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Evaluating the effectiveness of duplex corrosion protection systems applied to steel components of building structures

Ocena skuteczności ochrony antykorozyjnej systemów typu duplex stalowych elementów konstrukcji budowlanych

The article presents the results of research assessing the effectiveness of anti-corrosion protection provided by duplex systems manufactured according to several variants. Corrosion tests were carried out in a salt spray chamber and immersion corrosion resistance tests were performed in 5% NaCl. After exposure to corrosive environments, blistering, flaking, cracking, rusting, delamination and corrosion around the scratch were assessed. For the tested anti-corrosion protection systems, metallographic observations were conducted and a scratch resistance test was performed using a Rockwell scratch tester. Based on the tests, both the method of preparing the substrate before applying the paint coating and the coating itself were selected. The selected protection system was not damaged by corrosion after 1,440 hours of exposure in a salt chamber or after 5,500 hours of immersion in 5% NaCl.

Keywords: corrosion, anti-corrosion system type duplex, hot-dip galvanization, paint coatings, corrosion protection system

W pracy przedstawiono wyniki badań dotyczących oceny stopnia skuteczności ochrony antykorozyjnej systemów duplex wykonanych w kilku wariantach. Przeprowadzono cykliczne testy korozyjne w komorze solnej oraz badania odporności na korozję zanurzeniową w 5-proc. roztworze NaCl. Po ekspozycji w środowiskach korozyjnych oceniono spęcherzenie, złuszczenie, spękanie, zardzewienie oraz odwarstwienie i skorodowanie wokół rysy. Przeprowadzono obserwacje metalograficzne systemów ochrony antykorozyjnej oraz test odporności na zarysowanie przy użyciu testera zarysowań z wgłębnikiem typu Rockwell. Na podstawie badań dobrano zarówno sposób przygotowania podłoża przed nałożeniem powłoki malarskiej, jak i samą powłokę. Wytypowany system ochrony wykazywał wysoką odporność na zarysowanie i nie uległ uszkodzeniom korozyjnym po 1440 godzinach ekspozycji w komorze solnej ani po 5500 godzinach zanurzenia w 5-proc. roztworze NaCl.

Słowa kluczowe: korozja, system antykorozyjny duplex, cynkowanie ogniowe, powłoki malarskie, ochrona przed korozją

1. Introduction

Issues related to the durability of building structures reinforced with steel elements are a very important aspect in the life cycle assessment of buildings and civil engineering structures. The durability and service life of a structure allow planning of any necessary maintenance work. For materials operating under particularly harsh conditions of corrosive environment, friction or stress, one type of protection often seems insufficient, therefore several-layer protection systems are increasingly used [1, 2]. Elements requiring such protection include both micropiles and soil nails (Fig. 1). In geotechnical engineering, soil and rock nails are used

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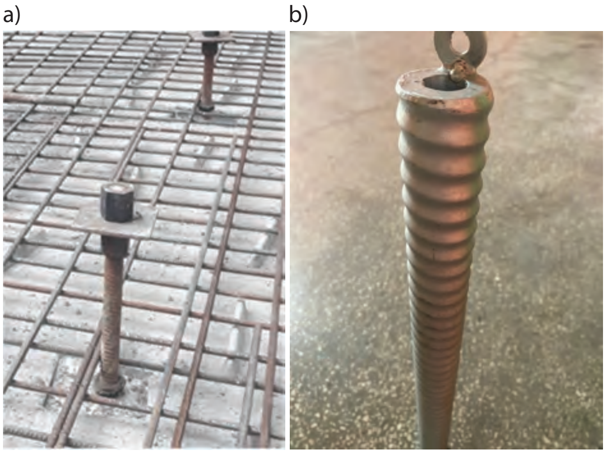


Fig. 1. The elements used in geotechnics: a) a micropiles installation, b) an element with an applied galvanized coating, before application of a paint coating

Rys. 1. Elementy używane w geotechnice: a) instalacja mikropali, b) element z naniesioną warstwą ocynku, przed nałożeniem warstwy lakieru

to stabilize natural or man-made slopes or to support structures, such as retaining walls. In underground applications, soil and rock nails are mainly used as advance driven shoring, for pile driving, face anchoring and radial anchoring. They are mainly exposed to tensile loading, but can also be subjected to bending and shear loads [3]. Micropiles, on the other hand, are load-bearing elements that transfer tensile, compressive or alternating loads to the soil. In addition, they can also be subjected to buckling loads, especially in soft soil [4]. Typical applications of micropiles include:

– foundations of new buildings,
– reinforcement of existing foundations,
– displacement control,
– core piles for tunneling.

The use of the well-known corrosion protection method of galvanizing sometimes proves to be insufficient in such special working conditions. In order to ensure a sufficiently long service life of components, double protection is often used, in which a paint coating is applied over the zinc coating. This method of corrosion protection of steel is referred to as the duplex system [5, 6]. The application of a paint coating over galvanized steel is designed to prevent the zinc coating from interacting with the environment, to form a barrier layer, and, thanks to a synergistic effect, to significantly extend the service life of the entire protection system [5]. However, the performance properties of the duplex system depend on a number of factors, the most significant of which include: the chemical composition of the substrate metal (mainly silicon and phosphorus content), the technological parameters of the galvanizing process, proper preparation of the galvanized surface and the proper selection of paint products [7–9]. Key in ensuring the long-term service life of the system, in addition to the type of paint product, is its good adhesion to the zinc coating [1, 7, 10, 11]. Improper bonding of layers can cause peeling, blistering or delamination [12, 13].

Minova Arnall is a manufacturer of mining shoring, steel self-drilling micropile elements and solutions for securing embankments and slopes. Products manufactured at Minova's plant near Częstochowa are used in geotechnics to support foundations

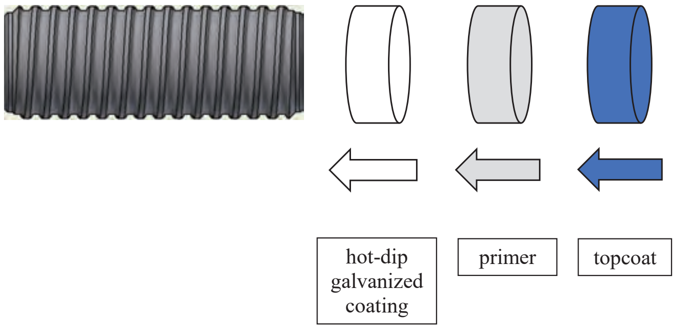


Fig. 2. Diagram of the Minova Twin Coat corrosion protection system

Rys. 2. Schemat systemu ochrony antykorozyjnej Minova Twin Coat

(micropiles) and to secure slopes and embankments (soil nails). The company has been conducting research for years to improve the strength and extend the life of manufactured components. One of its solutions is the duplex surface protection system, referred to by the company as Minova Twin Coat. The Twin Coat system consists of a hot-dip galvanized coating with a thickness of more than 85 µm, a primer layer and a topcoat layer. The combined thickness of the primer and topcoat exceeds 100 µm. Fig. 2 illustrates the Minova Twin Coat system.

The proposed corrosion protection system consists of several layers, and each layer has a specific role:

– zinc coating – surface protection, corrosion protection and high mechanical strength;
– primer – improving the adhesion of the topcoat to the steel substrate;
– topcoat – barrier and inhibiting effect, protection of the zinc coating against corrosion, aesthetic qualities.

The growing demand for steel components operating in adverse conditions of corrosive environment and stress, as well as the high requirements of customers for failure-free products, make it necessary to constantly upgrade and improve the corrosion protection used. The purpose of this study was to compare several variants of duplex corrosion protection systems differing in the preparation of the galvanized surface and the type of topcoat. The evaluation of their corrosion resistance is aimed at selecting the most effective system among those proposed, and will be the starting point for further studies aimed at determining the corrosion durability of the selected system applied to metal elements used in geotechnical engineering.

2. Study materials and methodology

<u>2.1. Determination of resistance to salt spray</u>

Steel plates (0.19–0.20% Si) measuring 150 × 100 × 10 mm hot-dip galvanized in accordance with PN-EN ISO 1461:2011 [14] were tested. The galvanizing process was carried out in an industrial galvanizing plant, where a traditional zinc bath with the addition of aluminum was used. The galvanized samples were not conditioned, and the fresh layer of zinc was cleaned by blasting to Sa 2½ grade using non-metallic abrasive shot before further treatment. The cleaned samples had a silvery-gray color and were free of any kind of damage or defects. Subsequently, the surfaces of some plates were additionally chemically cleaned (using Eskaphor recommended for subsequently painted surfaces): Be, covered with an epoxy primer and finally applied a coat of paint. The final layer, the topcoat, was one of two powder coatings. One type of paint is a dedicated thermosetting paint called OxyPlast, for which the manufacturer recommends using a primer on hot-dip galvanized surfaces [15]. The other type is the highly flexible PlastCoat paint used for a variety of metallic surfaces operating in variable climatic conditions, for which, according to the manufacturer, no primer is required before application [16]. The detailed operations scheme for the tested duplex coating variants is shown in Table 1.

Table 1. Duplex corrosion protection systems tested
Tabela 1. Systemy ochrony antykorozyjnej typu duplex poddane badaniom

Variant	Hot-dip galvanized coating	Surface preparation	Primer	Topcoat	Thickness [μm]
A	yes	Sa 2½	–	OxyPlast (dark blue)	190–200
B	yes	Sa 2½	–	PlasCoat (red)	190–200
C	yes	Sa 2½	yes	OxyPlast (dark blue)	260–300
D	yes	Sa 2½	yes	OxyPlast (grey)	120–160
E	yes	Sa 2½ + Be	yes	PlasCoat (brown)	260–300
F	yes	Sa 2½ + Be	yes	OxyPlast (blue)	120–160

The basic evaluation of the effectiveness and durability of anticorrosion coatings involves performing accelerated corrosion tests in diverse environments. For the evaluation of the anticorrosion systems in question, the cyclic test method in salt spray and the immersion method in NaCl solution were chosen. For samples after exposure in the applied corrosion environments, damage observations were performed and, in accordance with PN-EN ISO 4628:2005 (parts 2–5 and 8) [17], the following were evaluated:

– blistering,
– flaking,
– cracking,
– rusting,
– delamination and corrosion around the crack.

Three plates were prepared for each test, the side edges were carefully protected, and a cut was made at a distance of at least 20 mm from each edge.

2.2. Accelerated salt chamber tests

Salt chamber tests were performed using a qualitative method (visual evaluation) in a salt spray environment [18]. The spray mist was aerosolized using a 5% NaCl solution with pH = 6.5–7.2 and a temperature of 35°C. The tests were conducted in a cyclic system using a 24-hour exposure in the salt spray chamber followed by a 24-hour drying of the samples in air. The total exposure time in the salt spray environment, depending on the variant of surface protection, was 720 or 1440 hours (Table 1). A cut with a scratch width of 1 mm was made along the longer edge of the sample, loose coating fragments were removed with an upholstery knife, and measurements were taken with a caliper. After exposure, the samples were washed with demi water, dried, after which the changes in appearance and degree of corrosion were evaluated.

2.3. Determination of resistance to liquids – water immersion method

The test was conducted in accordance with PN-EN ISO 2812:2019 [19], which assumes exposure of the samples in a 5% NaCl solution. However, due to the results obtained in preliminary tests, in which the protection systems under consideration showed very high corrosion resistance, the pH of the solution used was additionally acidified to pH = 4–4.5. Exposure in the corrosion solution was carried out continuously for 3,500 hours (variant D) or 5,500 hours (variant C) at the Minova Arnall laboratory. After the exposure was completed, the samples were washed with demi water, dried, and the damage was assessed.

Metallographic observations were made for the specimens and a scratch resistance test was performed in accordance with PN-EN ISO 1518:2011 [20]. For the scratch test, a scratch tester with a Rockwell-type indenter was used instead of the sclerometer recommended by the standard. The test consisted of a controlled scratching of the surface of the sample with a diamond indenter under a normal force load of Fn. During the scratching, the tangential and normal force was recorded in the form of a graph, which made it possible to determine at what force the first crack, peeling or complete removal of the layer and exposure of the substrate occurs. The measurement was carried out with a load increasing linearly in the range of 1–200 N at an indenter moving speed of 10 N/min. Paint film thickness tests were performed by the magnetic induction method using a DeFelsko PosiTector 6000 coating thickness meter in six evenly spaced areas at a distance of no less than 1 cm from the edge.

3. Results and discussion

Below are the results of the tests for the samples, without primer, with the paint coating applied directly to the zinc coating; the samples were prepared according to variants A and B. Table 2 shows the appearance of the surface before and after 720 hours of exposure in the salt chamber, as well as the parameters determining the effectiveness of the anti-corrosion system used.

As can be seen from the data collected in Table 2, applying the topcoat directly to the zinc substrate provides effective corrosion protection for undamaged coatings. After an exposure time of 720 hours, no cracking, peeling, rusting or delamination was observed on the surface of the plates. However, blistering was observed in the scratch area for both variants. The amount and size of the blistering varied depending on the type of paint used. For the surface coated with PlasCoat paint (variant B), the blistering at the scratch can be described as grade 5(S5) and for OxyPlast paint (variant A) as grade 2(S4).

Another group of samples (variants C, D, E and F) were paint systems that used an epoxy primer dedicated to galvanized substrates. For variants E and F, chemical cleaning was additionally applied before applying the primer. The appearance and evaluation of the tested corrosion protection systems after exposure in a corrosive environment are presented in Table 3. Based on the results obtained, it can be concluded that all variants of protective anti-corrosion systems from Table 3 proved to be effective. After 720 hours of exposure, no damage was observed on the surfaces of the samples, which

Table 2. Surface appearance of the samples before and after 720 hours of exposure in the salt chamber for variant A and B and evaluation of corrosion changes

Tabela 2. Wygląd powierzchni próbek przed ekspozycją w komorze solnej i po 720 godzinach ekspozycji w komorze solnej oraz ocena zmian korozyjnych – warianty A i B

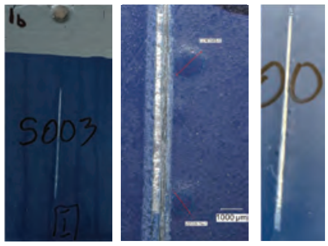
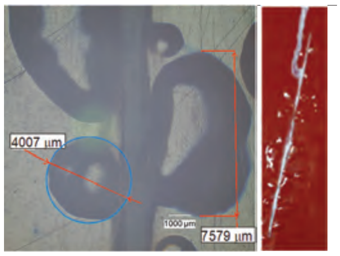
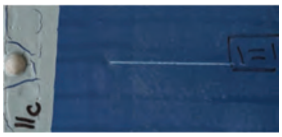
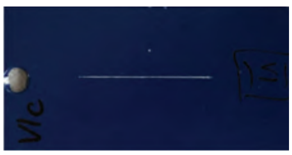
Variant	Evaluation of corrosion changes					Surface before exposure	Surface and its selected section after 720 hours of exposure in the salt chamber
	blistering	flaking	cracking	rusting	delamination [mm]		
A	1(S2)	0(S0)	0(S0)	Ri0	d = 0 c = 0		
B	4(S4)	0(S0)	0(S0)	Ri0	d = 0 c = 0		

Table 3. Number and extent of damage and intensity of uniform changes in the appearance of protection systems (variants: C, D, E and F) and surface appearance of the samples after 720 hours of exposure in the salt chamber

Tabela 3. Liczba i rozmiar uszkodzeń oraz intensywność jednolitych zmian w wyglądzie systemów ochrony (warianty C, D, E i F) oraz wygląd powierzchni próbek po 720 godzinach ekspozycji w komorze solnej

Variant	Evaluation of corrosion changes					Surface after 720 hours of exposure in the salt chamber
	blistering	flaking	cracking	rusting	delamination [mm]	
C	0(S0)	0(S0)	0(S0)	Ri0	d = 0 c = 0	
D	0(S0)	0(S0)	0(S0)	Ri0	d = 0 c = 0	
E	0(S0)	0(S0)	0(S0)	Ri0	d = 0 c = 0	
F	0(S0)	0(S0)	0(S0)	Ri0	d = 0 c = 0	

suggests that it is possible for all variants C–F to be used in environments with corrosivity categories C5 and Im2 [21, 22].

Considering the use of the tested protection systems to protect the surface of micropiles or soil nails in geotechnical engineering, where damage from the substrate (rock, soil) can occur during installation and assembly, damage resistance is a very important factor in determining applicability. In order to compare the damage resistance of the analyzed corrosion protection systems, scratch resistance tests of their paint coatings were performed. Fig. 3 shows the appearance of scratches on the paint coating using a scratch tester that allows measuring the force required to damage the coating when it is scratched.

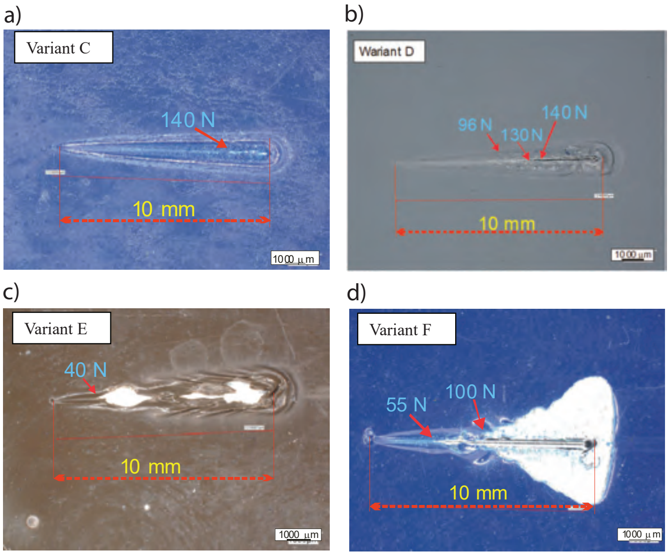


Fig. 3. The appearance of the scratch after a scratch test of the surface with an applied corrosion protection system: a) variant C, b) variant D, c) variant E, d) variant F

Rys. 3. Wygląd rysy po teście zarysowania powierzchni z naniesionym systemem ochrony antykorozyjnej: a) wariant C, b) wariant D, c) wariant E, d) wariant F

Table 4. The lowest values of normal force causing damage to the tested coatings
Tabela 4. Najmniejsze wartości siły normalnej wywołujące powstanie uszkodzeń badanych powłok

Damage	Variant	The lowest normal force values causing damage [N]	Average value [N]
Appearance of the first small cracks in the coating	C	not observed	–
	D	90, 96, 99	95
	E	40, 35, 39	38
	F	55, 60, 52	56
Appearance of the first signs of substrate exposure at the bottom of the crack as a result of scratching	C	140, 142, 139	140
	D	130, 135, 128	131
	E	40, 35, 39	38
	F	55, 60, 52	56
Complete removal of the coating at the bottom of the crack	C	not observed	–
	D	140, 130, 135	135
	E	40, 35, 39	38
	F	60, 65, 55	58

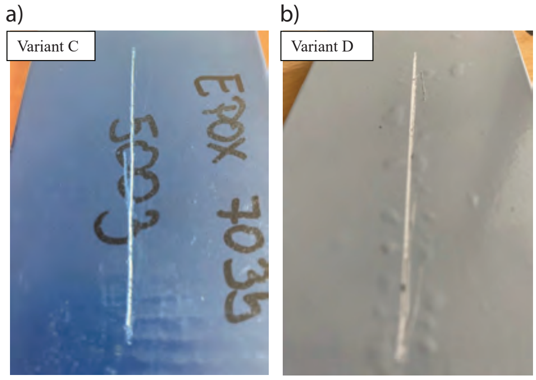


Fig. 4. Surfaces with applied duplex protection system: a) after 5,500 hours (variant C), b) after 3,500 hours (variant D) of immersion in 5% NaCl solution (pH = 4.5)

Rys. 4. Powierzchnie z naniesionym systemem ochrony typu duplex: a) po 5500 godzinach (wariant C), b) po 3500 godzinach (wariant D) zanurzenia w 5-proc. roztworze NaCl (pH = 4,5)

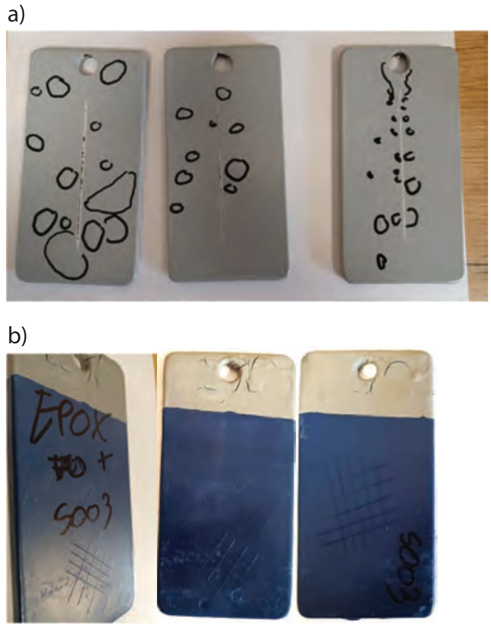


Fig. 5. Surface of samples after corrosion tests: a) blistering of the surface protected by variant D after 3,500 hours of immersion in acidified 5% NaCl solution, b) the appearance of samples protected by variant C after 5,500 hours of immersion in the same solution

Rys. 5. Powierzchnia próbek po testach korozyjnych: a) spęcherzenie powierzchni zabezpieczonej według wariantu D po 3500 godzinach zanurzenia w zakwaszonym 5-proc. roztworze NaCl, b) wygląd próbek zabezpieczonych według wariantu C po 5500 godzinach zanurzenia w tym samym roztworze

In assessing the damage of paint coatings due to scratching, the evaluation was limited to microscopic observations that allowed locating the first cracks in the coating and the degree of scratching, and assigning to them the corresponding value of the critical normal force. The isolated characteristic damages of the paint coating and the critical normal force values determined for them are shown in Table 4. Summarizing the results obtained in Table 4 and the appearance of the scratches in Fig. 3, it should be noted that the best scratch resistance was recorded for variant C (no complete removal of the coating under experimental conditions) and only slightly weaker for variant D, for which complete removal of the coating at the bottom of the scratch was observed at more than 135 N.

Of the variants collected in Tables 3 and 4, which include the results obtained for the samples after exposure in the salt chamber, variants C and D were selected to evaluate the immersion corrosion resistance of the coatings. Although variants E and F had the same corrosion resistance (Table 3), they showed low resistance to scratching (Fig. 3), which is critical in the effective protection of elements in the form of micropiles, anchors or soil nails. Additional chemical cleaning of their surfaces before painting would have made the manufacturing process more expensive. Fig. 4 shows the appearance of samples with the anti-corrosion system applied after immersion in the corrosion solution for 3,500 hours (variant D) or 5,500 hours (variant C).

Immersion of the test specimens protected according to variant D in a 5% NaCl solution for 3,500 hours resulted in severe surface blistering not only at the artificial damage of the paint coating (Fig. 4) but over the entire surface of the sample (Fig. 5a). For variant C, no corrosion changes were observed even after the immersion of the samples was extended to 5,500 hours (Fig. 4a and 5b).

a) b)

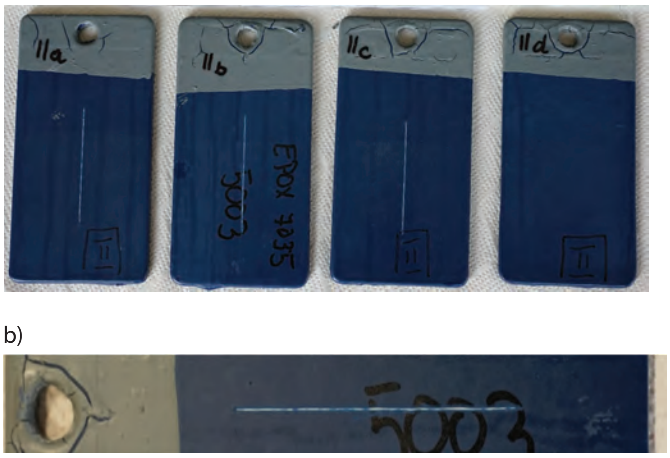


Fig. 6. Surface of the samples protected according to variant C after 1,440 hours of exposure in the salt chamber: a) set of samples, b) artificial damage to the corrosion protection system

Rys. 6. Powierzchnia próbek zabezpieczonych według wariantu C po 1440 godzinach ekspozycji w komorze solnej: a) zestaw próbek, b) sztuczne uszkodzenia systemu antykorozyjnego

As there were no corrosion changes after both 720 hours of exposure in the salt chamber and 5,500 hours of immersion in a 5% NaCl solution for the surface protected according to variant C, salt chamber testing was extended to 1,440 hours for this variant. The typical appearance of the samples (variant C) after 1,440 hours of exposure in the salt chamber is shown in Fig. 6.

No corrosion changes were observed after 1,440 hours of exposure of the samples protected according to variant C. The lack of visible corrosion damage in the form of blistering, peeling or delamination offers the possibility of long-term corrosion protection in environments with corrosivity categories C5, Im2 and Im3 for this variant. Accurate determination of durability, however, requires additional research, as there are many more factors influencing effective protection of metallic material with the duplex system than described in the paper. One of the key factors is good adhesion of the paint coating to the zinc coating. This problem for variant C after exposure to a corrosive environment of varying temperature and humidity will be the subject of further research by the authors.

4. Conclusion

The conducted tests confirmed the high effectiveness of protecting steel parts against corrosion with duplex coatings. However, the duration of effective protection depends on many factors, among which are the method of preparing the surface before painting and the type and properties of the topcoat.

A key element in ensuring the proper performance of the tested corrosion protection systems, regardless of the type of powder coating used, turned out to be the use of a primer before application. For the variants without primer, there was a lot of blistering in the area of damage to the paint coating, which was not observed for the variants with primer applied.

Of the studied variants of duplex corrosion protection systems, considering their application on elements used in geotechnical engineering, variant C turned out to be the most effective. The surface protected according to this variant showed the highest scratch resistance and no corrosion damage in the applied corrosion times and environments. The lack of corrosion damage offers the possibility of long-term protection, however, due to the multitude of factors determining effective protection, further research will be conducted to confirm this.

CRediT authorship contribution statement

Konrad Piątek: Conceptualization, Funding acquisition, Investigation, Resources, Visualization.

Karina Jagielska-Wiaderek: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

BIBLIOGRAPHY

[1] M. Nowicka-Nowak, M. Zubielewicz, A. Tatarek, P. Liberski. 2009. „Właściwości powłok lakierowych w systemie duplex – wpływ rodzaju stali i temperatury procesu cynkowania zanurzeniowego". *Ochrona przed Korozją* 52(12): 590–593.

[2] Ł. Bąk, T. Śliwiński. 2013. „Powłoki ochronne – ich zadania i zastosowanie w przemyśle motoryzacyjnym". *Zeszyty Naukowe Politechniki Śląskiej. Seria transport* 78: 5–12.

[3] B. Kłosiński. 2015. „Nowe europejskie normy dotyczące kotew gruntowych". *Geoinżynieria: Drogi, Mosty, Tunele* 3: 20–26.

[4] B. Kłosiński. 2014. „Zasady i problemy projektowania mikropali według Eurokodu 7". *Geoinżynieria: Drogi, Mosty, Tunele* 3: 26–32.

[5] J. F. H. van Eijnsbergen. 1994. *Duplex Systems: Hot-dip Galvanizing plus Painting*. Amsterdam: Elsevier.

[6] M. Bjordal, S. B. Axelsen, O. Ø. Knudsen. 2006. "Quality Criteria of Powder Coated HDG Steel in Corrosive Environment." *Progress in Organic Coatings* 56(1): 68–75. DOI: 10.1016/j.porgcoat.2006.02.006.

[7] M. Nowicka-Nowak, P. Liberski, A. Tatarek. 2013. „Przygotowanie zanurzeniowej powłoki cynkowej przed malowaniem". *Farby i Lakiery* 6: 3–9.

[8] A. Tatarek, P. Liberski, H. Kania, P. Podolski. 2008. „Systemy duplex: Powłoka cynkowa – doskonałe podłoże do malowania". *Lakiernictwo Przemysłowe* 5(55): 29–32.

[9] L. Komorowski. 2012. „Przygotowanie powierzchni powłoki cynkowej zanurzeniowej przed malowaniem". *Ochrona przed Korozją* 55(9): 380–385.

[10] A. Kazimierska, T. Skotnicki, W. Urbaniak. 2021. „Zastosowanie promotorów adhezji w systemie duplex". *Ochrona przed Korozją* 64(11): 373–375.

[11] I. Cabanelas, A. Collazo, M. Izquierdo, X. R. Nóvoa, C. Pérez. 2007. "Influence of Galvanised Surface State on the Duplex Systems Behaviour." *Corrosion Science* 49(4): 1816–1832. DOI: 10.1016/j.corsci.2006.10.018.

[12] K. J. Dunham. 2002. "Preparing Hot-Dip Galvanized Steel Surfaces for Painting or Powder Coating: A Primer." *Metal Finishing* 100(9): 20–25. DOI: 10.1016/S0026-0576(02)80746-2.

[13] B. del Amo, L. Véleva, A. R. Di Sarli, C. I. Elsner. 2004. "Performance of Coated Steel Systems Exposed to Different Media: Part I. Painted Galvanized Steel." *Progress in Organic Coatings* 50(3): 179–192. DOI: 10.1016/j.porgcoat.2004.02.003.

[14] PN-EN ISO 1461:2011: Powłoki cynkowe nanoszone na wyroby stalowe i żeliwne metodą zanurzeniową – Wymagania i metody badań.

[15] https://oxyplastuk.com/documents/PE51-TR9905-42-180-ENG.pdf (access: 15.07.2024).

[16] https://www.axalta.com/thermoplasticcoatings_global/en_GB/products/plascoat/ppa-571-range.html (access: 15.07.2024).

[17] PN-EN ISO 4628:2005: Farby i lakiery – Ocena zniszczenia powłok – Określanie ilości i rozmiaru uszkodzeń oraz intensywności jednolitych zmian w wyglądzie.

[18] PN-EN ISO 9227:2023-02: Badania korozyjne w sztucznych atmosferach – Badania w rozpylonej solance.

[19] PN-EN ISO 2812-2:2019-01: Farby i lakiery – Oznaczanie odporności na ciecze – Część 2: Metoda zanurzania w wodzie.

[20] PN-EN ISO 1518-2:2011: Farby i lakiery – Oznaczanie odporności na zarysowanie – Część 2: Metoda zmiennego obciążenia.

[21] PN-EN ISO 12944:2018-03: Farby i lakiery – Ochrona przed korozją konstrukcji stalowych za pomocą ochronnych systemów malarskich.

[22] WR-M-31: Wytyczne projektowania zabezpieczenia antykorozyjnego stalowych elementów drogowych obiektów inżynierskich. Wzorce i standardy rekomendowane przez Ministra właściwego ds. transportu.