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HOT DIP GALVANIZING TODAY 87

The Official Publication of the Hot Dip Galvanizers Association Southern Africa

CORROSION CONTROL OF STEEL

Contents

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7

21

24

REGULARS

FOCUS ON

GENERAL

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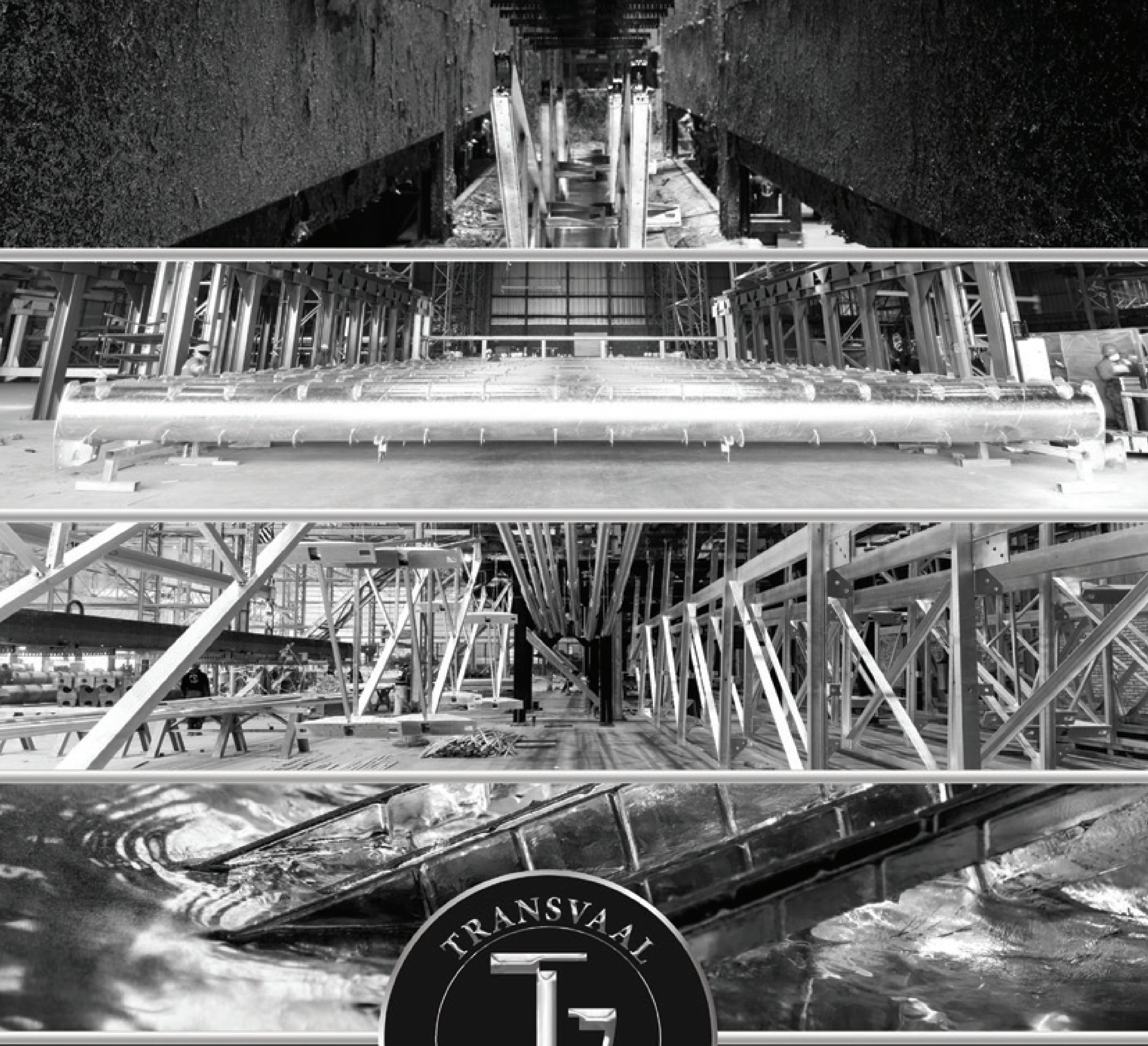

EXECUTIVE DIRECTOR'S Comment

The definitive position of AMSA as at end February 2025 was to wind down long steel production at both the Newcastle and Vereeniging works. The HDGASA has participated in several forums to prevent this. Our contribution to these discussions was to ensure that potential downstream consequences were clearly understood.

The loss of primary production and the sectors associated skills base will make it difficult for South Africa to produce speciality steels, such as those that may be required for strategically important sectors of the manufacturing industry. Further challenges related to import logistics, currency fluctuations, the potential of trade wars, i.e. duties and the loss of price leverage may develop over time. As an overarching view of the closures, also, this level of de-industrialization is not a positive development for support of local content. This is particularly so should the supposed infrastructure developmental plans mooted by government materialize, even in part. Job losses rather than job creation are the present reality.

So, whilst domestic steel demand remains low, the loss of the AMSA volumes may reasonably be made up by production from the local mini mills, as well as through imports.

Under such a scenario, downstream effects may be felt in terms of steel "quality". Whilst the primary consideration for steel quality is its physical attributes such as physical properties and dimensional accuracy, the galvanizers also require elementary controls by the steel producer on silicon and phosphorous levels. Ideally silicon killed steels in the 0.15 to 0.25%wt range, with low phosphorous levels of below 0.02%wt representing an ideal level of metallurgical reactivity with the molten zinc and ensuring known levels of zinc pickup. Such metallurgy also results in good coating thicknesses as well as pleasing aesthetics, that is, a reasonably smooth surface finish. Highly reactive steels, that is, Silicon levels outside of this range and when coupled to higher levels of phosphorous, result in thick and coarse coatings. In some instances, with very high phosphorous levels, normal coating alloy structures will not develop and a course tree bark type finish will result. To date, the HDGASA's evaluation of many fabricated articles constructed from imported steels and such evaluations have produced a range of results. It will therefore be necessary to ensure that appropriate steel quality is sourced for the best outcomes for all.

No doubt all the players in the steel value chain will take on the challenges with the usual levels of resilience characteristic of the steel merchants, designers, engineers, fabricators who partner with our galvanizers.

HOT DIP GALVANIZING... THE BEST PROTECTION!

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(length x width x depth)

RANDFONTEIN

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(length x width x depth)

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Armco Superlite is listed in accordance with the BSI ISO 9001: 2015 quality scheme which ensures the quality of all products and services produced by Armco Superlite. Specific customer quality plans are drawn up where required for any of our operations.

Armco holds the SATAS mark for Hot Dipped Galvanizing and all Galvanizing done at our premises is in accordance to the SANS 121 / ISO 1461 specifications. Galvanizing certificates are supplied on request.

ISANDO – Armco Galvanizers Isando has been operating since 1989. Geared up to accommodate heavy structural steel of up to 13m in length. Isando has an average output of approximately 2000 tons per month.

RANDFONTEIN – Armco Galvanizers Randfontein is our second facility based in the Randfontein area. Randfontein has an average output of approximately 800 tons per month and is geared up to handle light to medium structural steel of up to 6m in length.

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EDITORIAL COMMENT:
Going forward

"Be prepared" is well known as Baden Powell's rallying call. This simple statement is an excellent tenet by which to ensure that opportunities can be seized when they make themselves available. Longevity in infrastructure provides long-term capital savings that allows for even greater development in our economy. The essence of good business is being able to respond timeously with offerings that can meet and exceed the expectations of the end user. Considering technologies that provide extended service life to infrastructure is worth considering and being aware of, even in times of nominal growth.

In this issue:

- Galvanizing of rebar to provide longevity of reinforced concrete is a technology well worth exploring and understanding, the benefits aside from longevity allow for prepared responses to future requirements in the field of architecture and large-scale infrastructure projects.
- The earth and soils are an environment we have been known to take for granted, with somewhat unnecessary loss that could have been planned for at the initiation phases of projects. Considering 5 factors affecting corrosivity in soil allows us to plan accordingly.
- The effectiveness of galvanizing and duplex coatings is highlighted in a corrosion control case study of a marine weapon substructure manufactured in South Africa and offered globally.
- Training is a critical preparedness element; the knowledge we acquire is always valuable in the future. State-owned entities and private NGO's all benefit from the training available through the HDGASA.
- SABS accreditation is clarified in an open letter from the Acting CEO, Mr. Lizo Makele.

CLARIFICATION ON SABS accreditation status

Lizo Makele, Acting Chief Executive Officer, South African Bureau of Standards

Dear Valued Clients,

We would like to provide clarity regarding recent media reports suggesting that the South African Bureau of Standards (SABS) has lost all its accreditations.

SABS holds multiple accreditations across various conformity assessment services for products and systems. **The only area affected by a temporary and partial suspension of accreditation is the cement scope (SANS 50197).** This suspension, which was only three months, specifically impacted our cement manufacturing clients but had minimal effect on the continuation of certification activities within this scope.

All identified non-conformances were successfully addressed and cleared by **December 2024**. However, due to the **cyberattack incident in November 2024**, the SABS requested an extension from SANAS, as the records to verify the implemented corrective actions were being retrieved. As a result, an extension was granted and is **valid until April 2025**.

We assure our clients and stakeholders that all other accreditations remain valid and unaffected. This means that our numerous Product Certification Schemes, including the SABS Mark Scheme (SABS Approved Mark), continue to maintain their accreditation. Additionally, our Systems Certification Schemes and Inspection Schemes remain fully accredited and continue to operate without any impact.

We sincerely appreciate your ongoing trust and support of SABS as your quality assurance service provider.

For further information, please contact our Customer Engagement team at 012 428 7911 or 0861 27 7227, or email info@sabs.co.za.

CORROSION PROTECTION
of rebar for concrete structures

Introduction

There are numerous examples worldwide of "spalling concrete" found on structures within marine and inland urban and industrial environments. Clearly, there is a need to implement effective corrosion control methods in order to extend the long-term durability of steel-reinforced concrete.

Methods proposed for the corrosion protection of reinforcement do not, in any way, replace or usurp the importance of good quality concrete as the primary source of "barrier protection" against the corrosive attack of steel reinforcement. What is proposed in this paper is a "belt and braces", a cost-effective and site-practical method, of improving corrosion protection of embedded reinforcement, before actual placement within a structure, i.e. prior to, during delivery to site and final installation. In short, "prevention is better than cure".

The cost of adequate prevention carried out during the stages of design and execution are minimal compared to the savings they make possible during the service life and even more so, compared to the cost of rehabilitation, which might be required at later dates. The so -called De Sitter's "law of five" can be stated as follows: one dollar spent in getting the structure designed and built correctly is as effective as spending $5 when the structure has been constructed but corrosion has yet to start, $25 when corrosion has started at some points, $125 when corrosion has become widespread (Reference 3).

There are several methods of corrosion protection, such as, but not limited to the following:

- The use of membrane-type coatings applied to the surface of concrete structures.
- Painting the outer concrete surface to provide barrier protection.
- Addition of corrosion inhibitors to concrete.
- The use of stainless steel or 3CR12 as a substitute for normal carbon steel reinforcement.
- Cathodic protection of the reinforcement.
- Application of a coating to the reinforcement itself, i.e. epoxy coatings and specifically zinc in the form of hot dip galvanizing.

While these various methods provide varying degrees of success, this paper will examine the specific aspects of corrosion protection by the application of hot dip galvanizing for "barrier protection" (2nd line of defence) with the added benefit of cathodic protection (3rd line of defence) achieved by the fact that zinc is electro-negative to carbon steel. The main "barrier protection" (1st line of defence) is of course the concrete cover of the embedded reinforcement. It is abundantly clear that many misconceptions persist with regard to the use of hot dip galvanizing as a corrosion protection system for reinforcement.

This paper addresses many of these issues in order to facilitate informed decision making, during the design stage for projects where reinforced concrete is to be used as a structural component.

It is known from practical experience and site investigations, around the world and specifically along the Southern African coastline, as well as at numerous inland locations that **“The life to the first maintenance of an uncoated steel bar reinforced concrete structure which has failed by concrete spalling after approximately 10 years, could have been extended too over 30 years if the re-bar had initially been hot dip galvanized”.** This postulation assumes a quality concrete cover of 40mm minimum with >40 MPa strength concrete (ordinary Portland Cement) (*Reference 1).*

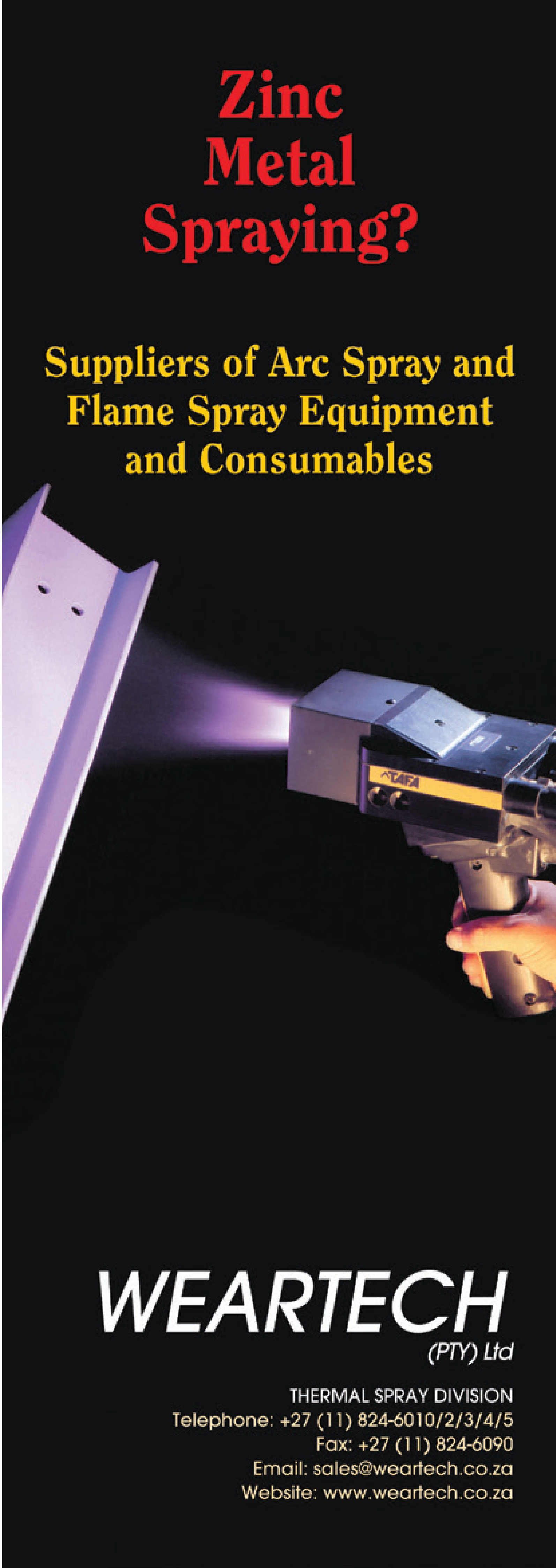
It is generally accepted that such concrete quality as well as correct site placement, presents practical difficulties that cannot always be avoided. A zinc coating, in the form of hot dip galvanizing, is suggested as a practical, and economical approach aimed at enhancing the durability of reinforced concrete.

Factors affecting the durability of reinforced concrete structures

Environment

Corrosion attack and hence, the ultimate service life of any material, is dependent on the environment in which such components are situated. The external environment is a major factor to be considered when designing all types of structures and reinforced concrete is no exception.

It is the environment that carries the corrosive-inducing elements and compounds such as oxygen, chlorides, sulphur dioxide and water to name but a few. Structures located along the coastline, which are exposed to prevailing winds from off the sea, are subjected to a greater degree of corrosion attack than at most inland sites. This applies particularly in the spray zone because of the presence of chloride-containing moisture in an oxygen-rich environment. Sulphur dioxide-containing atmospheres encountered in



polluted industrial areas can be even more severe. It is essential to assess the degree of corrosion pertaining at each specific site whether inland or in a coastal region. Determine the microclimatic conditions, whether coastal or inland.

There are many examples of the effective use of hot dip galvanized reinforcement in corrosive marine and industrial environments both in Southern Africa and throughout the world. Many of these examples date back to the late 1950s and early 1960s.

Quality of concrete

The quality and permeability of concrete represent the most important or critical factors to be considered when reviewing corrosion control and/or protection of the embedded reinforcement. Concrete permeability (1st line of defence) is influenced by the following factors, referred to as the four **C**s.

- *Concrete Mix* – Low concrete permeability is a function of the bonding between the aggregate and the cement, the water/cement ratio and the size and grading of the aggregate.
- *Compaction* – Adequate and controlled compaction has an influence on both the quality of the concrete and its permeability.
- *Curing* – Site curing procedures influence permeability and ultimately concrete quality and strength.
- *Depth of Cover* – Depth of cover over the embedded reinforcement is of major significance when corrosion prevention of steel is being considered. Notwithstanding the depth of concrete cover required in terms of the specification, the final cover is often determined or limited by practical considerations at the time of the actual placing or pouring of the concrete. The reinforcement could shift within the shuttering or formwork and this could remain undetected due to practical restrictions during the pouring process. Practical aspects encountered during construction could compromise the final depth of covers.

Indications of the reduction of the initiation time of corrosion due to local reductions in the thickness of the concrete cover in some areas of the structure are halved with respect to its nominal value, in these areas the initiation is reduced to less than one-quarter of that predicted. This analogue is only valid when concrete is exposed to chlorides *(Reference 3).*

In other words, considering a chloride environment the following is possible:

- 24mm nominal concrete cover estimated 100 years to initiation of reinforcement corrosion.
- With the reduction of the nominal concrete cover to half, (12mm) estimates reduce to 15 years to initiation of reinforcement corrosion (*Refer to annex C).*

From the above, it is clear that the structural performance of reinforced concrete and the onset of corrosion of the reinforcement is largely determined by the quality of the concrete and the practical placement of the embedded steel reinforcement. It is therefore clear that the provision of corrosion protection to the reinforcement, by hot dip galvanizing, does not replace the requirement for good quality concrete. The purpose of corrosion protection of reinforcement is to extend the ultimate service life of the structure once the corrosive agents, present in an aggressive environment, have penetrated the concrete cover (*consider Figure 1).*

1

Figure 1: While minimum cover may be specified the actual cover ultimately achieved is frequently dependant on practical site considerations.

2a

2b

2c

2d

Figure 2a: Ingress of corrosive substances is first indicated by rust staining.

Figure 2b: Cracks appear.

Figure 2c: Spalling concrete.

Figure 2d: Potential structural failure – once spalling has occurred, it becomes very difficult and expensive to repair.

Structural failure due to corrosion

In order to place the need for hot dip galvanizing of reinforcement into context, we must first discuss a typical failure of a reinforced concrete structure, due to corrosion of the reinforcement.

Figures 2a - 2d illustrate the sequence of events leading to the ultimate failure of a reinforced concrete structure.

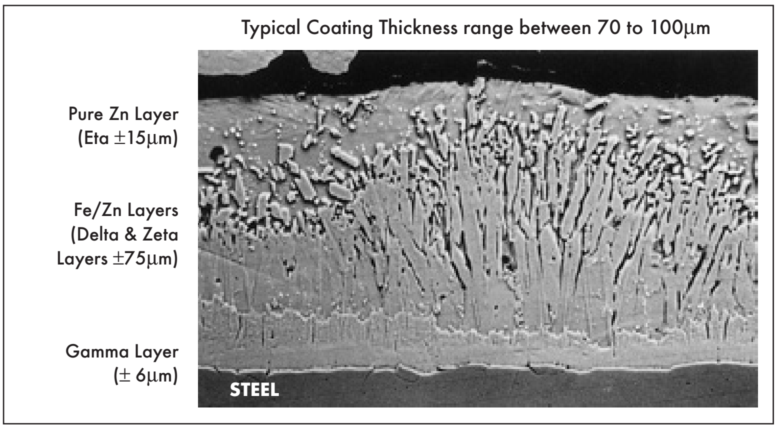
The service life of a structure can be defined as the period of time in which it is able to comply with the given requirements of safety, stability, serviceability, and function, without requiring extraordinary costs of maintenance and repair (*Reference 3).*

Hot dip galvanized steel reinforcing can be used to control corrosion in reinforced concrete exposed to the following conditions:

- Carbonation;
- Chloride and sulphate ion intrusion;
- Atmospheric pollution;
- A combination of chlorides and sulphates constituents;
- Freezing and thawing; and
- Expansive reactions e.g. alkali-aggregate reactions (*Reference 4).*

Hot dip galvanized reinforcement offers significant advantages compared to uncoated carbon steel under equivalent circumstances. These include: an increase of initiation time of corrosion; greater tolerance for low cover, e.g. in slender (architectural) elements, and corrosion protection is offered to the reinforcement prior to it being embedded in concrete *(Reference 3).*

The structural integrity and longevity of bridges, tunnels, coastal buildings, industrial chimneys and cooling towers, as well as many inland industrial installations can be effectively and economically improved by the use of a zinc coating in the form of hot dip galvanizing to protect the embedded reinforcement.



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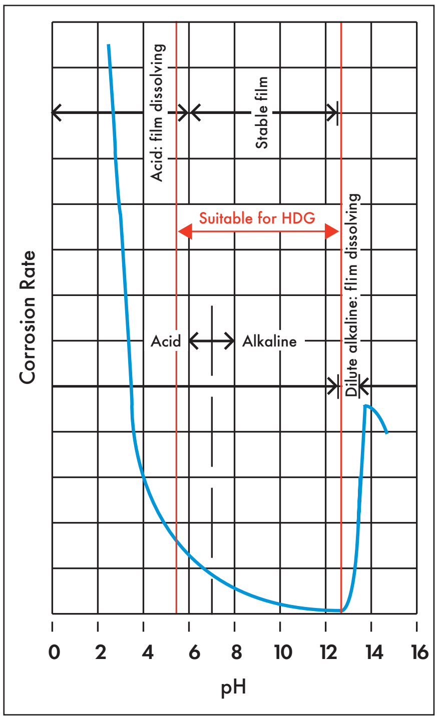

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Figure 3: Typical hot dip galvanized coating showing the metallurgical bonded layers of iron/zinc with a pure (eta) top layer.

Figure 4: The relative corrosion rates (y axis) of zinc in terms of the pH scale (x axis).

Before continuing, let us briefly review the hot dip galvanizing process. What do we know of hot dip galvanizing, how does zinc protect and what constitutes the zinc coating?

Hot dip galvanizing process

Hot dip galvanizing is a metallurgical process whereby perfectly cleaned steel is totally immersed into molten zinc at a temperature of approximately 450°C. During this process the carbon steel metallurgically reacts with the molten zinc forming a series of zinc/iron alloys together with a top pure zinc layer, chemically bonded to the parent steel.

The micrograph *(Figure 3)* is an illustration of a typical hot dip galvanized coating in which one can identify the various coating layers. Hot dip galvanized coatings provide "barrier protection" as well as "cathodic protection" of minor uncoated areas (handling damage), and micro-cracks that may be present, should cold bending be carried out after zinc coating.

Corrosion creep from an uncoated area is not possible as is the case with an epoxy coating, which is pure barrier protection. While zinc and/or iron/zinc alloys are present the zinc will "sacrifice" itself to protect the carbon steel. We therefore refer to zinc as a "wasting protector" due to the fact that it is electro-negative to carbon steel in terms of the galvanic series of metals. i.e. Zinc is anodic to cathodic carbon steel and will therefore provide "cathodic protection" of small-uncoated areas.

Hot dip galvanized coating thicknesses are dependent on factors such as immersion time, zinc temperature, speed of withdrawal and chemical analysis of the carbon steel reinforcement. It is possible that the chemical composition of the steel could result in coating thicknesses as much as 200µm. While such coatings improve corrosion protection, estimated at +30% better than pure zinc, it is advisable to limit the coating thickness to <200µm and avoid excess brittle alloy layers and potential for coating flaking. While excessive zinc/iron alloys need to be controlled, they do provide additional benefits of increased corrosion protection and abrasion resistance. Coatings should be restricted to <200µm with due care and control during the hot dip galvanizing process.

In the final operation, within the hot dip galvanizing process, steel is processed through a passivating solution (0.5% to 1% sodium di-chromate). While this process is aimed at the restriction and formation of zinc oxidise/hydroxide (white rust) during storage and in transit to the site, it has the added benefit, of passivating the hot dip galvanized zinc coating when exposed to high alkaline and reactive "wet" concrete. We will again refer to this issue later in this paper.

Zinc reaction with newly poured concrete

In order to place the question of hot dip galvanized reinforcing bars into context, we need to consider what transpires when reinforcing is cast into concrete. How does the zinc coating react with the newly poured and curing concrete? What reactions take place when corrosion-induced substances penetrate through to the reinforcement?

a. Zinc in a varying pH environment

From the diagram of the relative corrosion rates of zinc in terms of the pH scale, *Figure 4*, we see that zinc is attacked in an acid environment (pH <6) and again in highly alkaline conditions (pH >12.5). The fact that zinc corrodes at pH levels >12.5, gives rise to the misconception regarding the performance of hot dip galvanized reinforcement in contact with newly poured "wet" concrete.

Freshly poured "wet" concrete has a pH >12.5, which will cause it to react with zinc. In practice, the pH of the pour solution in concrete is usually below 13.3 during the first few hours after mixing, due to the presence of sulfate ions from the gypsum added to the Portland cement as a regulator.

This reaction progressively ceases whilst the concrete is curing, and is largely inhibited when the galvanized reinforcement is chromate passivated, as is normal practice, within the hot dip galvanizing process.

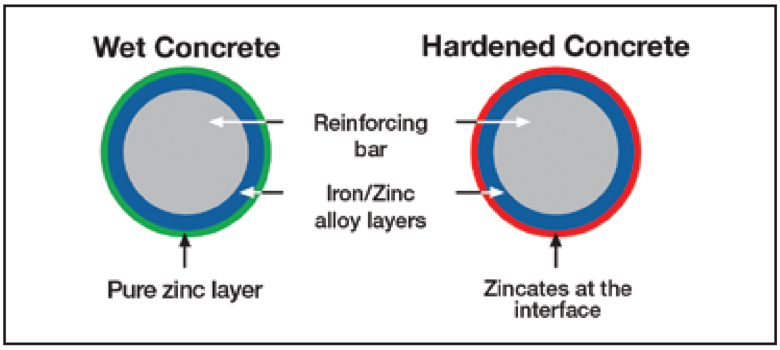

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Figure 5: Evolution of the hot dip galvanized coating from the "wet" concrete pour to that of the "hardened" concrete at 7 to 10 days.

The passive film that forms on zinc not only reduces the rate of the anodic process (zinc dissolution), but also even hinders cathodic reactions of oxygen reduction and hydrogen evolution (*Reference 3*).

During initial contact between hot dip galvanized reinforcement and wet concrete, the outer zinc layer of the galvanized coating reacts to form zincates, (calcium hydroxyzincate). The zincates formed, consuming between 5 to 10µm of the outer zinc (eta) layer in the establishment of a passivated layer. This reaction ceases as the concrete hardens leaving a coating of stable zincates and the remaining (approximately 75 to 85µm) original zinc and zinc-iron alloys intact and able to provide corrosion protection, both barrier and cathodic.

It is noteworthy that within a short time, pH levels within concrete are reduced into a range of 8 to <12, due to the inevitable ingress of carbon dioxide (CO_2), referred to as carbonation. In this pH range, zinc performs exceptionally well, while the rate of corrosion of unprotected steel increases due to the loss of a protective oxide passive film on steel. It could be argued that the formation of the zincates (calcium hydroxyzincate) is an additional corrosion protective barrier, which is perhaps debatable.

b. Evolution of hydrogen

It is known that when the wet concrete pour is exposed to zinc, a reaction takes place between the zinc and the cement paste or $Ca(OH)_2$ formed because of cement hydration. This corrosion reaction is controlled by diffusion processes and results in the evolution of hydrogen and the transformation of zinc into calcium hydroxyzincates, as shown by the following chemical formula *(Reference 4).*

$$2Zn + Ca(OH)_2 + 6H_2O \rightarrow Ca[Zn(OH)_3]_2 \, 2H_2O + 2H_2$$

The resultant hydrogen, so formed, is believed to reduce the bond strength between the reinforcement and the concrete. However, this zinc corrosion

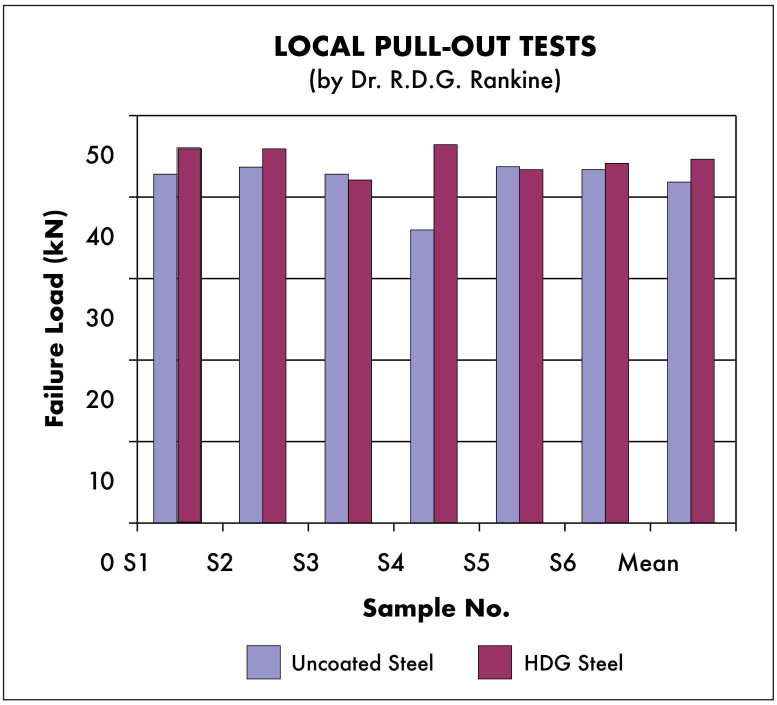

Figure 6: Bond strength tests conducted by The School of Concrete Technology, including six samples labelled S1 through to S6.

reaction is only active during the initial curing period of between 6 to 10 days. During this period, as already stated, approximately 5 to 10µm of the pure zinc (eta) outer layer is consumed, leaving the remainder of the eta and all of the zinc/iron alloy layers unaffected. Subsequent loss of zinc (eta) and alloy (gamma, delta & zeta) layer, due to continued reaction, is no more than about 2µm per year although, in carbonated concrete, this may increase *(Reference 4).* Depending on the coating thickness a further 60 to 90 years or more can be expected before all the zinc is sacrificed in the protection of carbon steel.

Notwithstanding the above, the corrosion rate between zinc and fresh concrete can be controlled by the presence of chromates. Such chromates are provided by way of the sodium di-chromate applied during the hot dip galvanizing process or alternatively as potassium dichromate as an additive to the concrete mix. In addition, naturally occurring chromates, present in most Portland cements, can be relied upon to provide adequate passivation with no reduction in bond strength.

6 Bond strength of concrete to hot dip galvanized reinforcing bars

A further misconception that arises is that due to the formation of insoluble zinc salts and the evolution of hydrogen formed at the interface between the newly poured (wet) concrete and the hot dip galvanized reinforcement, is the reduced bond strength.

Extensive programmes of pullout tests conducted by a number of research organisations around the world including a series of local tests conducted by Dr. R.G.D. Rankine of the School of Concrete Technology. Results show conclusively that the bond strength is not reduced when compared with uncoated reinforcement. In fact, an actual increase in the bond strength has been observed. The graph, illustrated in *Figure 6*, reflects the results obtained during the tests conducted by Dr. R.D.G. Rankine (*Reference 2).*

Generally, it is believed that during the early stages (6 to 10 days) of the concrete curing, the bond strength may be temporarily reduced due to the issues of hydrogen evolution and the formation of calcium hydroxyzincate etc. However, as the concrete hardens, the bond strength increases and there is no difference between uncoated reinforcement and that of the hot dip galvanized material. In fact, there is evidence to suggest that bond strength improves and is higher than that of uncoated reinforcement. The evolution of hydrogen is believed to be very short-lived and may well cease within approximately 1 hour *(Reference 4).*

A higher bond with respect to bare steel could be obtained, due to the formation of calcium hydroxyzincate crystals that fill the interfacial porosity of the cement paste and act as bridges between the zinc coating and the concrete (*Reference 3).*

Influence of temperature on steel tensile strength

A further misconception is that due to the hot dip galvanizing temperature of 450°C, the reinforcement will lose structural strength and its tensile integrity. This is not so, in that the transformation ranges of steel occurs between 700°C

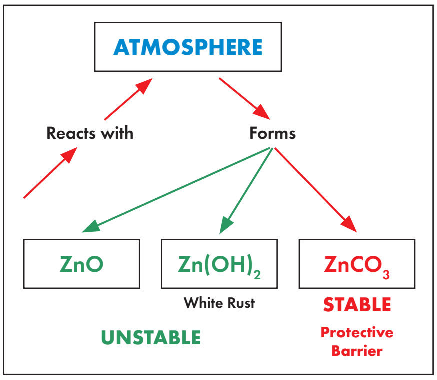

Figure 7: The reaction between zinc (Zn) and the atmosphere, including oxygen, water moisture, and carbon dioxide.

to 900°C, which is well above the hot dip galvanizing temperature. This fact is confirmed by laboratory tests as well as practical case studies with fasteners and structural steel components that have been hot dip galvanized.

Corrosion resistance

Two major factors cause the corrosion of steel reinforcement and hence long-term performance of reinforced concrete structures. Both are influenced by the permeability of the concrete cover.

a. **Carbonation**, i.e. the ingress of carbon dioxide (CO_2) from the atmosphere, and
b. **Chloride and sulphate ion intrusion**, again from the atmosphere or in other words the environment in which the structure is to function.

a. Carbonation

Carbon dioxide (CO_2) may well enhance the barrier protection of zinc by the formation of stable zinc carbonate ($ZnCO_3$), i.e. the reaction of zinc with carbon dioxide. At the same time, *Carbonation* is defined as a process whereby carbon dioxide in a moist environment reacts with hydrated cement paste to form an acid-aqueous solution that tends to reduce the concrete's alkalinity.

Zinc is amphoteric, i.e. able to react as a base and an acid, between a pH range >6 to <12.5, refer to *Figure 4*. As the pH is reduced, due to carbonation, into a range of 8 or 9, it is ideal for the corrosion protective properties of zinc, but less favourable in the case of uncoated steel. Hot dip galvanized reinforcement therefore presents an ideal solution to combat carbonation.

The passive film of hot dip galvanized reinforcement is stable ($ZnCO_3$), *Figure 7*, even in mildly acidic environments, (pH of 6) so that the zinc coating remains passive even when the concrete is carbonated down to a pH of 8 or 9. In extreme cases, where all the calcium hydroxide is depleted, the value of pH may drop to as low as 8.3 *(Reference 4)*. Zinc-coated reinforcement therefore remains passivated far longer than uncoated carbon steel where carbonation is encountered.

The corrosion rate of hot dip galvanized steel in carbonated concrete is approximately 0.5 to 0.8µm/yr, therefore a typical 80µm hot dip galvanized coating would be expected to last over 100 years. The corrosion rate of hot dip galvanized bars remains negligible in carbonated concrete even if a modest content of chloride is present.

b. Chloride attack

In chloride-contaminated concrete, which is the major reason for steel corrosion affecting the service life of reinforced concrete, the penetration of chloride ions can depassivate steel and promote active metal dissolution.

A combination of loss of alkalinity due to carbonation and the ingress or inclusions of chloride ions can act in combination and pose a serious destructive threat to the long-term stability of a concrete structure.

As chloride penetration of the concrete through to the embedded reinforcement is only possible through the concrete matrix, we can understand the significance of concrete quality and the need to ensure compliance to design and effective site management and supervision during construction.

Hot dip galvanized reinforcement can offer significant advantages over uncoated carbon steel in terms of substantial reduction or even total elimination of rust staining and greater tolerance to construction imperfections and greater resistance to chloride attack. Improved resistance to chloride attack is due, for a large part, to the lower value of free corrosion potential of hot dip galvanized steel.

It is worth pointing out that small-scale laboratory tests tend to indicate that hot dip galvanized steel is subject to corrosion in highly contaminated concrete. However, site experience and examination of several bridge decks exposed to chloride salts well in excess of the threshold value needed to induce corrosion of untreated steel, and of structures exposed to severe salt -water environments, have shown no evidence of corrosion or impaired performance of the concrete with no structural impairment due to lack of bond *(Reference 4).*

Another interesting feature is that potassium chloride; also present in seawater, as opposed to sodium chloride, inhibits the corrosion of zinc. It is for this reason that totally immersed hot dip galvanized steel, as opposed to spray zone applications, will provide extended corrosion free life.

Even if pitting corrosion is initiated, the corrosion rate tends to be lower for hot dip galvanized steel, since the zinc coating that surrounds the pits is a poor cathode and thus it reduces the effectiveness of the autocatalytic mechanism that takes place inside the pits on bare steel (*Reference 3).*

Up to date information, both from laboratory tests as well as site inspections and observations over the past 20years, is provided in a book, published during


8


9

2004, which clearly confirms the long-term benefits of hot dip galvanized reinforcing (*Reference 4*).

In this publication, Professor Yeomans has proposed a schematic representation to illustrate the benefits of hot hip galvanized reinforcement on the design and service life of reinforced concrete structures.

One of the major factors that contributes to the significant delay of the onset of corrosion of the base steel is the fact that the galvanizing provides a metallurgically alloyed coating of consistent quality that is highly resistant to damage during transportation, storage, site handling and concreting operations *(Reference 4, Page 59).*

Economic consideration of hot dip galvanizing reinforcement

The cost of hot dip galvanizing reinforcement is insignificant compared to the cost of repairing spalling concrete that results from the corrosion of uncoated reinforcement. *Refer to the so-called De Sitter's "law of five"* quoted earlier.

Costs vary from place to place and are subject to many factors such as the price of concrete, price of steel, site location, contractor's overheads and so on. However, notwithstanding this, it is believed that the increase in the overall cost of placed reinforced concrete is in the range of 5% to 10%. If one were to continue with this analysis and consider the use of hot dip galvanized reinforcement in strategic locations, such as the exterior walls of a structure and for high-risk corrosion areas, the overall cost increase for a project could be as little as 0.5 to 3%.

Whatever the final cost incurred to hot dip galvanize, it is more economical than many alternative methods of corrosion

10


11

Figure 8: Corroded reinforcement resulting in the "spalling off" of the concrete. Note the lack of concrete cover.

Figure 9: Repairs to the concrete on this bridge structure proved to be unsuccessful in that the corroding reinforcing bars have again removed the concrete.

Figure 10: The site of the 40-year-old pedestrian bridge (No. B776), which was demolished in 2008. It was established that hot dip galvanized reinforcement was used in the approach stairway, which was on the sea-facing side, indicated on the left of the photograph, with the sea some 50 meters further left.

Figure 11: Public seafront swimming pool in Cape Town, using seawater.

Figure 12: Sydney Opera House successfully employed hot dip galvanized reinforcements.

Figure 13: Johannesburg Civic Centre is an example of hot dip galvanized reinforcement being used as an architectural requirement to prevent rust staining on the slender (low concrete cover) fascia panels. Original construction period was from 1964 through to 1968. A recent inspection shown no sign of rust staining was evident.

protection, and perhaps more importantly for the project owner, the savings that will result over the life of the project, by the reduction in maintenance and rectification costs.

Recent site visits and observations

The following photographs provide examples of sites where uncoated reinforcing bars were used in concrete that was undoubtedly required to conform to the specified standards for concrete quality and minimum depths of cover. In the case of one particular site, both hot dip galvanized reinforcement as well as uncoated re-bar was used. Where hot dip galvanized reinforcement was used no spalling was found, while the uncoated bars were corroding and spalling of the concrete had commenced.

Some case studies

A recent case study resulting from a detailed investigation of a certain pedestrian bridge situated along the foreshore of Algoa Bay (Port Elizabeth South Africa) is briefly described.

The site of the 40-year-old pedestrian bridge (No B776), is due to be demolished (April 2005). It was established that hot dip galvanized reinforcement was used in the approach stairway, which was on the sea-facing side, indicated on the left of the photograph, with the sea some 50 meters further left.

Sample concrete cores were extracted from the sea-facing side, top slab and landside of the structure. These samples were sent to an independent concrete diagnostic & durability laboratory with instructions to establish the ingress of chlorides, carbonation and quality of the concrete. The depth of reinforcement cover was confirmed as being 45 to 60mm and a sample of hot dip galvanized bar was retrieved for examination.

Chloride concentrations (% as mass of cement) at a depth of 45 to 60mm ranged between 0.15 and 0.65 on the side facing inland, and 0.27 and 1.26 on the sea-facing side. At a depth of 30 to 45mm the chloride concentrations ranged between 0.19 and 2.6. Chloride levels at a depth of 15 to 30mm rise to between 0.49 to 8.8 as a % of cement mass. Accepting that the typical limit is 0.1% chloride for uncoated reinforcement, it should be totally unacceptable to use plain reinforcing without additional corrosion protection in this environment.

Carbonation was found to be more severe on the landside of the structure, with penetration depths of 18 to 22mm.

Concrete durability index testing results of oxygen permeability were as follows: 1 sample was "very good", 1 sample was "good", 4 were "poor" and 1 was "very poor". The sorptivity of 2 samples was excellent, 2 good and 2 were poor.

Examination of the hot dip galvanized reinforcing, after 40 years in service, revealed conclusive evidence that the zinc


12


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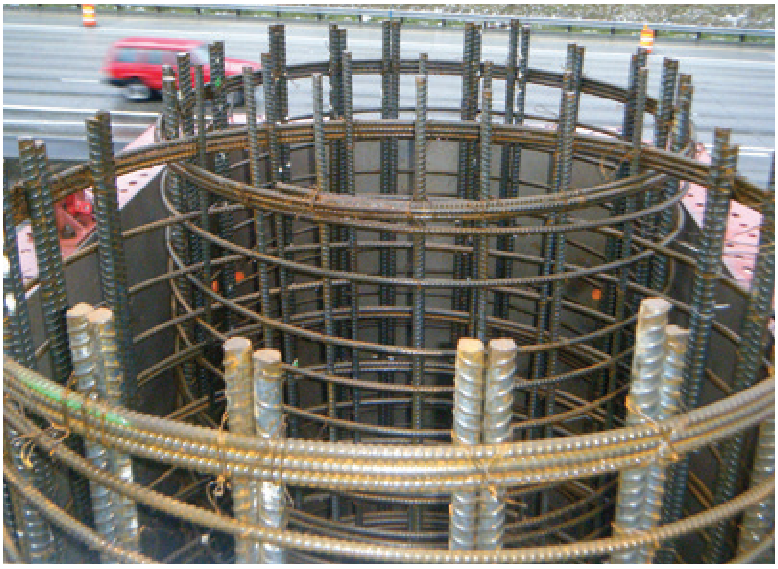

coating was providing excellent corrosion protection to the steel. *Further details of this case study may be found by visiting the HDGASA website, www.hdgasa.org.za.*

Perhaps the most published and long-standing examples of the performance of hot dip galvanized reinforcement are the numerous reinforced concrete structures, on the island of Bermuda. For over 50 years hot dip galvanized reinforcement has been effectively employed with commendable results.

Reference to Chapter 7 of the reference *(Reference 4)* details the results of investigations of a number of installations dating back to construction in 1953 and 1968. These were:

- Dock wall in Hamilton Harbour.
- Jetty at the Royal Yacht Club.
- Dock wall at Pennon's Wharf, St. George's.
- An approach span of Longbird Bridge near the airport.

Generally, the results are noteworthy and supportive of the motivation for this particular paper.

Conclusions

Hot dip galvanizing of reinforcement is not a substitute for good quality concrete standards. It will, however, add value and longevity to concrete structures while compensating for practical difficulties in fully complying with the requirements of relevant specifications. Hot dip galvanizing of reinforcement is an economical and cost-effective process that can be expected to substantially extend the useful service life of reinforced concrete structures in marine and other corrosive environments. The cost increase of the total cost of a project is money well spent and will, without doubt, provide a justifiable and economical return on an investment.

Finally, to quote from *Mr. Neil D. Allan (Chapter 7 of Reference 4):*

"Civil engineers are, by nature and training, analytical, logical and cautious. They usually need to have considerable confidence in any new product or technique before it is fully accepted. Galvanized reinforcement is slowly beginning to gain their confidence in the UK and USA. Galvanizing as a process has been around for over 100 years (175 years) and is well proven to delay significantly the onset of steel corrosion. Despite this, it is quite mystifying why designers who would happily specify galvanized handrails appear to baulk at the thought of using galvanized reinforcement".

References:

1. *A review of Hot Dip Galvanized Steel Reinforcing in Concrete Structures Exposed to South African Coastal Marine Environments* by Professor Dennis Twigg.
2. *Galvanized Steel Rebar in South Africa* by Dr. Rod Rankine.
3. *Corrosion of Steel in Concrete* by Luca Bertolini, Bernhard Elsener, Pietro Pedefferi and Rob Polder.
4. *Galvanized Steel Reinforcement in Concrete*, edited by Professor Stephen R. Yeomans and Elsevier Science Ltd. in the UK. First edition.
5. Hot Dip Galvanizers Association Southern Africa website – *www.hdgasa.org.za.*

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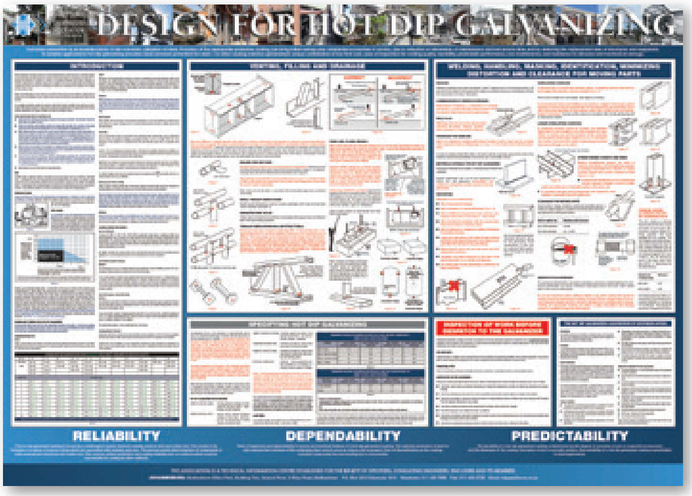

TECHNICAL GUIDES

The HDGASA **Steel Protection Guide** and **Facts about Hot Dip Galvanizing** are available in high-gloss printed material for reference and guidance.

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SHIPSHAPE duplex application

by Greg Combrink

A sophisticated ship-mounted weapon system assembly was designed and built by a local defence manufacturer services company. The system consisted of a warship deck-mounted weapon assembly able to be fitted with an assortment of guns, and a fire control system that can engage targets and control the gun to fire upon such threats.

Most warships operate in the marine environment where often waves break over the ships' bows wetting decks and moist sea winds laden with salt deposits onto the exposed surfaces on board the ship. It is in this highly aggressive and corrosive environment that the weapon system assembly does duty. Couple this with the shock wave conditions experienced when the weapon is fired and one has one of the worst operating conditions that one finds anywhere. And when an item of equipment is composed of an array of different materials and alloys it makes the situation even worse.

Historically on suitably calm days, one would often find sailors chipping and painting, greasing and cleaning decks, superstructure and of course this essential deck-mounted equipment on board navy ships. Often when deck equipment is not in use it is covered with waterproof tarpaulins and components such as gun barrels and void space access ports are masked up with temporary caps and doors in an attempt to prevent the highly aggressive environment from causing corrosion on these systems. Unfortunately, these methods are not always effective and one still often finds that equipment suffers corrosion despite these prevention attempts.

The weapon system assembly consists of several different materials and alloys and if they are left unprotected in the marine environment they will severely corrode. In the earlier prototypes, the focus was on getting the system functionally reliable and effective and very little attention was given to corrosion protection. Thus, after successfully fine-tuning the system's working ability, a specialist corrosion engineer was engaged to address the anti-corrosion design of the gun assembly for subsequent units.

Subsequently, units manufactured had the new anti-corrosion design implemented. The deck-mounted assembly and cover plates were of great concern as previously the steel and the aluminium components had purely been sent out for coating without much specialist anti-corrosion thought having been put in. In those cases, the carbon steel parts were dropped off at the galvanizer for hot dip galvanizing and thereafter along with the aluminium cover plates sent off to be painted. At the time it was thought that such action would be satisfactory as experience showed that duplex coatings give sufficient service under extreme corrosive conditions.

But as too often happens in practice when a good specification is thoughtlessly applied things go wrong in practice. Needless to say, many of the initial units that had not undergone specially designed and controlled anti-corrosion procedures and that had been sent out as prototypes for sea trials suffered serious corrosion almost right from the start and began to look unsightly within a few days of exposure. Why was the system rusting, being the question that the manufacturer had asked and approached the corrosion engineer to figure this out. The corrosion protective systems were reviewed and a comprehensive design governing not just the materials to be used but also the processes involved was drawn up. This involved assessing the worst-case environment, the corrosion protection systems to be used, their compatibility with each other, the substrate materials being protected, the physical configuration of the component, and the requirements of the application processes, and also the delegation of responsibility to ensure compliance with the quality assurance policy and recording of quality control parameters that were to be monitored were specified.

In addition to doing the overall anti-corrosion design, applicators were also vetted by the corrosion engineer so that only contractors with the correct equipment and with the correct track records and understanding of the needs were used. These contractors were also consulted to consider the specifications and to comment on any snag points or possible improvements to the design so that the final product protection was optimized. This typically involved ensuring that best engineering practice was followed through the project thus eliminating instances of reworking and providing a sound base for subsequent operations. The main structural part of the weapon system was an intricate carbon steel component with several difficult-to-access spaces and surfaces that were to be duplex-coated. On the hot dip galvanizing side, the advice and recommendations from the galvaniser were considered and where appropriate incorporated into the design specification. This resulted in a very good galvanized surface layer of the required coating thickness, suitable for post-galvanizing painting. As the silicon content of the steel was slightly high much skill, experience and care were required to successfully achieve the appropriate hot dip galvanizing thickness and suitable finish to ensure that the weapon system's final finish could be achieved. The galvanizer advised specific HDG processes to the anti-corrosion specification and these modifications were incorporated into the specification such as safety aspects linked with tasks such as dipping angle into account and air vent holes specifically for galvanising so that the hot dip galvanizing process could be done in a single smooth action dip resulting in an excellent uniform HDG finish on all surfaces (including the difficult to access spaces and surfaces.) The zinc film thickness achieved was between 108µm and 134µm. The unit unfortunately went through the passivation process. Thus, the galvanized surface was passivated. Most galvanizing goes into service in the same zinc coating but passivated as it comes out of the bath and it is the norm to passivate the component. When the galvanised item is to be subsequently coated, it is better not to passivate the article. As passivation has a negative influence on the adhesion of the paint coating to the galvanised surface. Thus, it fell upon the paint applicator to remove the passivated layer and ensure a superior attachment of the paint coating to the article. The specification was subsequently modified to take this into account.

On the organic coating application side, an in-house internationally qualified coating specialist from the paint coating application contractor managed the application ensuring that the correct surface preparation procedure was closely complied with. This entailed the surface passivation layer removed and a sweep blasted surface developed that roughened the surface but did not remove significant zinc coating from the surface. The paint coating operation took place under optimal conditions and followed the best practice procedures as required when using modern heavy-duty industrial organic coatings. The sweep blasting of the hot-dip galvanized surface was done at a delivery pressure, at the end of the blast hose, of <3 bar using Microblast© garnet blasting media. Only around 10μm of zinc was sacrificed resulting in a superb surface profile for keying of the paint coating.

Both of the contracted applicators (galvaniser and the organic coater) made valuable contributions ensuring that the subsequent final product had a well-finished appearance thereby ensuring that the weapon system had the best chance of lasting the designed lifespan with minimal maintenance. This aspect was also important to the manufacturer as they compete on the international stage against other weapon systems suppliers and a functional reliable unit that also looks good allows them to do so successfully. Working together the contractors and the corrosion engineer comprising the anti-corrosion team produced the result sought by the manufacturer.

Critical aspects that ensured success were the valuable inputs from the vetted contractors at the early design stage and the communication between the informal anti-corrosion team members and the manufacturer's project engineer. Also of utmost importance was the willingness of all parties to work together towards the common goal of ensuring that the best result possible sometimes under difficult working conditions was achieved.

Some specific and important factors

Galvanizing

- A contracting company with the correct galvanizing and handling equipment to ensure the correct and complete coating of the item being galvanized in a single dipping operation (if possible).
- A contractor that fully understands the preparation requirements (cleaning, and blasting) and how to correctly mask up areas that must not be galvanized during the dipping operation such as bearing surfaces.
- An experienced and knowledgeable galvanizer that can advise on critical requirements for galvanising such as an understanding of the dipping angle and component hanging point and the need for access and drainage ports.
- The silicon and phosphorous content of the steel that is to be galvanized as this influences dipping time and zinc film properties.
- The thickness and finish required for the zinc coating.
- The galvanizer must be told if the item galvanized is to be subsequently coated (i.e. duplex coatings) so that the passivation (conversion coating) process that is normally performed directly after dipping is avoided as this has an influence on subsequent organic coating adhesion to the galvanized surface (even if it will be sweep blasted before painting).
- The galvaniser should have the ability to do quality control tests to maintain a record thereof and to perform any repair that may be needed (preferably by zinc metal thermal spray).

Organic coating application

- A painting contractor who has much general paint application experience and knowledge.
- The contractor should have the required equipment to perform the coating application required as well as the surface preparation.
- The contractor should have specialist knowledge and a good track record of applying duplex coatings and especially fully understand and subsequently control the sweep blasting operation required. The type of coating to be used.
- The quality control measurements and records are to be kept updated during the painting application process and collated into a report.
- The contractor should have the knowledge and ability to repair any damaged areas with the same good finish and corrosion protection being achieved.

Generally: All the contractors involved in this project performed their tasks superbly even far exceeding expectations which reflected in a superior end product being achieved.

5 KEY FACTORS PRESENT
in corrosive soils

UNDERSTANDING THE SOIL CORROSION OCCURRENCE AND THE FIVE KEY FACTORS THAT CONTRIBUTE TO THE PROCESS IS IMPORTANT FOR MINIMISING CORROSION IN MOST LAND-BASED CONSTRUCTION PROJECTS.

Most construction projects involve interaction with the earth in one form or another. Almost all types of infrastructure, from above ground structures such as buildings and roadways, to buried structures such as undergrounds pipes, vessels and utilities, rely on the soil as a means of stability and support. However, many soils, depending on their composition, may be potentially corrosive to metallic materials.

The severity of corrosion that can be caused by a particular soil type is dependent on a variety of factors, including the soil's chemical properties, environmental conditions and the properties of the metal in contact with the soil. In this article, we shall look at the causes of corrosion in soils and the factors that contribute to the varying degree of soil corrosiveness in detail.

What is soil corrosion?

Simply put, soil corrosion is an electrochemical process whereby complex chemical reactions between the soil and the contacting metal result in the formation of corrosion products and deterioration of the metal. Corrosion is a natural redox (reduction-oxidation) reaction that converts a refined metal to its more chemically stable state. Three components must be present for corrosion to occur: an anode (the buried metal in contact with the soil), a cathode (oxygen) and an electrolyte (the moisture found in the soil). The degree of corrosiveness and the rate of corrosion differ between different soil types and properties.

Factors that influence soil corrosion

The key factors that influence the severity and rate of corrosion of soils are:

Aeration

Aeration refers to the amount of air within the voids of the soil particles. A higher degree of aeration (higher porosity) lowers the tendency for the formation of corrosion. Well-aerated soils promote higher rates of evaporation and retain less water, thus reducing the amount of electrolyte available for the corrosive redox reaction to take place.

The amount of aeration in soils is directly related to the soil particle size and gradation. For example, sandy soils, due to their relatively large particle size, possess better aeration and allow for quicker drainage and evaporation of moisture than clayey soils.

Moisture content

As mentioned previously, one of the key elements necessary for corrosion to occur is an electrolyte, which is responsible for facilitating the transfer of electrons between the anode and the cathode. The drier the soil, the less electrolyte present to facilitate the corrosion process.

Soil resistivity is directly related to the soil's moisture content and the levels of soluble salts in the soil. Increasing the moisture content lowers the soil resistivity. Since corrosion is an electrochemical process that involves electric potentials and the transfer of electrons, high levels of soil resistivity obstruct the corrosion process while soils with low resistance levels are deemed more corrosive. Sandy soils drain easily and therefore are considered to be the least corrosive, while by contrast, clayey coils retain electrolytes (moisture) and are considered to be at the higher end of the corrosive spectrum.

Dissolved salt content

Although the presence of water in soils enables oxidation and by extension corrosion, the process can be greatly accelerated by the presence of dissolved salts. Dissolved chloride salts in water increase the conductivity of the electrolyte (due to an increased number of dissociated ions) and enhance the number of electrolysis reactions. Generally, soils with chloride and sulfate levels below 100ppm and 200ppm respectively are considered mildly corrosive.

Soil acidity (pH level)

pH (potential of hydrogen) is a numerical scale used to measure the acidity or alkalinity of a solution. The scale ranges from 1 to 14, with 7 being the neutral (neither acidic nor alkaline) point. Values below 7 indicate acidity, with 1 being the most acidic and values above 7 indicate alkalinity, with 14 being the most alkaline.

The pH levels of soils vary widely, with values ranging anywhere from 2.5 to 10. A neutral pH of 7 in soils is considered to be ideal to minimize the potential for corrosion. Soils with pH values below 5 are considered to be aggressive and can lead to increased corrosion rates and premature pitting of metals. The inherent pH of a given soil can fluctuate due to environmental factors such as rainfall.

Temperature

The soil's resistivity is affected by the atmospheric temperature. As the temperature decreases, the resistivity of the soil increases, and hence the corrosive potential of the soil decreases. As pore water freezes at 0°C (32°F), its resistivity increases abruptly. A subsequent decrease in the temperature results in an almost exponential increase in soil resistivity. Therefore, the formation of corrosion is highly unlikely in sub-zero temperature environments.

Methods to reduce soil corrosion

There are several methods available to mitigate the potential for soil corrosion, which include cathodic protection, sacrificial anodes and protective coatings. All of these are highly effective and can help avoid costly repairs and replacements in the long term.

Conclusion

It is almost impossible in most land-based construction projects to avoid interacting with the surrounding soil. It is therefore important to understand the soil corrosion phenomenon and the key factors that contribute to the process.

COURSES OFFERED

"Knowledge is the only instrument of production that is not subject to diminishing returns" John Maurice Clark

Level I: Introduction to Hot Dip Galvanizing

The HDGASA one day INTRODUCTION TO HOT DIP GALVANIZING course is designed to provide an initial understanding of the concepts relating to hot dip galvanized coatings applied for corrosion control of steel components. The course comprises six modules. In order for the course to be viable we require six or more candidates to attend. Arrangements can also be made for this course to be held at a venue of your choosing for more than six candidates. In addition to the course, a special visit to a hot dip galvanizing plant may be arranged on a separate date, should six or more candidates be interested and able to attend.

Level II: Certified Galvanizing Inspectors

The HDGASA advanced Level II course provides the necessary skills to assess the quality and conformance of Hot Dip Galvanized coatings and Duplex Systems to the applicable specification. Delegates are introduced to other metallic type coating specifications and their application for corrosion control design.

The course provides an in-depth interpretation of the specifications and accepted best practice procedures for determining coating thickness, visual inspection of surface finishes as well as the evaluation of these coatings for corrosion control of steel components. The course includes a visit to a hot dip galvanizing plant where delegates will have an opportunity to assess finished product against the relevant quality standards on a real time first hand basis.

Three Continuous Professional Development (CPD) points are awarded to delegates attending the entire course. Bookings are limited to a maximum of 10 people, with applications treated on a first-come-first-serve basis. In order for the course to be viable we require 6 or more candidates to attend. Arrangements can also be made for the course to be held at a venue of your choice for more than 6 candidates.

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HOT DIP
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TRAINING: Hit the road running

The training of several entities at Level II has seen 2025 start like a sprinter out of the blocks. From training of the Department of Water and Sanitation's Mechanical Engineering Division in Tshwane to training of the operational technical specialists in De Aar, Northern Cape and a full house in Nigel, training has started well.

The need for up-to-date training for effective understanding of hot-dip galvanizing the standards applicable thereto and inspection and evaluation methodologies aligned with the standards is critical to achieving effective corrosion control of steel. From understanding the operational environments and the corrosion control mechanisms employed to designing articles for effective hot-dip galvanizing all come together to ensure a world-class galvanized product with an optimized service life to provide corrosion control over an extended period.

The year ahead has pre-booked courses sold out with a heightened interest in our Level II training, from consulting engineers to a vast number of top-notch organizations, seeking to ensure that they understand and can effectively assess and inspect hot-dip galvanized articles to the required standard. The HDGASA encourages all who deal with hot-dip galvanized products to consider training at Level II.

Apart from structured existing courses, workshops, and tailored courses can be arranged to suit the individual needs of an organisation in dealing with hot-dip galvanizing. From a basic understanding of the hot-dip galvanizing technology for non-operational staff to specialized training in specific requirements, the Hot Dip Galvanizers Association Southern Africa can accommodate your requests. Enquiries can be sent to hdgasa@icon.co.za for attention Chantell Aucamp and also via our website at www.hdgasa.org.za

Don't delay, set your training up today, as the saying goes "Tomorrow never comes."