

REPORT NUMBER 10655/01

Report on Compliance of LOGICWALL with the Durability Requirements of AS3600

Prepared For - CSR Building Products Limited

Abstract

This report reviews the durability of LOGICWALL, a permanent formwork system for walls consisting of an outer shell of fibre cement sheet supported by an inner galvanized steel stud framework. The system is designed for the construction of reinforced or non-reinforced concrete walls. Once constructed, the formwork does not contribute to structural capacity of the wall which acts as a normal reinforced concrete structure.

The concrete and reinforcement are encapsulated within the fibre cement shell and coating which together act as a protective barrier. When used in the construction of walls in interior and exterior environments, the presence of the protective barrier enhances the protection against the effects of the prevailing environment.

LOGICWALL walls designed in accordance with AS 3600 will be subjected to environments consistent with a B2 exposure classification. AS3600 states that protective coatings can be taken into account when assigning exposure classification. Accordingly, the coating system plays a significant role in the design of the system in compliance with AS3600. In a typical environment, the main agent of deterioration is carbonation. Therefore, the coated external skin in combination with concrete cover to the reinforcement, meets the durability and service life requirement of the standard.

The galvanised steel stud framework becomes embedded in concrete. Field evidence has shown that galvanised steel is durable in concrete in the harshest marine environment. In carbonated concrete, galvanized steel is more resistant to corrosion.

The report concludes that walls constructed using the LOGICWALL system comply with AS3600 provided that the concrete strength and cover meet the requirements of the standard. Additional protection is provided to the concrete and reinforcement as well as to the components of the LOGICWALL system by the specified protective coating.

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1. Background

Description of LOGICWALL

LOGICWALL is a sandwich panel with a hollow core that acts as permanent formwork for concrete used in the construction of reinforced concrete walls. The panel is made up of a galvanised steel stud frame with 6 mm fibre cement sheets bonded to both faces. The panels are erected onsite and the cores are filled with concrete. The galvanised steel stud frame is perforated to allow the insertion of both horizontal and vertical reinforcement. The LOGICWALL system acts as permanent formwork and does not play any structural role when used in the construction of a reinforced concrete wall.

The LOGICWALL system is available in five wall thicknesses: 120, 150, 162, 200 and 262 mm (Fig. 1). Standard panels are 1100mm and 1200mm wide although panels can be manufactured to lesser widths down to 200mm wide to suit intended wall dimensions. The height of panels can range from 200 mm to 4,200 mm, again to suit the intended wall dimensions.

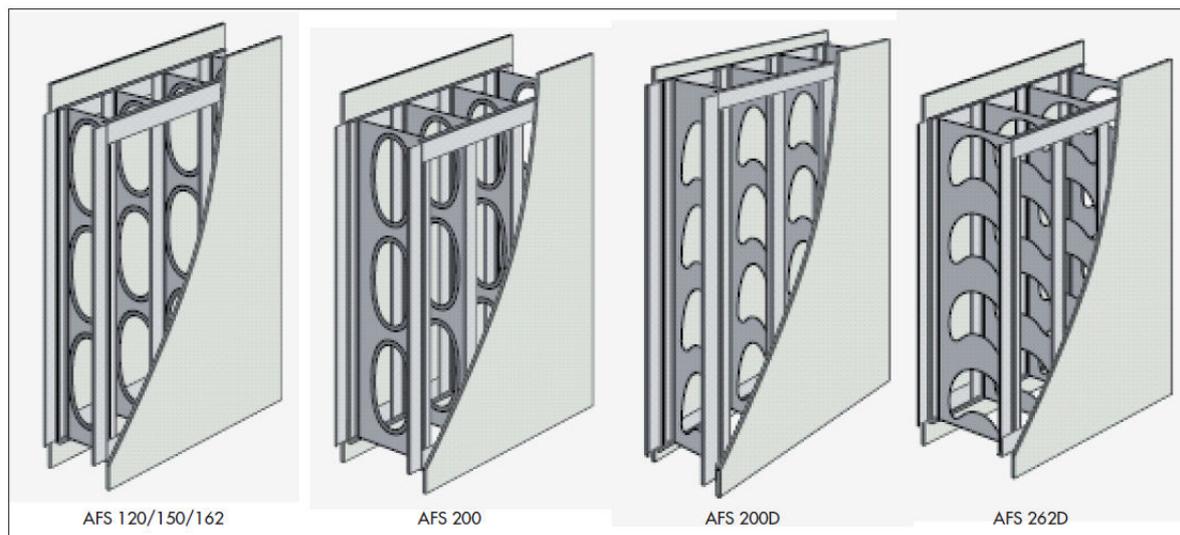


Figure 1: Range of available LOGICWALL thickness

A galvanised steel floor track is supplied to fix the walling system to the floor or footing. Individual panels are joined using galvanised studs with extended flanges. Corners are formed from prefabricated corner panels and window and door openings are designed into the panels at the factory. Figures 2 and 3 show singly and doubly reinforced LOGICWALL systems.



Figure 2: LOGICWALL system with single reinforcement

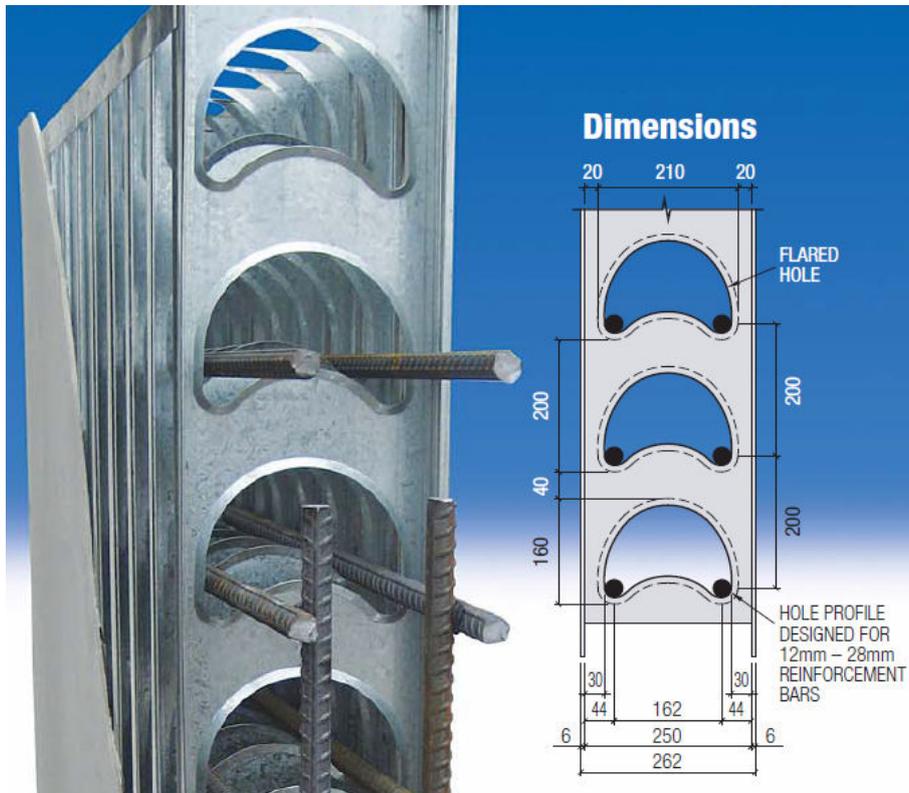


Figure 3: LOGICWALL system with double reinforcement

Properties of the LOGICWALL construction materials

The LOGICWALL permanent formwork is made of fibre cement sheets glued to galvanised steel stud frames. The fibre cement sheet is a 6mm thick CSR Cemineal. The galvanised steel stud frame sections are rated Z275, while the glue is Bostik Structural Adhesive. External surfaces of the complete system, after construction of the walls, are finished with a coating of Dulux AcraTex.

Figure 4 shows the complete system after it is installed and the core is filled with concrete.

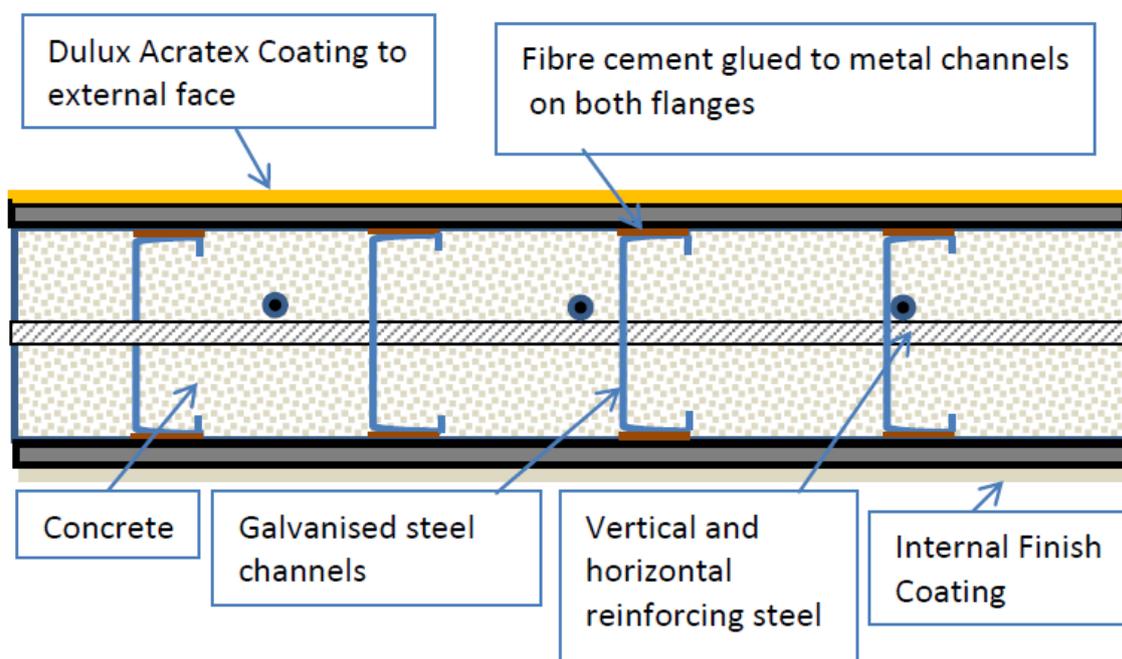


Figure 4: The complete LOGICWALL formwork with reinforcement and concrete

CSR Cemineal Fibre Cement (FC):

The fibre cement sheet facing of the LOGICWALL system is CSR Cemineal Fibre Cement (FC) wallboard that is suitable for use in wet areas.

Galvanised Steel Studs:

The central frame of the LOGICWALL system is constructed from perforated galvanized steel studs. The studs are galvanized by the hot-dip process.

The galvanized steel studs in the core of the LOGICWALL system have 275 grams minimum mass of zinc coating per square meter of steel sheet. This represents the total on both sides which translates to 137.5 g/m² per side or approximately 20 microns per side, according to data from the International Zinc Association (Table 1)

Table 1: Range of commonly available coating weights (Source: International Zinc Association)

| Product | Designation | Coating Weight (oz/ft ² /2-sides) | Coating Weight (g/m ² /2-sides) | Thickness (one side-inches) | Thickness (one side-µm) |
|------------|--------------|--|--|-----------------------------|-------------------------|
| Galvanized | G40 or Z120 | 0.40 | 120 | 0.0003 | 8 |
| | G60 or Z180 | 0.60 | 180 | 0.0005 | 13 |
| | G90 or Z275 | 0.90 | 275 | 0.0008 | 20 |
| | G200 or Z610 | 2.00 | 610 | 0.0017 | 43 |

Bostik AFS Structural Adhesive:

The construction of the AFS LOGICWALL formwork involves gluing the galvanized steel studs with a Bostik AFS Structural Adhesive to the outer shell of the Cemirseal FC sheets. AFS Structural Adhesive is a fast cure one component polyurethane adhesive. The adhesive has elongation and shorting at failure of 25% when tested in accordance with ASTM C719.

Dulux AcraTex Coating

Dulux AcraTex is a high build acrylic based coating. The complete coating system consists of one application of Dulux AcraPrime, one application of Dulux AcraTex (951) and one application of a Dulux AcraShield (955).

Areas of use

The AFS LOGICWALL panels are permanent formwork for the construction of reinforced concrete walls, The system allows for the insertion of conventional reinforcement and then filling of the core with concrete. The constructed reinforced concrete wall can be used for either load bearing or non-load bearing walls. The LOGICWALL system can be used for the

construction of internal party walls or external structural walls provided that an external surface coating or cladding is applied.

Specific areas of applications of AFS LOGICWALL system include but not limited to these are:

- Party Walls
- Façade Walls
- Balustrades
- Boundary Walls
- Lift & Stair Shafts
- Retaining Walls
- Basement Walls

2. Applicability of AS 3600 durability requirement to LOGICWALL

The durability of concrete structures is covered by Section 4 - *Design for Durability* in the Australian Standard AS 3600 – *Concrete Structures*. The section applies to plain, reinforced and prestressed concrete structures and members with design life of 50 years $\pm 20\%$. Section 4 mainly covers the durability of concrete elements reinforced with mild steel in specific defined classes of environmental exposures. It does not address the durability of metal embedded in concrete other than mild steel. In particular, it does not address the durability of galvanized steel in concrete.

The standard identifies corrosion of reinforcement as the most common and obvious form of durability failure, though abrasion, freezing and thawing, attack from aggressive chemicals, and alkali aggregate reaction (AAR) are mentioned. The durability of a structure or member is also related to the exposure environment in the Standard. Therefore, members in the interior of buildings have a lower exposure classification compared to members in an exterior environment. AS 3600 exposure classifications are A1, A2, B1, B2, C1 and C2, which represent increasing degrees of severity of exposure, while classification U represents an exposure environment not specified in Table 4.3 but for which a degree of severity of exposure should be appropriately assessed.

In general, members in the interior of buildings are exposed to dry conditions with carbonation as the main agent of deterioration. While the rate of carbonation may be high the propagation of corrosion, once started, proceeds at a negligible rate. External building elements on the other hand are exposed to varying conditions determined by their proximity to the ocean and atmospheric pollutions. The main agents of deterioration for external members are chlorides, or a combination of chlorides and carbonation.

The Standard defines reinforced concrete to include any concrete containing metals that rely on the concrete for protection against environmental degradation. Plain concrete members containing metallic embedments are treated as reinforced members when considering durability. By inference, it only addresses situations when the metallic embedments rely on the concrete for protection.

The Standard allows protective surface coating to be taken into account in the assessment of

the exposure classification (Notes 9 to Table 4.3).

- 9 In this Table, classifications A1, A2, B1, B2, C1 and C2 represent increasing degrees of severity of exposure, while classification U represents an exposure environment not specified in this Table but for which a degree of severity of exposure should be appropriately assessed. Protective surface coatings may be taken into account in the assessment of the exposure classification.

The implication is that while a member may be located in an environment that would be classified as aggressive, the presence of a protective coating would reduce the severity of the exposure classification. In this regard any protective coating applied to the surface of the LOGICWALL should be included in the durability assessment of the LOGICWALL system. Where the coating forms a complete barrier against the ingress of aggressive elements, the exposure environment would change from aggressive to benign.

Potential durability issues pertaining to LOGICWALL

Embedment – What is an embedment?

Note 1 to Table 4.3 in AS 3600 defines reinforced concrete to include any concrete containing metals that rely on the concrete for protection against environmental degradation. Embedment can therefore be taken as a metallic object contained within the concrete that relies on the concrete for protection.

Further Clause 14.2 defines embedded items to include pipes and conduits with their associated fittings, sleeves, permanent inserts for fixings and other purposes, holding-down bolts and other supports.

As already stated there is no mention of the type of metals. The emphasis is on metallic objects that depend on the concrete for protection.

Is the framing of LOGICWALL an embedment?

The galvanized steel stud core of the LOGICWALL system after construction will be located within two exposure environments. The web of the steel channels will be embedded in concrete, while the flanges will be situated between the surface of the concrete and the Cemiseal sheets. The metallic core frame of the LOGICWALL is a galvanised steel stud that relies on the galvanising as the primary form of corrosion protection. For the section of the

galvanized studs that is not embedded in concrete, an additional protection in the form of the polyurethane adhesive, a 6 mm layer of Cemirseal fibre cement sheet, and a Dulux AcraTex coating system is provided.

AS 3600 defines reinforced concrete as any concrete containing metallic embedments that rely on the concrete for protection against environmental degradation. While Note 1 of Table 4.3 in AS 3600 further states that plain concrete member containing metallic embedment should be treated as reinforced members when considering durability, this cannot be applied in the case of the AFS LOGICWALL frames because the core galvanised steel studs are not designed to rely on the concrete for protection and do not perform any structural function. The fact that they are embedded in concrete is incidental and once the concrete has set, they perform no function other than to act as a crack inducer.

The concept of embedded metal in concrete not relying on the concrete for protection is not new. For example, galvanised and epoxy coated reinforcement are used to provide additional durability if it is perceived that the protection provided by the concrete will not be sufficient over the life of a structure.

What are the requirements for embedments?

AS 3600 - Clause 4.10.3.7: *Embedded items cover* – states:

“Embedded items, as defined in Clause 14.2, shall be protected from corrosion or deterioration. The cover to embedded items that are not corrosion resistant shall be as given in Table 4.10.3.2 and Table 4.10.3.3, as applicable. The requirement in terms of durability is the provision of enough concrete cover to protect the embedment from corrosion.”

Cover -What are the requirements?

In normal concrete the thickness of the concrete cover is of great importance in preventing or retarding the corrosion of the reinforcement. The depth of the cover is determined by the exposure classification and the grade of concrete. However, in the case of reinforced AFS galvanised steel channels the concrete cover is not required for the protection of embedded

channels.

Cover requirement in AS 3600 for normal reinforcement is determined by the exposure classification of a member and the grade of concrete used. The required cover ranges from 20 mm (Class A1 irrespective of the grade of concrete) to 45 mm (Class B2 with 40 MPa Grade of concrete). If allowance is made for the protective barrier provided by the surface coating on the Cemiseal FC sheets, elements in class B2 will be reduce to a class B1. In which case, the cover reduces to 30 mm. Note that reducing the exposure classification from B2 to B1 is a conservative position, as an effective coating, if well maintained, would, in reality, reduce the exposure classification to A1.

The location of normal reinforcement in the single reinforced LOGICWALL system is such that the 45 mm cover requirement of AS 3600 is met for wall thickness 150, 162 and 200 mm, in exposure environment up to B2. This does not take the protective coating into account. For the 120 mm thick wall the above condition would be satisfied if the reinforcement diameter is not greater than 12 mm. However, if allowance is made for the protective barrier and the B2 exposure is reduced to B1, the required cover would be met.

In the case of the double reinforcement LOGICWALL systems, the designed cover is 30 mm (Fig. 7), which satisfies the cover requirement without reliance on the protective barrier up to exposure class B1. By allowing the effects of the protective coating and downgrading a B2 exposure to B1, the LOGICWALL system can be used for the construction of wall in all categories of exposure from A1 to B2.

Therefore, the actual concrete cover provided by the LOGICWALL system to any structural reinforcement meets the cover requirements of AS 3600 for exposure classification A1 to B1 without considering the allowance for protective barriers.

In exposure classification B2 – coastal, the protective barrier needs to be taken into account if reinforcement embedded in the concrete is to have sufficient cover to achieve the design service life of $50 \pm 20\%$.

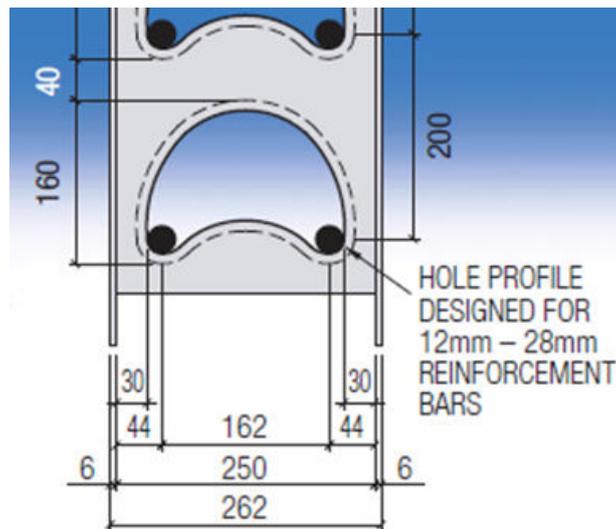


Figure 7: Reinforcement layout and cover provision for the double reinforcement LOGICWALL system

TABLE 4.10.3.2
REQUIRED COVER WHERE STANDARD FORMWORK AND COMPACTION ARE USED

| Exposure classification | Required cover, mm | | | | |
|-------------------------|------------------------------------|--------|--------|--------|----------|
| | Characteristic strength (f'_c) | | | | |
| | 20 MPa | 25 MPa | 32 MPa | 40 MPa | ≥ 50 MPa |
| A1 | 20 | 20 | 20 | 20 | 20 |
| A2 | (50) | 30 | 25 | 20 | 20 |
| B1 | — | (60) | 40 | 30 | 25 |
| B2 | — | — | (65) | 45 | 35 |
| C1 | — | — | — | (70) | 50 |
| C2 | — | — | — | — | 65 |

NOTE: Bracketed figures are the appropriate covers when the concession given in Clause 4.3.2, relating to the strength grade permitted for a particular exposure classification, is applied.

Are there alternatives to concrete that can be used to protect the steel?

For the majority of ordinary structures, the reliance on concrete cover as a protective barrier will normally result in a satisfactory service life. However, in some cases the concrete cover will not provide adequate protection. The shortcomings of reliance on concrete cover as a means of protecting steel reinforcement are evident by the huge cost of concrete repairs the world over.

In situations where concrete alone cannot be relied upon to provide the protection required, durability enhancement systems are applied. A number of approaches that have been used include:

- the use of membrane-type coatings applied to the surface of concrete;
- the impregnation of concrete with materials intended to reduce its permeability;
- the addition of corrosion inhibitors to concrete;
- the use of corrosion resisting reinforcement;
- cathodic protection of the reinforcement; and/or
- the application of coatings to the reinforcement itself

The most commonly used of these measures in normal reinforced concrete structures construction include:

- Protection of concrete surface with a barrier system which will also protect the reinforcement
- Protection of the reinforcement against corrosion by using among others
 - Non-corrodable reinforcement
 - Coating of reinforcement such as epoxy coated reinforcement or hot-dip galvanizing

The corrosion of reinforcing steel in concrete usually requires the ingress into the concrete of water, aqueous salt solutions, and air. Therefore, treating the concrete surface with a barrier system is a potentially effective anti-corrosive practice. Four general types of barriers are used: waterproofing, damp-proofing; protective barrier; and paint.

A waterproofing barrier consists of materials applied to the concrete surface to block the passage of liquid water and significantly reduce the passage of water vapour. Protective-barrier systems protect concrete from degradation by chemical attack and subsequent loss of structural integrity as well as to prevent staining of concrete. A decorative paint-barrier system stabilizes or changes the appearance or colour of a concrete surface. Such a system can resist the diffusion of gases, such as water vapour and carbon dioxide.

Decorative paints can be applied to the exterior surfaces of concrete structures above ground. The types of paints used are usually water-based Portland cement paints, water based polymer

latex paints, polymer paints (epoxy, polyester, or urethane), and silane/siloxane-based coatings.

Durability enhancement measures that have already been applied to the LOGICWALL system fall under the above measures of barrier system. The Dulux AcraTex coating on the surface of the LOGICWALL system forms a barrier between the environment and the core of the LOGICWALL. This has the advantage of protecting both the galvanized studs and the normal reinforcement. Galvanized coating on the surface of the steel studs act as a barrier which protects the steel from corrosion. The protective benefit of the galvanizing on the steel studs is discussed in detail in Section 3.

In a State of the Art Report on Coating Protection for Reinforcement (Comite Euro-International du Beton, 1992) the benefits from the practical use of galvanized reinforcement are reproduced below:

Benefits from the practical use of galvanized reinforcement

Finally, it is noteworthy that in the State of the Art Report on Coating Protection for Reinforcement (Comite Euro-International du Beton, 1992) 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.

This report is particularly relevant to the framing of LOGICWALL as it notes that galvanized hardware is acceptable at the surface of the concrete.

In particular, the outer face of the flange of the studs is not embedded in concrete. The State of the Art Report quoted above indicates the flanges will be acceptable from a corrosion point of view without any additional protection. However, additional protection is provided in this case in the form of the adhesive bonding the Cemiseal FC sheet to the flange and the finishing coat of Dulux AcraTex.

The second item on the above list recommends galvanized reinforcement should be passivated by chromate treatment for best results. The initial view in the industry was that chromate treatment was necessary to deal with the loss in bond due to hydrogen evolution.

More recent bond tests appear to show that the difference in bond strength between ribbed black bars and galvanized bars is not statistically significant, and that any early-age reductions in bond strength for galvanized bars completely disappear as the concrete ages. Overall, these

results confirm that galvanized bars can give just as good all-round bond-strength performance as uncoated bars.

The current view is that the bond strength between galvanized rebar and concrete is excellent. However, it often takes slightly longer to develop than the bond between bare rebar and concrete. According to laboratory and field tests, the bond between galvanized rebar and concrete is in fact stronger than the bond between bare rebar and concrete or epoxy-coated rebar and concrete (see Figure 8).

It is clear that there are complex chemical interactions between zinc/zinc-iron alloys and the cement matrix that lead to hydrogen evolution and the formation of zinc oxide. The formation of zinc oxide and other zinc compounds cause retardation of setting and lead to the slow development of good, strong bonding at the bar-concrete interface at early ages. However, with time, this early retardation of setting is overcome and a strong bond between the zinc coating and concrete is restored. It is thus clear that the early-age chemical interactions and hydrogen evolution have no measurable adverse effects on the bond characteristics of galvanized bars at ages beyond 7 days and on this basis, chromate treatment is not necessary to counteract the effects of hydrogen formation.

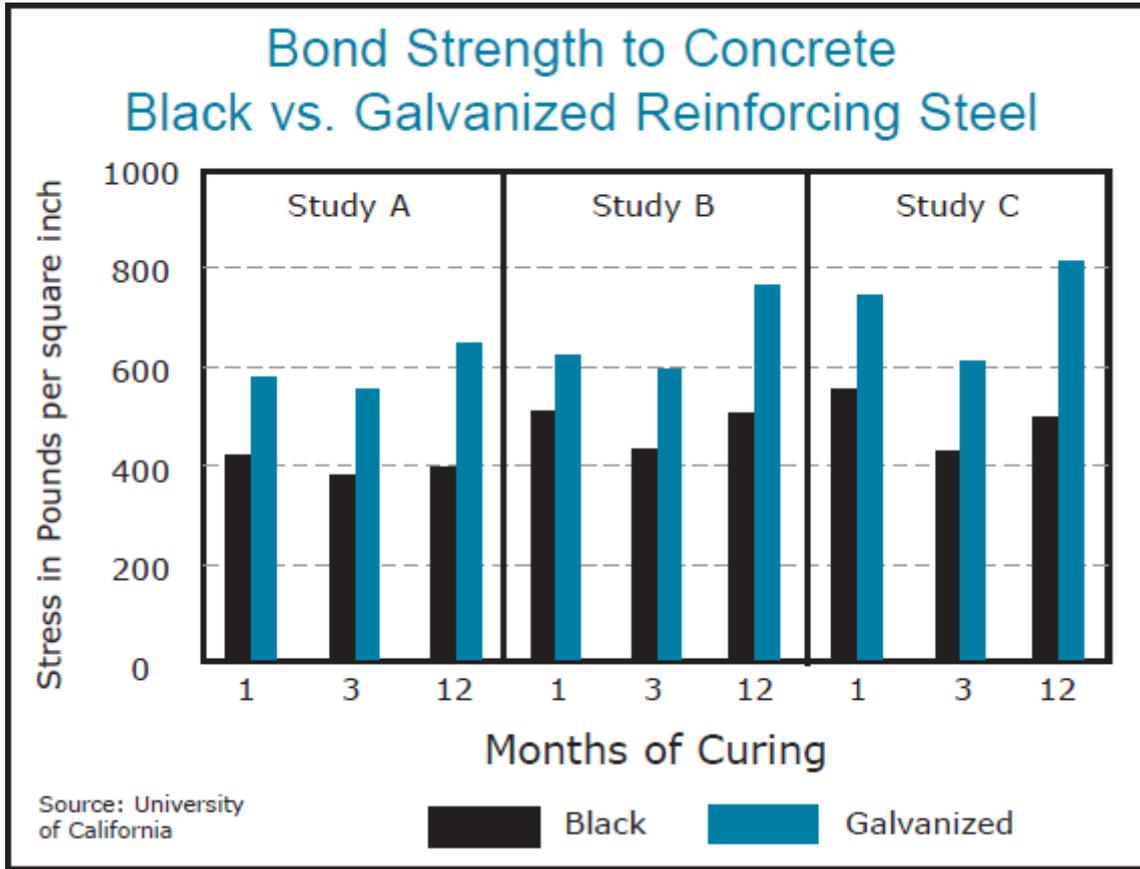


Figure 8: Bond strength to concrete black vs. galvanized reinforcing steel

3. Galvanizing as Protection

Galvanizing is a process for protecting iron and steel against corrosion by applying a zinc coating on the surface of these materials. Three of the most commonly used processes for applying zinc to iron and steel are hot-dip galvanizing, electro-galvanizing, and zinc spraying. Of these the hot-dip process is the most widely used. It involves immersing steel into a bath of molten zinc, which is at a temperature close to 465°C, to form a metallurgically bonded zinc or zinc-iron alloy coating. This same hot-dip immersion process is also used to produce other coatings such as zinc-aluminium alloys.

Galvanizing is a cost effective corrosion control process that solves many corrosion problems in most major industrial applications. The value of hot-dip galvanized steel stems from the relative corrosion resistance of zinc, which under most service conditions is considerably better than iron and steel. In addition to forming a physical barrier against corrosion, zinc, applied as a hot-dip galvanized coating, cathodically protects exposed steel. Furthermore, galvanizing for protection of iron and steel is favoured because of its low cost, ease of application and extended, maintenance-free service that it provides.

The reason for the extensive use of hot-dip galvanizing is the two-fold protective nature of the coating. As a barrier coating, it provides a tough, metallurgically bonded zinc coating that completely covers the steel surface and seals the steel from the corrosive action of the environment. Additionally, zinc's sacrificial action protects the steel even where damage or a minor discontinuity in the coating occurs.

Electrochemistry of galvanized steel in concrete

Zinc is an amphoteric metal which means that the zinc is stable over a wide range of pH, from approximately 6 - 12.5, but below and above these values the corrosion rate increases exponentially.

The depassivation of unprotected carbon steel occurs at pH values below about 11.5. In the presence of chlorides, however, such depassivation can occur at higher pH values. Zinc, on the other hand, is an amphoteric metal and so reacts with both strong acids and bases. The reaction is very severe below pH 6 and above pH 13, but the rate of attack is very slow and the zinc

remains passivated in the pH range 8 - 12.5 due to the complex chemical interactions between zinc and the fresh concrete. Zinc-coated reinforcement can therefore remain passivated to pH values as low as 9.5 and thus offers significantly greater protection for a longer time than black steel against the effects of carbonation in concrete. Further, the corrosion products of zinc in concrete occupy a much lower volume of 5.36 ml per mole of metal consumed compared with that of iron of about 7.8 ml per mole of parent metal consumed, resulting in much lower swelling pressures and reduced cracking of the cover concrete. This reduced destruction of the cover concrete can give reinforced concrete longer and better electrochemical stability when galvanized steel is used as reinforcement.

Measurements of pH after 3 years of natural marine exposure in the tidal zone showed that, generally, the pH value was more than 12 at a depth of 10 mm from the concrete surface. For all cover depths, the pH of the concrete in the neighbourhood of the reinforcing steel remained in the range 12.6-12.8. At this pH level, the corrosion rate of zinc is a minimum and this fact benefits the performance characteristics of galvanized bars in concrete. In any case, pH values of 12.6-12.8 are unlikely to be detrimental in real practice since pH values in exposed concretes will only decrease with time, not increase. Further, it is also important to note that galvanized steels remain passive in carbonated concrete and the corrosion rate is generally of the same order of magnitude as that in non-carbonated concrete. On the other hand, the corrosion rate of black steel is more than a factor of 10 times greater in carbonated concrete. These data also points to the distinct advantages to be gained by incorporating mineral admixtures such as fly ash, slag and silica fume in concrete. The incorporation of these materials in concrete will lower the pH of the concrete by reacting with the calcium hydroxide by-product of the hydration of cement. The use of these materials is commonplace in commercial concrete with the levels increasing in recent years in the interests of sustainability of concrete as a building material.

Corrosion of galvanized steel in alkaline environment

The main component of cement that influences the behaviour of zinc in an alkaline media is the alkali content (Na^+ , K^+). Different cements can produce different pore solutions due to the presence of alkali ions, which are the most soluble components and thus responsible for the final pH of the pore solution.

This approximate relationship between the cement alkali content and the corrosion rate may explain the observed different behaviours and life of galvanized coatings in concrete. The type of cement in contact with the galvanizing is very important because it allows the formation of a compact passive layer of calcium hydroxyzincate. This effect may also explain part of the controversy and poor performance of galvanized reinforcement in concrete when the type of cement used has not been taken into account.

What is clear is that the layer of passivating corrosion products develops during the first hours after mixing, when the pH value of the pore concrete solution is lower than 12.8 ± 0.1 . This protective layer completely passivates the galvanized steel. If the pH is between 12.8 and 13.2, the passivating layer develops slowly and the galvanized coating may continue to dissolve until full passivation is reached. If the pH is greater than 13.2, the passive layer is not developed and the galvanized coating continuously dissolves until it disappears.

Fortunately, pH values greater than 13.2; do not develop in concrete pore solutions during the first hours after mixing if sulphate is used as a setting regulator or enough alkaline sulphates are present. While sulphate ions are present in the pore solution, the pH value does not increase beyond 13.2. Only when the sulphates disappear from the solution, due to the formation of sulphoaluminates, does the pH rise to a maximum value which is a function of the total alkali content. This usually happens several hours or days after mixing, by which time the passivating CaHZn layer has all but completely formed and, as a result, the increase in pH is not harmful to the galvanized coating.

Corrosion of galvanized steel in carbonated concrete

The carbonation or neutralization of the cover concrete is one of the principal reasons for reinforcement corrosion. The pH of the aqueous phase changes from highly alkaline to values around neutrality (pH 7). As indicated in Fig 9, at or near neutral pH the rate of corrosion of zinc is very low and it would be expected that the galvanized coating would perform quite well. As a result, it is generally noticed that galvanized steel does not corrode in carbonated concrete.

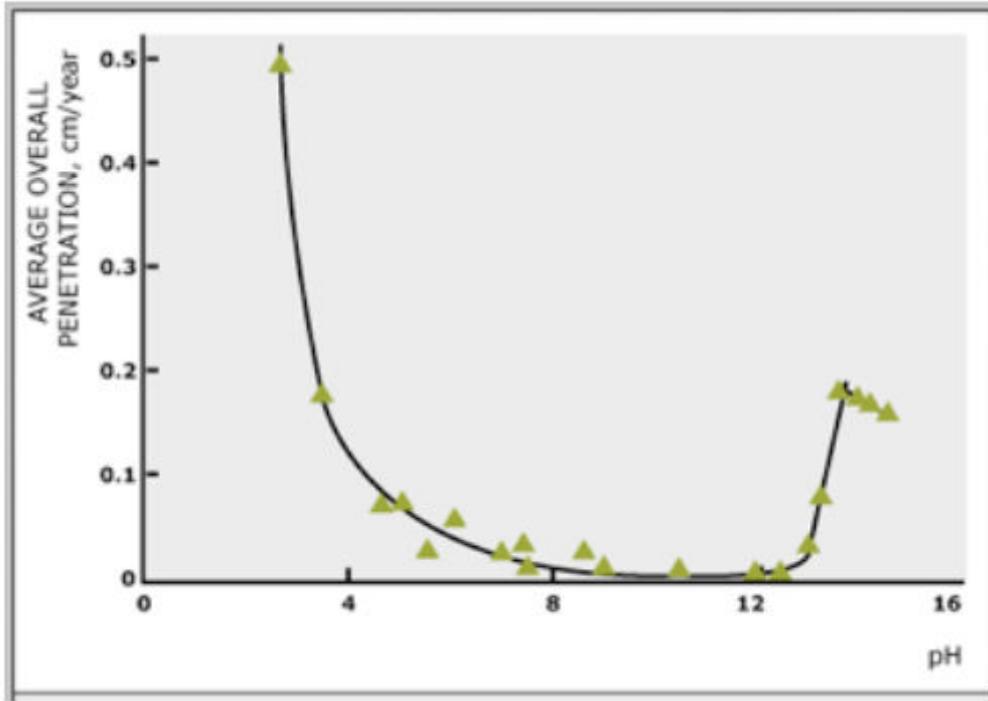


Figure 9A: Penetration of pure zinc due to corrosion as a function of pH

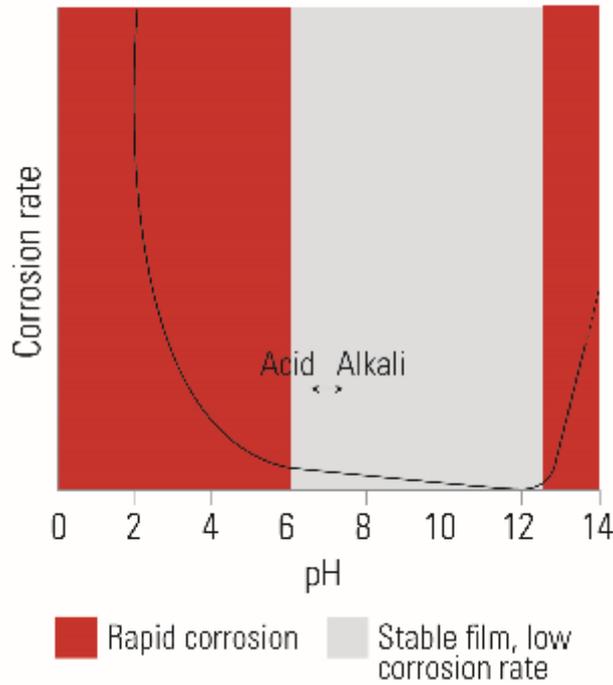


Figure 9B: Zone of stability of galvanized coating in carbonated concrete

From the results of extensive research and field observation it has been shown that carbonation does not increase the corrosion rate of galvanized bars in concrete and in some cases it is even reduced. This effect is shown in Fig. 10 where the corrosion rate of galvanized reinforcement embedded in carbonated and uncarbonated mortars, along with sequential changes in relative humidity, are plotted. From this data it can be seen that, before the concrete is carbonated, the galvanized steel shows high corrosion rates due to the coating being consumed in forming the protective layer of CaHZn. During carbonation, the galvanized coating may depassivate with a consequent rise in the corrosion rate, but later (after 6 days in Fig. 11) a sharp decrease in the corrosion rate occurs. A new passivated layer is formed in this condition, most likely due to the precipitation of zinc carbonates on the surface.

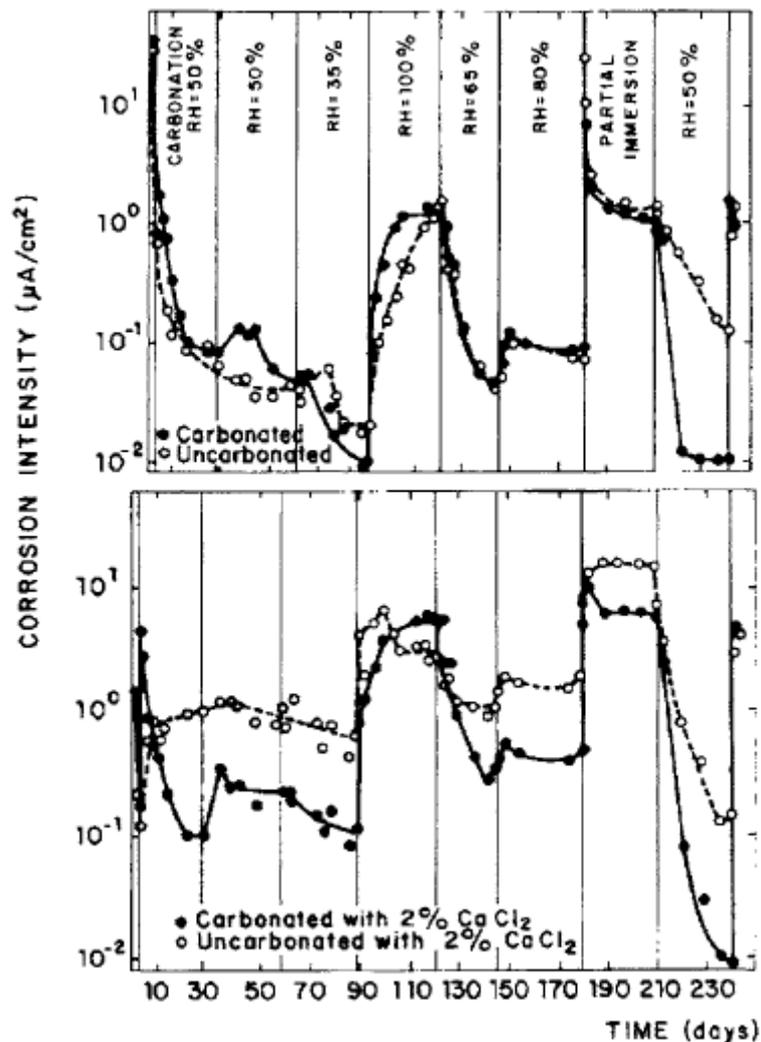


Figure 10: Evolution of I_{corr} of galvanized reinforcement embedded in carbonated and uncarbonated mortar, with and without chlorides

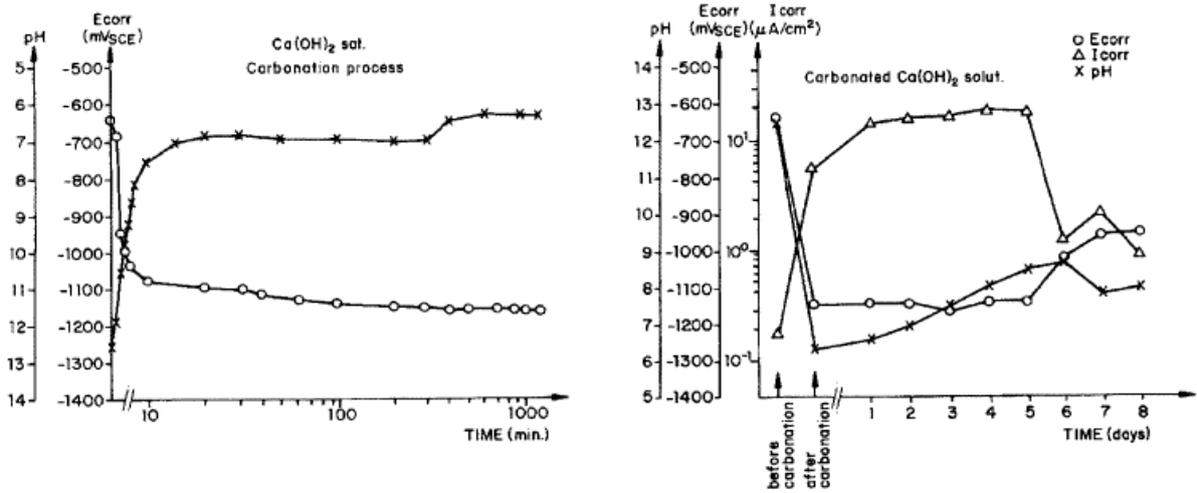


Figure 11: Changes of E_{corr} and I_{corr} of galvanized steel during carbonation of alkaline solutions

4. Coating as Protection

The LOGICWALL system includes the application of Dulux AcraTex to external surfaces. The Dulux AcraTex coating is a high-build acrylic coating of the type commonly referred to as anti-carbonation coatings. They are technically advanced products characterized by properties such as resistance to wind-driven rain, chalking and checking after weathering, high ultimate (breaking) elongation, elongation recovery and crack bridging capability.

Included in the Dulux AcraTex range is the mid-build elastomeric coating. This is an elastomeric membrane which provides the properties of a protective membrane. It protects the underlying material from the ingress of moisture, carbon dioxide and surface cracking. While the choice of the coating system may vary, the complete system should include a primer, AcraTex texture coating, and AcraShield

Can coatings be relied upon as protection under AS 3600?

As discussed in Sections of this report, AS 3600 allows for the inclusion of a protective coating in the assessment of the exposure classification of an environment. The result is that the exposure classification can be reduced in severity. Where the protective coating forms an impermeable membrane, the concrete member can be considered to be in a relatively benign environment.

Indeed application of surface coating on reinforced concrete structures is recognized as a durability enhancement measure when concrete alone cannot be relied upon to provide the required service life.

What properties does the coating need to have?

The performance properties of suitable protective coating should include high resistance to carbon dioxide and chloride ion diffusion, excellent adhesion to the substrate, resistance to wind-driven rain and enhanced crack-bridging capability.

Resistance to wind-driven rain is important because water penetration through the coating will allow water carrying contaminants, such as chlorides, to penetrate to the zone of the steel reinforcement and initiate corrosion.

Crack bridging pertains to elastomeric high-build coatings. It is the ability of the coating to bridge existing and potential concrete cracks, thus withstanding night-day temperature cycles throughout the seasons and over the years. These include crack movements induced by shrinkage and/or thermal cycles. Larger crack movements are frequently a sign of a structural problem and should not be concealed by an elastomeric coating.

By stretching over cracks, elastomeric coatings stop the ingress of harmful substances carried by water into the concrete. In addition, they mask random shrinkage cracks that become visible after rain and are not aesthetically appealing.

The crack bridging ability of an elastomeric coating depends on a series of factors: ambient temperature, coating thickness, and value of ultimate and recovery elongation.

A Dulux AcraTex coating system that does not include an elastomeric membrane coating will not provide the water proofing and crack bridging properties needed for the protection of the underlying LOGICWALL formwork.

How does the performance of the coating need to be demonstrated?

Various standards are available for testing the performance of a coating. The available test standards are covered by AS/NZS 4548 - *Guide to long-life coatings for concrete and masonry - Guidelines to methods of test*. The individual parts are listed below.

| | |
|--------------------------|--------------------------|
| Water Transmission | AS/NZS 4548.5 Appendix C |
| Water Vapour | AS/NZS 4548.5 Appendix C |
| Carbon Dioxide Diffusion | AS/NZS 4548.5 Appendix D |
| Chloride Ion Diffusion | AS/NZS 4548.5 Appendix E |
| Crack Bridging Ability | AS/NZS 4548.5 Appendix F |
| Elongation | AS/NZS 4548.1 |

International Standards

Resistance to wind driven rain

ASTM D6904 measures the ability of high-build coatings to provide an impermeable barrier against wind-driven rain over time. The test involves the exposure of the coated surface of a concrete block to rain at about 44 m/s (98 mph) for 24 hours. The test evaluation uses a visual inspection of the rear face of the masonry left untreated. The material passes the test if no dampness is detectable.

Elongation

Ultimate and recovery elongation depend on coating formulation and are covered by several tests. Ultimate (breaking) elongation is measured according to ASTM D412 and ASTM D2370. In both tests, a coating sample is stretched between two clamps in stress-strain controlled equipment. However, ASTM D412 requires dumbbell specimens that provide a higher degree of dimensional stability at the cross section under tension. In addition, ASTM D412 sets the standard for calculating elongation recovery, which is not considered in ASTM D2370.

Crack bridging

Crack bridging is tested according to ASTM C1305 and EN 1062-7. There is a significant difference between the two methods. The European EN test measures the number of crack bridging cycles a coating is able to withstand before failure between an assigned initial and final crack width, at fixed temperatures and movement rate. The final result is an average of the number of completed cycles, which should go up to the thousands.

On the other hand, ASTM C1305, which is designed for waterproofing membranes, sets up 10 cycles for a coating to pass the test.

Water vapor permeability

Water vapor permeability is tested according to ASTM E96 and ASTM D1653. The methods are similar, and both report the procedure for the desiccant (or Dry Cup) and water (or Wet Cup) tests. The Wet Cup usually generates higher permeance values than Dry Cup. ASTM D1653 is restricted to smooth coatings, which may be a limitation. The tests do not provide guidelines for the evaluation of the permeance value, which must be assessed comparatively between samples.

What is the expected life of the coating?

The Dulux technical data sheets states 7 years warranty for the individual AcraTex 951 coat and the AcraShield 955 top coat that make up the complete coating systems. Industry wide, such coatings are considered to have an effective life of a minimum of 10 years. In fact, there are many buildings with high build acrylic coatings that are left for 15 or even 20 years before re-application of the coating and no significant deterioration of the underlying structure occurs. The specified Acratex system is warranted for a period of less than 10 years, however, it is normal for a product warranty to be for a shorter period than the serviceable life of the product.

It is reasonable, therefore, that the service life of the three coat Dulux AcraTex coating specified for the LOGICWALL system be taken as 10 years. However, it is noted that Dulux state in their Technical Data Sheets that “the coastal area is considered a marine environment and as such salt potentially can shorten the life of the coating systems”. Monitoring of the coating is therefore required in more aggressive environments.

Are there any conditions under which the coating will not be effective?

The Dulux AcraTex acts as a barrier coating, therefore, some protection will be lost if the coating is damaged. The coating should be completely free of pin holes, holidays and other surface defects. The application should be in accordance with the manufacturer’s recommendations regarding moisture conditions of the substrates and the ambient temperature.

Exposure to substances that degrades the coating should be avoided to maintain its protective properties. Exposure to elevated temperature is not recommended. Periodic monitoring of the condition of the coating and maintenance when necessary is a requirement of any protective treatment.

5. Projected service life of LOGICWALL

Historical evidence from the use of galvanized steel reinforcement

In spite of the inherent advantages of galvanizing as a means of corrosion protection of steel in concrete, there is considerable confusion regarding the long-term stability and durability of galvanized steel in concrete

Part of this lack of confidence arises from conflicting and contradictory laboratory test data and various laboratory electrochemical studies reported in literature on the chemical reactions and corrosion of zinc in solutions supposedly representing the chemical environment in concrete.

Concrete remains in the plastic state for only a few hours. Once it has hardened, the amount of free moisture within is progressively and drastically reduced by cement hydration and drying. Ionic diffusivity in concrete will thus be fundamentally different to that of zinc immersed in liquid solutions. Further, both carbonation and chloride attack are time-dependent activities involving both chemical interactions and physical processes, and concrete contains many compounds whose interaction with zinc is not clearly established. Extreme care should therefore be exercised in extrapolating and translating into practice laboratory corrosion results obtained from short-term tests or tests in solutions simulating the liquid phase of concrete or mortar/concrete prism tests. Failure to take into consideration these differences is what has resulted in the confusion about the performance of galvanized steel in concrete.

Field performance of galvanized steel in concrete

A large number of cases of successful field performance of galvanized steel in aggressive exposure conditions have been reported in the literature. In one case, the sound condition of galvanized steel after 54 years of exposure in a marine environment has been reported. The good condition of galvanized reinforcement found in the Old Bus Garage in Hamilton, Bermuda was also reported when the structure was demolished after 45 years of service, despite exposure to an extremely aggressive marine environment. The concrete-reinforcement interface was found to be dense and showed no signs of any zinc-concrete reaction.

The islands of Bermuda have one of the worst marine-exposure conditions known in the world. Unprotected reinforced and prestressed steel used in concrete structures with 70 mm cover have

often shown signs of corrosion within 3 years of construction. Sound engineering design and careful attention to detailing with high-quality workmanship have, on the other hand, shown that galvanized reinforcement can give durable service life, even in such extremely aggressive salt-laden environments

The most comprehensive field study on the performance of galvanized steel in concrete structures was presented in a report prepared for the International Lead Zinc Research Organization. Data presented in the report show pH values of 11.2-12.4 in an Iowa bridge after 7 years of exposure and 12.4-12.7 in a Vermont Bridge 3 years after construction. These data confirm that pH itself is never critical to the stability of galvanized steel in concrete, although many laboratory tests in saturated solutions show otherwise. Bearing in mind that pH values in concrete structures will only decrease with time, not increase, and the fact that galvanized steel remains passive in carbonated concrete, the superior performance of galvanized steel in real environments is not surprising.

The conditions under which the LOGICWALL system will be used are not as harsh as the environments of the locations presented above. In the main the LOGICWALL system will be exposed to carbonation which is not as aggressive as chloride laden environments. No evidence to date of corrosion or deterioration where the AFS LOGICWALL system or similar permanent formwork has been used in the building industry has been reported. Furthermore, the rate of corrosion of zinc in carbonated concrete is negligible. Therefore, taking into account that in a very harsh chloride environment, galvanized steel remain sound after 54 years in concrete, it can be expected that, in an environment where it is exposed to carbon dioxide, the LOGICWALL system will provide a service life far greater than the expected service life of 50 ± 20 years nominated in AS 3600.

Theoretical approach

Much of the extensive studies into the corrosion of galvanized steel in concrete cover its performance in chloride environment. Understandably so, because chlorides are the more aggressive agents for reinforced concrete and are the most frequent cause of significant reinforcement distress. In spite of this there is no agreed threshold chloride level at which galvanized steel is attacked, which is a prerequisite for the theoretical prediction of the service life.

What has been reported by various investigators is that the threshold for the initiation of corrosion of galvanized steel in a chloride environment is 4 to 5 times that of mild steel.

The lack of an established threshold means there are no available models for the theoretical prediction of the service life of galvanized steel in concrete. The estimated service life of fully exposed zinc coating having varying coating thickness in various environments is shown in Fig. 12. The corrosion of the zinc coating on galvanized steel in concrete is not expected to behave in a similar manner because corrosion in the somewhat ‘fixed’ environment of concrete is more localized. The corrosion products that are formed are restricted in their movement away from the surface; the result is that the corrosion process tends to be suppressed.

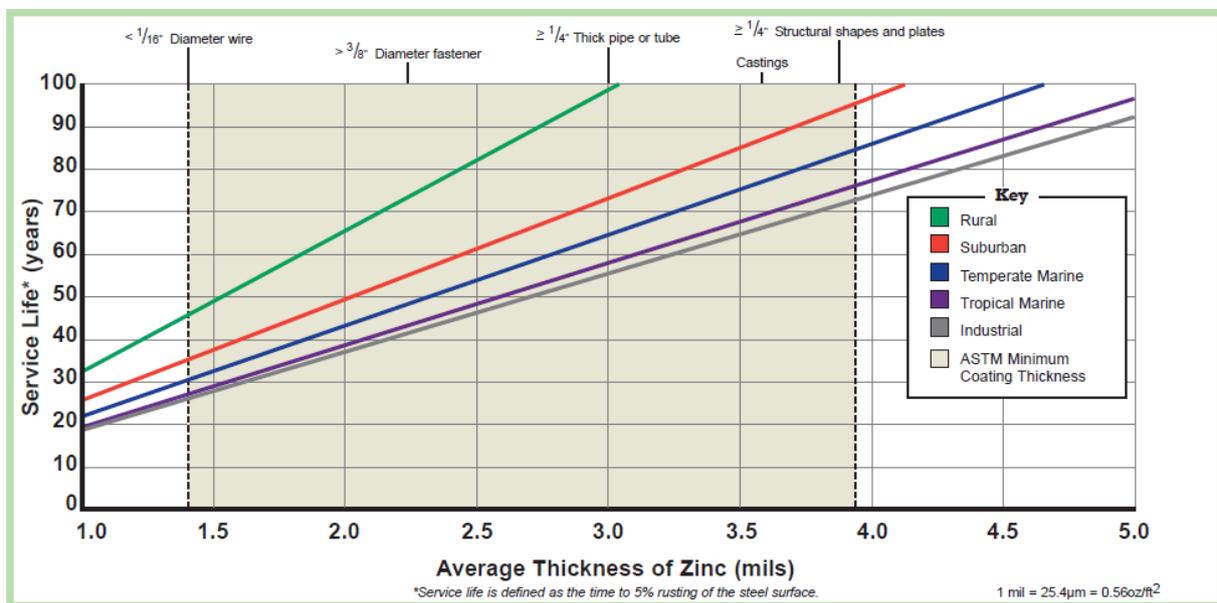


Figure 12: Service life chart for hot-dip galvanized coating in open atmosphere

The difference in the behaviour of galvanized coating in open atmospheric conditions and in concrete makes the available data and charts unsuitable for the estimation of the service life the galvanized studs of the LOGICWALL system.

An alternate approach to the theoretical estimation of the service life would be to estimate a service life using the atmospheric data and apply a factor to account for the expected longer life of galvanized steel in concrete. However, it should be remembered that service life is a function of the thickness of the galvanized coating and the nature of the surrounding environment. For example the environment is classified into six general categories or zones by ISO 9223, AS

4312 and AS/NZS 2312, as shown in Table 2 and Table 3 below. Figure 13 presents a chart that shows the coating life to first maintenance of hot dip galvanized steel in the six exposed zones. These commonly used Tables and Figure do not provide for the estimation of the service life of galvanized steel in carbonated concrete.

In view of the lack of data for the theoretical estimation of galvanized steel in carbonated concrete, it is recommended that an approach that uses historic evidence of the performance of galvanized steel in concrete be adopted for the estimation of the service life of the galvanized steel studs in the LOGICWALL system.

Table 2: Corrosion Categories and Typical Environments

| Corrosivity category | Corrosivity | Typical environments – Examples from ISO 9223 | |
|----------------------|-------------|--|--|
| | | Indoor | Outdoor |
| C1 | Very low | Heated spaces with low relative humidity and insignificant pollution, e.g. offices, schools, museums | Dry or cold zone, atmospheric environment with very low pollution and time of wetness, e.g. certain deserts, Central Arctic/Antarctica |
| C2 | Low | Unheated spaces with varying temperature and relative humidity. Low frequency of condensation and low pollution, e.g. storage, sport halls | Temperate zone, atmospheric environment with low pollution ($SO_2 < 5 \mu g/m^3$), e.g. rural areas, small towns Dry or cold zone, atmospheric environment with short time of wetness, e.g. deserts, subarctic areas |
| C3 | Medium | Spaces with moderate frequency of condensation and moderate pollution from production process, e.g. food-processing plants, laundries, breweries, dairies | Temperate zone, atmospheric environment with medium pollution ($SO_2: 5 \mu g/m^3$ to $30 \mu g/m^3$) or some effect of chlorides, e.g. urban areas, coastal areas with low deposition of chlorides Subtropical and tropical zone, atmosphere with low pollution |
| C4 | High | Spaces with high frequency of condensation and high pollution from production process, e.g. industrial processing plants, swimming pools | Temperate zone, atmospheric environment with high pollution ($SO_2: 30 \mu g/m^3$ to $90 \mu g/m^3$) or substantial effect of chlorides, e.g. polluted urban areas, industrial areas, coastal areas without spray of salt water or, exposure to strong effect of de-icing salts Subtropical and tropical zone, atmosphere with medium pollution |
| C5 | Very high | Spaces with very high frequency of condensation and/or with high pollution from production process, e.g. mines, caverns for industrial purposes, unventilated sheds in subtropical and tropical zones | Temperate and subtropical zone, atmospheric environment with very high pollution ($SO_2: 90 \mu g/m^3$ to $250 \mu g/m^3$) and/or significant effect of chlorides, e.g. industrial areas, coastal areas, sheltered positions on coastline |
| CX | Extreme | Spaces with almost permanent condensation or extensive periods of exposure to extreme humidity effects and/or with high pollution from production process, e.g. unventilated sheds in humid tropical zones with penetration of outdoor pollution including airborne chlorides and corrosion-stimulating particulate matter | Subtropical and tropical zone (very high time of wetness), atmospheric environment with very high SO_2 pollution (higher than $250 \mu g/m^3$) including accompanying and production factors and/or strong effect of chlorides, e.g. extreme industrial areas, coastal and offshore areas, occasional contact with salt spray |

Deposition of chlorides in coastal areas is strongly dependent on the variables influencing the transport inland of sea salt, such as wind direction, wind velocity, local topography, wind sheltering islands outside the coast, distance of the site from the sea, etc. Extreme effect by chlorides, which is typical of marine splash or heavy salt spray, is outside of the scope of this Chart. Corrosivity classification of specific service atmospheres, e.g. in chemical industries, is outside of the scope of this Chart. Surfaces that are not sheltered or rain-washed in marine atmospheric environments where chlorides are deposited can experience a higher corrosivity category due to the presence of hygroscopic salts.

In environments with expected “CX category”, it is recommended that the atmospheric corrosivity classification from one-year corrosion losses be determined. One-year exposure tests should start in the spring or autumn. In climates with marked seasonal differences, a starting time in the most aggressive period is recommended.

The concentration of sulfur dioxide (SO_2) should be determined during at least one year and is expressed as the annual average. However, in Australia, SO_2 is so low in most environments that it is generally considered that it can be ignored, other than for specific industrial applications or extreme traffic examples.

Coastal areas are normally defined as between 50 metres to 1 Km inland from sheltered seas and between 1 Km and 10-50 Km from surf beaches depending upon prevailing winds and topography. More details and examples are available in AS 4312.

The Australian Bureau of Meteorology provides weather charts for Australia at <http://www.bom.gov.au/climate/>. These show average and recent conditions, including rainfall, temperature, humidity, evaporation, wind and UV.

Table 3: Corrosion rates for steel and zinc for the first year of exposure for the different corrosivity categories (This table has been developed from Table 2 of ISO 9223)

| Corrosivity category | Comparative corrosion rates for steel and zinc from ISO 9223 | | |
|----------------------|--|-------------------------------|---------------------------|
| | Unit | Carbon steel | Zinc |
| C1 | g/(m ² ·a) | $r_{corr} \leq 10$ | $r_{corr} \leq 0.7$ |
| | µm/a | $r_{corr} \leq 1.3$ | $r_{corr} \leq 0.1$ |
| C2 | g/(m ² ·a) | $10 < r_{corr} \leq 200$ | $0.7 < r_{corr} \leq 5$ |
| | µm/a | $1.3 < r_{corr} \leq 25$ | $0.1 < r_{corr} \leq 0.7$ |
| C3 | g/(m ² ·a) | $200 < r_{corr} \leq 400$ | $5 < r_{corr} \leq 15$ |
| | µm/a | $25 < r_{corr} \leq 50$ | $0.7 < r_{corr} \leq 2.1$ |
| C4 | g/(m ² ·a) | $400 < r_{corr} \leq 650$ | $15 < r_{corr} \leq 30$ |
| | µm/a | $50 < r_{corr} \leq 80$ | $2.1 < r_{corr} \leq 4.2$ |
| C5 | g/(m ² ·a) | $650 < r_{corr} \leq 1,500$ | $30 < r_{corr} \leq 60$ |
| | µm/a | $80 < r_{corr} \leq 200$ | $4.2 < r_{corr} \leq 8.4$ |
| CX | g/(m ² ·a) | $1,500 < r_{corr} \leq 5,500$ | $60 < r_{corr} \leq 180$ |
| | µm/a | $200 < r_{corr} \leq 700$ | $8.4 < r_{corr} \leq 25$ |

The classification criterion is based on the methods of determination of corrosion rates of standard specimens for the evaluation of corrosivity (see ISO 9226^{xi}).

The corrosion rates, expressed in grams per square metre per year [g/(m²·a)], are recalculated in micrometres per year (µm/a) and rounded.

Corrosion rates in category CX are considered extreme. Corrosivity category CX refers to specific marine and marine/industrial environments.

Specific calculation models, guiding corrosion values and additional information on long-term corrosion behaviour, are given in ISO 9224^{xii}.

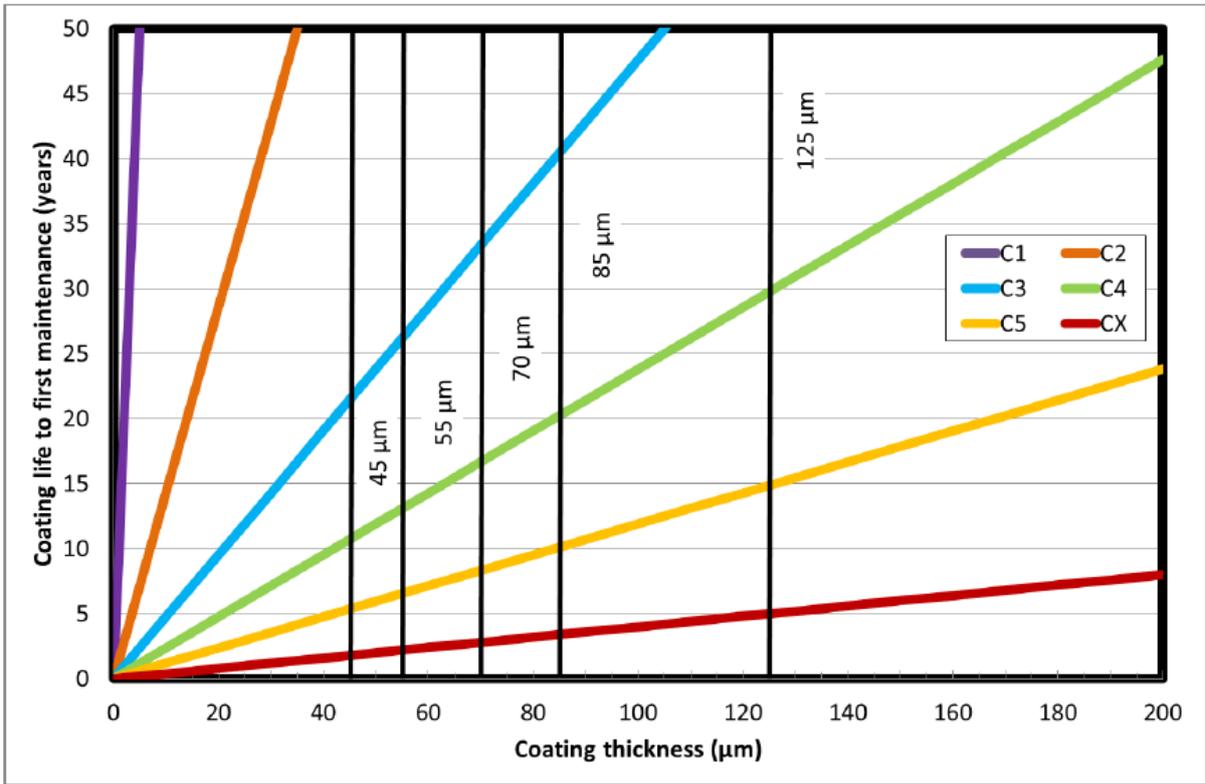


Figure 13: Life to first maintenance of hot dip galvanized steel in ISO 9223 corrosivity categories

6. Maintenance Requirements

Using a coating as a barrier between a corrosive environment and a material to be protected is the most widely used method of corrosion control for metals and other substrates. Because coating materials have a finite service life, effective coating maintenance is required for achieving the design life of an installed protective coating system as well as preserving the integrity of the underlying structure.

Coating systems need regular maintenance if they are to perform effectively. Protective coatings perform far more effectively for longer if they are regularly maintained. Dirt, grime and airborne salt deposits from the atmosphere can damage the coating surface and must be regularly cleaned off. Also, any mechanical damage to the coating must be promptly repaired to restore the original protection to the substrate. All this must be accomplished in a controlled, planned way. This is accomplished with a maintenance schedule that describes regular inspection, cleaning and repair and recoating. When a coating is refurbished, the objective is to maintain the integrity of the coating system and return the coating system to its original condition.

In this respect it recommended that the maintenance schedule for the newly applied coating should be first inspection at five years and another inspection carried out at age 8 years. Recoating should be undertaken when the original coating is 10 years old. During the 5-year and 8-year inspections, any damaged coating should be repair to ensure the protective coating is functional.

How should the performance of the coating system be monitored?

There are three types of coating inspection. The three types are:

1. General overview survey
2. Detailed visual survey
3. Physical coating inspection survey

For most buildings, the general overview and detailed visual survey methods are sufficient to identify coating and corrosion deterioration trends.

General overview survey — This qualitative survey can be accomplished in a few hours and it is adequate to ascertain severe corrosion conditions and degraded coatings. Only the major features of the structure or facility are inspected. The survey involves

1. Visually observe that examines:
 - a. The general condition of coating; check for defects or deterioration
 - b. Any evidence of rusting
2. Rate the condition of the coating on each major structural feature as good, fair, or poor.

Detailed visual survey — The time required to conduct this survey will vary from a few hours to about a day, depending on the size of the building. This is a semi-quantitative survey which requires a more detailed description and documentation of the coating condition and corrosion. Work to be carried out are

- Observe and document the following coating conditions:
 - Defects: blistering, chalking, cracking, erosion, delamination, pinholes, peeling, or other defects
 - Appearance: coating or top coat loss, abrasion streaks, rust staining, fading colour, weathering, or other abnormal appearance

Failure to inspect and maintain the coating as recommended may lead to deterioration of the coating and the loss of the protective barrier.

7. Final Assessment and compliance statement

When used in the manner specified by the manufacturer, reinforced concrete walls constructed with the AFS LOGICWALL system comply with the durability requirements of AS3600.

The primary protection of the reinforcement in the concrete is provided by the concrete cover. Where the cover requirements cannot be achieved in more severe exposures, the required additional protection is provided by the coating system applied to the surface of the panels.

The vertical galvanised steel studs act as crack inducers in the concrete. Given the very close spacing of the studs, the cracking that will occur in the concrete that runs through the studs will be consistent with a very high level of crack control. Cracking of this type would be expected in a traditionally reinforced concrete wall. The cracks will be fine enough that they will not be of any concern from a durability point of view and would not contravene any of the requirements of AS3600. Further, the cracked concrete will occur within the envelope created by the FC sheet facing and protection coating,

The studs themselves could be considered as an embedment. However, they do not require the concrete for protection. Therefore, the cover provisions of AS3600 do not apply to the studs. Protection of the studs is provided by galvanising and for the reasons stated in this report, the galvanising will provide the necessary protection to the studs for the life of the structure as nominated in AS3600.

The protective coating provides additional protection to the embedments and reinforcing steel, particularly in cases where the cover does not meet the requirements of AS3600 in more severe environments (B2, in particular). Therefore, maintaining the coating in accordance with the manufacturer's requirements is recommended.