**KINGA KRAWCZYK**

ORCID: 0000-0001-8664-7398

Łukasiewicz Research Network – Institute for Engineering of Polymer Materials and Dyes, Toruń, Poland

Paints and Plastics Department, Gliwice, Poland

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# Type of scribe mark as a factor influencing the degree of delamination around scribe after exposure to neutral salt spray

## Rodzaj nacięcia jako czynnik wpływający na stopień odwarstwienia powłoki wokół rysy po ekspozycji na działanie rozpylonej obojętnej solanki

*The results of a study on the influence of scribe mark type on the degree of delamination of coatings around scribe marks after exposure to neutral salt spray according to PN-EN ISO 9227 have been presented. Galvanised steel sheets with powder and KTL coatings were used for the study. The paint systems were scribed using tools with different blade geometries. It was shown that the method of scribing, taking into account the type of scribing tool, the orientation of the scribe mark and the width and cross-sectional shape of the mark, has a significant influence on the degree of delamination determined in accordance with PN-EN ISO 4628-8. In addition, the provisions of the standards regarding guidelines for making artificial defects on coatings for corrosion tests have been analysed.*

*Keywords: type of scribe mark, degree of delamination, neutral salt spray*

*W pracy przedstawiono wyniki badań wpływu rodzaju nacięcia na ocenę stopnia odwarstwienia powłok wokół rysy po ekspozycji na działanie rozpylonej obojętnej solanki, zgodnie z PN-EN ISO 9227. Do badań zastosowano ocynkowane płytki stalowe pokryte powłoką proszkową oraz KTL. Powłoki malarskie nacinano, stosując narzędzia o różnej geometrii ostrza nacinającego. Stwierdzono, że sposób wykonania nacięcia, z uwzględnieniem rodzaju narzędzia, ułożenia nacięcia oraz jego szerokości i kształtu przekroju poprzecznego, w istotny sposób wpływa na stopień odwarstwienia oznaczany według PN-EN ISO 4628-8. Omówiono także zapisy norm dotyczące wytycznych odnośnie do sposobu wykonywania sztucznych uszkodzeń powłok do testów korozyjnych.*

*Słowa kluczowe: rodzaj nacięcia, odwarstwienie powłoki, rozpylona obojętna solanka*

### 1. Introduction

Coating systems are widely used to protect metal surfaces from the damaging effects of corrosive agents. The use of such protection is particularly important in protecting outdoor metal components and structures from corrosion, which ultimately leads to deterioration of the mechanical properties of these materials, including their strength. Therefore, coating systems should be sufficiently effective and selected to provide the longest possible corrosion protection for the metal structures to which they are applied in a given environment [1–6]. Metallic coatings protect the substrate from aggressive weathering by providing barrier and cathodic protection, while organic coatings protect the substrate via the barrier effect of the coating or by actively inhibiting corrosion through the anti-corrosion pigments they contain [1, 5, 6]. However, the long-term effectiveness of organic coatings depends on a number of factors acting in a complex manner [7]. In addition to the protective mechanisms mentioned above, the anticorrosive properties of coatings are influenced by, among other things, good adhesion of the coatings to the substrate, which is achieved, for example, by imparting the appropriate roughness to the surface [8]. They are also determined by the appropriate thickness of the coatings [9] as well

**Mgr inż. Kinga Krawczyk** graduated from the Faculty of Chemistry at the Silesian University of Technology in Gliwice in 2010. She is employed at the Łukasiewicz Research Network – Institute for the Engineering of Polymer Materials and Dyes in Toruń in an accredited laboratory at the Paints and Plastics Department in Gliwice. Currently held position: senior specialist – analyst. Specialty: testing of properties of liquid coatings, testing of physical and mechanical properties of coatings made from paint products, testing of corrosivity of paint coatings in inert salt spray.

**Mgr inż. Kinga Krawczyk** w roku 2010 ukończyła studia na Wydziale Chemicznym Politechniki Śląskiej w Gliwicach. Pracuje w Sieci Badawczej Łukasiewicz – Instytucie Inżynierii Materiałów Polimerowych i Barwników w Toruniu, w Centrum Farb i Tworzyw w Gliwicach, w laboratorium akredytowanym. Obecnie zajmowane stanowisko: starszy specjalista – analityk. Specjalność: badania właściwości ciekłych wyrobów lakierowych, badania właściwości fizykomechanicznych powłok wyrobów lakierowych, badania korozyjności powłok lakierowych w obojętnej mgle solnej.

E-mail: kinga.krawczyk@impib.lukasiewicz.gov.pl

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as the method of application or the physical and mechanical properties of the coatings. The protective properties of coating systems can be verified by performing field tests under real conditions, and tests in artificial atmospheres [10]. Field tests are the most reliable. However, acquiring results from such tests is a time-consuming process and therefore not very practical, so accelerated tests are used instead. Test conditions in artificial atmospheres differ significantly from those in natural conditions, and it is often not possible to use these results to determine the long-term behaviour of coating systems in real conditions [11]. Despite this, accelerated tests are useful for verifying the corrosion properties of coatings and for revealing coatings with inferior performance. Nevertheless, tests under artificial conditions correlated with results obtained under natural conditions are characterized by higher reliability [10, 12, 13]. Accelerated tests are carried out with different atmospheres, using either constant or variable corrosion factors, such as humidity, temperature, salt spray, UV radiation. To determine the protective properties of coating systems or to visualize the corrosion processes of painted metals, electrochemical methods are used [14–20], of which EIS is the most common [10, 11, 21–27], as well as other methods such as scanning acoustic microscopy [12, 28, 29], or the use of a 3D profilometer [29], to name a few. Determination of the corrosion performance of coatings in relation to the requirements of standards or product specific documents is mainly based on visual assessment of corrosion damage resulting from exposure of coatings to artificial atmospheric conditions. The evaluation and quantification of the main defects that may occur on coatings after exposure to artificial atmospheres is carried out according to the PN-EN ISO 4628 series of standards. Artificial atmosphere tests can be performed on intact, undamaged samples as well as on samples with scratched coatings. The analysis of artificially damaged coatings can be used to characterise the behaviour of coatings damaged by mechanical scratches in service or of defective coatings.

In preparation for corrosion testing of panels with organic coatings on metal substrates, the coatings can be scribed using various types of scribing tools with blades of different shapes and widths. The scratches can be made either manually or using special equipment that makes the scribes automatically. The available standards or internal documents still lack standardised guidelines for the type of scribe and the tool used to make it [30–46]. Some standards define specific tools, others specify the possible shape of the scribe, while still others lack information on the characteristics of the scribe or the type of scribe tool that should be used to accurately reproduce a given test or experiment. Table 1 shows examples of how coatings are scribed for corrosion testing, depending on the standards used. The way in which an artificial scribe is made on a coating, taking into account the tool used to make the scribe and the resulting cross-sectional shape, is very important and can have a significant effect on the outcome of the test. Maples, Williams, and Rawlins [47] investigated the effect of the type of scribe on the progression of corrosion using nine different scribing tools, including manual tools and mechanically driven tools at different speeds. In their study, they showed that the depth of the scribe had no effect on the development of corrosion, but the width of the scribe made had a large effect on the visual assessment of corrosion and contributed to a higher rate of corrosion and a larger area of corrosion formed when tested in salt spray according to ASTM B117 [48]. In contrast, the width of the original crack had little effect on the result when corrosion cycles were carried out according to GMW 14872 [49]. Yasuda et al. [50] studied the size and type of defects on aluminium substrates using electrochemical impedance spectroscopy measurements and found that the initial scribe width and depth had no effect on the corrosion rate.

PN-EN ISO 9227 [51], which describes tests in a 5% salt spray, does not specify the type of scribing device. In a paragraph referring to the scribing of coatings prior to testing, the document [51] quotes the PN-EN ISO 17872 [52] standard for making scribes on metal plates for corrosion testing and states that the coating should be scribed so that the scratch has a rectangular or upwardly widening cross section, exposing the substrate to a width of between 0.2 mm and 1 mm, and the type of scribing tool used should be included in the test report. The scribe should be parallel to the long edge of the panel. In the case of aluminium sheets, two scratches should be perpendicular to each other and not intersect. However, the latest edition of the standard describing salt chamber exposure [51] already pays more attention to the type of scratch made, since in the section on information to be included in the test report, in addition to the type of tool used, the cross-sectional area of the scratch obtained by the tool used should also be specified. According to the guidelines of the PN-EN ISO 12944-6 standard [30], which describes test methods for coatings applied to steel structures, as far as the type of scribe is concerned, it should be made mechanically using a device such as a drill with a cobalt bit, and should have the shape of a horizontal line with a width of 2 ±0.2 mm, passing through the coating and the metal layer to the substrate. When performing the salt spray test according to ASTM B117 [48], the document refers to ASTM D1654 [53] for methods of evaluating specimens exposed to a corrosive environment in the section referring to the testing of scratched specimens.

EN ISO 17872 [52] gives examples of scribing tools, taking into account their geometry and the shape and width of the scratches produced by their use. The provisions of the standard [52] apply to the application of scratches to coatings with a thickness of less than 500 µm. The document describes several types of scribing tools, namely thin-bladed knives, bladed tools and tools with a cutting tip in the shape of a sharpened pencil, as well as milling machines. Thin-bladed knives are not suitable for coatings thicker than 150 µm and for coatings on sandblasted substrates, while a milling machine can scribe any coating regardless of its thickness. In any case, the tool must expose at least 0.2 mm of the substrate. With the above mentioned tools it is possible to obtain three different cross-sections of the scribe, namely a U-shape, a V-shape and a rectangular shape. Scribes can take the form of a single vertical line, a T-shape, an X-shape, an L-shape or an oblique shape. Standard [52] notes that the distribution of salt accumulation in the scribe is different depending on its shape, which can lead to different results, as well as the strong influence of the person making the scribe on its quality. In order to reduce the influence of the operator on the test result, the scribe can be made with an automatic scribing machine. Regarding the type of scribe, EN ISO 17872 [52] refers to the provisions of EN ISO 12944-6 [30] in the case of hot-dip galvanised steel specimens.

The ASTM D1654 standard [53] on methods for evaluating specimens after exposure to corrosive environments also lists several types of coating scribing tools. These include lathe-type tools with a 60° cutting tip, or tools with a pencil-like scribing tip and a 1 mm to 2 mm wide motor-driven circular blade, and other knife-type tools such as a scalpel, wallpaper knife, razor blade, or other

**Table 1. Examples of scribing methods for corrosion testing depending on the standards used**

**Tabela 1. Przykładowe sposoby nacięć powłok do testów korozyjnych w zależności od stosowanych norm**

| Standard and type of test | Type of scribe and instrument used |
|---|---|
| PN-EN ISO 12944-6:2018-03<br>(NSS)<br>(corrosion cycle) | 1. Type of scribe: horizontal with a width of 2 ±0.2 mm.<br>2. Tool: drilling machine with cobalt drill bit |
| PN-EN 13523-8:2017-08<br>(NSS) | Reference to ISO 17872<br>1. Type of scribe:<br>a) two scribes perpendicular to each other, not intersecting each other,<br>b) two oblique scribes intersecting in the middle.<br>2. Tool: a cutting tool with a hard metal tip with a radius or width to expose at least 0.2 mm of the metal substrate |
| PN-EN 10169:2022-08<br>(NSS) | 1. Type of scribe: according to EN 13523-8 or straight scribe.<br>2. Tool: Clemen stylus or equivalent, allowing a maximum scribe width of 1 mm |
| PN-EN ISO 11997-1:2017-10<br>(corrosion cycle) | 1. Type of scribe:<br>a) straight,<br>b) two parallel scribes (made parallel to the longer edge of the test plate),<br>c) two scribes perpendicular to each other, not intersecting each other (aluminium plates).<br>2. Tool: a knife with a single blade that makes it possible to obtain an upwardly expanding cross section, exposing the metal substrate over a width of 0.2 mm to 1.0 mm |
| PN-EN ISO 4623-1:2018-12 | 1. Type of scribe: two scribes perpendicular to each other, not intersecting each other.<br>2. Tool:<br>a) tools conforming to ISO 17827,<br>b) single-edged knife conforming to ISO 2409 |
| PN-EN ISO 4623-2:2016-09 | 1. Type of scribe: two scribes 1 mm to 2 mm wide perpendicular to each other, not intersecting each other.<br>2. Tool: none |
| BMW AA-0224 (04.2018)<br>(corrosion cycle) | 1. Type of scribe: straight.<br>2. Tool: Clemen stylus.<br>Note: The scribe should have a cross section that exposes the metal substrate to a width of 0.5 mm |
| MBN 10494-6:2016-03<br>(test NSS)<br>(corrosion cycle) | Reference to ISO 17872.<br>1. Type of scribe: straight.<br>2. Tool: Sikkens, Model 463, with a blade width of 1 mm |
| DBL 7391:2008-10<br>(test NSS)<br>(corrosion cycle) | 1. Type of scribe: straight.<br>2. Tool: Sikkens, Model 463 |
| DBL 7381:2021-01<br>(test NSS)<br>(corrosion cycle) | Reference to MBN 10494-6.<br>1. Type of scribe: straight.<br>2. Tool: Sikkens, Model 463, with a blade width of 1 mm |
| STD 1021,2 (02.2022) | 1. Type of scribe:<br>a) oblique,<br>b) horizontal.<br>2. Tool: a tool with a flat blade made of high-speed steel with a width of 0.50 ±0.02 mm or 1.00 ±0.02 mm |
| STD 121-0001 (10.2020)<br>(corrosion cycle) | Reference to STD 1021.2.<br>1. Type of scribe:<br>a) oblique,<br>b) horizontal.<br>2. Tool: a tool with a flat blade made of high-speed steel with a width of 0.50 ±0.02 mm or 1.00 ±0.02 mm |
| Fiat 9.55842 (11.2014)<br>(NSS test) | Reference to Fiat 50180; method B1.<br>1. Type of scribe: X-shaped.<br>2. Tool: scriber |
| M 3018:2018-02<br>(NSS test)<br>(CH test) | 1. Type of scribe: straight.<br>2. Tool: diamond cutter with a width of 0.5 mm |
| TL 260:2019-03<br>TL 262:2011-11<br>(corrosion cycle) | Reference is made to DIN EN ISO 9227, Appendix C.4.<br>All scribe marks should be made in accordance with ISO 17872.<br>1. Type of scribe:<br>a) straight,<br>b) two parallel scribes (made parallel to the longer edge of the test plate),<br>c) two scribes perpendicular to each other, not intersecting each other (aluminium plates).<br>2. Tool: a knife with a hard blade that makes it possible to obtain an upwardly expanding cross section, exposing the metal substrate over a width of 0.2 mm to 1.0 mm |
| DTRF150608 rev. G<br>(NSS test) | 1. Type of scribe: Λ-shaped.<br>2. Tool: ELCOMETER 1538/2, with a blade width of 0.5 mm |

sharp pointed tool. These tools should be capable of producing a V-shaped or rectangular cut. With regard to the use of the above tools, the standard [53] states that a razor blade may be less effective than a lathe for scratching organic coatings or coating systems containing metal layers. Each scratch should be uniform and the degree of penetration through the metal layers should be agreed between the manufacturer and the user. It is important that the quality of the scribe is checked at low power magnification and that any defects or flaws that may affect the result are noted in the test report. Standard [53] refers to a scribe in the form of a straight vertical line. Any other scribe is acceptable but must be agreed in advance between the parties involved.

When scribing coatings, it is important that the scribe is made down to the substrate and that a uniform and even cross section is maintained. It is recommended that the scribe mark is made in one smooth motion. If this is not possible, the scribe can be repeated, making sure that it is made in the same direction. However, it is necessary to maintain the cross section obtained in the previous operations [52, 53]. In practice, when testing thick or hard coatings, it is necessary to scratch the coating several times to expose the substrate, which sometimes requires great skill on the part of the operator. The scratch can be made either manually or using a special device that holds the scratching tool. If the scratch is made manually, positioning the blade in a way that is not perpendicular to the substrate can sometimes result in a scratch line that does not cut into the substrate on one side of the coating, resulting in a different width of scratch and cross-sectional shape. Therefore, unlike a scratch made with mechanical devices or blades mounted in special holders that apply uniform pressure to the coating, manual scratching of coatings can result in defects such as a non-perpendicular cut, jagged edges or uneven damage to the substrate. All of these factors can subsequently degrade the result, lead to a lack of reproducibility of the values obtained, or even affect the reliability of the test. When using scribing tools mounted in mechanical systems, it is important to control the scribing process to avoid localised overheating of the substrate and coating.

A standard often used in laboratories to characterise defects formed on test panels with a scratched protective coating is EN ISO 4628-8 [54], which describes the procedure for determining the degree of delamination and corrosion around an artificial scratch. This standard describes how to assess the delamination and corrosion around a scratch, but does not define which tool should be used to make the scratch and how wide it should be. It only gives designations for the degree of delamination and corrosion, using an example of a vertical and circular scribe, either by measurement and calculation or by comparison with image standards. Many laboratories continue to use human visual methods to evaluate surface defects and changes in the appearance of coatings, and to assess the degree of corrosion and delamination after artificial ageing. As an alternative, techniques based on the use of digital image processing offer the possibility of obtaining results that are more objective, accurate and reproducible, as they can offset the risk of human error [55, 56]. As a result, they can be used for more detailed evaluation of coating changes or defects that have occurred. In some automotive company standards [36, 37], the use of digital image processing in accordance with PN-EN ISO 21227-3 [57] is preferred for the characterisation of substrate and coating damage after exposure to various corrosive environments to assess delamination and corrosion around artificial damage. The degree of delamination is often one of the criteria to be considered in determining compliance with the requirements for the products in question. Different documents for specific products, depending on their application, have different limits as acceptance or rejection criteria, and these can range from 1.5 mm to as much as 4 mm for the degree of delamination determined after corrosion testing [43–45, 58].

Both PN-EN ISO 9227 [51] and ASTM B117 [48], which describe salt spray corrosion tests, do not define specific coating scribe tools, but only refer to standards in which a number of different types of scribe tools are presented. What is lacking are specific applications for these tools and a fuller description of their potential impact on the test result. It is therefore important that the type of scribe tool to be used and the shape and position of the scribe to be made on the coating are always agreed or specified on the basis of the referenced standard prior to commencing any corrosion test involving exposure of coatings to an artificial scratch. All this information should then be included in the test report. This is particularly important if the test needs to be repeated for the same type of coating system under the same test conditions. The arbitrary use of scribing tools could lead to unreproducible results or erroneous conclusions.

The purpose of this study was to analyse the provisions of the standard on guidelines for the methodology of making scribes on organic coatings applied to metal substrates prior to exposure to artificial atmospheres, and to determine the effect of the type of scribe mark on the degree of delamination of a coating exposed to salt spray. The study used KTL-coated and powder-coated galvanised steel sheets on which scribes were made using scribing tools with different blade shapes and widths. The scribes were made in the form of vertical and horizontal lines, by hand and mechanically.

The choice of tool used to scribe the coating can have a significant effect on the results obtained when measuring the degree of delamination. Therefore, when performing corrosion tests on artificially damaged coatings, it is essential to determine the type of scribe mark and scribe tool used in order to obtain repeatable measurements and to be able to compare results. However, it should be remembered that the type of scribing tool and the characteristics of the resulting scribe mark are only one of many factors affecting the outcome of delamination. It is also important that the quality of the scribe ensures uniform exposure of the substrate, which in both manual and automatic scribing is highly dependent on the person making the scribe or setting up the equipment. Factors critical to the adhesion of coatings, and therefore to the assessment of the degree of delamination of these coatings after corrosion testing, include proper and reproducible preparation of the substrate, and adherence to the correct conditions for application, drying/curing and conditioning of a coating product according to its specifications.

## 2. Experimental

### 2.1. Samples for testing

The test panels measuring 100 × 150 × 2 mm were made of galvanized steel and were coated on both sides with the following paint products:

– epoxy paint applied by the cataphoresis method,
– polyester powder paint applied by electrostatic spraying.

### 2.2. Physical and mechanical properties of the coatings

The thickness of the coating systems, comprising the zinc layer and coating, was determined according to PN-EN ISO 2808:2020-01 [59] using a PosiTector 6000 coating thickness meter with an FNDS Duplex probe, and the following physical and mechanical properties of the coatings were tested:

**Table 2. Average thickness and physico-mechanical properties of KTL and powder coatings**

**Tabela 2. Zestawienie średniej grubości systemów malarskich oraz właściwości fizykomechanicznych powłok KTL i proszkowej**

| Coating type | Average system thickness [μm] | | | Persoz pendulum damping time [s] | Adhesion (cross-cut method) | |
|---|---|---|---|---|---|---|
| | zinc thickness | coating thickness | overall thickness | | before exposure | after exposure |
| KTL | 29 | 22 | 51 | 346 | 1 | 1 |
| Powder | 31 | 54 | 85 | 279 | 1 | 1 |

**Table 3. Average degree of delamination of KTL and powder coatings around scribe after exposure to neutral salt spray [mm]**

**Tabela 3. Średnie wyniki pomiarów stopnia odwarstwienia powłok KTL i proszkowej wokół nacięcia po ekspozycji na działanie rozpylonej obojętnej solanki [mm]**

| Type of coating | Arrangement of the cut, the tool used and width of the cut | | | | | |
|---|---|---|---|---|---|---|
| | vertical Clemen 0.4 mm | vertical Sikkens 0.5 mm | vertical Sikkens 1 mm | vertical Sikkens 2 mm | horizontal Sikkens 2 mm | horizontal cutter 2 mm |
| KTL | 0.7 | 0.9 | 1.2 | 1.4 | 1.3 | 1.9 |
| Powder | 2.4 | 1.1 | 1.4 | 1.8 | 1.8 | 1.4 |

– hardness, determined by the Persoz pendulum damping method according to PN-EN ISO 1522:2023-02 [60],
– adhesion, determined by the cross-cut method according to PN-EN ISO 2409:2021-03 [61] (the test was performed on unexposed plates and after exposure to neutral salt spray).

### 2.3. Methods for scribing the coatings and exposure of coatings in neutral salt spray

Scribe marks were made on the test panels down to the substrate in the shape of a single line about 6 cm long. The following types of coating scribe tools were used:
– Clemen type scratch tool with a U-shaped cross section – vertical cut made by hand;
– Sikkens type scratch tool with a blade width of 0.5 mm, 1 mm and 2 mm, with a rectangular cross section – for a width of 0.5 mm and 1 mm a vertical cut is made by hand, for a width of 2 mm a vertical and horizontal cut is made by hand;
– a CNC milling machine with a cylindrical-front cutter with a width of 2 mm – horizontal cut.

For each type of scribe mark, three scratches were made on three different test panels. The scribed test panels were exposed to a neutral 5% salt spray according to PN-EN ISO 9227 [51] for 240 h. After exposure, the degree of coating delamination (*d*) was determined according to PN-EN ISO 4628-8 [54] using the calculation method following equation (1), measuring the width of the delamination every 5 mm.

$$d = \frac{(d_1 - w)}{2},$$

where:
$d_1$ – average of all widths of delamination [mm],
$w$ – width of the original scratch [mm].

The width of the original scribe marks and the width of the delamination after exposure in the salt chamber were measured using a measuring magnifier at 10× magnification with a line standard.

## 3. Discussion

The results of the physical and mechanical properties of the tested coatings and their thicknesses are shown in Table 2. In each case, the coating was cut several times to expose the substrate. The quality of the cut was verified using a 10× magnifying glass. Cuts made with a Clemen-type tool produced jagged coating edges in the scribe line, whereas cuts made with a Sikkens-type tool produced smooth edges with no jagged coating. The width of the cut with the Clemen-type tool was 0.4 mm for each of the coatings tested. The widths of the other cuts made corresponded to the widths of the blades and milling machine cutter used.

The results of the average degrees of delamination of the tested coatings around the scratches are shown in Table 3. The results of the degree of delamination obtained as a function of the width of the original vertical single line cut using a Clemen-type tool and Sikkens-type tool with blade widths of 0.5 mm, 1 mm and 2 mm are shown in Fig. 1. Analysis of the values obtained shows that for the KTL coating, regardless of the type of tool used (Clemen, Sikkens), the greater the width of the original vertical line cut, the greater the degree of coating delamination. The lowest delamination values, i.e. 0.7 mm, were obtained for the scribe using the Clemen type tool. For subsequent scribe widths, i.e. 0.5 mm, 1 mm and 2 mm, the delamination values increased by approximately 29%, 71% and 100% respectively. However, for the powder coating, the highest degree of delamination was observed for the smallest width value of the initial vertical cut, obtained using a tool with a U-shaped cross section (Clemen-type tool), and amounted to as much as 2.4 mm. With regard to the results obtained for the powder coating using a tool with a rectangular cross-section (Sikkens-type tool) with widths of 0.5 mm, 1 mm and 2 mm, the wider the original vertical cut, the greater the degree of delamination of the coating, as in the case of the KTL coating. Relative to the degree of delamination obtained for a width of 0.5 mm, the values for the powder coating increased by approximately 27% for a 1 mm wide scribe and by approximately 64% for a 2 mm wide scribe (Table 3, Fig. 1).

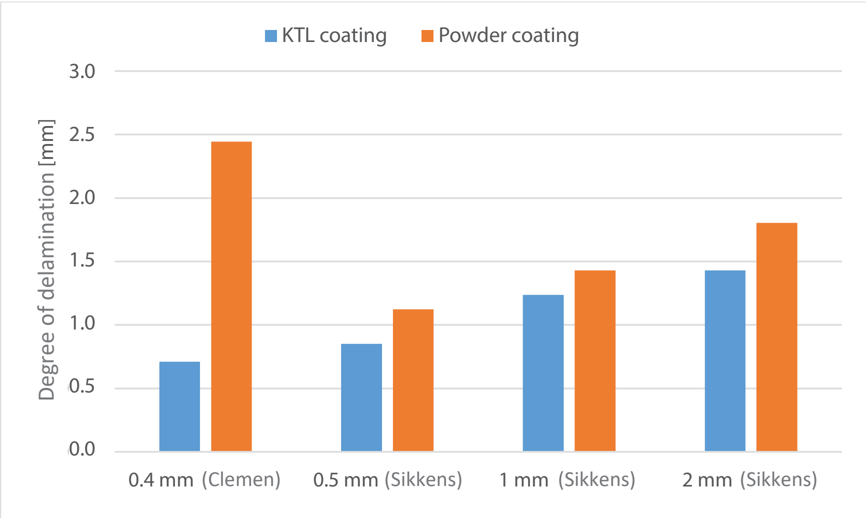


Fig. 1. Results of the degree of delamination around scribe on powder and KTL coatings for a vertical scribe mark made manually using Clemen and Sikkens scratch tools with blade widths of 0.5 mm, 1 mm and 2 mm

Rys. 1. Wyniki pomiaru stopnia odwarstwienia powłoki proszkowej i KTL po nacięciu pionowym wykonanym ręcznie z zastosowaniem noża typu Clemen oraz Sikkens o szerokości ostrza 0,5 mm, 1 mm i 2 mm

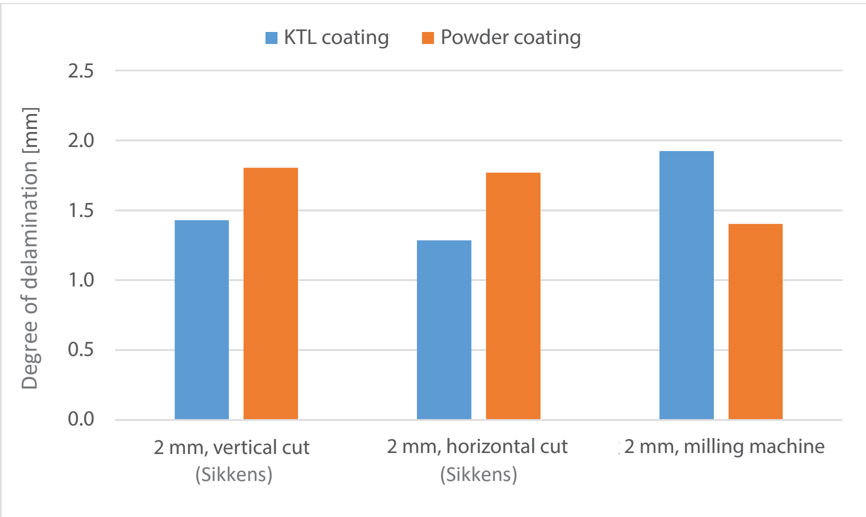


Fig. 2. Results of the degree of delamination around a scribe mark on powder and KTL coatings for a 2 mm wide vertical and horizontal scribe mark made manually using a Sikkens tool and a horizontal scribe mark made mechanically using a milling machine

Rys. 2. Wyniki pomiaru stopnia odwarstwienia powłoki proszkowej i KTL wokół pionowego i poziomego nacięcia o szerokości 2 mm wykonanego ręcznie z zastosowaniem noża typu Sikkens oraz nacięcia poziomego wykonanego mechanicznie za pomocą frezarki

The results of the degree of coating delamination obtained in relation to the position of the scribe (horizontal and vertical line) and the method of making a 2 mm wide scribe (manual and automatic) are shown in Fig. 2. Analysis of the results for the powder coating did not show any effect of the position of the scribe, i.e. vertical or horizontal, made manually, on the degree of coating delamination. In this case, the same delamination values of 1.8 mm were obtained. On the other hand, the horizontal scribe made with a cutter produced a lower delamination result than the horizontal and vertical cuts made by hand. For the 2 mm wide cuts made by hand on the KTL coating, slightly lower delamination results were obtained for the horizontal cut, while the highest delamination degree was obtained for the scribe made with the milling machine (Table 3, Fig. 2).

Analysis of the delamination values obtained for both coatings over all the corresponding widths of the original vertical cut made by hand shows that these values were higher for the powder coating than for the KTL coating (Fig. 1). Only for the horizontal cut made with the milling machine was the delamination level of the KTL coating higher than that of the powder coating (Fig. 2). The powder coating had a shorter Persoz pendulum damping time, i.e. a lower hardness. The adhesion of the coatings analysed to the substrate was the same, and in the cross-cut adhesion test, both before and after the salt spray test, a grade of 1 was obtained for both coatings (Table 2).

## 4. Conclusion

The width and cross-sectional shape of the cut made on the coatings had a significant effect on the degree of delamination of the coating systems tested, i.e. the polyester powder coating and the epoxy KTL coating applied to galvanised steel substrates. For the epoxy coating, regardless of the type of cutting tool used, the wider the initial cut, the higher the calculated degree of delamination. For the polyester coating, the highest degree of delamination was obtained for the narrowest cut width at the U-section.

In the delamination measurements, when taking into account the results obtained with all the scribe types, i.e. considering the type of scribe tools, scribe mark arrangement (vertical or horizontal), scribe mark execution (manual or mechanical), it was observed that the difference between the lowest and the highest delamination result obtained for the powder coating was 1.3 mm and for the KTL coating 1.2 mm, which represents a difference in the delamination degree value obtained of about 118% and 171% respectively.

It was found that the arrangement of the 2 mm-wide cut made by hand on the powder coating had no effect on the degree of delamination of the coating, whereas for the KTL coating a slightly lower delamination value was obtained for the horizontal cut.

For the 2 mm wide horizontal cut made by hand on the powder coating, a higher delamination value was obtained than for the 2 mm wide horizontal cut made by a milling machine. The opposite effect was observed on the KTL coating, i.e. a higher degree of delamination was obtained for the cut made mechanically.

A comparison of all the results obtained shows that around the corresponding types of cut, higher delamination values were obtained for the powder coating than for the KTL coating, with the exception of the cut made with a milling machine, where the KTL coating had a higher degree of delamination compared to the powder coating. It can be concluded that the KTL coating had better adhesion to the substrate than the powder coating. The result of the milling machine test deviates from the observed trend and could be due to various factors, including the quality of the cut, the application of the coating or the preparation of the substrate, which could be confirmed, among other things, by an SEM scanning microscope image of the test specimens.

*CRediT authorship contribution statement*

**Kinga Krawczyk:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft.

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