EVALUATION OF CORROSION RESISTANCE BY COMPUTER IMAGE ANALYSIS

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Abstract

The paper presents the possibility of using the ImageJ computer program for image analysis as a method of assessing the proportion of sample surfaces occupied by corrosion. The program allows to calculate the size of any graphic selection and calculates the number of pixels contained in it, can also measure distances and angles between points or elements of images. The study used a sample made of steel 23MnB4. After preparing the surface, the samples were divided into three groups, which were then subjected to galvanic, hot-dip and lamela process. After the galvanizing, metallographic examinations were carried out during which the thickness and structure of the applied layer were assessed, and then corrosion tests were carried out in a salt chamber. The final stage of the research was a computer analysis of the image of the sample surfaces to be tested. For this purpose, the ImageJ program was used. The evaluation of the corrosion process using computer image analysis proves that such an assessment is more accurate than the method recommended by standards or comparison with standards and can serve, in addition to traditional measurements, to quantify the corrosion rate in a salt chamber. The unquestionable advantages of the program are its free availability, the possibility of expanding its own extensions and cooperation with any operating system.

Keywords: Computer program, surfaces, steel, salt chamber, ImageJ

1. INTRODUCTION

Issues of resistance of engineering materials in natural and artificial environments are extremely important in the design of structures and machine parts. Improper selection of fasteners and the type of fastening has a significant impact on the premature appearance of corrosive foci and, consequently, on the reduction of the mechanical strength of the entire structure [1,2].

The common use of bolted connections results from the ease and speed of their assembly, often in difficult conditions (eg at significant altitudes or in hard to reach places), low labor intensity of these operations and lack of dependence on atmospheric factors (eg unfavorable weather, which sometimes becomes a problem for making welded joints). The time of assembly completion and the lack of the need to employ qualified employees for this work are also important [3,4]. Corrosion from the point of view of durability of screw connections in parts of machines and devices is of particular importance as it leads to changes in the chemical composition of the material in contact with the atmosphere. Corrosion results in, among others: reduction of the cross-section, increase in the weight of the structure, formation of gaps, pits and other losses [5].

Corrosion is a phenomenon that can not be completely eliminated, but can be significantly reduced. The degradation of materials due to corrosion can be effectively reduced by skilful prevention, eg through the proper selection of materials or the use of corrosion protection methods. Corrosion protection of screw products has, among others for the task of protecting the material against loss of mechanical properties [6,7]. Among the proposed methods, the application of protective coatings seems to be the most appropriate compromise between the cost and the effectiveness of anti-corrosion protection. For corrosion protection of threaded fasteners, the most frequently used element is zinc, which is applied to the surface of the screws by several methods (hot-dip galvanizing, galvanic, lamellar).

2. OWN RESEARCH

The tests were carried out on samples made of 23MnB4 steel with a typical chemical composition in accordance with EN 10263-4-2001 (**Table 1**). Samples were taken from hexagon bolts used, among others in the automotive industry. The next stage of the experiment was the galvanizing process made by three different methods: fire, galvanic and lamella. The parameters of galvanizing processes and surface preparation method are presented in **Table 2**. The tests of zinc coatings included: roughness measurements of the obtained zinc coatings, resistance tests in salt chamber and computer image analysis.

Table 1 Chemical composition of investigated bolts

Chemical composition (%) 23MnB4 (1.5535): EN 10263-4-2001							
C	Si	Mn	P	S	Cr	Cu	Ni
0.2 - 0.25	max 0.3	0.9 - 1.2	max 0.025	max 0.025	max 0.3	max 0.25	Max 0.005

Table 2 Parameters of Zn coating process

No	**Kind of process**	**Surface preparation**
1	**Electro-galvanizing acc. PN-EN ISO 4042**	• chemical degreasing, temp. 60 °C • etching in 18 % HCl and 10 % H_2SO_4 with inhibitors • degreasing and electro-polishing, temp. 60 °C, 1000 A • galvanization in the weak acid chlorine Zn bath, temp. 35 °C, • passivation - jons Cr^{3+}, Co^{2+}, NO_3^- temp. 45 °C, pH 1,9
2	**Hot-dip acc. PN-EN ISO 10684**	• etching in 12 % HCl • fluxing • galvanizing in the bath: Zn with additions Al, Bi, Ni; temp. 460 °C • cooling in water
3	**Lamellar acc. PN-EN ISO 10683**	• shot blasting 0.4 mm • triple painting (95 % Zn, 5 % Al) • temperature holding in 120 °C, cooling to temp. 25 °C - air jet

3. TEST RESULTS

After application of zinc coatings in accordance with the methodology presented in **Table 1**, surface geometry tests were carried out, which can significantly affect the final effect of the quality of the obtained protective coating. Stereometric examinations were carried out in 3D, using the Perthometer Concept (MAHR) profilometer. Sample isometric images of the surface are shown in **Figure 1**. The average measured values of roughness of applied zinc coatings before and after salt chamber tests are shown in **Figure 2**.

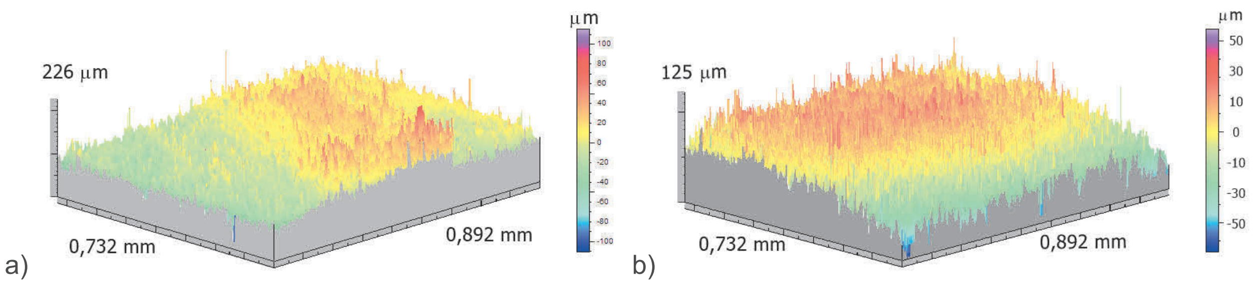


Figure 1 Isometric image of the surface: a) before corrosion test, b) after corrosion test

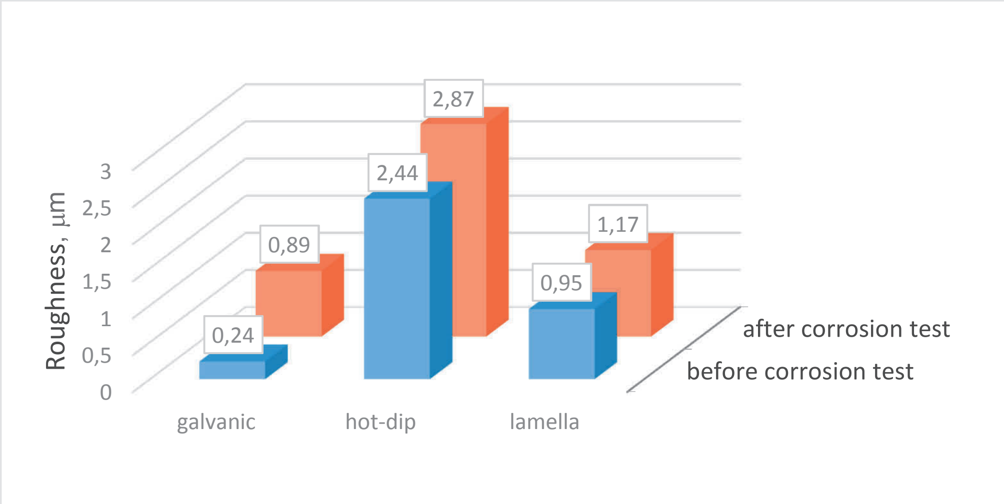


Figure 2 The average values of measured roughness parameter sRa

Corrosion resistance tests were carried out in a salt chamber (NSS). The parameters of the accelerated corrosion process were as follows: corrosive medium - NaCl 50 ±5 g/dm^3, air pressure 1 bar, inside temperature 35 °C. After removing from the chamber, the samples were cleaned and then a computerized image analysis was carried out. In order to more precisely determine the share of the surface of the samples occupied by the "red corrosion“, a computer image analysis was used - the "Image J" program, version 1.48. For example, in **Figure 3a** screen shot is presented during the process of processing photographs of the tested samples. **Figure 4** presents the next stages of computer image analysis on the example of sample number 2 - after 24 hours of corrosion test. First, the scale was calibrated by assigning a section of known length in mm or µm to the same section on the screen, which creates a row of pixels of a known number (**Figure 3**).

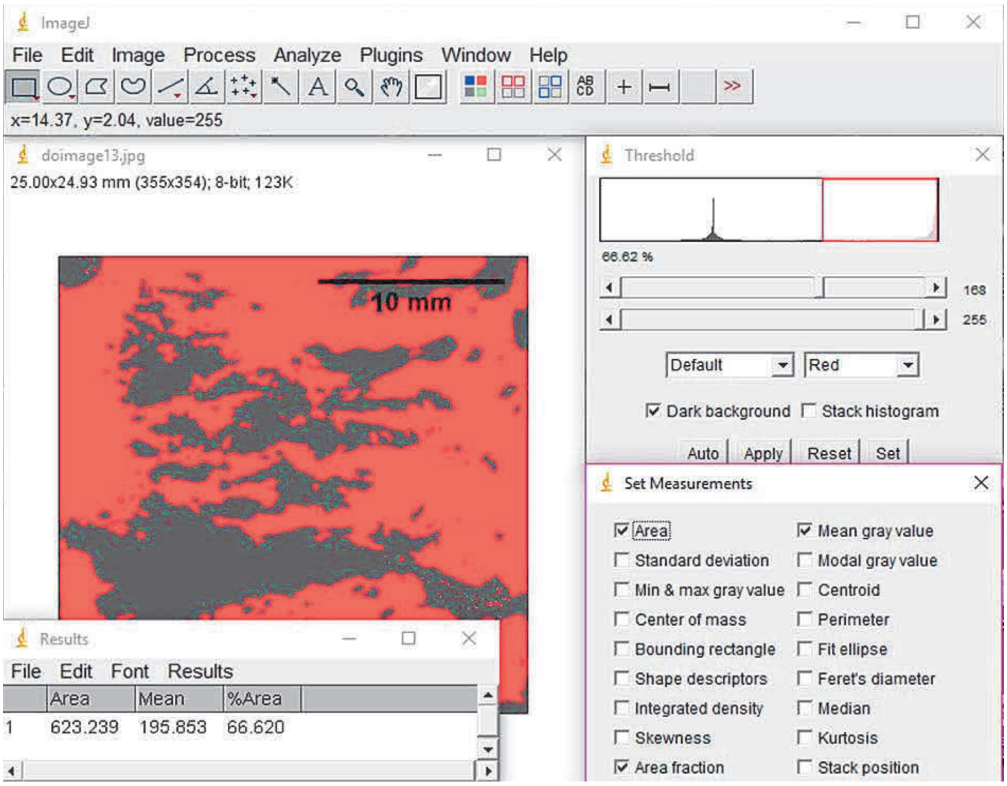
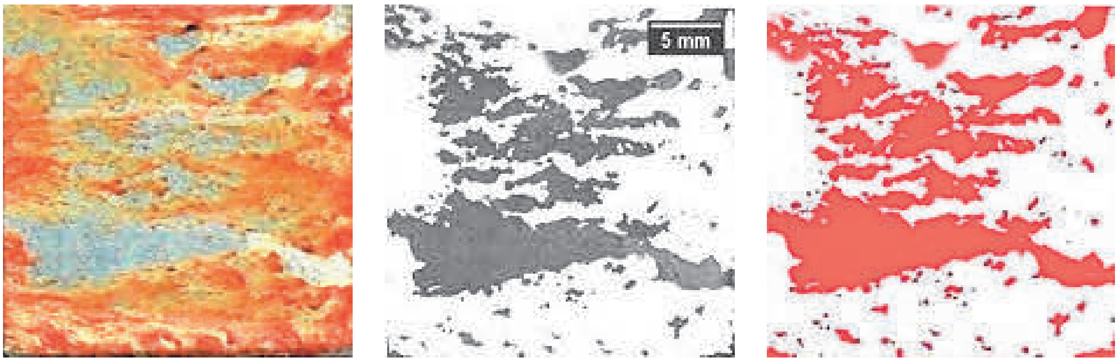


Figure 3 Screenshot of the "Image J" program along with the analyzed surface of the sample

In the analyzed case, these were the dimensions of the samples. Next, the area covered with corrosion was marked with appropriate thresholds of color limits, after which the picture mode was changed from color (RGB) to the image in shades of gray (**Figure 4b**). The last step was to mark a specific area and calculate the percentage of the surface covered by corrosion or free of its products - **Figures 3, 4c**. During the tests, the measurements were carried out 10 times, and their average results are shown graphically in **Figure 5**.



a) b) c)

Figure 4 The next stages of photo analysis from the surface of the samples subjected to the corrosion test: a) the surface of the analyzed sample, b) the surface covered with corrosion marked with white color, c) the final determination of the area covered with red corrosion

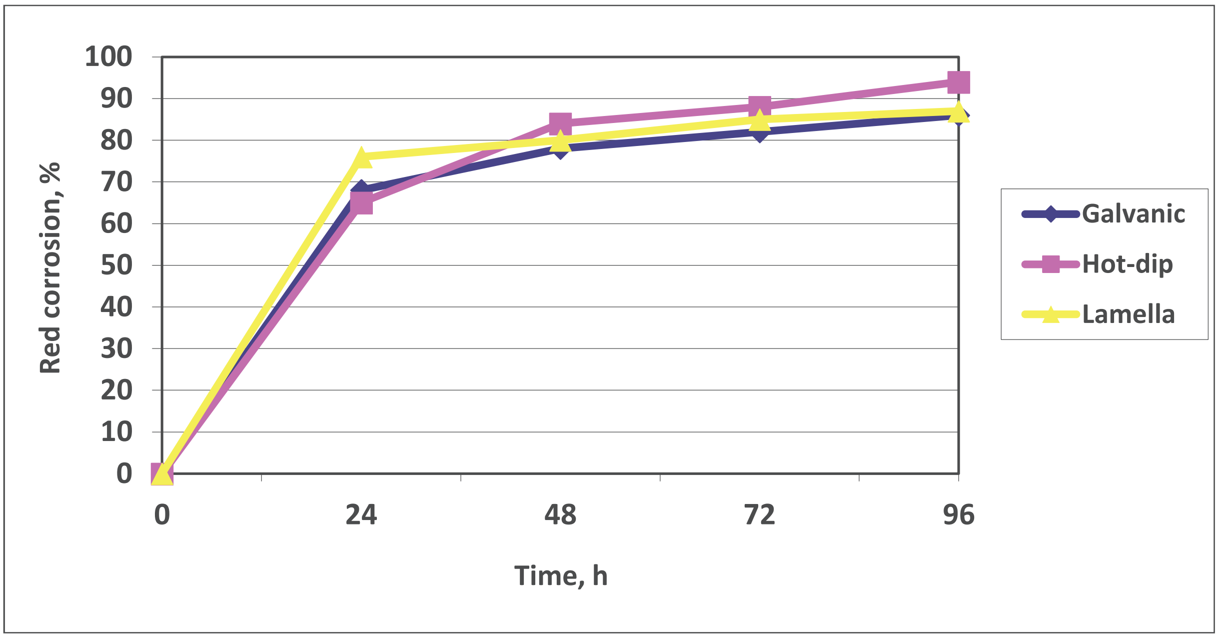


Figure 5 Kinetics of corrosion of samples after galvanizing expressed as a percentage of the area covered by "red corrosion"

4. RESULTS ANALYSIS

The analysis of the surface condition of the tested zinc coatings showed that the coatings obtained by the fire method are characterized by the highest roughness. The average measured value of the sRa parameter was 2.44 µm. In the case of the other two coatings, these values were decidedly smaller. For the lamella coating sRa = 0.95 µm and for the galvanic coating sRa = 0.24 µm. Surface condition tests were performed again for samples that were tested in a salt chamber. The mean arithmetic deviation of the sRa profile was slightly higher. For the fire coating sRa = 2.87 µm, for the lamella coating sRa = 1.17 µm, and the smallest value was measured for the galvanic coating sRa = 0.89 µm. The immediate cause of increased roughness of zinc coatings was the appearance of corrosion products on the surface.

Computerized image analysis enabled quantitative determination of the area covered by the so-called "red corrosion". Corrosion rate, which is expressed by the derivative of the characteristic from **Figure 5** according to time, can be estimated by intervals as the tangent of the slope of the characteristic curve to the time axis. In the initial phase of the test (0÷24 h), the corrosion rate for the galvanic coating is 2.75 %/h, for the fire 2.71 %/h, and for the lamel coating 3.16 %/h. In subsequent phases of the test, the rate of corrosion decreases and so for the interval 24÷48 h it is 0.42 %/h for the galvanic coating, 0.79 %/h for the fire coating, and for the lamel coating 0.58 %/h. For 48÷72 h times the corrosion rate did not change and amounted to 0.16 %/h for galvanic and fire coating, and for the lamella coating 0.2 %/h. For the last time interval 72÷96 h it was similar for all coatings and ranged from 0.125 %/h to 0.13 %/h.

The assessment clearly shows that in addition to traditional methods, such as mass change measurement, also using computer image analysis, the speed of the corrosion process can be determined quite precisely, not stopping on a zero-one evaluation (whether or not) by PN, or by comparing samples to patterns.

5. SUMMARY AND CONCLUSIONS

- The conducted research shows that computer image analysis can be used to determine the speed of the corrosion proces.
- For the determination of the corrosion kinetics of flat samples, computer image analysis can be successfully used, which enables a more precise comparison of the corrosion process than a macroscopic examination.
- The smallest roughness is shown by the surface of the galvanic coating, which is characterized by the highest corrosion resistence.
- Studies using computer image analysis confirmed that the highest corrosion rate of about 2.75 %/h, observed in the initial phase of the test (0-24 h).
- After 24 hours, the corrosion rate decreases to about 0.15 %/h.

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