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Application of fractal analysis to assess the quality of the appearance of paint and varnish coatings

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Abstract. The article provides information on the use of fractal dimension in assessing the quality of the appearance of paint coatings. It was established that with an increase in the surface roughness of the coating, a decrease in the appearance quality grade and an increase in the fractal dimension D are observed. A correlation between the fractal dimension and the quality class of the appearance of the coating is established. With an increase in the fractal dimension of the coating surface profile, its brightness decreases and the numerical values of the profile perimeter increase. A model of the coating surface profile length on the fractal dimension D is proposed. The results of evaluating the surface profile of the coatings indicate that with an increase in the surface tension of the paint composition, an increase in the fractal dimension and a lower quality of the appearance of the resulting coating are observed. Numerical values of the index of the fractal dimension of the surface profile of the paint coating are obtained depending on the porosity of the cement substrate. The influence of the method of applying paint on the quality of the appearance of coatings was established.

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1. *Introduction*

Various types of modern finishing of external concrete walls of buildings are effectively used to improve their architectural expressiveness and performance [1]. A painting of any building structures is one of the most popular types of finishing; it takes up to half of the finishing materials used in the world [2]. The coating for finishing the facade should not only protect the building from external influences, but also have an aesthetic appearance. In addition, the coating must be resistant to precipitation, temperature changes, and ultraviolet radiation. Moreover, it must have long service life and be easy to work and use [3]. The quality of the paintwork is assessed according to several parameters. One of them is the absence of defects. Stains, smudges, shagreen, streaks and scratches: all this can ruin the appearance of the coating.

Waviness and color variability are also not desirable phenomena [4]. An appearance quality class of a paint coating is determined by the presence or absence of defects on its surface [5].

Assessment of paint coating quality can be subjective, as it depends on the opinion of a particular person. There are various methods for assessing the quality of paint and varnish coatings. One of them is visual inspection. Vaspero et al [6] used electron microscopy to study the surface of paintwork. They found that surface quality could be improved by changing the paint composition and application conditions. Zhong et al [7] applied multimodal tomography to study organic paint coatings. They found that this method allowed them to obtain detailed images of the coating's structure and determine its properties. Oliveira and Ferreira [8-9] used electrochemical impedance spectroscopy to study the properties of paint coatings. They found that high-quality systems had lower impedance than defective systems. Quevauviller [10] suggests using certified reference materials to test the quality of paint coatings. Zhou et al [11] developed a mathematical model that describes the release of volatile organic compounds from paint coatings on porous surfaces. Aktas et al [12] systematic investigated different coating methods for marine propellers. They found that certain types of soft paints could protect the surface from cavitation erosion. Tanzim et al [13] created a model that predicts the width of the paint spray when using an electrostatic sprayer.

The method of applying the paint and varnish material and the preparation of the base surface play an important role in ensuring the quality of the appearance of the coating. The correct choice of application method and surface preparation will avoid problems with adhesion, roughness, color uniformity and other defects. Here are some key points to consider when choosing an application method and surface preparation:

1. Type of coating [14]: Before choosing an application method, it is necessary to consider the type of coating. Some coatings require special equipment and skills to apply. For example, powder coatings require a special curing chamber and spray gun, while brush or roller application may not be suitable.
2. Surface size and shape [15]: The size and shape of the surface to be painted also influence the choice of application method. Large flat surfaces can be painted using airless spray or electrostatic spray, while smaller or more complex surfaces may require a brush or roller.
3. Base surface preparation [16]: Base surface preparation includes cleaning, degreasing, sanding and dusting. It is important to ensure that the surface is clean and dry before applying the coating. Poor preparation can lead to poor adhesion of the coating to the surface, the appearance of bubbles and peeling.

According to the Russian standard GOST 9.032-74 classification, modern builders divide the quality of paint coatings into 7 classes, where the first class characterizes coatings without defects, and the seventh one has the maximum number of structural defects.

Scientists must continue to look for new methods to control the quality of paint coatings [17–22]. This will help improve the quality of construction products and make them more competitive in the market. The surface quality of a paint coating can be assessed by its roughness [23]. Surface roughness is determined by the surface profile [24]. The use of fractal physics methods may be promising for assessing the surface profile of paint and varnish coatings [25]. Fractal physics provides more accurate results than traditional roughness measurement methods [26–27].

Takada et al [28] used fractal analysis to study the dispersion of carbon nanotubes in polystyrene. They discovered that ultraviolet radiation can change the properties of nanotubes and affect their dispersion in the polymer. Zivic et al [29] studied the properties of polymer chains attached to the surface of three-dimensional fractal lattices. Li et al [30] developed a model for the fractal fracture of glassy polymers. This model takes into account material damage and hardening. Marquardt et el [31] used fractal analysis to study the surface of blast-cleaned steel. They found that the fractal dimension of a surface influences the adhesion of polymer films to adhesives. Pandey and Chandra [32] studied the effect of thermal degradation of a polymer on its redox-initiated fractal geometry.

Fractal structures play an important role in determining the surface and volumetric properties of materials [33–36]. Fractal geometry is used to comprehensively characterize the pore structure of cement-based materials, allowing the complex pore structure to be quantified and compared and correlated with the macro properties of cement-based materials. In [37–38], it was proven that cementitious materials have fractal properties at certain scales. Using X-ray scattering methods, it was found that the hardening products of cementitious materials can be described by fractal dimensions. Zeng et al [39] offered a comprehensive understanding of the fractal surface features of the porous structure of cement-based materials using massive backscattered electron images.

In [40], the porous structure of cement pastes is described based on the fractal method, which can be used to analyze and predict the durability and strength of cement composites. In [41–42], a connection was established between the fractal dimension and the process of development of frost-thawing damage to concrete at the microscopic level. It was found in [43] that the fractal dimension can characterize the characteristics of temperature cracks in a low-alkali cement matrix modified with microsilica.

Thus, the surface of paint and varnish coatings quality is determined, among other things, by its roughness (surface profile). Fractal physics can be used to evaluate the surface profile of paint coatings. The successful application of fractal analysis methods in the study of polymers allows us to hope that this approach will be successfully extended to assess the quality of the appearance of coatings. The development of an integral indicator of the surface quality of paint and varnish coatings can be very useful. This will help improve product quality and make it more competitive in the market. The use of fractal dimension can help in assessing the quality of paint and varnish coatings. However, it must be taken into account that the fractal dimension is not the only indicator of the quality of the coating. Other factors such as color, gloss, resistance to external influences, etc. must also be taken into account. For the coating surface profile, the fractal dimension D is in the range $1 < D < 2$ [44–48]. The greater coating roughness, the more curved the coating profile and the greater D value. Thus, the fractal dimension D of the coating profile can serve as a criterion for the quality of its appearance, reflecting the presence of inclusions, stripes, and waviness.

The use of fractal dimension for modeling paint coatings is an underexplored area. This is an interesting direction for this research. The authors of the current article made an attempt to evaluate the possibility of describing the quality of the appearance of coatings using the fractal dimension. To achieve this goal, the following tasks were solved: a correlation was established between the surface roughness of the coating, the appearance quality grade, and the fractal dimension; obtaining numerical values of the index of the fractal dimension of the coating surface profile depending on the porosity of the substrate; assessment of the effect of filling the paint composition on the quality of the appearance of coatings; consideration of the influence of the method of applying the paint composition and the preparation of the base surface on the coatings appearance quality.

2. *Materials and Methods*

2.1. Materials

Various types of paints were used in the study, as they are widely used in finishing building products and structures. This made it possible to obtain more complete and reliable results. The selected paints have different bases, which provides wider coverage and allows the results of the study to be used in different conditions. The following paint compositions were used in the work: alkyd enamel PF-115 (Yaroslavl paints, Yaroslavl, Russia), oil paint MA-15 (Lakra, Moscow, Russia), nitrocellulose paint NC-132 (Teks, Saint-Petesburgh, Russia), acrylate paint Universal (Teks, Saint-Petesburgh, Russia), acrylic water-dispersion paint Facade (Belyi dom, Kaluga, Russia), polyvinyl acetate cement (PVAC), polymer-lime, cement-perchlorovinyl (CPCV), and lime paint. The following materials were used for the preparation of colorful compositions:

- white Portland cement (Belgorod cement, Belgorod, Russia);
- colored cements (Yaroslavsky pigment, Yaroslavl, Russia);
- quartz sand (Volsk, Russia) for decorative powder;
- lime – fluff (Penza, Russia);
- lime paste, 50 % (Penza, Russia);
- polyvinyl acetate dispersions (PVAD), grades DF 47/70, and 48/50 (Penza, Russia);
- liquid glass (Penza, Russia);
- water-repellent liquid 136-41 (Penza, Russia).

The substrates were glass, expanded clay concrete M75, cement-sand mortar, and heavyweight concrete. The paint compositions were applied to substrates with different porosities (24 %, 28 % and 32 %) using a brush, pouring and pneumatics in two layers with intermediate drying for 20 minutes.

2.2. Methods

To assess the rheological properties of paints, the Stokes method was used, which allows one to determine the dynamic viscosity of paints. For this, the test liquid is poured into a graduated cylinder, a metal ball of known density ρ_{ball} and radius r is brought to the surface and lowered (without a push). As soon as the movement of the ball becomes uniform, start the stopwatch and determine the time it takes the ball to pass between the given marks. Liquid viscosity was determined by the formula:

$$\mu = \frac{2}{9} g r^2 \frac{\left(\rho_{ball} - \rho_{paint}\right) t}{l}, \quad (1)$$

where g is gravity acceleration, m/s^2; t is time during which the ball passes the distance between the marks A and B, sec; l is distance between the marks A and B, cm; ρ_{ball}, ρ_{paint} are density of the ball and paint, g/cm^3, respectively.

To determine the conditional viscosity of paint and varnish compositions, a VZ-4 viscometer (K-M, St. Petersburg, Russia) was used. The method is as follows: determine the duration (in seconds) of passing 100 mm of paint through a viscometer nozzle with a diameter of 4 mm.

The stalagmometric method was used to determine surface tension.

To evaluate the paint pouring technique, a method of applying five parallel stripes of paint was used and the degree of spreading was determined by the number of stripes stuck together. The strips were applied by a special device. The degree of spreading was assessed on a ten-point scale from 0 to 9, where 0 is no spreading, and 9 is complete spreading.

The coatings gloss was determined by the photoelectric method on an FB-2 gloss meter (K-M, Saint-Petersburg, Russia) according to the Russian Standard GOST 896-69.

The paint compositions were applied by brush to substrates with a porosity of 30 % in two layers with intermediate drying for 24 hours. The coating profile was determined by an A1 type profilometer-profilograph TR-100 (K-M, Saint-Petersburg, Russia). The length of the coating surface profile was determined using a curvimeter. The fractal dimension of the surface profile of the coatings was estimated using a geometric method. To do this, the image of the curve obtained using a profiler-profilometer was covered with a grid consisting of squares with a side L1. Then, the number of squares N, through which the curve N(L1) passes, was counted. By changing the scale of the grid, each time the number of squares intersecting the curve N(L2),N(L3)...N(Ln) was counted again. Then, the dependence N(L) was plotted in double logarithmic coordinates, the slope of which was used to determine the fractal dimension The quality of the substrates was evaluated by the index of total porosity P and surface porosity Ps. Surface porosity was determined by the ratio of the sum of the pore area to the total area of the measured surface. The pore diameter was measured using a measuring magnifier x24.

Statistical analysis was carried out in order to formulate logical conclusions about the correlation between surface roughness, quality grade and fractal dimension. The reliability and reproducibility of the results was ensured by the fact that 50 measurements were taken on each surface. Statistical indicators were calculated to assess the uniformity of the distribution of roughness indicators along the strike.

3. Results and Discussion

The results of assessing the quality of the appearance of coatings, carried out in accordance with Russian Standard GOST 9.407-2015 and using the fractal dimension of the surface of the coating profile, are given in Table 1.

Table 1. Evaluation of the coating appearance quality.

Type of paint	Coating surface roughness, R_a, μm	Fractal dimension, D	Surface profile perimeter, mm	Coating surface quality grade	Gloss,%
PF-115	0.22	1.17	106	V	70.8
	0.75	1.35	116	VI	67.7
MA-15	0.2	1.075	102	V	83.1
	0.48	1.125	109	VI	78
NC-123	0.2	1.1	105	V	76.9
	0.75	1.36	121	VI	67.7
Universal	0.75	1.3	216	VI	66.2
	1.26	1.42	221	VII	64.2
Facade	0.6	1.25	192	VI	66.2
	1.24	1.7	225	VII	62.2

A correlation was revealed between the roughness of the coating surface, the quality of appearance and the fractal dimension. As the roughness of the coating surface increases, the quality of appearance decreases, and the value of the fractal dimension D increases. The research results indicate that the fractal dimension of the surface profile of a coating based on PF-115 paint with a coating surface roughness of 0.2 microns and an appearance quality class of V is D = 1.17, and with a coating surface roughness of 0.75 microns and an external quality class For coating type VI, the fractal dimension is D = 1.35. This confirms that the fractal dimension of the coating surface profile depends on the surface roughness and the appearance quality class. Similar patterns are typical for other coatings types. The parameters of gloss and surface profile of the coating also depend on the roughness and quality class of the appearance. As the fractal dimension of the coating surface profile increases, the gloss of the coating decreases.

The correlation between the length L of the coating surface profile on the sample length l and the fractal dimension D can be approximated as:

$$L = lD^{bD}, \tag{2}$$

where l is a base length of measurement; b is a constant depending on surface roughness and appearance quality class. Formula (2) was obtained by the least squares method.

In particular, for the coatings based on paint PF-115 the expression (2) is

$$L = 99.62D^{0.33D}$$

– For paint MA-15 based coating

$$L = 99.08D^{0.63D}$$

– For paint NC based one

$$L = 99.55D^{0.416D}$$

– For acrylic paint based one

$$L = 115.28D^{1.47D}$$

– For water-dispersible façade paint based one

$$L = 131D^{0.645D}$$

The correlation coefficient ranged from 0.93 to 0.95.

The results of the research suggest that for fractal dimension D = 1–1.09 the coating appearance quality grade is IV, for D = 1.1–1.2 is V, for D = 1.21–1.4 is VI, for D = 1.41–1.99 is VII. Applying the integral performance index to the coatings appearance such fractal dimensions will let estimate paint coatings quality more objectively. The use of an integral indicator of the quality of the appearance of coatings, such as the fractal dimension, can complement existing indicators and make the assessment of the quality of paint and varnish coatings more objective. The results of calculations in accordance with model (2) are in good agreement with the data given in Table 1.

Research has shown that the quality of the appearance of coatings is determined by the nature of the bottling of the paint. Bottling is considered as a rheological process, which can be described by the following expression:

$$h = \frac{b^2}{8\sigma} f, \tag{3}$$

where h is stroke height; b is width of stroke; f is shift limit stress of the paint; σ is surface tension of the paint. Formula (3) is presented in [38].

Analysis of the data from Table 2, indicate that there is some slowing down of the time of restoration of the structure of paint when applied to the porous surface of the mortar. A slight slowdown in the restoration of the paint structure when applied to a porous surface of the solution has been established. On a glass substrate, the restoration time of the structure of the paint and varnish composition PF-115 is 3 minutes [39–42], and on the cement substrate is 5 minutes [43–44]. The structure of the paint and varnish composition depends on the porosity of the base and the rheological properties of the paint.

Table 2. Dependence of the quality of the appearance of a coating on the rheological properties of paints.

Type of paint	Surface roughness*, R_a, μm	Fractal dimension of the coating surface, D	Surface tension of the paint composition, mJ / m^2	Dynamic viscosity of the paint composition, Pa·s	Filling the colorful composition**, min.
Alkyd paint (PF-115)	0.61	1.30	19.36	7.89	≤5 / ≤5
	0.39	1.120	18.36	6.87	≤5 / ≤3
	0.19	1.05	16.68	5.79	≤5 / ≤3
Oil paint (MA-15)	0.79	1.29	17.50	23.70	≤5 / ≤3
	0.70	1.09	16.94	14.79	≤5 / ≤3
	0.45	1.04	16.20	10.37	≤5 / ≤3
Nitrocellulose (NC-132)	0.80	1.29	27.11	13.99	≤5 / ≤3
	0.59	1.09	24.11	7.40	≤5 / ≤3
	0.29	1.07	22.09	6.40	≤5 / ≤3
Acryl water dispersed (Façade)	2.99	1.39	37.38	40.05	≤15 / ≤15
	2.54	1.26	34.94	30.79	≤15 / ≤15
	1.86	1.09	31.90	21.57	≤15 / ≤15
Acrylate (Universal)	2.39	1.54	36.12	33.45	≤15 / ≤15
	1.78	1.29	33.88	24.29	≤15 / ≤15
	1.43	1.09	30.95	15.19	≤15 / ≤15

** The coating under study was applied to the glass substrate. Then, under microscope magnification, the roughness of the coating was assessed. Microscopic surface features such as irregularities, pores and inclusions were analyzed to determine the roughness of the coating. This method allows you to obtain accurate and objective data on the roughness of the coating.*

*** Numerical values of the paint structure recovery time when applied to a solution base are shown on the left, on a glass base – on the right.*

The results of assessing the surface profile of coatings show that with an increase in the surface tension of the paint and varnish composition, the quality of the appearance of the coating deteriorates. This may be due to the fact that higher surface tension prevents the paint from spreading evenly on the surface and forming a smooth film. As a result, the coating becomes rougher and less attractive in appearance. So, with the surface tension of the acrylate paint Universal equal to s = 36.13 mJ/m^2, the surface roughness of the coating is R_a = 2.4 μm, and the fractal dimension is D = 1.53. Similar patterns are typical for various types of coatings. The roughness and appearance of the coating can depend on various factors such as paint composition, application method and surface preparation.

At the next stage, the probability of coating failure due to the presence of surface defects was assessed. The probability of coating failure can be assessed based on an analysis of surface defects and their effect on the strength and durability of the coating. For this purpose, statistical data analysis methods such as Pareto analysis or cause-and-effect analysis can be used. An assessment of the probability of coating failure based on the safety factor and safety factor can also be used. It was suggested that there is one defect (inclusions, stripes, etc.) on the surface of the coating, which has a random location. Next, it was divided the area of the coating under study into n sections, the area of which is equal to the area of the defect. Possibility of a defect in a certain area during operation is equal to P. As a result, the condition must be observed that in real time $np = const.$ A coating is considered "failed" if more than n_{def} areas are found on its surface, which is determined from the formalas:

$$n_{def} = \frac{S_{def} n}{100}; \tag{4}$$

$$F(c) = \sum_{x=0}^{S_{def} n} \frac{c^x}{x!} e^{-c}, \tag{5}$$

where $c = np = const.$

It was proven that it is possible to evaluate the kinetics of the concentration of defects on the surface of a coating during its aging. This can help determine when the coating may become more susceptible to failure due to increased defects. The quality of the appearance of defects can be described using fractal dimension and surface roughness. After the coating had cured, the samples were subjected to various tests, such as freeze-thaw, to test their resistance to various impacts. It was been established that the quality of the appearance of the coating can be improved or deteriorated depending on the porosity of the base and the rheological properties of the paint and varnish compositions used. More porous substrates or more viscous paints can result in a rougher, less attractive finish. A coating area of 64 cm^2 was used for determination of the defect concentration.

It was that cracks appear locally and form near defects on the coating surface. For example, on the coating based on paint MA-15, characterized by a fractal dimension and roughness index of 1.089 and R_a = 0.23 μm, respectively, surface cracks appeared, visible to the naked eye, after 5 freeze-thaw cycles, and on a coating with an index of fractal dimension and roughness 1.069 and R_a = 0.14 μm, respectively, after 15 test cycles. Other coatings studied are also characterized by similar patterns (Table 3).

Table 3. Coatings appearance quality reducing during freezing–thawing.

Paint coating	Surface roughness*, R_a, μm / Fractal dimension	Number of defects after test cycles/failure possibility, %				
		0	5	10	13	15
Alkyd paint (PF-115)	0.09/1.111	37/17.0	40/42.8	49/99 Coating peeling off	-	-
	0.09/1.09	29/14.9	31/38.43	37/41.9	69/99 Coating peeling off	-
	0.11/1.11	19/13.8	26/35.4	30/40.8	57/47.1	58/53.9
	0.19/1.18	44/16.9	61/99 Coating peeling off	-	-	-
	0.20/1.09	29/16.0	48/199 Coating peeling off	-	-	-
	0.16/1.09	21/13.91	47/31.0	55/41.1	60/45.3	64/54.2
	0.27/1.20	53/17.7	68/33.5	79/99 Coating peeling off	-	-
Oil paint (MA-15)	0.24/1.09	30/24.9	59/199 Coating peeling off	-	-	-
	0.20/1.074	21/24.4	24/34.9	27/37.9	29/39.9	34/41.4
	0.16/1.08	9/23.3	16/33.9	19/34.9	20/39.3	27/40.9
	0.28/1.20	29/24.9	71/99 Coating peeling off	-	-	-
	0.19/1.076	22/24.6	50/99 Coating peeling off	-	-	-
	0.18/1.074	11/23.7	17/34.5	20/36.4	24/39.7	30/40.1
	0.29/1.25	33/25.5	81/99 Coating peeling off	-	-	-

Thus, by adjusting the rheological and technological composition of the paint, as well as the physical and mechanical properties of the base and other parameters, it is possible to obtain high-quality coatings with excellent external characteristics.

The porosity of the base certainly affects the quality of the appearance of the resulting coating (Table 4). As the porosity of the substrate increases, the surface roughness of the coating usually also increases. So, for example, the surface roughness of lime coatings increases to 83.4 μm (the porosity of the substrate is 9.7 %); for polymer lime up to 88.1 μm (substrate porosity 12.0 %); for PVAC coatings up to 46.2 μm (substrate porosity 12.7 %). An increase in the porosity of the base usually leads to some deterioration in the quality of the appearance of the resulting coatings.

Table 4. Dependence of the coatings appearance quality on the substrate porosity.

Coating type	Porosity,%	Coating roughness, μm	Coating grade
	0	34.0	V
Lime	5.8	50.6	V
	9.7	83.5	VI
	0	33.4	V
Polymer lime	4.2	41.4	V
	12.0	88.2	VI
	0	8.3	V
PVAC	3.1	20.4	IV
	12.7	58.5	V

Puttying and priming a surface with such porosity helps improve the quality of the appearance of the coating (Table 5).

Table 5. Effect of the substrate surface preparation method on the coatings appearance quality.

Viscosity determined by VZ-4 device, s	Paint application method	Porosity,%	Substrate surface preparation	Coating appearance quality grade according to Russian standard GOST 9.032-74
PVAC Paint				
50	brush	0	padding	VI
30	pneumatic	0	padding	V
50	brush	3.2	padding	VI
50	brush	4.3	padding	VI
50	brush	6	padding	V
50	brush	6	puttying, padding	IV
Lime Paint				
50	brush	0	padding	VI
35	pneumatic	0	padding	V
50	brush	6	padding	VI

The method of applying the paint composition also has a significant impact on the quality of the appearance of the resulting coating. Table 5 presents data about the coatings appearance quality of depending on the method of applying the paint composition for preparing the substrate surface. An analysis of the data given in Table 5 provides that, with an equal porosity of the cement base, the pneumatic application of the paint composition contributes to an increase in the coating class. Thus, in order to obtain a higher coating appearance quality, it is necessary to strive to create a surface porosity of the cement base that does not exceed 5 %.

Statistical processing was done for a more reliable assessment of the distribution of roughness indicators. Information analysis (Table 7) shows that regardless of the paint type, base porosity, there is a heterogeneity in the rough distribution. Thus, when using PF-115 paint on the base with porosity 24 % range R is 10.94 μm, and MA-15 paint is 10.12 μm. Swipe between surface roughness R_a of coatings based on paint PF-115 on putty surface is much lower (3.68 μm). For PF-115 paint a coating that is less uniform along the strike is formed when paint is applied to substrate with a porosity of 32 %. The spread of roughness indices R_a = 11.21 μm. Regardless of the type of paint composition, a smaller spread of indicators roughness R_a is typical for the surface of all coatings on putty substrate.

Table 7. Coating surface roughness and processing statistics sample information.

Type of paint	Substrate porosity,%	Roughness R_a, μm	RMS deviation σ / data range R
PF-115	24	6.7	2.88/10.94
	28	7.65	1.92/8.61
	32	6.98	3.32/11.61
	The surface is putty	2.6	0.95/3.68
MA-15	24	4.37	2.94/10.12
	28	4.53	2.6/10.31
	32	5.4	5.61/10.1
	The surface is putty	2.8	1.21/4/52

Provided that the surface roughness parameters of the coatings are distributed according to the normal law and taking into account the three-sigma deviations in the tolerance field, you can get the value of the defect level q by expression

$$q = 0.5 - \Phi\left(\frac{ULT - R}{\sigma}\right),$$

where Φ is the Laplace function; σ is standard deviation; ULT is upper limit tolerance; R is the average value of the surface roughness.

It was calculated the defectiveness level of coatings for roughness with surface grades N4 and N5 according to ISO1302 (for roughness class N4, ULT equals 8 μm, for N5 – 16 μm). The results of the calculation are given in Table 8.

Table 8. Defect level of coatings.

Type of paint	Substrate porosity,%	Defect level, %, at roughness grade, %,	
		N4	N5
PF-115	24	32.64	0.069
	28	36.84	0.103
	32	38.21	0.33
	The surface is putty	0.001	0.001
MA-15	24	10.93	0.007
	28	12.34	0.012
	32	32.38	3.01
	The surface is putty	0.006	0.001

It was established that coatings based on PF-115 and MA-15 paints, estimated by the N4 roughness grade, have a high defect level (up to 38 %), and by the N5 roughness grade - no more than 0.007–3.01 %. This means that with increasing coating roughness class (i.e. increasing surface roughness), the number of defects on the coating surface increases. Regardless of the type of paint, the porosity of the substrate surface puttying before painting contributes to the formation of coatings with a low level of defects, amounting to 0.001–0.006 %.

So, it is necessary to take into account the porosity of the cement base and select the appropriate type of paint and varnish material to achieve high quality paint coatings on building products and structures.

4. Conclusions

As a result of the conducted study, the following conclusions were drawn.

1. Based on the obtained patterns, recommendations were developed for optimizing the formulations of paints and varnishes to ensure high quality coatings. It was revealed that with an increase in the surface tension of the aqueous paint composition, a lower quality of the appearance of the resulting coating is observed. This may be due to the fact that high surface tension prevents the uniform distribution of pigment and binder particles in the paint and varnish material, which in turn leads to a deterioration in the appearance of the coating.
2. With an increase in the porosity of the substrate, an increase in the roughness of the surface of the coatings is observed. This may be due to the fact that the paint and varnish material fills the pores

of the substrate unevenly, which leads to the formation of irregularities on the surface of the coating. To reduce the roughness of the coating, you can use substrates with less porosity or use special primers to reduce surface porosity.

3. It was established that coatings based on PF-115 and MA-15 paints, estimated by the N4 roughness grade, have a high defect level of (up to 38 %), and by the N5 roughness grade, no more than 0.007–3.01 %. This means that with increasing coating roughness class (i.e. increasing surface roughness), the number of defects on the coating surface increases.
4. Fractal dimension is a quantitative measure of surface roughness and can be used to assess the surface quality of paint and varnish coatings. A correlation was established between the surface roughness of the coating, the quality class of their appearance, and the fractal dimension. This makes it possible to use the fractal dimension as an objective criterion for assessing the surface quality of paint and varnish coatings and determining their appearance class.
5. A model is proposed that allows one to calculate the fractal dimension of a coating surface based on data on the length of the surface profile and other parameters. Numerical values of the index of the fractal dimension of the coating surface profile are obtained depending on the porosity of the substrate. This makes it possible to determine the optimal parameters of paints and varnishes and their application technologies to obtain coatings with the required level of quality.
6. To ensure the quality of paint and varnish coatings of building products and structures, it is necessary to take into account the porosity of the cement base and select the appropriate type of paint and varnish material. The results obtained can be used in various industries to improve the quality of paint and varnish coatings. For example, not only in the construction industry, but also in the automotive industry, furniture production and other areas where paint and varnish coatings are used.

5. Prospects for further development of the topic

Consideration of interdisciplinary approaches can lead to new ideas and solutions in the field of building materials science and the production of paints and varnishes. However, the possible environmental and economic consequences of the use of natural and man-made resources in these processes should be taken into account. More research is needed in this area to determine the effectiveness and safety of such approaches. The algorithm used in the article can be useful in the development of composite finishing coatings for building materials. This can help expand the range of production of building materials and improve a comfortable human environment in architectural design and production of composites.

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