Statistical assessment of damnification risk due to inconformity of paint coating quality

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Abstract. Provides information about the values of the risk of paint and coatings mismatch with the requirements of regulatory documentation. Risk considered as the probability of an adverse event. The probability of destruction of the adhesion strength of paintwork coatings of building products and structures is considered. The probability of destruction of the paintwork was calculated taking into account the Laplace function. It is established that the probability of paint coating adhesive destruction is minimal. The risk was calculated as expected damage. The values of risk as expected damage because of coating adhesive destruction are from 0.068 to 11.18 rubles per square meter depending on the coating type.

1. Introduction
Recent years have been characterized by an increase in the proportion of colorful compositions in the decoration of buildings. The service life of protective and decorative coatings is on average 5-6 years. However, often the destruction of coatings occurs much earlier [1,2]. In accordance with the law “on technical regulation” of December 27, 2002 No. 184-FL, updating the quality of finishing of construction products and structures requires determining the degree of risk of harm if the quality of paint and coatings does not meet the requirements [3,4].

The values of paintwork materials and coatings are set by some limitations, for example:

\[ x \geq x_{\min} \]
\[ x \leq x_{\max} \]
\[ x_{\min} \leq x \leq x_{\max} \] (1)

However, the regulatory documentation does not reflect the risk of harm that may be caused to the consumer of paint and varnish materials. In this regard, the issues of risk assessment due to non-compliance of paint materials are extremely relevant today.

Currently, a large number of methods for calculating risks have been proposed [5-7]. Analysis of scientific and technical information shows that statistical methods are often used to assess risks. Risk is considered as the probability of an event having adverse consequences [8-10].
2. Materials and methods

We estimated the risk of destruction of coatings of construction products and structures. To this end, a statistical analysis of the test results of the adhesion strength of colorful compositions was carried [11-14]. In order to assess the risk in the work, the study used polyvinyl acetate cement (PVAC) paint, MA-15 oil paint, PF-115 alkyd paint, AK-111 water-dispersion acrylic paint, KO-168 organic-silicone paint, and PI polymer lime paint as paint compositions.

The adhesion strength was determined by the method of detachment of washers on the samples of coatings of each type. In this paper, the risk was considered as the probability of an adverse event (destruction of the paint coating) [15-20]. In addition to this, a calculation of the risk R as the expected damage Y due to destruction of the coating was performed.

The probability of destruction of the paintwork was calculated by the formula

$$r = 0.5 - \Phi \frac{R - R_{\text{lim}}}{\sigma^2 - \sigma_{\text{lim}}^2} \quad (2)$$

where $\sigma$ is the standard deviation of value of the coating quality indicator; $\sigma_{\text{lim}}$ - standard deviation of the limiting value of the indicator of the quality of paintwork; $\Phi$ is the Laplace function; $R$ is the value of the quality indicator of the coating; $R_{\text{lim}}$ - the limiting value of the indicator of the quality of the paintwork.

The standard deviation of the limiting value of the quality index of the paint coating was determined as

$$\sigma_{\text{lim}} = R_{\text{lim}} V_n \quad (3)$$

where $V_n$ is the normative value of the coefficient of variation.

The standard value of the coefficient of variation at the normal distribution law was calculated by the formula

$$V_n = \frac{0.3290(nK - 1)}{(n - 1)(K + 1)} \quad (4)$$

where $n$ is the number of intervals of the series of distribution of the characteristic; $K$ – the ratio of the maximum value of the feature to the minimum.

3. Research results

20 samples of coatings of each type were subjected to tests for the adhesive tensile strength (Ra). The test results, presented as a series of variations, are shown in table 1, 2. Histograms of the distribution of relative frequencies of the adhesive strength of the coating are shown in figure 1, 2.

| Table 1. Distribution of PVAC coating $R_a$ |
|---|
| Value, MPa | 1.0 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.1 | 2.4 |
| Occurrence number, $n_i$ | 1 | 1 | 2 | 2 | 3 | 4 | 2 | 2 | 1 |
| Average: $\bar{R}_a = 1.7$ MPa, standard deviation: $\sigma_{R_a} = 0.313$ MPa |

| Table 2. Distribution of polymer lime coating $R_a$ |
|---|
| Value, MPa | 0.9 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 |
| Occurrence number, $n$ | 1 | 1 | 1 | 2 | 2 | 4 | 3 | 2 | 1 | 1 | 1 |
| Average: $\bar{R}_a = 1.53$ MPa, standard deviation: $\sigma_{R_a} = 0.296$ MPa |
The resulting histogram forms allow us to put forward a hypothesis about the normal distribution for all the considered sets. The results of testing the hypothesis using the Pearson criterion $\chi^2$ (significance level $\alpha = 0.05$, number of degrees of freedom $k = s-3$, where $s$ is the number of intervals) are shown in Table 3.

The results obtained showed a good correspondence between the empirical distribution law and the normal distribution.

Table 3. The results of hypothesis testing by the Pearson criterion $\chi^2$.

| Coating          | Function $f(R_a)$ | $\chi^2_{null}$ | $\chi^2_{sppm}$ |
|------------------|-------------------|------------------|------------------|
| PVAC             | $f(R_a)$          | 3.62             | 11.1             |
| Polymer lime     | $f(R_a)$          | 0.47             | 9.5              |

Table 4 shows the numerical values of the actual and standard values of the coefficients of variation, as well as the maximum permissible values of the standard deviation for some protective and decorative coatings. Analysis of the obtained data shows that a number of coatings are characterized by less uniformity of adhesion values than is required, based on the ratio of the actual and standard coefficients of variation. The maximum allowable standard deviation for statistical control of the coloring process for some coatings (PVAC, polymer lime, PF-115) should be less than the actual values and correspond to the values specified in Table 4.

Based on the requirements of regulatory documents, the limit value of the adhesive strength of paint coatings $R_{lim}$ construction products and structures should be at least 0.6 MPa. Risk values $r$ (Table 4) indicate that the probability of failure of the adhesive strength of coatings is minimal. The
risk value for the studied coatings is 0.00034-0.0559. However, after 120 days of humidification, the probability of failure for polymer lime coatings is 0.1168, for PVAC coatings-0.0618.

Table 4. Values of coating adhesion strength variation coefficients.

| Type of coating | Adhesion strength value $\bar{R}_a$ [MPa] | Roof-mean-square deviation, $\sigma$, [MPa] | Roof-mean-square deviation of ultimate quality indicator value $\sigma_{lim}$ [MPa] | Risk value $r$  |
|-----------------|------------------------------------------|---------------------------------------------|---------------------------------------------|----------------|
| Based on PVAC paint | 1.7 | 0.313 | 0.26 | 0.0035/0.0618 * |
| Based on polymer lime paint | 1.53 | 0.296 | 0.23 | 0.0066/0.1168 * |
| Based on AK-111 water-dispersion acrylic paint | 1.5 | 0.225 | 0.22 | 0.0021/0.04 * |
| Based on KO-168 organic-silicone paint | 1.7 | 0.204 | 0.24 | 0.00034/0.0015 * |
| Based on MA-15 oil paint | 0.9 | 0.126 | 0.14 | 0.0559/0.14 * |
| Based on PF-115 alkyd paint | 1.2 | 0.192 | 0.18 | 0.0301/0.1 * |

Note. * Risk values after coating curing and after 120-day damping (after humidification).

The calculation of the risk $R$ as the expected damage $Y$ as a result of the destruction of the coating was carried out using the formula

$$R = rY$$

(5)

where $r$ is the probability of destruction of the coating; $Y$ - expected damage as a result of the destruction of the coating, rub.

We accept the cost of painting on average 200 rubles per 1 m$^2$. The results of calculating risk $R$ as expected damage $Y$ are shown in Table 5.

The results of calculations show that the maximum risk values are typical for MA-15 oil paint, PF-115 alkyd paint and polymer-lime paint. The value of risk $R$ after curing the coating is from 1.32 to 11.18 rubles per square meter. After 120 days of humidification, the risk $R$ is 20-23.36 rubles per square meter.

Table 5. Values of risk as expected damage.

| Type of coating | Value of risk $R$ as expected damage, [rubles per square meter]  |
|----------------|-------------------------------------------------------------|
| Based on PVAC paint | 0.7/12.36 * |
| Based on polymer lime paint | 1.32/23.36 * |
| Based on AR-111 water dispersion acrylic paint | 0.42/8 * |
| Based on KO-168 silicone paint | 0.068/0.2 * |
| Based on MA-15 oil paint | 11.18/28 * |
| Based on PF-115 alkyd paint | 6.02/20 * |

Note. * Above the line, the values of risk $R$ are presented as the expected damage after coating curing, below the line - after 120 days of moisturize
4. Conclusion
It was found that the probability of destruction of the adhesive strength of the paint coating is minimal. The risk of expected damage from the destruction of the coating ranges from 0.068 to 11.18 rubles per square meter, depending on the type of coating. During the period of operation (less than 3 years) with a warranty period, the increase in the expected damage increases and is 20-23.36 rubles per square meter for these paints.

These values indicate the impact of the risk of destruction on the economic damage of the enterprise and the consumer, depending on the type of coating. When making a management decision on paint production, it is necessary to assess the risk of economic damage.

Given that the nature of destruction of coatings may vary, the company's management should assess the risk of economic damage from other types of destruction.

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