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Problems connected with use of hot-dip galvanized reinforcement in concrete elements

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Abstract

The goal of this article is to evaluate risks arising from using hot-dip galvanized reinforcement in concrete elements. The article provides detailed summary of current experimental activities but also earlier positive remarks about applicability of hot-dip galvanized reinforcement, mainly from the perspective of corrosion and bond strength with concrete. Based on previously obtained data, the article disproves barrier effect of zinc coating on base steel. The reason is the initial corrosion reaction of zinc coating in fresh concrete producing hydrogen. Further data prove that forming hydrogen irreversibly increases porosity of cement on reinforcement/concrete interface which can significantly reduce bond strength. Sufficient filling of pores by zinc corrosion product could not be confirmed.

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Keywords: Hod-dip galvanized; steel reinforcement; concrete; porosity; corosion; phase interface.

1. Introduction

Unacceptable corrosion rate of common unalloyed steel caused by carbonation or, more frequently, contamination of concrete by chlorides significantly limits functional lifetime of steel-concrete constructions. It is in fact the voluminous corrosion products of steel which compromise the integrity of covering layer of concrete, eventually requiring fast and expensive countermeasures [1,2].

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Despite that the research focused on use of alternative reinforcing materials (e.g. fabric, stainless steel, alkaline-resistant glass, polymer and carbon fiber) has greatly progressed, their application in common constructions is still marginal (typically only as complementary reinforcement – e.g. for strengthening of common ribbed carbon steel reinforcement). Some alternative materials do not provide concrete with sufficient mechanical properties, respectively, their benefit is less effective compared to common steel. Large scale application of the other materials would greatly increase the construction [1,3].

For this reason, common rebar from unalloyed (carbon) steel with surface geometry adjusted to form standardized ribs or imprints. Corrosion protection of such reinforcement is facilitated almost exclusively by ensuring sufficient thickness of covering concrete and increasing the resistance of concrete against chloride and CO_2 penetration (e.g. by reduction of w/c factor, increasing prolonging the concrete treatment period and its quality, application of more suitable cement types).

Use of other anti-corrosion measures is uncommon. Deployment of corrosion inhibitors seems to be only mildly effective because of its inability to maintain critical concentration over long term on steel/concrete interface). Application of cathodic protection (sacrificial anode or by DC source) cannot be used everywhere and is unambiguously on of the more expensive anti-corrosion systems [2,3].

Evaluation of effectivity of protective coatings for common steel rebar is the focus of expert community since the beginning of the last century. Reasons are logical – possibility of fast and easy application of corrosion protection system (coating) without the need to maintain it while also keeping the mechanical properties of reinforcing steel. From this point of view, epoxy coatings and coatings produced by hot-dip galvanizing are of the highest interest. The economic studies show that application of hot-dip galvanized coatings for steel rebar protection does not significantly increase the construction expenses. Idea of their application is further supported by the data of their resistance to atmospheric corrosion. Use of standard-prescribed thickness, sufficiently thick coating (often a combination of coatings: galvanized coating and organic coating) can assure required longevity of given construction [3,4].

From the perspective of corrosion engineering, protective coatings provide only barrier protection (unless it provides any other: either by destimulation, inhibition or electrochemical mechanism) i.e. they work as an “insulation” separating the susceptible material from aggressive environment. They ensure longer time until activation of steel which will then corrode at unhindered rate. In reality, transport of oxygen and humidity from the surface to the rebar also has some effect.

This article strictly focuses on coatings produced by hot-dip galvanizing [1,4].

Nomenclature

A	Surface treatment of steel by hot-dip galvanizing
B	Unclear key questions about application of hot-dip -galvanized steel in concrete
C	Evaluation of initial corrosion damage to zinc coating in fresh concrete
D	Extent of effect of initial corrosion damage on rebar/concrete bond strength

2. Surface treatment of steel by hot-dip galvanizing

During hot-dip galvanizing (liquid zinc of 450-470 °C) alloy-like iron-zinc coating grows on coated components. This is a result complex process of reciprocal diffusion of both metals resulting in elementary intermetallic bonds and subsequently phase transformations. These phenomena take place in both the surface layer of zinced metal but also at the interface of solid metal and liquid alloy. Depending on steel composition, temperature, liquid alloy composition, wall thickness of zinced component, coating time, surface state and mode and rate of cooling, different intermetallic Fe-Zn compounds can be formed. Appearance of typical hot-dip galvanized coating is shown in Fig. 1(a) [5,6]. Coating layers vary in composition and thickness. Iron content increases in the direction toward the steel substrate. The layers are denoted by Greek alphabet letters: gamma (Γ), gamma$_1$ (Γ_1), delta (δ), zeta (ζ), eventually eta (η). Individual phases significantly differ not only in composition and grain morphology but also in mechanical properties [6].