Rapid assessment of adhesion of paint coatings by digital image analysis

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Abstract. A program is developed that allows to numerically assess the area of defects in protective coatings by analyzing digital images of surfaces. The program is implemented in Microsoft Visual Studio programming environment. The possibility of estimating the area of flaking of the paint coating from the base layer (%) and determining the adhesion in points, in accordance with the cross-cut test method in the context of paint production is shown. The created program does not require a large computing power of the computer and can reduce the time to obtain calculation results for one plate with a coating from 20 minutes to 1-2 seconds. An example of using the developed program for calculating the area of metal surface areas with different chemical composition is given.

1. Introduction

Paint coatings are widely used to protect metals, wood, plastics, concrete and other materials from destruction. The strength of the coating’s connection with the surface to be protected is one of the most important characteristics of the coating, as it determines its scope and performance. The bond between the surfaces of two dissimilar contact surfaces is called adhesion, and the adhesion strength is its objective indicator. This characteristic is determined experimentally, assessment methods are very diverse, the results obtained largely depend on the test conditions, sample sizes, and structural features of the applied compositions. At present, theoretical methods for calculating adhesion are being actively developed [1-3], attempts have been made to create universal criteria that theoretically predict the adhesive or anti-adhesive properties of a certain pair of materials [3-5]. A significant part of the literature is devoted to the study of the effect of the components of applied compositions, modifiers, inhibitors, physical factors on the adhesion and adhesive strength of coatings, and the improvement of existing approaches to the determination of adhesion [6-13].

Methods for assessing adhesive strength (non-destructive, destructive or indirect) used in practice are all quite laborious. There are many works aimed at studying approaches to reduce the complexity of determination or the length of time spent evaluating the adhesive strength of the contacting materials. In a number of works, the adhesion strength of contacting materials is estimated by the adhesion of the initial liquid phase (melt, suspension) to the base layer [14], and the dependence of the adhesion energy on the atomic density [15] is established. A technique is used to assess the adhesion of coating structures to the surface using atomic force microscopy [16], sclerometry methods are used in combination with microhardness measurements [17, 18]. Ultimately, in practice, the choice of the
adhesion determination method is determined by the expected load to which the adhesive joint will be subject during operation and the expediency of the method.

For paint coatings under production conditions, the adhesive strength is determined by the cross-cut test method, according to the technique described in ISO 2409:2013. This method is the most used, since it does not require special equipment, and the test can be performed promptly in laboratory and field conditions. According to the technique, cuts are applied to the coating surface up to the base layer in mutually perpendicular directions, resulting in a grid of squares separated from each other. On a five-point scale, coating adhesion is evaluated by comparing the area of flaking with tabulated values. The method has several disadvantages:

- assessment of the damage area on the coating according to the requirements of the standard is determined with the naked eye or with a magnifier, therefore, it is subjective;
- complexity of the operation for the laboratory assistant making such an assessment on a series of samples is high.

Therefore, the idea of work arose - to obtain a digital image of the surface with flakes and using the developed program to evaluate the defect area. This approach is relevant, allowing to assess numerically the fracture zone and reduce significantly the analysis time. Of interest was also the possibility of using a program to estimate surface regions having a chemically different composition.

The purpose of the work is to develop a program that allows, by analyzing digital surface images, to numerically evaluate the area of flaking from the base layer of the samples and calculate its adhesion in points.

2. Materials and methods

To determine the adhesion strength, PF-115 painted with pentophthalic enamel plates made of 08kp steel with a size of 100x150 mm were used. Before the test, the painted plates were kept at a temperature of (23 ± 2) °C for at least 16 hours. Cross cuts were applied on three different surface areas; the number of cuts with dimensions of at least 20 mm was six. Crosswise over the squares, a few strokes were carried out several times with a bristle brush. Then a piece of adhesive tape with a length of at least 75 mm was placed on the grate parallel to one of the cut directions, smoothed out and after 5 minutes smoothly removed, having taken at the free end, with a separation angle close to 60 °. To calculate the adhesion in points, the images of cut plates obtained using a USB Digital microscope 800X were used.

For a numerical assessment of the surface zones’ area having a different chemical composition, we used the results of mapping of a steel surface with MoS2 anti-friction solid lubricant coating. Information on the distribution of MoS2 on the surface was obtained using INCA Energy 450 energy dispersive microanalyzer (with an X-Act ADD detector) from OXFORD Instruments Analytical based on a Tescan Vega LMU scanning electron microscope (Center for the Study of Mineral Raw Materials and the State of Environment of Southern Federal University). Measurements were performed at an accelerating voltage of 20 kV. The coating was applied in accordance with the technique described by the authors in [3].

To create a program that enables you to calculate the area of flaking on the surface of a painted plate, we used the development environment Visual Studio on the resulting image. Figure 1 shows the initial image of the cut plate obtained using a digital microscope.
Figure 1. Example of an initial image of a cut plate obtained with a digital microscope.

3. Result and discussions
According to ISO 2409:2013, the following classification of the results of adhesion testing by the cross-cut test method is adopted:
- edges of the cuts are completely smooth, not one of the squares in the grid has flaked off (0 points);
- separation of small coating flakes at the intersection of cuts. The area of flaking slightly exceeds 5% of the grid area (1 point);
- coating flaked along the edges and/or at the intersection of cuts. The area of flaking slightly exceeds 5%, but it is not more than 15% of the grid area (2 points);
- coating flaked along the edges of the cuts partially or completely on different parts of the squares. The area of flaking slightly exceeds 15%, but it is not more than 35% of the grid area (score 3 points);
- coating flaked along the edges of the cuts in wide strips and/or some squares were partially or completely separated. The area of flaking exceeds 35%, but it is not more than 65% of the grid area (4 points);
- any degree of flaking that cannot be classified with a 4th point on the scale (5 points).

To process the results of the conducted tests, when determining adhesion, a program in C ++ was developed. The development environment VS includes a library of image processing algorithms ‘Open cv’, a set of controls for two-dimensional and three-dimensional graphics. We analyze the images of test plates with coatings of ‘.jpg’, ‘.jpeg’ and ‘.png’ formats. To process the image, you must download the selected file. In the program, this can be done using the dialog box by selecting the button ‘open’. After loading the image, the program automatically processes the image and displays the results in a new window. In the process of image processing, the program analyzes and compares each pixel by its intensity relative to the threshold. To identify the pixels in the program, the value ‘0’ for black is used, the value ‘255’ for white is used.

For the data selected by the program, the area of pixels is calculated, the% of this area of the total area is calculated, and the result is determined in points:
- the total area of the picture in pixels is calculated (the number of pixels in width × the number of pixels in height);
- the counter of the number of white pixels is reset (variable).

All pixels of the picture are enumerated:
- compares the color of the pixel with the color of the pixel plate;
- if the colors match (the values are equal), then the value of the color of the pixel is assigned the value ‘white’ and the counter of the number of white pixels is increased by one, the next pixel is taken;
- if the colors do not match (the values are not equal), then the value of the pixel color is assigned the value ‘black’, the counter of the number of white pixels does not increase, the next pixel is taken.
Enumeration of pixels is carried out to the end of the image (the last pixel). The change (in percent) is calculated by the following formula:

\[ k = \frac{S - S_1}{S} \cdot 100 \]

Where \( S \) is the total image area (number of pixels), \( S_1 \) is the number (area) of white pixels.

The program compares the result \( k \) with a set of ranges and assigns a value in points and displays it in a form. An example of the result of calculating the area of flaking of the coating (in percent), and adhesion (in points) is presented in Figure 2.

On the left is a photo of the plate in black and white, on the right is a digital result with comments: classification in points (from 1 to 5), the area of flaking in percent. In similar way the analysis of the next image of the plate is carried out.

![Example of coating adhesion calculation result.](image)

The program makes it possible to numerically evaluate surface areas that differ in color. The usage of the proposed program in conjunction with other methods of structural analysis enables us to estimate the area of defects, areas of distribution of chemical elements, and various inclusions. As it is known, when forming a coating layer on the surface of the base, the coating must have a given chemical composition and morphology.

Surface images obtained by electron microscopy, as a rule, do not allow to correctly assess the area where there is no coating. The situation is exacerbated when it comes to relatively ‘thin’ coatings. In this case, application of the program allows to obtain more complete information about the presence of a coating on the surface. Figure 3, as an example, shows the results of mapping a steel surface with an anti-friction coating of molybdenum disulfide powder. The coating was applied by a vibration mechanochemical method according to the technique described by the authors in [3]. An analysis of the EDM (energy dispersive microanalysis) map of the coating enabled us to conclude that after coating on the steel base layer there are areas that are not protected by the coating. Using the program, the surface area where MoS\(_2\) coating is absent was estimated: 32.5\%.
Thus, the proposed program enables us to estimate the size of surface defects, both at the macrostructural level and at the microstructural level.

4. Conclusions
The program developed in Microsoft Visual Studio programming environment enables you to numerically estimate the surface area of a coating surface by analyzing its digital image. The program is applicable for the numerical analysis of surfaces, both microobjects and macroobjects.

The possibility of using the program to assess the adhesion strength of paint coatings to the base layer in points, in accordance with the classification of the cross-cut test method, is shown. Application of the proposed approach reduces the time required for processing test results for one test sample from 20 minutes to 1-2 seconds.

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