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THE IMPACT OF GALVANIZING ON THE MECHANICAL PROPERTIES OF REBARS

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This article reports on the results of tests on the impact of hot dip galvanizing on the strength of B500SP reinforcing bars. The bars were hot-dip galvanized in baths with different process parameters. Following each hot dip galvanizing, the structure of the coatings obtained was inspected and tensile tests were conducted. Tensile testing results were compared with the properties of non-galvanized reinforcing bars. It was established that, regardless of the parameters set for the hot dip galvanizing process, zinc coatings slightly increase the mechanical properties of B500SP reinforcing bars.

Key words: steel, reinforcing bar, chemical composition, hot dip galvanizing, mechanical properties

INTRODUCTION

Steel reinforcing bars are commonly used in the construction industry. Combined with concrete, they form reinforced cement concrete (RCC), which is highly resistant to compressive stresses of the concrete matrix, with steel reinforcement providing tensile strength [1].

The alkaline concrete environment provides anticorrosive protection for reinforcing bars [2]. However, concrete carbonation due to the concentrations of carbon dioxide, as well as the penetration of chloride ions from the environment, significantly lower the alkalinity of concrete. This decrease in alkalinity triggers intensive corrosion of reinforcement steel, resulting in a discontinuous matrix [3].

There is a critical need for improved reinforcement protection against corrosion. Currently, hot-dip zinc coating is known to be the most effective protection. The 2009 data show that about 2 % of US reinforcing steel was galvanized, while in Europe the share was 1 % [4]. The European General Galvanizing Association (EGGA) statistics show a significant increase in the amount of galvanized steel manufactured for the construction industry in the last decade. At present, this industry is consuming about 45 % of galvanized steel, in both reinforcement and steel structures.

Strength requirements for reinforcing steels are specified in the Eurocode 2 classification. The chemical composition of steel ensures its adequate strength and ductility, and carbon equivalent (Ceq) determines its weldability. ISO 14657:2005 [5] specifies requirements for hot-dip zinc (galvanized) coating on steel reinforcing bars, specifying three classes (A, B and C) which differ in coating mass (g/m^2). However, the impact of galvanizing on the mechanical properties of reinforcing steel has not been assessed. In order to address this issue, this article reports on tests on the impact of hot-dip galvanizing parameters on strength properties of B500SP reinforcing bars.

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RESEARCH METHODOLOGY

Tensile strength tests were conducted on galvanized B500SP reinforcing bars (ϕ 12 mm). The chemical composition of the steel used is presented in Table 1. The hot-dip galvanizing process was a typical zinc bath with an alloying additive (Al) content of 0,005 %. The temperature was maintained at 450 °C and 550 °C (high temperature hot dip galvanizing HT-HDG), with the immersion times of 1 and 10 minutes. At the pre-treatment stage, the test samples were subjected to the standard surface preparation procedure of degreasing, pickling and fluxing. Following the zinc immersions, the samples were air-cooled.

Table 1 **Chemical composition of B500SP steel / mas. %**

Content of elements	Fe	C	Mn	Si	P
mas. %	rest	0,21	0,78	0,18	0,02
Content of elements	S	Ni	Mo	Cu	Cr
mas. %	0,02	0,07	0,04	0,44	0,11

The structures of the coatings obtained were examined with an Olympus GX51 optical microscope. The analySIS software was used for image recording and coating thickness measurements.

An MTS Landmark Servohydraulic Test System testing machine was used for testing the mechanical properties at room temperature [6-8]. The speed used in the tensile tests was 4 mm/min.

RESULTS AND DISCUSSION

The microstructures of the zinc coatings on B500SP for different parameters of the galvanizing process are shown in Figure 1 a - d. The structures of the coatings obtained differ depending on dipping temperatures, and an extended immersion time increases the thickness of coating layers. The average thickness of the coatings is shown in Table 2.

Table 2 **Average coating thickness on B500SP**

Process parameters	Average coating thickness / mm
450 °C, 1 min	63,29 ± 9,85
450 °C, 10 min	176,87 ± 9,08
550 °C, 1 min	40,07 ± 1,50
550 °C, 10 min	140,27 ± 10,24

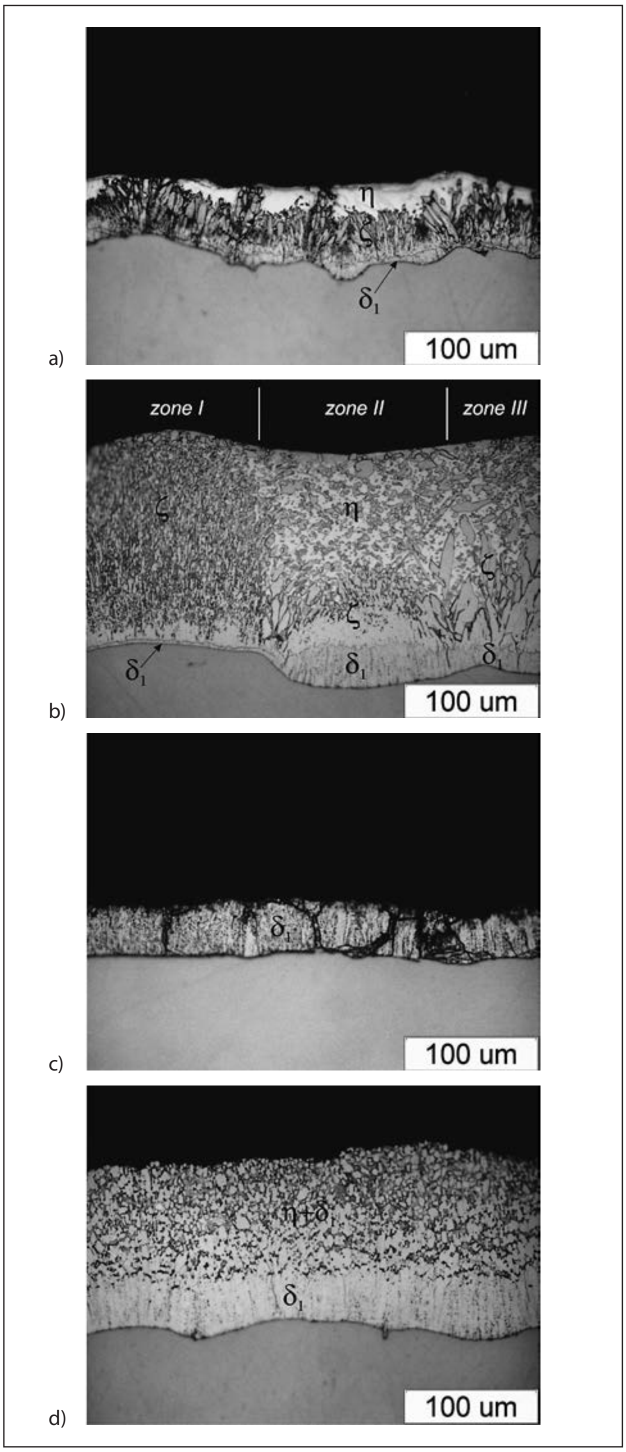

Figure 1 Coating structures on B500SP obtained at respective immersion temperatures and times: (a) 450 °C, 1 min; (b) 450 °C, 10 min; (c) 550 °C, 1 min; (d) 550 °C, 10 min

The coating obtained at the standard temperature of 450 °C (Figure 1 a - b) shows a layered structure, with the diffusion layer consisting of intermetallic phases d_1 and ζ. With a short immersion time (1 minute), the outer layer of the coating, formed in a zinc bath saturated with iron – η [9], is also clearly visible. An extended dipping time causes changes in the morphologies and phases of the coating and a significant increase in their thickness (Figure 1 b).

A variety of structures can be identified in the coating. The Sandelin effect is observed in zone I, with a very thin layer of the delta δ_1 phase beneath a thick layer of the zeta (ζ) phase which extends up to the external surface of the coating. In zone II, there is an increase in the delta δ_1 layer thickness, a decrease in the zeta ζ layer thickness, and the emergence of the eta (η) phase. Such a structure is typical of low-silicon steels. While in zone III, the ζ phase is a layer of loose elongated crystals, which is characteristic of Sebisty steels [10]. The chemical composition of the steel (Table 1) indicates an average Si content of 0,18 wt. %, i.e. within the Sebisty range. The diversified structure of the coating would indicate high segregation effects and uneven Si distribution in the steel.

The coating obtained in the HT-HDG process shows a different structure of the coating. At temperatures above 520 °C, the ζ phase is not stable. With 1-minute hot dip (Figure 1 c), the coating is a solid δ_1 phase layer, which - with the dipping time extended up to 10 minutes (Figure 1 d) - transforms into an area of a two-phase (δ_1+η) mixture. The external phase η layer is absent in the coating obtained [11]. Simultaneously, no changes are detected in phase morphologies in the coating inspected, which proves that there is no effect of silicon concentration fluctuations in the substrate on the structure of the coating in HT-HDG [10].

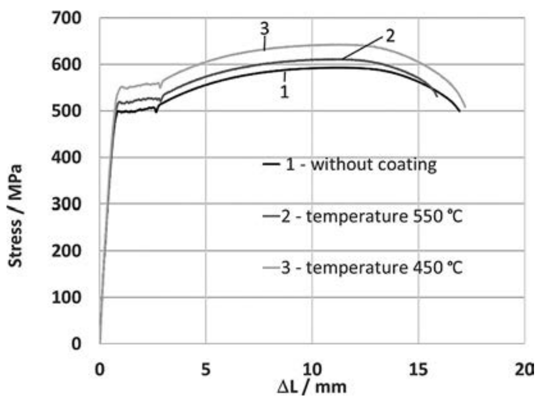

Figure 2 Tensile testing diagram for a non-galvanised bar and galvanized rebars with coatings obtained at temperatures of 450 and 550 °C (dipping time = 1 min)

Tensile testing of non-galvanized rebars and hot-dip galvanized rebars (under different process parameters) was conducted in 3 trials. Tensile stress-strain curves for respective samples are presented in Figure 2.

Figures 3 - 4 shows yield strength and tensile strength values for non-galvanised rebars versus those obtained for hot-dip galvanized rebars. Calculations assume the same cross-section areas for all test samples.

The values of the k coefficient, as specified in EN 1992-1-1 [8], can be estimated from:

$$k=f_{tk}/f_{yk} \quad (1)$$

where:

f_{tk} – tensile strength
f_{yk} – yield strenght.

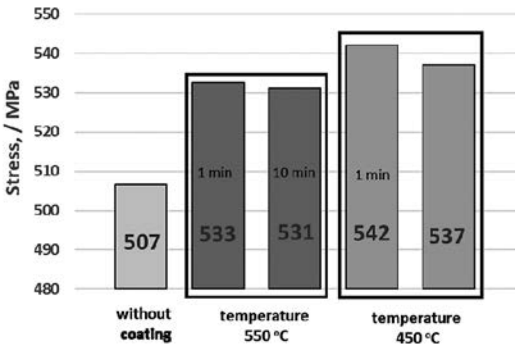

Figure 3 Mechanical properties of rebars: f_{yk}

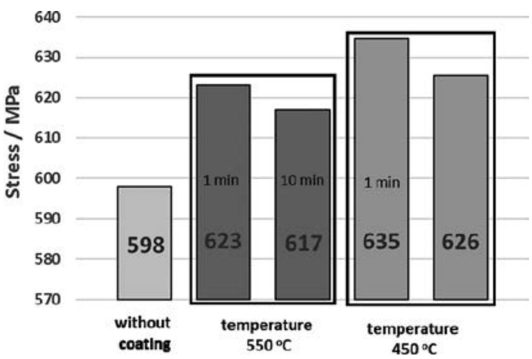

Figure 4 Mechanical properties of rebars: f_{tk}

Table 3 **k coefficient values**

No.	1	2	3	4	5
Temperature galvanizing / °C	-	450	450	550	550
Time galvanizing / s	-	1	10	1	10
k / -	1,18	1,17	1,16	1,17	1,16

Table 3 lists values of the k coefficient obtained for galvanized and non-galvanised samples.

The values of the k coefficient for galvanised samples (1-minute dip) was 1,17 and for zinc-coated samples (10-minute dip), it was 1,16. These values were slightly different from those determined for non-galvanised samples.

CONCLUSIONS

The analysis of the impact of hot-dip galvanizing on the structure and strength of B500SP rebars indicates that:

The structure of the coating depends on galvanising parameters. While fluctuations in Si content in B500SP steel affect the morphology of the phases in the coating obtained at the temperature of 450 °C, they do not affect the structure of the coating obtained in HT-HDG.

Hot-dip galvanizing does not adversely affect the strength of B500SP rebars. The application of the zinc coating slightly increases the strength of the rebars, yet the effect is reduced when hot-dip galvanizing bath temperatures and dipping times are increased.

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Note: The responsible for English language is E. Gieroń – Czepczor.