Galvanized Reinforcement in Concrete Structures

An Introduction For Engineers and Designers

EGGA
GALVANIZING EUROPE

Contents

Version 2.0
July 2021

Introduction

Hot dip galvanizing has been used as an optimal solution for prolonging the life of reinforcing steel in concrete for over 100 years. The most common early use of galvanized reinforcing steel was in the construction of concrete water tanks where galvanized wire was used to pre-stress the tank walls. From the 1950s, the use of galvanized reinforcing steel became more common in many countries and by the 1960s and early 1970s a considerable tonnage of reinforcing steel was being galvanized especially for use in bridge and highway construction in the USA. In Australia, the highest profile use of hot dip galvanized reinforcing steel is in the chevron tile assemblies of the Sydney Opera House, installed from 1963 and still intact, clean and free of signs of corrosion. Over the last 25 to 30 years, there has been a steady increase in the worldwide use of galvanized reinforcing steel in a wide variety of concrete construction and exposure conditions.

For example, since 1995 all reinforcing steel on New York Thruway Authority bridge projects has been galvanized. Many bridges throughout the USA undergo periodic testing of the state of the galvanized reinforcing steel that was used in their initial construction and these have all been shown to still be in excellent condition today. In Europe, galvanized reinforcement has been mainly used in particularly aggressive environments so far, such as coastal applications, sewer systems, road tunnels, etc. and to construct tailor-made products for specific projects.

Beyond these applications, the use of galvanized reinforcement can solve technical problems, achieve light and thin designs and enhance architectural design. Galvanized reinforcement is not yet widely used despite its many benefits. This is because there is still little awareness of these benefits: galvanized steel reinforcement can not only represent a very effective solution for clients, it can also be an advantage for constructors and concrete prefabricators in economic, technical and environmental terms.

Today, hot dip galvanized reinforcing steel is recognized as a cost-effective solution for eliminating the effects of carbonation and significantly delaying the onset of chloride-initiated corrosion compared to uncoated reinforcing steel in coastal and industrial environments. Galvanized reinforcing steel is also ideally suited for external façades, precast panel joints and surface elements where freedom from rust staining and spalling is essential.

The continued success of structures built with galvanized reinforcement is in large part responsible for the growing interest in designing with hot dip galvanized reinforcing steel.

The recently completed Mario M. Cuomo Bridge was the largest bridge project in New York state history. The new bridge replaced the previous Tappen Zee Bridge over the Hudson River north of New York City.

The bridge deck of the Mario M. Cuomo Bridge comprises nearly 6000 precast panels, each 3.66m long and 6.7-13.7m wide, for the approach spans and 963 main span deck panels. The panels are joined by pouring concrete around the protruding galvanized steel reinforcement.

Over 27,000 tonnes of galvanized steel reinforcement ensures the long-term durability of the main span towers, approach span piers, abutments and road deck panels of the Mario M. Cuomo Bridge. (Image courtesy of New York State Thruway Authority)

The Cost of Corrosion

A study published in 2016 showed that the global cost of corrosion in 2013 stands at $ 2.5 trillion (EUR 2.16 trillion), corresponding to about 3.4 percent of the global gross domestic product (GDP). The study, which examined the impact of corrosion and its management on the real economy, revealed that applying “best practices” to prevent corrosion damage could result in annual savings of 15-35 percent (EUR 324 to EUR 755 billion).

The Hot Dip Galvanizing Process

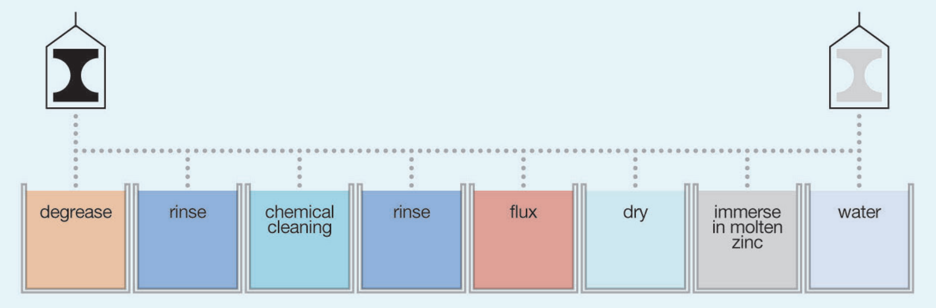
The hot dip galvanizing process begins with superficial cleaning of the steel items to be galvanized by immersing them in a series of pre-treatment tanks. Once cleaned, the steel is lowered into a bath of molten zinc.
The molten zinc reacts with the steel to form the galvanized coating (a metallurgical reaction). Steel bars can be galvanized in batches (for example, by the use of special gabions). In addition, reinforcing mesh that is used to make reinforced armours is typically hung on a jig and dipped into the bath of molten zinc.

The Mario M. Cuomo Bridge is a 5km long, 8 lane twin-span cable stayed bridge designed for a minimum 100-year life using galvanized reinforcement.

Prior to selecting galvanized reinforcing steel for the Mario M. Cuomo Bridge, the New York Thruway Authority developed a Corrosion Protection Plan to identify exposure, degradation mechanisms, design and constructions strategies, and life-cycle costs.

Corrosion causes significant costs to society

By applying best practice to prevent corrosion, global annual savings could be €324 to €755 billion



Typical galvanizing process

Galvanizing is the immersion of clean steel into a bath of molten zinc to apply a metallurgically-bonded coating that has high levels of durability

Corrosion of Uncoated Reinforcing Steel

The highly alkaline environment of concrete allows conventional uncoated reinforcing steel to develop a stable, passive iron oxide film on its surface, which protects the steel from corrosion. However, concrete is an inhomogeneous material, mainly composed of the hydration products of cement (cement paste), sand and aggregates. The inherent porosity of cured concrete provides a pathway for the diffusion of gaseous and aqueous species which, over time, can break down the passivity of the steel and initiate corrosion. Corrosion of reinforcing steel in concrete is initiated when the protective oxide layer on its surface is depassivated. Depassivation can occur by either of these two mechanisms:

1. Carbonation of the concrete
2. Chloride-induced corrosion.

Once corrosion of the reinforcing steel is initiated, corrosion products begin to form on the surface of the reinforcing steel. These products are substantially more voluminous than the steel (rust, which is a product of iron oxidation in reinforcement steel, is characterized by a volume 7 times greater than the volume of iron consumed). This increase in volume from the steel corrosion applies significant tensile stresses to the concrete and eventually causes the formation and propagation of cracks. These cracks in turn provide a pathway for the rapid ingress of aggressive agents to the reinforcing steel, which will accelerate the steel corrosion process, thereby causing damage such as the delamination or spalling of the concrete cover.

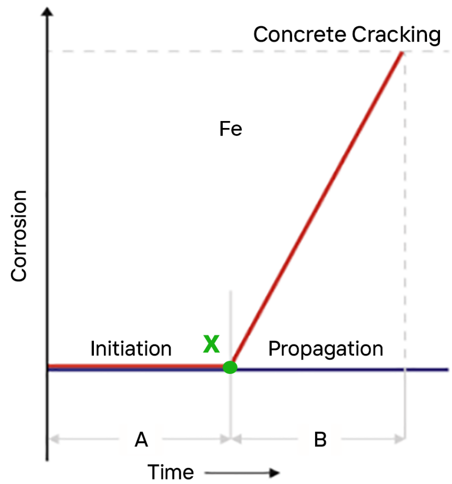
The corrosion process for uncoated reinforcing steel is shown graphically in the adapted Tuutti Model below, where:

A. The initiation stage – the reinforcing steel remains passivated (until the point x).
B. The propagation stage – destruction of the passive layer on the reinforcing steel occurs and the steel is actively corroding. At the end of this time, cracking and spalling of the concrete occur.

The corrosion process is most commonly initiated by either neutralization of the area surrounding the reinforcing steel, e.g. carbonation, or activation of the surface by strongly corrosive anions, e.g. chlorides. The time to corrosion initiation is determined by the concentration and flow rate of penetrating substances into the concrete cover and by the threshold concentration required for corrosion to start.

When reinforcing steel is unprotected, the volume of rust can grow up to 7x greater than the volume of iron consumed by corrosion - leading to formation and propagation of cracks in concrete

Schematic model for the corrosion of reinforcing steel in concrete, after Tuutti 1982




Cracking and spalling of concrete due to corrosion of the reinforcing steel

Carbonation

Carbonation is a natural process that occurs when the high alkalinity of the cover concrete is neutralized due to a reaction with atmospheric carbon dioxide.

Over time the carbonation front migrates through the concrete mass, eventually reducing the pH to near neutral levels (pH 7). As the pH of the concrete drops, the reinforcing steel inside the concrete becomes more susceptible to corrosion.

Typical characteristics of the carbonation of concrete are:

- Carbonation occurs more slowly at deeper concrete depths
- The depth of carbonation depends on the concrete permeability and cracks, voids and pores
- Once the pH of the concrete drops below 11.5 the reinforcing steel will begin to corrode
- The effect and rate of the neutralization is stronger when sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) react with water to form highly acidic solutions. These chemicals are of higher concentration in the environment in industrial areas.

Based on field measurements, the quality of the concrete is critical in reducing the effects of carbonation. Testing has revealed that:

- In good quality structural concrete, carbonation may be seen up to as little as 5–10 mm after 20 years of atmospheric exposure (for example, structural elements of buildings in an urban environment)
- In poor quality concrete, full carbonation of 200 mm thick wall panels (from both sides) occurs in 5 – 8 years (for example, low cost public housing).

Chloride Attack

Chloride-induced corrosion is the single biggest cause of reinforcing steel corrosion and consequential damage to reinforced concrete structures worldwide. Chloride ions can migrate through concrete and build up to the levels required to cause depassivation of the protective film on the surface of the reinforcing steel, thereby initiating corrosion. The chloride ions activate the surface of the steel to form an anode with the remaining passivated surface being the cathode.

Chloride ions then attack the ferrous oxide, forming complexes that move away from the steel and become rust. Newly exposed iron atoms form more ferrous oxides, thus continuing the corrosion process.

Chlorides enter the concrete via:

- Contaminated aggregates, marine sands, and admixtures
- Brackish or saltwater used for mixing and/or curing
- Exposure to marine and coastal environments
- Use of de-icing salts

Chlorides migrate through the concrete over time by diffusion, thereby increasing the chloride concentration at the reinforcing steel surface. A chloride threshold of 0.2 – 0.4% of the cement content (or 0.6 kg/m^3 of concrete) has been identified as the range in which uncoated reinforcing steel can begin to corrode.

Reinforcement and concrete degradation in a high chloride (coastal) environment

Corrosion induced by chlorides is the main cause of corrosion of reinforcing steel

Increasing the Lifespan of Reinforced Concrete

The need to incorporate durability into design, construction and maintenance in order to prevent premature deterioration of concrete structures is well recognized.

The planning of durability consists of the selection and use of materials, design processes and construction methods aimed at guaranteeing the achievement of the service life of the structure envisaged by the customer and excluding premature and unexpected maintenance interventions.

A technical analysis can be used to determine the nature and rate of deterioration of materials under certain macro and micro environmental conditions and to plan the design, construction and maintenance of a concrete structure during its life accordingly.

There are typically three ways to prevent the corrosion of steel in concrete:

1. Modify the concrete

- Supplementary cementitious additions (for example, fly ash, slag and silica fume)
- Impregnation (for example, polymers)
- Inhibitors (for example, nitrates)
- Barrier layers (for example, membranes and paints)

2. Modify the reinforcing steel

- Coated reinforcing steel (for example, galvanized steel)
- Corrosion resistant metals (for example, stainless steel)
- Non-metallic materials (for example, fibre reinforced polymer and glass reinforced polymer fibres)
- Cathodic protection (for example, impressed current and sacrificial anodes)

3. Increase The Concrete Cover

Increasing the concrete cover provides an increase in the time that it takes for the carbonation front to reach the reinforcing steel, and the time taken for the chloride concentration at the surface of the reinforcing steel to reach a critical level.

However, there is a paradox to consider in this approach, as the thicker the concrete cover, the larger the peak value of the expansive pressure from reinforcing steel corrosion and the greater the subsequent size of any cracks.

These three methods may be used individually, or in conjunction with other methods.
Each method has its own advantages and disadvantages. The approach used should be developed based upon the individual situation, environment and required life expectancy of the asset.

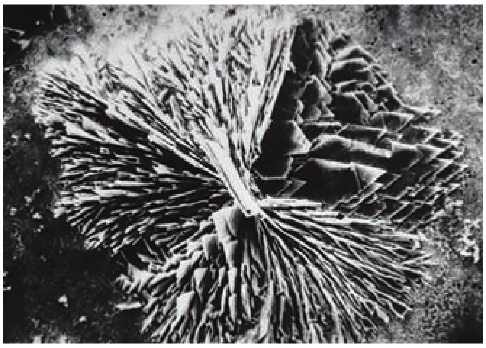
The floating pontoons at the marina at Sandringham, Victoria (Australia) used galvanized reinforcement

Galvanizing provides long term corrosion protection and allows thinner concrete cover – saving resources and costs

Why is Galvanized Reinforcing Steel so Effective?

Formation of the Passive Film

As for uncoated reinforcing steel, galvanized reinforcing steel also forms a protective passivating layer in concrete. Zinc in strongly alkaline solutions (pH 12.5 – 13.2) is passivated by the formation of a layer of adherent crystals of calcium hydroxyzincate – $Ca(Zn(OH)_3)_2 \cdot 2H_2O$. This reaction commences immediately on contact with the wet cement solution, forming a surface film which stabilizes the zinc and isolates it from the surrounding environment. The final products of the passivation are CaHZn crystals on the surface of the galvanized reinforcing steel.

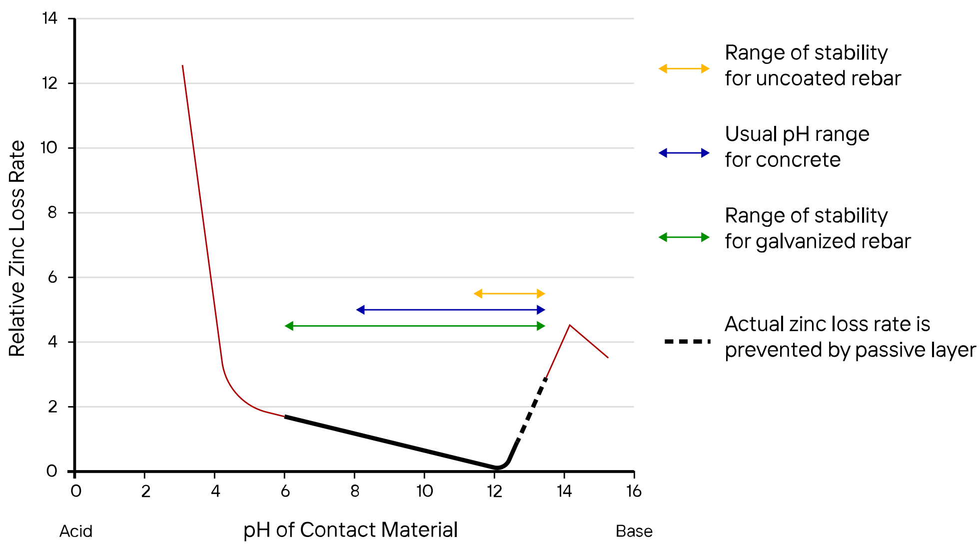


CaHZn crystals after 24 h in $Ca(OH)_2$ solution of pH 12.6

In forming the passive layer, roughly 10 µm of the original pure zinc outer layer of the galvanized coating is consumed. This is a small proportion of the overall coating thickness. The reaction with zinc ceases once the concrete hardens, and after 28 days when the concrete has developed its normal bond and compressive strength, the formation of the calcium hydroxyzincate layer results in galvanized reinforcing steel typically developing a higher bond strength and reduced load-induced slip than equivalent black steel reinforcement.

Galvanized reinforcing steel can develop a higher bond capacity compared to uncoated reinforcing steel

The properties of this passivating layer are key to galvanized reinforcing steel's effectiveness in concrete, particularly its chemical stability at neutral pH and at high chloride concentrations.



The range of pH stability of reinforcement in concrete

Carbonation Resistance

A hot dip galvanized coating has a very low corrosion rate over a wide range of pH values (pH 6 – 12.5). Because of this, galvanized reinforcing steel remains stable as the pH level of the concrete drops due to carbonation over its lifetime. Conversely, uncoated reinforcing steel is only stable in a small range (pH 11.5 – 13.2) and will begin to corrode once the pH level of the concrete drops below 11.5. In concrete with a pH between 12.5 and 13.2 the galvanized reinforcing steel is protected by the formation of the passive layer of calcium hydroxyzincate and this prevents the zinc from experiencing high loss rates in the highly alkaline environment.

Over time the carbonation front migrates through the concrete mass, eventually reducing the pH to near neutral levels (pH 7). As the adjacent figure illustrates, galvanized reinforcing steel is therefore completely unaffected by the carbonation of concrete.

Resistance to Chloride Attack

Galvanized reinforcement has a higher resistance to chloride attack than black reinforcement.

Recent research on this topic (Jaśniok, Sozańska, Kołodziej and Chmiela, 2020) found that: *"Results obtained from corrosion (LPR, EIS) and structural (SEM, EDS) tests on the specimens of concrete reinforced with steel B500SP demonstrated a very favorable impact of zinc coating on rebars by providing effective protection against corrosion in chloride environment".*

An industry-proposed chloride threshold for uncoated reinforcing steel is 0.06% by weight of concrete, based on a 20% chance of corrosion initiation. Galvanized reinforcing steel can tolerate chloride concentrations well above that which causes corrosion of uncoated reinforcing steel, due to the stability of the calcium hydroxyzincate film, and while there is no universal agreement, a literature review on the subject shows the chloride threshold of galvanized reinforcing steel to be 2 – 6 times higher than uncoated reinforcing steel. In general, a conservative value for the critical chloride threshold for galvanized reinforcing steel is considered to be 2 to 2.5 times higher than for uncoated reinforcing steel.

Furthermore, the rate of chloride diffusion through concrete is not consistent, it slows down over time, so in practical terms the higher critical chloride threshold of galvanized reinforcing steel means that the time to corrosion initiation is much greater than for uncoated reinforcing steel – at least twice and in some reports, up to 10 times longer.

Because chloride attack is the single biggest cause of damage to reinforced concrete structures in worldwide infrastructure, it must be carefully considered in any durability plan. Hot dip galvanizing is a simple and cost-effective method to improve the chloride resistance, and therefore the durability, of concrete structures, and its performance relative to uncoated reinforcing steel can be modelled using conventional chloride diffusion models.

An important fact to note is that deterministic chloride diffusion modelling only models the time to corrosion initiation, which is independent of the thickness of the galvanized coating. When considering the propagation phase of corrosion, during which the galvanized coating corrodes at a slower rate than steel, durability is further increased by the thick galvanized coating.

Barrier Protection

Another advantage provided by the zinc coating on galvanized reinforcing steel is that the hot dip galvanizing process provides complete coverage of all surfaces. This metallurgically bonded barrier protection acts as another defense between the steel and the atmosphere. This coupled with the coating's excellent abrasion resistance and toughness makes it ideal for protecting reinforcing steel during transport to site and the construction stage of a project.

Minimal Disruption to Concrete Mass

Should corrosion initiation of the galvanized coating occur, the corrosion process enters the propagation phase. The resulting zinc corrosion products are fine and powder-like, expanding in volume only up to 1.3 times the original zinc volume (compared to uncoated reinforcing steel which expands up to 7 times the original steel volume because of corrosion).

The zinc corrosion products are also more soluble in the alkali pore water and diffuse away from the reinforcing steel and into the concrete matrix, unlike iron corrosion products which won't migrate away from the reinforcing steel until after concrete cracking has occurred. This avoids the build-up of internal pressures which lead to concrete cracking and spalling.

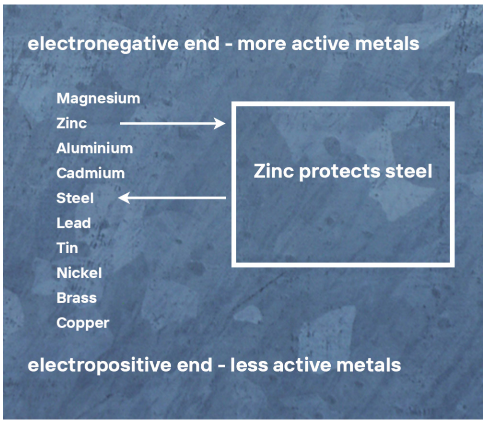
Furthermore, the addition of the microscopic corrosion products to the concrete matrix decreases its permeability by filling pores and voids, thus slowing the supply of aggressive species from the concrete surface to the reinforcing steel. The result of this process is a significant increase in time for the propagation phase of corrosion and a corresponding delay in the time to initiation of cracking of the concrete.

Sacrificial Protection

The galvanic series of metals is a list of metals and alloys arranged according to their relative potentials in each environment. The picture to the right shows a series of metals arranged in order of electrochemical activity in seawater (the electrolyte). The metals are arranged from top to down according to their sacrificial capacity; metals at the top of the scale provide cathodic or sacrificial protection to metals downward.

Zinc is anodic to steel. Therefore, the galvanized coating will provide cathodic protection to exposed steel. When zinc and steel are connected in the presence of an electrolyte, the zinc is slowly consumed while the steel is protected. Zinc's sacrificial action offers protection to the steel in the event of damage during rough handling or site erection.

Zinc protects steel

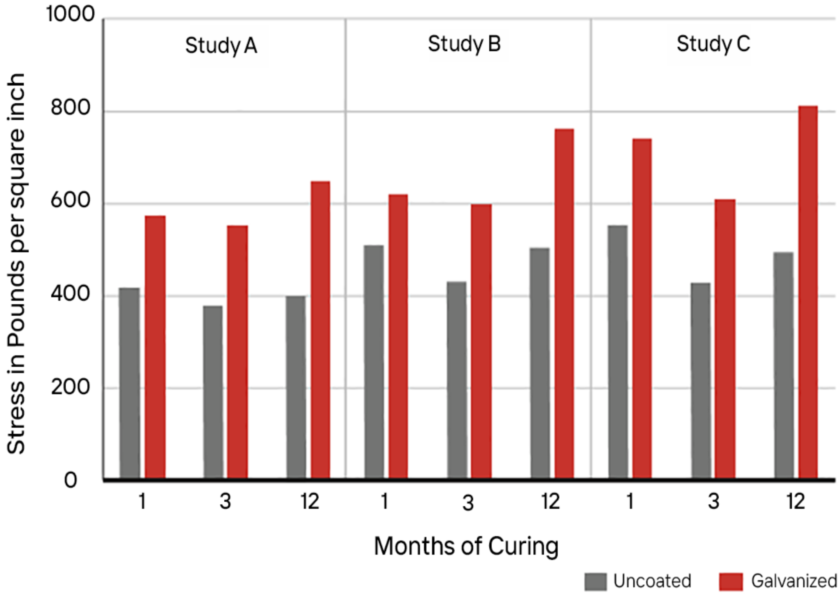


Zinc's position in the galvanic series

Bond Strength

There is extensive evidence that supports the galvanized reinforcing steel's superior bond strength characteristics compared to uncoated reinforcing steel.

The bond strength formed is closely linked to the formation of the passive calcium hydroxyzincate film and, while it has been reported in accelerated tests that the bond strength of galvanized reinforcing steel lags behind that of uncoated reinforcing steel, this effect only lasts for the first 1 – 2 weeks and is related to the initial reaction of zinc to the highly alkaline conditions. After 28 days, when the concrete has developed its normal bond and compressive strength, the galvanized reinforcing steel will develop a higher bond capacity when compared to uncoated reinforcing steel. This is because of the precipitation of the calcium hydroxyzincate film at the reinforcing steel/concrete interface.



Comparing the bond strength of uncoated and galvanized bars (Source: University of California)

Corrosion Profile of Uncoated Reinforcing Steel versus Galvanized Reinforcing Steel

The adapted schematic below showcases the performance of galvanized reinforcing steel compared to uncoated reinforcing steel in concrete.

The higher chloride threshold of galvanized reinforcing steel and its immunity to the effects of carbonation delay the onset of corrosion initiation (shifts point x to point y) of the corrosion process. The barrier protection offered by zinc, combined with the minimal disruption of the zinc corrosion products, serve to extend the propagation phase of the process.

Each stage of corrosion is outlined below:

A. The initiation stage – the period in which the concrete is progressively exposed to corrosive products (chlorides / carbonation) and the uncoated reinforcing steel remains passivated (until the point x). The time to corrosion initiation can be quantified by deterministic chloride diffusion and carbonation models (only required for uncoated reinforcing steel) that are based on Fick's Second Law.

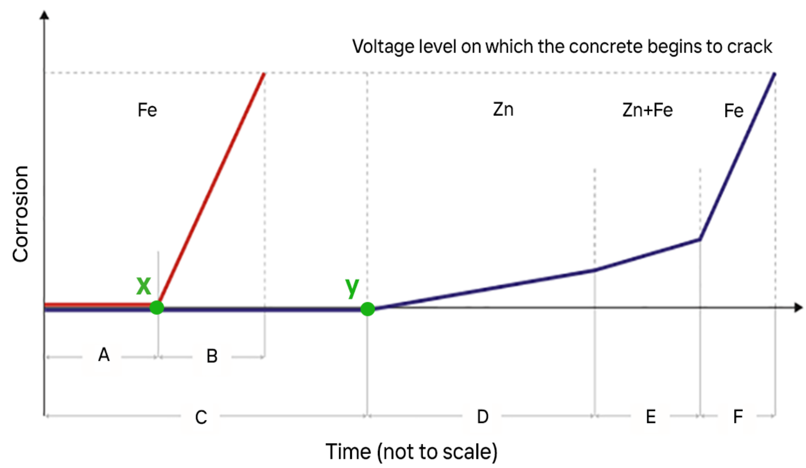
B. The propagation stage – Destruction of passivating layer on the uncoated reinforcing steel and corrosion of reinforcing steel to the acceptable limit of concrete deterioration. At the end of this time cracking and spalling of the concrete occurs.

C. The service life of the galvanized reinforcing steel passivating layer. The corrosion initiation stage is extended due to the increased tolerance to chloride attack and the complete avoidance of depassivation from concrete carbonation.

D. The period of protection of the galvanized reinforcing steel from rust as chlorides attack a small portion of pure zinc layer on the steel surface and corrosion products diffuse away from the reinforcing steel.

E. The period of additional protection where corrosion causes dissolution of the FeZn alloy layers.

F. By this stage all of the galvanized coating is consumed and the corrosion rate of the reinforcing steel becomes identical to that of the exposed uncoated reinforcing steel in stage B – however by this stage the galvanized coating has done its job and the time to initiation of concrete cracking has been increased significantly.



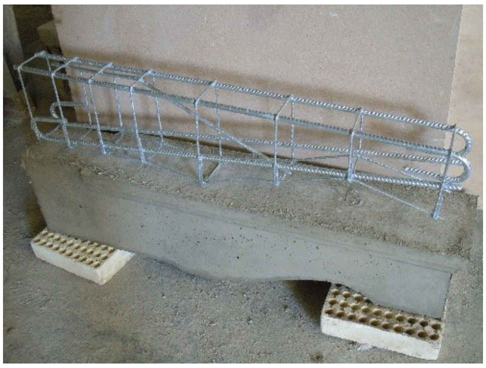
Schematic model for the corrosion of galvanized reinforcing steel in concrete, after Tuutti 1982

Design Advantages

A hot dip galvanized coating on reinforcing steel provides a significant increase in the durability of steel reinforced concrete structures. The formation of a passive calcium hydroxyzincate film on the galvanized reinforcing steel surface significantly increases the critical chloride threshold of the reinforcing steel, thereby significantly delaying the time to corrosion initiation. This delay in corrosion initiation may be quantified using conventional deterministic chloride diffusion models based on Fick's Second Law.

Time to corrosion initiation is further increased as galvanized reinforcing steel is immune to the effects of carbonation. Should the galvanized reinforcing steel be depassivated, the resulting zinc corrosion products are much less voluminous than the iron corrosion products formed on uncoated reinforcing steel, and thus cause minimal disruption to the concrete mass. This avoids the build-up of internal pressures which lead to concrete cracking and spalling.

The addition of the microscopic zinc corrosion products to the concrete matrix decreases its permeability by filling pores and voids, thus slowing the supply of aggressive species from the concrete surface to the reinforcing steel. The result of this process is a significant increase in time for the propagation phase of corrosion and a corresponding delay in the time to initiation of cracking of the concrete.



Hot dip galvanized steel reinforced concrete support beams for the balconies of an elegant apartment in Genoa. Galvanized steel reinforcement was chosen to best preserve the support beams of the balconies over time, in particular to protect them from smog, rain, frost and humidity. (Images courtesy of Prefabbricati Torti di Pietro e Lino Torti snc)

A hot dip galvanized coating provides a significant increase in the durability of reinforced concrete structures

Specifying a Galvanized Coating for Reinforcing Steel

Galvanized reinforcing steel is specified according to EN 10348-2:2019 (Steel for the reinforcement of concrete - Galvanized reinforcing steel - Part 2: Galvanized reinforcing steel products). EN 10348-2 gives requirements for galvanized reinforcing steel products that have been manufactured from bars that have met the requirements of EN 10080.

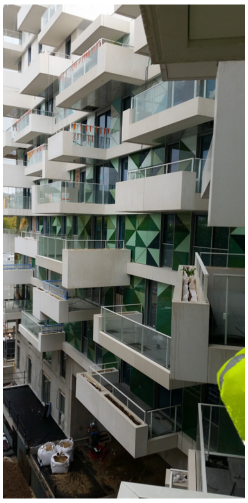
Requirements for galvanizing of the bars are in accordance with the international standard for batch galvanizing – EN ISO 1461, with the exception that coating thickness requirements for reinforcing steel products are specifically defined as follows in the table to the right.

EN 10348-2 also ensures that the rib geometry (rib height or indentation depth) is satisfactorily retained after galvanizing. To avoid the possible effects on the mechanical properties, the standard sets minimum bend diameters for bars that are bent before galvanizing.

Coating thickness requirements of EN 10348-2:2019

Steel diameter (mm)	Coating mass (g/m²)	Coating thickness (µm)
> 6	610	85
≤ 6	505	70

The Cost of Galvanized Reinforcing Steel



Galvanized reinforcement has been used for the pre-cast white concrete planter-style balconies in the Zac Seguin Housing Project in the West of Paris. This solution was chosen to ensure that the appearance of the white pre-cast concrete elements did not suffer from rust stains over time. The use of galvanized reinforcement also allowed the reduction of the concrete cover to facilitate an improved thin design. (Images courtesy of Aldric Beckmann Architectes/ Françoise N'Thépé Architecture & Design. Paris)

The overall cost in using galvanized reinforcing steel in concrete construction depends largely on the extent to which it is used throughout the structure. For example, it is rarely necessary for the structural core or internal elements of a high rise building or the deeply embedded components of large abutments and foundations to be galvanized. In these situations, it may only be necessary to use galvanized reinforcing steel in surface exposed elements or where foundations may be affected by aggressive or fluctuating groundwater.

In building construction, it is generally found that the cost of galvanizing increases the overall cost of concrete as placed by about 6–10% depending on the size and type of reinforcing steel used, the galvanizing price and the quantity of steel per cubic meter of concrete.

On average, the cost of the reinforcing steel would not be more than about 25% of the total cost of the concrete as placed. Considering that the cost of the structural frame and skin of a building normally represents only about 25–30% of total building costs, the additional cost of galvanizing reduces to between 1.5–3.0% of total building costs.

This premium reduces to as little as 0.5–1.0% if galvanizing is restricted to surface panels only. When taken against the total project cost or final selling price, the added cost of galvanizing becomes very small indeed, often not more than 0.1–0.2%.

An analysis in 2017 by Professor Richard Weyers, Virginia Tech University, examined the diffusion of chloride into concrete decks and its effects on service life in Virginia, USA for epoxy-coated reinforcing steel, batch galvanized reinforcing steel, and 316LN stainless steel reinforcing steel. The total present cost and life-cycle cost figures show that galvanized reinforcing steel provides the most cost-effective protection for reinforced bridge decks with a 100-year life.

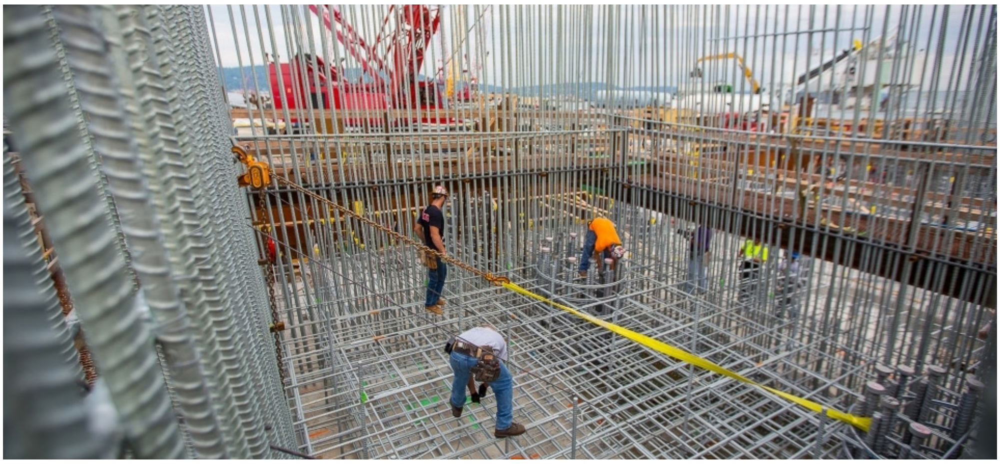
When the costs and consequences of corrosion damage to a reinforced concrete building are analyzed, this extra cost of galvanizing is a very small investment for superior long-term corrosion protection.

Bending, Welding, Repair, Handling, Transport and Storage

Guidance and requirements on bending, welding, repair and other processing aspects are given in EN 10348-2:2019.

Due to the improved durability of the galvanized coating, no special handling or care is necessary when transporting galvanized reinforcing steel but some recommendations for transport include:

- The use of chains, wire ropes or cables to lift is acceptable;
- Bundles should be lifted at multiple pick-up points;
- The use of a spreader bar is recommended to prevent unnecessary bar-to-bar abrasion in longer bundles;
- No special placement is necessary, although the reinforcing steel and mesh should be stacked to allow for drainage and air flow to avoid early wet storage stain;
- As the coating is not sensitive to UV light it can be stored anywhere on site.



Installation and Cover

Due to the excellent abrasion resistance of galvanized reinforcing steel no special requirements are needed when installing it on site. This, in conjunction with galvanized reinforcing steel's improved bond strength, means that no extra steel needs to be installed (some protective coatings require overlap lengths that are an additional 20% – 50% greater compared to uncoated reinforcing steel).

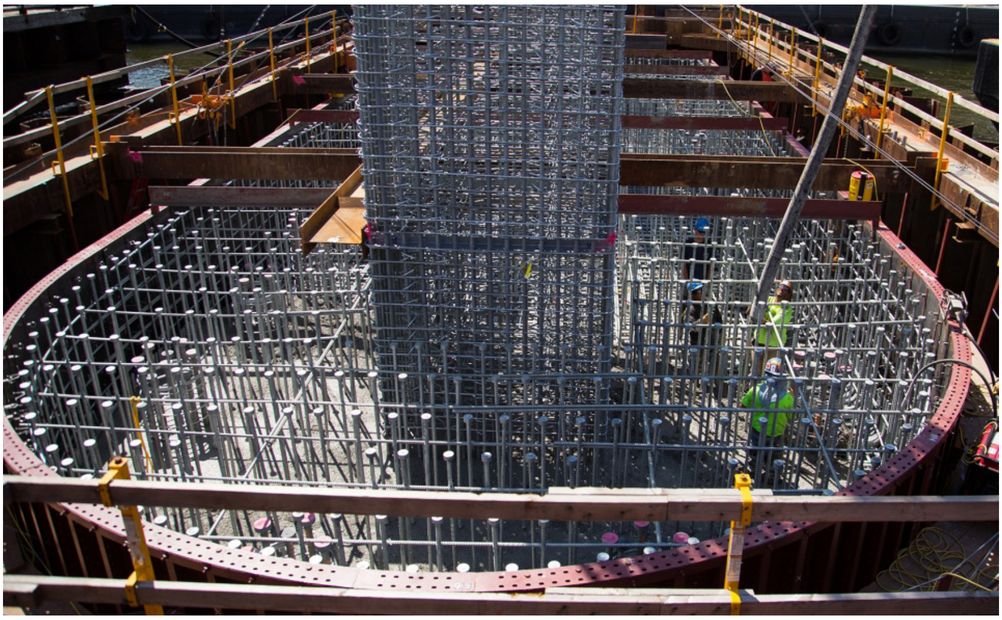
Like uncoated reinforcing steel, no specific weather conditions are required for installation and due to the surface coating, galvanized reinforcing steel is much cleaner to work with. Also, because the coating is metallurgically bonded with the steel, little damage is created during installation.

Mixing Hot Dip Galvanized and Uncoated Reinforcing Steel

In concrete, corrosive reactions would not be expected to occur between uncoated and galvanized reinforcing steels so long as the two metals remain passive. To ensure this is the case, the concrete cover over uncoated reinforcing steel and connections should not be less than the cover required to protect uncoated reinforcing steel alone under similar conditions.

Where hot dip galvanized reinforcing steel is used it is best practice that all steel in contact with the reinforcing steel should be galvanized including tie wire, inserts and bar chairs or that non-metallic or plastic-coated ties and bar chairs be used. If hot dip galvanized reinforcing steel is placed in contact with uncoated reinforcing steel in areas prone to corrosion, the coated steel will sacrificially protect the uncoated steel, resulting in a reduction in the life of the coating near the area of contact.

Should contact with uncoated reinforcing steel be unavoidable and a concern, polyethylene and dielectric tape can be used to provide electrical insulation between the two metals. Galvanized tie wire or plastic clips should be used when assembling or installing galvanized reinforcing steel and bar supports also should be galvanized steel, plastic, or some other inert material such as masonry. If mechanical couplers are being used, they should be galvanized as well.



The 43 pairs of concrete piers of the Mario M. Cuomo Bridge are reinforced by galvanized reinforcing steel cages.

Reasons to Use Hot Dip Galvanized Reinforcing Steel

1 Galvanized reinforcing steel is passivated in wet concrete by the formation of an adherent film of calcium hydroxyzincate. In forming this film, **the bond strength between the galvanized reinforcing steel and concrete is increased.**

2 Galvanized reinforcing steel is stable over a wide pH range and is **completely unaffected by the carbonation of concrete.**

3 Conservatively, galvanized reinforcing steel has a 2 to 2.5 times higher threshold to chloride attack when compared to uncoated reinforcing steel – this more than doubles the time to reinforcing steel depassivation and corrosion initiation. Typically, galvanized reinforcing steel **increases the service life of the structure by 4 to 5 times** when compared to uncoated reinforcing steel.

4 The **time to corrosion initiation of galvanized reinforcing steel in concrete can be modelled** using conventional industry chloride diffusion models based on Fick's Second Law.

5 The passive behaviour of galvanized reinforcing steel in concrete makes it suitable for use in aggressive environments and is ideally suited for external facades, precast panel joints and surface elements, indeed **any application where carbonation or chloride ingress is of concern.**

6 In applications affected by carbonation exposures, **galvanized steel allows the option for a thinner cover** to be used compared to uncoated reinforcing steel while achieving the same durability. There are no special requirements for the design of concrete using galvanized reinforcing steel and no extra steel or overlay is required.

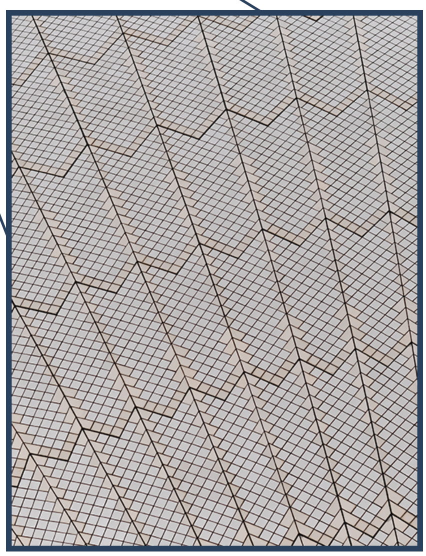
7 Should galvanized reinforcing steel become depassivated, zinc will corrode at a slower rate than iron, and the zinc coating provides a barrier to iron corrosion. Unlike iron, zinc corrosion products will migrate from the galvanized coating, and by reducing the porosity, will slow down the rate of chloride ingress. The relatively smaller volume of zinc corrosion products compared to iron, lessens the expansive pressure generated by the corrosion process, thereby **reducing the size of any cracks which may form.**

8 Galvanized reinforcing steel is an effective way to ensure the durability of a concrete structure at a **much lower capital cost than using stainless steel reinforcement.**

9 Galvanized reinforcing steel **doesn't have the ongoing testing and maintenance costs** associated with cathodic protection systems.

10 Unlike epoxy coatings, a galvanized coating on reinforcing steel provides **barrier protection, improved bond strength, a superior passivating layer and acts as a sacrificial anode should the reinforcing steel beneath the coating be exposed. It has excellent abrasion resistance, is unaffected by UV light and has no special requirements for storage, transport, handling and fixing.**

11 The galvanizing process has **no significant effect on the mechanical properties of reinforcing steel,** and all available grades may be successfully galvanized.



The chevron tile assemblies of the Sydney Opera House were built with hot dip galvanized reinforcing steel.

12 **Galvanizing is a sustainable option**. An Environmental Product Declaration (EPD) is available for galvanized steel, and at the end of the life of the structure, any remaining zinc coating may be recycled along with the steel. The small environmental impact of the galvanizing process is offset by the huge CO_2 savings associated with the increased durability of the galvanized steel reinforced concrete structure.

References

American Galvanizers Association, Hot-Dip Galvanized Reinforcing Steel: A Specifiers Guide, AGA, Centennial, CO, USA, 2012.

Concrete Institute of Australia, The Use of Galvanized Reinforcement in Concrete, Current Practice Note 17, 2008, Concrete Institute of Australia, Sydney.

Concrete Institute of Australia (2014), "Concrete Durability Series: Z7/05 Durability Modelling", Sydney.

Concrete Institute of Australia (2018), "Concrete Durability Series: Z7/02 Durability Exposure Classifications", Sydney.

ILZRO, Galvanized Reinforcement for Concrete – II, 1981, International Lead Zinc Research Organization, NC, USA

Mariusz Jaśniok, Maria Sozańska, Jacek Kołodziej and Bartosz Chmiela, "A Two-Year Evaluation of Corrosion-Induced Damage to Hot Galvanized Reinforcing Steel B500SP in Chloride Contaminated Concrete", 2020

NACE International, "International Measures of Prevention, Application and Economics of Corrosion Technology (IMPACT)", CORROSION CONFERENCE 2016, Vancouver, Canada

Tuutti, K. (1982) "Corrosion of steel in concrete". Swedish Cement and Concrete Research Institute, Stockholm

Yeomans S R (Editor), Galvanized Reinforcing Steel in Concrete, Elsevier UK, December 2004, ISBN 008044511

Yeomans, S R (2004), "Chapter 1 – Galvanized Steel in Concrete: An Overview", in Yeomans, S R (ed.) Galvanized Steel Reinforcement in Concrete, Elsevier Science, pp. 1–7.

Zhao Y, Jin W, Damage Analysis and Cracking Model of Reinforced Concrete Structures with Reinforcing steel Corrosion in Steel Corrosion-Induced Concrete Cracking, 2016

Acknowledgements

Image credits

Cover, pages 1, 2, 9, 10:	New York Thruway Authority
Pages 3, 4, 5, 7:	Galvanizers Association of Australia
Page 3, 4:	Shutterstock.com
Page 11:	stock.adobe.com

Our thanks to the Galvanizers Association of Australia for their helpful assistance in preparation of this document.

Further Information on Galvanized Reinforcement for Concrete:

European General Galvanizers Association

14-16 Reddicroft
B73 6AZ
United Kingdom

Boulevard du Souverain 68
1170 Brussels
Belgium

www.egga.com
Email: mail@egga.com

EN ISO 1461

EGGA GALVANIZING EUROPE

© 2021 EGGA