MAGNETIC-INDUCTIVE MEASUREMENT OF THE ZINC LAYER ON THE NON-ALLOY STEEL SHEET

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Abstract

Surface treatments of metals are important areas of mechanical engineering. Galvanizing, which is a zinc coating on the steel base material by electrolytic deposition, belongs among the wide range of methods. Zn layer protects anodically the base material (usually unalloyed or low-alloy steel) against corrosion. In the final phase of the galvanic process final finish is performed - yellow or blue chromate surface coating. For correct function of the Zn layer it is important to abide the prescribed thickness. In the electroplating plants the thickness of Zn layer is usually measured by magnetic-inductive method. This method is fast, simple and non-destructive. The aim of this work is to verify the accuracy of this method using optical microscopy. Optical microscopy is here understood as the reference method, because this method is accurate and correct.

While dealing with the given problems the statistical tests shown, that the differences between the results of the two methods are statistically significant. Therefore results of magnetic-inductive method must be corrected using the calculated conversion factor. After conversion of the measured values the magnetic-inductive method can be recommended to operating measurement of the Zn layer thickness on unalloyed and low-alloyed steels. Furthermore, it was found that the type of final surface treatment (chromate surface coating) does not affect accuracy of measurement of Zn layer.

Keywords: Galvanizing; Zinc layer; Optical microscopy; Magnetic-inductive method

1. INTRODUCTION

One of the important areas of engineering production is surface finishing of metals that provide corrosion protection and modify the external appearance [1]. Thus surface finish changes functional properties of modified basic materials. Among a wide range of methods we can include galvanic zinc coating, which is application of zinc layer on the cold steel. Zinc protects the surface of the material mechanically and chemically as well. In a humid environment Zinc creates a galvanic cell with Iron; therefore zinc coating provides anodic protection against corrosion to the base material [2-4].

The thickness of the Zinc layer can be accurately determined by optical microscopy [5]. This method is destructive, time-consuming, and economically demanding. Therefore, in galvanic plants is used magnetic induction method during production. Measuring probe MP0 Dualscope-R (Fischer) (see **Fig. 5**) contains a ferromagnetic core and exciter winding, which is fed by low frequency current. The probe creates in its surroundings an alternating electromagnetic field (60-400 Hz). If the probe is in the vicinity of ferromagnetic material, the probe will intensify its array. This amplification is measurable in the second coil and corresponds to a distance from ferromagnetic substrate to the probe. This method of non-destructive thickness measurement of coating is based on the evaluation of the intensity of the electromagnetic field, which is a function of the thickness.

The method is applied as informative and indicative for the simplest operational control. Magnetic induction method allows measurement of all non-magnetic layers (zinc, chrome) on the magnetic base material (steel). The measurement can be influenced by surface roughness, curvature of the surface, thickness of the substrate or alloy coatings with different ferromagnetic conductivity. The accuracy of measurement, changes with the thickness of the coating, the measurement error is lower than 10 % of the thickness of the coating in accordance with CSN EN ISO 2178, or 1.5 µm.

This method is quick and simple. Due to a lower accuracy it is necessary to carry out measurements repeatedly. This article aims to verify its truthfulness and accuracy.

2. EXPERIMENTAL MATERIAL

It was used steel plate with electrolytic Zinc coating as a base material. Dimensions of the plate were 50 x 30 x 0.5 mm. For the determination of the composition of the base material there was made "Bulk" analysis by Glow Discharge Optical Emission Spectroscopy (GDOES). The measurement was carried out in "Bulk mode" spectrometer Spectruma GMBH, exciter conditions 700 V and 35 mA. The results are listed in **Table 1**.

Table 1 Bulk analysis of base material

C	Mn	Si	P	S	Cr	Ni	Mo
hm. %							
0.034	0.449	0.011	0.016	0.006	0.014	0.047	0.013
Cu	**Ti**	**Co**	**B**	**Pb**	**V**	**W**	**Al**
hm. %							
0.034	<0.0001	<0.0001	0.002	<0.0001	0.014	<0.001	0.054

Samples were prepared by galvanizing of Zn coating on the surface of the substrate. Before plating, the samples were placed on the hanger (see **Fig. 1**). Galvanizing is composed of several successive repetitive operations: chemical and electrochemical degreasing, rinsing, pickling, galvanizing, chromating and drying (see **Fig. 2**).

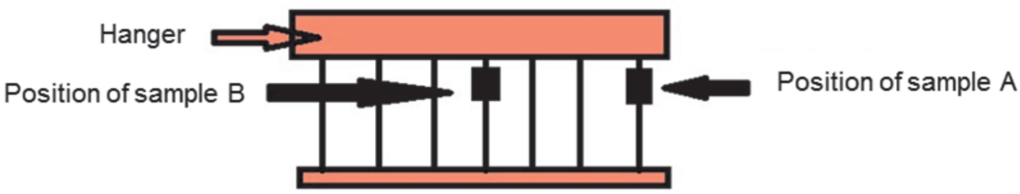

Fig. 1 Location of specimens on the hanger

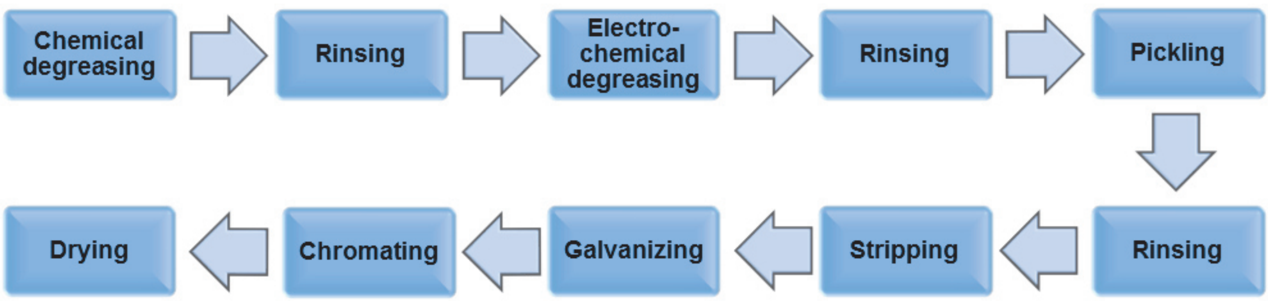

Fig. 2 The basic scheme of the galvanizing process

After zinc plating there is produced a surface with a matt gray color (see **Fig. 3a**). Atmospheric corrosion form Zinc corrosion products, which are known as "White corrosion". This prevents e. g. passivation (chromating of zinc coating). During Passivation is formed protective layer - hydroxy compounds of trivalent chromium and Zinc, which increases the corrosion resistance of the coating. The resulting passivation layer is formed of amorphous shell. **Fig. 3** shows yellow (b), and light blue (c) chromate layer.

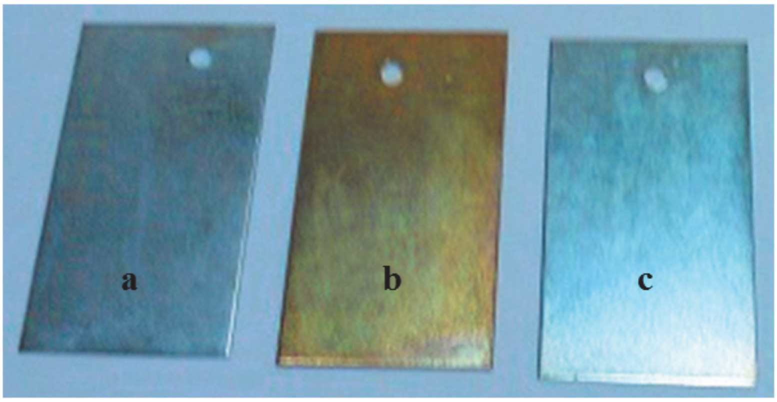

Fig. 3 Samples coated with Zn (**a** - pure Zn, **b** - Zn + yellow chromate, **c** - Zn + blue chromate)

Comparison of the results of optical microscopy and magnetic-inductive method was performed on 10 samples differing in terms of the galvanic process, and thus the thickness of Zn and chromate layer (see **Table 2**). Samples A and B differ by placing on a hanger (see **Fig. 1**).

Table 2 List of samples with Zn and chromate coating

Sample		Surface finish
1A	1B	Zn + yellow chromate
2A	2B	Zn + yellow chromate
3A	3B	Zn + blue chromate
4A	4B	Zn + blue chromate
5A	5B	Zn + blue chromate

3. EXPERIMENTAL METHODS

3.1. Optical microscopy

Optical microscopy is a destructive method, universal for all types of coatings, except soft coatings (waxes, vaseline). In the present work there is optical microscopy taken as a reference method for its precision and accuracy. Zn and chromate layer thickness measurements on the samples were performed on an optical microscope Olympus IX70 (see **Fig. 4**) at a magnification of 200 x, the results were analyzed using Image Pro software Micro G.

Samples were cut on Struers devices and were embedded by two-part sealing compound Durocit Kit (Struers) into forms.

3.2. Magnetic-inductive method

The aim of this work was to test the reliability of magnetic-inductive method commonly used in electroplating plants to determine the thickness of the Zn and chromate layer. All samples were measured by Dualscope MP0-R (Fisher) (see **Fig. 5**) at atmospheric pressure.

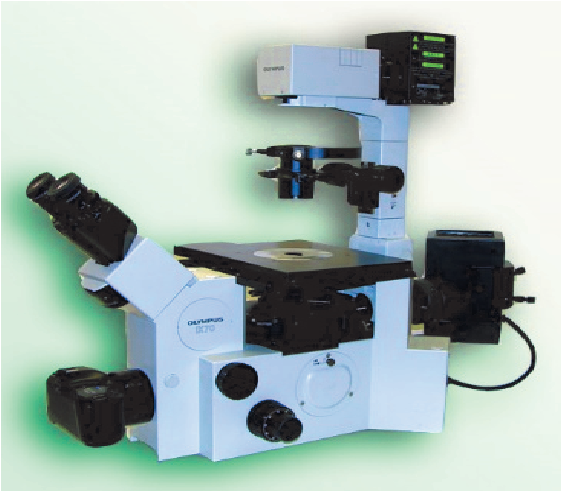

Fig. 4 Optical microscope Olympus IX70

Fig. 5 Dualscope MP0-R (Fischer)

4. RESULTS AND DISCUSSION

All analyzes were performed repeatedly at least in ten locations. In **Fig. 6** is shown a metallographic image of the sample 2A and one image of the sample 4A (see **Fig. 7**).

All averaged measured values are shown in **Table 3**. These results were evaluated by QC-Expert program using the "Compare Two Selections - Pairwise Comparison," method and it was demonstrated that the differences are statistically significant. Therefore, it was established regression relationship of results of both methods (see **Fig. 8**) and a dependency was tested using the "linear regression" method. The result is a confirmation of homoscedasticity and normal distribution of residues and therefore the dependency can be used.

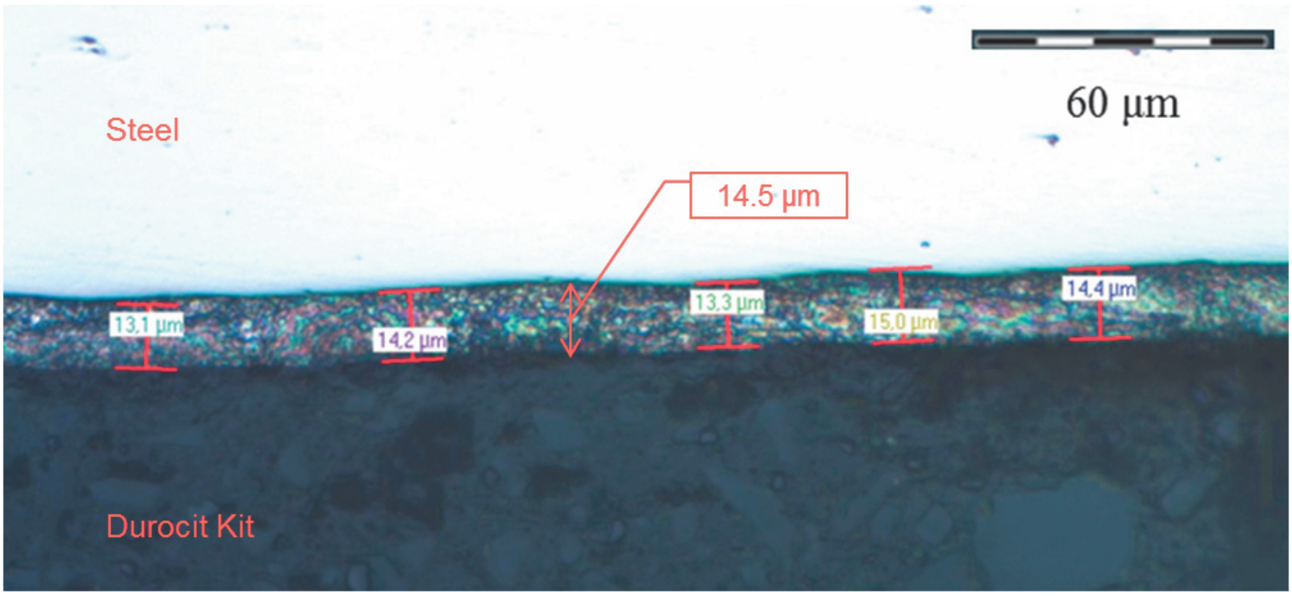

Fig. 6 Metallographic image of the sample 2A

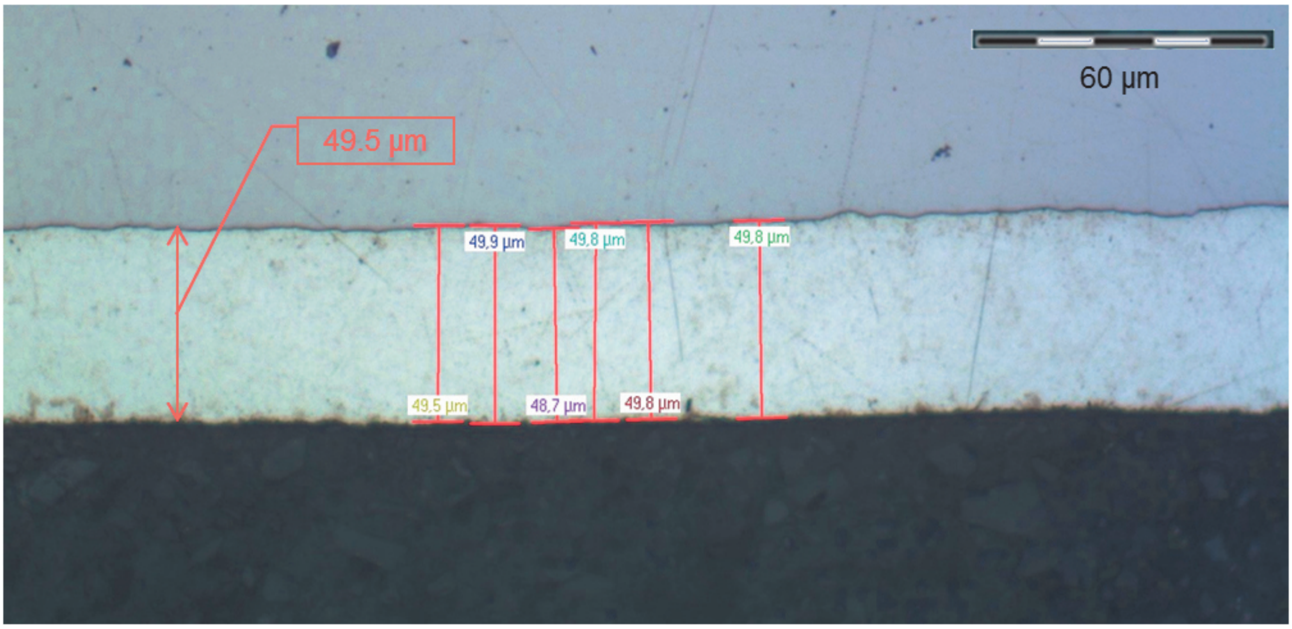

Fig. 7 Metallographic image of the sample 4A

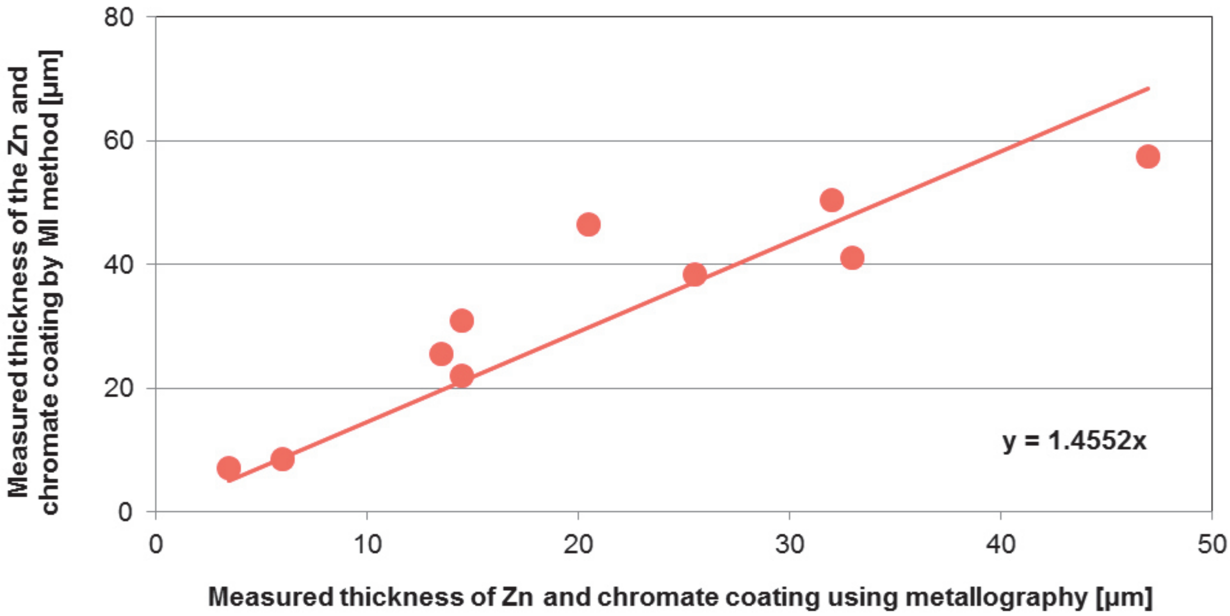

Fig. 8 The relationship between the thickness of Zn and chromate layer measured by optical microscopy and magnetic-inductive (MI) method

The result of a regression is a relationship between the two methods: y = 1.4552x. On the basis of this relationship Zn layer thicknesses measured by magnetic-inductive method were converted (third column in **Table 3**) and the results were statistically analyzed by paired comparison (fourth column in **Table 3**). This test showed that the differences are statistically insignificant and the results can be considered to be correct, after divided by a factor of 1.4552.

Table 3 Comparison of the results obtained by optical microscopy and magnetic-inductive (MI) method

Sample	Thickness of Zn and chromate coating measured using **metallography**	Thickness of the Zn and chromate coating measured by MI method - **measured** values	Thickness of the Zn and chromate coating measured by MI method - **calculated** values
	μm		
1A	6.0	8.5	5.9
1B	3.5	7.0	4.8
2A	14.5	31.0	21.3
2B	33.0	41.0	28.2
3A	20.5	46.5	32.0
3B	14.5	22.0	15.1
4A	47.0	57.5	39.6
4B	13.5	25.5	17.6
5A	25.5	38.5	26.5
5B	32.0	50.5	34.8

5. CONCLUSION

In the framework of the measurement there was determined the thickness of the non-ferrous protective coating based on Zn and chromate. It was evaluated the accuracy of measurement of the coating thickness by magnetic induction method and compared with the results of microscopy measurement. On the basis of the experimental results there were found differences between both measurements. Using regression analysis there was determined the correction coefficient by which the results of magnetic induction method were recalculated. The obtained results are comparable with the results of the microscopy measurement. Magnetic induction method can be fully recommended after conversion of the measured values using the correction coefficient. Inaccuracy of the results is also affected by uneven thickness of the coating caused by the production process and especially by the placement of samples on the hanger in the galvanic bath.

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