Review

Evaluation of the impact of corrosion of hot-dip galvanized reinforcement on bond strength with concrete – A review

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HIGHLIGHTS

- This review article describes in detail the impact of corrosion of hot-dip galvanized steel on bond strength with concrete.
- This work focuses on the influence of all aspects (not only corrosion induced aspects) of the development of bond between hot-dip galvanized steel and concrete.
- To evaluate the extent of effective corrosion protection, investigations evaluating the corrosion behavior of galvanized steel in fresh and hardening concrete must be re-opened.

ARTICLE INFO

ABSTRACT

This review focuses on the effect of initial corrosion of hot-dip galvanized reinforcement in both fresh and curing concrete on total bond strength.

Corrosion behavior of hot-dip galvanized steel is studied in detail in both alkaline solutions without calcium cations and model pore solutions (with Ca^{2+}). Relation between pH and resulting extent of corrosion attack on coating is also discussed. The effect of top layer of coating, consisting of various intermetallic phases on corrosion resistance is also discussed.

Regarding the standardized bond strength test procedures, the effects of hydrogen evolution on porosity of adjacent cement and bond strength of galvanized steel and concrete were analyzed. Negative effect of zinc corrosion products is described – concrete curing and hardening of concrete is retarded in their presence, their growth can cause local disintegration.

Close attention is also given to eventual surface modification of galvanized reinforcement aimed at reducing the negative effect of reinforcement corrosion on bond strength (chromate, phosphate, organosilane and other coatings).

The review points out many contradicting results and therefore the fact that real consequences of galvanized reinforcement corrosion are not, even at present day, known. Use of galvanized zinc coatings for protection of conventional steel reinforcement cannot, to this day, be considered clearly beneficial and research regarding the topic to be finished.

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1. Introduction

Concrete is the most widely used composite building material in the world. The global expansion of concrete is primarily due to its high stability under normal atmospheric conditions, high compressive strength, relatively low cost, and simplicity of production. The drawback of simple concrete is a low tensile strength. This problem is usually solved by using reinforcing internal steel mesh, bars, rods, or fibers. With regard to cost, availability and ability to assume the majority of structural tension, the most appropriate material for concrete reinforcement is unalloyed steel [1–4].

The service life of reinforced concrete structures is always closely limited by corrosion of ordinary structural steel reinforcement. Steel corrodes in fresh concrete in a passive state negligible corrosion rate, due to the high pH of the pore solution (i.e. 12.6–13.5 according to the content of alkali metal oxides in the cement). However, with carbon dioxide from the atmosphere (possibly due NO_x), which results in neutralizing the alkaline components of the pore solution to activate the steel reinforcing associated with the unacceptable corrosion rate. Increased corrosion rate of transition of steel into an active state without a drop in pH is often associated with exceeding the critical concentration of chlorides from thawing salts or seawater, which the surface of the reinforcing steel receives from the concrete cover [4–6].

Corrosion of steel not only reduces the effective diameter of the reinforcement, thereby decreasing strength of the structure, but very bulky corrosion products are also created on the steel surface. These produce tensile stresses within the concrete with consequent cracking [7,8].

Efforts to increase the service life of reinforced concrete structures must be related to the use of aqueous corrosion protection of steel. In practice, most civil life of a structure – a system of corrosion protection of steel – provide an adequate thickness of concrete cover. Sacrificial anode cathodic protection or involvement of direct current source can be used successfully to limit corrosion. This method of protection is, however, very expensive and cannot be used everywhere. The use of corrosion inhibitors on reinforcing steel is very difficult because it is impossible to guarantee stable maintenance of the critical chloride concentration on the steel surface, while the use of certain corrosion inhibitors can cause significant deterioration in the mechanical properties of the concrete. The use of alternative reinforcing materials is significantly limited due to the poorer mechanical properties of potential materials, which are associated with reduced transmission of sufficient tensile stress [5,8,9].

A financially attractive method of concrete reinforcement corrosion protection, which guarantees the preservation of the favorable mechanical properties of steel and does not require periodic maintenance is coating the reinforcement's surface. Based on technological as well as ecological, economic and even historical factors, coatings of epoxy (or polyurethane) and the hot-dip conventional galvannealing have been contemplated. Neither of these technologies increased the total cost of implementation of the construction by more than a few percent [9].

2. Epoxy-coated reinforcement

The use of quality (i.e. defect-free) epoxy coating (or polyurethane) can significantly prolong the time until activation of the underlying steel, allowing extension of the life of the structure. For sufficient lifetime extension, coatings of a uniform thickness of at least 200 μm are recommended [10]. It is probably because they produced lower coating thicknesses that cannot be guaranteed to be free of cracks. Occasionally, the recommended coating thickness can be up to 300 μm [11]. After activation, the underlying steel is provided corrosion protection coating [10].

The main problem reinforcement protected using epoxide coating is handling, because the coating is very sensitive to mechanical damage. Defects in the coating can arise during deposition and from bending the reinforcing bars, and often in the process of its own production. Dangerous epoxy coating cracking was also seen during prolonged storage at temperatures lower than 10 °C. Another disadvantage is the need to carry out any welding reinforcement before coating, additional joining can be realized only with the use of sleeves. It is also easy to damage the coating at the site of the defect due to corroded samples already anchored in the concrete [10,12].

There are a number of problems associated with the use of reinforcing concrete with epoxy coating. The most fundamental problem is an experimentally-verified reduction in bonding with concrete. In some instances, the reduction in bonding of coated reinforcement compared to uncoated reinforcement was only a few percent (6.5%) [13], but some authors report a greater reduction in bonding (20–25%) [14,15].

Reduced bonding of coated reinforcement with concrete is probably due to the emergence of significantly weaker binding interactions, or simply reducing the surface ribs (R) [16]. Some experts also argue that only low material stiffness epoxy coating can reduce the bonding, which must be transferred from the internal forces of steel in concrete [17].

Currently, epoxy protected reinforcement is only used in construction to a limited extent, due to the reduced bonding with concrete. To overcome this deficiency, it is necessary to prolong the