THE INFLUENCE OF SIDE SURFACE OF THE SLINK ON THE NATURE AND CORROSION RESISTANCE OF THE HOT-DIP ZINC COATING

Sylwia WĘGRZYNKIEWICZa, Dariusz JĘDRZEJCZYKb, Dariusz SOŁEKc, Ilona SZŁAPAd, Maciej HAJDUGAb

a BELOS-PLP S.A., Bielsko- Biała, Poland, EU
b AKADEMIA TECHNICZNO- HUMANISTYCZNA, Bielsko- Biała, Poland, EU
c MED. GROUP Sp. z o.o., Zywiec, Poland, EU
d BISPOL S.A. Bielsko- Biała, Poland, EU

Abstract:
Paper presents the results of investigation regarding the influence of the surface state of steel S355JR achieved after different cutting methods 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. In the process of samples cutting the following methods were used: water-jet, laser and flame cutting. 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 °C, dipping time 2,5 min).

The effects were evaluated on the basis of metallographic analysis and corrosion tests (according to PN-EN ISO 9227). It was found out that the hot-dip zinc coating on the water-jet cutting surface demonstrates the best corrosion resistance. The corrosion resistance of the zinc coating on laser cutting surface is better than on flame cutting surface. The flame cutting surface needs additional mechanical (grinding) or electrochemical (electropolishing) processing.

Keywords: laser cutting, water cutting, oxygen cutting, heat affected zone, hot-dip zinc galvanizing

1. INTRODUCTION

The industry use in the wide range the mechanical forming: flame cutting (oxygen plasma), laser, water JET or water-abrasive cutting and electrical discharge. Cutting methods differs in the amount of consumed energy, the impact of heat on the material and the quality of the cutting edge [1, 2].

The applied method influence among others on the structure and properties of outer layer - that depend on the creation of so-called Heat Affected Zone (HAZ). The HAZ thickness depends above all on process temperature and beam concentration, that next influence on puncture thickness and heating rate of the forming material.

The thermal impact of beam results in hardening of layers surrounding the cutting kerfs (even in low-carbon steel) and the quenching of the cut surface of steel with higher carbon content [3].

Changes in the structure of the cut material influence on the structure and properties of zinc coatings. ISO 1461 and ISO 14713 standards indicate a problem with the achievement of required Zn coating thickness and adhesion in the zones close to thermal cutting surface [7, 8].

This problem is also observed in the production of fittings for overhead power lines. In accordance with the requirements of PN-EN 61 284 fittings for overhead power lines made of steel (except stainless steel) are protected by hot-dip galvanizing or otherwise provides similar protection against corrosion [9]. Overhead power lines are an important element in the transmission of electricity over long distances. They connect with the places of generating receipt. Due to, they are carried out by a vast area, subject to various factors: the
climatic, environmental and topographical features. In connection with this extremely important issue is to ensure the sustainability of elements of fittings. Destruction of fittings lowers the stability of the whole product. The lack of resistance due to the progressive corrosion can cause such damage to the structure by pin fall out and off line. This results in very high costs and delays due to interruptions in energy supply [9].

Due to the fact that these products are used in a corrosive environment of varying aggressiveness [9], it is important to try to reduce described difficulties basing upon the action modifying the forming process.

An important factor determining the course of the growth of the zinc coating on iron alloys is the chemical composition of the base. Similarly, as the temperature, the base chemical composition affects the structure and morphology of the phases created inside the coating. Zinc coatings have a complex structure and are composed of diffusive Fe-Zn phases (gamma, delta, zeta) and outer layer – almost pure zinc - η. Layer η provides the necessary resistance of the coating in its initial stage of operation.

Phases Fe-Zn reduces the corrosion rate and intensity during process progress. This is one of the most important advantages of the hot-dip zinc coatings in corrosive environments. Chemical composition intensively affects the nature of δ₁ and ζ layers [10-12].

Difficulties in achieving the required thickness and adhesion on the steel surface forming by flame cutting, very large differences in the thickness of coatings on the flat surfaces and the side surfaces caused this study initiation.

The aim the study is the evaluation the influence of the steel S355JR surface state achieved as a result of different cutting methods on the nature and corrosion resistance of the zinc coating.

2. TESTED MATERIAL

The study was conducted on links commonly used in fittings (Fig. 1) - made of S355JR steel. Research was focused on a double eyes link type SLINK 626502006. Chemical composition of materials used in experiment is presented in Table 1. Carbon and sulphur were determined using LECO CS-125 analyzer. Other elements were analyzed on the ICP-OES spectrometer.

### Table 1 Chemical composition of steel used in the experiment

<table>
<thead>
<tr>
<th>Source of data</th>
<th>Chemical composition [% wg.]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>PN-EN 100025-2004</td>
<td>≤ 0,24</td>
</tr>
<tr>
<td>Chemical analysis</td>
<td>0,18</td>
</tr>
</tbody>
</table>

2.1. Preparation of material for galvanizing

Links (Fig. 1) were cut from steel sheet with a thickness of 20mm. Three series were prepared. The main difference between analyzed series was a method of the material cutting. The cutting stream of water, laser and oxygen were used. Marking materials for testing is shown in Table 2.

![Fig. 1. Tested materials - SLINK](image_url)
Table 2  Characteristic of the tested material

<table>
<thead>
<tr>
<th>Group</th>
<th>Methods of cutting</th>
<th>Cutting tool</th>
<th>Cutting parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Stream water cutting</td>
<td>water</td>
<td>Waterjet –Jet EDGE 40°C, u=82mm/min</td>
</tr>
<tr>
<td>B</td>
<td>Laser cutting</td>
<td>laser</td>
<td>Laser BYSTRONIC - model BYSPEED 3015 power 4kW 1200°C, u =800mm/min</td>
</tr>
<tr>
<td>C</td>
<td>Oxygen cutting</td>
<td>oxygen</td>
<td>CNC 500 MESSER 1200°C, u =400mm/min</td>
</tr>
</tbody>
</table>

After cutting, the prepared materials were subjected to an abrasive blasting – steel shot GL40. In the next stage samples were treated chemically - pickling (hydrochloric acid 12 %, 30 g/l Fe), rinsing in cold water and fluxing (TIBFLUX60 - pH 4,9, 0,17 g/l Fe, 292 g/l ZnCl₂, 189 g/l NH₄Cl).

2.2. Hot-dip Zn galvanizing

Hot-dip Zn galvanizing process was made in industrial conditions in temperature: 457 °C and time t=2,5 min in Zn bath enriched in: nickel, bismuth and aluminium. 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. 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: A - 158,2 HV10, B - 420,7 HV10, C - 364,5 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. 3.

![Fig. 3 Results of hardness measurement (HV0,5) on the side surface of links (1-water cutting, 2- laser cutting, 3- flame cutting) in direction from cutting edge to the sample core](image)

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% HNO₃. To microscopic observation the microscope Axiolmager 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. 4 and 5. 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 3.

### Table 3 Results of Zn coating thickness measurement

<table>
<thead>
<tr>
<th>Group</th>
<th>Method of cutting</th>
<th>The average coating thickness on the flat surface [µm]</th>
<th>The average coating thickness on side surface [µm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Water cutting</td>
<td>159</td>
<td>156</td>
</tr>
<tr>
<td>B</td>
<td>Laser cutting</td>
<td>160</td>
<td>137</td>
</tr>
<tr>
<td>C</td>
<td>Flame cutting</td>
<td>158</td>
<td>57</td>
</tr>
</tbody>
</table>

**Fig. 4** The steel structure after cutting with visible subsurface layer, magnification 100 and 1000x (HAZ) (A - water cutting, B - laser cutting, C - flame cutting)

**Fig. 5** The zinc coating structure on the side links surfaces, magnification 200 (A - water cutting, B - laser cutting, C - flame cutting)

### 3.3. 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 °C; salt fog fall 1,6 ml/h. The results of NSS test after 640 h in salt chamber are presented in Table 4.
Table 4 NSS Test results

<table>
<thead>
<tr>
<th>Group</th>
<th>Cutting method</th>
<th>Time to white corrosion appearance [h]</th>
<th>Time to red corrosion appearance [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water cutting</td>
<td>24</td>
<td>618</td>
</tr>
<tr>
<td>2</td>
<td>Laser cutting</td>
<td>24</td>
<td>552</td>
</tr>
<tr>
<td>3</td>
<td>Flame cutting</td>
<td>24</td>
<td>408</td>
</tr>
</tbody>
</table>

4. RESULTS DISCUSSION AND CONCLUSIONS

In available literature there is no the detailed information describing the influence of the state of the surface created after cutting on the structure and the corrosion resistance of the zinc coating. Only few authors like Kulik V. and Sepper S. analyze this problem but only casually. In practice the problem of the Zn coating quality created on elements of power network of overhead lines is important especially considering the operational lifetime.

The structure of the material in the initial state was ferritic with small amount of pearlite. In the observed HAZ zone created as a result of the heat treatment caused by cutting the needle shape structure appeared - lower bainite, martensite (in the subsurface zone of sample B – fine-needle, C – coarse - needle) (Fig. 4).

The decarburized layer in the sample B is narrow and its thickness amounts to 3 µm. In the subsurface zone of sample C the additional layer can be distinguished being the product of reaction proceeded during flame cutting.

The size of the HAZ in the subsurface layer of sample B and C was determined on the basis of typical changes in the steel structure. The HAZ area boundary in both cases is distinct (Fig. 4) and is running parallel to cut edge. In the case of the flame cutting - sample C - the HAZ thickness amounts to 0.8 – 1.8 mm, whereas in sample B - cut with the laser, HAZ is narrower and its thickness amounts to 1 mm (Fig. 4).

The compared effects results from differences in the maximal values of temperatures gained in the area of cutting when using individual methods.

The metallographic analysis and hardness measurement confirmed that application of thermal methods of cutting results in the hardening of the steel subsurface zone. The hardness of S355JR steel core is on the level - 155 HV10. In case of area A - cut with water, the hardness didn’t change (Fig. 3). The application of the laser beam caused the increase in the hardness to 400 HV10, cutting by gas flame increased the hardness to 350 HV10 (Fig. 3).

The thickness of the coating on flat surfaces of all tested elements - links was stable and amounted to ab. 160 µm (Tab. 3). The measurement of the coating thickness on the side surface of the sample A – cut by water revealed values similar to the average. The greater deviation from the value get on the flat surface was stated for side surfaces in samples B and C. The coating observed on the surface C – cut by gas flame is characterized by a thickness even about 100 µm smaller (Tab. 3) in relation to the flat surface.

The coating on the surface A - after cutting by water reveals typical structure for this grade of steel. Diffusion layer occupies the greater part of the coating thickness. The coating growth was not disturbed by the heat affection during cutting and the application of shot-blasting before galvanizing additionally supported proper process course. In the case of the coating created on the surface B - cut by the laser the alloy coating layer has a much smaller thickness. The planned examinations with application of the X-ray analyzer will enable the more accurate assessment of the mechanism of creation of observed zinc coatings. Investigations confirmed that the abrasive blasting applied after flame cutting - sample C is insufficient.

The results of NSS corrosion test allowed to state that, so called "white corrosion" is observed on all samples after 24h. The corrosion breakdown was observed after 408 h on the surface of sample C, 552 h on sample 2 and 608 h on sample A.

On the basis of investigation results and its discussion the following conclusions can be formulated:
- The corrosion resistance of zinc coating covering the steel S355JR surface shaped by laser cutting is much higher than the corrosive resistance of the coating on the flame cutting surface.
- Cutting the steel S355JR by water does not disturb the hot-dip zinc coating growth and provides very good corrosion resistance.
- The applied abrasive blasting – shot blasting of the flame shaped surface is insufficient. To create proper zinc coating necessary is additional treatment, i.e. grinding or electrolytic degreasing.

LITERATURE

[4] BYLICA, A., ADAMIÁK, S. Laserowe umacnianie stali niestopowych Archiwum Odlewnictwa, 2, 6, 2002 s. 43-54
[9] WĘGRZYNIEWSKI, S., HAJDUGA, M., SOŁEK, D., MASALSKI, J. Wpływ przygotowania powierzchni stali 30MnB4 na strukturę i ciągłość powłoki Zn uzyskanej w procesie cynkowania ogniowego, Ochrona przed korozją, 4-5, 2011, s.181-185