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Evaluation of the properties of anti-corrosion coatings of steel structures

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Introduction. The properties of an object with metal structures and the safety of its use depend on the environmental impact. This explains the urgency of the problem of universality of anticorrosive coatings.

Problem Statement. The main goal of the study is to find a new approach to choosing the most rational means of protecting metal structures from corrosion based on experimental data. This takes into account the possibility of obtaining fuzzy information on various evaluation criteria.

Theoretical Part. The main objectives of the study: the formation and justification of necessity of application of concepts (axioms) of sufficiency; analysis of the quality of anti-corrosion materials; constructing a measure for assessing (analyzing) the quality of facilities; evaluation (analysis) of quality of corrosion resistance in accordance with the concept of sufficiency.

Conclusion. The original approach to the problem of choosing the most rational means of protecting metal structures from corrosion is based on experimental data. The considered general methodology can be used for selecting criteria for evaluating the safety of metal structures, since it is based on proven decision-making methods.

Keywords: operational safety, risk minimization, uncertainty, decision theory, anti-corrosion coatings.

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Introduction. From the point of view of industrial safety, the issues of managing the technical condition of metal structures remain relevant. In this work, the atmospheric effect of water of different salinity, temperature etc. is considered as factors leading to corrosion. When operating a metal structure in unfavorable conditions, the load-bearing capacity and the level of strength, safety of the object are reduced, and operational qualities deteriorate. In this regard, the task of finding new approaches to protecting metal structures from destruction due to corrosion is urgent.

The purpose of the research is to develop a method for finding universal methods and means of anti-corrosion protection of metal structures based on the available database.

The originality of this approach lies in the fact that for the analysis of protective coatings, the authors of the presented study take into account fuzzy information. To assess the quality of coatings, an integral sufficiency indicator is used. It is assumed that its numerical value has a boundary value, the exceedance of which does not make sense at best, and at worst will lead to a negative change in the indicators not taken into account in this work. We will accept this statement as an axiom or concept of sufficiency.

The main objectives of the study: formation and justification of the need to apply the concept (axiom) of sufficiency; analysis of the quality of anticorrosive materials; development of a model for constructing an indicator for assessing (analyzing) the quality of objects; assessment (analysis) of the quality of anticorrosion resistance in accordance with the concept of sufficiency on the example of the selected coatings.

Problem Statement. Metal structures of mechanical objects are operated in various climatic conditions. They are affected by temperature, solar radiation, humidity, and water (including salt). Primers and two types of enamels (anticorrosive and coating) are proposed to consider as anticorrosive materials. These means can be used to process:

— pure metal,

— structures with strong protective coatings,

— structures with remnants of previously used materials.

The studied coatings have high indicators of the adhesion force of the product to the surface, anti-corrosion and aesthetic properties. The wear resistance of anticorrosive coatings (ACC) can be improved by changing the influence of the parameters of mechanical interaction (for this purpose, the composition is applied to a wet surface) and the heat-reflecting effect in the infrared region of the spectrum [1-4].

For a comparative analysis of the most common anticorrosive materials, their physical and mechanical properties were studied in the laboratory.

In this study, the main indicators that determine the quality level of a protective anti-corrosion coating are considered: uniformity, flexibility, weather resistance, adhesion, thickness.

Adhesion of the coating (i.e., the strength of adhesion between the protected surface (substrate) and the anticorrosive material was controlled by the cross-cut test method.

Thickness of the dry coating on steel samples was controlled using MT-30N and Microtest devices.

Uniformity, which determines the protective properties of coatings, is the number of microcracks per square centimeter of the coating. It was checked by a DUK-60 M flaw detector.

Flexibility, that allows you to predict the behavior of coatings during operation, is the maximum amount of deflection of the sample. If it is exceeded, a macro-crack (main crack) is formed in the anticorrosive coating. This quality was checked using a special flexibility scale (FS).

Weather resistance is the ability of the material to maintain its physical and mechanical characteristics under the influence of various climatic factors [5-8].

In some cases, it is not obvious to take into account quality indicators, including data on their quantity, measurement method, and significance, from the point of view of multi-criteria assessment of technical condition. Of course, the list of criteria should include those that cover all the essential aspects of the objects under study.

In most cases, the quality assessment is based on some positive characteristics of the research object and assumes that the corresponding indicator should grow. However, this approach is impractical to use when assessing the technical condition. The input of an integral indicator is determined by the need to set the limit of the numerical value of the factors under consideration. The consequences of going beyond this limit, presumably, may be:

— it is not advisable to further increase the indicator,

— negative results due to changes in unrecorded indicators (that is, a decrease in the quality of the protective coating).

The described above approach is accepted as an axiom of sufficiency.

Theoretical Part. Quality analysis (assessment) has five stages.

1. Preliminary analysis: statement of the problem taking into account the elements that characterize the initial set of objects to be evaluated.

2. Structural analysis: formulation of the main goal of the assessment and the goals of subsequent levels, determining the possibility of achieving them.

3. Uncertainty analysis: search for unifying elements of the actual technical condition of the object and its place in one- and multidimensional factor spaces.

4. Utility or value analysis: placing points on the numeric axis that display a certain set of options for the object's state. In this case, each point is assigned the value "better — worse". This is how the criterion's usefulness is established.

5. The procedure of optimization: maximization of the expected utility, in particular, the search for solutions leading to the achievement of the required technical condition.

Methodological approaches to building the structure of goals and developing a list of criteria are described in [1]. We assume that for numerical evaluation, it does not matter which source array of objects is considered. At the same time, it is preferable to identify the best objects in terms of technical condition using a special integral indicator that gives a higher (or lower) rating from a mathematical and methodological point of view. The principles of selecting and evaluating objects based on their placement within a set of criteria are described in [2]. Thus, the approach considered here is not the only one. Its main element is the rule (or principle) of evaluating π, which defines the relation of a multiplicative metrized linear order on a set of partial criteria.

For a pair of objects a_ν and a_μ the choice will be based on the following principles:

— $a_\nu > a_\mu$ — the first object according to the considered factors is "better" than the second one,

— $a_\nu \sim a_\mu$ — the objects are equivalent,

— $a_\nu < a_\mu$ — the first object according to the considered factors is "worse" than the second one.

Pairs of objects are characterized by comparison vectors $S_{\nu\mu}$.

The principle of the generalized criteria and so-called lexicographic approaches with a strong preference for a set of particular criteria are useful for research. In this variant, the objects are equivalent ($a_\nu \sim a_\mu$), and their estimates correspond to the established minimum values [4].

Let us consider the condition

$$a_\nu \sim a_\mu \Leftrightarrow x_i^\nu \geq d_i, \quad x_i^\mu \geq d_i, \quad i = 1, \ldots, m, \tag{1}$$

where d_i — the specified threshold value (sufficiency level); m — the number of indicators under consideration; $x_{i\nu}$ and $x_{i\mu}$ — the estimates of the compared objects (ν-th and μ-th).

We will consider the described condition as a mathematical formulation of the concept of sufficiency and apply it to assess the technical condition. However, the direct use of this quality assessment principle limits the possibility of its application in practice, since it assumes the presence of a strong preference relation on the set of criteria $K = \{K_1, K_2, \ldots, K_m\}$ in the form of:

$$K_1 \geq K_2 \geq K_3 \geq \ldots \geq K_m. \tag{2}$$

We conclude that it is more appropriate to set a metrized multiplicative relation of linear order, that is, to apply a generalized criterion.

In this case

$$a_\nu \succ a_\mu \Leftrightarrow \sum_{i=1}^{m} \alpha_i K_i(a_\nu) > \sum_{i=1}^{m} \alpha_i K_i(a_\mu); \quad a_\nu \sim a_\mu \Leftrightarrow \sum_{i=1}^{m} \alpha_i K_i(a_\nu) = \sum_{i=1}^{m} \alpha_i K_i(a_\mu). \tag{3}$$

Here α_i — the coefficients that satisfy, for example, the condition

$$\sum_{i=1}^{m} \alpha_i = 1. \tag{4}$$

As a monotone operator for mapping (convolution) of the initial set of the evaluated objects to the numerical axis "better — worse", we can use the suggestions of the authors of works [5, 6]. In this case, the integral indicator will be a scalar linear function of the original criteria, defined by a blurred (according to Zadeh) relation on the pairs of specially defined objects.

Let us move on to the model for building an indicator for assessing (analyzing) the quality of objects. The task is to determine the vector component B, obeying the condition (4), and constructing the index z, approximating objectively known or specifically set (training) matrix of pairwise interactions between artificial objects (means of transport).

$$Q = \| q_{rk} \|_{p,p}. \tag{5}$$

Let us take p — as the amount of the artificial objects, which is determined by the size of the matrix Q; q_{rk} — the elements of the matrix; r, k — artificial objects on the number line of "better — worse".

On the z axis, the square of the distance between the *r-th* and *k-th* artificial objects (protection options) has the form:

$$d_{rk}(B) = (z_r - z_k)^2 = \left[\sum_{j=1}^{m} b_j (x_{rj} - x_{kj}) \right]^2, \tag{6}$$

$$D(B) = \| d_{rk} \|_{p,p}. \tag{7}$$

Matrix $D(B)$ is assessed using the functional

$$J(B)=\sum_{r=1}^{p-1}\sum_{k=r+1}^{p}[d_{rk}(B)-q_{rk}]^2\ . \qquad (8)$$

The required integral criterion is a function Z^* if $J(B)$ is minimal and the vector b meets the specified conditions. The resulting indicator is used to assess the technical condition.

Here is an example of evaluating (analyzing) the quality of corrosion resistance of objects.

The ACC of the processed design will be "best" at the maximum level of sufficiency. The main task is to distribute the weight coefficients, that is, to assign a degree of significance to each indicator in comparison with the others [9, 10].

The following variant of modeling indicators is proposed for forming an assessment of the sufficiency of properties of anticorrosive agents (table 1).

Table 1

Modeling indicators for evaluating the sufficiency of properties of anticorrosive agents

Anticorrosive coating		Value of indicators			Unit of measurement
Parameter	Property	min, y_{0j}	max, y_{Mj}	sufficient, y_{tj}	
y_1, σ	Adhesion	10^{-2}	2	0.3	MPa
y_2, H	Thickness	1	100	30	um
y_3, S	Uniformity	0.2	50	20	1/sm^2
y_4, h	Flexibility	1	5	3	mm
y_7	Weather resistance	0.03	3	1.0	year

To evaluate anticorrosive materials, the indicators were modeled that characterize the adhesion of the coating, its thickness, continuity, flexibility, and weather resistance. The minimum, maximum, and sufficient values of indicators are taken from the database, which contains the data obtained during the maintenance and repair of real objects. The number of objects and indicators that characterize the automatic transmission parameters can increase or decrease.

Let us calculate the level of sufficiency z_i and determine the best of the analyzed ACC by ranking (table 2).

Table 2

Determination of the best anticorrosive coatings

No.	ACC name	Sufficiency indicator z_i	Place in the rating
1	Primer FL-03к	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	Enamel KhS-5226	0.9	3
7	Primer Tectyl BT Coat	0.92	1

The table shows that the best of the compared anticorrosive coatings is Tectyl BT Coat (the sufficiency index is 0.92). According to the indicator "corrosion resistance", the technical condition of the treated structure will be better taking into account the adhesion of the coating, its thickness, uniformity, flexibility and weather resistance. VL-02 and VL-023 primers (sufficiency index 0.91), as well as KhS-5226 enamel (sufficiency index 0.9) are also acceptable for use.

Conclusion. The developed method of searching for universal methods and means of anticorrosive protection of metal structures is based on the experimental data and assumes the possibility of processing fuzzy information. The considered methodology for constructing a criterion for evaluating the quality of anticorrosive coatings can be used to build the required criteria for evaluating the safety of metal structures, since it is based on the proven decision-making methods.

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Contribution of the authors:

V. V. Deryushev — formulation of the main concept, goals and objectives of the research, development of an original approach to the problem of choosing the most rational means of protecting metal structures from corrosion based on experimental data, preparation of the text, correction of conclusions; M. M. Zaytseva — development of a model for constructing an indicator for evaluating (analyzing) the quality of objects, analysis of research results, formulation of research conclusions, correction of the text; E. E. Kosenko — practical application of the developed approach, solution to the problem of evaluating (analyzing) the quality of corrosion resistance of objects; S. K. Mamberger — search for examples for practical application of research results, revision of the text, formulation of conclusions.