Integral assessment of anti-corrosion materials’ quality

V V Deryushev 1, M M Zaitseva 1*, I V Kundryutskova 2, O S Ovchinnikov 3

1Don State Technical University, 1, Gagarin sq., Rostov-on-Don, 344002, Russia
2Kamensk Technological Institute (branch), Platov South-Russian State Polytechnic University (NPI), St. Saprygina, 6, Kamensk-Shakhtinskiy, 347800, Russia
3Platov South-Russian State Polytechnic University (NPI), St. Prosvescheniya, 132, Novocherkassk, 346400, Russia

E-mail: marincha1@rambler.ru

Abstract. In modern conditions, protective paint and varnish coatings are used everywhere to ensure the safety of metal structures and include the materials of various composition and application. The paints and varnishes market offers conventional hard and thixotropic anticorrosive coatings applied by the devices using airless spray technology. The article describes the experiment results, which consists in conducting a comparative analysis of protective materials in the framework of laboratory studies. The main physical and mechanical properties are determined. Modeling of anticorrosive coatings’ indicators, which determine the degree of change in material properties in terms of adhesion, thickness, uniformity, flexibility and weather resistance of the treated surface of a metal structure, has been carried out. The values of the indicators were formed within the framework of the existing database, created and replenished using the real data obtained during the maintenance and repair of the existing facilities. The considered method is applicable for any number of analyzed surfaces and parameters of anticorrosive materials. As a result, it was found that the traditional coatings within the considered sufficiency indicators meet the specified requirements by 85-90%. However, the primer “Tectyl BT Coat” is the best option for using anticorrosive materials to protect the steel structures exposed to aggressive environmental influences. The sufficiency level for this primer is 92%, which determines its first place in the rating. The proposed method of experimental research and subsequent integral assessment of satisfying the requirements adequacy is versatile and is a tool that can be used when solving the problems of multi-criteria selection or ranking of a finite number of different anti-corrosion coatings or other objects.

Introduction

Natural-climatic and man-made factors negatively affect metal structures and materials during operation, which leads to corrosion destruction. The impact of temperature changes, its sharp fluctuations lead to a violation of the protective coatings’ integrity, their cracking and peeling due to the occurrence of internal stresses due to the difference in the thermal expansion coefficients of the film and the substrate. Moisture leads to swelling, coating softening, washing out the water-soluble impurities from it, and accelerating the binders’ destruction process. Salt water has a particularly destructive effect on protective coatings and metal structures in general.

Therefore, one of the directions for solving the urgent problem of ensuring the efficiency and safety of the metal structures’ operation in modern conditions is the search for the most rational ways to protect
them from corrosion. Of course, the operating conditions should be taken into account, focusing on the maximum environment aggressiveness, when choosing a protective coating.

1. Methods and materials
In modern conditions, protective paint and varnish coatings are used everywhere to ensure the safety of metal structures and include the materials of various composition and application.

The surface to be protected is processed in a technological sequence. The first coat provides good adhesion between the coatings and is called “primer”. At this stage, primer that combines not only the paint and varnish material applied directly to the metal structure is used, but also the coating film formed from this material can be used. Primer prevents potential differences at the metal-coating interface, reducing the possibility of static electricity on the metal structure surface. In addition, the use of priming materials practically excludes diffusion development in metal [1-4]. The properties of this protective coating are influenced by the chemical composition of the primer (Figure 1), the type of metal structure surface, as well as the thoroughness and adherence to the technology of preparing the processed metal before painting.

![Figure 1. The chemical composition of the primer affecting its properties](image)

The next step in protecting the metal structure surface is the application of anticorrosive and coating enamels designed to create a physical barrier in the form of a film that prevents the penetration of corrosion agents, in particular, the streams of salt water. These coatings provide high values of the weather resistance of the metal structure surface.

Anti-corrosion primers FL-03k, EF-065, VL-02 and enamels MS-17, HS-5226, EP-46u were selected for the study. The materials in question are popular among the consumers and are used not only to protect the metal structures operating in difficult conditions, including salt water, but also to provide a decorative effect.

In addition, there are thixotropic anticorrosive coatings on the paints and varnishes market, applied by the devices using airless spray technology. Due to the application of this processing method, such paints and primers change the viscosity parameters already in a single-layer application, which makes it possible to create the coatings with a thickness of 80-200 microns. The primer “Tectyl BT Coat”, having a thixotropic composition based on mineral oil, was chosen for the analysis. This material is designed to protect the metal structures operating in the aggressive environment of fresh and sea water. It differs by the peculiarity that during surface treatment it creates a thick, oily, translucent film with a recommended thickness of 80 microns and a coating 12.5 m²/l.

The experiment, which consists in carrying out a comparative analysis of protective materials, was carried out in the framework of laboratory research. The main physical and mechanical properties were determined. In article [5] adhesion, thickness and weather resistance were considered. This paper evaluates the uniformity and flexibility of the coating.

Coating uniformity is the ability of the applied material to fill the entire required volume, excluding the formation of voids or other composition defects.

The coating flexibility is assessed by checking the ability of the treated surface in bending, exposure to negative temperatures not to form cracks and breaks.

The study was carried out on the pre-made samples in the form of plates 150x100mm in size and 5mm thick, made of materials St45 and aluminum alloy D16T. Airless spray “Fakel-4” was used to
apply anti-corrosion coating. The physical and mechanical properties were evaluated under normal conditions (temperature 22°C and relative humidity 60%) after the time required for the protective dry film formation on the treated surface. Further, the samples were exposed to various types of effects (Table 1), carried out independently of one other.

### Table 1. Types of anti-corrosion coating impact and the necessary equipment.

| №  | Impact type                | Equipment                                      |
|----|----------------------------|------------------------------------------------|
| 1  | Low and high temperatures  | Climate heat chamber “Nema”                    |
| 2  | Impact impact              | Setting the pendulum tumblebug type            |
| 3  | Vibration loads            | Vibration stand                               |
| 4  | Influence of sea water salinity | Container with sea water                  |

The change in the physical and mechanical parameters of the coating was assessed by comparison with the indicators obtained under normal conditions after each type of exposure.

### 2. Results and discussion

The first step was to study the temperature effect on the protective coating quality. When the temperature changes from -10°C till 50°C with a step equal 5°C the parameters of physical and mechanical properties were determined. The experiment was carried out by placing the coated samples in a Nema climate heat chamber for 20 minutes. The time was chosen taking into account the sufficiency for complete cooling or heating of the paint and varnish material layer. The results of the experiment were used to plot the uniformity dependences $S$ and flexibility $h$ anti-corrosion coatings from the temperature (Figure 2). Numerical values for common primers and enamels were given to average values.

![Figure 2. Coating characteristics’ dependence on temperature:](image)

1- Primers EF-065, FLK-03k, VL-023; 2- Enamles EP-46u, MS-17

At normal temperature, the number of microcracks per unit surface of the “Tectyl BT Coat” coating was observed as twice less than that of conventional coatings, due to the viscosity of the oily film, which very densely covers the sample surface. With increasing temperature “Tectyl BT Coat” becomes even more viscous, and all microcracks seem to “collapse”, while the number of microcracks in hard coatings increases. At low temperatures, cracking of both conventional coatings and “Tectyl BT Coat” occurs.

The flexibility of hard coatings is half that of “Tectyl BT Coat”, which is due to the presence of viscous binders in the latter. When investigating the effect of low temperatures, it was found that cooling significantly affects the limiting value of the sample bending. Moreover, the flexibility of “Tectyl BT Coat” and conventional hard coatings are reduced by 50 and 60% respectively. It is worth noting that the flexibility of a thixotropic coating, even at low temperatures, is higher than that of hard coatings at normal temperatures.
The second step was to assess the effect of the number of freeze-heating cycles on the properties of conventional and thixotropic primers. The coated samples were cooled from 22°C (normal temperature) to -10°C. Then they heated up to 50°C and cooled back to normal temperatures. Thus, the real operating conditions of the metal structure were simulated by passing the temperature through the zero value. The experimental dependences of the uniformity $S$ and flexibility $h$ on the number of cycles $n$ are shown in Figure 3. Each coating was first subjected to 10 cycles, then the number of cycles was increased in increments of 5. Maximum $n$ was 70 cycles, which is equal to the average value of the number of days per year with temperature changes during the metal structures operation in a moderately cold climatic region.

![Figure 3. The dependence of the primers’ characteristics on the number of “Freeze-heating” cycles.](image)

The number of microcracks in hard coatings starts increasing sharply after 30 cycles and doubles at the maximum number of cycles. The number of microcracks on “Tectyl BT Coat” covering increases linearly without sharp jumps and reaches a value equal to the initial number of microcracks in a conventional hard coating.

Flexibility with an increase in the number of cycles is reduced by 2 times for all coating types.

The third stage was to study the vibration loads effect on the anti-corrosion coating properties. To carry out the experiment, the painted samples were fixed in the installation in such a way that the blow of the pendulum tumblebug head hammer fell on the sample’s back. The magnitude of the kinetic energy of impact $E$ varied in the range from 1 to 6 J with a step of 1 J. The results are shown in Figure 4 in the form of uniformity dependences $S$ and flexibility $h$ from impact energy $E$.

![Figure 4. The primer characteristics’ dependence on impact energy](image)
The number of microcracks in conventional coatings increases exponentially more than twofold with an increase in the impact energy, which is explained by cracking and spalling of the material. The quantity $S$ increases linearly on “Tectyl BT Coat” covering.

At the fourth stage of the experiment, the coated samples were placed for 10 days in containers with sea water of varying degrees of salinity. It is known that sea water salinity can reach 40%, which certainly has a significant effect on the physical and mechanical properties of anti-corrosion materials. During the experiment, the samples were exposed to aggressive action of water with varying salinity degrees. The water salinity content varied from 0 to 50% with an increase of 10% in each container. The influence of the seawater salinity is especially typical for metal structures, some of which are in salt water or in contact with it, as well as for the tanks of various values filled with water. The obtained dependences of the physical and mechanical properties of the paint coatings under study on the percentage of salts in water are shown in Figure 5.

![Figure 5. The primer characteristics’ dependence on water salinity](image)

Prolonged exposure to salt solution leads to cracking of all coatings, that is, to a decrease in uniformity. This increases the permeability of the anti-corrosion material. The flexibility of the coatings is also reduced. Deflection value $h$ at “Tectyl BT Coat” is reduced by half, for conventional coatings – by almost three times.

As the study on the assessment of the main physical and mechanical properties of conventional and thixotropic anticorrosive materials has shown, when considering various operating conditions, the characteristics of coatings have both advantages over others and disadvantages. The problem of choosing a rational option for the protective treatment of metal structures is solved using the methods described in [6-8], by applying a multi-criteria selection (ranking) of technical objects, the concept of sufficiency and the criterion that implements it. The option of corrosion protection, which has the maximum value of the sufficiency indicator will be considered the “best” option. In this case, the scatter degree of the integral assessment of particular indicators from the criteria (levels of sufficiency) will be minimal, providing maximum protection of the processed surface of the metal structure from the aggressive effects of various environmental factors [9-12].

The basis for obtaining the sufficiency criterion for the anti-corrosion coatings analysis (ACC) is to find the weighting factors that establish the advantage of some criteria over others. A functional method is used to determine the weighting factors. The main physical and mechanical properties of anticorrosive materials are selected as estimated indicators $y_i$: adhesion, thickness, uniformity and flexibility, weather resistance. Their minimum $y_{0i}$, maximum $y_{Mi}$ and sufficient $y_{ti}$ values in accordance with the technical characteristics (Table 2).

Table 2. Modeling indicators.
Modeling of indicators of anticorrosive coatings, which determine the degree of change in material properties in terms of adhesion, thickness, uniformity, flexibility and weather resistance of the treated surface of a metal structure, has been carried out. The indicators values were formed within the framework of the existing database, created and replenished with the help of real data obtained during the maintenance and repair of the existing facilities [14, 15]. This method is applicable for any number of surfaces under consideration and parameters of anti-corrosion materials.

The values of the sufficiency indicator obtained as a result of modeling \( z_i \) are ranked, determining the place in the rating for each considered protective material (Table 3).

### Table 3. Anti-corrosion coatings.

| No. | Name ACC                      | The value of the sufficiency indicator \( z_i \) | Ranking place |
|-----|-------------------------------|-----------------------------------------------|---------------|
| 1.  | Primer FL-03k                 | 0.88                                          | 4-5           |
| 2.  | Primer EF-065                 | 0.85                                          | 7             |
| 3.  | Primers VL-02 and VL-023      | 0.91                                          | 2             |
| 4.  | Primer MS-17                  | 0.88                                          | 4-5           |
| 5.  | Enamel EP-46u                 | 0.87                                          | 6             |
| 6.  | Enamels HS-5226               | 0.9                                           | 3             |
| 7.  | Primer “Tectyl BT Coat”       | 0.92                                          | 1             |

### 3. Summary

Thus, we can conclude that traditional coatings within the considered sufficiency indicators satisfy the specified requirements by 85-90%. However, the primer “Tectyl BT Coat” is the best option for using anticorrosive materials to protect the steel structures exposed to aggressive environmental influences. The sufficiency level for this primer is 92%, which determines its first place in the rating.

The proposed method of experimental research and subsequent integral assessment of the adequacy of satisfying the requirements is versatile and is a tool that can be used when solving the problems of multi-criteria selection or ranking of a finite number of different anti-corrosion coatings or other objects.

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