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Certain aspects of testing anti-corrosion coatings of machine elements on the example of SaMASZ, a Białystok production company

KAROLINA SOSNA[1], ANGELIKA MIKUTOWICZ[1], KRZYSZTOF KRYSTOSIAK[2], JERZY JAROSZEWICZ[3]
[1]WYDZIAŁ INŻYNIERII ZARZĄDZANIA POLITECHNIKI BIAŁOSTOCKIEJ, KATEDRA ZARZĄDZANIA PRODUKCJĄ, [2]WYDZIAŁ ZARZĄDZANIA POLITECHNIKI BIAŁOSTOCKIEJ,
[3]STUDENCKIE KOŁO NAUKOWE WYNALAZCZOŚCI I RACJONALIZACJI WYDZIAŁU INŻYNIERII ZARZĄDZANIA POLITECHNIKI BIAŁOSTOCKIEJ, KATEDRA ZARZĄDZANIA PRODUKCJĄ

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SUMMARY:

This paper discusses certain aspects of testing anti-corrosion coating of machine elements on the example of SaMASZ, a Białystok production company. The main methods of painting are powder coating and cataphoresis. In this paper we will provide information on the methods of corrosion losses testing as well as on the technological processes of cataphoresis and powder coating. The measurements of paint coating thickness in the tested samples and machine components showed significant differences ranging from approx. 100 µm up to almost 160 µm. The simulation of reducing the paint fixation time by 10 minutes was performed for one dryer operating in a two-shift mode, which demonstrated that reducing the dryer's working time from 30 to 20 minutes saved time, maintaining simultaneously the assumed quality parameters of the coating. It was shown that cataphoresis is more effective against corrosion than powder painting and can be used to cover non-visible surfaces (internal) with paint coatings.

1. METHODS OF APPLYING PAINT COATING TO MACHINE ELEMENTS

Powder coating consists in covering the conductive surface, e.g. metal, with electrified particles (from c. 20 to c.100 µm) of powder paint. A layer of paint is deposited on the substrate surface due to electrostatic forces [1, 4-6, 12].
Various types of paint are used for such protection. The most popular ones are:
• epoxy paints – give hard coating, resistant to scratch, impact, etc., resistant to chemicals,
• polyester-epoxy paints – give a coat that is resistant to overheating and may be used for painting objects with direct food contact, e.g. household appliances,
• polyester paints – used for painting objects exposed to various weather conditions (e.g. household and garden equipment, aluminium doors and windows, elements of building facades, bicycle and motorcycle parts, etc.) [1].

1.1 Stages of powder coating

The first stage involves a thorough cleaning of an element being coated to remove dirt (dust, fat) and other particles which create uneven coating and may weaken the coat. Then, anti-corrosion coating of iron phosphates is applied and the whole surface of the element is dried.
Incorrect or incomplete preparation of the surface leads to:
• the reduction of coat adhesion to the base,
• the reduction of surface smoothness,
• corrosion creepback
The second stage involves paint application by means of special sprayers which distribute paint particles on the surface of an electrically grounded element.
Being positively charged, the powder adheres well to the element coated [2, 7].
The aim of the final stage is hardening an applied layer of powder. Due to the use of high temperature, the layer of powder applied is polymerizable/gets polymerized and acquires suitable properties of the coat, such as durability and resistance to both mechanical damage and external agents.
There are two basic techniques of electrization and application of powder coat:
• electrostatic spraying – high-voltage method 40-100 kV, commonly called „the crown",
• electrokinetic spraying – triboelectrization method, frictional, called „tribo".
Objects covered with powder coats are preserved in convection dryers in the temperature of 100 to 200°C. Further technological operations or transport to other department require cooling of the elements to the temperature of 30-40°C.
Sometimes, to accelerate the cooling process, cool air supply or water spraying are applied [1, 5, 8, 11].
There are four spray booths installed in the powder coating hall of „SaMASZ: one with a single stadion and three two-station ones. Powder spraying is carried out with devices called sprays made by: Wagner and RBC-Tech Białystok companies[4].

1.2 Cataphoretic coating

Cataphoresis is one of the latest technologies used for applying a coat of paint to various metal objects – particularly steel elements, galvanized, aluminium and cast iron in order to protect them against corrosion. This method is also called electrophoretic coating, based on the phenomenon of electrophoresis [3]. It consists in coating an object with waterborne paint with the application of electric current. Thus, the surface is covered with electrically charged paint particles migrating along the electric field lines, which allows the paint to reach the spots impossible to paint by any other method.
A deposited layer of polymer does not conduct current, so the surface is gradually coated – from the places near the counter electrode to the ones most difficult to access, and has a uniform, but not too large, thickness. Coat thickness depends partly on the voltage applied and amounts to 10-50 micrometers [3, 9, 10].
In cataphoresis the object coated becomes a cathode. Cataphoretic coating applied even to a complex-shaped object has very good thightness, weather resistance and it efficiently protects metal substrates against the destructive activity of corrosive agents.
The coat obtained fulfills high anti-corrosion requirements confirmed by tests in a salt chamber in aggressive environments, in the presence of moisture, heat and salt (e.g. it lasts up to 1000 hours in NSS – Neutral Salt Spray – PN-EN ISO 9227). Besides, the coat is characterized by high aesthetic qualities and the production process causes little

damage to the natural environment due to little waste and low emission of volatile contaminants during polymerization. It is also a very efficient method, which makes it competitive with regard to other techniques. Its weak point is a harmful UV effect on the coat; that is why it is recommended to protect properly the surfaces exposed directly to UV radiation

The electrophoretic coating installation consists of a series of baths where the following processes occur: surface preparation, including zinc phosphating (Rys. 1), coat application and polymerization.

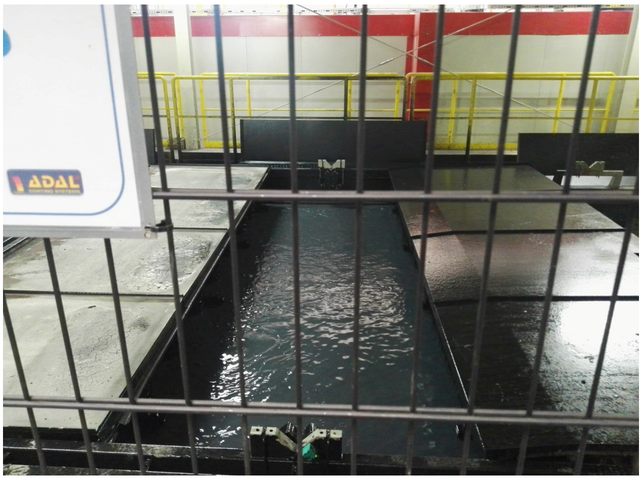


Figure 1. A bath for KTL coating.
Source: own elaboration

Degreasing is the first task in surface preparation, so the elements to be coated cannot have hard-to-remove impurities, foreign bodies or corrosion spots.

The other task is applying to the clean surface a tight microcrystalline coat of zinc, nickel and manganese phosphates of suitable density. It guarrantees perfect adhesion of cataphoretic coat to the substrate and the best protective barrier [3, 9, 10].

After careful rinsing in Demi water and obtaining conductivity below 30 µS, the elements are coated with paint of selected parameters, which is followed by rinsing with paint ultrafiltration and condensate blowoff.

Another very important sub-process is polymerization, or paint crosslinking through annealing/heating of previously coated elements, which helps suitably hardened paint to make a uniform and aesthetic overlay.

Each element has annealing time and temperature matched to a kind of material it is made of. On completing the polymerization sub-process, the elements must cool down. The final process involves their end check and packaging according to the client's wish. Maximum dimensions of a bath batch are:

- length – 3100 mm,
- width – 850 mm,
- height – 1500 mm.

2. TEST METHODS FOR CORROSION LOSSES

The test methods of corrosion losses include [3, 4, 11]:

- **Techniques of electromagnetic field detection.**

Electromagnetic techniques can be successfully used for the location of corrosion pitting or other surface defects, with the application of single or aggregate sensors in the form of boards aimed at the detection of electromagnetic field induction changes.

- **Pulsed eddy current method.**

This technique (called in short PEC) consists in detecting the disappearance of electromagnetic field emitted by eddy currents appearing in a tested corroded area. Eddy currents are induced by a pulsed electromagnetic field of a low frequency emitted from a pulse transmiter. An advantage of this contactless measuring method is a possibility of deep penetration (also through insulation layers) in order to detect corrosion in ferritic objects. It is a basic technique to test corrosion losses in insulated elements without a necessity of a direct contact.

The INCOTEST system (Insulated Component TEST), developed by a Dutch company – Rontgen Technische Dienst BV – and patented by ARCO from USA, is used for industrial application of pulsed eddy current technologies.

INCOTEST – a new method of insulated ferritic elements inspection

It is a unique technology to test wall thickness (changes in thickness due to corrosion losses) of ferritic pipes and tanks through thermal insulation, contactlessly, on rough or dirty surfaces, also of higher temperature. Weakening of pulsed eddy current signal from the tested area of a steel object is registered by INCOTEST equipment. It calculates an average wall thickness by comparing it with a signal from the calibration standard of known wall thickness and the same material as the object tested.

Measurement results are subject to an error resulting from composite magnetic and electrical properties as well as temperature changeability of the material tested. The measurement lasts from 2 to 40 seconds depending on the thickness of wall tested. Calculated current thickness and confirmation of measurement validity are displayed on the screen and archived for subsequent processing.

The INCOTEST system is easy-to-use equipment for quick testing. Carrying out tests with new generation appliances, a two-man team is able to check daily up to 1000 measuring points depending on the access to the facility. INCOTEST offers good repeatability of results and can be used both to detect and to monitor the condition of the facility.

INCOTEST is typically used in industrial diagnostics for: the detection of corrosion losses in insulated pipes and tanks; the detection of erosion in materials used in utility installations; the inspection of undersea piping without the necessity of the removal of sediment from water and sea organisms; the possibility of supervising facilities with higher temperatures.

• **Magnetic Flux Leakage method – MFL.**

This technique consists in the observation of magnetic induction flux leakage above the surface in the place where the element cross-section (thickness) was significantly reduced.

• **MINI-FLOORSCANER** – is a minature, compact version of Floorscaner system of minimalized height. It allows conducting tests in places of limited access. There are two versions of the appliance: a manually controlled version or a remote controlled automatic one. It may be used for the examination of inaccessible places, bottoms and walls of storage and pressure tanks, also on slightly curved surfaces.

The equipment offers test output up to 150 m2/day. The allowed thickness of plates is 15 mm (laminate cover to 2 mm), and the detection of a corrosion cavity is signalled optically (diodes) and sonically.

3. COAT ADHESION TESTING APPLIED IN SAMASZ

Testing for coat adhesion conducted with the cross-cut method is one of three kinds of quality tests for coating made in powder technique, which are conducted by authorized persons from quality control department in „SaMASZ” production company. Such tests are carried out approximately once a week, on a previously prepared reference sample of steel plate with powder coat applied and fixed, as the technique cannot be used on manufactured products due to its damaging effect. After the test, the samples are stored for the subsequent verification of conducted tests. Each sample is signed with a name and surname of a person performing the test and contains short information on the way the sample was prepared.

Except for adhesion testing, the company carries out a test for coat thickness by means of an electronic gauge for paint thickness measurement – ETG Mini made by ETG company.

ISO2409 is not the only standard for testing varnish adhesion with the cross-cut test.

Next to ISO, the test method was also elaborated by i.a.: Automotive Industry Association (VDA 621-411), British Standards (BS), German Committee for Standardization (DIN) and American Society for Testing and Materials (ASTM D 3359).

The third type of coat testing is examining the samples in so-called ‘salt baths’. The test is done by an external firm and, due to the cost involved, it is conducted once in half a year on average.

Testing the adhesion of the coating aims to check the impact of powder paint fixing time on the adhesion of the coating. According to the paint manufacturer, the time necessary to polymerize powder paint is 10 minutes at the temperature of the element – 170°C. The standard annealing time for powder coated elements on the tested line was 30 minutes. The loading time of the batch to the drying chamber is c. 5 minutes, whereas the time of heating the chamber to working temperature of 210°C is approximately 30 minut.

The adhesion test for varnish coating with a cross-cut method was performed in „SaMASZ" production company on 6-7 December, 2010. Samples of steel in pieces of sheet metal of c. 100 × 150 mm and 1.5; 3; 5 and 6 mm thickness were used for the test. The samples of different thickness were marked with letters: A, B, C and D and, additionally, with numbers indicating the fixing time: 10, 15, 20, 30 minutes. The samples were coated with powder paint of Worwag: Woralit W899G Pulverlack, orange in RAL 2008, which was used to paint snow ploughs produced by„SaMASZ” at that time. The manufacturer recommended fixing time of 10 minutes at 170°C as the temperature of the element. The test samples were prepared during a regular working day in the powder painting hall with the equipment used then in the snow ploughs production process.

1) Surface preparation

The surface of A10, A20 and A30 samples of 1.5 mm thickness were prepared by chemical phosphating in the spray chamber washer TW – 0262.

The surface of B10, B20, B30, C15 and D30 samples of 3, 5 and 6 mm thickness were cleaned mechanically by means of a rotary hook cleaner OWH – 1.0 × 1.5 in blasting process.

2) Powder paint application

Powder coating was done with the use of KMP-1,4/6F powder booth and Wagner PEM-C4 spray.

3) Powder paint fixing

The samples with powder coating were fixed in the convection oil dryer of „Promal” Wieruszów, PO-1/16/22/40-2D-G. After the first ten minutes of fixing process, two samples, A10 and B10, were taken out; after the next ten minutes another two, A20 and B20, whereas A30 and B30 samples were removed at the end of the fixing cycle, together with the whole content of the batch. C15 and D30 samples were prepared in a similar way.

An Erichsen cutter, model 295, was used in the cross-cut test method. It has six edges, cutting distance 2 mm and is prepared for testing adhesion of coats of 60 μm to 120 μm in compliance with applicable standards.

The samples were cut and then tested with adhesive tape in the way defined by the standard. Testing in „SaMASZ” showed perfect adhesive properties of powder-treated coating with respect to metal substrate, irrespective of the fixing time in the dryer, on condition of maintaining minimal parameters recommended by powder paint manufacturer.

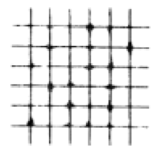
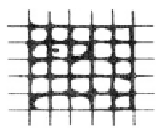
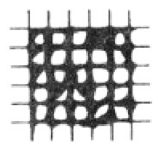
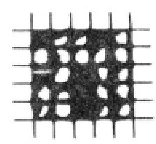
4. REVIEW OF SAMPLES TESTED IN SAMASZ WITH THE CROSS-CUT METHOD

Applying the cross-cut test method in compliance with ISO 2409 standard demonstrated an excellent powder coat adhesion to metal elements. All samples tested reached 0 class according to ISO 2409 standard (Tab. 1).

Below there are photographs of cross-cut tested samples in compliance with ISO2409 standard.

Additionally, the coat thickness in each of the above-presented samples was measure. Worwag,

Table 1 Coat adhesion classification by the cross-cut method

Description	Surface	Standard: BS/ISO/DIN	Standard: ASTM
The edges of the grid are smooth; none of the squares of the grid are detached.		0	5B
Only small flakes of the coating peel off at the edges of the grid. None of the perpendicular grid squares has/have been peeled off. Total area of the damaged coat is not larger than 5%.		1	4B
Small flakes of the coat detach along the cutting lines; cracks and small flakes of the coat are visible among the lines of the grid. Total area of the damaged coat is larger than 5% but does not exceed 15%.		2	3B
The coat flakes off along the cutting lines partly or completely as long ribbons and/or flakes off partly or completely from the grid squares. The affected area is larger than 15%, but smaller than 35%.		3	2B
The coating flakes off along the edges of the cuts in large ribbons and/or partly or wholly from the squares of the grid. The area affected is greater than 35%, but not greater than 65 %.		4	1B
Any degree of flaking of the coat that cannot be classified as 4.		5	0

Source: own elaboration, based on ISO2409 and BS/DIN/ASTM

the manufacturer of powder paint Woralit W899G Pulverlack recommends a 50-80 µm thick coat of paint.
Exceeding this threshold significantly may result in adverse consequences, namely, coating defects such as e.g. orange peel effect, which may be caused by a too thin or too thick paint coat.

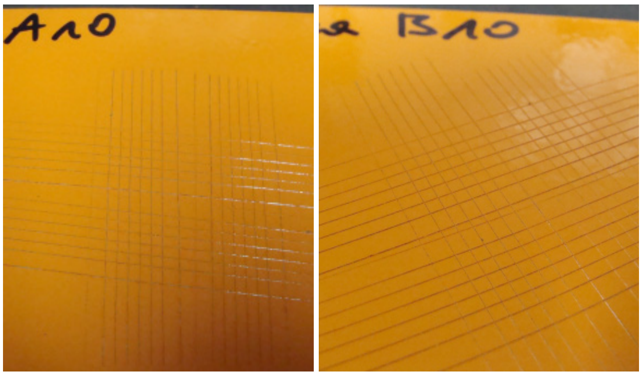


Figure 2 A10 and B10 samples after the cross-cut test
Source: own elaboration

The graph (Fig. 3) presents the results of coat thickness measurement in the tested samples. The measurment indicated significant differences in thickness amounting from c. 100 µm to almost 160 µm. The reason for such large differences may be incompetent spraying of powder paint.

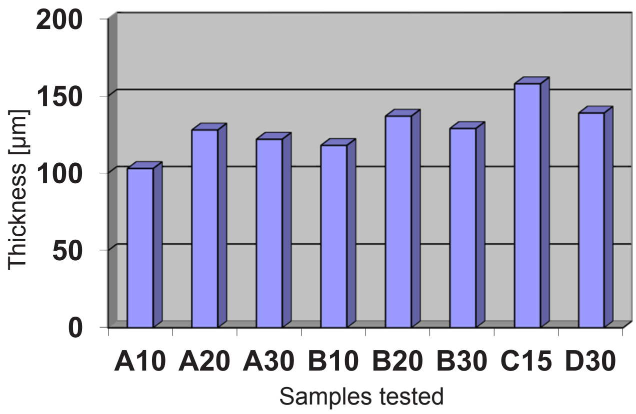


Figure 3 Comparison of coat thickness in the samples tested.
Source: own elaboration

The simulation of time saving in the powder paint fixing process is shown below in Table 2.
The simulation involves 10 minutes shorter fixing time for one dryer working in a two-shift mode, i.e. from 7:00 to 21:00. The simulation below shows that by reducing the drying time from 30 to 20 minutes, the time saved will allow fixing of two additional batches during a two-shift working day, which increases productivity of fixing process by c. 15.5%.

Table 2 Simulation of the dryer's working time in 30- and 20-minute mode

Drying time 30 minutes			Reducing the drying time to 20 minutes		
Warm-up	Start	End	Warm-up	Start	End
07:00	07:30	08:00	07:00	07:30	07:50
08:05	08:40	09:10	07:55	08:25	08:45
09:15	09:45	10:15	08:50	09:20	09:40
10:20	10:50	11:20	09:45	10:15	10:35
11:25	11:55	12:25	10:40	11:10	11:30
12:30	13:00	13:30	11:35	12:05	12:25
13:35	14:10	14:40	12:30	13:00	13:20
14:45	15:15	15:45	13:25	13:55	14:15
15:45	16:15	16:45	14:20	14:50	15:10
16:50	17:20	17:50	15:15	15:45	16:05
17:55	18:30	19:00	16:10	16:40	17:00
19:05	19:35	19:55	17:05	17:35	17:55
20:00	20:30	21:00	18:00	18:30	18:50
			18:55	19:25	19:45
			19:50	20:20	20:40

Source: own elaboration

5. DISCUSSING THE OBTAINED RESULTS

The conducted adhesion test proved that it would be possible to reduce the fixing time even by 15-20 minutes in case of such elements as covers or flats of 1.5 - 4 mm thickness, but in manufacturing conditions it is not always possible to select elements of similar size and thickness for a batch. An optimal dryer batch should contain the elements of approximately equal size and – then the fixing process would be more effective. Measuring the temperature of elements dried in a convectional dryer (Fig. 4) performed by research workers of Białystok University of Technology and presented at VI Symposium on 'Simulation, measurements and diagnostics in electroheat" demonstrated that thicker elements get warm more slowly, that is, they reach optimal temperature later [5].

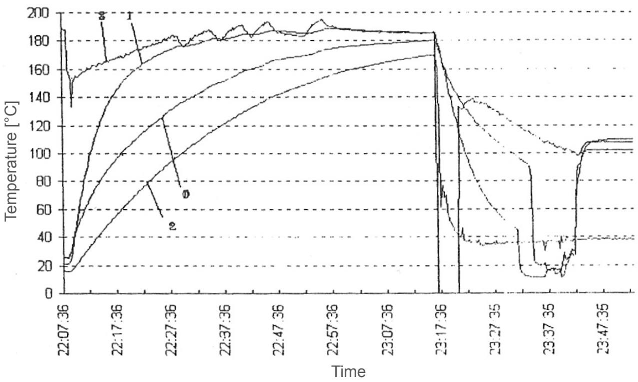


Figure 4 Temperature changes on the surface
0 – brackets, 1 – covers, 2 – thick frames, 3 – flats.
Source: [6]

Applying an excessively thick coat of paint leads to unnecessary high costs for a company owner. As the manufacturer informs, at the recommended thickness of 50-80 µm, the paint efficiency is 8-12 m2/kg depending on its colour. Applying the coats as thick as in the tested elements may result in the reduction of powder paint efficiency to 50% of the defined output, to 4-6 m2/kg, which will drastically inflate the cost of paint used.
The problem would be solved by the application of an automatic line for powder coat spray, with a manual station to reach hard-to-access areas. The advantages of automatic application of powder paints are [1, 2, 8]:
• a constant amount of powder applied to the elements,
• uniform thickness of the coat on the surface of all elements,
• elimination of coat defects resulting from the application of a too thick powder coat,
• a more efficient process of powder coating,
• lower costs of paint used.
The photo in Figure 5 shows a typical booth for the automatic application of powder paint. Such a solution facilitates a uniform application of powder paints on objects of various dimensions.

Figure 5 Paint booth for automatic
powder paint application

6. SUMMING UP

To sum up, it must be concluded that cataphoresis is more efficient as far as anti-corrosion is concerned and is used for coating invisible surfaces (internal). The speed of coat electrodeposition is proportional to the voltage of electric field in a given area, which is regulated by the quantity of the stabilized DC voltage transmitted from the rectifier; however, in the extent provided by the paint manufacturer and the content of solids in the paint, coat thickness is regulated by the voltage magnitude and current density as well as the time of coat electrodeposition.
A characteristic feature of cataphoresis is higher paint penetration in microcracks on the substrat surface, and the coat application time is up to c. 3 minutes. After this time, coat thickness slightly increases and, as the exemplary graphs show, the curve approaches asymptotically to the horizontal line, which is consistent with the mechanism of the process.
Powder painting aims to improve the aesthetics and colouring of coating and is used mainly to external surfaces. The effect is a uniform coat which can mask the machining inaccuracies of the substrate painted. The coats have very good mechanical properties and high resistance to chemical agents.

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