Galvanized steel reinforcement for concrete

Hot dip galvanizing is a viable means of protecting reinforcement, particularly where the durability of concrete cannot be guaranteed. Its use should be considered for harsh exposure conditions, precast construction and prestige facades where long life, freedom from rust staining and low maintenance are important criteria. Rust-stained surfaces and cracking and spalling of concrete in recently completed structures demonstrate the wide need to protect steel reinforcement.

Current Practice Note 17 published by and available from Concrete Institute of Australia concludes that "Wherever there are serious doubts that (impermeable concrete) will be achieved and maintained for the design life of the structure, then galvanizing should be given serious consideration".

Galvanized coatings provide important advantages for the protection of reinforcement.

Research and practical experience since the 1950s have shown the corrosion resistance of galvanized steel reinforcement to be greatly superior to uncoated steel, while the bond strengths of galvanized and black steel bars to concrete are not significantly different, as discussed on page 31.

The corrosion protection of the galvanized coating ensures that the design strength of concrete is maintained and the possibility of surface rust staining and eventual corrosion of reinforcement and spalling of concrete is removed.

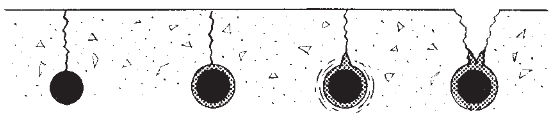
Steel accessories for use in reinforced concrete structures, particularly fittings and inserts which may be partially exposed, are susceptible to the effects of corrosion and should be galvanized.

Black steel and galvanized reinforcing bars may be used in contact in applications where galvanizing is used selectively to provide a high degree of corrosion protection in exposed areas, as discussed on under 'Economics of galvanized reinforcement in concrete' on page 31. In a cured concrete environment any corrosion of black bar can induce only very localised sacrificial protection from contacting galvanized bars. As a result, the effect on the coating life of contacting galvanized bars is negligible.

Corrosion of reinforcement

Corrosion of steel reinforcing bars inevitably weakens concrete members, reducing load bearing capacity and safety factors. In extreme cases failure of reinforced concrete members can occur, partly because of loss of strength due to corrosion of the reinforcement itself, and partly because of the breaking up of the concrete surrounding the reinforcement.

When steel reinforcement corrodes, the corrosion product occupies more than three times the volume of the original steel, exerting great disruptive tensile stress on the surrounding concrete, leading to further cracking, more weather access and further corrosion. In mild cases rust staining occurs. In more serious cases, severe spalling of concrete may occur and ultimately concrete members may fail completely.



Steps in the corrosion of uncoated steel reinforcing bars. Galvanized rebar is not subject to this effect and retains full bond strength to concrete.

In normal circumstances uncoated steel reinforcing bars give satisfactory service provided the following requirements are maintained:

1 The design provides for adequate concrete cover over the steel reinforcement.
2 Precise placement of reinforcement is maintained.
3 Uniformly high quality concrete is used.
4 Complete compaction of concrete is attained with no voids or pockets.

It is sometimes impractical or impossible to achieve all these requirements and depending on exposure conditions, corrosion of uncoated reinforcement may begin.

The benefits of galvanizing reinforcement include:

- Protection to the steel during storage and construction prior to placing the concrete.
- Diminished effect of variations in concrete quality.
- Safeguards against poor workmanship, especially misplacement of reinforcement, poor compaction, and inadequate curing.
- Delayed initiation of corrosion and the onset of cracking.

- Reduced likelihood of surface staining.
- Increased structural life of concrete, particularly where chloride contamination is likely.

Factors determining the durability of reinforcement

Environment

The external environment of the concrete provides the agents which commonly cause corrosion in reinforcement: oxygen, water, carbon dioxide and chloride ions.

Marine structures and structures close to coastal waters are particularly at risk from corrosion of reinforcement due to the ingress of chloride ions from sea spray and salt-laden air.

Away from the sea coast most corrosion of reinforcement in concrete is due to the process of carbonation, which reduces the alkalinity of the surrounding concrete. This process can occur at any geographic location. The rate of carbonation is at a maximum when the relative humidity is about 50 per cent, and increases with increasing temperature.

Surveys have shown that the corrosion problem in relatively new buildings is worst in coastal areas.

Carbonation resistance. Galvanized reinforcement is better able to resist the effects of carbonation because of the much wider range of pH (to about pH 8) over which the zinc coating remains passivated. Since black steel typically depassivates when the pH of concrete drops below about 11.5, it is apparent that as the carbonation 'front' moves past a galvanized rebar, little or no effect will occur until the concrete adjacent to the reinforcement is almost completely neutralised.

Chloride tolerance. Though zinc can be depassivated and attacked in the presence of chloride ions, the tolerance of galvanized reinforcement to chloride depassivation is substantially higher than that of black steel. In a survey of a number of long-serving marine structures* galvanized bars were shown to have been exposed to chloride contents as high as 2.2% (by approximate weight of cement) over periods of 10-20 years, with less than 10% loss of original coating thickness and no record of failure. This should be compared to chloride levels in the range of 0.2-0.3% by weight of cement leading to severe corrosion of black steel in similar circumstances.

* Tonini, DE and Cook, AR (1978) 'The performance of galvanised reinforcement in high chloride environments – field study reports.' International Corrosion Forum, NACE, Houston

Quality of concrete

In preventing corrosion of reinforcement, the most critical property of concrete is permeability. The degree of permeability determines the extent and rate of the diffusion of chloride ions and carbon dioxide through the concrete. Permeability is a function of mix design, compaction and curing:

Mix design. To achieve low permeability, concrete must be dense, with a good bond between aggregate and cement paste. These desirable characteristics can be obtained by using good quality materials, with an adequate portland cement content, a low water/cement ratio, and small sized, well graded aggregates.

Compaction. Proper compaction of concrete is of vital importance in minimising permeability. Problems are likely to arise when placing and vibrating techniques are incorrect, slump is too low, reinforcement is congested, or form shapes are not conducive to the necessary flow of concrete during placement.

Curing. Proper curing of concrete is essential to achieve low permeability, as the continued hydration of the cement increases the volume of the gel and hence decreases pore spaces and blocks capillaries. Proper field curing must be provided for.

Depth of Cover

Lack of concrete cover for reinforcement has been identified as a major problem associated with 'failures' in high rise buildings.* In a survey of 95 Sydney buildings ranging in height from 5 to 36 storeys and aged between 2 and 17 years, the average depth of concrete cover at sites where spalling occurred was 5.45 mm. The maximum depth of cover at any failure point was 18 mm compared with recommended covers to AS 3600 'Concrete structures' in the range 25-30 mm, depending on the type of member.

* Marosszeky, M and Sade, D (1986). "Concrete durability – the problem of reinforcement corrosion and improving workmanship". Building Research Centre, University of NSW.

Cracks in concrete

The type and size of cracks have an important influence on durability of concrete. Cracks caused by shrinkage or thermal stresses may contribute significantly to reinforcement corrosion, particularly when they run parallel to reinforcing bars and are close to the concrete surface.

Crack widths of less than 0.1 mm are generally regarded as not causing significant corrosion risk, provided cover is adequate and the structure is not exposed to highly corrosive environments. Flexural cracks are not generally a problem as they decrease in width from a maximum at the surface and become narrower at the level of the reinforcing steel.

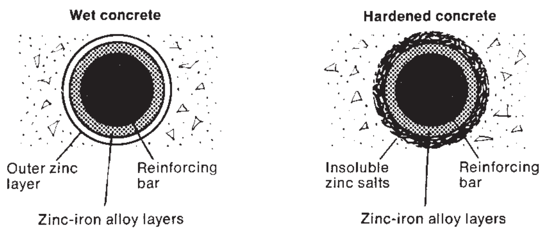
Surface treatment of concrete

In the production of architectural finishes the concrete surface is sometimes washed or treated to expose the aggregate. These practices are not recommended if there is any possibility of aggressive chemicals such as acids or salts being left behind to permeate the concrete.

Etching, washing and mechanical concrete surface finishing may also result in loss of the valuable cement-rich paste which forms the surface layer of the concrete, reducing carbonation resistance and depth of cover.

Reaction between galvanized coatings and concrete

During initial contact of galvanized reinforcement with wet concrete, the outer zinc layers of the galvanized coating react to form stable insoluble zinc salts. Attack ceases as the concrete hardens and the galvanized coating remains intact.



Corrosion protection provided by galvanizing

In areas where the reinforcement may be exposed accidentally due to thin or porous concrete, cracking, or damage to the concrete, the galvanized coating provides extended protection. Since the corrosion product of zinc occupies a smaller volume than the corrosion products of iron, any small degree of corrosion which may occur to the galvanized coating causes little or no disruption to the surrounding concrete mass.

Studies were made at the Structural Engineering Materials Laboratory, University of California, Berkeley California, of the effects of corrosion on reinforced concrete test prisms.

Prisms 300 x 100 x 100 mm were axially-reinforced with 19 mm diameter galvanized or black steel bars. A 12.5 mm deep notch was cut at the mid section of each prism to enforce formation of a crack at the notch should corrosion products exert sufficient disruptive stresses. Prisms were placed in loading frames and the steel reinforcing bars stressed to 140 MPa. Prisms were then subjected to alternate immersion/drying cycles in a 4% NaCl solution.

Cracks occurred in test prisms reinforced with uncoated steel bars in less than ten months exposure. Large crack areas had developed by about 18 months and were still increasing at 24 months. No cracks were observed in prisms reinforced with galvanized bars until almost 16 months exposure. These crack areas were very small compared to those in prisms reinforced with uncoated steel bars and crack development ceased after a further $2^1/_2$ months exposure.

Economics of galvanized reinforcement in concrete

When the costs and consequences of corrosion damage to a reinforced concrete building are analysed, the extra cost of galvanizing is small. It can be regarded as an 'insurance premium', but a premium which is low and need be paid once only.

While the cost of galvanizing may be up to 50% of the cost of the steel, the cost of galvanized reinforcement as a percentage of total building cost is much lower than generally realised. It can be as little as 0.5%, depending on the nature of the structure. For most structures, even in the most aggressive environments, the use of galvanized reinforcement can be confined to the exposed surfaces and critical structural elements such as:

- Thin precast cladding elements
- Facades of prestigious buildings
- Surface exposed beams and columns
- Window and door surrounds
- Prefabricated units
- External facades of buildings near the sea coast
- Architectural features.

Determining the likely cost

Recent case histories show that the galvanizing of reinforcement increases reinforced concrete costs in a typical building by about 6 to 10%. Since the cost of the structural frame and skin of a building normally represents only about 25 to 30% of total building costs, multiplying these figures out shows that the additional cost of galvanizing the reinforcement adds between 1.5 and 3.0% to total building cost.

However, in the majority of structures only certain vulnerable or critical elements require protection. If only these critical areas are galvanized the additional cost of galvanizing comes down still lower, to as little as 0.5 to 1.0%.

These percentages relate only to total building costs. When related to total project costs and to final selling prices the added cost of galvanizing becomes very small indeed.

Such costs represent a very small proportion of the cost of repairs should unprotected reinforcement corrode. In recent cases repair costs on major buildings and structures have been as high as 5-10% of the original building costs. Frequently such repairs eliminate only the visible damage and cannot be relied upon as a long-term solution.

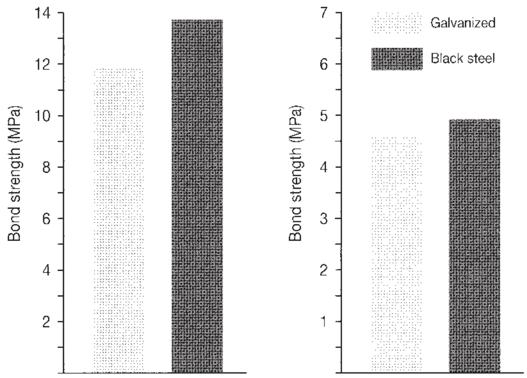
Accordingly, whenever there is concern that premature corrosion of reinforcement might occur, reinforcement should be galvanized. The use of galvanizing however should not be considered an alternative to the provision of an adequate cover of dense, impermeable concrete.

Bond strength of concrete to galvanized reinforcing bars

The results of extensive programs of pull-out testing by a number of researchers reveal no significant difference in the bond strengths of black and galvanized steel deformed (ie, ribbed) reinforcing bars in concrete.

The tests also indicate no significant difference in the bond strengths of black and galvanized plain bars in concrete.

Bond strengths of galvanized unpassivated steel bars and black steel bars to concrete*



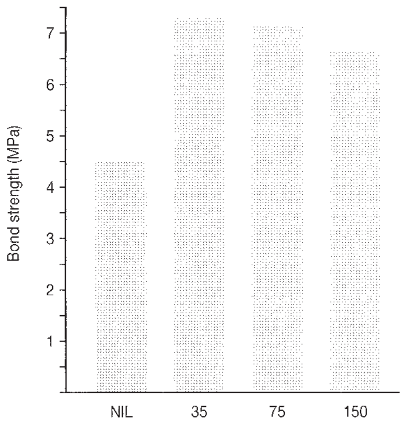
Deformed bars

Pull-out testing showed no significant difference in bond strengths, due to the effect of mechanical interlock. Tests showed no significant effect of chromate additions on the bond strength of deformed galvanized bars.

Plain bars

Pull-out testing showed no significant difference in bond strengths of black plain bars and unpassivated galvanized plain bars.

Bond strengths of galvanized plain bars at various levels of chromate additions to concrete*



Mix water additions of 35-150 ppm chromates by weight of cement increased bond strength of galvanized bars by at least 50%

*Yeomans SR and Ellis DR, 'Further studies of the bond strengths and slip characteristics of galvanized and epoxy coated steel reinforcement in concrete'. ILZRO Project ZE-341, University of New South Wales, Canberra ACT. Progress report No 5, December 1992.

Passivation and additives

The research into bond strengths reported on page 31 also shows that there is little or no need for the current practice of chromate passivation of galvanized reinforcement by the galvanizer (other than to minimise the possibility of wet storage staining), or the alternative addition of chromium trioxide to the concrete mix. While the addition of chromates to the concrete mix in the ratio of 35-150 ppm by weight of cement increases the bond strength of galvanized plain bars significantly, there is no measurable improvement in the bond strength of galvanized deformed bars, as the mechanical interlock effect provides almost all of the bond.

Specification and installation of galvanized reinforcement

BHP TEMPCORE bar and Smorgon Consolidated Industries Welbend 400 SE bar produced to Australian Standard 1302 'Steel reinforcing bars for concrete' Grade 410Y easily meet all reinforcing standards and codes. Their superior properties are retained after galvanizing and are altered only marginally on bars bent prior to galvanizing.

Properties of galvanized 410Y bar

Tensile properties:	No change from ungalvanized condition
Bending properties:	No change from ungalvanized condition
Toughness:	Similar to ungalvanized

Galvanizing pre-bent Grade 410Y bar

Grade 410Y reinforcing bar bent prior to galvanizing remains ductile, allowing straightening and re-bending. The following minimum diameters (for 90° bends) are recommended in AS3600 if subsequent straightening* of the bar is required.

up to 16 mm dia:	5d
greater than 20 mm dia:	8d

* Re-bending from these bend diameters may cause cracking of the galvanized coating.

Grade 410Y that has been bent, galvanized and straightened in accordance with the above practices retains the full yield and tensile strength of the original bar. Tensile elongation may be slightly reduced, but still easily meets the requirements of AS 1302-410Y

Do not use heat for bending or re-bending

The use of heat for bending or re-bending galvanized Grade 410Y or any other reinforcing bar should be avoided due to the possibility of the zinc coating causing liquid metal embrittlement. Similarly, should welding of galvanized bar be required, the galvanized coating should first be removed by pickling, grinding or grit blasting.

Where possible, bend after galvanizing

The galvanizing of straight bars is easier and more economical. Transport costs are lower, and special bend configurations cannot be lost or misplaced during handling and storage.

Bending, re-bending after galvanizing

Although the bendability of galvanized Grade 410Y bar is only marginally altered from that of uncoated bar, to minimise cracking of the galvanized coating the following minimum bend diameters (for 90° bends) are recommended in AS 3600.

Up to 16 mm diameter:	5d
Greater than 16 mm diameter:	8d

Effect of bending on the coating

Some cracking or flaking of the galvanized coating may occur at bends using smaller diameters than those recommended above. Any damage to the galvanized coating should be repaired using a suitable zinc-rich paint in accordance with AS/NZS 4680, Appendix E 'Renovation of damaged or uncoated areas'. Cut ends of galvanized bars should also be repaired.

Specifying galvanized reinforcement

Reinforcing steel should be specified to comply with Australian Standard 1302 Grade 410Y, and galvanized in accordance with AS/NZ 4680 'Hot-dip galvanized (zinc) coatings on fabricated ferrous articles', and GAA's standard specification for hot-dip galvanized steel (see page 40).

Welding galvanized steel reinforcement

In order to volatilise the zinc coating and so achieve adequate weld penetration, both tack welds and load-bearing welds in galvanized steel reinforcement require greater heat input than similar welds in uncoated steel reinforcement. Manual metal arc, GMA and torch welding processes are all suitable techniques, as detailed in Australian Standard 1554 Part 3. In the case of GMA welding, the use of pure CO_2 shielding gas will help weld penetration.

Comment on welding techniques is given later in this book.

Butt splice welds. In general, welds are made without changes to standard operating parameters other than reduced welding speed to achieve greater heat input. To achieve sound welds, all cracked or damaged areas on bar ends must be removed by sawing or grinding. To provide access for welding at least one bar end must be bevelled.

Lap splice welds. Welds are made satisfactorily using the welding processes listed above. A reduction in welding speed and an increase in heat input will help to volatilise the zinc coating and achieve adequate weld penetration.

For manual metal arc welding, the use of electrodes of a size and type which facilitate volatilisation of the zinc coating will minimise the possibility of weld porosity and liquid metal embrittlement. Cellulose-coated electrodes have given good results. Procedure testing may be helpful.

Alternatively, the galvanized coating may be removed prior to welding by using an oxy-fuel gas flame, or by grit blasting or grinding.

For all welding processes, attention should be given to ventilation or fume extraction to minimise zinc oxide fume in the welder's breathing zone.

Acknowledgement

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