifying the relationship of gas corrosion of concrete with the volume of its pores, as well as an indirect characteristic of the porosity of concrete water-cement ratio - *W/C*. It is noted that, depending on the porosity of concrete, aggressive acid gases penetrate to a certain depth determined by the gas permeability of the material. (Fig. 1)

The density of the concrete structure also has a great influence on gas corrosion.

It is obvious that dense concrete can retain moisture for a longer time than porous concrete, the degree of its compaction by moisture condensing from the atmosphere will be higher. In a structure with large pores, where filling microcapillaries with water cannot increase diffusion resistance, the intensity of carbonation does not depend much on atmospheric humidity. In concrete with a finely porous structure, moisture condensation in microcapillaries can significantly increase the resistance to CO_2 diffusion in a gaseous medium.

The main amount of CO_2 is transferred deep into the concrete through a relatively small number of large pores.

In all likelihood, any communicating pores, regardless of their origin and size, should be considered dangerous from the point of view of gas corrosion.

Pores formed by air entrainment resulting from the use of surfactants can have a positive effect on durability.

These theoretical provisions on the effect of the nature of pores on the gas corrosion of concrete were taken into account by us when developing the structural parameter of gas corrosion.

The results of calculating the relative depth of carbonation of samples with different W/C were used. By processing by the least squares method about 2000 measurements of the depth of carbonation of concrete samples stored indoors at a relative humidity of about 60%, the following dependence was obtained:

$$Xrel = 4{,}6\ W/C - 1{,}3 \qquad (1),$$

where *Xrel* is the relative depth of carbonation.

Analysis of the formula shows that concrete will not carbonize if its water-cement ratio reaches about 0,3. (Fig. 1)

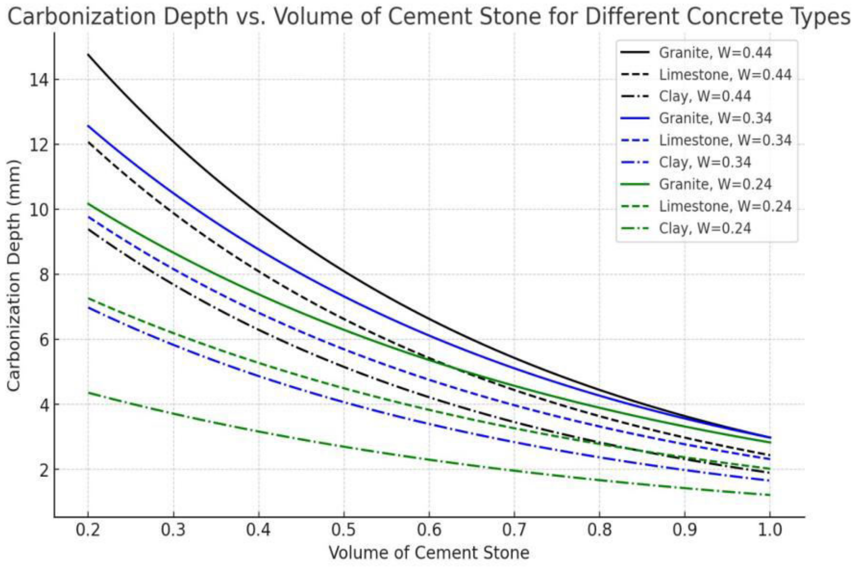

Figure 1. Dependence of the depth of carbonization of concrete on the volume of cement stone

5. Dependence of the depth of concrete carbonization on the structural parameter of gas corrosion

The dependence of gas corrosion on cement consumption has been studied previously. According to the science of concrete, the depth of carbonation is inversely proportional to the consumption of cement. [10]

In our studies, a decrease in the depth of carbonization was also noted with an increase in the volume of cement. (Fig. 2)

The important role of communicating porosity, including the porosity of the contact zone, in the development of gas corrosion processes has been confirmed. Interestingly, concrete on carbonate crushed stone turned out to be more resistant than concrete on granite, although the latter are superior in durability to expanded clay concrete. This is explained by the peculiarities of the pore structure of concretes: carbonate concretes have a better contact zone, while expanded clay concrete has a porous filler that seriously increases gas permeability.

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Thus, there is every reason to consider the volumes of pores of the 1st and 2nd groups as a destructive element of the concrete structure, from the point of view of gas corrosion.

In the first (microcapillaries) gases dissolve, through the second (macrocapillaries) they penetrate into concrete. The pores of the contact zone are mainly related to the second ones. The constructive volume, as in the case of describing other corrosion processes, should be considered the volume of cement stone preserved during the corrosion process.

During carbonization, the degree of chemical degeneration of cement stone does not play such a significant destructive role as with other types of corrosion, its most unpleasant consequence is considered to be the depassivation of steel reinforcement - a decrease in the alkalinity of the medium. But this type of gas corrosion, although common, is still a special case. If the effects of other aggressive gases on concrete are considered: hydrogen chloride, chlorine, sulfur dioxide, etc., then the calculation of the degenerated cement stone is necessary. [10]

A graphical dependence of the depth of concrete carbonization on the value of the structural parameter (Fig. 2) of the forecast of this type of gas corrosion of concrete is constructed.

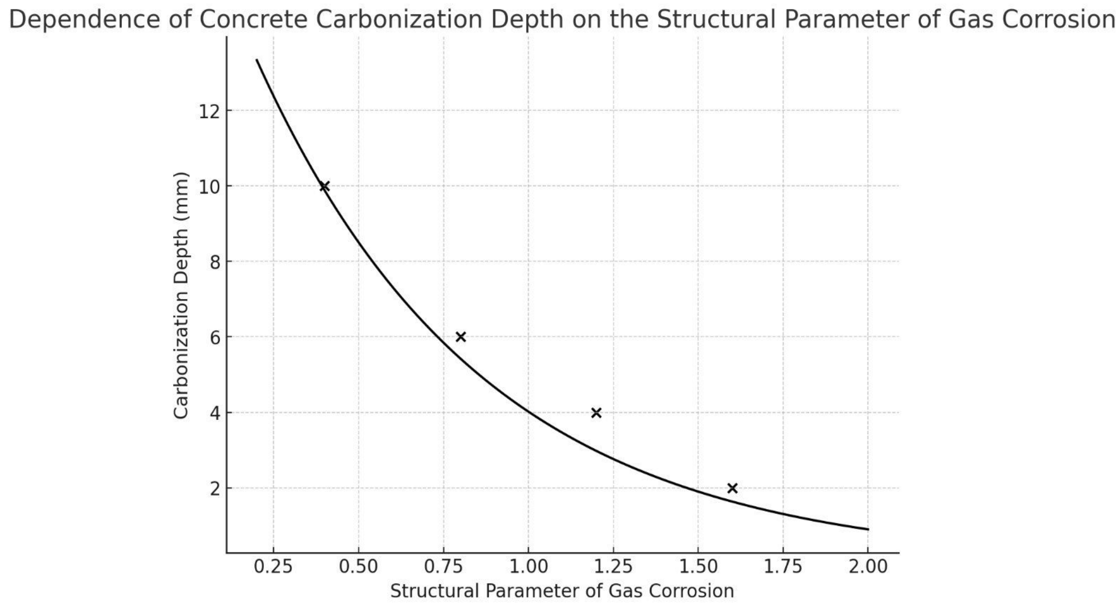
Dependence of Concrete Carbonization Depth on the Structural Parameter of Gas Corrosion

Figure 2. Dependence of the depth of concrete carbonization on the structural parameter of gas corrosion

As a result, it turns out that the structural parameter of gas corrosion (*Pgc*), in principle, should not differ from the structural parameter of other types of chemical corrosion. Calculations of the structural parameter have been performed and are reflected in Tab. 1, a graphical dependence of the depth of concrete carbonation on the value of the structural parameter has been constructed (Fig. 2). It is expressed analytically in the form of an equation that can be used to predict gas corrosion of concrete.

Table 1

Definition of the structural parameter resistance to gas corrosion

Nr.	**The volume of cement stone**	**W/C of cement stone**	**Porosity, a fraction of the volume of concrete**			**Structural parameter of gas corrosion**	**Carbonization depth, mm**
			Pores of the 1st group	*Pores of the 2nd group*	*Total porosity*		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
CONCRETE ON GRANITE RUBBLE							
1	0,2	0,24	0,042	0,085	0,125	0,36	14,0
2	0,3	0,24	0,043	0,087	0,169	0,67	8,0
3	0,4	0,24	0,044	0,088	0,174	0,94	4,4
4	0,5	0,24	0,045	0,091	0,179	1,81	2,8

5	0,6	0,24	0,047	0,093	0,185	2,32	1,6
6	0,2	0,34	0,060	0,091	0,150	0,17	17,0
7	0,3	0,34	0,065	0,120	0,228	0,18	12,4
8	0,4	0,34	0,073	0,146	0,267	0,38	10,0
9	0,5	0,34	0,081	0,160	0,290	0.61	8,2
10	0,6	0,34	0,087	0,173	0,310	0.82	7,0
11	0,2	0,44	0,080	0,101	0,175	0,09	20,0
12	0,3	0,44	0,089	0,131	0,250	0,12	16,4
13	0,4	0,44	0,094	0,188	0,334	0,18	14,0
14	0,5	0.44	0,100	0,220	0,374	0.22	12,0
15	0,6	0,44	0,120	0,240	0,415	0,23	11,0
CONCRETE ON LIMESTONE RUBBLE							
16	0,2	0,24	0,045	0,090	0,124	0,39	10,6
17	0,3	0,24	0,047	0,093	0,138	0,84	6,4
18	0,4	0,24	0,050	0,097	0,154	1,27	3,6
19	0,5	0,24	0,051	0,098	0,164	1,75	1,8
20	0,6	0,24	0,052	0,100	0,174	2,24	1,0
21	0,2	0,34	0,063	0,102	0,147	0,18	14,4
22	0,3	0,34	0,072	0,135	0,209	0,26	11,2
23	0,4	0,34	0,080	0,160	0,242	0,47	9,0
24	0,5	0,34	0,083	0,165	0,271	0,67	7,4
25	0,6	0,34	0,090	0,175	0,293	0,87	6.2
26	0,2	0,44	0,085	0,138	0,169	0.1	17,2
27	0,3	0,44	0,094	0,178	0,237	0,13	15,0
28	0.4	0,44	0,103	0,205	0,326	0,2	13,0
29	0,5	0,44	0,111	0,232	0,368	0,24	11,6
30	0,6	0,44	0,125	0,257	0,408	0,36	10,4
CLAYDITE-CONCRETE							
31	0,2	0,24	0,060	0,319	0,114	0,15	15,6
32	0,3	0,24	0,062	0,291	0,128	0,36	11,4
33	0,4	0,24	0,064	0,265	0,144	0,39	8,6
34	0,5	0,24	0,065	0,240	0,154	0,89	6,4
35	0,6	0,24	0,067	0,211	0,164	1,24	4,6
36	0,2	0,34	0,067	0,358	0,140	0,10	18,0
37	0,3	0,34	0,072	0,340	0,180	0,16	14,0
38	0,4	0,34	0,077	0,320	0,212	0,35	11,8
39	0,5	0,34	0,081	0,298	0,252	0,49	10,0
40	0,6	0,34	0,088	0,275	0,273	0,69	8,8
41	0,2	0,44	0,080	0,470	0,163	0,05	20,4
42	0,3	0,44	0,094	0,450	0,220	0,09	17,2
43	0,4	0,44	0,101	0,430	0,243	0,16	14,6
44	0,5	0,44	0,110	0,408	0,298	0,21	13,0
45	0,6	0,44	0,120	0,385	0,356	0,32	11,6

Interestingly, at values of *Pgc* < 2, the depth of carbonation increases rapidly, approaching 1 cm, i.e., the value critical for the protective properties of cement stone. Concretes with a carbonation depth of less than 2 cm are considered resistant to gas corrosion; according to our research, these concretes have a structural parameter exceeding 2.

Since the parameter "depth of carbonization" is not related to fixing the loss of strength, the explanation of the critical value of the parameter, equal to two, the beginning of the effect of interaction of defects, as in the case of frost resistance, does not look convincing. Probably, when individual structural defects (communicating pores) approach to a distance between them equal to the diameter of the pores (parameter 2 corresponds to this distance), the gas permeability of concrete increases sharply and, naturally, the depth of its carbonation.

Conclusion

The analysis of experimental material using a neural network based on the GPT (Generative Pre-trained Transformer) model showed that gas corrosion, despite certain specifics, when predicting its indicators, can be considered as a special case of corrosion of the 1st or 2nd type. [11]

This fact is another proof of the objectivity of the proposed structural parameters of chemical resistance, as well as proof of the effectiveness and expediency of using a neural network in the analysis of voluminous and long-term experimental material.

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