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HOT DIP Zn-5Al COATINGS WITH IMPROVED CORROSION RESISTANCE OF REINFORCEMENT STEEL

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The article presents the results of tests of Zn-5Al coatings obtained on reinforcement bars made of B500SP steel. The microstructure using Scanning electron microscopy (SEM) and chemical composition in micro-regions using Energy dispersive spectroscopy (EDS) are shown. The electrochemical parameters of the corrosion process of the coatings were determined and the mechanical properties of the reinforcement bars after the coating were tested. It was found that the coating consists of the outer layer consisting of hypoeutectic regions of Al solution in Zn (α) and the ZnAl eutectic (α+β), and a diffusion layer composed of $FeAl_3$ phase. Potentiodynamic tests have shown that the Zn-Al5 coating provides sacrificial protection for the reinforcement steel and has a much lower corrosion current density compared to the traditional zinc coating.

Key words: coating, hot dip galvanizing, Zn-5Al, corrosion resistance, X-ray research

INTRODUCTION

Reinforced concrete is one of the basic materials used in construction. Its high compressive strength is ensured by a concrete matrix, and tensile stresses are transferred by steel reinforcement bars. Concrete is a moderately aggressive corrosive environment for steel, but its carbonation causes intensive corrosion of the reinforcement [1]. Hot dip galvanizing coatings are most often used to protect the reinforcement against corrosion [2]. Zinc coatings show good adhesion to concrete, and the products covered with them are suitable for further plastic processing [3]. The diffusion layer of zinc coatings consists of intermetallic phases of the Fe-Zn system [4], which show better corrosion resistance than zinc [5]. Currently, the production of zinc coatings takes place in multicomponent zinc alloy baths, containing additives, among others: Al, Ni, Pb, Bi and Sn [6]. These additives improve the process technology and the appearance of the coating. Their impact on reducing the reactivity of Si-containing steels is particularly important [7]. Reactive steels also include reinforcement steels with an Si content of up to 0,55 wt. % [8]. However, the presence of the addition of Pb [9], Bi [10] and Sn [11] in the bath may lower the corrosion resistance.

Zinc-aluminum coatings exhibit much better corrosion resistance [12]. These coatings are mainly produced on sheets and wires. So far, they are not produced on reinforcement bars. It is estimated that the corrosion resistance of coatings made in the Galfan (Zn-5Al) bath on sheets is 2-3 times higher than that of traditional zinc coatings. In the work, the structure of coatings obtained on B500SP steel bars was examined and the influence of the produced coating on the corrosion resistance and strength properties of the bars was determined.

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RESEARCH METHODOLOGY

Reinforcement bars with a diameter of ϕ 14 mm B500SP intended for concrete reinforcement were used for the tests. The chemical composition of the steel included: 0,21 wt. % C, 0,78 wt. % Mn, 0,18 wt. % Si, 0,02 wt. % P, 0,02 wt. % S, 0,44 wt. % Cu, 0,11 wt. % Cr, 0,07 wt. % Ni, 0,04 wt. % Mo, 0,003 wt. % V and rest was Fe and others.

Zn-5Al coatings were prepared by the double hot dip method. First, the samples were immersed in the Zn-5Al bath at 450 °C for 30 s. Immediately, after being taken out of the Zn-bath, samples were immersed in the Zn-5Al bath at 450 °C with the immersion time of 120 s. After removing from the Zn-5Al bath, the samples were cooled in air. Prior to immersion in the Zn bath, the surface of the sample was degreased, etched and fluxed.

The Hitachi S-3400 N scanning electron microscopy (SEM) equipped with an energy dispersion spectroscope (EDS) was used for microstructure analysis and chemical composition studies in microregions.

Potentiodynamic studies were carried out on a Potentiostat/Galvanostat Radiometer PG201 device using the Voltamaster 1 software. A normal calomel electrode was used in the studies, which is used as a standard reference electrode. In order to standardize the test results, the potential values were converted to a normal hydrogen electrode (NHE) by shifting the measurement values by 244 mV. Potentiodynamic tests were performed at the temperature of 20 °C. A 3,5 % NaCl solution in distilled water was used as the electrolyte.

The static tensile test was performed on the MTS Landmark Servohydraulic Test System machine at room temperature at a speed of 4 mm/min according to the standards [13-15]. R_{eH} was taken as the yield point.

RESULTS AND DISCUSSION

The microstructure of the coating obtained on reinforcement steel in the Zn-5Al bath with marked EDS micro-areas and the results of the chemical composition tests are presented in Figure 1.

The average thickness of the coating is 34 ± 73 μm. The coating is composed of an outer layer located in micro-area 1 and 2 and a diffusion layer located in micro-area 3. In micro-area 1 (Figure 1c) the content of 0,6 wt. % Al and 99,4 wt. % Zn was found. The chemical composition indicates the presence of hypoeutectic Al solid solution in Zn in this zone [16].

The rest of the outer layer contains a fine crystalline mixture with an eutectic morphology. The chemical composition of the zone defined in micro-area 1 is 5,9 wt. % Al and 94,1 wt. %. Zn (Figure 1b). According to the Zn-Al equilibrium system [17], this composition is slightly above the eutectic point, hence it can be concluded that in this area alternate precipitates of Al solution in Zn (α) and Zn solutions in Al (β) occur. Such a structure of the outer layer is similar to that of Zn-5Al coatings produced on steel sheets called Galfan [18].

The diffusion layer contains 38,0 wt. % Al, 36,0 wt. % Zn and 26,0 wt. % Fe (Figure 1d). Converting the content of Al and Fe to the atomic fraction (58,1 at. % Al and 19,2 at. %) it can be concluded that the ratio of the atomic fraction of Al:Fe is very close to the 3:1. Therefore, it can be said with high probability that it is the $FeAl_3$ phase. This phase contains dissolved zinc as confirmed by the reports of Tang et al. [19] that the phases of the Fe-Al system can dissolve significant amounts of zinc. The formation of a diffusion layer consisting of the $FeAl_3$ phase was also confirmed by Šalgó and Kusý, who made coatings in the Zn-5Al-0.5Mg bath on the wires using the double hot dip method [20]. The Al-rich $FeAl_3$ phase may cause the depletion of the Al bath in its vicinity. This creates conditions for the formation of a hypoeutectic areas of solid solution of Al in Zn (α) in the outer layer, even though the composition of the bath is kept at the level of the eutectic Al content.

The polarization curves of the coating obtained in the Zn-5Al bath on the reinforcement steel are shown in Figure 2. The electrochemical corrosion parameters were determined by the extrapolation of cathode and anode lines using the Tafel method [21]. The specific corrosion potential (E_{corr}) of the Zn-5Al coating is -825,46 mV (vs. NHE). Zinc coatings in a 3,5 % NaCl solution, depending on the alloying additives in the bath, show a corrosion potential of -766,26 to -781,26 mV (vs. NHE) [10, 11]. The obtained Zn-Al coatings therefore provide a similar sacrificial protection for steel [22]. In contrast, the specific corrosion current (j_{corr}) of Zn-5Al coatings is 1,65 μA/cm^2. Traditional zinc coatings in an environment of 3,5 % NaCl solution show much higher values of the corrosion current density. Research by Kania et al. [10, 11] show that the corrosion current density of coatings ob-

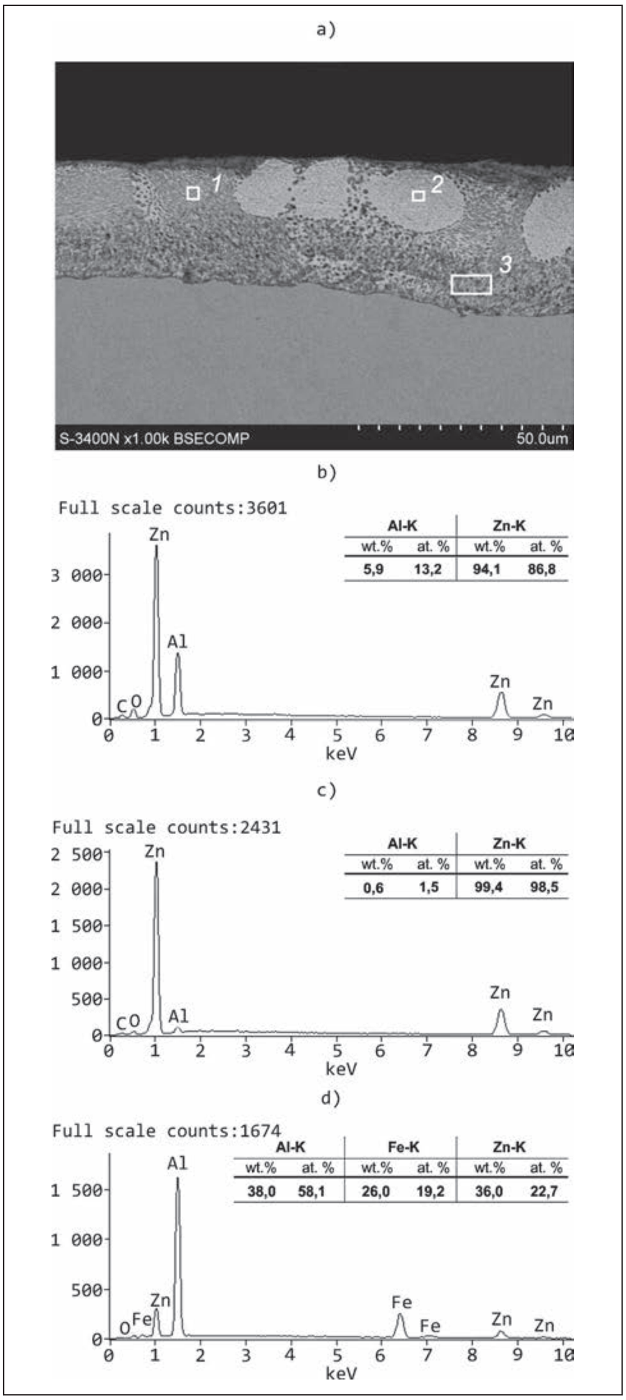

Figure 1 Microstructure of the Zn-5Al coating on reinforcement steel (a) and results of EDS microanalysis in the diffusion layer of the coating

tained in a "pure" Zn bath is 10,18 mA/cm^2 [10]. An even higher value of the corrosion current density was observed for the coatings obtained in the commonly used zinc baths containing the addition of Bi (14,26 mA/cm^2) [10] and the combined addition of BiSn (18,84 mA/cm^2) [11]. Corrosion current density (j_{corr}) according to Faraday's law [23] determines the amount of mass loss. The lower value of the Zn-5Al corrosion current density testifies to its much better corrosion resistance compared to traditional zinc coatings.

The diagram of the static tensile test of the reinforcement bar without the coating and with Zn-5Al coating is shown in Figure 3.

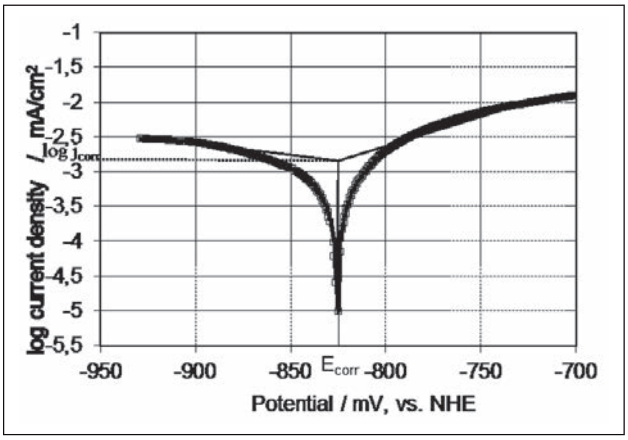

Figure 2 Curves of anodic and cathodic polarization of Zn-5Al coating in 3,5 % NaCl solution

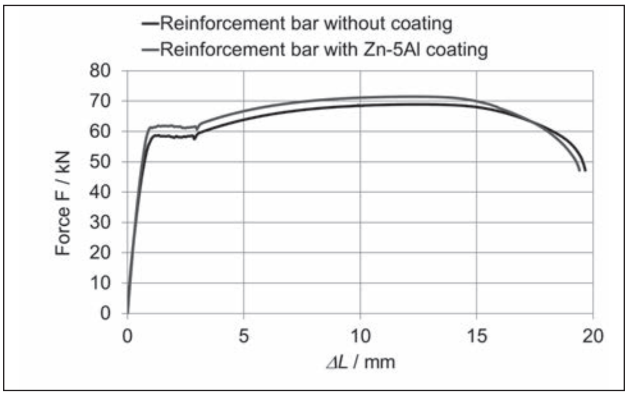

Figure 3 Tensile diagrams for reinforcement bar without coating and with Zn-5Al coating

CONCLUSIONS

Based on the analysis of the structure of the materials, and their corrosion resistance, the following conclusions were formulated:

1. Zn-5Al coatings on B500SP reinforcement steel consist of an outer layer and a diffusion layer. The outer layer consists of hypoeutectic regions of the solid solution of Al in Zn (α) and regions of the eutectic mixture of solutions of Al in Zn (α) and Zn in Al (β).
2. Zn-5Al coatings on reinforcement bar provide sacrificial protection of steel and show better corrosion resistance than traditional zinc coatings.

The research will be continued in order to determine the relationship between the parameters of the technological process and the functional properties of reinforcement bars with anti-corrosion coatings applied.

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Note: The responsible for English language is M. Hegde.