

Reinforcing the Future: The Case for Galvanized Rebar in Concrete

Abstract

The durability and longevity of concrete structures are significantly influenced by the quality of the reinforcing steel used within them. While traditional bare steel rebar has been the industry norm for decades, the advent of hot dip galvanized rebar offers a compelling alternative that provides superior corrosion resistance and enhanced structural integrity.

This presentation will delve into the intricacies of hot dip galvanizing, a process that involves immersing steel rebar in molten zinc to create a protective zinc coating. The zinc layer acts as a sacrificial anode, protecting the underlying steel from corrosion by preferentially corroding itself. This mechanism ensures that the rebar remains intact, even in harsh environmental conditions.

The benefits of using galvanized rebar in concrete are multifaceted. Firstly, its exceptional corrosion resistance extends the service life of concrete structures, reducing the need for costly maintenance and repairs. Secondly, galvanized rebar can enhance the bond strength between the rebar and concrete, leading to improved structural performance. Additionally, galvanized rebar can contribute to sustainable construction practices by reducing the environmental impact associated with premature failure and replacement of concrete structures.

The presentation will explore the factors that influence the selection of galvanized rebar in concrete construction projects, including environmental conditions, design requirements, and cost-benefit analysis. Case studies of successful implementations of galvanized rebar will be presented to illustrate its effectiveness in various applications, such as bridges, buildings, and infrastructure projects.

In conclusion, this presentation will make a compelling case for the adoption of galvanized rebar as a preferred choice for reinforcing concrete structures. By understanding the advantages of galvanized rebar, engineers, contractors, and developers can make informed decisions to ensure the long term durability and sustainability of their projects.

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1.0 Introduction

Concrete, a ubiquitous material in modern construction, is renowned for its durability and strength. However, its longevity is often compromised by the corrosion of the reinforcing steel within it. This phenomenon can lead to structural degradation, safety risks, and costly repairs. To mitigate these issues, various corrosion protection methods have been developed. One such approach, gaining widespread acceptance, is the use of hot dip galvanized steel reinforcing bars (rebar).

This review will examine the mechanisms by which hot dip galvanized rebar protects against premature corrosion of the steel and how it contributes to the durability of concrete structures. It will explore the principles of hot dip galvanizing, the corrosion processes that affect concrete, and the synergistic interaction between galvanized rebar and concrete that enhances structural integrity.

2.0 Understanding Corrosion

Before discussing the protective properties of galvanized rebar, it is necessary to understand the mechanisms of steel corrosion. Corrosion is a natural process that occurs when a metal reacts with its environment. In the case of steel, it involves the oxidation of iron, the primary component of steel. This oxidation results in the formation of rust, a porous, hydrated iron oxide that weakens the steel's structural integrity.

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2.1 Several factors can influence the rate of steel corrosion, including:

- **Exposure to Oxygen:** Oxygen is a key reactant in the corrosion process. When steel is exposed to oxygen, it reacts to form iron oxides.
- **Presence of Water:** Water acts as an electrolyte, facilitating the movement of ions and accelerating the corrosion process.
- **pH:** The pH of the environment can influence the rate of corrosion. Acidic conditions tend to promote corrosion, while alkaline conditions can inhibit it. In the case of steel rebar in concrete, the alkaline nature of cement paste prevents the corrosion of steel.
- **Electrolyte Concentration:** The presence of chlorides, salts, acids, or other electrolytes in the environment can increase the conductivity of water, thereby enhancing corrosion.

3.0 The Role of Galvanized Rebar

Hot dip galvanizing is a metallurgical process that involves immersing steel in a bath of molten zinc. The resulting zinc coating provides a durable and protective barrier against corrosion. The galvanizing process involves several key steps:

1. **Surface Preparation:** The steel is thoroughly cleaned by acid pickling and alkaline degreasing, so as to remove any contaminants, such as dirt, grease, or mill scale, that could interfere with the zinc galvanizing process.
2. **Fluxing:** A flux is applied to the cleaned steel to prevent the formation of zinc oxide during the dipping process.

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3. **Dipping:** The steel is submerged in a molten zinc bath, typically at a temperature of around 450°C. The zinc reacts with the steel's surface to form a series of zinc-iron alloy layers.

4. **Cooling:** The galvanized steel is then removed from the zinc bath and allowed to cool. The zinc coating solidifies, forming a tightly bonded, protective layer.

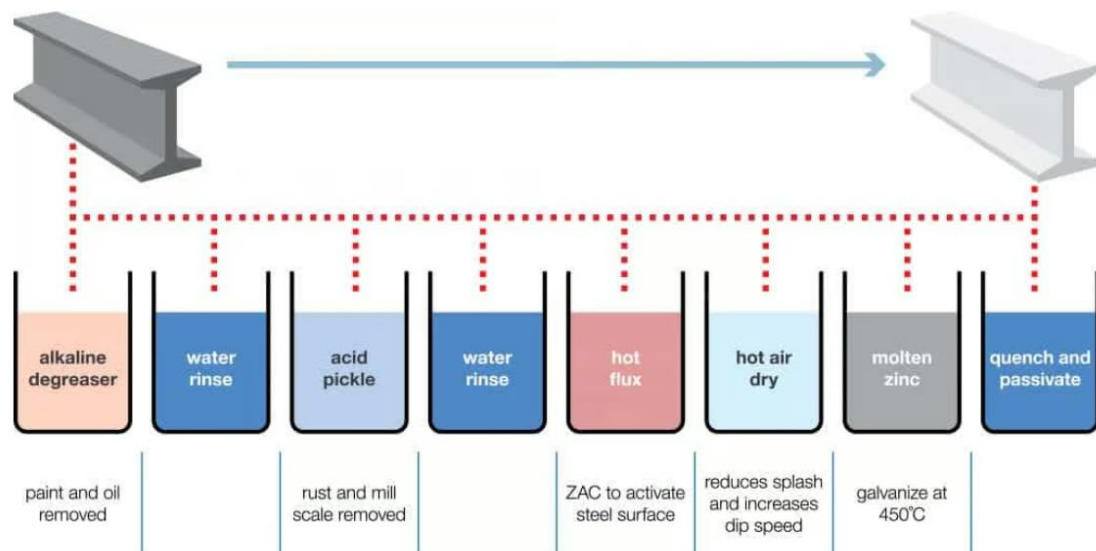
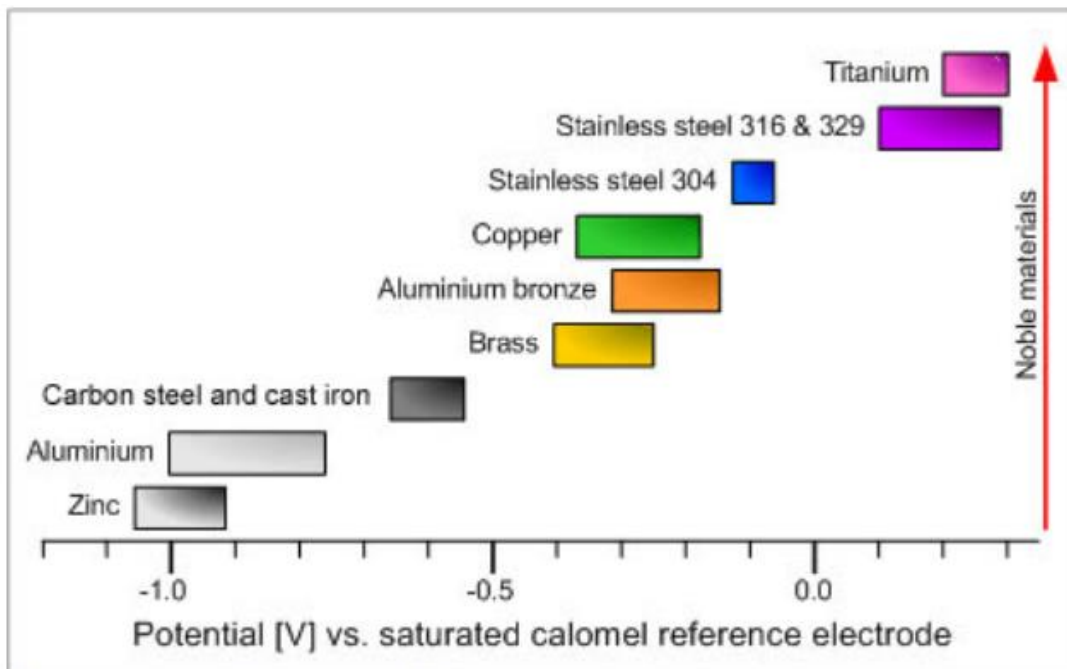


Fig 1 – the hot dip galvanizing process (courtesy Galvanizing Australia)

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Galvanic series for metals in sea water

Fig 2 – the position of Zinc used in galvanizing shown in the Galvanic Series

The zinc coating on galvanized rebar offers several mechanisms to protect against corrosion:

1. **Barrier Protection:** The zinc coating acts as a physical barrier, preventing the direct contact of corrosive agents with the underlying steel.
2. **Sacrificial Protection:** Zinc is more reactive than steel. When exposed to corrosive environments, the zinc will corrode preferentially, protecting the steel. This is known as sacrificial protection or galvanic protection.
3. **Self-Healing Properties:** If the zinc coating is damaged, the zinc-iron alloy layers can react with the environment to form a new, protective layer, helping to maintain corrosion resistance.

4.0 The Physico-Chemistry of Cement

Cement, a fundamental component of concrete, is a finely ground, hydraulic material that binds with water to form a hard, durable mass. Its unique properties are a result of complex chemical and physico-chemical processes.

4.1 The Chemical Composition of Cement

Cement is primarily composed of calcium silicates, aluminates, and ferrites. The most common types of cement are Portland cement and blended cement. Portland cement is typically composed of:

- **Tricalcium silicate (C3S):** The primary component responsible for early strength development.
- **Dicalcium silicate (C2S):** Contributes to long-term strength and durability.
- **Tricalcium aluminate (C3A):** Reacts rapidly with water, generating heat and contributing to early strength.
- **Tetracalcium aluminoferrite (C4AF):** Similar to tricalcium aluminate but reacts more slowly.

Blended cements incorporate additional materials, such as fly ash, slag, or silica fume, to enhance specific properties like strength, durability, or environmental sustainability.

4.2 The Chemistry of Hydration

When cement is mixed with water, a process known as hydration occurs. During hydration, the calcium silicates, aluminates, and ferrites react with water to form a complex mixture of hydrated compounds, including calcium silicate hydrates (C-S-H), calcium hydroxide (CH), and calcium aluminate

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hydrates. The formation of calcium hydroxide results in the pH of cement being alkaline in which pH regime steel does not corrode.

The formation of C-S-H is crucial for the development of strength and durability in concrete. C-S-H is a gel-like material that fills the voids between the cement particles, creating a strong, interconnected network.

4.3 Physico-Chemical Properties of Cement

- **Hydraulic Property:** Cement's ability to set and harden underwater or in moist environments is known as its hydraulic property. This is due to the chemical reactions that occur between the cement and water.
- **Setting Time:** The time required for cement paste to lose its plasticity and become firm is known as its setting time. This is influenced by factors such as the type of cement, water-to-cement ratio, and temperature.
- **Strength Development:** The strength of cement-based materials increases over time as the hydration process continues. The rate of strength development depends on factors such as the type of cement, water-to-cement ratio, and curing conditions.
- **Heat of Hydration:** The hydration process releases heat, which can affect the setting and hardening of cement. Excessive heat generation can lead to cracking or other defects in concrete.
- **Shrinkage and Cracking:** Cement-based materials tend to shrink as they dry and harden. This shrinkage can cause cracking, especially in large structures or under extreme environmental conditions.

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4.4 Factors Affecting Cement Performance

- **Water-to-Cement Ratio:** The ratio of water to cement significantly affects the properties of concrete. A higher water-to-cement ratio can result in lower strength, increased permeability, and greater susceptibility to cracking.
- **Curing:** Proper curing is essential for the development of strength and durability in concrete. Curing involves maintaining a moist environment to allow the hydration process to proceed effectively.
- **Temperature:** Temperature can influence the rate of hydration and the final properties of concrete. Extreme temperatures can accelerate or retard the setting and hardening process.
- **Admixtures:** Admixtures are substances added to concrete to modify its properties. They can be used to improve workability, strength, durability, or other characteristics.

The physico-chemistry of cement plays a crucial role in determining the properties and performance of concrete. Consequently, steel rebar when placed in cement paste is exposed to alkaline conditions and does not corrode however if the physico-chemical condition of the cured concrete is changed by the diffusion of chlorides into concrete or the carbonation of the concrete, then the rebar experiences not a pH > 13.0 but a decreasing pH below pH = 11.0 and steel corrosion will follow. This is when galvanized rebar comes into its own.

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5.0 Corrosion Mechanisms in Concrete

Concrete, while generally durable, is susceptible to corrosion due to various factors:

1. Carbonation

Carbonation in concrete occurs when carbon dioxide from the atmosphere penetrates the concrete and reacts with the calcium hydroxide present within it. This reaction forms calcium carbonate, which is less alkaline than the original calcium hydroxide. As the alkalinity of the concrete decreases, it becomes more susceptible to corrosion. The reinforcing steel within concrete is typically protected by a passive layer of iron oxide. This layer is maintained by the alkaline environment provided by the concrete.

However, when carbonation reduces the alkalinity, the passive layer becomes unstable, making the steel vulnerable to corrosion.

Corrosion of the reinforcing steel can lead to a variety of problems, including:

Cracking: Corrosion can cause the steel to expand, leading to cracking of the concrete.

Spalling: The concrete may spall or flake away from the reinforcing steel.

Loss of strength: Corrosion can weaken the structural integrity of the concrete.

To prevent carbonation and the associated corrosion, it is important to use high-quality concrete, ensure proper curing, and consider corrosion protection measures such as using galvanized rebar or applying protective coatings.

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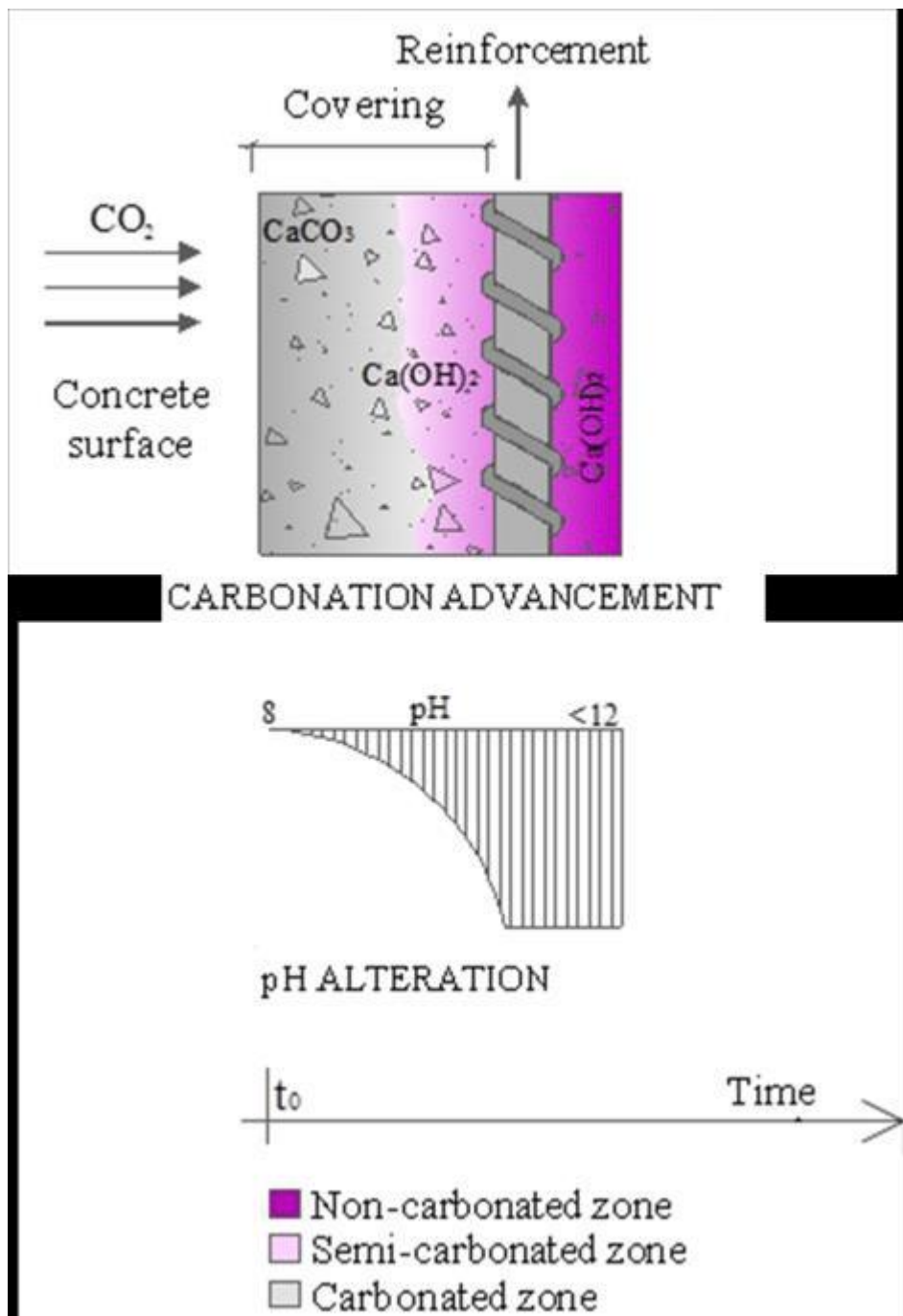


Fig 2 – Representation based on the advance of carbonation and pH change in concrete over time- E. Possan et al. Case Studies in Construction Materials 6 (2017) 147–161

2. **Chlorides:** Chlorides, often introduced through sea spray, water or concrete admixtures, can penetrate the concrete and attack the reinforcing steel. Chlorides disrupt the protective passive layer on the steel, initiating corrosion. The rate of chloride-induced corrosion is influenced by factors such as the concentration of chlorides, the permeability of the concrete, and the presence of cracks or fissures.

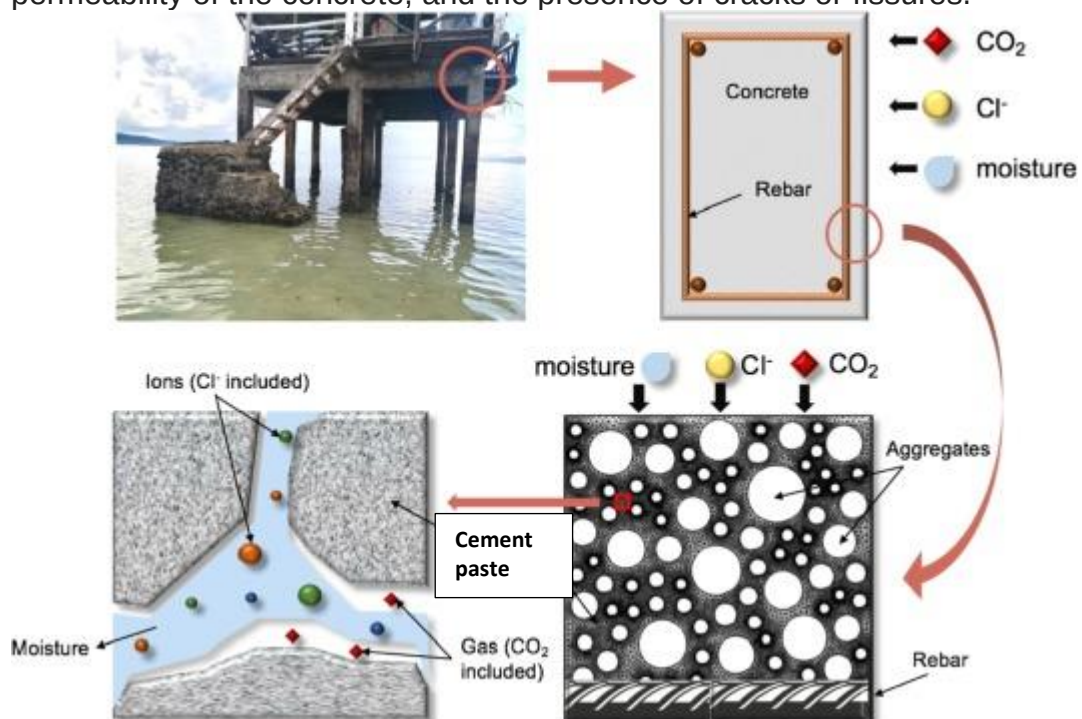


Fig 3 – carbonation and chlorination from Shen et al- *Ocean Engineering*
Volume 189, 1 October 2019, 10

3. **Sulfates:** Sulfates, present in certain soils and water sources, can react with the calcium aluminate hydrates in concrete, causing expansion and cracking. This can facilitate the ingress of moisture and chlorides, accelerating corrosion. Sulfate attack is particularly prevalent in areas with high sulfate concentrations in the soil or groundwater.

6.0 Factors Promoting Corrosion of Steel in Concrete

Several factors can promote the corrosion of steel in concrete:

- **Concrete Quality:** Poor concrete quality, characterized by low strength, high permeability, or inadequate curing, can increase the risk of corrosion.
- **Environmental Factors:** Exposure to aggressive environments, such as those with high levels of carbon dioxide, chlorides, or sulfates, can accelerate corrosion.
- **Design Flaws:** Inadequate design or construction practices, such as insufficient cover for reinforcing steel or the use of incompatible materials, can contribute to corrosion.
- **Maintenance and Repair:** Neglecting maintenance and repair activities can allow corrosion to progress unchecked, leading to more severe structural damage.

7.0 The Synergistic Interaction Between Galvanized Rebar and Concrete

The combination of galvanized rebar and concrete creates a synergistic effect that enhances corrosion protection:

1. **Alkaline Environment:** Concrete provides an alkaline environment that inhibits corrosion. The high pH level helps to maintain the passive layer on the steel, even if the zinc coating is damaged. However, if due to carbonation the concrete pH is reduced to the level where steel corrosion is likely the zinc galvanizing coating provides galvanic protection of the steel and also forms a passive calcium hydroxy zincate payer.

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2. **Cracking Resistance:** Galvanized rebar's superior corrosion resistance can help to prevent the initiation and propagation of cracks in concrete, reducing the risk of chloride ingress and further corrosion.
3. **Long-Term Durability:** By providing effective corrosion protection, galvanized rebar contributes to the long-term durability and serviceability of concrete structures.

4.

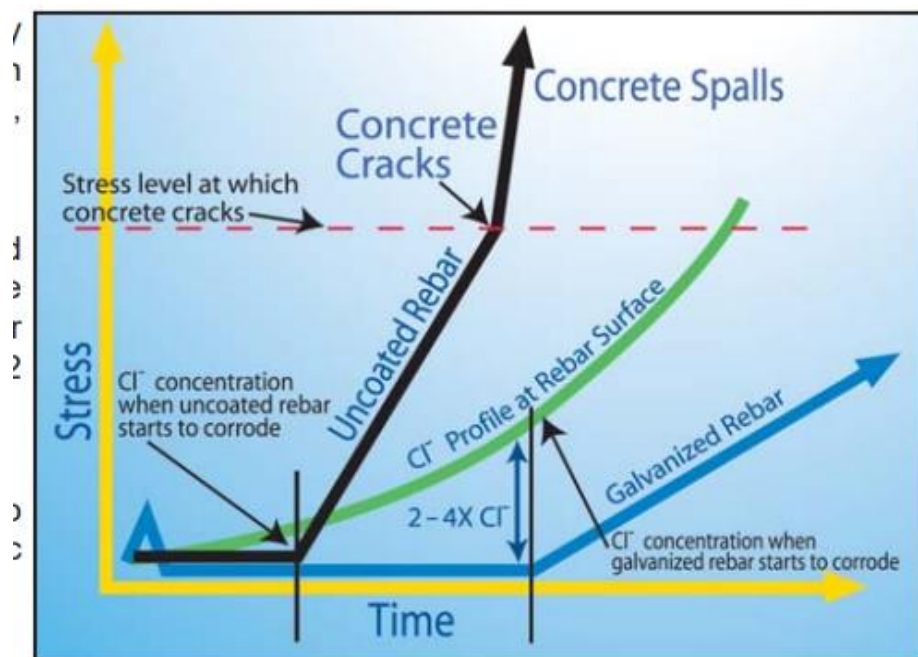


Fig 4....comparison between galvanized & ungalvanized rebar in concrete (courtesy American Galvanizers Association & Yeomans, S – Galvanized steel rebar in concrete 2004)

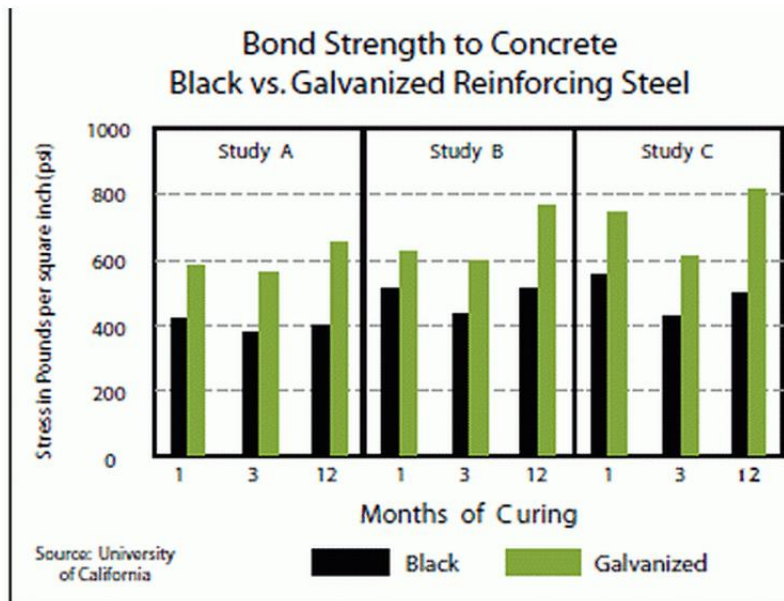


Fig 5 – Data from 3 studies showing the improved bond strength to concrete of galvanized rebar as compared to ungalvanized black steel (courtesy IZA USA)

To illustrate the benefits of galvanized rebar in concrete structures, let's examine a few case studies:

- Bridge Construction:** In coastal areas, bridges are exposed to harsh environments with high levels of humidity, salt, and chlorides. Galvanized rebar has been successfully used in bridge construction to ensure long-term durability and prevent corrosion-related failures. All new bridge construction or repair in the City of Cape Town South Africa is required to utilise zinc galvanized rebar.
- Parking Garages:** Parking garages are subjected to de-icing salts, traffic related pollutants, and other corrosive agents. Galvanized rebar can help to protect the reinforcing steel in parking garages, preventing structural damage and ensuring the safety of users. This is a phenomenon seen in the USA, Europe and elsewhere in cold climates but not in South Africa where the main source of chlorides is at the coast.

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Fig 6- a new concrete sea front at Clovelly, Cape Town SA where the entire sea facing retaining concrete wall contains hot dip galvanized rebar (author)

- **Marine Structures:** Structures exposed to seawater, such as piers and docks, are particularly vulnerable to corrosion. Galvanized rebar provides excellent protection against marine corrosion, extending the service life of these structures.

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Fig 7- the new sea front retaining wall at Clovelly, Cape Town showing close proximity to the sea in False Bay & exposed to very corrosive south east wind. An ISO 9223 -C5M environment.

All the concrete contains galvanized rebar. (author)

In conclusion

Hot dip galvanized steel reinforcing offers a reliable and effective solution for protecting concrete structures against premature corrosion. The zinc coating provides a combination of barrier and sacrificial protection (galvanic protection), while the synergistic interaction with concrete enhances the overall durability of the structure. By incorporating galvanized rebar into construction projects, civil engineers and contractors can ensure the long-term performance and safety of their structures.

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