THE PROBLEM WITH THE ZINC COATING DIVERSIFICATION OF THE HOT-DIP GALVANIZED STEEL

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Abstract:

In industrial practice on various production stages of the fittings for overhead power line, there are many factors that cause the zinc coating thickness diversification, that in the next step determine its corrosion resistance. This effect is observed especially in the thermal cutting process. The changes in the structure of the cut material influence the structure and properties of zinc coatings.

The paper presents the results of investigation regarding the typical production process of fittings for overhead power lines (double-eye links). The research was conducted on the link's flat surface (after rolling) and the side surface (after oxy-acteylene blowpipe cutting). The zinc coatings thickness and structure diversification were evaluated on the basis of metallographic analysis and corrosion tests (according to EN ISO 9227).

It has been proved that the existence of HAZ in the oxy-acetylene cutting material and, as a consequence, bigger hardness have an impact on the diffusion pace on the edge of steel/coating, and on the processes of substrate melting which assist zinc coating growth.

Keywords: oxy-acetylene blowpipe cutting, heat affected zone, zinc coating, hot-dip zinc galvanizing

1. INTRODUCTION

The economic losses caused by corrosion, increase the cost of production and exploitation of steel constructions to a large extent. The selection of technological operation and corrosion protection methods is often determined by the amount of financial resources to be invested. The selection of a cutting method depends on many factors of the production process. The economic factor together with the quality are of great importance, especially in high-volume production. However, considering minimizing the negative influence on the quality metallic coatings it is also important.

Oxyacetylene blowpipe cutting (OAB) belongs to one of the most popular and economic methods of elements formation. This process consists in dividing the material by local burning of its particles by use of the stream of pure oxygen, and simultaneously heating the metal to a suitable temperature [1]. The lowest temperature in which the combustion process may occur is the ignition temperature of steel. For pure iron it equals 1050 ^{o}C, however for steel with the addition of 1,5% of carbon equals 1380 ^{o}C. The item being cut along the cutting line has to be heated intensively throughout the process [1]. Liquid oxides blown successively out of the developing crevice are the combustion products. The steel surface after thermal cutting is always covered by a metal layer, which underwent in uncontrollable way through all phase changes - from ferritic structure to austenite and the other way round. The applied method determines, among others, the outer layer structure and properties, which are related to the Heat Affected Zone (HAZ) appearance [2].

The changes in the structure of treated material have an impact on the composition and properties of coating applied by hot dip galvanizing [3-5]. It may cause difficulties with achieving the required thickness and adhesiveness of zinc coatings. It determines their resistance and the period of their exploitation. In practice the problem of zinc coatings quality is significant, especially taking into consideration the corrosion protection of network equipment elements used in electrical overhead power lines.

EN ISO 14713-2 standard indicates the problem of achieving, in the zone of thermal cutting, the required thickness and adhesiveness of the coating to the surface. Practically, we achieve coatings of the thickness not exceeding 100 µm in thermally cut surfaces, while on the remaining element part, the thickness of zinc coating is from 2 to 6 times higher [3,4,6].

Diversification of zinc coating thickness is considered as a failure and it lowers the product quality. Due to the fact that fittings for overhead power lines are used in a corrosive environment of varying aggressiveness, it is important to try to reduce described difficulties basing upon the action modifying the forming process. Using the products which are invalid with the standards (e.g. EN 61284), or which quality does not meet the requirements may lead to disastrous consequences.

The aim of research was the indication of the causes of a difference in thickness of the zinc coating on the surface shaped by OAB cutting.

2. TESTED MATERIAL

The study was conducted on links commonly used to connect fitting elements on insulator strings. The products are part of so called double tension insulator strings, installed on the superstructure of electric power lines. Double tension insulator string is presented in Figure 1 a. The research was focused on a double eye link type SLINK 626502006 (Fig. 1 b) made of S355JR steel.

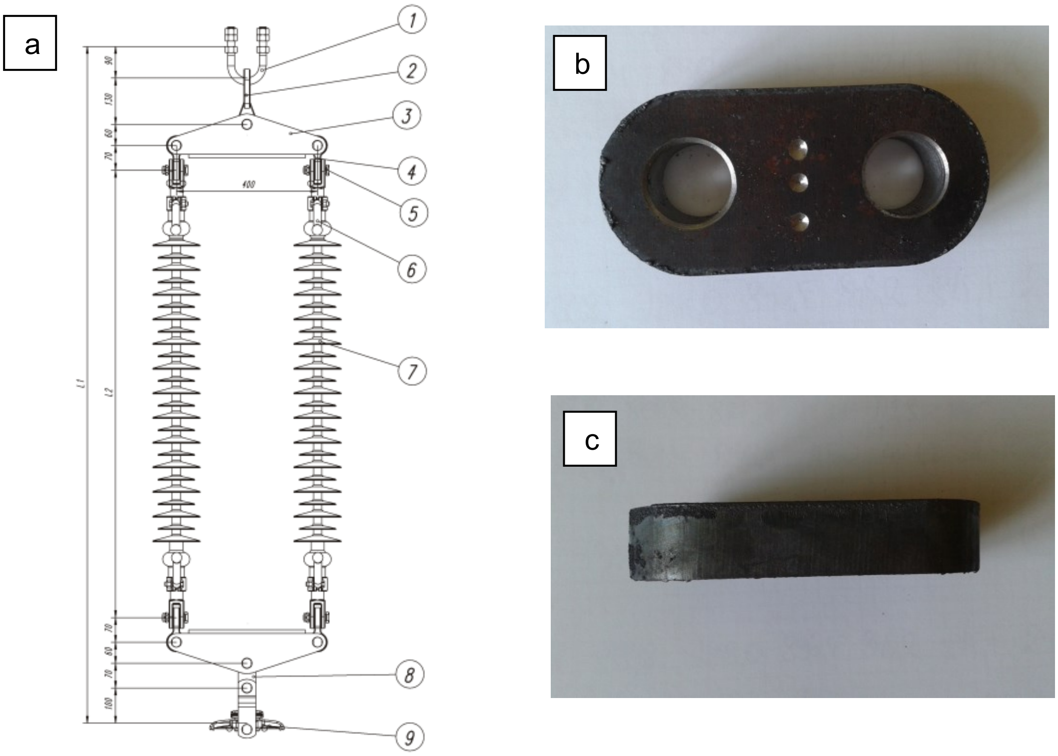

Fig. 1 Fittings for overhead power line: a - double tension insulator string (ŁO2 110kV) *1 - hinge U-bolt type, 2 - double eye link, 3 - yoke triangular, 4 - double eye link twisted, 5 - bolt, 6 - arcing horns, 7 - insulator,* ***8 - double eye link type SLINK****, 9 - suspension clamp, L1, L2 - dimensions depends of the length of the insulator*; b - the flat surface of link type SLINK, c - the side surface of link type SLINK

Chemical composition of material used in experiment was as follows: 0,18 %C; 0,23% Si; 1,5 %Mn; 0,012 %P; 0,008 %S; 0,030 %Cu. Carbon and sulphur were determined using LECO CS-125 analyzer. Other elements were analyzed on the ICP-OES spectrometer.

Links were cut from steel sheet with a thickness of 20mm by oxy-acetylene blowpipe (OAB) - CNC 500 MESSER cutter (temp. 1200 ^{o}C, v=400 mm/min).

Then the prepared materials were subjected to an abrasive blasting - steel shot GL40. The holes (d = 21 mm [+0,5]) were drilled and chamfered in tested materials. In the next stage links were treated chemically: pickling (hydrochloric acid 12 %, Fe contents 30 g/dm^3, pickling time t = 600 s), rinsing in cold water, fluxing (TIBFLUX60 - pH 4,9, Fe contents: 0,17 g/dm^3, fluxing time t = 180 s).

Hot-dip Zn galvanizing process was made in industrial conditions in temperature: 457 ^{o}C and time t=150 s in Zn bath enriched in: nickel, bismuth and aluminum. The bath chemical composition was as follows: 99,859 %Zn, 0,0481 %Ni, 0,0417 %Bi, 0,0002 %Al, 0,037 %Fe, 0,0058 %Pb, 0,0014 %Sn, 0,0067 %Cu, 0,0006 %Cd.

3. METHOD OF INVESTIGATION AND RESULTS ANALYSIS

3.1. Roughness and surface topography

Perthometer Concept (MAHR), with 3D equipment and software, was used to measure surface roughness and topography. The surface roughness was described according to EN ISO 4287 and EN ISO 13565-2 standards [8,9]. The surface roughness measurement was made on the flat surface (after rolling) and on the side surface (after OAB cutting). It was made before and after shot-blasting. The results of surface topography are shown in Figure 2. The average values of presented parameters to describe Ra, Rp and Rv may be analyzed in Table 1, where Ra - it is an arithmetic mean of profile ordinates, Rp - height of highest peak of the profile, Rv - depth of the lowest valley of the profile.

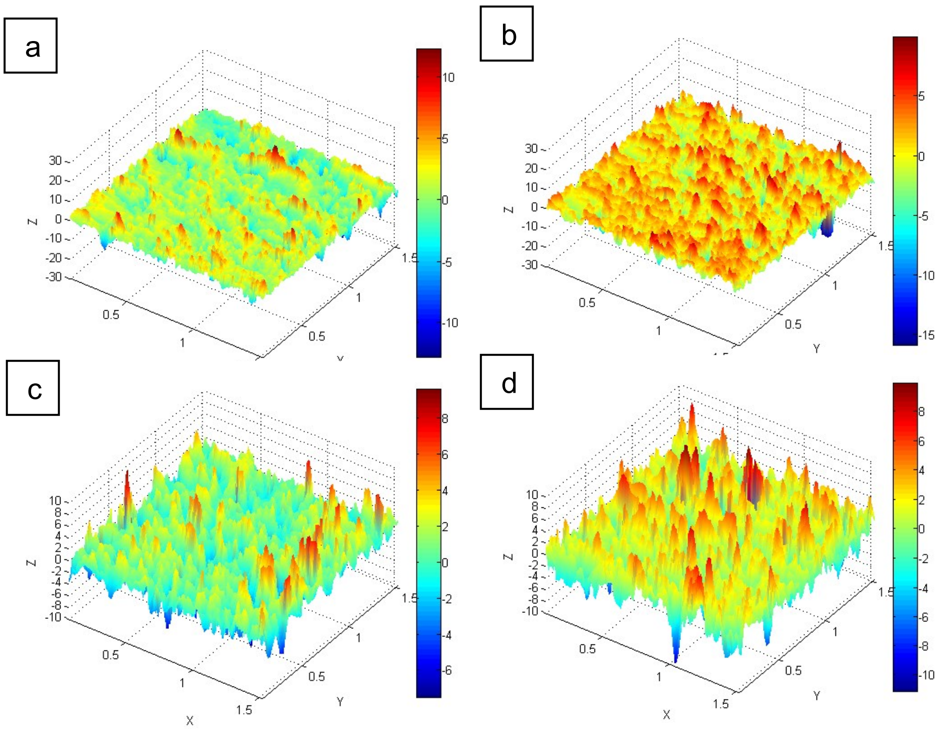

Fig. 2 Surface topography of links: a,b - the flat surface (after rolling), c,d - the side surface (after cutting); a, c - before shot-blasting, b, d - after shot-blasting

Table 1 The average values of the basic parameters of roughness (acc. Fig. 2)

Roughness parameters	The flat surface of link (crude- after rolling)		The side surface of link (after OAB cutting)	
	Before shot-blasting	After shot-blasting	Before shot-blasting	After shot-blasting
Ra [µm]	1,42	2,44	5,31	5,72
Rv [µm]	10,38	14,66	16,20	11,12
Rp [µm]	9,85	9,84	14,59	9,88

3.2 Hardness measurement

The hardness measurement was carried out using Vicker's method according to EN ISO 6507 [10]. The examination was divided in two stages.

In the first stage the hardness (HV10) of flat and side surface was measured. The measurement was conducted perpendicularly to cutting plan. The average values from a dozen places of the measurement were as follows: on the flat surface - **155 HV10**, on the side surface - **356 HV10**.

In the second stage the hardness measurement (HV0,5) was carried out starting from the cutting edge toward the sample core. The step of the measurement was established for 200 µm. The microhardness measurement results are presented in Figure 3.

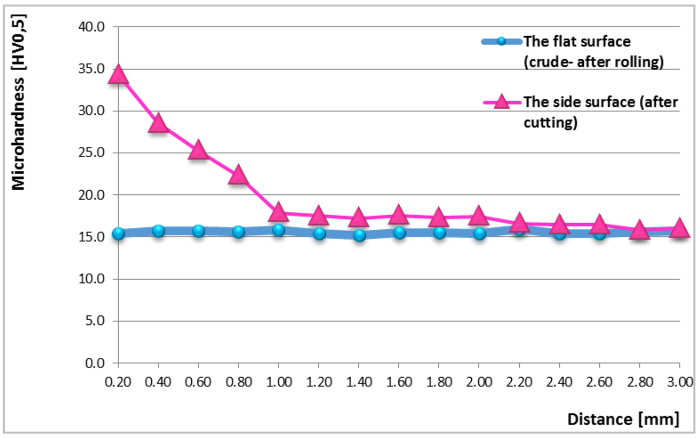

Fig. 3 Results of hardness measurement (HV0,5) on the flat and side surfaces of link in direction from cutting edge to the sample core

3.3 Metallographic and X-ray analysis

Metallographic examinations for samples after cutting and hot-dip zinc galvanizing were carried out. Metallographic specimens were prepared in classic way. The surface was etched with 4% HNO_3. To microscopic observation the microscope AxioImager M1m Carl Zeiss was used with magnification: 50, 100, 200 and 1000x. The results of selected observation are presented in Figure 4.

In order to fully identify the particular phases occurring in the surface layer after OAB cutting, an examination by scanning microscope PHILIPS XL30 with X-ray analyzer was conducted. The cross section of the steel structure observed after OAB cutting before shot-blasting and hot dip zinc galvanizing is shown in Figure 5 a, together with typical EDS graph of the oxides layer generated by thermal impact (Fig. 5 b).

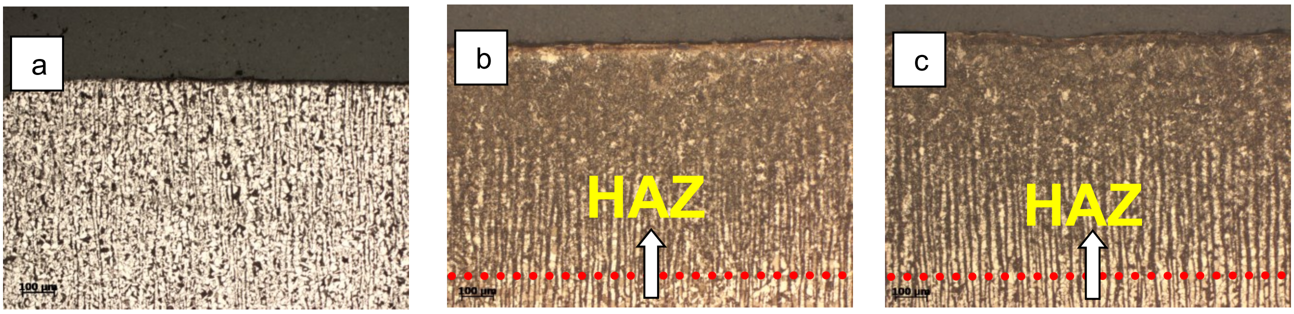

Fig. 4 The S355JR steel structure: a - the flat surface (rolled), b - the side surface (after OAB cutting) , c - the side surface (after OAB cutting) and shot-blasting

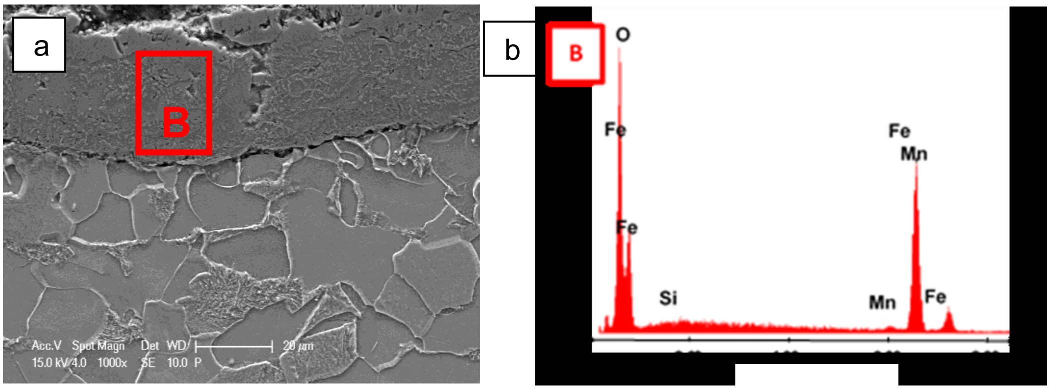

Fig. 5 The analysis of selected micro area in the surface layer after OAB cutting: a - the place of examination, b - EDS graph in micro area B

Metallographic examination were made for link after hot dip galvanizing and also confirms the diversification of zinc coating thickness and its structure. The measurement of Zn coating thickness was made for all samples after galvanizing. The average values from a dozen places of the measurement on flat and side surfaces are **158 µm** (Fig. 6 a) and **59 µm** (Fig. 6 b).

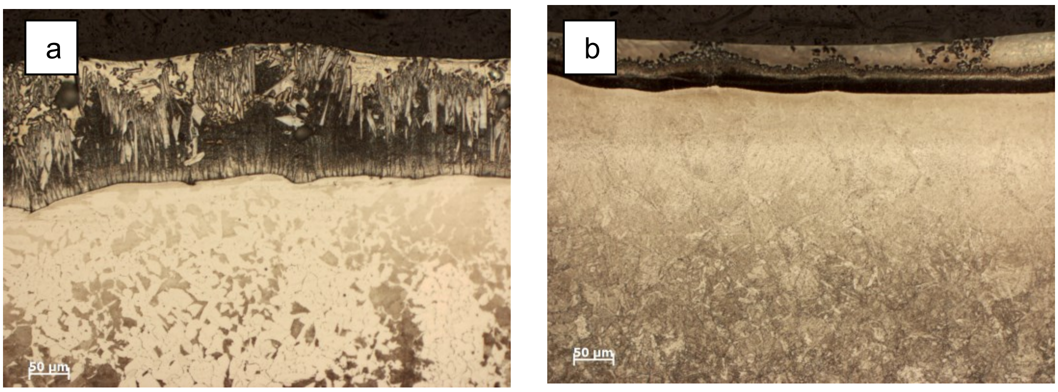

Fig. 6 The zinc coating structure: a - on the flat surface of link, b - on the side link surfaces of link

X-ray analysis was executed in order to determine chemical composition of zinc coatings. Research of chemical composition was carried out in selected cross-sections of samples with zinc coatings that were stated as representative samples. The measure step was 10 µm. Intermetallic phases distribution was determined at the coating cross section.

The cross section of the zinc coating structure on the flat surface of link is shown in Figure 7 a, together Zn distribution at the cross section of the coating (Fig. 7 b). The cross section of the zinc coating structure on the side surface of link is shown in Figure 7 c together Zn distribution at the cross section of the coating (Fig. 7 d).

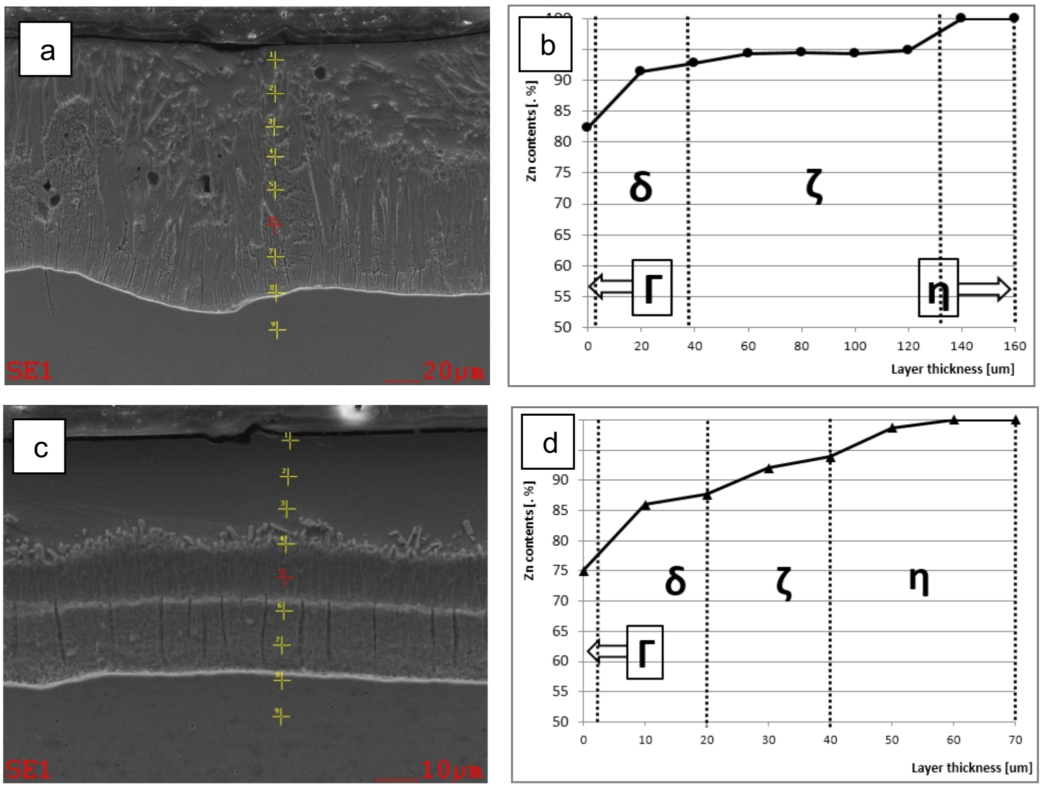

Fig. 6 The microstructure and Zn distribution at the cross section of the coating created on link: a, b - flat surface; c, d - side surface;

3.4 Corrosion test in neutral salt fog (spray)

The NSS test was conducted according to the requirements of EN ISO 9227 standard [11]. The following process parameters were applied: 5 % NaCl; pH 6,7 - 6,9; temperature 35 °C; salt fog fall 1,6 ml/h. The results of NSS test after 840 h in salt chamber were as follows: time to white corrosion appearance (time to red corrosion appearance): flat surface - **24 h (840 h)**; side surface - **24 h (408 h)**.

4. RESULTS DISCUSSION

Although the OAB cutting belongs to the cheapest methods of steel elements forming, in some cases, i.e. when the hot-dip zinc galvanizing is applied, this method can cause serious, difficult to avoid problems - diversification of zinc coating growth dependent on the base steel surface condition.

The structure of the material in the initial state was a little bit anisotropic, mainly ferritic with small amount of perlitic. Figure 4 a presents a dark perlite area and a light ferrite area. In the observed HAZ zone the needle shape structure appeared - lower bainite, martensite (Fig. 4 b, c) created as a result of undesirable quenching treatment caused by cutting. The HAZ area boundary is running parallel to cut edge. Its width in the analyzed area amounts to about 800 µm. After OAB cutting it is necessary to use mechanical treatment -

shot-blasting in order to remove scale, which has an influence on the surface roughness. In this case, a layer of about 30 μm scale (Fig. 5) was removed. Roughness observed on the examined surface resulted from the steel shot used during the treatment before galvanizing. The more stress steel surface after shot-blasting than after OAB cutting is presented in Figure 4 c.

It has been observed that the abrasive blasting method - shot-blasting which was carried out in order to clean the surface before hot dip galvanizing is insufficient for a surface after OAB cutting. Zn coating thickness diversification on the flat surface and side surface is unacceptable. Shot-blasting may probably eliminate the lack of coating adhesiveness to the substrate. In this study no problems with this phenomenon occurred.

The zinc coating structure diversification. The Zn coating put on the flat surface (after rolling) reveals typical structure for this grade of steel - composed of phases: Γ, δ, ζ and η (Zn) (Fig. 6 a). Layers created by iron diffusion (δ+ζ) occupy the greater part of the coating thickness (135μm - 84% of total thickness). The coating growth was not disturbed/hindered by the heat affection results of cutting (there is no HAZ) and the application of shot-blasting before galvanizing additionally supported proper process course. In case of Zn coating created on the side surface (after OAB cutting) the observed structure is quite different: the alloyed area is much thinner (40μm - 57% of total thickness) - the rest is occupied by pure zinc.

The differentiation of corrosion resistance measured during the NSS test on the rolled surface and side surface is closely related to the structure of the zinc coating. It was stated that so-called "white corrosion/rust" appears on all samples after 24 h. The time of red rust appearance on the flat surface of link is twice as long as the surface after cutting.

5. CONCLUSION

The reduced iron diffusion rate to Zn coating on the cut side surface is probably the reason of both thickness of the entire coating and its individual sublayers diversification due to the reduction of the solubility of the steel basis resulting from the creation of HAZ zone. The insufficient cleaning of the steel surface after OAB - remaining oxide layers can also create the barrier hindering the diffusion process.

The problem with Zn coating diversification may be solved in two ways:

- using different cutting methods (laser and water-jet cutting)- thanks to that eliminating OAB cutting from the production of difficult fittings or
- using an additional treatment after OAB cutting for example normalizing annealing or grinding.

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