THE INFLUENCE OF ADDITIONAL PROCESSING AFTER OXY-ACETYLENE CUTTING ON THE STRUCTURE AND CORROSION RESISTANCE OF THE ZINC COATING

Sylwia WĘGRZYNKIEWICZ[a], Dariusz JĘDRZEJCZYK[b], Ilona SZŁAPA[c], MaciejHAJDUGA[b]

[a] BELOS-PLP S.A., Bielsko- Biala, Poland, EU, Sylwia.Wegrzynkiewicz@belos-plp.com.pl
[b] University of Bielsko-Biala, Bielsko- Biala, Poland, EU,
djedrzejczyk@ath.bielsko.pl, mhajduga@ath.bielsko.pl
[c] BISPOL S.A., Bielsko- Biala, Poland, EU, iszlapa@bispol.com.pl

Abstract

Paper presents the results of investigation regarding the influence of additional processing after oxy-acetylene cutting on the structure and corrosion resistance of the zinc coating. Research was focused on fittings for overhead power lines - a double eyes links type SLINK. Additional processing were used after oxy-acetylene cutting: softening annealing, grinding and electro-polishing. Then, prepared materials were subjected to an abrasive blasting - steel shot GL40 and chemical treatment - pickling (hydrochloric acid) and fluxing (TIBFLUX60). The hot - dip Zn galvanizing process was conducted in industrial conditions. Parameters were fixed: temperature 457 ^{o}C, dipping time 2,5 min. It was found out that the hot-dip zinc coating on the softening annealing surface demonstrates the best corrosion resistance.

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

1. INTRODUCTION

The corrosion process has become a problem of worldwide significance that has serious consequences especially in industrial applications. The most popular method of overhead power lines elements anti-corrosion protection is the hot-dip zinc galvanizing. Also in this case there are many factors that cause the zinc coating thickness variations that in the next step determine its corrosion resistance. The heterogeneity of the coating thickness is also regarded as a defect and reduces the quality of the final product [1]. Changes in the structure of the work piece influence on the structure and properties of the zinc coatings created by hot-dip galvanizing. This effect is observed especially in the thermal cutting process.

Depending on the applied method the cutting process is an effect of metal oxidation in a formed gap and the oxides being blown out or else metal melting and liquid fraction evaporation or removal by the gas jet [2]. The thermal impact of beam changes the properties of the surface layer. The presence of heat affected zone (HAZ) interferes with zinc coating growth on steel [3-5]. At higher carbon contents in the steel the bainitic and martensitic structure is observed that results in hardening of the cut surface. The martensitic structures are formed as a result of rapid changes in temperature. The bainitic structures visible in the material are created by supercooling of austenite [5-7]. This decreases the rate of diffusion on the steel / coating boundary, which influence on the zinc coating thickness variation [1,4,5,7], and in the process affects the corrosion resistance.

To analyse of the zinc-coating structure created on steel, the basis is the Fe-Zn phase equilibrium diagram [8, 9]. Generally, it was proved, that the zinc coating has a complex structure. Phases Fe-Zn reduces the corrosion rate and it's intensity during process progress. This is one of the most important advantages of the hot-dip zinc coatings in corrosive environments. Chemical composition of steel intensively affects mainly the nature of δ_1 and ζ layers [10-12].

Proper surface preparation (formed by thermal cutting) before hot-dip zinc galvanizing is necessary and complex process. Difficulties in achieving the required thickness and adhesion on the steel surface forming by oxy acetylene blowpipe (OAB) cutting as well as very large differences in the thickness of coatings on the flat surfaces and the side surfaces caused this study initiation. Due to the presence of the heat-affected zone very often the final machining or grinding is recommended [7]. Continuing the previous investigation [1, 4] authors decided to evaluate the effect of softening annealing, grinding and electro polishing upon the kinetics of growth of the zinc coating.

2. TESTED MATERIAL

The study was conducted on links commonly used in fittings - made of S355JR steel. Research was focused on a double eyes link type SLINK 626502006. 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, υ=400 mm/min). Three series of samples were prepared - the main difference between analyzed series was a method of the additional treatment conducted after material cutting. The labeling way of materials for testing is shown in **Table 1**.

Table 1 Characteristic of the tested material

Group	Kind of additional treatment after oxy-fuel cutting	Treatment parameters
A	GRINDING	Grinding Shotblasting (steel shot GL-40) Pickling (HCl, 12 %) Fluxing (TIBFLUX 60)
B	ELECTROPOLISHING	Alkaline degreasing (temp. 60 ^{o}C), Pickling (H_2SO_4 10 % and HCl 18 %) Electropolishing (alkaline degreasing 60 ^{o}C). Fluxing (TIBFLUX 60)
C	SOFTENING ANNEALING	Softening annealing in temp. 920 ^{o}C Shotblasting (steel shot GL-40) Pickling (HCl, 12 %) Fluxing (TIBFLUX 60)

2.2 Hot-dip Zn galvanizing

Hot-dip Zn galvanizing process was made in industrial conditions in temperature: 457 ^{o}C and time t=2.5 min in Zn bath enriched in: nickel, bismuth and aluminum. The bath chemical composition was as follows: 99.846 %Zn, 0.0531 %Ni, 0.0486 %Bi, 0.0002 %Al, 0.039 %Fe, 0.0048 %Pb, 0.0018 %Sn, 0.0059 %Cu, 0.0004 %Cd. During the coating of all elements the special attention was paid to maximum repetitiveness of technological parameters of galvanizing process.

3. METHOD OF INVESTIGATION AND RESULTS ANALYSIS

3.1. Hardness measurement

The hardness measurement was carried out using Vicker's method according to PN - EN ISO 6507 - 2007 [13]. The examination was divided in two stages. In the first stage the hardness (HV10) of side link SLINK surface after cutting was measured. The measurement was made perpendicularly to cutting plane. The average values from a dozen places of the measurement were as follows: A - 329 HV10, B - 299 HV10 and C

- 158 HV10. In the second stage the hardness measurement (HV0.5) was made starting from the cutting edge toward the sample core. The step of the measurement was established on 200 μm. Results are presented in **Fig. 1**.

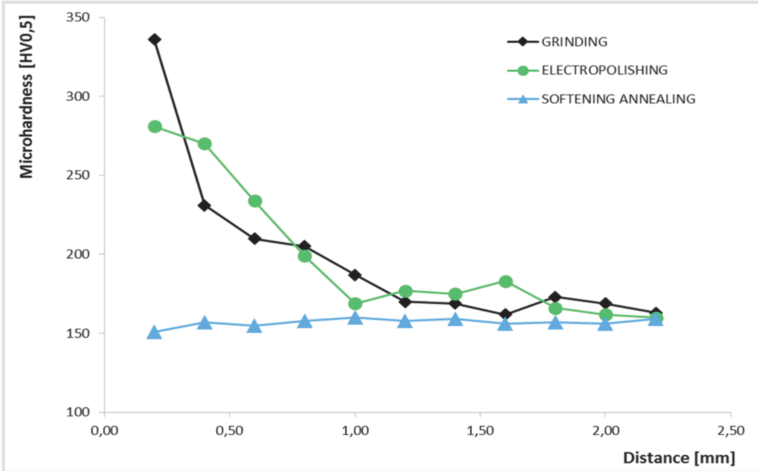

Fig. 1 Results of hardness measurement (HV0,5) on the side surface of links in direction from cutting edge to the sample core

3.2 Metallographic analysis

Metallographic examinations was made for all samples after cutting and hot-dip zinc galvanizing 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. Chosen results of observation - the structure of base material and Zn coatings are presented in **Fig. 2 and 3**. The measurement of Zn coating thickness was made for all samples after galvanizing. Results measured in several places on flat and side surfaces are put together in **Table 2**.

Table 2 Results of Zn coating thickness measurement

Group	Method of cutting	The average coating thickness on the flat surface [μm]	The average coating thickness on side surface
A	GRINDING	**144**	**66**
B	ELECTROPOLISHING	**140**	**68**
C	SOFTENING ANNEALING	**146**	**134**

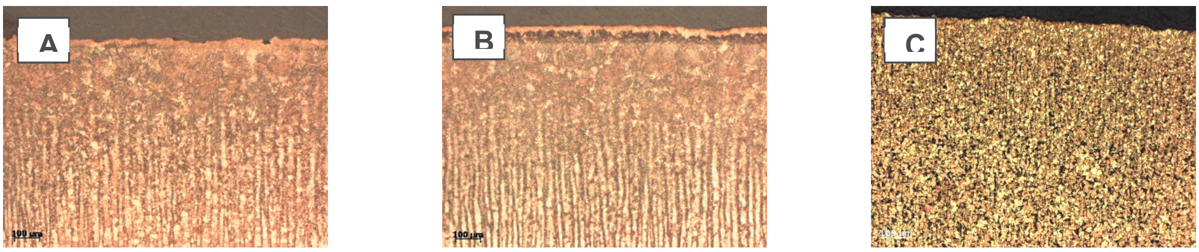

Fig. 2 The steel structure after cutting with visible subsurface layer, magnification 100 (HAZ) (A- grinding, B- electropolishing, C- softening annealing)

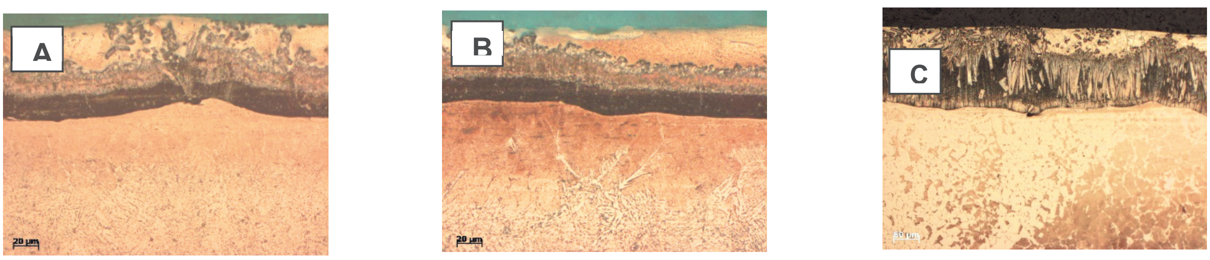

Fig. 3 The zinc coating structure on the side links surfaces, magnification 500 (A,B) and 200 (C) (A- grinding, B- electropolishing, C- softening annealing)

3.3. X-ray analysis

Further examination was made with application of scanning microscope “PHILIPS XL30” equipped with X-ray analyser. Intermetallic phases distribution that was determined at the coating cross section (the measure step was 5-10 μm) is enclosed in **Fig. 4**.

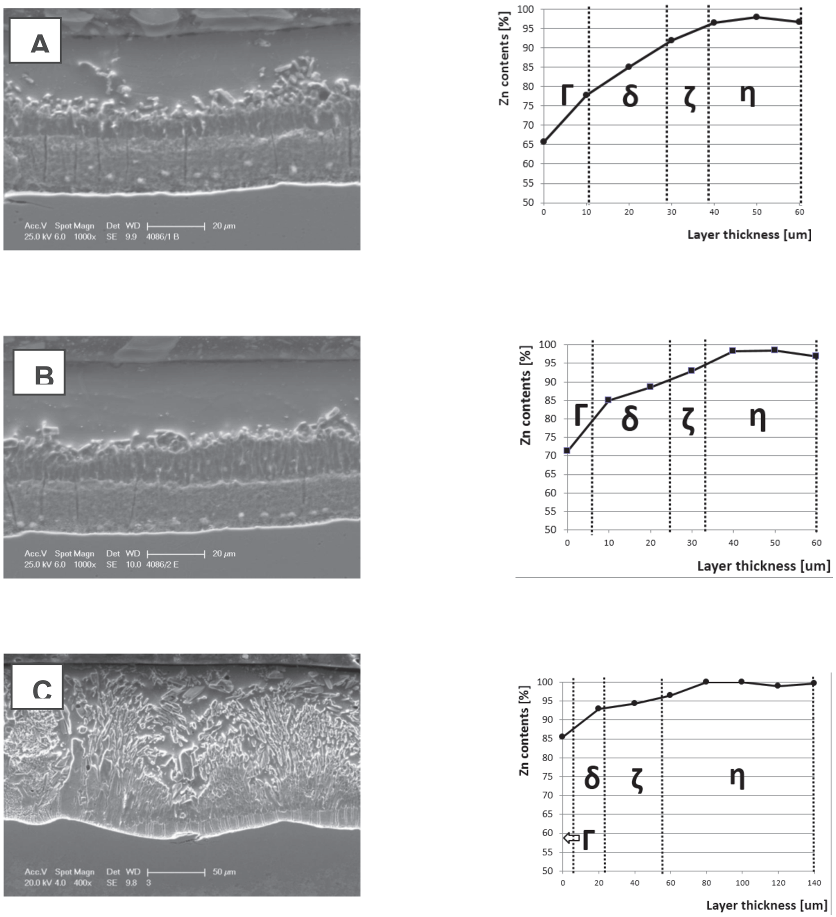

Fig. 4 The Zn coating cross section after OAB cutting and additional treatment and Zn distribution at the coating cross section after OAB cutting and additional treatment (A- grinding, B- electropolishing, C- softening annealing)

3.4. Corrosion test in neutral salt fog (spray)

The corrosion tests in salt chamber were made in F.Ś. BISPOL S.A. in Bielsku - Białej. The NSS test was conducted according the requirements of PN-EN ISO 9227:2012 standard [14]. The following process parameters were applied: 5 % NaCl; pH 6.7 - 6.9; temperature 35 ^{o}C; salt fog fall 1.6 ml/h. The results of NSS test after 640 h in salt chamber were as follows: time to white corrosion appearance (time to red corrosion appearance): grinding - 24 h (312 h); electropolishing - 24 h (264 h); softening annealing - 24 h (576 h).

4. RESULTS DISCUSSION

No prescriptions either recommendations had been found for galvanizing plants in the literature, both constructional and technological which would suggest that the way of reaching the required coating quality with uniform thickness created on components, which surfaces were shaped by various methods - also by thermal cutting. Authors of a many works indicate in the general way the need to apply additional treatment after the cutting (heat treatment or the grinding).

The reason of presented investigation was considerable diversification of the zinc coating thickness (reaching the 300%) put in industrial conditions on surfaces of steel elements which were shaped with various methods: rolling and the thermal cut. Examined elements - material in initial stage showed the ferritic-pearlitic structure. As a result of the heat treatment caused by cutting in the surface steel layer the heat affected zone (HAZ) is observed - samples A and B - the needle structure appeared - lower bainite, martensite. The size of the heat affected zone in surface layer of samples A and B was determined basing on typical changes in the steel structure. Boundary of HAZ in both cases is distinct (**Fig. 2**) and is running parallel to the cut edge.

Metallographic analysis and the hardness measurements confirmed that the hardness increase after application of thermal cutting methods is totally reasonable. The initial hardness of S355JR steel was about 155 HV10. The research shows that cutting with OAB results in hardness increase to the level of 352 HV10 (**Fig. 1**). Application of softening annealing causes hardness reduction to the level 157HV10, however in case of other tested methods the hardness is equal correspondingly to A- 329 HV10 and C- 299 HV10.

The coating thickness on flat surfaces (crude - after rolling) of all tested links was stable and amounted to about 140 μm (Tab. 2). Thickness measurement of the sample C coating - on the side surface cut with OAB revealed value similar to the average measured on the flat surface. In samples A and B, on side surfaces significant deviation of coating thickness from average value for flat/rolled surface was stated. Differences amount in this case from 72 up to 78 μm (total coating thickness is about 140 μm) (Tab. 2).

HAZ existing in the material cut with OAB - changes the steel structure (martensitic - bainitic structure), and in consequence the higher hardness influence on diffusion rate at the steel/coating boundary and base dissolving processes accompanying of the zinc-coating growth. At the Zn coating cross section created on the surface A and B fundamentally three phases are visible (η, ζ, δ) - phase Γ is very thin and difficult for the identification at the measuring step equal to 5-10 μm. In both cases thickness of alloyed layer is about 60% of the total Zn coating thickness. Coating growth on the surface C was realized on typical for S355JR steel ferritic-pearlitic structure (restored to original condition by heat treatment). So, the coating in this case has greater thickness, and phases δ and ζ are dominating in the structure (**Fig. 3** and 4).

On the basis of the corrosion examinations - the NSS test, it was stated that so-called the "white corrosion" appears on all samples after 24 h. The highest corrosion resistance (time to the appearance of the red corrosion) was measured for the Zn coating on the surface C - 576 h. Time to red corrosion appearance in the case of sample A amounted to 312 h, and for the sample B - 264 h.

CONCLUSIONS

On the basis of above results analysis the following conclusions can be expressed:

1. 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 problems difficult to avoid (diversification of zinc coating growth dependent on the base steel surface condition).
2. The best way to reduce the Zn coating thickness diversification put on steel elements, which surfaces were formed among others with oxyacetylene blowpipe (OAB) cutting, is application of additional heat treatment - softening annealing that removes the heat affected zone (HAZ) created after thermal cut.
3. The application (after OAB cutting) of additional processing: grinding or electro polishing doesn't reduce in the significant way of Zn coating thickness diversification observed on the cut surface in comparison to rolled one.
4. There is direct relation between Zn coating thickness diversification and corrosion resistance of galvanized elements. Time to the appearance of the red corrosion in the environment of the 5%NaCl, on galvanized elements after the additional heat treatment is almost twice longer than on samples galvanized after the additional grinding or electro polishing.

REFERENCES:

[1] WĘGRZYNKIEWICZ, S., JĘDRZEJCZYK, D., SOŁEK, D., SZŁAPA, I., „Wpływ metody cięcia stali S355JR na strukturę i odporność korozyjną powłoki cynkowej," Ochrona przed korozją , nr 5, pp. 191 - 195 , 5 2013.

[2] KLIMPEL, A., Spawanie, zgrzewanie i cięcie metali. Technologie., Warszawa: Wydawnictwa Naukowo-Techniczne, 1999.

[3] THEIBAUD, R., DREZET, J., LEBET, J.P., Experimental and numerical characterisation of heat flow duringflame cutting of thick steel plates, Journal of Materials Processing Technology, 214, pp. 304 - 310, 2014.

[4] WĘGRZYNKIEWICZ, S., JĘDRZEJCZYK, D., SZŁAPA, I., SOŁEK, D., HAJDUGA, M., BOCZKAL, S., Struktura i odporność korozyjna powłok cynkowych na powierzchniach stalowych ciętych różnymi metodami, Inżynieria Powierzchni , nr 3, pp. 61 - 67 , 2013.

[5] KUKLIK, V., Povlaky žárového zinku na pálených plochach, 17 konference zaroveho zinkovani, Ostrava, Czech Republic, 2011.

[6] BONEK, M., Struktura i właściwości warstw wierzchnich uzyskanych w wyniku obróbki laserowej stali narzedziowej stpowej do pracy na gorąco, Gliwice : Biblioteka Główna Politechniki Śląskiej, 2003.

[7] SCHULTZ, W., THIELE, M., Cynkowanie ogniowe jednoskowe. Materiał - Technologia - Powstawanie powłoki-Właściwości- Błędy, Bad Saulgau: Eugen G. Leuze Verlag KG, 2012.

[8] BURTON, P., PERROT, P., Phase Diagram of Binary Iron Alloys, American Society for Materials, pp. 459-466, 1993.

[9] MASSALSKI, T.B., Binary Alloy Phase Diagrams, ASM International, 1990.

[10] KOPYCIŃSKI, D., GUZIK, E., Oddziaływanie składu chemicznego podłoża wyrobów ze stopu Fe-C na powłokę cynkową, Ochrona przed korozją, 3, pp. 82-87, 2011.

[11] KOPYCIŃSKI, D., GUZIK, E., WOŁCZYŃSKI, W., Coating Zn formation during hot dip galvanizing, Inżynieria materiałowa, 4, pp. 289-292, 2008 .

[12] WOŁCZYŃSKI, W., GUZIK, E., KOPYCINSKI, D., OKANE, T., SENDEROWSKI, C., Reactions at a solid / liquid interface during formation of the intermetallic multilayer, Inzynieria materiałowa, 3-4, pp. 745-748, 2007.

[13] PN-EN ISO 6507-1:2007 Metale - Pomiar twardości sposobem Vickersa - Część 1: Metoda badań

[14] PN-EN ISO 9227:2012 - Badania korozyjne w sztucznych atmosferach - Badania w rozpylonej solance