Field tests of the efficiency of the corrosion inhibitor IFKhAN-80 for reinforcement steel in concrete under tropical conditions. 1. Contact protection

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Abstract

The corrosion of reinforcement steel in concrete is a serious and widespread problem in construction. Inhibitors play an important role in protection against it. The Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences has developed an inhibitor against corrosion of reinforcement steel in concrete named IFKhAN-80. It is a non-toxic and non-flammable formulation based on raw materials available in Russia. Its functional properties have been studied in detail under laboratory and field conditions of moderate climate. IFKhAN-80 is widely used in practice, but there was no experience of its application in the tropics. The ability of IFKhAN-80 to provide contact protection of reinforcement of steel reinforcement under tropical conditions has been studied in this work by corrosion and electrochemical methods. The high efficiency of the inhibitor even for concretes with high chloride content was shown.

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Introduction

The corrosion of reinforcement steel in concrete is a serious and widespread problem in construction [1, 2].

The pore fluid in concrete is highly alkaline, which ensures the passivity of the metal under ordinary conditions. However, a decrease in the pH of the environment in the pores of concrete due to its carbonization, penetration of chemical reagents (primarily chlorides) into the concrete from outside, and failure to comply with the procedure of concrete works can lead to corrosion initiation [3].

To date, various methods and materials have been developed to slow down the corrosion of reinforcement in concrete and extend the service life of structures. An important place among these belongs to corrosion inhibitors, i.e., compounds and their formulations capable of inhibiting corrosion without changing the concentration of the main corrosive components [2].

Corrosion inhibitors for steel reinforcement in concrete are classified into contact and migrating ones [4–6]. Contact inhibitors are added into concrete with mixing water when making reinforced concrete structures intended for operation under severe conditions. Migrating inhibitors are applied to the surface of concrete during repair and restoration works, penetrate into it, reach the steel reinforcement, and slow down its corrosion.

Scientists at the Institute of Physical Chemistry and Electrochemistry of the Russian Academy of Sciences have developed an efficient inhibitor against the corrosion of steel reinforcement in concrete, IFKhAN-80. It is a non-toxic and non-flammable formulation based on raw materials available in Russia. In its commercial form, the product is a 30% aqueous solution of the inhibitor. It is versatile and can be used both as a contact and migrating inhibitor. Its functional properties have been studied in detail under laboratory and field conditions with moderate climate [7–13]. The developers believe that IFKhAN-80 can be used at least for the contact protection of steel reinforcement in concrete and in the tropics. However, the tropical climate is very specific and highly corrosive, and there was no direct confirmation of the effectiveness of IFKhAN-80 under these conditions. This study aims to fill this gap. Its purpose is to test the efficiency of IFKhAN-80 as a contact inhibitor under tropical conditions. The protective properties of this formulation as a migrating inhibitor will be discussed in a separate publication.

Experimental

Reinforced concrete specimens of 160x40x40 mm in size, with cores made of steel bars of 6.5 mm diameter and 120 mm long, were prepared for the tests. Cement from the Starooskol plant (RF), sand sieved through a sieve with a mesh size of 2 mm, and 08 ps reinforcing steel were used. The steel bars were completely hidden by the concrete layer. In all cases, sodium chloride was added in an amount of 3% with respect to the cement mass. Such a chloride content exceeding that usually encountered in practice was chosen to estimate the inhibitor's maximum capabilities. 1.5% of IFKhHAN-80 (with respect to the active ingredient) was also added with mixing water to one third of the samples. One more third of the samples contained 3% of the inhibitor. The appearance of samples prepared for testing is shown in Figure 1.

The samples were exposed under a shelter at Dam Bai corrosion station (Socialist Republic of Vietnam, Nha Trang, Che Island) for 31 or 44 months. After the exposure, the corrosion-electrochemical state of steel was estimated in accordance with GOST 31383-2008 [14].

Figure 1. Appearance of specimens prepared for testing in the tropics.

For this purpose, the specimens were kept for 24 hours in tap water. Then, by chopping concrete off, reinforcing bars were exposed from one edge of the specimens, the specimens were placed in an electrochemical cell with water, a P-5848 potentiostat was connected to them, and anodic polarization curves were recorded. The appearance of the samples prepared for electrochemical experiments is shown in Figure 2. All potentials (*E*) were recorded with respect to silver chloride electrode. A stainless-steel plate served as the auxiliary electrode. Polarization was performed by shifting the potential by 0.1 V every minute from the steady-state value to 1 V. After reaching this potential, polarization was turned off.

Figure 2. Appearance of a sample prepared for electrochemical experiments.

During the experiments, the anodic current density at E=0.3 V (i*) and the potentials of the reinforcing steel one minute after the polarization was turned off (E*) were recorded. The values of i* and E* according to [14] serve as the criteria in the evaluation of the reinforcing steel condition. If $i^*>25$ μA/cm^2 and $E^*<0.005$ V, it is believed that the reinforcing steel is in the active state. If $i^*<10$ μA/cm^2 and $E^*>0.005$ V, the reinforcing steel is considered to be in the passive state. The i* values in the range from 10 to 25 μA/cm^2 indicate an intermediate (active-passive) state of steel.

In addition to the electrochemical estimation, the efficiency of inhibitors was inferred from the surface condition of steel bars after exposure of samples under corrosive conditions. Concrete from the reinforcing steel was chopped off completely and the areas of corroded metal surface were determined.

Results and Discussion

The curves of anodic polarization of reinforcement steel after 31 months of exposing the samples under corrosive conditions are shown in Figure 3. The values of i* and E* characterizing the steel state are given in Table 1.

As it can be seen in Figure 3, the anodic polarization curves of steel in the background samples containing no inhibitor there is no pronounced passivity region. The potential shift in the positive direction leads to a sharp intensification of metal dissolution. At the same time, though the value of i* lies in the range of values characterizing a passive metal, it is close to its upper boundary (Table 1).

Once polarization was turned off, *E* was falling to reach the value of –0.220 V, which characterizes the active state of the metal, after one minute.

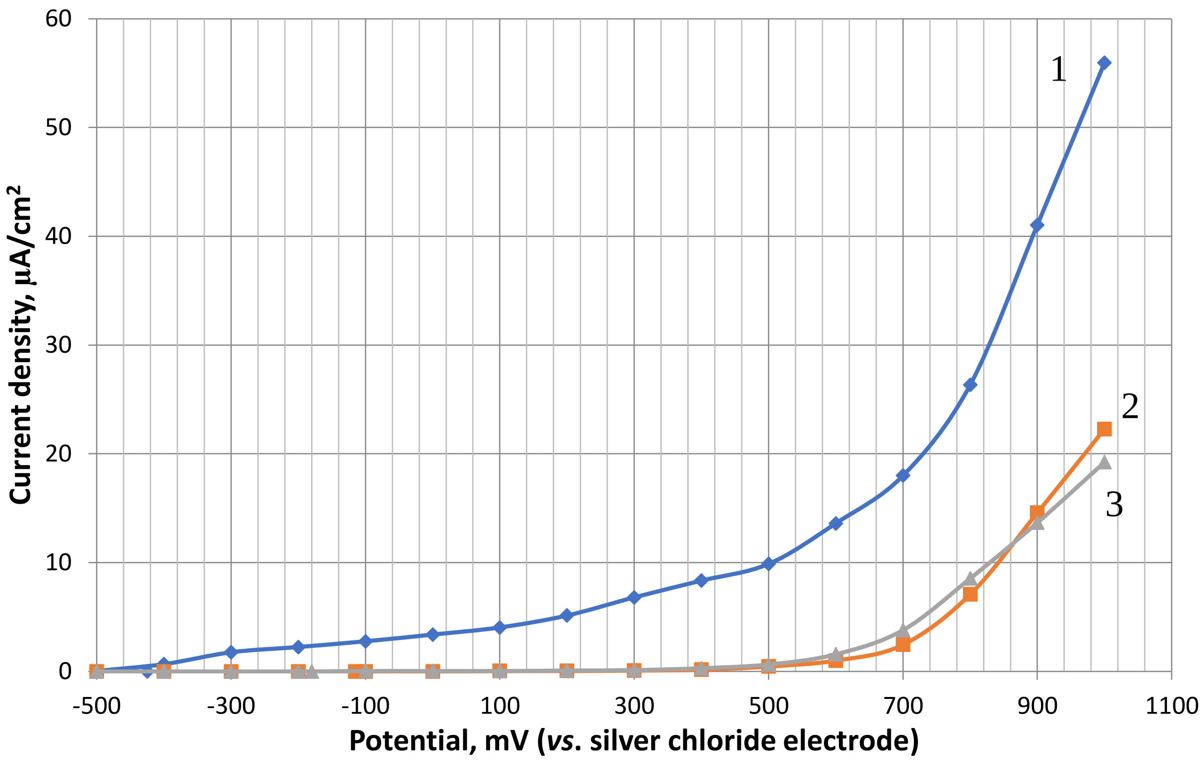

Figure 3. Anodic polarization curves of reinforcing steel samples containing 3% sodium chloride and IFKhHAN-80 inhibitor additive: 0% (curve 1), 1.5% (curve 2) and 3% (curve 3) exposed to corrosive conditions for 31 months.

Table 1. Characteristic values of anodic polarization curves of reinforcing steel for specimens exposed to corrosive conditions for 31 months.

Concrete treatment method and inhibitor dosage	*i**, μA/cm^2	*E**, V
Samples not treated with the inhibitor	6.8	–0.220
1.5% IFKhAN-80 added with mixing water	0.1	0.490
3% IFKhAN-80 added with mixing water	0.1	0.470

Thus, based on one of the criteria suggested in [14] (*E**), the metal state in the background samples is characterized as active, while based on the other one (*i**) as passive, close to active-passive. The experience of the authors' studies testifies: if at least one of the criteria indicates that the metal is in active state, it should be considered as active.

This conclusion is supported by the result of inspection of steel bars in the background specimens after the tests. After exposure for 31 months in the corrosive environment, the specimens continued to corrode. After 31 months of exposure of specimens at the station, corrosion occupied 29% of the specimen surface, and after 44 months, already 37%.

Addition of IFKhHAN-80 into concrete markedly reduced the anodic dissolution currents of steel. The polarization curves contained passivity regions. The metal state estimated by the *i** and *E** values is also characterized as passive.

The anodic polarization curves of reinforcing steel after 44 months of exposing the specimens under corrosive conditions are shown in Figure 4. The values of *i** and *E** are provided in Table 2.

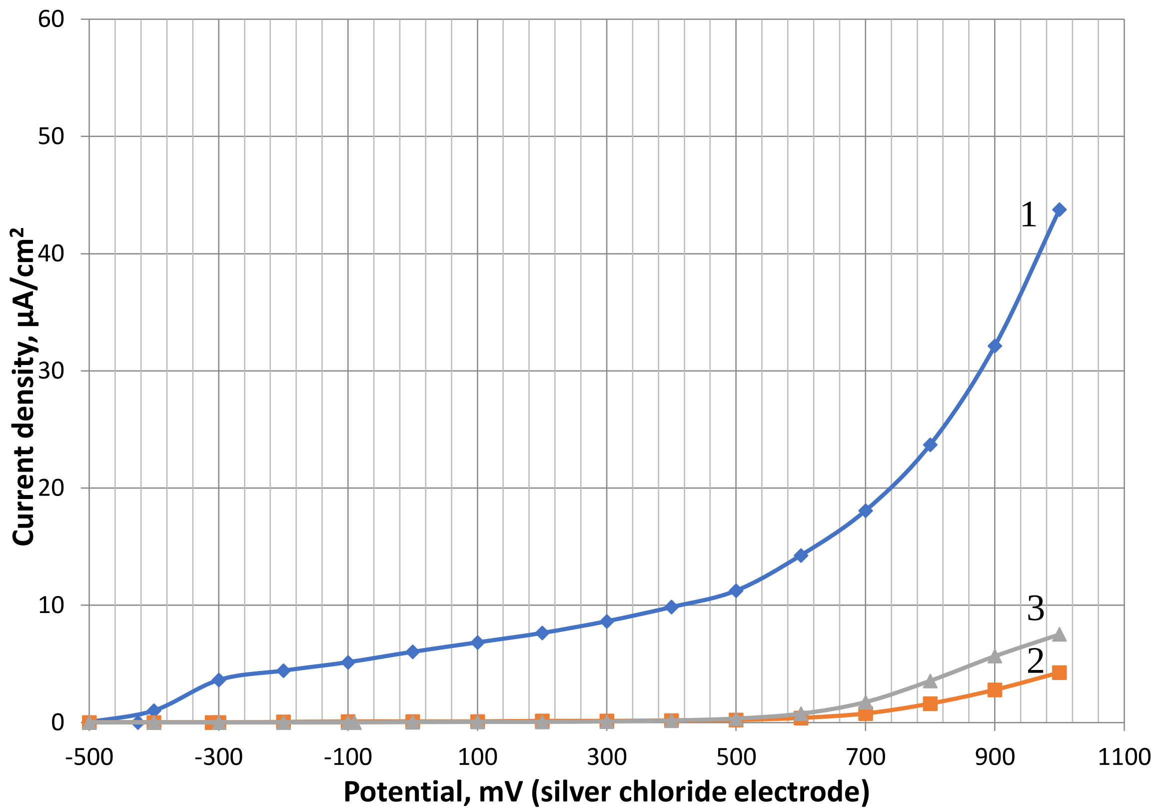

Figure 4. Anodic polarization curves of reinforcing steel for samples containing 3% sodium chloride and IFKhHAN-80 inhibitor additive: 0% (curve 1), 1.5% (curve 2) and 3% (curve 3), exposed to corrosive conditions for 44 months.

Table 2. Characteristic values of anodic polarization curves of reinforcing steel for specimens exposed to corrosive conditions for 44 months.

Concrete treatment method and inhibitor dosage	***i****, μA/cm²	***E****, V
Samples not treated with the inhibitor	8.6	–0.010
1.5% IFKhAN-80 added with mixing water	0.1	0.400
3% IFKhAN-80 added with mixing water	0.1	0.480

The appearance of polarization curves after 44 months of exposure in corrosive conditions almost repeats the appearance of the curves in Figure 2. The background samples are characterized by rather high values of steel dissolution current densities. Addition of the inhibitor into concrete sharply inhibits the anodic process.

The condition of the metal in the background samples is characterized as active based on the values of E^*, and as passive based on i^*. Nevertheless, the values of i^* are close to the values characteristic of the active-passive state.

The values of E^* and i^* indicate the reinforcing steel in the samples containing IFKhHAN-80 is passive.

Additional information on the efficiency of IFKhHAN-80 is provided by inspection of reinforcing bars after exposure for 44 months under corrosive conditions. Photographs of the bars are shown in Figure 5.

In the absence of the inhibitor, steel in chloride-containing concrete corroded intensely. At the end of the experiment, corrosion products covered 37% of the surface. Addition of IFKhHAN-80 to concrete significantly improved the corrosion condition of the metal. The area of the corroded surface decreased to 5% at the inhibitor concentration of 1.5% and to 0.6% at the concentration of 3%.

1 2 3

Figure 5. Appearance of reinforcing bars after 44 months of exposure of specimens with 3% sodium chloride in the tropics. 1 – samples containing no inhibitor, 2 – samples containing 1.5% inhibitor, 3 – samples containing 3% inhibitor.

Thus, the results of field tests confirm the efficiency of IFKhHAN-80 as a corrosion inhibitor in chloride-containing concrete under tropical conditions.

Conclusion

The inhibitor IFKhHAN-80 provides efficient contact protection against corrosion of steel reinforcement of concrete items with high chloride content under tropical conditions.

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