Development of Bath Chemical Composition for Batch Hot-Dip Galvanizing—A Review

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4.2. Effect of Nickel

The addition of nickel to the galvanizing bath is now widely accepted as a way to reduce the reactivity of Si-containing steels in liquid zinc. The first commercial applications of nickel additive began in 1982-then 0.13 wt % Ni was added to the bath. During the first 20 years of industrial use of the Ni additive in the bath, a number of changes were introduced and many studies on this subject have been published. Nickel as a pure metal dissolves relatively slowly in liquid zinc. Hence, it was initially added to the bath in the form of Zn-2%Ni mortar. In order to increase the efficiency of equalizing the Ni content in the bath volume, it was also introduced into the bath in the form of a powder with intensive stirring. Currently, Ni is most often added as the Zn-0.5% Ni alloy. At that time, its content in the bath also changed. Even in the 1990s of the last century, its content in the bath decreased to 0.9 wt %. Finally, the optimal range of Ni concentration in the zinc bath used so far was determined as 0.04 wt % to 0.06 wt % [5,6]. Nickel in this content range enables the suppression of Sandelin peak, and the coating on Sandelin steel obtained in such a bath has a structure similar to that of the coating obtained on low-silicon steel (Figure 4a). The presence of nickel in the bath does not change the structure of Sebisty steel (Figure 4b) and high-silicon steel (Figure 4c).

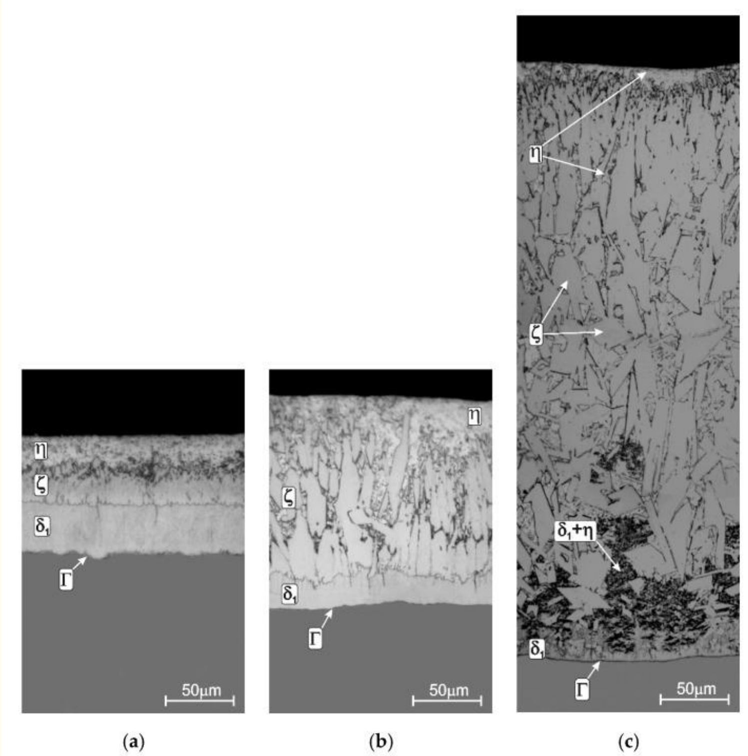

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Figure 4

The structure of the coating obtained in the Zn + 0.05% Ni bath on: Sandelin's steel (**a**), Sebisty's steel (**b**) and high-silicon steel (**c**), adapted from [36].

There is also a clear reduction in the thickness of the coating on Sandelin steel (0.05 wt % Si), while on Sebisty steel (0.18 wt % Si) and high-silicon steel (0.27 and 0.32 wt % Si), the reduction in the thickness of the coating is insignificant (Figure 5a). The higher Ni contents in the bath, in addition to higher costs, may adversely affect the galvanizing process and the quality of the coating. Excessive Ni content in the bath causes floating dross, which contaminates the bath [41]. Floating dross is formed by fine particles of the Γ_2 phase described by the $Fe_6Ni_5Zn_{89}$ formula, which is isostructural with the Γ phase of the Fe-Zn binary system [42]. In the Fe-Ni-Zn triple equilibrium system [43], the Γ_2 phase is stable at Ni content over 0.06 wt %. The Γ_2 phase particles have a regular shape and separate from the Zn + Ni bath supersaturated with iron at the border with the ζ phase layer. In such conditions, the floating dross is pulled out with the product from the bath, creating defects on the surface of the coating and increasing the amount of zinc withdrawn. The formation of the Γ_2 phase also entails a faster depletion of Ni from the bath. In such a situation, increasing the Ni content in the bath above 0.06 wt % becomes unreasonable.

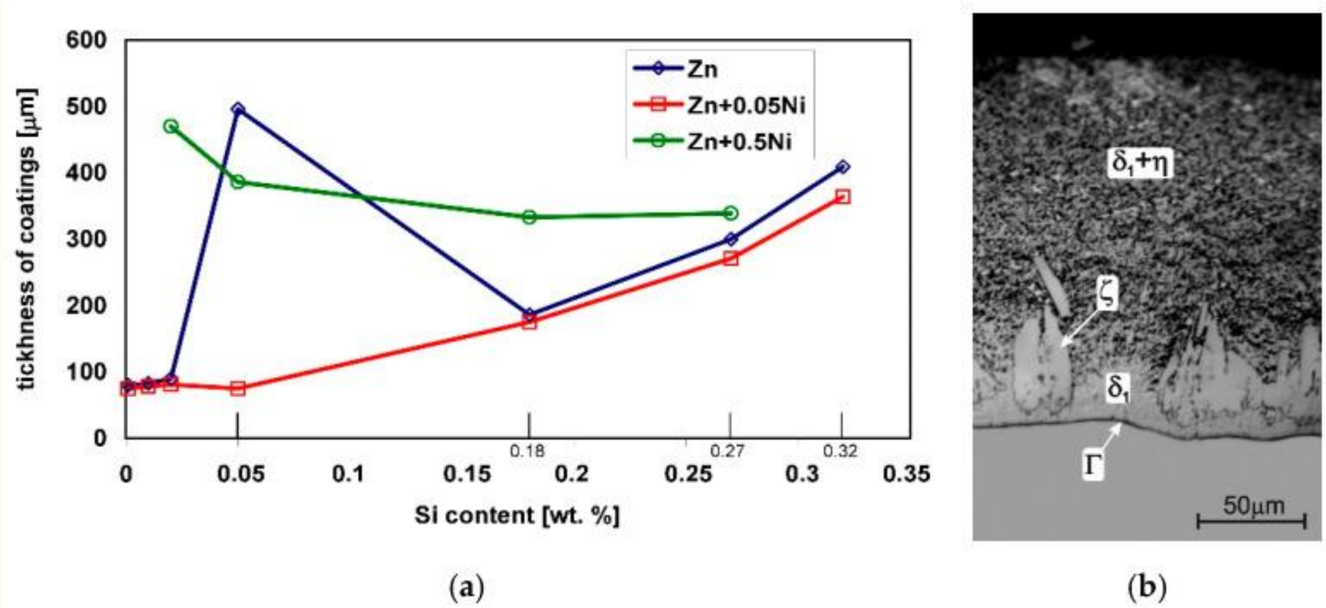

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Figure 5

Comparison of changes in the thickness of coatings obtained in the Zn, Zn + 0.05% Ni and Zn + 0.5% Ni baths; data from [36] (**a**) and the structure of the coating obtained in the Zn + 0.5% Ni bath on high-silicon steel (**b**).

Higher Ni contents cause a significant increase in the thickness of the coating. Simultaneously with the increase in the Si content in the steel, the thickness of the coating slightly decreases (Figure 5a). The coating structure also changes. Higher Ni content changes the equilibrium in the Fe-Ni-Zn system. The δ_1 phase is in equilibrium with liquid zinc [44]. Direct contact of the δ_1 phase with liquid zinc causes its growth. In the structure of the coating, the occurrence of the two-phase zone $\delta_1 + \eta$ can be observed (Figure 5b). The ζ phase does not form a continuous layer, but single, loose crystals at the boundary with the δ1 phase [45].

Nickel, along with aluminum, is now the standard alloying additive introduced into the zinc bath to reduce the reactivity of the steel. The vast majority of galvanizing plants use a Ni additive in combination with other alloying additives improving the efficiency of the galvanizing process.