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Новый перспективный метод выявления карбонизации железобетонных строительных конструкций в практике обследований

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Рассмотрен новый метод выявления карбонизации бетона, который можно успешно применять на полевой и лабораторной стадиях обследования строительных конструкций из железобетона. Рассмотрены случаи протекания карбонизации и оценены аспекты её влияния на долговечность бетонных и железобетонных строительных конструкций гражданских, промышленных, транспортных и других различных объектов. Приведены примеры объектов, на которых можно проводить обследования с применением нового метода. Также проведено сравнение эффективности указанного метода с методом фенолфталеиновой пробы. Отличие нового метода состоит в том, что он позволяет оценить состояние защитного слоя бетона и выявить зоны, в которых процесс коррозии бетона, связанный с массопереносом целевого компонента только начинается или полноценно протекает. Недостаток метода фенолфталеиновой пробы (МФФП) состоит в том, что он не позволяет понять полную картину распределения pH бетона по слоям, поскольку индикатор имеет 1 рабочий интервал перехода окраски. Новый перспективный метод позволяет оценивать состояние обследуемых железобетонных конструкций на предмет их долговечности и степени повреждения, поскольку обладает повышенной точностью по сравнению с методом фенолфталеиновой пробы. Результаты, полученные новым методом можно использовать как для разработки/расчета физико-математических моделей развития процесса массопереноса при коррозии бетона, так и при организации ремонта железобетонных и бетонных строительных конструкций.

Ключевые слова: коррозия, карбонизация, бетон, железобетон, обследование, фенолфталеиновая проба, универсальный индикатор, массоперенос

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A new promising method for detecting carbonization of reinforced concrete building structures during inspections

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The paper considers a new method of detecting the carbonization of concrete that can be successfully applied at the field and laboratory stages of examining building structures made of reinforced concrete. The study included cases of carbonization and evaluated its influence on durability of civil, industrial, transport and other various building structures made of concrete and reinforced concrete. The paper includes examples of facilities where surveys can be conducted using the new method. This method was also compared with that of the phenolphthalein indicator solution in terms of its effectiveness. The new method makes it possible to assess the state of the protective layer of concrete and identify the zones where the corrosion of concrete, which is associated with mass transfer of the target component, has just begun or is fully running. A disadvantage of the phenolphthalein indicator solution method (PISM) is that it does not show a complete picture of the pH distribution of concrete over the layers, since the indicator has 1 working color transition interval. A new promising method makes it possible to assess the condition of the examined reinforced concrete structures for their durability and the degree of damage, since it has an increased accuracy in comparison with the phenolphthalein indicator method. The results obtained by the new method can be used both to organize/calculate physical and mathematical models of mass transfer process development during concrete corrosion and to organize the repair of reinforced concrete and concrete building structures.

Key words: corrosion, carbonization, concrete, reinforced concrete, inspection, phenolphthalein indicator, universal indicator, mass transfer

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INTRODUCTION

The inspection of concrete and reinforced concrete building structures operated in conditions of atmospheric air and moisture often includes identifying areas of concrete carbonization (other common types of concrete corrosion may also be identified). The condition of reinforced concrete structures of civil, industrial, transport structures, e.g. piers and slabs of bridges, overpasses, etc., directly depends on the degree of carbonization (Fig. 1) [1, 2].

Fig. 1. A road bridge in the Ivanovo region. The combined effect of carbonization and chloride corrosion. Burning and corrosion of longitudinal reinforcement

Another name for carbonization is neutralization, since the corrosion is associated with chemical reaction of one of the main components of cement stone – free calcium hydroxide (according to the terminology of S.V. Fedosov, academician of the Russian Academy of Architecture and Construction Sciences) [1-4]. The process can be roughly divided into 2 stages:

1) calcium carbonate formation

$$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3\downarrow + 2H_2O \quad (1)$$

2) calcium hydrogen carbonate formation and entrainment in the medium

$$CaCO_3\downarrow + H_2CO_3 \rightarrow Ca(HCO_3)_2 \quad (2)$$

The first stage (1) develops due to the specific aspects of the microstructure of the cement stone, which is a porous material. When interacting with atmospheric air (including humid environment), the pores of concrete are saturated with carbon dioxide (CO_2) or carbon dioxide solution (H_2CO_3), which leads to the formation of calcium carbon dioxide ($CaCO_3$) [1-4]. Calcium carbon dioxide ($CaCO_3$) is an insoluble compound so that it remains in the structure of the reinforced concrete structure [2-4].

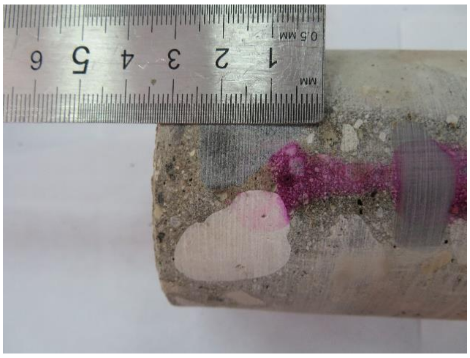
The second stage of the process (2) proceeds with an excess of carbon dioxide or carbonic acid. In the case of atmospheric operation, this condition is fully met because the air contains carbon dioxide. As a result, calcium hydrogen carbonate ($Ca(HCO_3)_2$), which is a soluble compound, is formed in solution. Further, when the structure gets wet, calcium hydrogen carbonate diffuses, and a solution forms, which is carried away into the external environment [1-4], and the cement stone of the concrete loses one of its most valuable components.

The carbonization is accompanied by a decrease in the pH of the protective layer of concrete [3-5]. According to various studies [4, 5], when the pH of concrete decreases below 10-9, it jumpstarts the chemical and electrochemical corrosion of reinforcement, since the passivating properties of concrete in relation to metal reinforcement may be lost [4, 5]. It should be noted that often carbonization affects concrete and reinforced concrete structures together with chloride corrosion [1, 4, 5, 10, 13] and biological corrosion [5, 7, 9]. The carbonization process directly affects the durability of concrete and reinforced concrete structures [1-5, 7, 8, 10, 13-15].

EXPERIMENT

It is important to detect carbonization during the field or laboratory stage at corrosion screening of concrete and reinforced concrete building structures. The phenolphthalein indicator solution method is one of the most used methods both in the field and in the laboratory stage [4, 6, 15]. The phenolphthalein indicator solution method (PISM) can be performed not only on-site by applying the indicator solution to fresh splinters of concrete or to newly prepared test holes, but also in the laboratory on pre-selected cylindrical samples (cores) (Fig. 2) [4, 6].

The phenolphthalein solution changes color depending on the pH value of the concrete. For example, at pH = 8-10 (alkaline environment), the coloring of phenolphthalein solution changes from colorless to pink (1 working transition interval). At a pH < 8, the phenolphthalein solution is colorless, which shows the boundaries of carbonized concrete zones and the depth of carbonization (see Fig. 2) [4, 6].



a

b

Fig. 2. Phenolphthalein indicator for carbonization conducted on a selected core sample (**a**) and the diamond drill site selected for the core sample (**b**)

Due to its simplicity and accessibility, PISM has been successfully used in inspection, but it still has drawbacks [4-6], which may contribute to losing time or insufficient accuracy of the results obtained. Consider as an example an unprotected concrete structure (without primary and secondary protection measures) [4, 6]. At pH > 10.5, the phenolphthalein solution is practically colourless, and the transition of indicator can easily be missed, especially in field conditions [4, 6]. For example, the pH of freshly made concrete is approximately 13-14 (strongly alkaline environment), while the pH of concrete of a newly erected (1-3 years, 3-5 years) concrete or reinforced concrete structure can be 11.5-12.5. In this range, the phenolphthalein solution is also colorless [4, 6]. If the neutralization of concrete has already «started», and its pH decreases gradually from initial values, the alcoholic solution of phenolphthalein will not show the dynamics of the process and the boundaries of the zones most vulnerable to carbonization, especially if the concrete damaged by corrosion visually does not differ from the whole [4, 6].

That is why, apart from phenolphthalein solution, the researchers look for solutions of other indicators, which can show indicative pH values of concrete and the boundaries of their distribution zones [4, 6].

The alcohol solution of the universal indicator ZIV-1 has been proposed as an alternative at the moment [6]. The indicator solution is applied to the walls of newly prepared test holes on the surface of reinforced concrete structures, which are located at a certain distance from each other (Fig. 3). The hole cavities are thoroughly cleaned of concrete dust and dirt, and rinsed with distilled water to remove any contamination. The indicator solution can also be applied to fresh concrete splinters if making the test holes is difficult (see Fig. 3) [6].

IMPORTANT! When using the method, it is necessary to have good quality lights that will illuminate the test holes. It is also necessary to have a hammer drill with drills of required diameters (from 16–24 mm).

a **b**

Fig. 3. Example of an inspected reinforced concrete structure (**a**), which has been outdoors for more than 15 years, and test holes 30-50 mm deep in the surface of the reinforced concrete structure (**b**)

Since the universal indicator is a mixture of different indicators, it has several transition intervals, unlike phenolphthalein (Fig. 4) [6]. Each transition interval corresponds to a unique solution coloring (it contrasts significantly with the initial one), which simplifies determining pH in the specified area (see Fig. 4) [6].

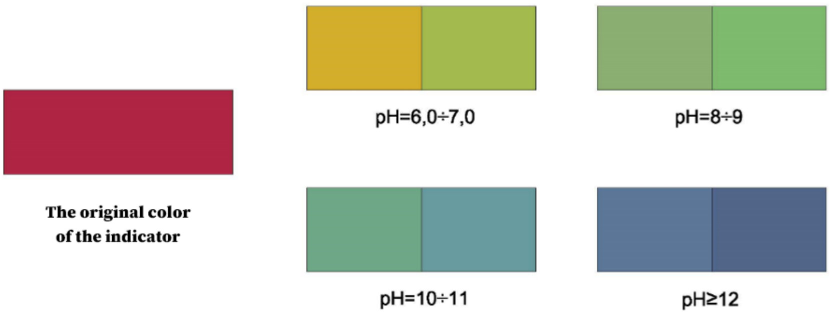


Fig. 4. Transition intervals of ZIV-1 universal indicator solution

Thanks to this indicator, it is possible to get an idea of the boundaries of concrete zones with specific pH values (Fig. 5). The same area of fresh concrete splinter is shown as an example. Alcohol solutions of phenolphthalein and the universal indicator ZIV-1 were applied to its surface (see Fig. 5) [6].

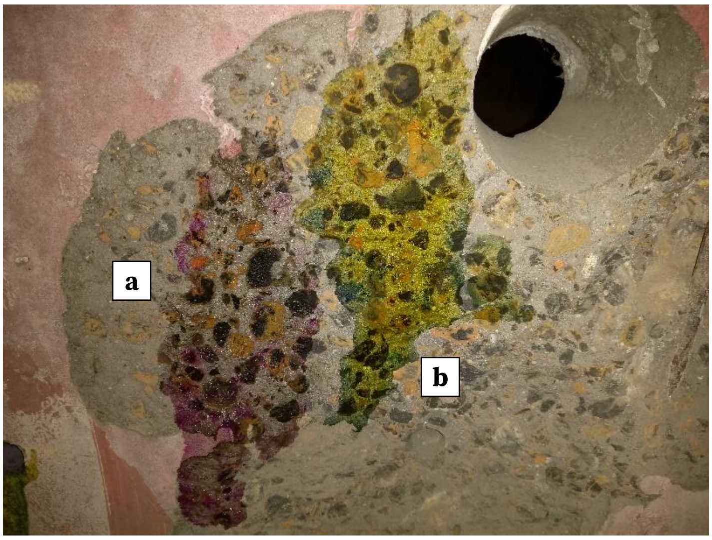


Fig. 5. Comparison of readings of alcoholic indicator solutions:
a – phenolphthalein; **b** – universal indicator ZIV-1.
In colorless areas of phenolphthalein, carbonized concrete, pH of which can be determined using the universal indicator solution

CONCLUSIONS

We used this method to inspect more than 10 areas of a reinforced concrete structure (cover slab of the road bridge in the Ivanovo region) which has been in use for a long time (more than 30 years) affected by atmospheric air and moisture. The structure is made without primary and secondary concrete protection [2, 3, 14]. The comparison results are shown in Table 1.

Note that, in areas **N 4** and **N 9**, the phenolphthalein is colorless, i.e., according to the phenolphthalein indicator, it is assumed that the pH of the concrete in this area is less than 8 (visually, the concrete is similar to the corroded areas). However, the ZIV-1 universal indicator solution shows that the pH of these concrete areas is above 12. This means that the area is completely «healthy» [6] – when repairing a reinforced concrete structure, it does not have to be removed and restored subsequently using repair compositions [2, 3].

In areas **N 2** and **N 8**, where the phenolphthalein solution is almost colorless (i.e., pH of concrete ≈ 8), the solution of the universal indicator ZIV-1 provides almost completely accurate values (see Table 1). A similar situation is observed at areas **N 5**, **N 6**, **N 10**, where at pH values < 8, the new method shows boundaries of completely neutralized concrete zones with greater accuracy [6].

The proposed method of determining concrete carbonization zones is promising and more accurate in comparison with phenolphthalein indication method, and also shows the dynamics of the process (boundaries of concrete zones with different pH values) [6]. Even in field conditions, taking into account factors of operation of reinforced concrete structures, it helps estimate the distribution of concrete zones most vulnerable to carbonization and determine the moments of possible beginning of chemical and electrochemical corrosion of reinforcement in these areas [6].

Table 1. Comparison of readings of the proposed method with the phenolphthalein indicator method

Area N	Phenolphtalein indicator solution method		Proposed method	
	Color	pH	Color	pH
1	Pink	8–10	Light green	9–9.5
2	Pale pink	~ 8	Pale green	7.5–7.9
3	Pink	8–10	Light green	~ 9.5
4	**Colorless**	**< 8**	**Blue**	**~ 12.5**
5	Colorless	< 8	Yellow	~ 6
6	Colorless	< 8	Yellow-green	6.5–7.0
7	Dark pink	8–10	Dark green	~ 10.5
8	Pale pink	~ 8	Pale green	7.5–7.9
9	**Colorless**	**< 8**	**Blue**	**~ 12.5**
10	Colorless	< 8	Yellow	~ 6

The method can be used not only in assessing the durability of concrete and reinforced concrete structures [6], but also in testing the latest acid, alkaline, and saline additives in concrete, because it will provide insight into their influence on the pH of freshly prepared concrete. All the data thus obtained make it possible to take into account the development of physical and mathematical models of mass transfer process during concrete corrosion [1, 5, 7, 9, 14, 15] and, consequently, to simplify inspection and forecasting of residual service life of building structures made of reinforced concrete.

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