# Use of Galvanized Rebars in RC Structures

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## 1. Introduction

Steel embedded in concrete is normally protected from corrosion due to the presence of a passive film on the surface of the metal. This film forms in the highly alkaline environment of hydrated cement, with a pH >13, and as long as the passive state is maintained the steel will not corrode. To ensure long-term corrosion protection to the steel, the concrete mass must be sufficiently impermeable so as to limit the transport of species such as water, chloride ions, oxygen, carbon dioxide and other gases through the concrete to the depth of the reinforcement. The presence of threshold levels of these species, which are usually carried into the concrete in solution in water, either change the nature of the concrete or alter the condition of the embedded steel.

Chloride ions above threshold concentrations have the effect of depassivating the steel even if the pH of the adjacent concrete remains high. On the other hand, carbon dioxide and other gases which penetrate the concrete mass in aqueous solution react with the alkali-rich pore water - the carbonation reaction – resulting in a lowering of the pH of concrete below the value at which the steel is passivated. Further, in aqueous conditions, the reduction of oxygen at cathodic sites in the corrosion cell is an essential component of the corrosion process and so the rate of supply of oxygen is also important.

Should corrosion of embedded steel in concrete occur physical damage to the concrete mass is likely to follow. Steel corrosion products are quite voluminous and the swelling caused by their presence generates stresses sufficient to exceed the tensile capacity of the concrete (about 3-4 MPa) and as a result the concrete cracks in tension. Such cracks usually run from the bar to the nearest adjacent surface, which may be the edge of a column or precast element or the surface of a slab or beam. Once cracking has occurred, unsightly rust staining of the surface is often observed and further swelling caused by the laying down of more corrosion product usually leads to delamination or the element or spalling of pieces of concrete from the surface.

## 2. Corrosion Prevention in Reinforced Concrete

There can be little doubt that the most cost effective way to minimize the risk of corrosion in reinforced concrete is to ensure that the cover to the reinforcement is of adequate thickness and that the concrete itself is dense and impermeable. While this appears to be a simple solution to the issue of reinforcement corrosion, it is an unfortunate fact that the deterioration of concrete due to corrosion is not uncommon. This is often the result of combinations of poor design, the use of concrete of inadequate quality in aggressive conditions and/or poor workmanship.

In order to mitigate these effects, a number of measures are available to the engineer and builder to minimise the risk of reinforcement corrosion. One such method is the use coated reinforcement, the two most common coatings in use being fusion bond epoxy coatings and hot dip galvanizing. The use of fusion bonded epoxy coated reinforcement has been widely reported in the literature and technical press and will not be dealt with further here. The use of galvanized reinforcement has also been widely reported over a period of more than 30 years and several major reviews of this topic - in addition to a considerable body of research-have been published (1-4). The most recent, that by Yeomans (4) is a comprehensive treatment of the technical literature dealing with the materials, electrochemistry, structural performance, and field and laboratory performance of galvanized steel in concrete.

## 3. Galvanized Reinforcement

Galvanizing is a process of coating steel with zinc for the purpose of providing corrosion protection. Zinc can be applied to the surface of steel in a variety of ways but for structural steelwork (generally >5 mm thick) hot dipping is the preferred and most widely used method (5). Hot dip galvanizing involves the immersion of cleaned steel in a bath of molten zinc at about 470°C allowing a metallurgical reaction to occur between the steel and the zinc. This reaction produces a coating on the steel made up of a series of iron-zinc alloy layers (gamma, delta and zeta) which grow from the steel/zinc interface with a layer of essentially pure zinc (eta) at the outer surface. The typical layout of the hot dip galvanizing process is given in Figure 1, and the morphology of a galvanized coating on steel (>5 mm thick) is in Figure 2.

What distinguishes galvanizing from other types of coatings on steel such as electroplated coatings, powder coatings or paints, is that the coating is metallurgically bonded to the steel. As a result, galvanizing produces a tough and adherent coating which resists abrasion and fairly heavy handling, and which can be fabricated by bending without substantial damage to the coating and with little or no effect on its corrosion resistance (5-7). In most situations, galvanized bar can be treated and transported as would be the case for conventional black steel bar. In particular, it does not require any special precautions to protect the coating against superficial damage that may occur during fabrication and transport to site. Further, the design and construction of reinforced concrete utilizing galvanized reinforcement is essentially the same as that for conventional steel reinforcement and best practice when utilising galvanized reinforcement is to use appropriately designed and placed concrete such as would normally be used in general construction.

Galvanizing has been used since the 1930s for corrosion protection in many types of reinforced concrete structures and elements exposed to a range of environmental conditions. Evidence from field applications, supported by a growing body of experimental data, has demonstrated that galvanizing extends the life of reinforcement in concrete and provides a safe-guard against premature cracking and rust staining of the concrete (4). The corrosion protection afforded by galvanizing is due to a combination of beneficial effects as considered below. Of primary importance is the substantially higher chloride threshold for zinc coated steel in concrete compared to conventional (uncoated) steel (8,9). In addition, galvanized reinforcement is resistant to the effects of carbonation of the concrete mass (10). The net effect of the presence of the zinc coating is that it not only delays the initiation of the corrosion process, but it continues to provide barrier protection during the ensuing period when the coating is reacting (i.e. dissolving) but remains intact.

What has become clear from the considerable body of research that has been undertaken is that the life of the galvanized coating, and thus the reliability of the corrosion protection it provides, depends on many factors. These include the morphology and thickness of the coating, the quality of the concrete in which it is placed and the severity of the environment to which the concrete is exposed (11,12). Where the underlying steel is exposed, the zinc sacrificially protects the steel thereby further extending the life of the reinforcement (9).

### 3.1 Behaviour of zinc in concrete

Zinc in solution reacts with both strong acidic and strong bases, the attack being most severe below pH 6 and above pH 13. Between these values the rate of attack is very slow due to the formation of protective layers on the zinc surface. Zinc in concrete is passivated for pH values between about 8 and 12.5 due to the formation of a protective surface film of corrosion product that is relatively insoluble below pH 12.5 (11). Zinc reacts quite vigorously with wet cement, but this reaction effectively ceases once the concrete has hardened. The result of these reactions is the formation of a barrier layer of calcium hydroxyzincate accompanied by the evolution of hydrogen.

In ordinary concrete, uncoated steel depassivates once the pH level drops below about 11.5, though in chloride-contaminated concrete this depassivation occurs at higher pH levels. In contrast, zinc coated steel in concrete remains passivated to pH levels of about 9.5 thereby offering substantial protection against the effects of carbonation of concrete. Zinc coated bars can also withstand exposure to chloride ion concentrations several times higher (at least 4-5 times) than causes corrosion of black steel reinforcement (4,8,9).

### 3.2 Chloride tolerance

Accelerated corrosion studies in chloride contaminated concrete have revealed the improved corrosion behaviour of galvanized reinforcement over that of conventional steel (9). Under identical exposure conditions, galvanized reinforcement resisted chloride levels in concrete at least 2.5 times higher than for black steel and delayed the time to the onset of corrosion of the underlying steel by some 4-5 times. These results have been recently confirmed in other work (13) where it was also demonstrated that galvanizing had a higher chloride threshold relative to bare steel and delayed the onset of corrosion.

In chloride contaminated concrete, galvanizing increases the time to depassivate the reinforcement thereby significantly extending the service life of concrete structures in environments where there is a low-to-moderate chloride presence. In concrete with very high chloride levels, the life of the zinc coating may be somewhat reduced due to early depassivation of the zinc. In these circumstances however, though the longevity of the galvanized coating may be reduced, the overall life of the reinforcement would still be somewhat longer than that of conventional steel in equivalent concrete and exposure conditions due to the inherently higher chloride tolerance of the zinc coating.

### 3.3 Behaviour of the coating and corrosion products

An understanding of the reaction mechanism of the zinc alloy coating when placed in concrete and the characteristics of the corrosion products so formed is fundamental to a full appreciation of the corrosion protection afforded by the galvanizing of reinforcement. Considerable work has been done over many years (11,12) to investigate these effects including the reaction of the various coating alloy layers when in contact with wet cement, the nature of the corrosion products that form when zinc reacts with cement, and the mixing of the corrosion products into the concrete matrix.

This research has indicated that when the galvanized coating first comes in contact with wet cement and is initially passivated, about 10 µm of zinc is dissolved from the pure zinc (eta) layer of the coating. This effect is shown in Figure 2a for a galvanized steel with an initial coating thickness of 180 µm (refer Figure 1) embedded in non-chloride contaminated concrete for a short period. The average thickness of the coating remaining at this stage is 164 µm and the coating retains a smooth and bright surface. Studies of galvanized bars recovered from field structures indicate that the coating remains in this condition for extended periods of time provided the conditions in the concrete do not significantly change.

Once active corrosion of the zinc initiates, usually due to the accumulation of high levels of chloride at the depth of the reinforcement, continued dissolution of the eta alloy layer occurs followed by progressive dissolution of the underlying alloy layers as shown in Figure 2b. This form of attack results in the formation of deep tunnels and holes in the alloy layers, particularly around and through the delta phase which comprises the bulk of the coating. Though the coating appears to be disintegrating at this stage, a dense layer of both the gamma and delta phases remains intact at the bar surface and this affords ongoing corrosion protection to the underlying steel.

Considerable work has also been done to identify the nature of the corrosion products produced and the effect of these on the integrity of the concrete mass (4,12). A number of minerals have been identified in the corrosion products but primarily zinc oxide and zinc hydroxide. A unique feature of these products is that they are friable (loose and powdery) minerals, are less voluminous than iron-rich corrosion products, and are able to migrate away from the bar and into the adjacent concrete matrix where they fill voids and microcracks. These effects are shown in Figure 3 in which the plume of zinc-rich corrosion products appears white against the gray calcium-rich cement matrix.

In contrast to the situation encountered when iron-rich corrosion products form when steel corrodes in concrete, the presence of the zinc corrosion products cause very little physical disruption to the surrounding matrix. This assists in maintaining the integrity of the cover concrete itself even though active corrosion of the coating may be occurring. There is also a suggestion that the presence of these corrosion products and the filling of the pore space in the matrix may create a barrier in the matrix of reduced permeability which not only increases the adhesion of the matrix to the bar but may also reduce the transport of aggressive species such as chlorides through the matrix to the coating surface.

### 3.4 Experience with galvanized steel in concrete

Practical experience and research over many years has clearly demonstrated the benefits of galvanizing for corrosion protection of steel reinforcement in many types of environments including high chloride exposure situations (4,11). Galvanizing has been shown to extend the time-to-corrosion of reinforcement and reduce the risk of physical damage to concrete structures such as delamination, cracking and spalling.

Considerable research has been done in the USA in particular to investigate the use of galvanized reinforcement for concrete bridge and highway construction exposed to high levels of accumulated chlorides due to the application of deicing salts or in marine exposure. In the case of top and bottom mat reinforcement for bridge decks for example, when both top and bottom mat bars were galvanized, very low corrosion current densities resulted compared to black steel, and the extent of corrosion on the galvanized bars was significantly less with no ferrous corrosion products (i.e. red rust) apparent. It has been shown (14) that when galvanized bars were used in the top mat only with black steel bottom mats, significant corrosion of the zinc occurred though with very much less red rust corrosion compared to black bars in equivalent conditions.

Other work (15) indicated that for a 0.5 w/c (water/cement ratio) concrete, galvanized bars performed better than black bars, though in a 0.4 w/c concrete there was similar behaviour for both black and galvanized bars after 8 years cyclic exposure, and meaningful comparisons could not be made. It was also noted that the worst case corrosion occurred when top mat galvanized bars in high chloride concrete were coupled to black steel bars in relatively chloride-free concrete at the bottom of the slab; the best case was when galvanized bars were used in both the top and bottom mats.

Other data has also verified the enhanced field performance of galvanized reinforcement in both marine and bridge deck applications (4,14). Surveys of many structures at various ages of exposure with varying concrete quality (high w/c and low cover) and high-to-extreme chloride levels (up to 10 times recommended ACI levels) at the reinforcement, have consistently revealed that galvanized steel outperforms black steel where meaningful corrosion comparisons were able to be made. For example, in 1991 a survey (16) a number of bridges in Iowa, Florida and Pennsylvania was undertaken to compare the performance of galvanized and uncoated reinforcement in decks exposed year round to humid marine conditions or deicing salts in winter. This survey complemented earlier surveys in 1974-6 and 1981 of many of the same bridges. After periods of up to 24 years exposure it was found that generally the galvanized bars had suffered only superficial corrosion in sound, uncracked concrete even when the chloride levels were high. Though the chloride levels had increased since the 1981 survey, no major change in the galvanized bars was detected and average thickness of zinc remaining on the reinforcement had not significantly changed since 1981 and was still well in excess of that required by ASTM A767 for new material.

Similar data reported from Bermuda (4) has also verified the long-term durability of galvanized reinforced concrete in marine environments. Commencing shortly after WW2, a number of docks, jetties and other infrastructure were constructed using a mix of galvanized and bare steel bars. A major survey of these structures in 1991 showed that the galvanizing was providing continuing corrosion protection to reinforcement at chloride levels well in excess of threshold levels for bare steel corrosion. Follow-up examination confirmed the findings of the earlier survey and revealed that the galvanized bars maintained a residual zinc coating thickness at a structure age of 42+ years well in excess of the minimum ASTM requirement. Detailed SEM examination of concrete cores from these structures confirmed the previously mention observations that the zinc corrosion products had migrated a considerable distance (15-20 mils) beyond the surface of the coating and into the adjacent concrete matrix with no visible effect on the concrete mass.

Studies such as these clearly indicate that galvanized bar, when properly used as the exclusive reinforcing material, can provide enhanced corrosion protection compared to black steel in equivalent concrete and exposure conditions. What is clear is that in good quality concrete that is well compacted, cured and of adequate cover, galvanized bar survives for extended periods of time and offers a cost-effective method of corrosion protection. In poor quality concrete however, particularly those with high w/c ratio and low cover to the reinforcement, galvanizing will delay the onset of chloride induced corrosion of the reinforcement, but this may be of limited benefit.

### 3.5 Economics of galvanized reinforcement

When the costs and consequences of corrosion damage to a reinforced concrete building are analyzed, the extra cost of galvanizing is seen as a small investment in corrosion protection. While the initial cost of galvanizing may add up to 50% to the cost of the reinforcement, depending on the country of origin and the availability and access to galvanizing plants within the country, the cost of using galvanized reinforcement as a percentage of total building cost is always significantly less than this. The overall cost depends, of course, on the nature and location of construction and the extent to which galvanized bar is used throughout the structure. For example, it is rarely necessary for the structural core or internal elements of large reinforced concrete structures such as high rise building, or the deeply embedded components of large abutments and foundations, to be galvanized.

Cost analysis for building construction (3,17) reveals that the galvanizing of reinforcement increases the overall cost of reinforced concrete as-placed by about 6-10%. The actual value will vary depending on many factors including the type of bar and the galvanizing price, the amount of steel used per cubic meter of concrete poured, and the unit cost of the concrete mass. The concrete price is made up of several main components including the supply of the concrete, the formwork and steel supply and fixing costs. On average, the cost of the steel would not be more than about 25% of the total cost of the concrete as placed. Considering also that it is rarely necessary to galvanize all steel in the structure, and 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 cost. However, by galvanizing only certain vulnerable or critical elements, e.g. surface panels, the additional cost of galvanizing reduces further still, perhaps to as little as 0.5-1.0%. These percentages, of course, relate only to total construction costs and when taken against total project costs or final selling prices the added cost of galvanizing becomes very small indeed, often less that 0.2%. This represents a very small fraction of the cost of repairs should unprotected reinforcement corrode.

## 4. Applications of Galvanized Reinforcement

Galvanized steel bar and other fittings including bolts, ties, anchors, dowel bars and piping, have been widely used in a variety of reinforced concrete structures and elements. The rationale for this is based on the philosophy that the coating provides a safeguard against early or unexpected corrosion of the reinforcement. Should such damage occur costly repair and remediation of the structure may be necessitated in order to realise the full design life of the structure. This represents an ever-increasing economic burden and the redirection of scarce resources.

Particular circumstances where the galvanizing of reinforcement is likely to be a cost-effective and sound engineering decision include:

- light-weight precast cladding elements and architectural building features;

- surface exposed beams and columns and exposed slabs;
- prefabricated building units, e.g. kitchen/bathroom modules and tilt-up construction;
- immersed or buried elements subject to ground water effects and tidal fluctuations;
- coastal and marine structures;
- transport infrastructure including bridge decks, roads and crash barriers; and
- high risk structures in aggressive environments.

Many examples exist where galvanized reinforcement has been successfully used in a variety of types of reinforced concrete buildings, structures and general construction including:
- reinforced concrete bridge decks and pavements;
- cooling towers and chimneys;
- coal storage bunkers;
- tunnel linings and water storage tanks and facilities;
- docks, jetties and offshore platforms;
- marinas, floating pontoons and moorings,
- sea walls and coastal balustrades;
- paper mills, water and sewerage treatment works;
- processing facilities and chemical plants;
- highway fittings and crash barriers; and also
- lamp posts and power poles.

Some prominent examples, many of which are well-known buildings and major structures from around the world, are listed in Table 1 (4). Other examples in general construction, buildings, bridges and highways, and coastal and marine structures are shown in Figures 4-7.

Finally, it is worth recording that in the State of the Art Report on Coating Protection for Reinforcement, originally published in 1992 by the Comite Euro-International du Beton (3), the benefits from the practical use of galvanized reinforcement were listed as follows:
- proper galvanizing procedures have no significant effect on the mechanical properties of the steel reinforcement;
- for best performance, galvanized reinforcement should be passivated by chromate treatment;
- zinc coating furnishes local cathodic protection to the steel, as long as the coating has not been consumed;
- galvanized reinforcement provides protection to the steel during storage and construction prior to placing the concrete;
- corrosion of galvanized steel in concrete is less intense and less extensive for a substantial period of time than that of black steel;
- galvanized steel in concrete tolerates higher chloride concentration than black steel before corrosion starts;
- galvanized reinforcement delays the onset of cracking, and spalling of concrete is less likely to occur or is delayed;
- the concrete can be used in more aggressive environments. Thus a standard design of concrete components can be retained for various exposure conditions by the use of galvanized steel in the most aggressive cases;
- lightweight and porous concretes can be used with the same cover as for normal concretes;

- greater compatibility is obtained with low alkali cement;
- poor workmanship resulting in variable concrete quality (poor compaction, high water/cement ratio), can easily be tolerated;
- accidentally reduced cover is less dangerous than with black steel;
- unexpected continuous contact between concrete and trapped water can be tolerated;
- repair of damaged structures can be delayed longer than with black steel;
- galvanized hardware is acceptable at the surface of the concrete, as it is for the joints between precast panels;
- the use of galvanized reinforcement ensures a clean appearance of the finished concrete with no trouble arising at cracks either from spalling or rust staining; and
- galvanized reinforcement is cleaner and easier to work with, and makes it possible to consider the use of thinner wires as welded fabrics.

The report goes on to say that "it is important to remember that even if these benefits are achieved, the use of galvanized reinforcement should not be considered as an alternative to the provisions of adequate cover of dense, impermeable concrete, unless special design criteria have to be met. Galvanizing of reinforcement is a complementary measure of corrosion protection - a kind of insurance against the inability of the concrete to isolate and protect the steel."

## 5. Summary

Over a very long period of time, the galvanizing of steel reinforcement has been shown to provide a cost-effective and reliable means of corrosion protection to concrete in a variety of exposure conditions. Clearly, galvanizing is only one of a number of protection systems that can be used in reinforced concrete. However, the convenience of manufacture and supply of the product, the ease of handling, transportation and installation, and the fact that no special design requirements are needed, has meant that it has been accepted in many countries for a wide range of concrete construction.

The last 15-20 years in particular has seen extensive research and field investigations undertaken of the characteristics and behaviour of galvanized reinforcement. This considerable body of work has repeatedly highlighted the benefits of galvanizing in delaying the onset of corrosion in reinforced concrete and in reducing the risks of cracking and rust staining of the concrete mass. The higher chloride threshold for zinc compared to steel, and that zinc in concrete is virtually unaffected by carbonation, provides galvanized reinforcement with an inherent corrosion resistance well beyond that of conventional steel bar. The very presence of the coating itself further extends the service life of galvanized bar because of the time delay during which dissolution of the coating occurs.

Above all however, it is important to remember that when using galvanized reinforcement (as with any protection system for concrete), that the concrete is properly designed and placed and is appropriate for the type of element and the exposure conditions. Unless specific design requirements apply, such as reduced cover or ultra light-weight construction, the concrete should be designed and placed as though conventional steel reinforcement was to be used. In essence, the use of galvanizing should not be at the expense of this basic quality and integrity of the concrete. In this way, the galvanizing can be considered to provide protection against those circumstances that may lead to premature corrosion of conventional reinforcement and deterioration of the concrete mass.

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Table 1. Examples of prominent structures utilising galvanized reinforcing steel.

| | |
|---|---|
| Sydney Opera House: 35 mm thick galvanized panels for cladding of sails and seawall units | Hydro-Electricity Commission, Hobart: clad with 950 galvanized reinforced precast panels |
| NZ Parliament House, Wellington: clad with galvanized reinforced precast fascia panels | Telecom Exhibition Exchange, Melbourne: clad with galvanized reinforced precast panels |
| Bank of Hawaii, Waikiki: thin decorative precast arches reinforced with galvanized bar | Intercontinental Hotel, Sydney: 1549 precast windows and fascia units |
| National Theatre, London: over 1000t of galvanized reinforcement in exposed parapet walls | ANDOC North Sea Oil Rig: 2000t galvanized reinforcement in the roof of sea-bed storage tank |
| Crocker Building, San Francisco: galvanized reinforcement in structural elements | Eastbourne Congress Theatre, UK: cladding panels and window mullions |
| Collegiate Buildings, University College, London: galvanized reinforcement and mesh | University Sports Hall, Birmingham: 37 mm thick panels using galvanized reinforcement |
| Staten Island Community College, New York: brilliant white galvanized reinforced precast panels | High Court and National Gallery, Canberra: galvanized reinforcement in all critical areas |
| New Parliament House, Canberra: 1800 galvanized precast cladding panels and window units. | Barclays Bank, City of London: galvanized precast window surrounds |
| Offices, Westminster Bridge, London: galvanized reinforced white facing panels | National Tennis Centre, Melbourne: precast stadium support beams |
| Department of Housing and Urban Development, Washington, DC | University of Wisconsin: precast panels and insitu concrete in numerous buildings |
| Wrigley Field Sports Arena, Illinois: galvanized reinforced precast panels in seating decks | Georgetown University Law Centre, Precast panels |
| Frontier Chemical Company, USA: galvanized reinforcing mat for floor slabs | US Coast Guard Barracks, Elizabeth City, NC: galvanized bar in 237 precast panels |
| Bridge decks/roads in New York, New Jersey, Florida, Iowa, Michigan, Minnesota, Vermont, Pennsylvania, Connecticut, Ontario and Quebec | John F Kennedy Parking Garage, Detroit: galvanized reinforcing steel to protect against subsurface rusting |
| IBM Data Processing Division HQ, White Plains, NY: hot dip galvanized precast facade panels | Football Hall of Fame Stadium, Canton, OH: galvanized reinforcing steel |
| Coke quenching towers, Dunkirk, France: galvanized structural reinforcement | Dome of the Mosque, Rome, Italy: galvanized reinforcement |
| Arkansas Civic Centre: galvanized reinforcement in slim external columns | Power station cooling water ducts, Spijk, Netherlands: fully galvanized reinforced |
| Offshore piers at Ominichi, Japan and Riva di Traiano, Rome, Italy | Toutry Viaduct, St Nazaire Bridge and Pont d'Ouche Viaduct, France |

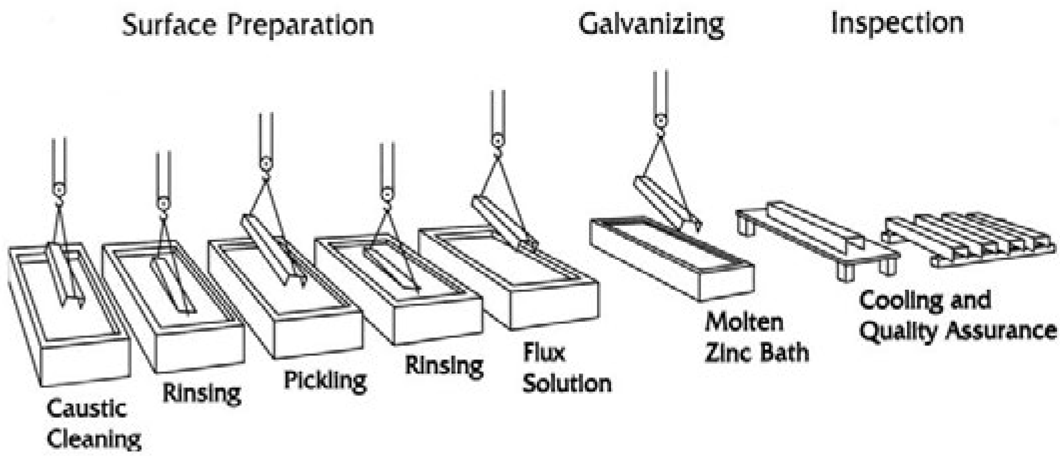



Figure 2. Layout of hot dip galvanizing plant.

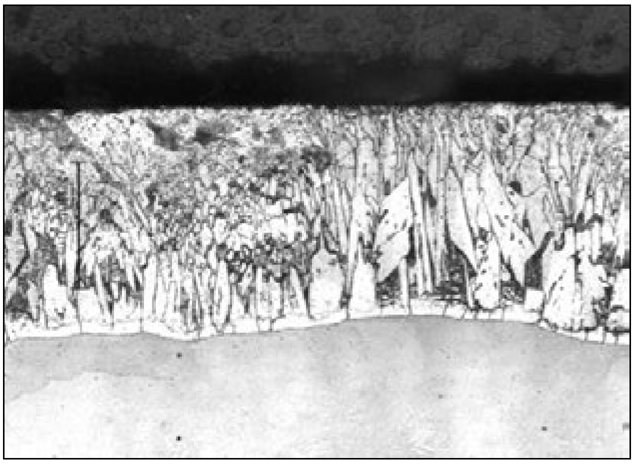
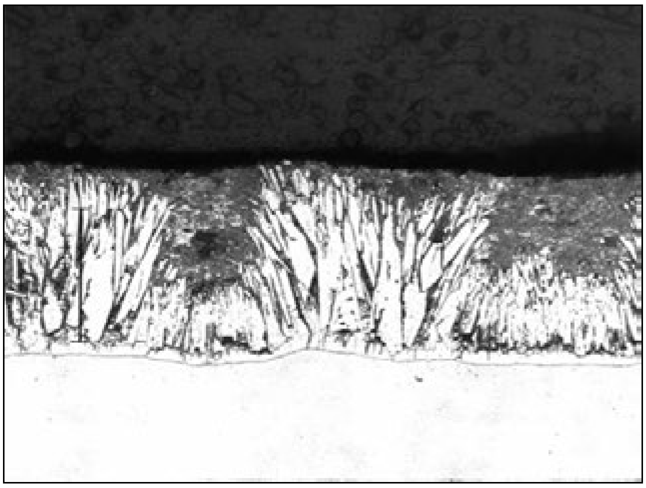
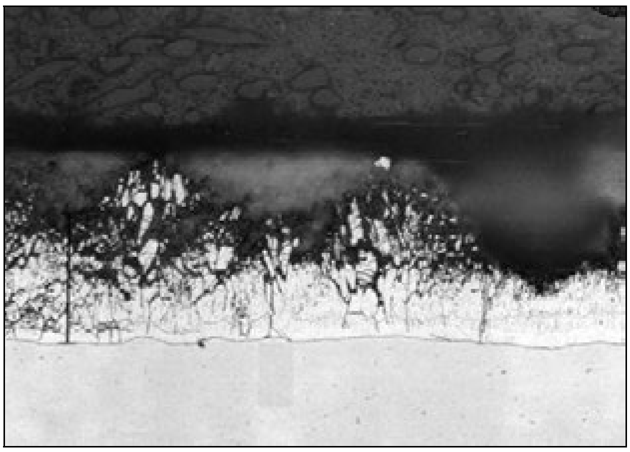


Figure 1. Freshly galvanized steel with 180 µm thick alloy layer coating. (200x)

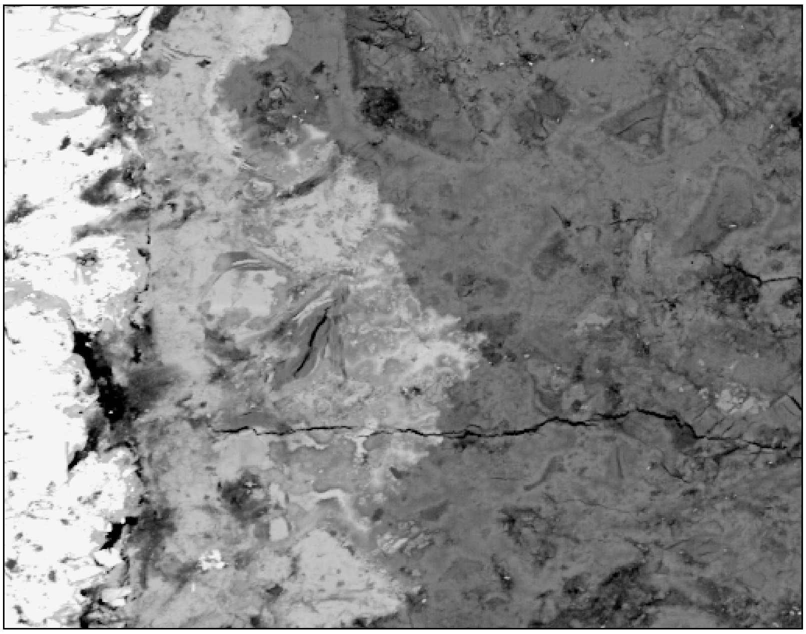


a) Galvanized bar exposed to fresh concrete showing partial loss of outer pure zinc layer. Remaining coating ~164 µm thick.

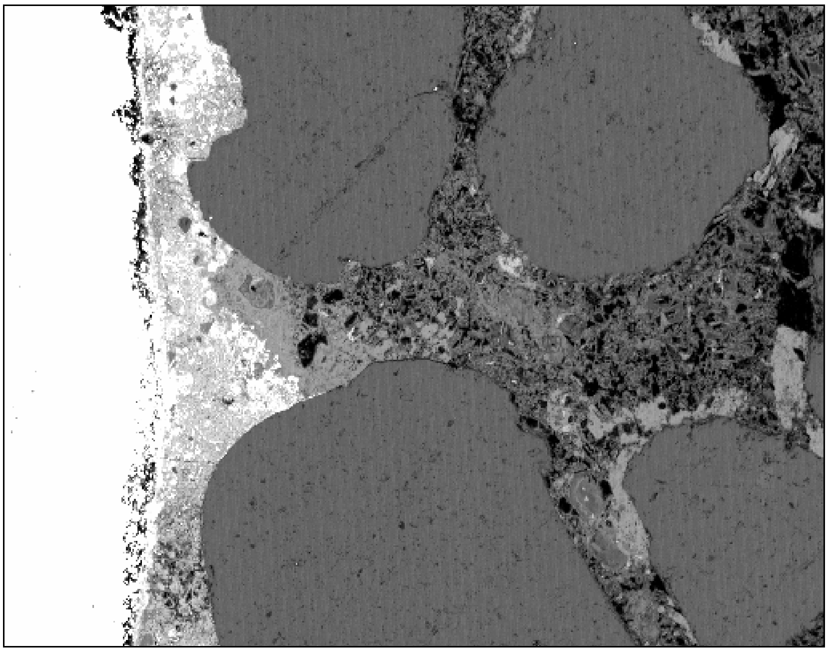


b) Long-term exposure to chloride-contaminated concrete showing loss of pure zinc layer with intrusions around alloy layers. Average coating thickness remaining ~110 µm.

Figure 2. Changes in the galvanized coating with exposure to concrete. (200x)



a) Showing partial dissolution of the galvanized coating (left) and plume of zinc-rich corrosion product (centre) migrating into the cement matrix (right). (1000x)



b) Migration of zinc-rich corrosion products away from the bar/matrix interface and well into the cement matrix. Large particles are fine sand. (100x)

Figure 3. SEM images of interfacial zone between bar and matrix showing presence of zinc corrosion products (24)

Reinforced wall, Long Bay, NSW

Access hole steps

Steelworks - coke ovens storage

Rail tunnel, Melbourne

Slip formed chimney

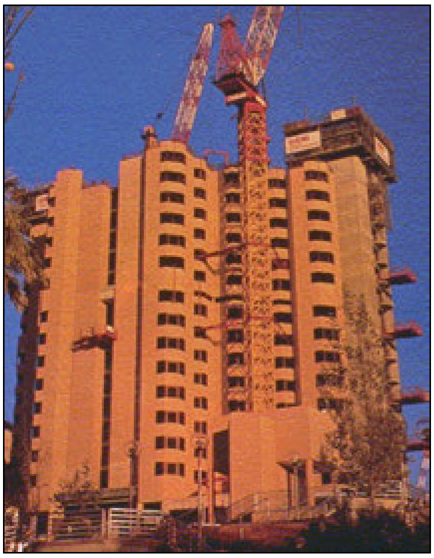
Sundial - Singleton, NSW

Figure 4. Galvanized reinforcement concrete - general construction.


Courthouse, Townsville, Qld


Parliament House, Australia

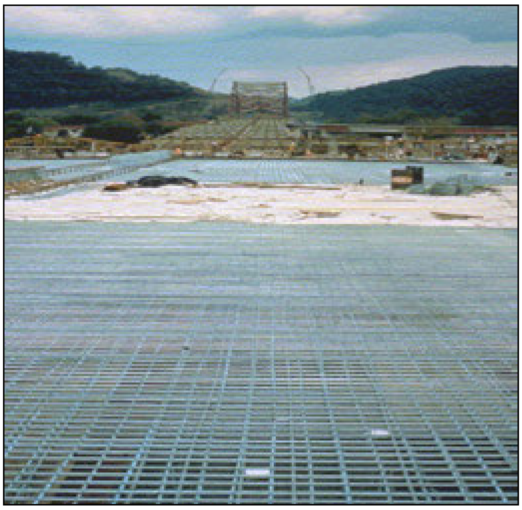

100 William Street, Sydney


ASER Tower, Adelaide


Precast window panels


Spandrel beams

Figure 5. Galvanized reinforcement concrete – buildings.



Bridge deck, USA

Safety barrier, Auto route

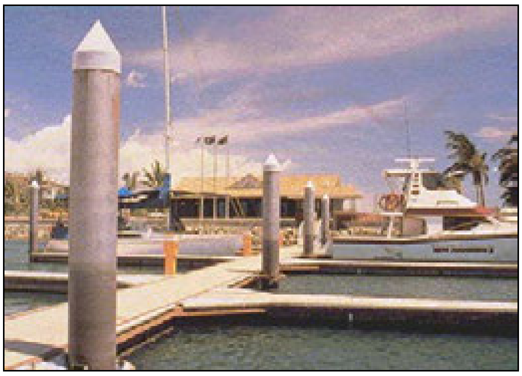
Road pavement, USA

Elevated roadway - USA

Bridge construction – USA

Crash barrier, Canada

Figure 6. Galvanized reinforcement concrete – bridges and highways.



Floating marinas, Australia

Ominichi Pier, Japan

Sewerage outfall tunnels – Australia

ANDOC oil platform – North Sea

Seawater cooling channels – Holland

Seawall – Australia

Figure 7. Galvanized reinforcement concrete – coastal and marine.