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DOI: 10.15199/40.2023.5.1

Influence of bath type for zinc plating and passivation with trivalent chromium compounds on the corrosion resistance and appearance of coatings obtained

Wpływ rodzaju kąpeli do cynkowania i pasywacji trójwartościowymi związkami chromu na odporność korozyjną i wygląd uzyskanych powłok

Zinc coatings obtained in electrolytic zinc plating differ in terms of corrosion resistance and their visual aspect depending on the brightener and basic components used. In order to achieve industrial properties and a desired appearance of the coatings, commercial organic additives made by Galvano-Partners and Dipsol were used. It has been shown that a greater effect on corrosion resistance can be achieved when the same passivation is applied to different zinc substrates. Electrolytically applied zinc from a zinc chloride solution and with thin-film passivation shows a higher polarization resistance after 24 h compared to a coating obtained using two technologies utilizing (alkaline) baths based on sodium zincate, despite having the same conversion coating. In the aspect of one electrolytic zinc coating with different chromate coatings, disproportions between the successive conversion technologies are noted in the polarization resistance. Potentiodynamic curves describing a zinc coating with different chromate layers applied indicate a major variation in the barrier properties of the studied material.

Keywords: weak-acid zinc, conversion coating, passivation, zinc electroplating, electroplating, chromating, alkaline zinc, electrochemical metal deposition

W zależności od wykorzystanego składnika wyblyszczającego oraz składników podstawowych otrzymywane powłoki cynkowe z cynkowania elektrolitycznego różnią się pod względem odporności korozyjnej oraz wizualnie. By uzyskać właściwości przemysłowe oraz określony wygląd powłok, wykorzystano komercyjne dodatki organiczne firm Galvano-Partners oraz Dipsol. Jeszcze większy wpływ na odporność korozyjną ma zastosowanie pasywacji chemicznej przez wytworzenie powłok konwersyjnych na powłokach cynkowych. Istotne różnice daje nawet zastosowanie tej samej pasywacji na różnym podłożu cynkowym: cynk nałożony elektrolitycznie w kąpeli sporządzonej na bazie chlorku cynku (zwanej słabo kwaśną) i z pasywacją cienkopowłokową ($0,07 \mu\text{m} \pm 0,03 \mu\text{m}$) wykazuje po 24 h wyższą rezystancję polaryzacyjną w porównaniu z powłoką wytworzoną zgodnie z dwoma technologiami, w których wykorzystuje się kąpiele sporządzone na bazie cynkanu sodu (zwane alkalicznymi), pomimo tej samej powłoki konwersyjnej. W wypadku takich samych powłok cynkowych wytworzonych elektrolitycznie, lecz pokrytych różnymi powłokami konwersyjnymi uzyskanymi chemicznie w wyniku zastosowania kąpeli sporządzonych na bazie związków chromu trójwartościowego obserwuje się różną odporność korozyjną w zależności od zastosowanych technologii wykonywania powłok konwersyjnych. Krzywe potencjodynamiczne otrzymane dla próbek z powłoką cynkową z nałożonymi różnymi warstwami konwersyjnymi wskazują na różnicowanie odporności korozyjnej badanego materiału.

Słowa kluczowe: cynk słabo kwaśny, powłoka konwersyjna, pasywacja, cynk galwaniczny, galwanotechnika, chromianowanie, cynk alkaliczny, elektrochemiczne osadzanie metali

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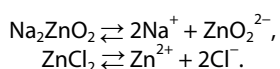
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■ Otrzymano / Received: 13.01.2023. Przyjęto / Accepted: 21.03.2023

1. Introduction

Zinc coatings are mainly used on steel products in order to protect the substrate from corrosion in atmospheric conditions. This protection is achieved by the potential difference of zinc ($E_{\text{Zn}/\text{Zn}^{2+}} = -0,762 \text{ V}$) and iron ($E_{\text{Fe}/\text{Fe}^{2+}} = -0,447 \text{ V}$) in a wet environment, therefore ensuring sacrificial protection for steel.

The quality of galvanized zinc coatings depends on the parameters of the electrolytic process, mainly on the type and composition of the bath (whether it is a weak acid bath based on zinc chloride or an alkaline bath based on sodium zincate), which affect the morphology of their surface and corrosion resistance. The different baths differ in the type of salt that is the donor of the film-forming agent: in alkaline baths the zinc is in the form of an anion, while in weak acid baths it is in the form of a cation, which can affect the crystal structure of the deposited zinc and the morphology of the surface of the coatings. This can also affect their corrosion resistance:



The main difference in the operation of the described baths is the method of obtaining zinc ions. Weak acid baths require zinc anodes, and it is these anodes that dissolve, providing zinc ions. In the case of alkaline baths, it is necessary to use non-dissolvable steel anodes, therefore making it necessary to replenish the loss of zinc ions in the bath by continuously dispensing a solution containing zinc ions of high concentration (automatic dispensers are used for this purpose).

Improving the corrosion resistance of zinc coatings can be achieved by performing chemical passivation, such as producing a conversion coating in solutions containing trivalent chromium compounds. This process involves thick-film passivation, in which conversion coatings with a thickness of $0.3 \mu\text{m} \pm 0.2 \mu\text{m}$ are obtained, or thin-film passivation, in which conversion case the coatings then have a thickness of $0.07 \mu\text{m} \pm 0.03 \mu\text{m}$.

It is therefore important to determine how the parameters of the galvanizing and passivation process impact the quality of zinc coatings. For this reason, it is necessary to determine the difference between zinc coatings produced in baths based on zinc chloride and coatings obtained in baths based on sodium zincate. It is also necessary to resolve the following questions: Do differences in the appearance of zinc coatings affect their corrosion resistance? How does the conversion layer affect the corrosion resistance of coatings? To be able to answer these questions, it is necessary to determine the effect of the applied galvanizing technology (weak acid or alkaline bath) and chemical passivation on the quality of coatings, including surface morphology and corrosion resistance.

Galvanizing is a widely used process for protecting metal surfaces from corrosion by applying a thin layer of zinc coating. The durability and appearance of the galvanized surface depend on various factors, including the type of galvanizing bath and the passivation treatment used. The development of durable and environmentally friendly passivation methods is an area of growing research interest. Trivalent passivations have gained popularity because they are less harmful to the environment and health compared to hexavalent passivations [1].

The purpose of this paper is to analyze the effect of the type of galvanizing bath and trivalent passivation on the corrosion resistance and visual qualities of a metallic coating. In recent years, many experiments have been conducted to evaluate the corrosion resistance of galvanized coatings in various environments [2–5], but few studies have investigated the effect of the type of galvanizing bath and trivalent passivation on the visual qualities of coatings.

Within the framework of the presented research, several experiments were carried out using different types of galvanizing baths

Table 1. Chemical composition of Zinlevel T-50 bath with deposition parameters

Tabela 1. Skład chemiczny kąpielii Zinlevel T-50 wraz z parametrami osadzania

Component and parameter	Value
Zn [g/dm ³]	30
Cl ⁻ [g/dm ³]	140
H ₃ BO ₃ [g/dm ³]	25
Temp. [°C]	24 (±2)
pH	5.1
Current density [A/dm ²]	2
Zinlevel T-50: brightener [cm ³ /dm ³]	2.5
Zinlevel T-50: carrier [cm ³ /dm ³]	40
Anodic material	zinc
Anode : cathode area ratio	4 : 1

Source: [9].

Źródło: [9].

Table 2. Alkaline electrolyte compositions and deposition parameters

Tabela 2. Składy elektrolitów alkalicznych wraz z parametrami osadzania

Component and parameter	Ecolozinc 150	NZ-98
Zn [g/dm ³]	12	12
NaOH [g/dm ³]	140	140
Na ₂ CO ₃ [g/dm ³]	30	0
Temp. [°C]	25 (±2)	27 (±2)
Current density [A/dm ²]	2	3
Organic component	brightener: 2 cm ³ /dm ³	NZ-98S: 10 cm ³ /dm ³
	carrier: 10 cm ³ /dm ³	–
	conditioner: 10 cm ³ /dm ³	NZ-Conditioner: 20 cm ³ /dm ³
Anodic material	steel	
Anode : cathode area ratio	2 : 1	

Source: [10, 11].

Źródło: [10, 11].

and trivalent passivation treatments. The corrosion resistance of the coatings was evaluated by conducting salt spray tests, electrochemical impedance spectroscopy and scanning electron microscopy. The visual qualities of the coatings were also evaluated by measuring their thickness, adhesion and colorimetric properties [6–8].

Galvanizing and passivation processes with trivalent chromium compounds were analyzed using commercial processes provided by Galvano-Partners and Dipsol. The criterion for evaluating the quality of coatings obtained by galvanizing and chemical passivation processes was surface morphology and corrosion resistance. To this end, the produced coatings were subjected to surface morphology analysis by SEM scanning microscopy and corrosion tests by DC polarization in a 0.5 M NaCl solution.

2. Research methodology

Coatings produced using three electrolytic galvanizing baths were selected for the study: one using zinc chloride (weak acid) and two based on sodium zincate (alkaline). In the weak acid bath (Zinlevel T-50 process), an aldehyde brightener was used [9]. In one of the alkaline baths the brightener was vanillin (Dipsol NZ-98 process) [10], and in the other – thiourea (Ecolozinc 150 process) [11]. Tables 1 and 2 show the chemical composition of the commercial solutions used, along with the recommended galvanizing process parameters.



Fig. 1. Test stand for deposition of zinc coatings
Rys. 1. Stanowisko badawcze do osadzania powłok cynkowych



Fig. 2. Schematic diagram of the process line for galvanizing and passivation
Rys. 2. Schemat ciągu technologicznego cynkowania galwanicznego i pasywacji

Zinc and conversion coating application tests were carried out at the Galvano-Partners laboratory. Baths with an operating capacity of 10 l for zinc electrolytes and 2 l for chromate solutions were used. The baths were characterized by constant physical and chemical conditions, as provided by heaters with a temperature sensor and a filter with a pump of 5 μm porosity [12] responsible for refreshing the electrolyte at the workpiece, as well as constant current conditions – the rectifier used was equipped with a milliampere scale connected to a voltage and current stabilizer and deviations recording function [13]. The galvanizing stand is shown in Fig. 1. The workpiece used in the tests was a 1.5 dm² (0.75 dm × 1 dm) sheet made of black steel. The process line met surface preparation standards [11] (Fig. 2).

Each process was followed by three rinses in demineralized water (conductivity <0.1 μS) in countercurrent. Hot water (80°C) was used for the rinse preceding the drying process, which was carried out in hot air (120°C). Process times were optimized taking into account the workpiece (steel sheet) and the possibility of achieving the desired results. The assumed thickness of the zinc coating was 8–12 μm [14], as these are the most common requirements of the industrial market.

The selection of solutions for zinc passivation was based on PN-EN ISO 4042:2018-11. According to its guidelines, the most commonly used passivations are those using trivalent chromium compounds: transparent (transparent with a blue glow), known in industry as blue/thin film passivation, light iridescent (iridescent to slightly yellow), so-called thick film passivation, yellow iridescent (yellow), black (black with possible light iridescence) and olive (olive-brown). All types of passivation, except the olive variant, were applied to freshly prepared galvanized samples. Olive passivation was not used because solutions containing hexavalent chromium compounds can only be used in companies with the appropriate water permit, according to the guidelines of REACH and its subsequent amendments, and only olive passivations based on hexavalent chromium meet industry requirements [15]. Due to the significant harmfulness of hexavalent chromium compounds, baths based on

trivalent chromium compounds are now almost used exclusively. In many applications, the conversion coatings produced in this way match the properties of coatings produced with hexavalent chromium-containing compounds and even surpass them in quality. Therefore, only passivation processes based on trivalent chromium compounds were selected for the study from the available offerings of Galvano-Partners and Dipsol. They operate on the European and global markets offering technical coatings for numerous applications.

Table 3. Selected types of passivation used in the study including the assumed parameters

Tabela 3. Pasywacje wybrane do badań wraz z przyjętymi parametrami

Name	Concentration [cm ³ /dm ³]	T [°C]	t [s]	pH
Acid activation	1	r.t.	10	1.8
ProPass BlueSpecial (blue passivation)	30	25	25	2.0
ProPass 1500 LT (thick-film passivation)	120	25	90	1.8
Dipsol ZTB-447 ASA (black passivation)	ASA ^a – 50 S2 ^a – 20 S3 ^a – 4	30	45	2.4
Dipsol ZTB-447 S1S2S3 (black passivation)	S1 ^a – 60 S2 ^a – 25 S3 ^a – 10	30	50	2.3

^a Trade names of passivation solution components/Nazwy handlowe składników roztworów pasywacyjnych.
Source: [16–19].
Źródło: [16–19].

At each stage of the study, eight plates were prepared, which were then labeled according to the following key: technology Ecolozinc 150 – E, Zinclevel T-50 – T, NZ-98 – N. The stages were described as: 1 – zinc only, 2 – plate after galvanizing and brightening, 3 – plate after stages 1 and 2 and Propass BlueSpecial, 4 – plate

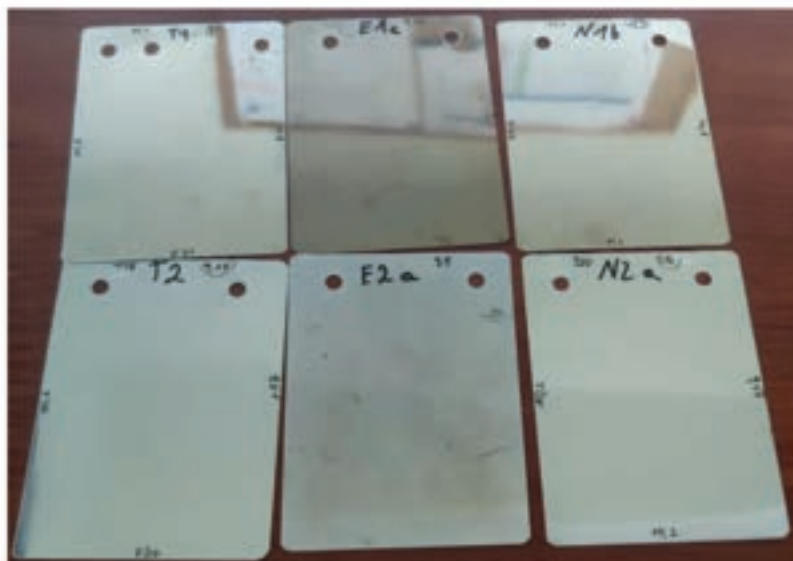


Fig. 3. Zinc-coated samples (T1, E1c, N1b), and after acid activation (T2, E2a, N2a); T – Zinclevel T-50, E – Ecolozinc 150, N – Dipsol NZ-98

Rys. 3. Próbkę pokryte powłoką cynkową (T1, E1c, N1b) i po aktywacji kwaśnej (T2, E2a, N2a); T – Zinclevel T-50, E – Ecolozinc 150, N – Dipsol NZ-98

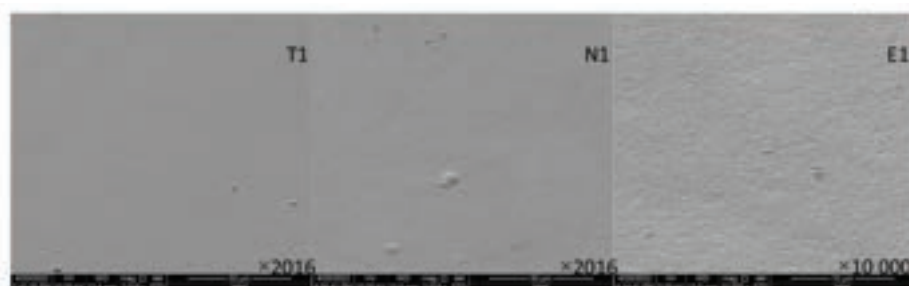


Fig. 4. SEM images of zinc coatings without passivation

Rys. 4. Obrazy SEM powłok cynkowych bez pasywacji

after both stages and Propass 1500 LT, 10 and 11 – plates after galvanizing and brightening and black passivation. Passivation process parameters were applied in accordance with the manufacturers' process instructions, taking into account the knowledge and industrial expertise of the members of the research team. Samples were produced in triplicate, each time using fresh electrolytes.

Microscopic analyses of zinc-coated steel specimens' surface morphology were performed using a FEI Quanta 250 scanning electron microscope (SEM) in a 10^{-4} Pa vacuum at an accelerating voltage of 5 kV using a secondary electron detector.

Corrosion resistance tests were carried out using a Gamry Reference 3000 potentiostat in a three-electrode system: test electrode, graphite counter-electrode and chlorosilver (3 M KCl) reference electrode. All potential values are given in the article for this electrode. The tests were carried out in a Gamry MultiPort corrosion vessel in 1 dm³ deaerated 0.5 M NaCl solution to which the samples were exposed for 24-hours. The sequence of measurements included measurement of polarization resistance in the potential range of ± 15 mV relative to the open-circuit potential (E_{OC}) every hour (the rate of potential change was 0.125 mV/s) and, finally, potentiodynamic measurements (so-called polarization curves) in the potential range from -100 mV to $+100$ mV relative to the E_{OC} with a rate of potential change equal to 0.167 mV/s.

3. Effect of the type of galvanizing and passivation bath on the appearance and surface morphology of samples

The first conclusion from observing the coatings is that it is necessary to verify the validity of using acid activation, which is referred to in the industry as brightening. In the case of weak-acid galvanizing, brightening does not affect the macroscopic appearance of coatings, but the brightening bath is the last bath and it

prevents the transfer of boric acid and chloride and zinc ions with rinse water to subsequent baths. In contrast, in the case of coatings obtained in baths based on sodium zincate with a brightening bath containing vanillin, the zinc coating with a slightly yellowish appearance becomes colorless and acquires a mirror-like gloss. This effect was even more pronounced after the second alkaline bath, in which a brightener containing thiourea was used. From a dark brown shiny coating, a mirror-like coating with a slightly dark coloration was obtained, which was not much different from the two previously described coatings after acid activation, i.e. brightening (Fig. 3). The thickness distribution of the zinc coating was 10–11 μm .

The galvanized samples were subjected to surface morphology analysis using scanning electron microscope (SEM) images. Among the zinc coatings without passivation, sample E1 has a more undulated surface than the other two samples (Fig. 4), indicating a stronger representation of the topography of the steel substrate by the zinc coating.

This observation is confirmed by the appearance of the samples after "brightening", that is, after activation in a 0.1% nitric acid (V) solution prior to application of the conversion coating. A fairly accurate representation of the substrate topography can be seen on the surface of the E2-galvanized sample, not visible in the other two samples (Fig. 5). In addition, spherical inclusions can be spotted in the zinc coatings. Upon examination of one of them, contamination was found with iron particles left over from grinding and polishing, which could not be removed during the initial stages of galvanizing (surface preparation). Note the reproduction by the galvanized coatings of cracks present on the surface of the substrate, which were formed during grinding. The surface morphology of the other two coatings is that of sample E (Ecolozinc 150) immediately after galvanizing itself.

The samples after blue passivation turned blue (Fig. 6), but the surface morphology of samples T3, with coatings applied in a weak

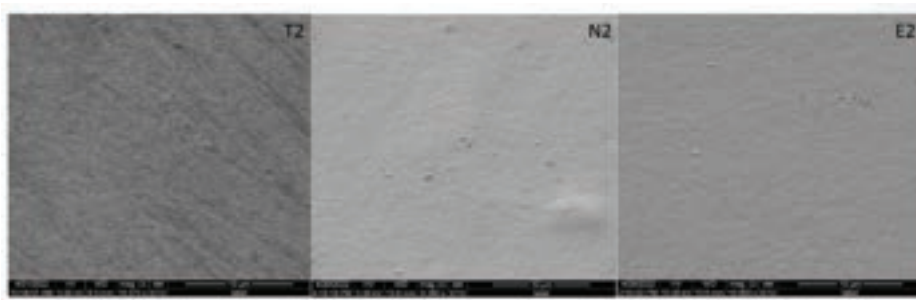


Fig. 5. SEM images of zinc coatings after passivation

Rys. 5. Obrazy SEM powłok cynkowych po rozjaśnianiu

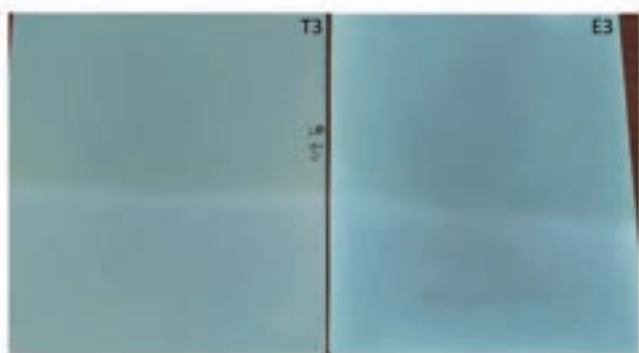


Fig. 6. Photographs of galvanized steel samples after so-called blue passivation
Rys. 6. Fotografie próbek stali cynkowanej po tzw. pasywacji niebieskiej

acid bath, and E3, which had coatings applied in an alkaline bath with the addition of Ecolozinc 150 brightening agent, did not change and is the same as that of samples after brightening (Fig. 7).

The blue color was more pronounced on the samples after galvanizing in a weak acid bath, but in both cases was uniform and without local discoloration (Fig. 6). The surface morphology of the N3 sample (presumably the conversion coating itself) was more complex despite the same thickness of the applied zinc coating (Fig. 7). This is most likely related to the conversion coating formation process itself, which may not have proceeded uniformly on a microscale across the surface.

The differences in the surface morphology of zinc coatings produced in alkaline baths and coatings produced in a weak acid bath are particularly evident after the so-called thick-film passivation process. On the coatings obtained in the alkaline bath, surface cracks are present, i.e. fine grids of cracks evenly distributed over the observed area of the samples (E4). No significant changes were observed on the surface of the coatings produced in the chloride bath (T4) – the entire observed sample was smooth and without cracks, the same as the surface before passivation (Fig. 8).

Similar cracks were visible after black passivation was carried out on the substrate (zinc coating) deposited from an alkaline bath (Fig. 9). A black and uniform color could not be achieved on the coating deposited from weak acid zinc during laboratory tests. The color was dark gray, even after repeatedly extending the time of immersion of the workpiece in the bath and changing the process parameters (pH, temperature) to more aggressive ones. Cracks were already visible at low magnification over the entire surface of the plate. At several times higher magnification, a clear network of micro-cracks (presumably of the conversion coating) was already visible.

4. Corrosion testing of galvanized and brightened steel, and galvanized steel with conversion coatings

Figure 9 shows a plot depicting the correlation between polarization resistance (R_p) and exposure time for zinc coatings obtained in different baths and subjected to brightening. The largest changes

in R_p were recorded during the first six hours of exposure. After this time, there was a relative stabilization of the measured values.

The zinc coating obtained in the Zinlevel bath showed the highest polarization resistance values after six hours of exposure. Between 6 and 16 hours of exposure, the values were ca. $1.5 \text{ k}\Omega \text{ cm}^2$, after which the polarization resistance dropped to $1.15 \text{ k}\Omega \text{ cm}^2$. Lower values of polarization resistance were registered for the sample with a coating obtained in the Ecolozinc bath. During the entire exposure time, the polarization resistance of the Ecolozinc coating decreased from about $1.18 \text{ k}\Omega \text{ cm}^2$ after the first hour to $0.75 \text{ k}\Omega \text{ cm}^2$ after a day of exposure. The zinc coating deposited in the NZ-98 bath had the highest polarization resistance in the first four hours of exposure (about $2.2 \text{ k}\Omega \text{ cm}^2$ after 4 h). However, in the next hour, the R_p value dropped sharply (to about $0.65 \text{ k}\Omega \text{ cm}^2$) and remained in the range of $0.45 \text{ k}\Omega \text{ cm}^2$ to $0.6 \text{ k}\Omega \text{ cm}^2$ in the following hours until the end of the series of measurements.

Figure 10 shows the dependence of the polarization resistance of zinc coatings with additional ProPass BlueSpecial passivation on exposure time in a 0.5 M NaCl solution. During the first two hours of exposure, the sample with the Ecolozinc 150 coating coated with ProPass BlueSpecial passivation showed the highest polarization resistance value ($108 \text{ k}\Omega \text{ cm}^2$). Longer exposure of this sample in a NaCl solution resulted in a decrease in the measured value to as low as $26 \text{ k}\Omega \text{ cm}^2$. In contrast, the same conversion coating applied to a zinc coating deposited in a Zinlevel T-50 bath behaved differently: changes in the measured values were evident in the first eight hours of exposure, but this was followed by a stabilization of the resistance at around $50 \text{ k}\Omega \text{ cm}^2$. The NZ-98 zinc coating with ProPass BlueSpecial passivation ($R_p \approx 50 \text{ k}\Omega \text{ cm}^2$) behaved similarly after a longer exposure time (16 h). However, the polarization resistance values in the first hours of exposure of this sample were lower ($30 \text{ k}\Omega \text{ cm}^2$).

The formation of a conversion coating (ProPass BlueSpecial) on the zinc coating resulted in an approximately 80-fold increase in polarization resistance after 24 hours of exposure in 0.5 M NaCl for coatings produced in the NZ-98 bath, approximately 50-fold for coatings produced in the Zinlevel bath, and approximately 35-fold for coatings obtained in the Ecolozinc bath. In contrast, passivation with ProPass 1500 LT resulted in an approximately 64-fold increase in the polarization resistance of coatings produced in the Ecolozinc bath and an approximately 35-fold increase for samples produced in the Zinlevel bath.

A comparison of the changes in the polarization resistance values characterizing the zinc coating produced in the Ecolozinc bath after the passivation processes investigated is shown in Fig. 11. The largest increase in polarization resistance after 24-hour exposure in the solution studied occurred for the sample with ProPass 1500 LT passivation, while the lowest for the coating with Dipsol ZTB-447 ASA passivation.

Polarization curves recorded in potentiodynamic mode (Fig. 13) illustrate the differences in the corrosion process taking place in a 0.5 M NaCl solution with regard to zinc coatings deposited

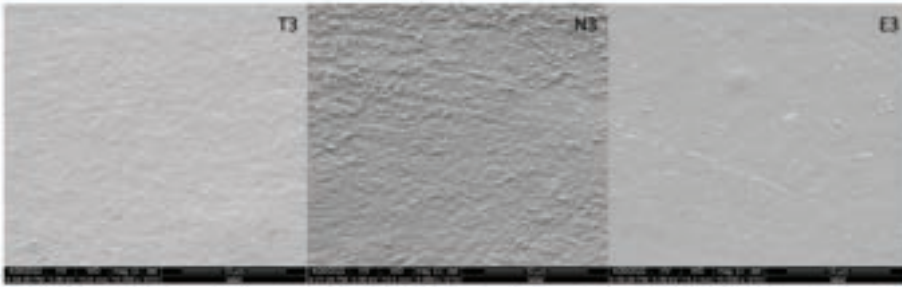


Fig. 7. SEM images of galvanized steel samples after so-called blue passivation

Rys. 7. Obrazy SEM próbek stali cynkowanej po tzw. pasywacji niebieskiej

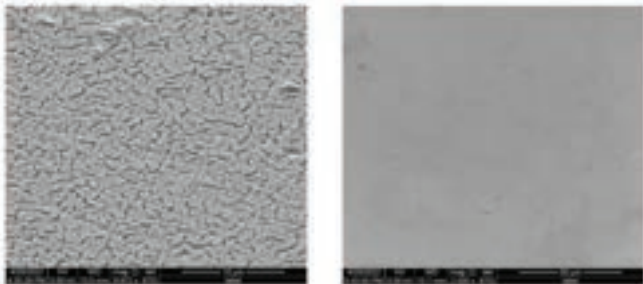


Fig. 8. SEM images of galvanized steel samples after so-called thick passivation

Rys. 8. Obrazy SEM stalowych próbek ocynkowanych i poddanych tzw. pasywacji grubopowłokowej

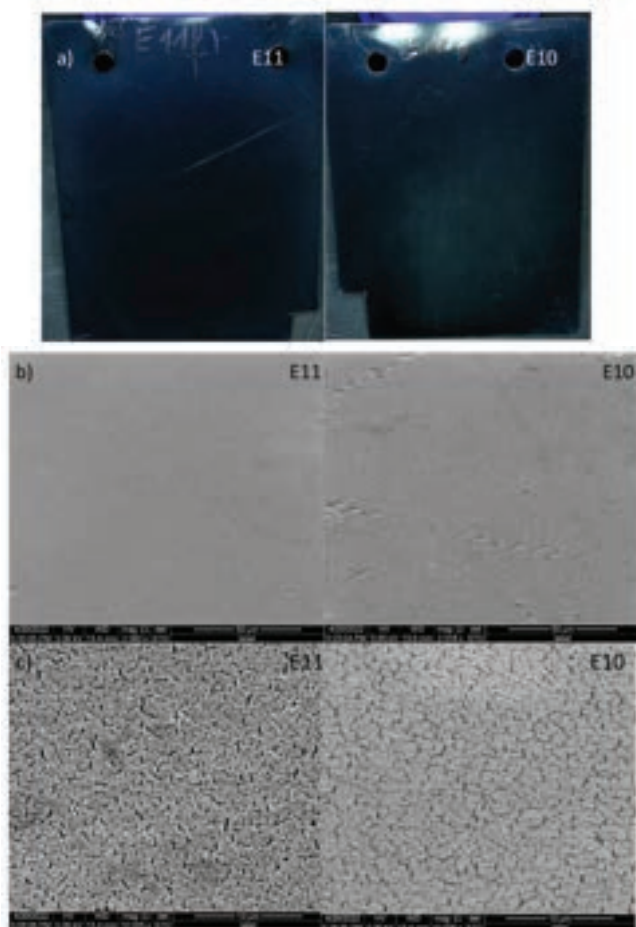


Fig. 9. Coating crack grid after black passivation produced on zinc coating deposited in an alkaline bath: a) macroscopic photographs of samples, b) SEM images with a lower magnification of 2000x, c) SEM images with a higher magnification of 10 000x

Rys. 9. Siatka spękań powłok po pasywacji czarnej wytworzonej na powłoce cynkowej osadzonej w kąpielii alkalicznej: a) fotografie makroskopowe próbek, b) obrazy SEM o powiększeniu 2000 razy, c) obrazy SEM o powiększeniu 10 000 razy

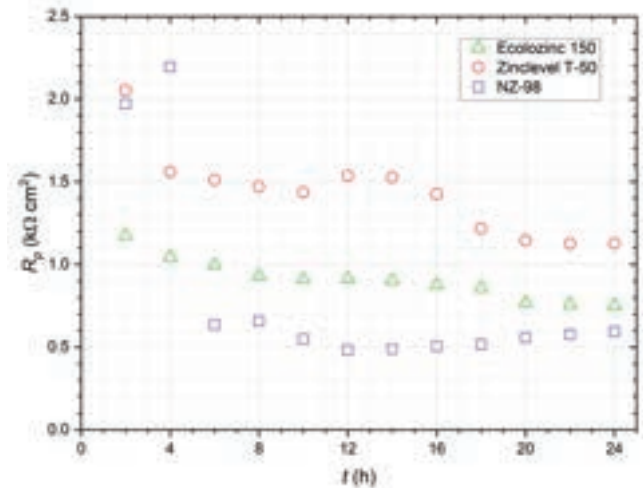


Fig. 10. Dependence of polarization resistance on exposure time of zinc coatings obtained in different electroplating bath immersed in a 0.5 mol dm⁻³ NaCl solution

Rys. 10. Zależność rezystancji polaryzacji od czasu ekspozycji w 0,5 mol dm⁻³ roztworze NaCl powłok cynkowych otrzymanych w różnych kąpielach galwanicznych

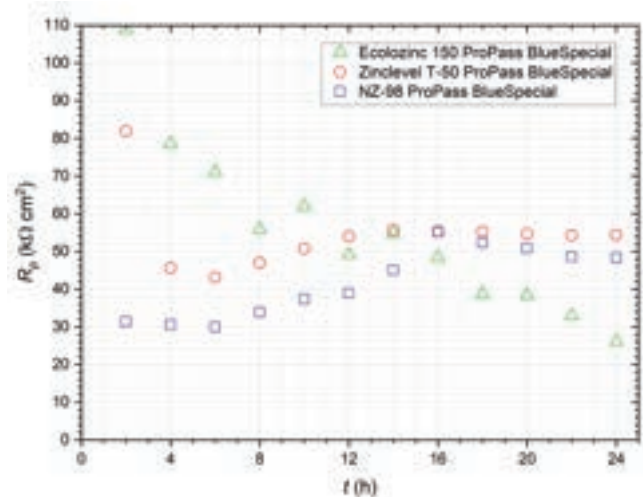


Fig. 11. Dependence of polarization resistance on exposure time of zinc coatings with additional conversion coating produced in ProPass BlueSpecial bath immersed in 0.5 mol dm⁻³ NaCl solution

Rys. 11. Zależność rezystancji polaryzacji od czasu ekspozycji w 0,5 mol dm⁻³ roztworze NaCl powłok cynkowych z dodatkową powłoką konwersyjną wytworzoną w kąpielii ProPass BlueSpecial

in Ecolozinc 150 bath with additional conversion coatings. The coating with additional ProPass 1500 LT passivation showed the lowest corrosion potential after 24-hour exposure (-1.01 V), while the coating with ProPass BlueSpecial passivation showed the highest value (-0.90 V). The highest values of current density in the anodic polarization range were achieved by the zinc

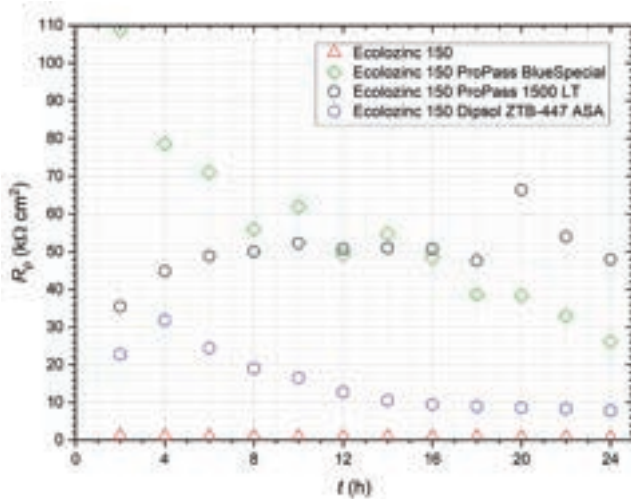


Fig. 12. Dependence of polarisation resistance on exposure time of zinc coatings (Ecolozinc 150 bath) with additional conversion coatings immersed in 0.5 mol dm^{-3} NaCl solution

Rys. 12. Zależność rezystancji polaryzacji od czasu ekspozycji w $0,5 \text{ mol dm}^{-3}$ roztworze NaCl powłok cynkowych (kąpiel Ecolozinc 150) z dodatkowymi powłokami konwersyjnymi

coating without additional passivation (Ecolozinc 150). Application of the conversion layer reduced the measured values of current density. This indicates a slowing down of the corrosion process. The lowest values were characteristic of the coating with ProPass 1500 LT passivation. The anodic curve of this sample in the potential range from -0.96 V to -0.87 V shows a distinct passive range (Fig. 13). This demonstrates the good barrier properties of this conversion coating.

5. Conclusions

It has been shown that depending on the galvanizing technology used, different coating appearance and corrosion resistance are achieved. Zinc coating deposited from a zinc chloride-based bath produces the most glossy appearance and achieves the highest polarization resistance in a 0.5 mol dm^{-3} NaCl solution. However, it should be noted that the differences in corrosion resistance of coatings deposited from alkaline zinc were not significant (about $0.5 \text{ k}\Omega \text{ cm}^2$). Thin-film passivated coatings were characterized by similar corrosion resistance. The exception was a very clear downward trend in the polarization resistance value of the conversion coating on zinc deposited from the Ecolozinc 150 bath. By contrast, the Propass 1500 LT thick-film passivation made it possible to gradually achieve the highest corrosion resistance from an initially low resistance value, as confirmed by the recorded polarization curves.

Macroscopically, the appearance of the workpieces changed after virtually every process. The exceptions were pure zinc from the NZ-98 and Zinlevel T-50 processes and brightening of the workpieces. Attention was drawn to the morphology of the layers (zinc and chromate) while keeping the same substrate (steel + galvanized zinc) and using different finishes (type of conversion coating). The clean coating without chromating was free of micro-cracks, as was the coating after brightening and thin film passivation. The coating after thick-film passivation and black-coat passivation was different – an even grid of micro-cracks was visible over the entire surface of the observed workpiece. After deposition of thin-film passivation layers, no clear changes in morphology were observed regardless of the bath used.

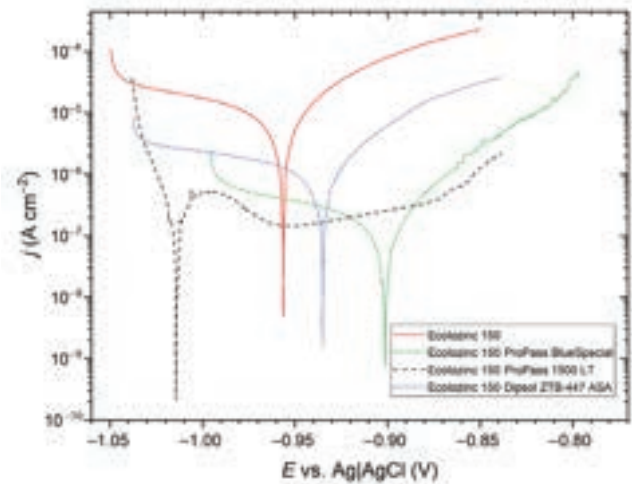


Fig. 13. Potentiodynamic curves of zinc coatings obtained in the Ecolozinc 150 bath after passivation, with conversion coatings, after 24-hour exposure in 0.5 mol NaCl solution

Rys. 13. Krzywe potencjodynamiczne powłok cynkowych otrzymanych w kąpiel Ecolozinc 150 po procesie pasywacji z wytworzonymi powłokami konwersyjnymi po 24-godzinnej ekspozycji w roztworze $0,5 \text{ mol dm}^{-3}$ NaCl

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