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IMPACT OF EDGE PREPARATION ON SURFACE FINISHING PROPERTIES

K. Sternadelova[1]*, H. Krupova[1], D. Srom[1], J. Vontorova[2], R. Siostrzonek[3]

[1]VSB - Technical University of Ostrava, Department of Mechanical Technology, Ostrava, Czech Republic

[2]VSB - Technical University of Ostrava, Department of Chemistry and Physico-Chemical Processes, Ostrava, Czech Republic

[3]ViaKont s.r.o., Ostrava, Czech Republic

*Corresponding author; e-mail: kristyna.sternadelova@vsb.cz

Abstract

The properties of protective coatings made from organic coatings on metallic substrates strongly depend on the condition of the substrate surface. This refers to the condition of the edges, welds, and the surface in general. Edge treatment is one of the most important operations prior to the actual coating application. The coating's protective properties and its susceptibility to mechanical damage are directly affected by the edge treatment. The article deals with the problem of edge treatment of the base material and the effect of this treatment on the quality of surface finishing. The edges were modified in three ways on the prepared Kosmalt E 300 T samples. Subsequently, some samples were hot-dip galvanized. An organic coating was then applied as the final surface treatment to all samples. The evaluation of the quality of the surface finishing was carried out on the above-mentioned, differently treated edges. The results strongly indicate the importance of the condition of the substrate surface and its influence on the quality of the final surface finish.

Keywords:

Edge Preparation, Surface Finishing, Quality Testing

1 INTRODUCTION

Edge treatment of steel structures is essential to the durability and performance of organic coatings in corrosion protection. Sharp edges can be problematic for coating systems as they can present a site of premature degradation due to increased susceptibility to environmental influences such as moisture, UV radiation and mechanical stresses. Sharp edges represent areas where the coating or coating system may thin or break due to its surface tension, making the substrate vulnerable to corrosion and other forms of degradation [Sandor 2024, Buchbach 2012]. Even though organic coatings are designed to provide a protective barrier against corrosion, abrasion and other forms of damage, thinning due to poor edge treatment leads to inadequate protection.

Proper edge treatment is essential to mitigate these risks and ensure the effectiveness of the coating system [Momber 2017]. Techniques such as rounding, beveling, or filleting can be used to reduce edge sharpness [Cada 2021, Osawa 2011]. Inadequate treatment of sharp edges can lead to the coating's premature failure, compromising the integrity of the substrate and requiring costly repairs [Chung 2003]. Therefore, careful consideration should be given to edge treatment prior to the actual coating process to extend the service life of coated structures and components.

Hot dip galvanizing is one of the most commonly used options for corrosion protection [Mesicek 2019, Kania 2020, Sproch 2020]. The coating is created by immersing the steel structure in a molten zinc bath [Kuklik 2016]. However, the effectiveness of the galvanized coating can be compromised if the edges of the steel are not adequately prepared before immersion.

Proper edge preparation involves cleaning and profiling the edges of the steel substrate to ensure uniform coating coverage and adhesion, likewise for organic coatings. Inadequate preparation, both of the surface itself (cleaning) and of the edges can lead to several problems during the galvanizing process. Common problems include the formation of uncoated areas or "unprotected zones" along the edges of the steel, leaving them vulnerable to corrosion. The main contributor to this problem is poor or inadequate surface pretreatment, where the surface is contaminated with contaminants such as rust, mill scale, or oils. The presence of contaminants prevents the zinc from properly interacting and bonding to the steel [Kuklik 2016].

Moreover, inadequate edge preparation can lead to uneven coating thickness, which compromises the overall corrosion protection provided by the galvanized layer. The chemical composition of the galvanized steel, particularly the content of silicon, is determinant for the structure of the coating [Sandelin 1940, Rusz 2019]. The crystalline structure, together with the quality of the steel surface and the manner of its mechanical and heat treatment, also influence the overall properties of the coating. The combination of these factors results in a zinc coating formed by hot-dip galvanizing characterized by a broad range of different morphological variations. The iron-zinc metallurgical reaction is very vulnerable to various extrinsic influences. [Fojtik 2023]. The aforementioned properties together with the galvanizing process conditions lead to the formation of diverse coating structures. The advantages of the process include uniform and high-quality coating over the entire surface as well as on internal and difficult-to-access surfaces. At the same time, there may be an increase in coating thickness on sharp edges and protrusions than on flat surfaces due to the larger area exposed to the zinc melt [Kuklik 2016].

In practice, metallic coatings and organic coatings are most commonly used for steel protection against corrosion. The different coating systems differ in their principle of corrosion protection. In a duplex system (duplex coatings), the two coatings synergistically reinforce each other. The organic coating avoids erosion of the patina covering the zinc coating and protects it from corrosion. The passivated zinc does not decrease the adhesion of the organic coating to the underlying substrate. The system is thus intact (untouched, intact) for a long time concerning the corrosive environment. As long as the organic coating does not deteriorate to the point where it starts to decay. Only then does corrosion of the zinc coating occur. These facts significantly affect the life of the duplex coating system. When structures are treated in this way, their physical lifetime often equals their technical and economic service lifetime [Kuklik 2016].

Edges as possible failure points for protective coatings have been investigated in the past mainly in the field of off-shore structures or ballast tanks [Ault 2006, Chung 2003]. The German research group focuses on evaluating edge treatment effects on coatings by electrochemical impedance spectroscopy together with the dry film thickness (DFT) measurements on polished cross-sections used in this study [Buchbach 2010, Buchbach 2012, Momber 2017, Momber 2024].

This paper aims to enrich the knowledge in the field of edge preparation influence on the coating protection properties behavior through DFT measurements and comparison of different edge preparations.

2 MATERIALS AND METHODS

2.1 Material

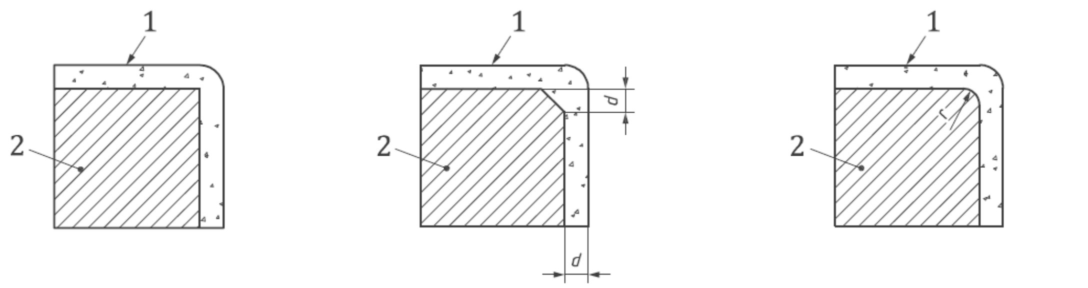
The structural steel selected for this experiment is Kosmalt E300T, the chemical composition of which was determined using a Spectrum Analytik GMBH glow discharge optical emission spectrometer (model GDA 750) under excitation conditions of 700 V and 35 mA [Vontorova 2018] and elemental analysis (Eltra CS 2000) [Veverka 2021] (elements marked with *) and is shown in Table 1.

Tab. 1: Example of table centered across two columns.

C*	**Mn**	**Si**	**P**	**S***	**Cr**	**Ni**	**Mo**	**Cu**
wt.%								
0.05	0.20	0.03	0.014	0.014	0.017	0.027	0.002	0.028
Ti	**Co**	**B**	**Pb**	**V**	**W**	**Al**	**Nb**	
wt.%								
0.081	0.056	0.0002	<0.0001	0.006	<0.001	0.060	<0.001	

2.2 Samples, edge treatment

For organic coatings, the resulting thickness is reduced due to the surface tension at the edge of the substrate material. The extent to which the thickness is reduced depends on how the edge is treated. Standard ISO 12944, Part 3 (pains and varnishes-corrosion protection of steel structures by protective paint system - Part 3: design considerations) clearly illustrates in a graphic example 3 possibilities for edge treatment and their substitutability or unsuitability for use: a sharp (untreated) edge is “bad”, the chamferred edge is “better” and rounded edge with a radius R min. 2mm is good – see Figure 1.



a) Sharp edge, poor **b) Chamferred edge, better** **c) Rounded edge ≥ 2 mm, good**

Key

1 protective paint system

2 steel

Fig. 1: Examples of surface treatment

To carry out an evaluation of the effect of edge treatment on the properties of the applied paint system the following steel specimens (dimensions 100 x 100 x 5) mm) with edge treatment were prepared: untreated sharp edge, chamferred edge and rounded edge with a radius R of min. 2 mm – see Figure 2. The chamfered edges were machined by the milling in such a way that two 45° chamfers were created, which did not intersect, so part of the edge was not affected. The rounded edges were rounded by grinding to R of min. 2 mm. According to ISO 12944, this type of edge treatment should be the ideal pre-treatment of the edges before subsequent surface treatment.

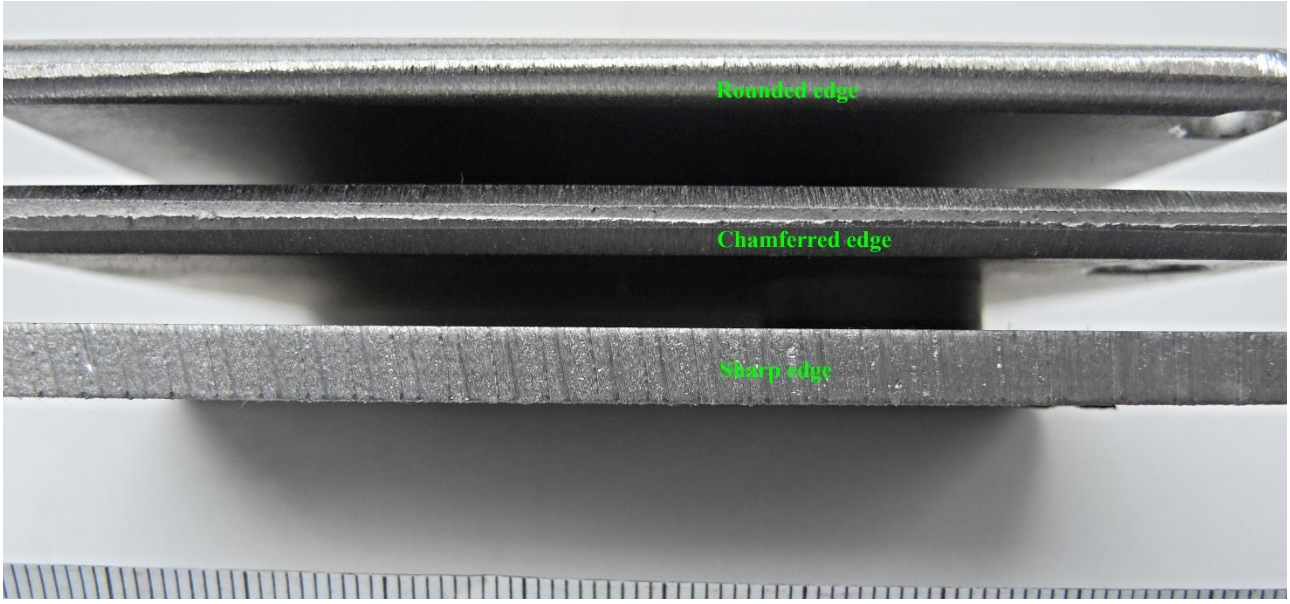


Fig. 2: Edge treatment of the test specimens: rounded edge, chamferred edge, sharp edge

Edge-treated specimens were divided into two groups. The first group of specimens was coated with the duplex system, i.e. hot-dip galvanized coating followed by the application of an organic paint system. Samples were degreased before the hot-dip galvanizing process. The requested thickness of the zinc layer was 50 µm. The second group of specimens was coated with an organic paint system.

Before the application of the paint, the surface was cleaned, recleaned with compressed air, degreased with isopropyl alcohol (p.a.) and left to air dry for 5 minutes. A two-component water-based epoxy paint was used, which was applied to the test specimens by air spraying technology. The following Table 2 shows the basic parameters of the paint material, a description of surface preparation and application conditions.

Tab. 2 – paint parameters, surface preparation, application conditions.

paint used	**two-component water-based epoxy paint**	
	content of non-volatile substances	58–65 % wt. / 48–53 % vol.
	density	1.24 – 1.40 g·cm^{-3}
	application technology	air spraying
	work pressure	2.5 atm.
surface preparation	**abrasive blasting**	
	used abrasive	steel grit GL80
	achieved level of surface cleanliness	Sa 2½ according to ISO 8501-1:2007
	achieves surface roughness	medium (G), ISO comparator, according to ISO 8503-1:2012
climatic conditions	air temperature	20.0 °C
	relative air humidity	50.0 %
	surface temperature	20.0 °C
	dew point temperature	9.3 °C
	delta	10.7 °C

3 RESULT AND DISCUSSION

3.1 Thickness measurement

After sufficient curing of the paint system, the thickness was measured on the surface of the specimen and on the edge. Prepared samples were labeled, and their specification is listed in Table 3 below.

Tab. 3 – Division of samples.

sample	edge treatment
1A_1	sharp edge, organic coating
2A_3	rounded edge, organic coating
3A_3	chamfered edge, organic coating
4A_1	sharp edge, duplex system
5A_2	rounded edge, duplex system
6A_1	chamfered edge, duplex system

The thickness was measured on images of the metallographic specimens of the samples (see section 3.2) acquired on the optical microscope Zeiss Axio Observer 3. The images were then processed in the JMicroVision software. Thirty values were measured on each sample. The mean values and standard deviations were calculated for the measured data.

The results of measurement and evaluation of the effect of edge preparation (treatment) on coating thickness are presented in the following Table 4 and Figure 3.

Tab. 4 – Coating thickness measurement results

sample		thickness (μm)				
		min	max	mean	std. dev.	variance
1A_1	coating layer	63.73	161.75	114.94	31.81	1011.91
2A_3	coating layer	143.29	204.16	167.64	14.92	222.50
3A_3	coating layer	110.76	170.77	138.90	17.86	319.13
4A_1	coating layer	68.98	181.35	120.14	33.32	1110.28
	zinc layer	103.70	236.24	130.65	28.63	819.42
5A_2	coating layer	161.57	217.62	181.19	15.14	229.18
	zinc layer	59.56	92.58	80.48	9.22	85.02
6A_1	coating layer	84.08	201.65	137.48	36.21	1310.94
	zinc layer	78.00	178.69	134.57	32.11	1030.80

The results of the coating thickness measurement presented in Table 4 show how edge treatment affects the resulting thickness of the coating. Samples with sharp edges (both with coating and duplex) exhibit high values of both deviation and variance. This fact points to a very broad range of measured values of thickness on those samples. On the contrary, for only coated samples, both samples' variations with rounded and chamfered edges show a significant decrease in both deviation and variance. This trend is similar to duplex sample with rounded edges. However, the duplex sample with chamfered edges exhibits even higher values of deviation and variance for the coating layer in comparison to only coated sharp-edged sample.

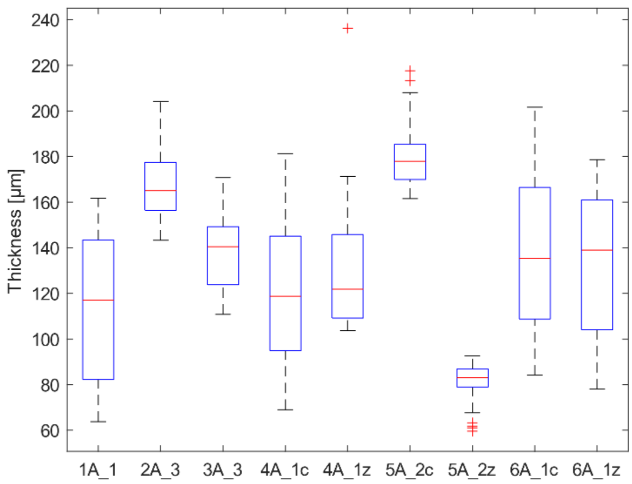


Fig. 3 – Box plot of measured coating thickness

The boxplot shown in Figure 3 shows the graphical comparison of the measured values of the coating thickness. It is clearly visible that in the case of the sharp-edged samples (1A_1 and 4A_1), the variation in the coating thickness is greater than in the other cases. For the samples that had only the organic coating, both edge treatments led to a decrease in the thickness variation. In the case of the duplex system applied on the samples, the comparison shows that a rounded edge (samples 2A_3 and 5A_2) is the best treatment leading to the most even coating thickness.

3.2 Metallographic analysis

Metallographic analysis was used to destructively measure the thicknesses of the coating system layer and the duplex system layer (for the results see section 3.1). The following Figures 4-9 show the individual systems. In the figures, minimum layer thicknesses are marked in green and maximum layer thicknesses in red.

Figure 4 shows the sample 1A_1. The thinning of the coating system layer can be seen on the edge of the sample. Figure 5 shows the sample 4A_1. Thickness minima and maxima are shown separately for the coating system and the zinc layer. The thinning of the coating system layer can also be observed in this sample. For the zinc coating layer, the thickening is not so obvious. Figure 6 shows the sample 2A_3, the layer thicknesses are more uniform. Figure 7 is a sample 5A_2. The coating system and zinc coating layers do not show large variations. Figure 8 is a sample with chamfered edges (3A_3), here too, a uniform coating thickness can be observed. The zinc layer (Figure 9) looks similar to the one in Figure 5, i.e. on a sharp edge. Due to surface tension on the edge, there is an increase in the zinc coating thickness and the coating layer is thinned. The samples with rounded edges perform best in the overall comparison.

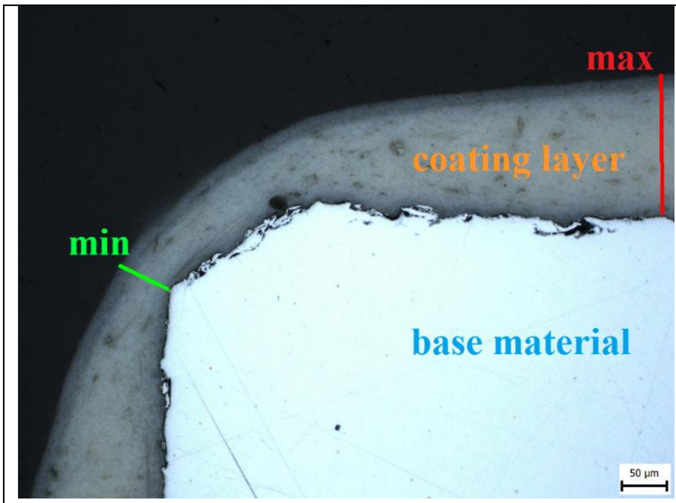


Fig. 4 – 1A_1 sharp edge, organic coating

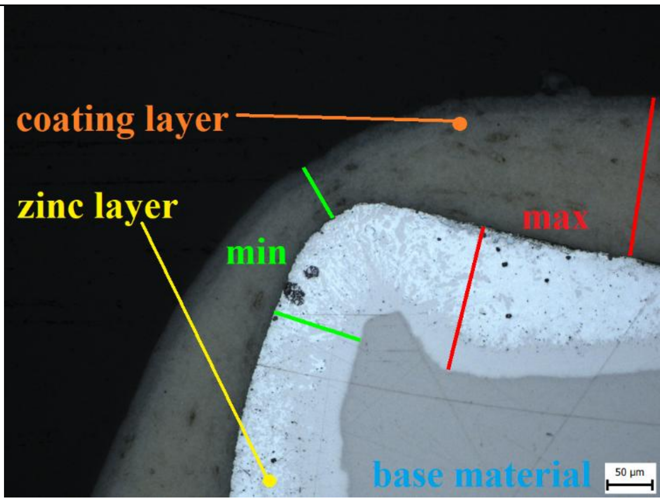


Fig. 5 – 4A_1 sharp edge, duplex system

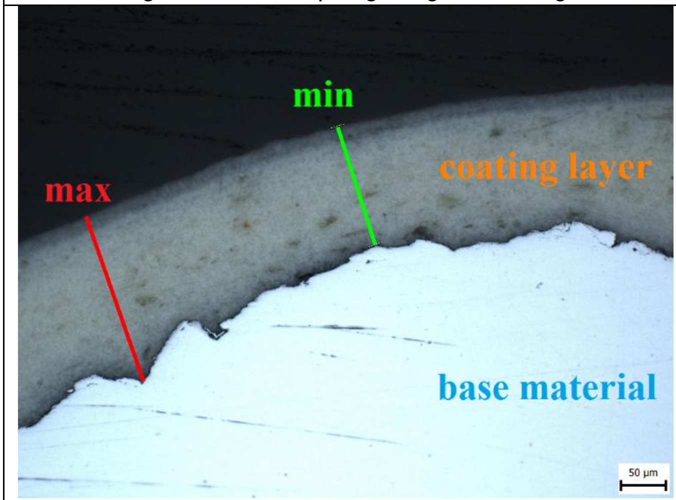


Fig. 6 – 2A_3 rounded edge, organic coating

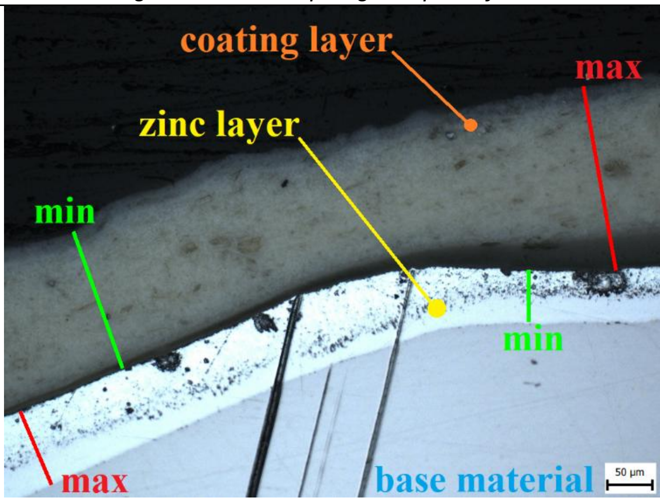


Fig. 7 – 5A_2 rounded edge, duplex system

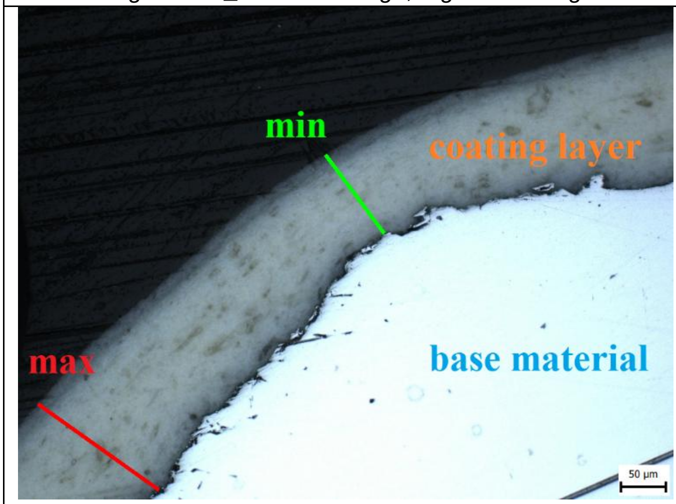


Fig. 8 – 3A_3 chamferred edge, organic coating

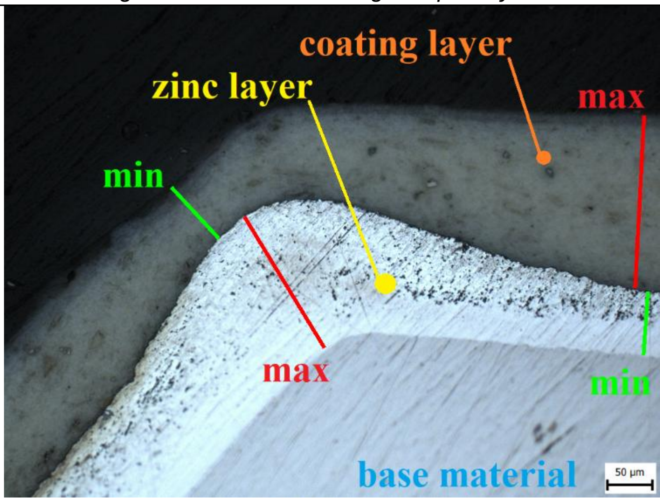


Fig. 9 – 6A_1 chamferred edge, duplex system

4 SUMMARY

The results of the experiments presented in this paper show how significant the effect of the edge treatment has on the thickness of the paint system. The paint thickness was reduced by up to 50 % on untreated sharp edges. According to the overall comparison, the samples with rounded edges stood the best (in terms of thickness). The major differences in thickness values throughout the surface may lead to spots more prone to start the corrosion (thinner vs. thicker barrier of the paint system).

Up to 80% of all damage to paint systems can be attributed to insufficient surface preparation and treatment of edges, welds and surface defects. The result is rusting or peeling of the paint system on critical surfaces of the structure. Repairing these defects entails significant financial costs, which can be higher than the cost spent on surface preparation. Therefore, it is very important that great emphasis is placed on these areas of the structure and that such technological and construction steps are taken that delay or, ideally, prevent damage to the paint system.

Another very important finding of the paper is that the loss of thickness at the edges reduces the service life of the paint system in a corrosive environment. We should not forget that material finishes always come at the end of the technological process, but they are the 1st to be "seen" and the first to be claimed.

5 ACKNOWLEDGMENTS

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