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Tetiana Yarova,
Roman Khmyzenko,
Anna Yanovska

ANALYSIS OF THE FUNCTIONAL ADDITIVES EFFECT ON THE CORROSION RESISTANCE OF PAINT COATINGS

The paper deals with the issue of protecting metals from corrosion, which can damage their structures. Anti-corrosion coatings are widely used to ensure the durability of steel structures. It was described that the durability of the coating depends on the chemical and physical characteristics of the system, such as the type of coating, dry film thickness, water resistance, and adhesion. The importance of artificial aging tests for assessing the durability of coatings is considered, emphasizing that the results of such tests should be interpreted with caution, taking in consideration that artificial aging may not have the same effect as natural exposure. Various anti-corrosion additives for acrylic water-dispersion enamels are also described, which can improve the corrosion resistance of the coating, depending on the service conditions. The object of the research is the properties of enamels with functional additives in salt fog. The study results of the effectiveness of the anti-corrosion additives in acrylic enamels using salt fog from the BGD 881/S chamber are discussed. The research showed that the main requirement for increasing the effectiveness of the anti-corrosion additive in acrylic LPM is a comprehensive approach to improvement of the coating barrier properties, which additionally reduces the aggressive influence of the environment. The advantages of new complex anti-corrosion additives compared to traditional anti-corrosion pigments are multifunctionality – complex additives like Askonium 142 DA contain several active components that affect various coating properties, including anti-corrosion protection, adhesion, and water resistance. Traditional pigments, such as zinc phosphate, usually have only one function – to create a protective film on the metal. The main research idea of the article is to study the influence of anti-corrosion additives in paint coatings for metal protection from corrosion and the extension of the service life of structures.

Keywords: *anti-corrosion additives, corrosion protection, salt spray, paint coatings, durability of lacquer coatings.*

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1. Introduction

Unprotected steel in the atmosphere, water, and soil undergoes corrosion, which damaging it. Therefore, to avoid corrosion, steel materials are usually protected using anticorrosive coatings [1]. The problem of functional coatings formation will combine corrosion resistance, hardness, wear resistance, and catalytic activity, which is crucial for the creation of new materials, leading to progress in many areas of modern technology [2].

Corrosion resistance is the leading indicator of paint coating performance. The research includes experiments to simulate the conditions of the corrosive environment that can occur in different climate. The chemical process of corrosion is complex and can be considered as an electrochemical phenomenon. During corrosion, oxidation occurs at a certain point on the surface of an iron-made object. The spot on the object's surface acts as an anode, releasing electrons. These electrons travel through the metal and move to another point on the metal. In this process, oxygen is reduced in the presence of H^+ (which can be formed from H_2CO_3 due to the dissolution of carbon dioxide from the air in water under humid atmospheric conditions) at the point where oxidation occurs. In addition, hydrogen ions in the water may also be available due to the dissolution of other acid oxides from the atmosphere. In this process, the stain on the metal surface acts as a cathode. An important factor affecting corrosion is the pH of the medium (Fig. 1), which can change due to hydrogen or oxygen depolarization [3, 4].

The choice of a paint system for a particular situation should be based primarily on the experience with similar applications. The reason for this is the dependence of the paint system's durability on many external factors, such as the environment, type of construction, surface preparation, application, and drying procedures. Of course, durability is also related to the chemical and physical characteristics of the system, such as the type of film-forming agent and the thickness of the dry film. Artificial aging tests can assess the impact of these characteristics on durability. The most important is resistance to water or moisture, as well as salt spray, as an indication of wet adhesion and barrier properties. The aging and durability tests specified here and, in the following, have been chosen to ensure that it is very likely that the paint systems do have the characteristics necessary to provide the durability required in the intended application. However, the results of artificial aging tests should be used with caution. It should be clearly understood that artificial aging will not necessarily have the same effect as natural aging [5].

Anti-corrosion additives for waterborne acrylic enamels play an essential role in protecting metal surfaces from corrosion and extending the service life of coatings. Additives such as zinc phosphates, modified silicates, metal oxide-based corrosion inhibitors, organic corrosion inhibitors, nano-metal oxides, polymer additives, and metal passivators are often used to improve the corrosion properties of paints and coatings. Each of these additives can be used for specific operating conditions of acrylic enamels, depending on the type of metal, aggressiveness of the environment, and requirements for coating durability.

The aim of this research is to test the anticorrosive properties of enamel formulations with functional additives using the salt spray test method.

2. Materials and Methods

Salt spray testing is a widely used accelerated corrosion test method. In this method, metallic and non-metallic materials are exposed to an aggressive corrosive environment for an extended period of time to evaluate their resistance to corrosion in a salt spray chamber. A typical salt spray chamber (Fig. 1) has an air saturation tower that stabilizes the salt concentration, a tank for the solution itself, a spray nozzle to create the mist, supporting mechanisms to hold the parts, a way to distribute heat inside the chamber, and a temperature controller [6].

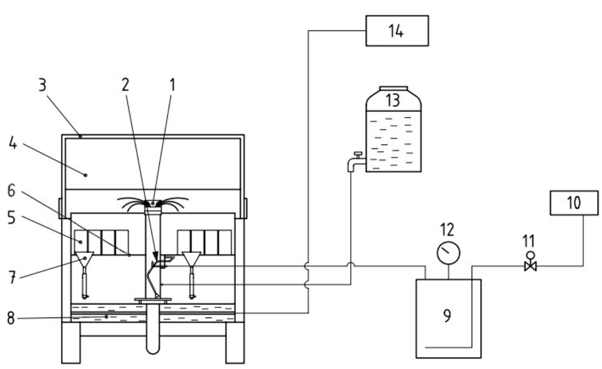

Fig. 1. Schematic of the BGD 881/S salt mist chamber (front view) [7]: 1 – mist dispersion tower, 2 – atomizer, 3 – cover, 4 – test chamber, 5 – test specimen, 6 – test-specimen support, 7 – fog collector, 8 – chamber, 9 – air saturator, 10 – air compressor, 11 – solenoid valve, 12 – pressure gauge, 13 – solution tank, 14 – temperature controls

The salt spray test is an accelerated corrosion test that induces corrosive effects on coated samples to predict their suitability for use in aggressive environments. The appearance of corrosion products (oxides) is evaluated after a certain period of time. The duration of the test depends on the corrosion resistance of the coating; the more resistant the coating is to corrosion, the longer the test period without showing signs of corrosion [8].

The test apparatus consists of a closed test chamber where a saline solution (5 % sodium chloride solution) is sprayed using a nozzle. This creates a corrosive environment of dense salt mist in the chamber, so that the parts exposed to it are subjected to severe corrosive conditions. The test can last from a few hours to several weeks or months depending on the standards and requirements.

The climate testing procedure in salt mist installations is carried out in two ways [7]:

1) continuous spraying of a concentrated solution;

2) cyclic impact on the object.

Cyclic testing includes the following stages:

1. Creation of salt fog – the standard phase involves spraying small particles of saline solution that fall on the material under testing.

2. Drying – the material is dried at the specified humidity and temperature parameters.

3. Formation of condensate – the procedure is characterized by an increase in moisture parameters in the working environment up to 100 %, since condensation provides favorable conditions for the development of corrosion processes.

4. Regulation of humidity indicators – provides for the establishment and stable maintenance of the required humidity indicators at a temperature of +35 °C for 16 hours to 28 days.

Modifications of climate control equipment include units for short-term testing (up to 10 days) and long-term testing, the duration of which exceeds 240 hours. The devices are equipped with controllers designed to record the condition of the samples and sound indicators that notify the equipment operator of changes in the material structure.

A study of the effectiveness of anti-corrosion additives in acrylic enamel was conducted. The tests were carried out using a BGD 881/S salt spray chamber. The test involved samples of 3 in 1 water-dispersion acrylic enamel in three colors: white, black, and orange. The enamel was applied in 2 layers with a total dry film thickness of approximately 80–90 microns. The following anticorrosive additives were chosen: Heucopos ZCP zinc phosphate and ASCONIUM 142DA. For comparison, the third sample was enamel without the addition of anti-corrosion additives.

Zinc phosphate is widely used as an anti-corrosion additive in paints and varnishes to protect metal surfaces. Zinc phosphate forms a passive layer on the metal surface that prevents contact with corrosive substances such as oxygen and water. It is effective in protecting metals in conditions of high humidity and aggressive chemical attack. Unlike other pigments, such as chromates, zinc phosphate is considered more environmentally friendly.

ASCONIUM 142DA is an advanced liquid corrosion inhibitor designed for use in water and solvent-based coatings, especially in direct metal contact applications. It is very effective in providing long-lasting corrosion protection, as well as improving adhesion, water resistance and reducing film blistering. ASCONIUM 142DA produces coatings that meet the requirements of corrosion resistance class C5 (ISO 12944) [9], making it ideal for harsh environments. In addition, it helps coatings maintain a high gloss and allows for painting without compromising performance.

Unlike zinc phosphate, which forms a passive layer through chemical processes, Askonium 142 DA adsorbs to the metal surface to form a protective layer. This layer isolates the metal from aggressive agents such as water, oxygen or chlorides that cause corrosion. This reduces the number of active sites on the surface where corrosion can begin.

3. Results and Discussion

The following parameters were examined to evaluate the effectiveness of anticorrosive protection of paint and varnish coatings [10]: assessment of the degree of blistering, assessment of the degree of rusting, assessment of the degree of peeling and corrosion around an incision of artificial defect, assessment of the adhesion of the coating to the metal before and after the test.

The samples morphology with and without additives after 240 hours of salt spray test is presented in the Fig. 2.

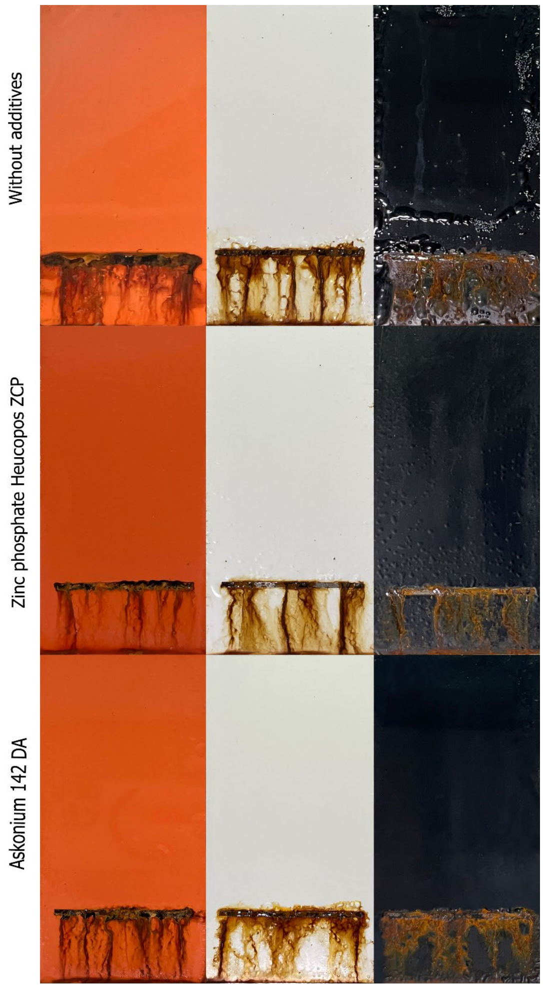

Fig. 2. Samples after salt spray test (240 hours)

Among the enamel samples tested, those containing Askonium 142 DA demonstrated the best anticorrosive properties and improved adhesion to metal surfaces and enhanced water resistance. Results of coatings destruction (Table 1) and artificial aging for a specified time (Table 2) are presented below.

Any defect occurring within 1 cm of the edges of the test plates is not taken into account.

The coating is considered to have withstood the salt spray test if the results of the assessment of the destruction of the paint and varnish coatings of the test samples meet the requirements of DSTU ISO 12944-6. After determining the conformity of the assessments, each coating sample is assigned a durability class. If the destruction does not meet the requirements, the coating is assigned a lower durability class for the corresponding test period. Results of salt spray test is given at the Table 3.

The durability of the samples of this enamel in accordance with DSTU ISO 12944-1 will be for *C3 L (low)* – up to 7 years, *C3 M (medium)* – from 7 years to 15 years in conditions of medium corrosiveness: Urban and industrial atmospheres, moderate sulfur dioxide pollution; Coastal areas with low salinity; Production facilities with high humidity and some air pollution, such as food processing plants, laundries, breweries, dairies; for *C4 L (low)* – up to 7 years in conditions of high corrosive aggressiveness: Industrial areas and coastal areas with moderate salinity; chemical plants, swimming pools, coastal vessels and shipyards [1].

Among the proposed enamel samples, the best anticorrosive properties were found in enamel samples with the addition of Askonium 142 DA. Based on the results of the study, this additive is particularly suitable for acrylic-based systems and can replace traditional anti-corrosion pigments such as zinc phosphate, outperforming them at lower doses.

Coating the sample with Askonium 142 DA showed better adhesion to the metal surface and water resistance. Therefore, it can be concluded that this additive is more effective for this water-dispersion system.

Table 1

Evaluation of paint and varnish coatings destruction of the tested samples after the test

Color	Functional additive	Degree of blistering	Degree of rusting	Corrosion from the cut after the salt test	Adhesion of the coating to the base (or metal)
Orange	Without additives	S1	Ri 0	0.5 mm – grade 2	3 points
	Askonium 142 DA	0(S0)	Ri 0	0.5 mm – grade 2	0 points
	Heucopos ZCP	3(S3)	Ri 0	1 mm – grade 1	3 points
White	Without additives	3(S5)	Ri 2	4 mm – grade 2	3 points
	Askonium 142 DA	0(S0)	Ri 0	0.5 mm – grade 2	1 point
	Heucopos ZCP	4(S4)	Ri 1	2 mm – grade 1	2 points
Black	Without additives	5(S5)	Ri 2	6 mm – grade 2	1 point
	Askonium 142 DA	0(S0)	Ri 0	1.5 mm – grade 2	0 points
	Heucopos ZCP	5(S4)	Ri 1	2 mm – grade 1	1 point

Table 2

Evaluation after artificial aging for a specified time (DSTU ISO 12944-6)

Assessment methods	Requirements	Assessment time
ISO 4628-2, blistering	0 (S0)	Immediately
ISO 4628-3, degree of rusting	Ri 0	Immediately
ISO 4628-8, corrosion from cut after salt test	Max. 1.5 mm pitting corrosion as an average value	As soon as possible, but within 8 hours of the end of the test
ISO 2409, lattice cut test	Classification 0 to 2	Assessment after 7 days in a standard atmosphere as defined in ISO 3270

Table 3

Results of salt spray tests of the above samples

Color	Functional additive	Salt spray test ISO 9227	Durability class ISO 12944
Orange	Without additives	<240	C3 L low
	Askonium 142 DA	240	C3 M medium, C4 L low
	Heucopos ZCP	<240	C3 L low
White	Without additives	<240	C3 L low
	Askonium 142 DA	240	C3 M medium, C4 L low
	Heucopos ZCP	<240	C3 L low
Black	Without additives	<240	C3 L low
	Askonium 142 DA	240	C3 M medium, C4 L low
	Heucopos ZCP	<240	C3 L low

Practical significance: Thus, by adding Askonium 142 DA anti-corrosion additive to enamels, the manufacturer extends the service life of the coating from 7 to 15 years, which in turn has a positive impact on the environment due to the lower consumption of this product.

Limitations of the study: In order to implement the results obtained in practice, it is necessary to select the amount of anticorrosive additive required for a certain enamel formulation with the corresponding raw materials.

Impact of martial law conditions: The study was also influenced by the conditions of martial law in Ukraine, namely: due to scheduled and emergency power outages, the operation of the salt fog chamber could be suspended. Therefore, it was necessary to constantly monitor the uninterrupted power supply, which was provided by a current generator. Since the generator has a high fuel consumption, the cost of the experiment increased.

Further research will be aimed at selecting the amount of Askonium 142 DA anticorrosive additive in the enamel in order to achieve a higher durability class of the coating, thereby ensuring a longer service life. And to implement the research results in production.

4. Conclusions

The study showed that the main requirement for increasing the effectiveness of an anti-corrosion additive in acrylic paintwork is a comprehensive approach to improving the barrier properties of the coating itself, which further reduces the aggressive effects of the environment. However, an acrylic material containing water in its composition needs additional protection against instantaneous corrosion, which acts on the metal during physical drying until all the water evaporates from the coating.

Askonium 142 DA is a multicomponent mixture of active substances, each component of which is responsible for certain properties of the paintwork, such as corrosion protection, water resistance, and adhesion of the coating to the metal. Zinc phosphate is a single-component additive that is solely responsible for creating a protective film that prevents further interaction of the metal with the corrosive environment, but the coating itself is less resistant to mechanical damage and weathering.

Thus, the main difference and advantage of Askonium 142 DA is its multicomponent nature and integrated approach to creating a barrier coating, which is why it has the best anti-corrosion properties.

During the experiment, it was found that enamels with Askonium 142 DA additives according to DSTU ISO 12944-1 belong to the C3 M (medium) durability class, which corresponds to the operation of the coating for 7–15 years under conditions of medium corrosion activity and to the C4 L (low) class – up to 7 years under conditions of high corrosion aggressiveness. In contrast, enamels without functional additives and with zinc phosphate belong to the C3 L (low) class, which guarantees a durability period of up to 7 years in conditions of medium corrosivity.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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✉***Tetiana Yarova,*** *Department of Theoretical and Applied Chemistry, Sumy State University, Sumy, Ukraine, ORCID: https://orcid.org/0009-0002-8297-6965, e-mail: tania3316yarova@gmail.com*

Roman Khmyzenko, *Head of Research Department, Company MC "POLYSAN" LTD, Sumy, Ukraine, ORCID: https://orcid.org/0009-0008-5855-4766*

Anna Yanovska, *PhD, Associate Professor, Department of Theoretical and Applied Chemistry, Sumy State University, Sumy, Ukraine, ORCID: https://orcid.org/0000-0001-8040-7457*

✉*Corresponding author*