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Application of the Method of Multivariate Analysis to Assess the Quality of Coatings

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Abstract

Information is given on the application of multivariate statistical techniques for analyzing the causes of the declining quality of the coatings and the occurrence of defects. It is shown that the porosity of the surface is a decisive factor in determining the quality of the coating.

Keywords: coatings, quality of appearance, surface porosity and application method, the roughness of the coating

Introduction

Previous studies show that the resistance of coatings, among other factors determined by the quality of appearance of coatings [1, 2, 3]. The quality of the appearance of the coatings are strongly influenced by the technology of applying paint, its rheological properties, the quality of the surface. It is known that any process is subject to variation, the nature of which is determined by the influence of a set of random and non-random factors. These include variability in feedstock from party to party, wear process equipment, inadequate technological methods, different qualifications and other performers.

Earlier studies show that the process of creation of coatings on porous cement substrate is often unstable and irreproducible [4, 5, 6]. In this connection is urgent assessment of the most significant factors affecting the quality of the coatings.

Methodology of the research

In this paper we present the results of the evaluation of the possibility of multivariate statistical analysis to assess the causes of the most significant factors reducing the quality of the coatings and the occurrence of defects. The method of canonical correlation allows to simultaneously analyze the relationship of several output parameters and a large number of determinants. Algorithm of calculation method of canonical correlation is constructed in such a way that the original variables are replaced by their linear combinations. The coefficients in the canonical variables characterize the effect of influence factors relevant traits

At the same time a high degree of connection between the linear combinations of the factors and linear combinations of the output parameters.

Briefly present the essence of the method. Primarily through the array of measured values is calculated covariance matrix of factors reflecting the statistical picture of the state of the process:

$$S = \begin{pmatrix} K_{x_1x_1} & K_{x_1x_2} & \dots & K_{x_1x_m} & K_{x_1y_1} & \dots & K_{x_1y_n} \\ K_{x_2x_1} & K_{x_2x_2} & \dots & K_{x_2x_m} & K_{x_2y_1} & \dots & K_{x_2y_n} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ K_{x_mx_1} & K_{x_mx_2} & \dots & K_{x_mx_m} & K_{x_my_1} & \dots & K_{x_my_n} \\ K_{y_1x_1} & K_{y_1x_2} & \dots & K_{y_1x_m} & K_{y_1y_1} & \dots & K_{y_1y_n} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ K_{y_nx_1} & K_{y_nx_2} & \dots & K_{y_nx_m} & K_{y_ny_n} & \dots & K_{y_ny_n} \end{pmatrix}$$

where $K_{x_ix_j} = M\left[\left(x_i - \overline{x_i}\right)\cdot\left(x_j - \overline{x_j}\right)\right]$ - the covariance of these variables

$$\begin{array}{c|c} S_{11} & S_{12} \\ \hline S_{21} & S_{22} \end{array}$$

Then the matrix S is represented as a block matrix, combining the characteristics of individual blocks of variations of factor variables, result indicators and their pair wise combinations. In fact, we divide the matrix S into four parts:

where S_{11} - the covariance matrix of the factors $x_1, x_2, ..., x_m$, the dimension of the matrix $(m \times m)$;

S_{22} - Covariance matrix of the parameters $y_1, y_2, ..., y_n$, the dimension of the matrix $(n \times n)$;

S_{12} - Covariance matrix containing the covariance $K_{x_i y_j}$, $i = \overline{1,m}$, $j = \overline{1,n}$ the dimension of the matrix $(m \times n)$.

S_{21} represents the transpose of the matrix S_{12}.

Canonical correlation coefficients can be calculated and based on the sample correlation matrix, especially if you have to work with these disparate units of measurement.

R_{11}	R_{12}
R_{21}	R_{22}

The problem of determining the maximum correlation between the canonical variables $U = U_1 x_1 + U_2 x_2 + ... + U_m x_m$ and $V = V_1 y_1 + V_2 y_2 + ... + V_n y_n$ reduced to the determination of eigenvalues of matrices $R_{11}^{-1} R_{12} R_{22}^{-1} R_{12}^T$ and $R_{22}^{-1} R_{12}^T R_{11}^{-1} R_{12}$ their eigenvectors. Given that the dimension of said matrix obtain n eigenvalues $\lambda_1^2 \geq \lambda_2^2 \geq \ldots \geq \lambda_n^2$, m eigenvectors U and n eigenvectors V.

To analyze the influence of the method of application of the paint composition, its rheological properties and quality of the substrate on the surface quality of the coatings we had to do the following experiment.

Colorful compositions with different rheological characteristics of the mortar applied onto the substrate porosity of 24%, 28%, 32% in two layers with intermediate drying for 20 minutes. Before applying the colorful composition of the surface of the substrate priming. In addition, part of the mortar samples leveled spackling compounds. The rheological properties of paints were evaluated in terms of their conditional dynamic viscosity and surface tension. As colorful compositions used alkyd enamel brand ПФ-115, oil paint brand MA-15, an acrylic latex (facade) paint. Colorful compositions were applied pneumatically, brush. The surface quality of the coatings was evaluated in terms of roughness and adhesion of coatings. The surface roughness of the coating was determined by the device profiler mark TR-100, the adhesion strength - the pull washers.

The research results

Analysis of the data presented in Table 1 indicates that the value of the surface roughness of the coating depends on the application of the paint composition, rheology of the cement and the porosity of the substrate. Thus, for oil paint MA-15 (green color) the minimum value of surface roughness Ra = equal 3,12mkm achieved on a substrate with a porosity P = 24% when the ink viscosity $0{,}00261*10^3$ Pa*second when applying it with a brush. To paint ПФ-115 minimum value of roughness Ra = equal 1,3mkm achieved on a substrate with a porosity P = 28% when the ink viscosity $0{,}00065*10^3$ Pa*second when applying it with a brush. For latex paint minimum roughness value equal to Ra = 3,5mkm achieved on a substrate having a porosity P = 32% when the ink viscosity $0{,}013*10^3$ Pa*second when applying it with a brush, and a maximum roughness value equal to Ra = 6,5mkm achieved on the substrate with a porosity P = 24% when the ink viscosity $0{,}0347*10^3$ Pa*second when applying it with a brush. The minimum value of the roughness characteristic of the surface coating formed on the substrate, the filler irrespective of the method of application and the rheological properties of colorful compositions.

Table1-Influence of technological factors on the quality of the appearance of coatings

	The porosity of the substrate x_1	Viscosity of paint x_2	Roughness coatings y_1	Strength of adhesion y_2
MA-15 brush	24	0,0026	3,12	1,4
	24	0,0021	7,4	1,1
	28	0,0026	4,3	1,2
	28	0,0021	6,27	0,7
	32	0,0026	5,65	0,6
	32	0,0021	3,76	0,9
	0	0,0026	1,79	1,8
	0	0,0021	2,54	1,7

Since the dispersion factor variables are significantly different from one another and are dissimilar units, it is reasonable to use the correlation matrix for the preparation of which apply the Table 2.

Table 2- Factors of variation of the experiment

	porosity x_1	*viscosity* x_2	*roughness* y_1	Strenght of adhezion y_2
porosity x_1	1	0	0,6532	-0,8831
viscosity x_2	0	1	-0,3518	0,1822
roughness y_1	0,6532	-0,3519	1	-0,7619
Strenght of adhezion y_2	-0,8831	0,1822	-0,7619	1

The correlation matrix has the form

$$R = \begin{pmatrix} 1 & 0 & 0{,}6532 & -0{,}8831 \\ 0 & 1 & -0{,}3518 & 0{,}1822 \\ 0{,}6532 & -0{,}3518 & 1 & -0{,}7619 \\ -0{,}8831 & 0{,}1822 & -0{,}7619 & 1 \end{pmatrix}$$

Correlation matrix of factor variables x_1 *and* x_2 *has the form*

$$R_{11} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

The correlation matrix of indicators of quality y_1 *and* y_2 *has the form:*

$$R_{22} = \begin{pmatrix} 1 & -0{,}7619 \\ -0{,}7619 & 1 \end{pmatrix}.$$

The correlation matrix $R_{12} = \begin{pmatrix} 0{,}6532 & -0{,}8831 \\ -0{,}3518 & 0{,}1822 \end{pmatrix}$ contains paired coupling coefficients of variables x_1, x_2, y_1, y_2. Thus $R_{21} = R_{12}^T$.

The auxiliary matrix has the form:

$$C = R_{11}^{-1} R_{12} R_{22}^{-1} R_{12}^T = \begin{pmatrix} 0{,}7808 & -0{,}1510 \\ -0{,}1510 & 0{,}1413 \end{pmatrix}$$

The solution of the equation $\left| C - \lambda^2 E \right| = 0$ gives the following results on the eigenvalues of the matrix C: $\lambda_1^2 = 0{,}815$, $\lambda_2^2 = 0{,}107$. The corresponding eigenvectors:

$\lambda_1^2 = 0{,}815$	$\vec{\theta_1} = (0{,}976;\ -0{,}219)$
$\lambda_2^2 = 0{,}107$	$\vec{\theta_2} = (0{,}219;\ 0{,}976)$

Obtain a canonical combination of technological factors. $0{,}976x_1 - 0{,}219x_2$.Thus, the contribution factor of the first variable in the overall instability of quality indicators is greater by more than 4 times greater than the contribution of the second factor.

If you change the application method on air, the canonical combination of MA-15 is as follows: $0{,}999x_1 + 0{,}054x_2$ at $\lambda_1 = 0{,}766$.

Studying the principal canonical correlation paint MA-15 at various ways of its application, it can be seen that in both linear combinations retained the greatest coefficient of (the porosity of the substrate). Similar conclusions can be made for other dyes studied

ПФ-115, brush	$0{,}993x_1 - 0{,}115x_2$	$\lambda_1 = 0{,}678$
ПФ-115, pneumatically	$0{,}932x_1 - 0{,}363x_2$	$\lambda_1 = 0{,}921$
acrylic latex (facade), brush	$0{,}995x_1 + 0{,}1x_2$	$\lambda_1 = 0{,}89$

Conclusion

Analysis of the results of the research suggests that the porosity of the substrate is a critical factor in determining the quality of the coating. When applied paint pneumatically ink viscosity (factor) has a weaker effect on the quality of the coating compared with brushing.

Studying the dynamics of factor characteristics of instability result can be an important component of the detection and elimination of causes producing substandard coverage.

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