CHARACTERISTICS OF ZN COATING CREATED BY HOT-DIP GALVANIZING ON A WELDED JOINT OF STRUCTURAL STEEL KOSMALT E300T WELDED USING MAG TECHNOLOGY

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Abstract

Hot-dip galvanising is one of the most widely used methods for protecting structural steel against corrosion. This article examines the quality and thickness of the Zn coating on Kosmalt E300T low carbon deep-drawing structural steel Kosmalt E300T MAG-welded. The steel meets the requirement for hot-dip galvanising according to the Sandelin diagram, with a silicon content below the critical amount of 0.03 % wt. In contrast, the welding wire contains a critical amount of 0.9 % wt. silicon, which is unsuitable for hot-dip galvanising. On the basis of this fact and the Sandelin diagram, the Zn coating on the welded joint is expected to have a higher thickness and a different structure compared to the unaffected steel surface. The article evaluates the quality of the Zn coating on the welded joint by adhesion testing and condensation chamber testing. According to the results of the experimental tests, the Zn coating on the welded joint was twice as thick as that on the unaffected steel surface. The Zn coating on the welded joint shows changes in the content of individual phases, good adhesion to the welded joint, and resistance to corrosion.

Keywords: Hot-dip galvanizing, Zn layer, MAG welding, adhesion test, condensation chamber test

1. INTRODUCTION

Steel corrosion is the deterioration of metal due to its electrochemical or chemical reaction with the corrosive environment. Hot dip galvanising is one of the most effective and widely used methods for protecting steel against corrosion [1]. It enables the creation of high-quality coatings, ensuring long-term corrosion protection [2], at relatively low operational costs [3]. These coatings act as a barrier on the steel surface and also protect it as sacrificial anodes. The most commonly hot-dip galvanised material is ferritic or ferritic-pearlitic structural steel of various grades.

The technology of hot dip galvanising steel involves creating an alloy coating of hot zinc on the surface of the steel component at a bath temperature of zinc of 420 – 470 ° C. Galvanising is a complex process that involves diffusion processes, elemental metallurgical reactions, and thermodynamic changes. Hot-dip galvanising of steel parts is standardised in EN ISO 1461 [4] and EN ISO 14713-2 [5].

The quality of the galvanised surface (smoothness, thickness, adhesion, etc.) varies and depends mainly on the chemical composition of the steel, particularly the content of silicon, carbon, sulphur, and phosphorus [6]. According to the Sandelin diagram (**Figure 1**), critical (i.e., unsuitable for hot dip galvanising) is in the range of 0.03% to 0.12% and above 0.25%. These silicon contents result in an increased reactivity of iron with zinc, causing the coating thicknesses of such steels to reach extreme values. Very thick coatings are characterised by reduced adhesion to steel and a high risk of zinc layer delamination.

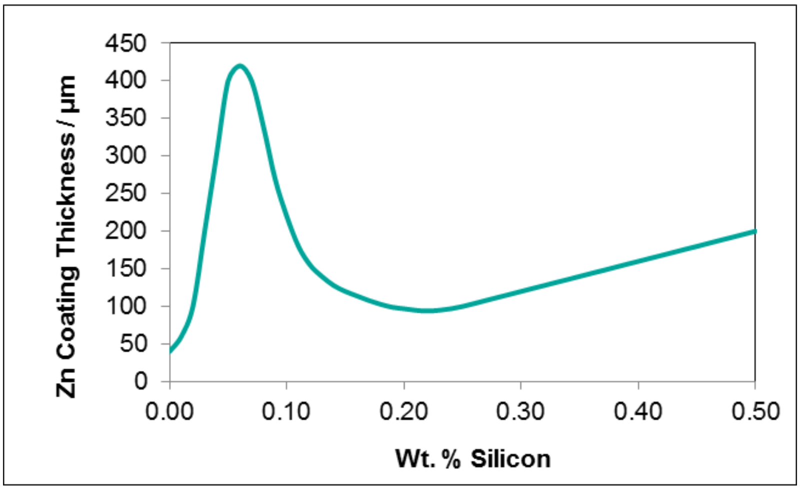

Figure 1 Sandelin diagram [7]

In cases where the base material meets the Sandelin rule and the hot dip galvanising is carried out through a standard process, the hot dip zinc coating consists of four primary phases: η, ζ, δ, and Γ (intermetallic Fe-Zn compounds) (**Figure 2**).

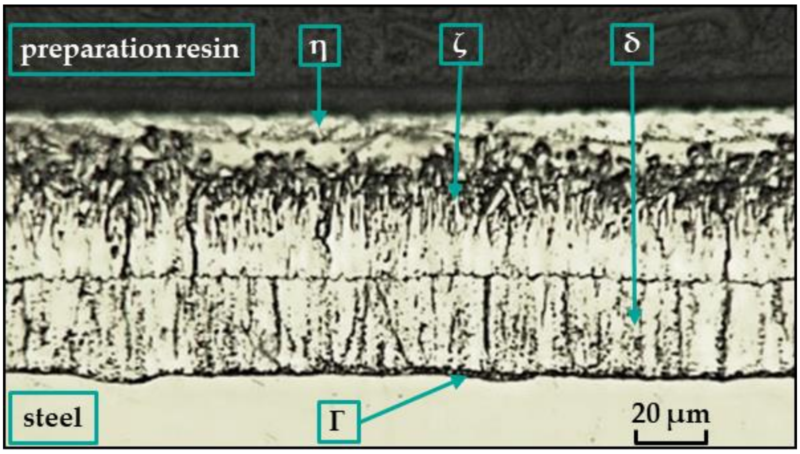

Figure 2 Structure of hot-dip zinc coatings [8]

MAG welding is among the most commonly used methods for joining structural steels. For subsequent hot-dip galvanizing, it would be advantageous to use welding wire with the same chemical composition as the welded material. However, this is usually not feasible in practice. Therefore, the authors of this study aimed to assess the adhesion and corrosion resistance of the Zn coating based on its thickness on the welded joint, where the welding wire used had a different chemical composition than the welded structural steel. The higher silicon content, according to the Sandelin diagram, should lead to the formation of an unsuitable Zn coating.

2. EXPERIMENTAL MATERIAL

For the research, the structural steel designated as Kosmalt E300T was selected. The chemical composition of this steel, determined using an optical emission spectrometer with glow discharge (GDOES) Spectruma Analytik GMBH (model GDA 750) under operating conditions of 700 V and 35 mA, is shown in **Table 1**.

Table 1 Chemical composition of Kosmalt E300T

C	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Cu**
wt. %								
0.05	0.2	0.02	0.014	0.014	0.017	0.027	0.002	0.028
Ti	**Co**	**B**	**Pb**	**V**	**W**	**Al**	**Nb**	**Zr**
wt %								
0.081	0.056	0.0002	<0.0001	0.006	<0.001	0.06	<0.001	<0.001

The welding of the base material was carried out in protective gas M21 (designation according to the ČSN EN ISO 14175 standard [8]) with a content of 82 % Ar and 18 % CO_2 under the following parameters: welding current 200 to 210 A, welding voltage 23 to 24 V, and welding speed 7.0 to 7.4 mm/s. The filler material was a G3Si1 wire (designation according to the standard SN EN ISO 14341 [9] with a content of 0.09 % C, 0.9 % Si and 1.5 % Mn.

The galvanising was performed in an industrial hot-dip galvanising plant along with regular custom production. The structural steel samples, 5 mm thick, were first degreased, rinsed, pickled, rinsed again, dipped in flux, and after drying, immersed in molten zinc according to the dry hot dip galvanising process.

a b

Figure 3 Sample (**a**) after welding, (**b**) after galvanizing

3. RESULTS AND DISCUSSION

3.1. Optical microscopy

First, the thickness and quality of the zinc coating were examined using optical microscopy (Olympus GX51). **Figure 4a** shows the base material, the heat affected zone and the weld metal. The figure shows the microstructure of the Zn coating with marked phases, including phase descriptions. **Figure 4b** then shows the heat-affected zone with the Zn coating at higher magnification. The Zn coating on the weld metal is continuous, but its structure and thickness differ from the coating on the base material due to the different chemical compositions of the weld metal (G3Si1) and the base material (Kosmalt E300T). In the structure of the zinc coating, the η phase (pure zinc) is almost absent and the ζ phase reaches the surface of the coating.

Using optical microscope software, the thickness of the Zn coating was measured at 120 locations on the sample (60 on the weld and 60 outside it). The average thickness of the zinc coating on the base material is 58 μm with a sample standard deviation of 4.43 μm, and on the weld it is 168 μm with a sample standard deviation of 6.42 μm.

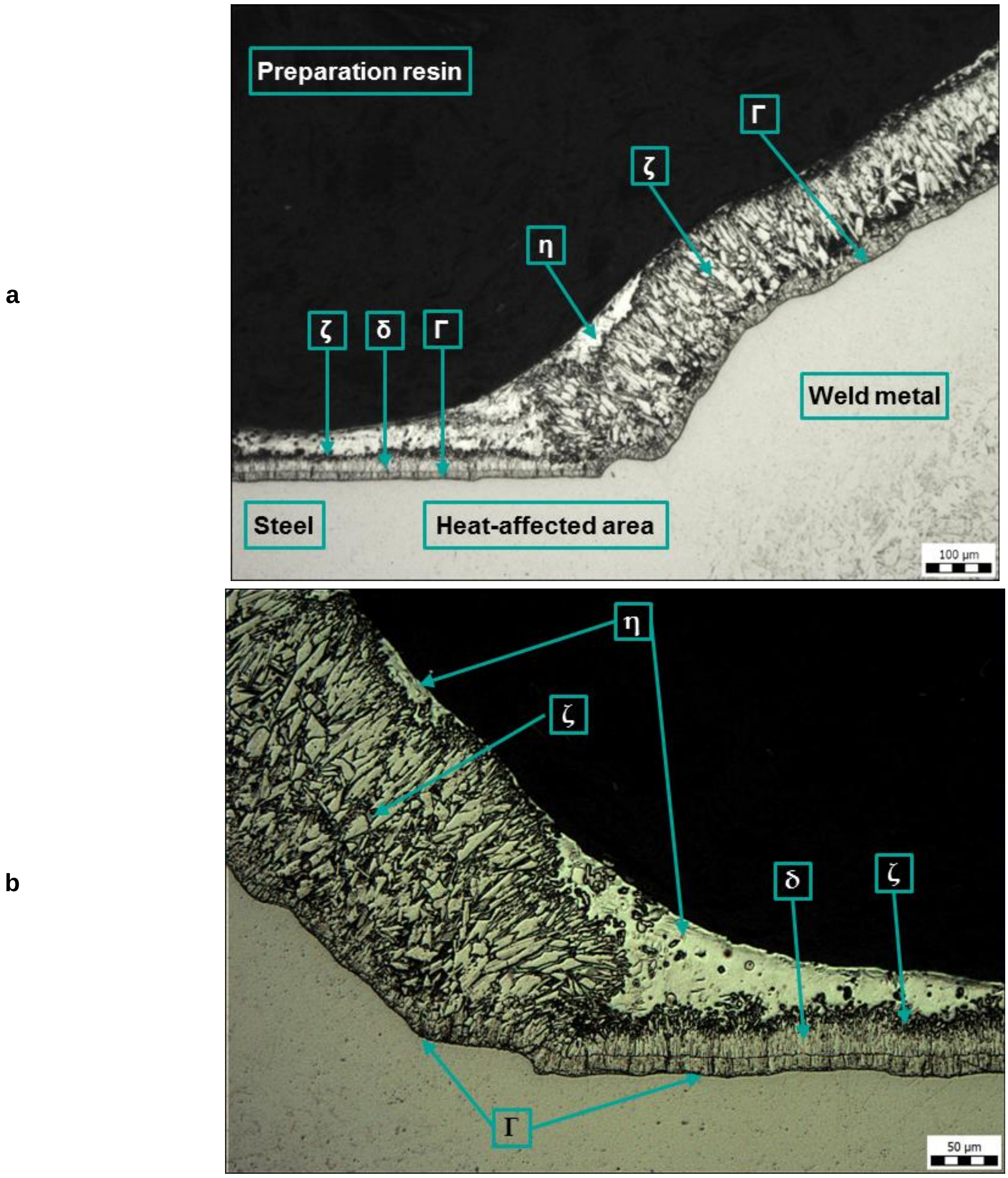

Figure 4 Microstructure Zn coating in the area of transition from base metal to weld metal

(**a**) magnification 100x, (**b**) magnification 200x.

3. 2. Adhesion Test

Figures 5-7 show that the zinc coating did not peel off on the base material or the weld metal after the test, and the sample meets the parameters specified by the standard (no loss of adhesion of the zinc coating on 50 % of the area between the individual scribe lines).

Figure 5 Photograph of the sample after the adhesion test on the weld.

Figure 6 Detail of the scribe on the weld metal, 50x magnification

Figure 7 Detail of the scribe on the base material, 50x magnification

3. 3. Condensation chamber test

The following image (**Figure 8**) shows the surface of the hot dip galvanised weld sample after exposure to a corrosive environment. The test was carried out according to SN 03 81 31 / eqv. ASTM D4585 / in a condensation chamber for 200 hours at a temperature of 35°C, 100 % relative humidity, and water condensation [11].

In the image, it is evident that where the adhesion test of the zinc coating was not performed (both on the base material and the weld joint) and the Zn coating was not mechanically damaged down to the base steel substrate, the sample shows no signs of corrosion caused by the corrosive environment on the steel substrate. The zinc coating is only slightly covered with a thin layer of white-grey zinc corrosion products.

Figure 8 Photograph of the sample after the condensation chamber test.

4. CONCLUSION

- The Zn coating on the weld metal is integral, its structure and thickness are different from the coating on the base material, which is due to the different chemical composition of the weld metal (G3Si1) and the base material. The η phase (pure zinc) is almost absent in the structure of the zinc coating, and the ζ phase reaches the surface of the coating (**Figure 4a**).
- The results of the experimental tests demonstrated the influence of the increased content of silicon Si on the thickness of the Zn coating, which was approximately 3x higher at the weld joint compared to the base material.
- Welded Material Kosmalt E300T: Thickness of the Zn coating: 58 µm ± 4.43 µm. Weld Metal: Thickness of the Zn coating: 168 µm ± 6.42 µm.
- Basic material, weld metal - there is no peeling of the Zn coating, the sample meets the parameters given by the standard (no loss of adhesion of the zinc coating on 50% of the area between individual scratches).
- Condensation chamber test according ČSN 03 81 31 / eqv. ASTM D4585 /, 200 hrs, temperature 35 °C, relative humidity 100%, water condensation. The zinc coating is slightly covered with a thin layer of white-gray zinc corrosion products (**Figure 8**).

Welding is one of the technologies for joining structural steels. Since welding technology uses welding wire suitable for the base material but with some differences in the content of certain elements, especially carbon and silicon, there can be issues with subsequent galvanising of welded joints, particularly in the formation of the thickness and chemical composition of the protective zinc layer. The authors aimed to verify whether the different thicknesses of the zinc layer on the surface of the welded component, especially the 168-micron zinc layer on the weld joint/metal, meet the adhesion and corrosion resistance parameters of hot-dip galvanising as specified by the standard. For this purpose, an adhesion test and a condensation chamber test were used.

The condensation chamber test demonstrated that corrosion occurred only where there was no continuous layer of hot dip zinc. The adhesion test confirmed that the quality of the zinc coating was satisfactory not only on the surface of the weld joint but also on the surface of the unaffected zone of the structural steel.

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REFERENCES

[1] Marder, A.R. Metallurgy of Zinc-Coated Steel. *Prog. Mater. Sci.* **2000**, *45*, 191–271, doi:10.1016/S0079-6425(98)00006-1.

[2] Bhat, R.S.; Balakrishna, M.K.; Parthasarathy, P.; Hegde, A.C. Structural Properties of Zn-Fe Alloy Coatings and Their Corrosion Resistance. *Coatings* **2023**, *13*, doi:10.3390/coatings13040772.

[3] Kania, H.; Mendala, J.; Kozuba, J.; Saternus, M. Development of Bath Chemical Composition for Batch Hot-Dip Galvanizing-A Review. *Materials (Basel).* **2020**, *13*, doi:10.3390/ma13184168.

[4] EN ISO 1461 *Hot Dip Galvanized Coatings on Fabricated Iron and Steel Articles Specifications and Test Methods*; 2022;

[5] ISO 14713-2 *Zinc Coatings — Guidelines and Recommendations for the Protection against Corrosion of Iron and Steel in Structures — Part 2: Hot Dip Galvanizing*; 2019;

[6] Kuklík, V.; Kudláček, J. *Hot-Dip Galvanizing of Steel Structures*; Elsevier, Butterworth-Heinemann: Amsterdam, 2016; ISBN 9780081007532.

[7] Vontorová, J.; Mohyla, P.; Kreislová, K. Quality of Zinc Coating Formed on Structural Steel by Hot-Dip Galvanizing after Surface Contamination. *Coatings* **2024**.

[8] EN ISO 14175 *Welding Consumables — Gases and Gas Mixtures for Fusion Welding and Allied Processes*; 2008;

[9] EN ISO 14341 *Welding Consumables - Wire Electrodes and Deposits for Gas Shielded Metal Arc Welding of Non Alloy and Fine Grain Steels - Classification.*; 2020;

[10] ASTM A123 *Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products*; 2017;

[11] ASTM D4585 *Standard Practice for Testing Water Resistance of Coatings Using Controlled Condensation*; 2018;