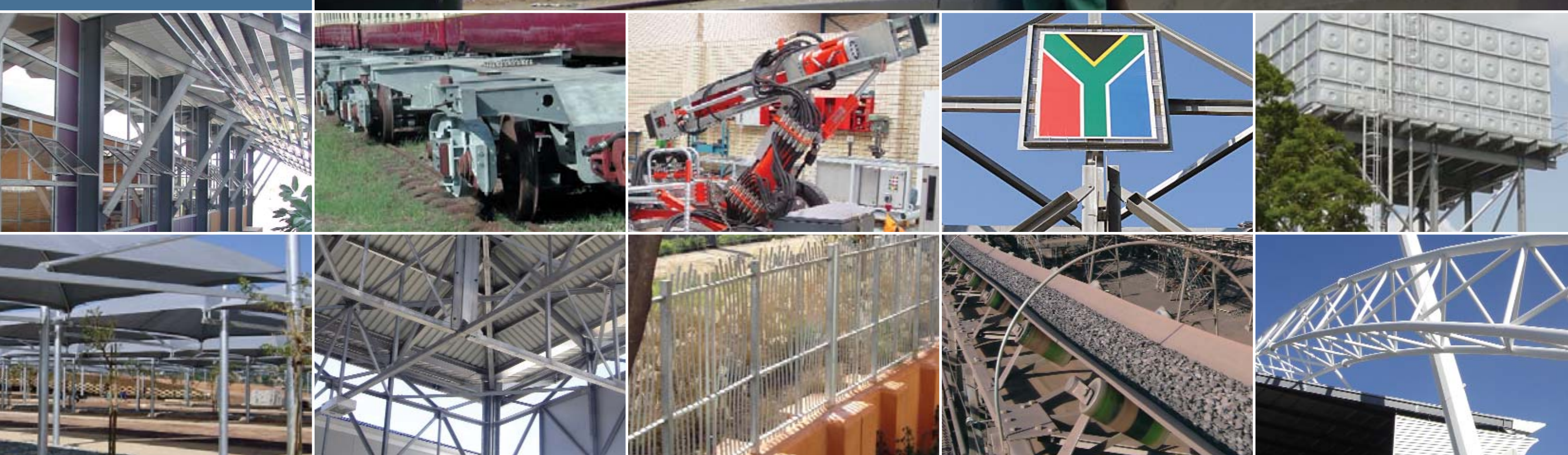
THE HOT DIP GALVANIZERS ASSOCIATION OF SOUTHERN AFRICA

# STEEL PROTECTION

## BY HOT DIP GALVANIZING AND DUPLEX COATING SYSTEMS

# The Hot Dip Galvanizers Association of Southern Africa

## Introduction:

The Hot Dip Galvanizers Association of Southern Africa was founded in 1965 and its membership represents the majority of the available hot dip galvanizing capacity in Southern Africa.

## The Vision:

To position the Hot Dip Galvanizers Association of Southern Africa, comprising all its Members and other interested parties, as a professional organization serving the interests of all parties dependant upon the hot dip galvanizing industry.

## Mission Statement:

To develop and expand the demand for hot dip galvanizing, identify and develop new market opportunities for the benefit of Members and other stakeholders.

## Strategic Objective:

To convince users and specifiers to use hot dip galvanized steel in preference to other coatings and alternative materials, where suitable. This is carried out in three ways:

1. Through general promotional activities.
2. Through focused technical marketing support.
3. Through training and education programmes.

## Delivery Activities:

- Promoting the use of hot dip galvanizing for cost effective corrosion control in applications where its use is appropriate.
- Providing technical assistance and advice for specifiers, fabricators and end users while also recommending alternative protective methods where appropriate.
- Identifying and investigating potential new applications for hot dip galvanizing.
- Participating in development projects on behalf of industry by providing assistance in the form of technical consulting, practical recommendations and assistance with the preparation of design specifications.
- Providing assistance with quality control during fabrication and hot dip galvanizing.
- Disseminating technical knowledge by providing a consulting and training service as well as the publication of technical literature.
- Providing training and education for member companies to ensure a high standard of quality and service throughout the hot dip galvanizing industry.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PROMOTING THE BENEFITS OF HOT DIP GALVANIZING

# Foreword

Steel Protection by Hot Dip Galvanizing and Duplex Coating Systems has been revised and updated to include the SANS/ISO specifications for hot dip galvanizing. This includes the specifications applicable to general galvanizing as well as tubes by the semi-automatic process. In addition, more comprehensive information has been added to the sections covering continuously galvanized wire and sheet. The latter provides the latest available information on pre-coated sheet products available in South Africa.

The design and inspection of hot dip galvanized articles and their expected service life performance in a range of environments is critical to the successful application of hot dip galvanizing for corrosion control. Bolting and welding as well as comprehensive coating repair of hot dip galvanizing is also discussed. This guide provides ample support for the specifier, designer and user to utilize the unique properties of hot dip galvanizing when applied to steel. As in other editions, information in this guide is based on scientific literature supported by the invaluable experience of various authorities, both local and overseas.

This edition is the 6$^{th}$ available in South Africa and the 4$^{th}$ written specifically for the local market. Based on earlier overseas editions, the contribution is acknowledged and greatly appreciated.

**Members of staff of *The Hot Dip Galvanizers Association of Southern Africa* are available to provide support and advice on the design, application and performance of hot dip galvanizing. Please feel free to contact us.**

*It is estimated that this pressed steel panel water storage tank, known as a "Braithwaite" water tank has been in service for about 70 years and the hot dip galvanized coating is still in a serviceable condition. The coating on the fasteners has now failed and must be replaced or overcoated to ensure further service life. The original "Braitwaite" tank was imported but several reputable local companies produce similar product of equal quality.*

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# About Corrosion and Rust Prevention

Corrosion can be defined as the destruction or deterioration of a material by reaction with its environment. Corrosion usually results in compromising the function of a metal, damage to its surroundings, or damage to the technical system in which they are both included *(figures 1 to 4)*. Broadly speaking, all metals, with the possible exception of precious metals, are corroded and destroyed with time.

For steel to corrode – or rust – in normal environments, it must have access to both oxygen and water. In most environments both oxygen and water are available in sufficient quantities through most of the year to enable the corrosion process to take place.

The engineering properties of steel have made it the most widely used metal. However, its tendency to corrode readily means that corrosion protection is of great economic importance. The rusting process of steel can be impeded by any of the following:

- **By alloying** the steel with elements such as chromium, nickel, molybdenum, etc. For ordinary steel structures, however, these steels are too expensive.
- **Changing of the corrosive environment** by reducing the access of water and oxygen through techniques such as dehumidification, inert atmospheric blankets, etc. In totally immersed aqueous environments inhibitors may be added to reduce the aggresivity of the solution.
- **Cathodic protection** through the utilization of sacrificial anodes or impressed direct current. The method using sacrificial anodes can be said to be a form of controlled galvanic corrosion, since the metals are arranged so that one of them is allowed to corrode while the other is protected. Cathodic protection can only be used in the presence of an electrolyte, such as water or moist soil. The method is used for the protection of ships, small boats, quays, offshore oil platforms, tanks, pipelines, etc..

*Figure 1*

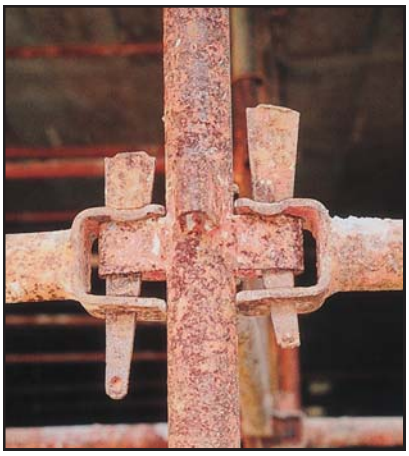


*Figure 2*

- **Coating** with inorganic or organic material, for the purpose of excluding water and oxygen from the steel surface. This is the most widely used method of protection against corrosion. The inorganic materials can be metals and vitreous enamels. The organic materials can be paints, bitumen products or plastics.

**Metal coating** of steel will provide protection against corrosion, give wear resistance, and sometimes a decorative effect.

Only a few of the metals that can be deposited on steel are cost-effective and cathodic to steel. In fact, only zinc and aluminium can really be considered. Cadmium is used to some extent but environmental concerns limit its use.

Aluminium has good durability in most environments, although it is difficult to apply. Thin sheet is aluminized on a small scale. Thermal spraying is used to a certain extent.

A more detailed analysis of the different aspects of corrosion and corrosion control would go beyond the scope of this publication. For those who are interested, further information can be obtained from the Hot Dip Galvanizers Association Southern Africa.

*Figure 3*

*Figure 4*

# Choice of Rust Prevention Method

When choosing a rust prevention method for a steel component or structure, there are many technical issues to be addressed. The environment in which the steel component or structure is to work must be analysed carefully. The need for handling, transport, fabrication and final erection require careful consideration.

There are numerous paint systems for steel and a wide range of possible specification and application variables. These variables can substantially influence the performance of a given system and therefore its cost effectiveness. By contrast, the hot dip galvanizing process is simple, standardised and virtually self-controlling, governed mainly by the laws of metallurgy. As a result it is inherently reliable and predictable.

The reliability factor of a coating may be defined as the extent to which its physical, chemical and mechanical characteristics can be consistently realised during and after application.

The reliability factor determines the overall cost-effectiveness of a coating in a given environment.

*Table 1* summarises factors determining the reliability of typical paint systems for steel, and for hot dip galvanizing. The reliability factor for hot dip galvanizing is shown to be superior, mainly because it is not influenced by most of the variables which can reduce the ultimate performance of most heavy duty paint systems.

Paints are available in countless variations, with different properties.


*Figure 5. Abrasion resistance of hot dip galvanized vastrap stairs (coating thickness - 49µm, taken 10 years after installation).*

Conditions and demands are variable in practice, hence a comparison with actual parameters is often advisable.

An economic study of different control methods should be undertaken. It is important that the choice of method be based not only on initial costs but also on packing costs for transportation, touch-up painting after erection and future maintenance costs.

A good guide to the selection of corrosion control methods in different environments can be found in **SANS 14713/ISO 14713** – Protection Against Corrosion of Iron and Steel in structures – Zinc and Aluminium Coatings – Guidelines and in **SANS 12944/ISO 12944** Parts 1 - 8 – Corrosion Protection of Steel Structures by Protective Paint Systems.

The environmental classifications defined in these standards concern only the environment in which the structure will function. However, transportation, storage and erection environments can change the environmental classification, and therefore the choice of rust prevention method.

*Figure 6* serves as a guide for comparing the technical characteristics of different types of coating.

It should be noted that, even if zinc and paint are applied with the same objective - to prevent corrosion - they act in completely different ways. The zinc coating corrodes from the surface in towards the steel, and gives cathodic protection in the event of damage to the coating. Corrosion does not occur between the zinc coating and the steel.

Conversely, paint coatings are often destroyed through the development of a layer of rust between the paint and the steel. Since the paint coating gives no cathodic protection, rust is able to penetrate further beneath the paint film once the coating has been damaged. Paints containing zinc are produced in order to provide a degree of cathodic protection.

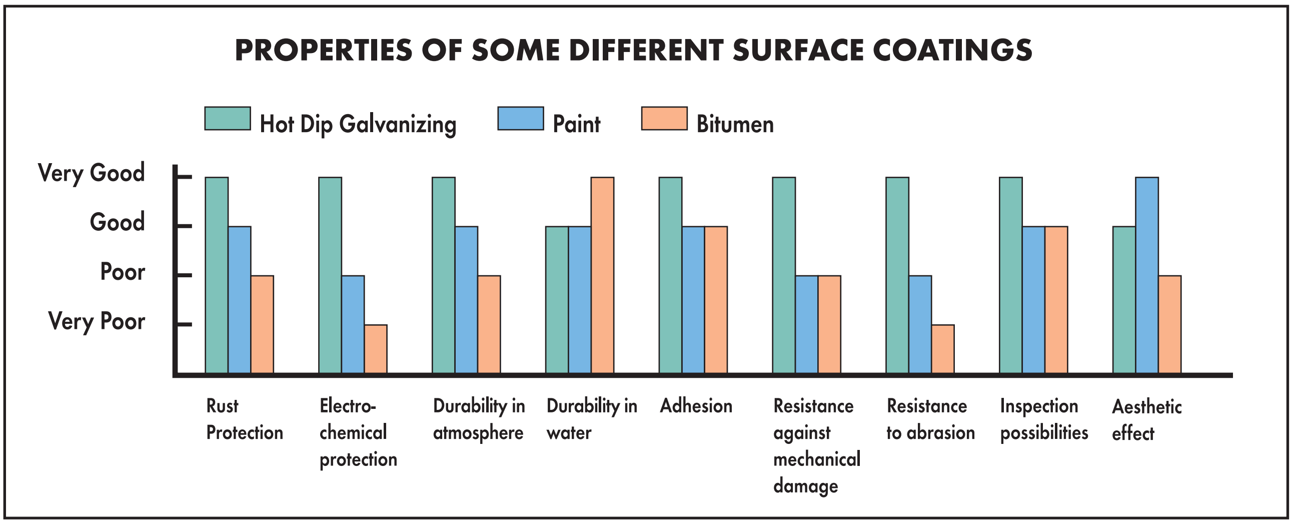


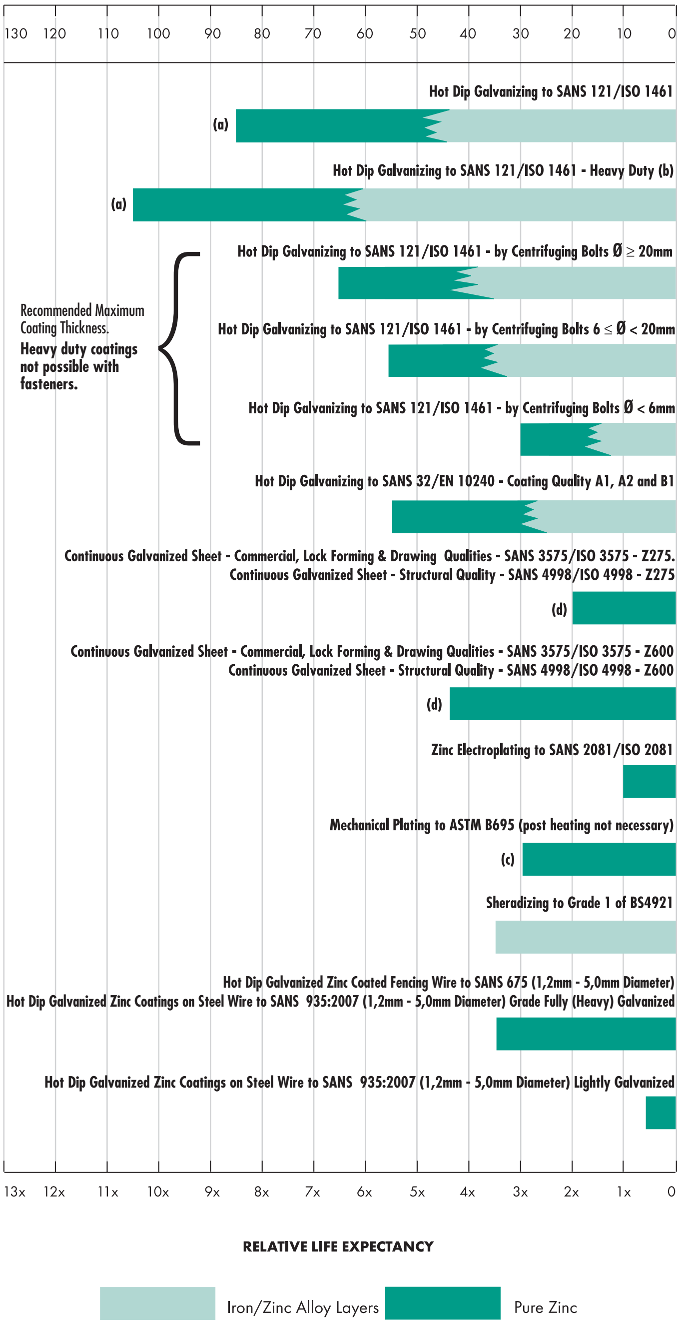

*Figure 6. Comparison between the properties of different surface coatings.*

| Factor | Paint System | Hot Dip Galvanizing |
|---|---|---|
| **Preparation** | ISO 8501-1:1988 prescribes abrasive blasting to Sa 2½. Unsatisfactory cleaning can reduce the service life of the paint system by 60-80%. Preparation control is of decisive significance. | Pickling in acid is an essential part of the process. If the surface is not clean, no coating will be formed. Preparation control is not essential. |
| **Process** | Careful formulation, mixing, agitation and correct thinning are factors of great significance. | The small variations that are possible have little or no influence on the quality of the zinc coating. |
| **Application** | The composition and uniformity of the coating varies with the method of application. Inspection of each stage of application is important. Abrasively-blasted surfaces are reactive and must be painted very soon after blasting. | The zinc coating is formed through a reaction between iron and zinc. The reaction is controlled by physical and chemical laws. |
| **Application Conditions** | | |
| **1. Temperature** | Good results are difficult to obtain if the air temperature is below +10°C. Surfaces exposed to direct sunlight can easily become too hot. | Not affected by the air temperature or normal variations in the process temperature. |
| **2. Humidity** | Dew and surface condensation delay painting, which should not be carried out if relative humidity exceeds 80%. | Not affected. |
| **3. Air pollution** | Steam, fumes, gases, dust and other pollutants have an adverse effect on the quality of the paint coating. | Not affected. |
| **Type of steel** | No influence. | The content of, primarily, silicon and phosphorous in the steel affects the thickness and appearance of the coating. |
| **Properties of the Coating** | | |
| **1. Thickness** | Of great significance to service life. Varies with the number of layers and method of application. Inspection of thickness important for each layer. | The reaction between molten zinc and iron gives a certain standard minimum thickness. Silicon and phosphorous content at certain levels in steel, increased mass, material thickness and surface roughness give increased coating thickness. |
| **2. Adhesion** | Depends on preparation, type of paint system, interval between preparation and priming and hardening interval between layers. | The zinc coating is bonded to the steel metallurgically. |
| **3. Uniformity** | The paint coating is thinner over corners and sharp edges. Holes and narrow crevices normally remain uncoated. "Shaded" sections can be subject to thinner layers. | Total uniform coverage through dipping in molten zinc. Coating generally 50% thicker over sharp edges. |
| **Hardening time** | Can vary, depending on type of paint and application conditions, from a few hours to several days for good handling characteristics, and up to several weeks for ultimate hardness. | The coating hardens completely within a few seconds of withdrawal from the zinc bath. |
| **Dimensional Stability** | None. | Residual stresses caused by rolling, cold-working or welding can, in certain cases, be released so that some deformation may occur. These, however, can to a greater degree be minimized by correct design, good fabrication and best practice galvanizing. |
| **Inspection** | Various hold points to allow for interim inspections to be conducted i.e. after preparation and after each stage in the treatment to ensure good quality. Inspection of layer thickness upon application and on finished goods. | Visual inspection and measuring of layer thickness after hot dip galvanizing is all that is required. |
| **Risk of damage during transportation and handling** | Great. Can necessitate repair to primer coating and complete overcoating. | Coating withstands mechanical impact. Minor damage does not need to be repaired. More serious damage must be repaired by means of zinc metal spraying or coating with zinc-rich paint, preferably containing an epoxy. |

*Table 1. Comparison of the properties between a paint system and hot dip galvanizing.*

# LIFE EXPECTANCY IN RELATION TO THE THICKNESS OF COATING ACHIEVED BY THE DIFFERENT ZINC COATING PROCESSES

**MEAN COATING THICKNESS MEASURED IN MICRONS FROM STEEL SURFACE**




(a) Determined on thickness of material - example t ≥ 6mm steel plate

(b) Deviation from standard coating thickness. A requirement for a thicker coating (25% greater than standard) can be requested for components not centrifuged, without affecting specification conformity.

NOTE: Where steel composition does not induce moderate to high reactivity, thicker coatings are not always easily achieved.

(c) Should mechanical plating be specified for fasteners, similar rules apply for oversizing nuts or undercutting bolt threads. *Chapter 3 and 13 refer.*

(d) Also available in other coating classes. *Tables 6 and 7 refer.*

*Table 2. Zinc coatings compared in terms of coating thickness and relative life expectancy.*

## COMPATIBILITY OF GALVANIZED COATINGS WITH VARIOUS MEDIA

**Compatibility of hot dip galvanized coatings with various media is summarised in the table below. Further specific information is available from Hot Dip Galvanizers Association Southern Africa.**

| | | |
|---|---|---|
| **Aerosol propellants** | | excellent |
| **Acid solutions** | down to pH 6.0<br>strong | fair<br>not recommended |
| **Alcohols** | anhydrous<br>water mixtures<br>beverages | good<br>not recommended<br>not recommended |
| **Alkaline solutions** | up to pH 12.5<br>strong | fair<br>not recommended |
| **Detergents** | inhibited | good |
| **Diesel oil** | sulphur free | excellent |
| **Fuel oil** | sulphur free | excellent |
| **Gas** | towns, natural,<br>propane, butane | excellent |
| **Glycerine** | | excellent |
| **Inks** | printing<br>aqueous writing | excellent<br>not recommended |
| **Insecticides** | dry<br>in solution | excellent<br>not recommended |
| **Lubricants** | mineral, acid free<br>organic | excellent<br>not recommended |
| **Paraffin** | | excellent |
| **Refrigerants** | | excellent |
| **Sewage** | | excellent* |
| **Fertilizers** | dry<br>aqueous | good<br>use with care |
| **Timber preservatives:**<br>Copper-chromium-arsenic, freshly treated<br>After drying is completed<br>Boron | | <br>poor<br>excellent<br>excellent |
| Trichlorethylene | | excellent |

* *Anaerobic conditions to be avoided.*

**Sewage Treatment**

Hot dip galvanized coatings perform extremely well by comparison with other protective coatings for steel in the severely corrosive conditions prevailing in most sewage treatment operations. As a result hot dip galvanized steel is used extensively in sewage treatment plants throughout the world.

*Table 3. Compatibility of hot dip galvanized coatings with various media.*

## GENERAL INFORMATION ABOUT ZINC

| | |
|---|---|
| Atomic Weight | 65.37 |
| Density<br>- *rolled – 25°C*<br>- *cast – 25°C*<br>- *liquid* | <br>7192 kg/$m^3$<br>6804 kg/$m^3$<br>6620 kg/$m^3$ |
| Melting Point | 419.5°C |
| Boiling Point | 907°C |
| Appearance | bluish-white metal |
| Atomic number | 30 |
| Modulus of elasticity | 7 x $10^4$ MN/$m^2$ |
| Specific heat | 0.382 kJ/kg.K |
| Latent heat of fusion (419.5°C) | 100.9kJ/kg |
| Latent heat of vapourisation (906°C) | 1.782 MJ/kg |
| Heat capacity<br>- *Solid*<br>- *Liquid*<br>- *Gas* | <br>22.40 + 10.5 x $10^{-3}$ TJ/mol<br>31.40 J/mol<br>20.80 J/mol |
| Linear coefficient of thermal expansion (20–400°C) | 39.7μm/m.K |
| Volume coefficient of thermal expansion (20–400°C) | 0.89 x $10^{6}$/K |
| Thermal conductivity: solid (18°C) | 113W/m.K |
| Electrical resistivity (20°C) | 5.9uΩm |
| Standard electrode potential ($H_2$ electrode) | -0.762V |
| Enthalpy of Vapourisation | 114.2 kJ/mol |

*Table 4. Properties of zinc.*

# Corrosion Protection Methods

## 3.1 HOT DIP GALVANIZING

Steel components, cleaned of rust, mill scale and other contaminants, are dipped into molten zinc, producing a coating of iron/zinc alloys with pure zinc on the surface. *Chapter 4 refers.*

## 3.2 ELECTROPLATING

The steel surfaces are degreased and pickled to remove rust and mill scale. The component is then submerged in a zinc salt solution and connected as a cathode to a direct current source. Rods or balls of pure zinc are connected as anodes. The solution (electrolyte) can be acidic, neutral or alkaline, which determines the type of zinc salt. When the current flows, zinc from the electrolyte is deposited on the steel surfaces. At the same time, the anode dissolves and supplies new zinc to the electrolyte.

Items can either be supported in jigs or baskets or they can be placed in drums for movement between the necessary baths.

The deposited layer has a very fine crystalline structure with a distinct boundary between the plated zinc and the metal substrate *(figure 7)*. Thicknesses vary from 5 to 25 µm. However, layers thinner than 5 µm can often be found on items such as fittings, small bolts, etc.. Layers thicker than 25 µm can only be obtained on components or structures of simple smooth geometry, e.g. wire.

The surface of the zinc coating is very even, with a silvery, metallic sheen. Through the addition of special additives to the bath, very shiny coatings can be obtained (bright zinc). Electroplated components are usually dipped in chromate to prevent corrosion during storage and transportation. The chromate layer is often colourless but can, in the case of thicker layers, be yellow-brown or green in colour.

Because of the thinness of the zinc layer, electroplated components should be finished with a layer of paint or other organic coating prior to outdoor exposure in order to increase the service life.

See also **SANS 4042/ISO 4042** for fasteners and **SANS 2081/ISO 2081** for other components.

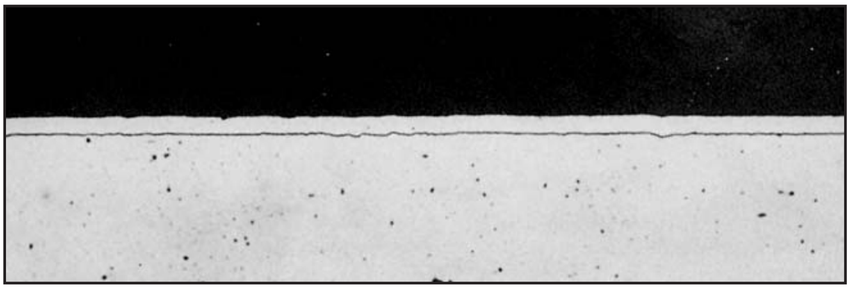


*Figure 7. Section through electrolytically applied zinc layer.*

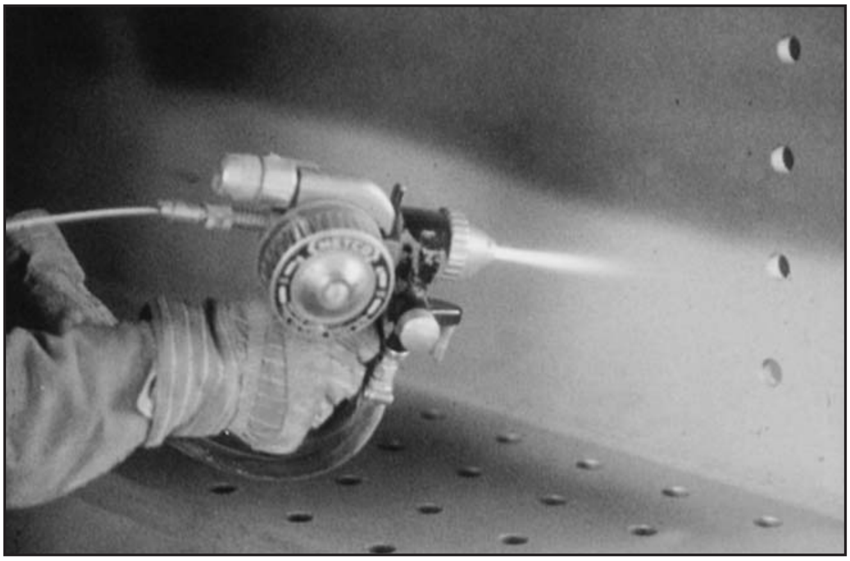


*Figure 8. Zinc metal spraying.*

## 3.3 ZINC METAL SPRAYING

The steel is cleaned by means of abrasive blasting - at least to Sa 2$^1/_2$, according to **ISO 8501-1.** Zinc is fed into the spray gun in the form of wire or powder and melted by a gas flame or electric arc *(figure 8)*. The molten droplets are then sprayed on to the steel surface with the aid of compressed air.

The zinc layer can exhibit porosity and the surface may be coarse *(figure 9)*. The thickness of the coating can be varied from about 30µm to (in practice) about 300 µm. Adhesion to the steel surface is purely mechanical.

The method is suitable for larger objects of relatively simple shape. It is also well suited to the repair of zinc coatings on hot dip galvanized components that have been damaged by mechanical impact or welding.

See also **SANS 2063/ISO 2063.**

## 3.4 SHERARDIZING

Steel components, cleaned through pickling, are packed together in a drum with zinc powder and sand. The drum is rotated and heated to just below the melting temperature of the zinc. During a period at this temperature, and with continued rotation, iron and zinc react with each other to form an iron/zinc alloy on the steel surfaces.

Sherardizing gives relatively thin coatings (15-40 µm) with dark grey surfaces. The coatings have good adhesion properties and a very uniform thickness, even on objects of complex shape. The method has about the same range of application as for electroplating.

See also **SANS 53811:2006 / EN 13811: 2003** *Sherardizing – Zinc diffusion coatings on ferrous products.*

## 3.5 MECHANICAL PLATING

Degreased objects are placed in a drum, together with glass balls. They are first tumbled in an acidic cleaning agent and then in a copper-plating agent. The objects are then tumbled with zinc powder and certain activating chemicals.

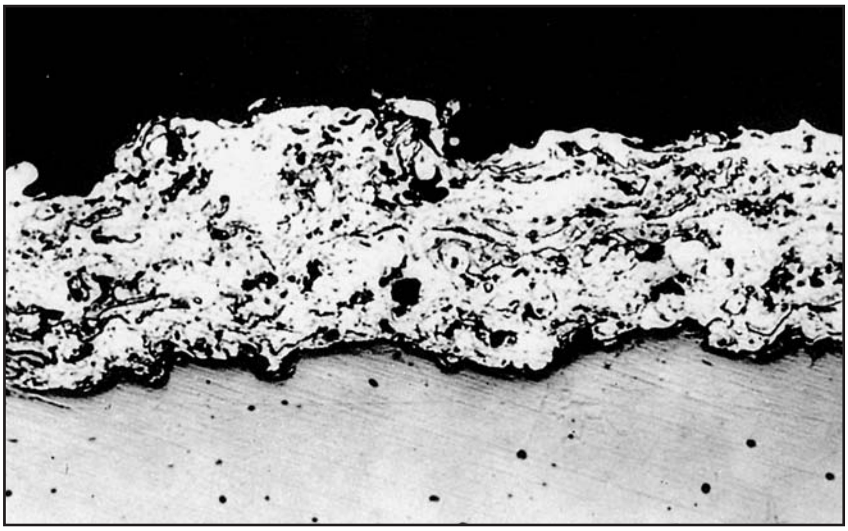


*Figure 9. Section through zinc metal sprayed coating.*

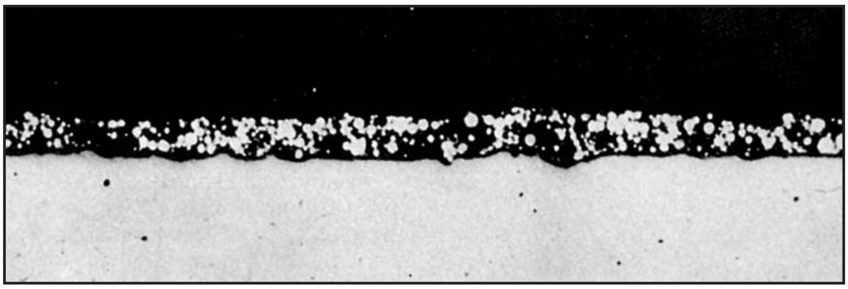


*Figure 10. Section through zinc rich paint layer.*

Zinc is usually deposited in layers with thicknesses between 12 and 15 μm, although thicker layers of about 75 μm are said to be obtainable. When coatings thicker than 30μm are applied, low temperature heat treatment is necessary after plating, to avoid flaking. The coatings are very uniform, even on objects of complex geometry. The surface is matt. The iron/zinc alloys produced by the hot dip galvanizing process are absent in mechanically plated zinc coatings and unlike hot dip galvanizing, the coating on edges and corners is thinner than that on flat surfaces. This is due to impact during the tumbling process and for this reason, products with a mass of more than 0,25kg are not recommended for coating by this method. When thicker coatings are applied, >20μm, oversizing of internal threads or undercutting of external threads, is necessary. Since there is little risk of hydrogen embrittlement even hardened steels can be treated in this way.

**ASTM-B695** may be applied.

### 3.6 COATING WITH ZINC-RICH EPOXY OR PAINT

As with zinc metal spraying, steel components should be cleaned by means of careful abrasive blasting - at least to Sa $2\frac{1}{2}$, according to **ISO 8501-1.** Scraping or wire-brushing alone does not give satisfactory results when coating an entire component. However, when reconditioning a coating on site, proper abrasive paper cleaning or wire brushing can be quite successful.

Zinc-rich paint consists of fine grained zinc powder in an organic or inorganic bonding agent. Both one and two-component paints are available. The zinc content in the dry paint film should be at least 80% by mass, which corresponds to 54% by volume. Whilst the zinc in the zinc rich paint does provide an element of initial cathodic protection due to interspersed resins and binders, which are required to allow the paint to adhere to the substrate, proper cathodic protection is short lived to about 80 days ($2\frac{1}{2}$ months). The zinc rich paint at this time becomes a normal barrier coating. The paint is applied by brush or spray gun, depending on paint formulation.

Painting with zinc-rich paint is some times called "cold galvanizing", gives the impression that zinc-rich paints provide zinc coatings with similar properties to those obtained by hot dip galvanizing. This is not so, compare *figure 10* to *figure 23*.

The designation "cold galvanizing" has been legally tested in Germany. Zivilsenats des Bundesgerichthof, said in a verdict dated 12th March 1969 that "cold galvanizing" was an illegal product description.

Coating with zinc-rich paint is a painting procedure and not a method of metal coating.

The properties of zinc coatings applied by these various methods are given in *figure 11*.

*Refer to Chapter 15 - "Reconditioning Coatings Damaged or On-site Modified Hot Dip Galvanized Components".*

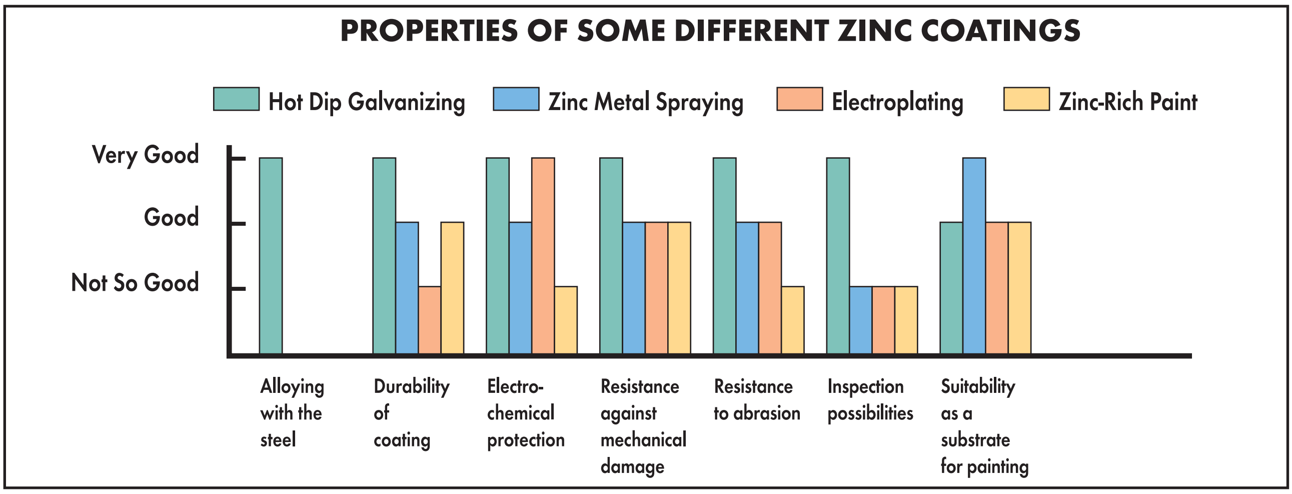



*Figure 11. Comparison between the properties of different zinc coatings.*

# Hot Dip Galvanizing

The French chemist, Melouin, discovered as long ago as 1741 that zinc was capable of protecting steel from corrosion. However, the method was not used much until another Frenchman, Sorel, introduced pickling in sulphuric acid as a preparatory measure. He subsequently applied for his first patent on hot dip galvanizing on 10th May 1837. The main part of the procedure that Sorel sought to patent is still used today.

In an appendix to his patent application in July 1837, Sorel called the method "galvanizing", referring to the galvanic cell that is created if the zinc coating is damaged. The steel in the damaged area becomes a cathode in the cell, and is protected from corrosion. The name has subsequently been adopted by other methods for coating steel with zinc and is sometimes used for electrolytic metal deposition in general. To avoid confusion, hot dipping in zinc should be referred to as hot dip galvanizing.

## 4.1 THE ADVANTAGES OF HOT DIP GALVANIZING

- **Lower first cost.** Hot dip galvanizing generally has the lowest first cost when compared to other commonly specified protective coatings for steel. The application cost of labour intensive coatings such as painting has risen far more than the cost of factory applied hot dip galvanizing.
- **Lower maintenance / lower long term cost.** Even in cases where the initial cost of hot dip galvanizing is higher than alternative coatings, galvanizing is invariably more cost effective, due to lower maintenance costs during a longer service life. Maintenance is even more costly when structures are located in remote areas. Maintenance programmes also invariably have a negative impact on productivity.
- **Long life.** The life expectancy of hot dip galvanized coatings on structural members is in excess of 50 years in most rural environments, and between 10 to 30 years in most corrosive urban and coastal environments.
- **Surface preparation.** Immersion in acid ensures uniform cleaning of the steel surfaces. In contrast heavy duty organic coatings must be applied on abrasive blast cleaned surfaces (generally to **ISO 8501 - 1** to SA2½) and verified by third party inspection.

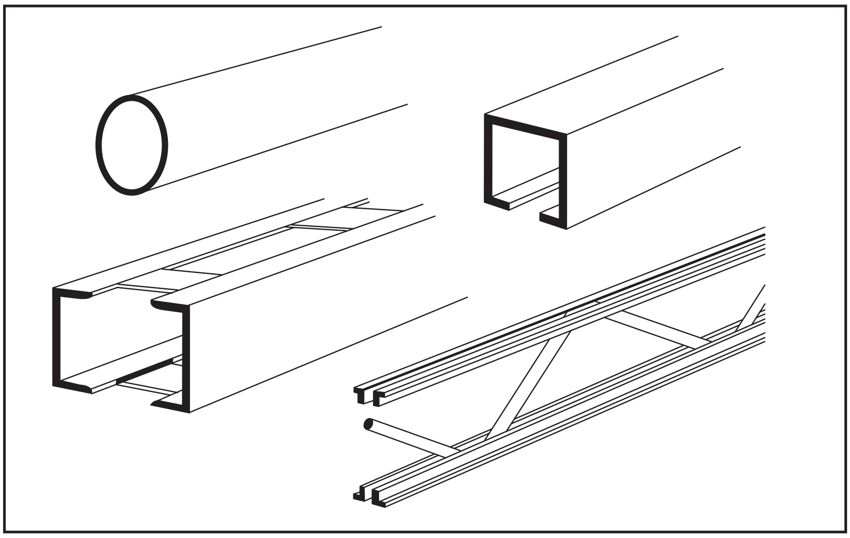


*Figure 12. Examples of profiles and structures that are difficult to access for mechanical cleaning. In hot dip galvanizing, all surfaces receive equally good coatings.*

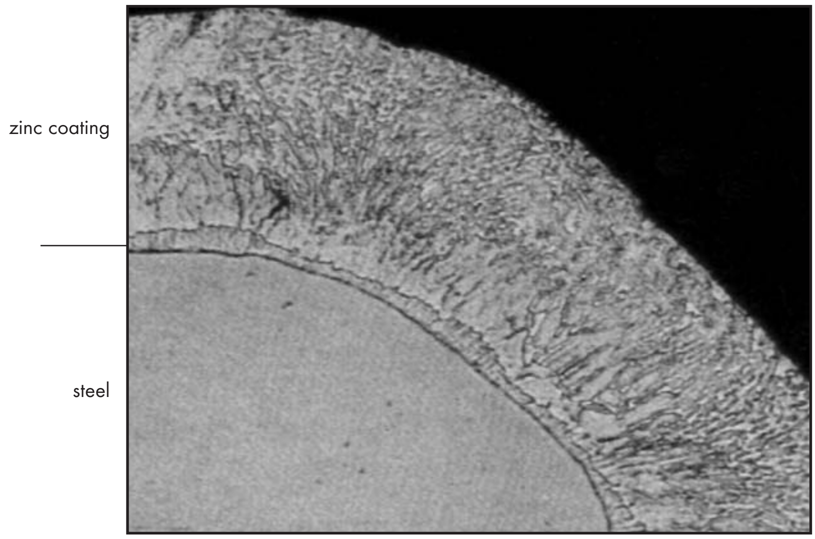



*Figure 13. Micrograph showing the slightly thicker hot dip galvanized coating at corners.*

Additionally, the application of organic coatings is limited in terms of prevailing ambient temperature and relative humidity. This adds to the cost of applying a heavy duty paint system.

- **Adhesion.** The hot dip galvanized coating is metallurgically bonded to the steel surface.
- **Environmentally friendly.** The coating is not toxic, and it does not contain volatile substances.
- **Speed of coating application.** A full protective coating can be applied in minutes. A comparable multicoat paint system, may require several days. The effective application of a

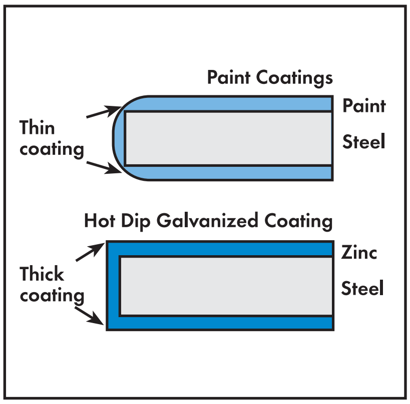



*Figure 14. Paint coatings are usually thinner over corners and sharp edges. Hot dip galvanized coatings, on the other hand, are at least as thick or greater at these locations.*

hot dip galvanized coating is not influenced by weather conditions.

- **Uniform protection.** All surfaces of a hot dip galvanized article are protected both internally and externally, including recesses, sharp corners and areas which are inaccessible for the application of other coating methods *(figure 12)*. The coating is thicker over sharp corners and edges than on flat surfaces *(figures 13 and 14)*. Thickness, coating adhesion and uniformity are features of the process. No other coating applied onto a structure or fabrication can provide similar uniform protection.
- **Sacrificial protection at damaged areas.** A hot dip galvanized coating corrodes preferentially to steel, providing cathodic or sacrificial protection to small areas of steel exposed through damage. Unlike organic coatings, small damaged areas need no touch up while corrosion creep under the coating cannot occur *(figures 89 and 90)*.
- **Toughness.** A hot dip galvanized coating has a unique metallurgical structure, which gives outstanding resistance to mechanical damage during transport, erection and service.
- **Reliability.** Hot dip galvanizing is required to conform to the **SANS 121/ISO 1461** specification. The coating thicknesses specified are related to steel thickness. Coating life is reliable and predictable.
- **Faster erection time.** Once steel is hot dip galvanized it can immediately be inspected, transported and erected. When assembly of structures is complete, they are immediately ready for use. No time is lost on-site for surface preparation, painting, drying, curing and final inspection.
- **Ease of inspection.** Hot dip galvanized coatings are readily assessed visually. Simple non-destructive testing methods are used to determine coating thickness. Inspection of organic coatings is necessary after surface preparation and each stage of coating application thereafter. The hot dip galvanizing process is such that if coatings appear sound and continuous, they are sound and continuous.
- **Over coating with paint, (duplex protection).** If correctly applied a duplex system will provide durable colour, chemical resistance and a synergistically extended service life.
- **Unsightly graffiti is easily removed.** Painted graffiti can be easily removed by solvents with no damage to the hot dip galvanized coating. This is not easily achieved with a paint coating.

## 4.2 THE DISADVANTAGES OF HOT DIP GALVANIZING

- Hot dip galvanizing can only be done in a galvanizing plant. Site application is not possible.
- The colour of the zinc coating can be changed only by painting.
- The dimensions of the component or structure are limited by the size of the zinc bath. *Innovative methods of accommodating larger components have been achieved, discuss with the Association or hot dip galvanizer. For member bath sizes, see www.hdgasa.org.za*
- Residual stresses in metals due to rolling, bending and welding may result in unexpected distortion. However, careful design, good fabrication following the design criteria outlined in this booklet and controlled galvanizing, will eliminate the major causes of distortion. Removal or redistribution of suspected residual stress by heat or other methods in

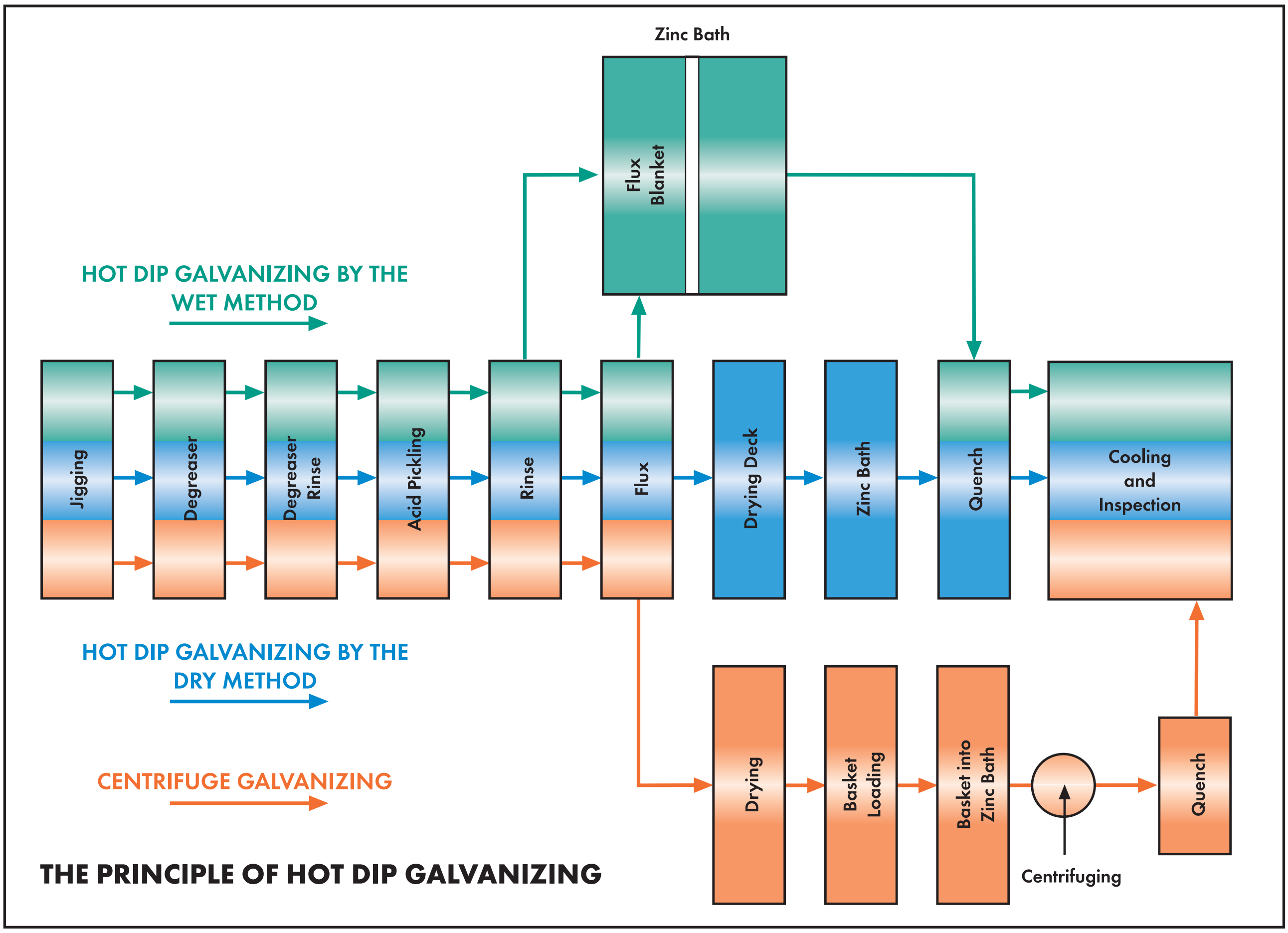



*Figure 15. The principle of hot dip galvanizing.*

critical components can be achieved.

- The welding of zinc-coated steel can demand a somewhat different procedure compared to uncoated steel. The welding of hot dip galvanized steel results in a degree of coating loss through the 1st and 2nd Heat Affected Zones although a portion of the original coating remains intact right up to the edge of the weld. It is necessary to recondition the coating over the weld and surrounding coating.

## 4.3 THE HOT DIP GALVANIZING PROCESS

**General Hot Dip Galvanizing**

The metallurgical reaction between steel and molten zinc, which produces a hot dip galvanized coating, can only take place if surfaces are free from contaminants. If steel surfaces are contaminated with marking paint, weld slag and other substances not readily removed by acid, these must first be removed by mechanical means, such as abrasive blasting or grinding. Moulding sand on the surfaces of castings is removed by means of abrasive blasting.

Grease and oil is removed by the galvanizer with degreasing chemicals, either caustic or acid based. Rust and millscale are removed from steel surfaces by pickling in diluted hydrochloric or sulphuric acid. After pickling and rinsing, a fluxing agent is applied. The purpose of fluxing is to dissolve surface oxides on both the steel and the molten zinc surfaces thus enabling steel and zinc to make metallic contact with each other. Fluxing can be applied in two different ways, designated wet and dry galvanizing respectively. As far as coating quality is concerned, both methods give equally good results.

In wet galvanizing the surface of the zinc bath is divided into two sections by a weir. The fluxing agent - ammonium chloride, is deposited on the zinc surface in one section of the bath. The steel components, still wet from pickling and rinsing are dipped through the molten flux into the zinc. The components are then moved into the flux-free section of the zinc bath. The flux residue and oxides are skimmed from the surface of the bath, whereupon the components can be lifted up through a pure, smooth zinc surface. Wet galvanizing is largely confined to small components and semi-automatic tube galvanizing.

Dry galvanizing is the preferred method for coating batch galvanized components. After pickling and water rinsing, the components are dipped in a flux solution of ammonium chloride and zinc chloride. In this way a thin layer of flux salts is deposited on the surfaces of components. Before components are dipped into and withdrawn from the bath, the surface of the molten zinc is skimmed to remove zinc oxide and flux residues. After withdrawal from the zinc bath, components are quenched either in a sodium dichromate rinse or plain water. Alternatively, they may be aircooled. Components are then ready for fettling (if necessary), inspection and dispatch *(figure 15)*.

**Centrifuge Hot Dip Galvanizing**

Small components such as nails, nuts, bolts, washers and fittings are cleaned as described above and placed in perforated baskets, which are then dipped into the molten zinc. Upon withdrawal from the zinc bath, the basket is placed in a centrifuge. Rotation has the effect of throwing excess zinc off the coated surfaces, leaving the components free from uneven deposits of zinc. The zinc layer on centrifuged articles is somewhat thinner, than that obtained by the general process. Centrifuging is essential for threaded articles, where thread clearance and coating thickness tolerance are critical *(figure 15)*.

**Tube Hot Dip Galvanizing**

Tubes are hot dip galvanized either by the dry or wet methods in semi-automatic production lines. Immediately after withdrawal from the zinc bath, excess zinc is wiped off external surfaces to provide a smooth and uniform coating. The thickness of the zinc coating can be controlled to some extent by adjusting the air pressure in air wiping equipment. Internal surfaces are cleaned of excess zinc with the aid of steam, which is forced down the bore of the pipe. The tube hot dip galvanizing process is normally only applied to flangeless tubes with a maximum nominal bore up to 114mm OD. Larger diameters and tubes with flanges are galvanized by way of the general process.

**EVALUATION OF WET STORAGE STAIN**

*(Refer to Chapters 5 and 12)*

| VISIBLE EFFECT | CAUSE | REMEDIAL ACTION |
|---|---|---|
| LIGHT WHITE DISCOLOURATION - THIN, WHITE POWDERY DEPOSIT | Caused by moisture trapped between sheets or components during transportation or storage, or by condensation in the absence of adequate ventilation. | None required. The protective properties of zinc are not impaired by the presence of superficial white discolouration. Existing white discolouration deposits will slowly convert to protective basic zinc carbonate. Not suitable for post painting before removing loosely adhering deposits. |
| HEAVY WHITE DISCOLOURATION- THICK, CRUSTY DEPOSITS | Prolonged adverse storage or inadequate protection during transport, allowing considerable water ingress between closely stacked sheets or components. | Before painting, remove all traces of loosely adhering deposits with stiff bristle brush (not a wire brush). Check residual zinc coating thickness with an electromagnetic thickness gauge. (On continuously galvanized sheet, the electromagnetic thickness gauge is used merely as an indicator of the zinc coating thickness. The method cannot be used to fail the coating in terms of thickness.) If the coating thickness is within specification and if the sheet or component is to be used in reasonably dry or freely exposed conditions, no action is required. |
| BLACK STAINING AND WHITE DISCOLOURATION WITH POWDERY DEPOSITS | Usually very early stage of superficial zinc corrosion normally due to the formation of complex surface zinc corrosion product. Black staining does not imply that the zinc coating has been destroyed. | Check zinc coating thickness using an electromagnetic thickness gauge. (The electromagnetic thickness gauge is used merely as an indicator of the approximate zinc coating thickness on continuously galvanized sheeting. The method cannot be used to fail the coating in terms of thickness.) If in doubt contact the HDGASA before painting, due to the complex nature of stains. |
| RED RUST | Corrosion of steel substrate where zinc coating has broken down completely. Should not be confused with superficial staining. | In general, sheet or components showing red rust should be repaired or not used at all. |

*Table 5. Evaluation of wet storage stain.*

# Hot Dip Galvanizing of Sheet Metal

Hot dip galvanized sheet is produced on continuous zinc coating lines, *(figure 16)*, from either cold rolled (thickness range 0.27 to 2.0mm) or hot rolled (thickness range 2.1 to 3.0mm) steel coil to the requirements of **SANS 4998 and SANS 3575 or ASTM A653.** Specification **SABS 934** should no longer be referred to as it has been replaced by **SANS 4998/ISO 4998** and **SANS 3575/ISO 3575.**

Steel coils are welded end on end to form a continuous strip. After degreasing the strip is pickled or oxidized. Oxides are then removed from the surfaces by reduction at 950°C. At the same time the strip is soft-annealed. The surfaces of the strip, now chemically clean, are moved through a protective gas atmosphere and directly down into the zinc bath.

The strip is withdrawn from the bath vertically and passed through "air knives". Controlled jets of air or steam are blown through the knives, wiping the zinc coating to the desired thickness.

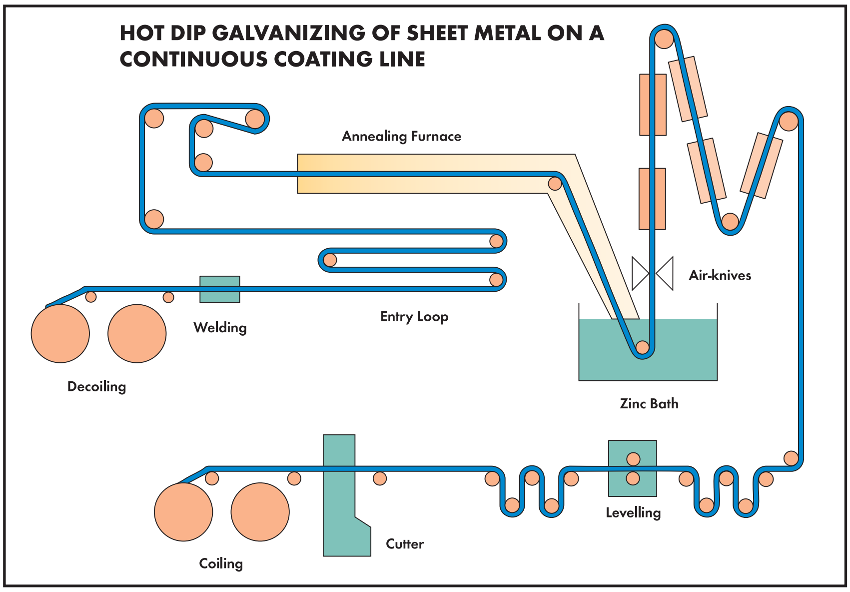



*Figure 16. Schematic diagram showing the continuous hot dip galvanizing process for the coating of sheet.*

The galvanizing process yields an even zinc coated sheet with a bright smooth metallic finish. The zinc coating can be supplied with a regular or flattened minimised spangle finish. *(Refer to 7.8 The Iron/Zinc Reaction in Continuous Galvanizing).*

After cooling, straightening and treatment against wet storage stain, the strip is cut into suitably sized sheets or rolled into coils for delivery or subsequent painting and/or profiling *(figure 16).*

## 5.1 ZINC COATING SURFACE FINISH

The following surface finishes may be ordered to suit specific end-use requirements:

**Regular spangle (also known as normal spangle)**
This is the unaltered, large, multifaceted crystal structure that occurs during normal solidification of a hot dip zinc coating on a steel sheet.

Variations in the size and brightness of the spangles are possible, depending on the galvanizing process and conditions, but this has no effect on the quality and corrosion resistance of the coating. Regular spangle is supplied for a wide range of applications where overpainting for maintenance purposes can be undertaken at a later stage.

**Flattened minimised spangle**
This is a zinc coating that is obtained by restricting the normal zinc crystal growth followed by the application of a skin pass process. The zinc coating thus obtained has improved formability and the zinc surface serves as an excellent base for pre-painting, post-painting and powder coating applications.

This finish is recommended for applications where a high gloss paint finish is required. It is available for zinc coatings of mass up to Z275, and a maximum steel thickness of 1.20mm if passivation is required, or a maximum steel thickness of 1.60mm if passivation is not required.

Zinc coatings of different thicknesses in accordance with **SANS 4998/ISO 4998** or **SANS 3575/ISO 3575** may be ordered to suit specific end use requirements. Certain coating grades are more readily available *(tables 6 and 7 respectively).*

The thickness and type of steel substrate is selected on the grounds of mechanical and structural consideration, whereas the thickness of the zinc coating is selected according to the corrosion-resistant life expectancy required.

**Corrosion resistance**
The protection afforded by a hot dip galvanized coating under normal conditions of exposure is directly related to its thickness. The coating on sheet, normally stocked by retailers, is Z 275, which is suitable for a mild environment.

It is recommended that galvanized sheeting be overpainted timeously, preferably before the first appearance of red corrosion products. Where conditions require greater corrosion protection, a thicker class of coating ie. Z 600 or the addition of a paint coating should be considered. In the case of the heavier coating, the sheet is not suitable for severe forming other than normal corrugating or curving.

Bend tests to evaluate the adhesion of the zinc coating are carried out and evaluated in accordance with relevant specifications *(table 8).* In addition to this, impact adherence cupping tests are performed on all products, irrespective of specification, to ensure good adhesion of the zinc coating.

**Wet storage stain (white rust)**
When galvanized sheet in coil or sheet packs is stored under wet conditions, the galvanising may be damaged by wet storage staining.

Rainwater or water vapour can easily be drawn in between tightly profiled or flat sheets, or between laps of coils by capillary action. Due to the absence of freely circulating air, this moisture cannot evaporate, causing unfavourable conditions that may result in white rust on galvanized sheeting.

Normally, light white staining on galvanized sheet is not serious. The wet storage corrosion process will stop when the affected areas are dried and exposed to the atmosphere. The discoloration will disappear within a few months during the normal weathering of the material. Where affected surfaces will form part of unexposed overlaps or other concealed areas that may be subject to extended periods of dampness, such areas should be cleaned and additionally protected.

Galvanized material must under no circumstances be stacked directly on a floor. *See* *figures 19, 20 and 21, table 5 and Chapter 12 and also Removal of Wet Storage Stain, page 16.*

## 5.2 SURFACE TREATMENT

The following surface treatments are normally used to reduce the possibility of wet storage stain during transport and storage:

**Passivation**
Passivation by potassium dichromate is normally applied to all galvanized material. In cases where this treatment may interfere with subsequent processing, the galvanized steel may be ordered without passivation, in which case oiling of the zinc surface is recommended.

**Oiling**
A special corrosion-preventive oil is used to coat galvanized sheet as an additional protection against wet storage staining during handling and storage. Oil is only used if requested.

If unoiled unpassivated galvanized steel sheet is ordered, proper protective packing should be requested to protect the material against the ingress of moisture during transport and storage. *(Refer to Safe Storage, page 16).*

## 5.3 CUT EDGE CORROSION RESISTANCE

The introduction of continuously galvanized coil that is subsequently cut into sheet lengths, has tended to focus attention on the behaviour of cut edges which are exposed to atmospheric corrosion. Sheet, thinner than 1.6mm is usually adequately protected at cut edges by the cathodic action of the zinc coating. Similarly, side trimmed edges seldom present a corrosion problem.

Thicker coatings provide superior cathodic protection.

## 5.4 STRAIN AGEING

Galvanized steel sheet tends to strain age and this may lead to the following:

1. Surface markings from stretcher strain (Lüder's lines) or fluting when the sheet is formed.
2. Deterioration in ductility.

It is recommended that the period between final processing at the mill and fabrication be kept as short as possible, preferably not exceeding six weeks.

## 5.5 PAINTING

Chemical conversion coatings and primers have been developed to provide good adhesion of subsequent paint films on zinc coated surfaces. To obtain optimum results it is essential to adhere to the instructions of the paint manufacturers.

**ZINC COATING MASS IN ACCORDANCE WITH SANS 4998/ISO 4998 AND SANS 3575/ISO 3575**

| Coating Designation | Mass of coatings * (both sides inclusive) g/m², min. | | Equivalent thickness per side * * µm, min | |
|---|---|---|---|---|
| | Average | Individual | Average | Individual |
| Z 100† | 100 | 85 | 7 | 6 (4,8) |
| Z 180† | 180 | 150 | 13 | 11 (8.5) |
| Z 200† | 200 | 170 | 14 | 12 (9,7) |
| Z 275 | 275 | 235 | 20 | 17 (13,4) |
| Z 350 | 350 | 300 | 25 | 21 (17,1) |
| Z 450 | 450 | 385 | 32 | 28 (22) |
| Z 600 | 600 | 510 | 43 | 36 (29) |
| Z 700 | 700 | 595 | 50 | 43 (34) |

*Table 6. Mass per unit area of zinc coating.*

| Coating Designation | Mass of coatings * (both sides inclusive) g/m², min. | | Equivalent thickness per side * * µm, min | |
|---|---|---|---|---|
| | Average | Individual | Average | Individual |
| Z160[1,2] † | 160 | 135 | 11 | 9 (7.7) |
| Z275 | 275 | 235 | 20 | 17 (13.4) |
| Z600[3,4] | 600 | 510 | 43 | 36 (29) |

*Table 7. Readily available zinc coating grades in Southern Africa.*

**NOTES**

* Not less than 40% of the individual value should normally be found on each surface, indicated in brackets.

† Although coating Classes Z 100, Z160, Z 180 and Z 200 are included in this table, these classes are not recommended for bare external applications but have been included for products which would subsequently be further protected by suitable paint systems.

* * For information only. The equivalent thickness is calculated from the following formula:

$$\text{Thickness; } \mu\text{m} = \frac{\text{Mass per unit area, g/m}^2}{2 \times 7}$$

(7 is the approximate specific gravity of zinc)

**The letter Z in the coating designation indicates a pure zinc coating and the number denotes the total mass of the coating on both faces of the sheet (g/m²)**

1. Only available in 0.27 to 0.30mm full-hard material, except Z160
2. Iscor specification only
3. Not recommended for forming grades
4. Not available on full hard material

| Coating Designation | Commercial Steel (CS), Forming Steel (FS) and Deep Drawing Steel (DDS) ASTM A653M-97 | | | Structural Steel (SS) ASTM A653M-97● | | |
|---|---|---|---|---|---|---|
| | Galvanized Sheet Thickness t(mm) | | | Grade 230 | Grade 255 | Grade 275 |
| | $0.4 \le t \le 1.0$ | $1.0 < t \le 2.0$ | $t > 2$ | | | |
| Z275 | 0 | 0 | 1 | 1.5 | 2 | 2.5 |
| Z600 | 2 | 2 | 2 | 2 | 2 | 2.5 |

● **Note:** Grades 340 and 550 do not have specified requirements for this property

*Table 8. Ratio of the inside bend diameter to the thickness of the specimen.*

## 5.6 PRIMER COATED GALVANIZED STEEL SHEET PRODUCED IN A CONTINUOUS COATING LINE (CHROMAPREP®)

**Coating Process**
CHROMAPREP® is a registered trade name for cold rolled or hot dip galvanized steel sheet, coated with a high quality, flexible and corrosion inhibiting chrome free primer. The substrate is chemically cleaned and treated to ensure good adhesion of the chromate free primer.

The coating has a nominal thickness of 4-6 micrometres applied by a sophisticated continuous roller coating process, permitting control of coating uniformity and film thickness within narrow limits. The primer coat is finally oven cured and is suitable for overcoating with most locally available finishing paint systems. (*Refer to table 9).*

CHROMAPREP® is supplied with a chrome free primer on both sides of the steel sheet. CHROMAPREP® with a cold rolled steel substrate may be used for indoor applications while CHROMAPREP® with a hot dip galvanized substrate can be used for both internal and external applications. However, for external uses it is intended that it is used after application of a final paint coating.

**Typical primer coat properties**

| | |
|---|---|
| Dry film thickness | 4-6 micrometres |
| Heat resistance | Max 120°C |
| Resistance to common water based detergents | Excellent |
| Resistance to mild solvents(1) | Fair |
| Flexibility(2) | 1T |
| UV - resistance(3) | Fair |

*(1) Sensitive to common lacquer thinners, i.e. chlorinated or aromatic hydro-carbons and ketones but resistant to mineral turpentine, solvent naphta, methylated spirits and paraffins.*
*(2) No coating failure or loss of adhesion when bent around a mandrel with a diameter as indicated (T is the thickness of the sheet in mm)*
*(3) As is the case with most chrome free primer coatings, CHROMAPREP® is sensitive to ultra-violet radiation and should not be exposed to direct sunlight for prolonged periods before application of the final coating system. When directly exposed to sun-light (ultra-violet radiation) the final coat must be applied within seven days of being exposed.*

*Table 9.*

**Corrosion resistance**
CHROMAPREP® serves as a good corrosion inhibiting primer coat for subsequent painting. Resistance to corrosion creep is improved by using a galvanized steel substrate, which is strongly recommended for exterior applications.

**Cleaning of primer coat before final painting**
Surfaces should be cleaned by removing surface contaminants by wiping with natural mineral turpentine, solvent naphta or methylated spirits, followed by a warm water detergent wash and a clean water rinse. Users are advised to ensure that thinners or adhesives used, are compatible with CHROMAPREP®. The CHROMAPREP® primer coat is slightly undercured to ensure good bonding of subsequent top coats. The liberal use of strong solvents can and will detach the primer coat, which may lead to premature peeling of the paint.

Common lacquer thinners such as chlorinated hydrocarbons or ketones (MEK) should not be used for cleaning purposes as these may affect the adhesion of the epoxy primer-coat.

**Application of paint coatings**
The required paint finish can be applied by normal spray, airless spray or brushing techniques. Usually an additional primer coat will not be necessary, but for most paints a better bond between the CHROMAPREP® surface and the top coat, as well as a higher quality paint surface, may be obtained by application of a primer or intermediate coat for the selected paint systems.

Amongst current industrial products, the following paint systems can be applied to CHROMAPREP®: alkyds, vinyls, acrylics, polyesters, powdercoatings, stoving enamels, epoxies and poly-urethanes.

## 5.7 PAINTED COLD ROLLED GALVANIZED STEEL SHEET PRODUCED IN A CONTINUOUS COATING LINE (CHROMADEK® OR CHROMADEK® PLUS)

CHROMADEK® is the trade name for this pre-painted galvanized steel sheet. CHROMADEK® is a colour coat comprising a Z200 hot dip galvanized substrate with a 4 to 6 micron DFT primer underneath the top coat and an 8 micron DFT single coat paint on the reverse side.

CHROMADEK® paint is then applied at 20 microns DFT to the top surface *(figure 17)*.

The colour coated products are coated on a sophisticated continuous roller coating line. The modern coating process permits good control of the important painting parameters and rigid quality control on each finished coil ensures that every batch conforms to specification. Excellent paint adhesion is achieved and corrosion resistance enhanced by careful preparation of the steel sheet under factory conditions prior to paint application. The paint systems are oven cured. The aesthetic appearance and durability of CHROMADEK® cannot easily be achieved by conventional hand painted systems.

The coating is highly formable and provides additional protection under conditions where the corrosion resistance of unpainted galvanized sheeting may prove inadequate.

**Corrosion resistance**
CHROMADEK® is intended for exposure to rural, mildly chemically polluted or moderate marine conditions. Best results can be obtained through the correct application, good workmanship and maintenance procedures.

***NOTE: CHROMADEK® is not recommended for application in marine environments (area approximately 5km from the sea) or exposure to industrial environments where there is an accumulation of strong acid vapours. CHROMADEK® PLUS is recommended for these areas between 1 and 5km from the sea.***

CHROMADEK® PLUS is a colour coat comprising a Z275 hot dip galvanized steel substrate, pre-primed on one or both surfaces with 20 - 25 micron DFT chrome free universal primer. Alternatively, only one surface is coated in accordance with the above and the other surface as per the standard CHROMADEK® (4 - 6 micron DFT). CHROMADEK® paint is then applied to both surfaces, both to 20 micron DFT *(figure 17)*.

The Plus system has excellent physical properties, excellent flexibility, excellent corrosion resistance with excellent resistance to ultraviolet radiation (UV performance).

CHROMADEK® PLUS is recommended for exterior building profiles in applications requiring high formability, good gloss retention, high colour stability and excellent corrosion resistance. It is suitable for corrosive environments such as industrial and marine environments. Marine environments can generally be defined as areas within 1km of the sea *(table 10)*.

| PROPERTY | TEST CONDITIONS | METHOD | SPECIFICATION | TYPICAL |
|---|---|---|---|---|
| Resistance to colour change | QUV (1000 hours) | ASTM G154 | | ΔE<5, e.g. Gemsbok Sand |
| Resistance to chalking | QUV (1000 hours) | ASTM G154<br>ASTM D4214 | | Rating Range: 1-2 |
| Resistance to corrosion:<br>- Edge creep<br>- Blister size | Salt spray (1000 hours)<br>After 1000 hours<br>After 1000 hours | ASTM B117<br><br>ASTM D714 | ≤ 3mm<br>≤ 8F | < 2mm<br>< 8F |
| Flexibility: bend test | | ASTM D4145 | 3T.<br>No adhesion loss | 2T.<br>No adhesion loss |
| Flexibility: reverse impact | | ASTM D2794 | No cracks<br>No adhesion loss | No cracks<br>No adhesion loss |
| Film hardness | | ASTM D3363 | F - H | F - H |
| Dry film thickness | | NCCA 4.2.2 | 22µm minimum inclusive of primer | 22µm minimum inclusive of primer |
| Gloss at 60° | At time of coating | ASTM D523 | 25 - 35% | 25 - 35% |

*Table 10. CHROMADEK® paint system properties.*

## 5.8 FASTENING METHODS

Mechanical fastening systems such as rivets, self-tapping screws, bolts and nuts, spring clips and wire staples can be used, as well as various seaming methods including lock- and box seaming.

Where protection is needed, fasteners should, where possible, be:

- hot dip galvanized; or
- manufactured from a corrosion resistant material; or
- electroplated and overcoated with a suitable top coat.

Further information can be found in the latest copy of SANS 1273.

**Cutting, touch-up and maintenance**
Abrasive cutting or trimming of CHROMADEK® sheeting on roof tops should be avoided. Should cutting be necessary, remove all iron particles by vigorous brushing with a broom or bristle brush after cutting, to avoid tarnishing the CHROMADEK® paint surface.

In order to site cut a sheet with clean edges and no paint damage, a sheet nibbler is recommended.

Specially formulated air-drying touch-up paints are available. Care should be exercised to minimise overpainting as this might accentuate the defect. The ultra-violet resistance of air-drying touch-up paints is generally less than the oven-cured CHROMADEK® finishes. Accordingly, touching-up of scratches should be done with a thin paint brush to minimise unnecessary overpainting. If aesthetically acceptable, it is recommended that minor scratches resulting from erection and rough handling be left uncoated as the galvanized substrate will offer adequate sacrificial protection against corrosion.

The life of a CHROMADEK® painted surface can be extended and the appearance maintained by washing down periodically with water and a mild detergent to prevent any build-up of corrosive deposits, especially in marine or industrially polluted environments.

The extent of the damage to CHROMADEK® paint coatings is rather difficult to assess. In cases where the original gloss and colour have been retained, there should be no cause for concern. On proper drying of the moisture contained between closely nestled sheets, no further deterioration will occur. Where discolouration and/or signs of white corrosion products (except cut edges) are evident, such sheets should be substituted with new material.

Certain situations can create unusually aggressive conditions for the exposed, reverse sides of roof sheets. These include coastal locations (and therefore the risk of saline spray and deposits collecting on the exposed reverse sides of overhangs), extremely polluted industrial environments, and very low pitched roofs. In these or similar conditions, extra protection may be necessary. This can be achieved by specifying CHROMADEK® PLUS to both surfaces.

**Compatibility**
Most materials used in contact with traditional galvanized steel can be safely used with CHROMADEK®. Run-off water from Cor-Ten, lead or copper products, however, may cause staining and should not be allowed to come into contact with the painted surface.

**Edge protection**
Generally cut edges on CHROMADEK® sheets do not present a corrosion problem even in coastal areas as the galvanized coating will sacrificially protect the exposed steel. Small traces of white deposits on cut edges should therefore, not be a reason for concern.

## 5.9 THE HANDLING AND PROTECTION OF GALVANIZED AND PREPAINTED STEEL SHEET DURING STORAGE

Galvanized and prepainted galvanized sheet is known to perform exceptionally well when exposed to the elements. Under normal wet-and-dry conditions, e.g. when galvanized sheet is used as roofing and for cladding of buildings, a protective zinc oxide/zinc carbonate layer naturally forms on the exposed surfaces of the material, which improves the resistance against corrosion. In the case of pre-painted sheeting, the protective paint coating offers an additional physical barrier against the elements.

However, the protective nature of these coatings may be seriously impaired when exposed to wet conditions for extended periods in the absence of air. The material is at its most vulnerable during prolonged storage without the necessary precautions.

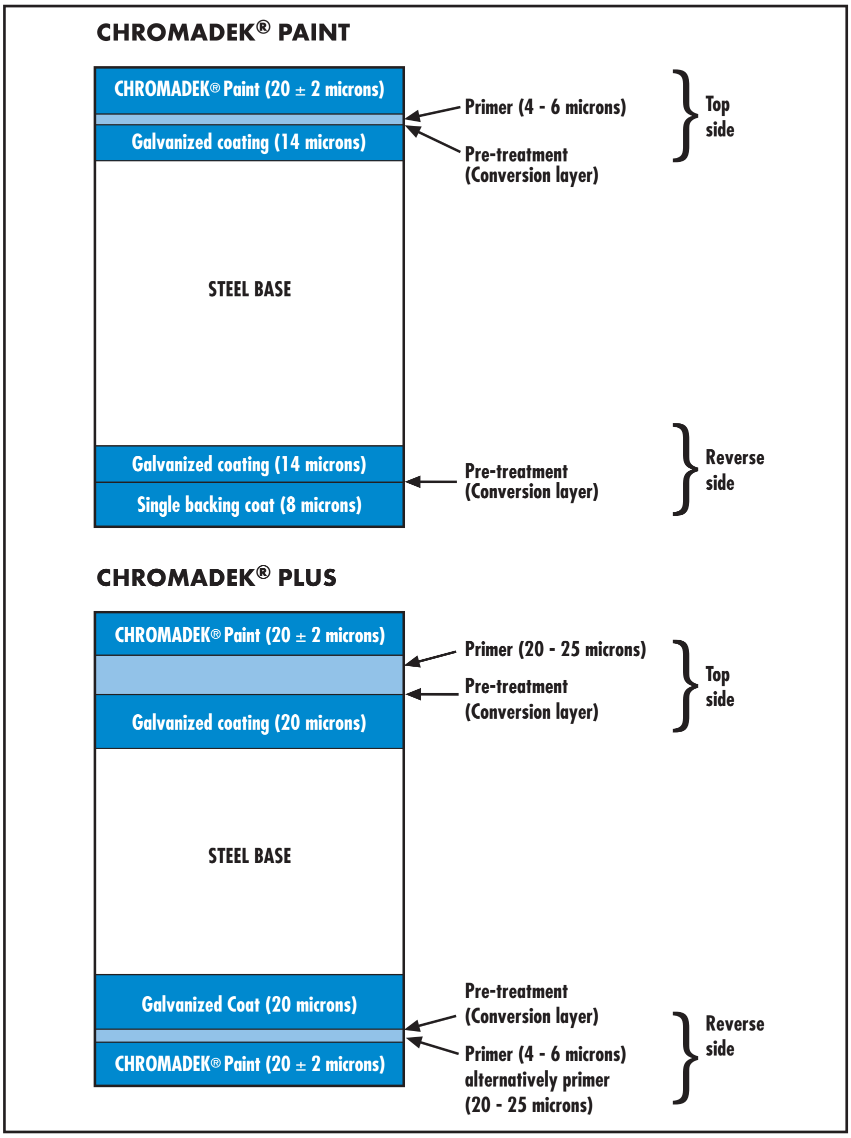



*Figure 17.*

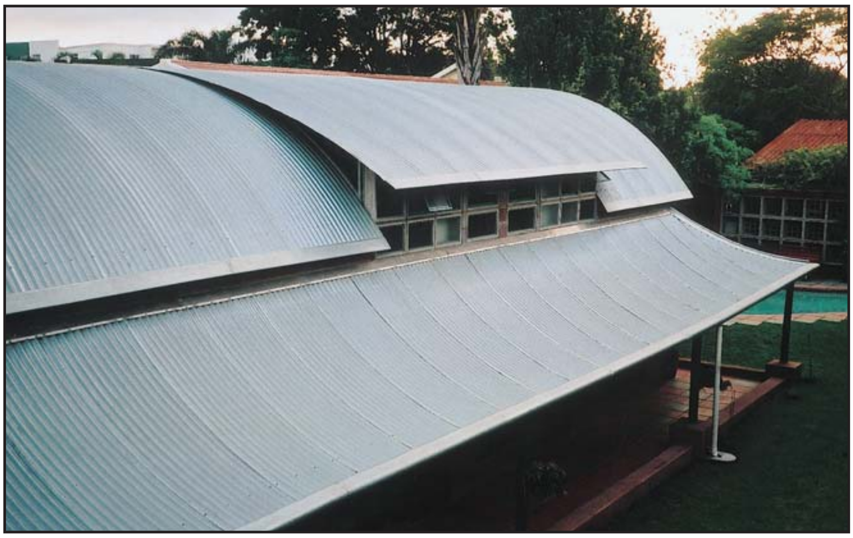


*Figure 18. S-Rib galvanized steel sheeting – Z600 coating classification used for architectural applications.*

Rain water or water vapour can easily be drawn in between tightly nested profiled or flat sheets, or between laps of coils, by capillary action *(figure 19)*.

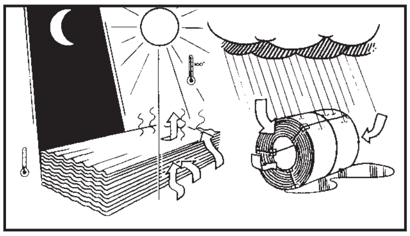


*Figure 19.*

Due to the absence of freely circulating air, this moisture cannot evaporate, causing unfavourable conditions which may result in wet storage stain, often referred to as "white rust" on galvanized sheeting. *See Evaluation of Wet Storage Stain – table 5.* In the case of prepainted sheeting these conditions may cause discolouration of the paint film and in extreme cases wet storage staining, similar to galvanized sheeting.

Wet storage stain may start soon after nested packs or coils of sheet are exposed to wet conditions and may affect the expected maintenance-free life of the sheeting unless arrested at an early stage. The material has to be thoroughly dried and exposed to freely circulating air to stop this corrosion process *(figure 20)*.

**Steps taken to protect galvanized sheet against damage by wet storage stain**

It is standard practice to passivate the surfaces of galvanized sheet by chemical treatment during processing, in order to inhibit the occurrence of wet storage stain. Furthermore, galvanized sheet can be ordered with a special protective oil, which is supplementary to the normal passivation and is intended to provide additional protection during handling and storage.

In spite of these precautions, galvanized sheet cannot be entirely safeguarded against wet storage stain, especially when stored incorrectly under adverse conditions.

A special type of packaging is provided for flat sheets and coils. Users, who do not have the necessary facilities to temporarily prevent the ingress of moisture are advised to specify such protective packaging.

Every endeavour is taken by manufacturers to ensure that coated sheet products leave the works dry and in prime condition. Such products, whether despatched in coils or cut lengths, are packed, handled and loaded, under cover, onto vehicles where they are covered with tarpaulins or canopies.

**Safe storage**

To prevent unnecessary damage to galvanized or colour-coated sheets, proper measures should be taken to prevent contamination by moisture while the material is still bundled or nested in stacks *(figure 20)*.

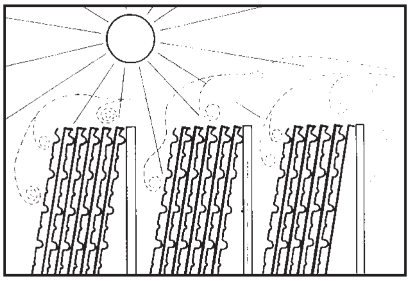


*Figure 20.*

If not required for immediate use, coils or packs of sheets must be stacked on site under properly designed cover, clear off the ground and protected from wind-driven rain *(figure 21)*.

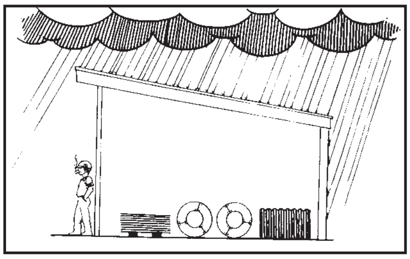


*Figure 21.*

Plastic tarpaulins which completely envelop packs of sheets or coils should not be used, as a sudden drop in ambient temperature may cause condensation of water vapour, which can easily be drawn in between nested sheeting by capillary action.

Ideally, deliveries of galvanized and colour-coated steel sheet to the building site should be scheduled for a storage period of not longer than two weeks prior to installation. Inspect the storage site regularly to ensure that moisture does not penetrate the stock.

**Removal of wet storage stain**

Wet storage stain should rather be prevented than cured.

Although in extreme cases the protective value of the coating may be impaired, wet storage stain attack is often superficial despite the relative bulkiness of the corrosion product. Where surface staining is light and smooth without growth of the zinc oxide layer as judged by lightly rubbing fingertips across the surface, the staining will gradually disappear and blend in with the surrounding zinc surface as a result of normal weathering in service.

When the affected area will not be fully exposed in service or when it will be subjected to a humid environment, wet storage staining must be removed, even if it is superficial. This is essential for the basic zinc carbonate film to form. The formation of this zinc carbonate film is necessary to ensure long term service life.

Light deposits can be removed by cleaning with a stiff bristle (not wire) brush. Heavier deposits can be removed by brushing with a 5% solution of sodium or potassium dichromate with the addition of 0.1% by volume of concentrated sulphuric acid. Alternatively, a 10% solution of acetic acid can be used. These solutions are applied with a stiff brush and left for about 30 seconds before thoroughly rinsing and drying.

***Unless present prior to shipment from the galvanizer, the development of wet storage stain is not the responsibility of the galvanizer. The customer must exercise proper caution during transportation and storage to protect against wet storage staining.***

# Hot Dip Galvanizing of Wire

Hot dip galvanized fencing wire is produced from mild, high tensile or very high tensile steel wire, on a continuous coating line which includes annealing, acid cleaning, fluxing, galvanizing, wiping to remove excess zinc and recoiling of the finished wire.

## 6.1 THE PROCESS

The process is similar in arrangement to the continuous hot dip galvanizing process for the coating of coil.

Zinc coatings on wire are made by passing wire beneath a skid immersed in a zinc bath *(figure 22)*. The skid has multiple contact areas which enable molten zinc and the alloy layers to act as lubricants to ease the passage of the wire.

Between 20 and 40 individual strands pass through the plant in parallel.

An even coating is obtained by wiping the wire after galvanizing and this helps to control the coating thickness. The wires are generally drawn through a bed of charcoal, gas, gravel or nitrogen and for thinner coatings, synthetic fibre is used.

For heavy zinc coatings the interval taken for the wire to pass through the molten zinc is extremely short, thereby limiting the iron/zinc alloy growth. This is essential so that the galvanized wire can readily be bent to make chain-link fencing or even products such as barbed wire. In other aspects, the galvanized coating on wire has properties similar to those of batch hot dip galvanized products.

Once the wire exits the wiping stage, unless specifically excluded on the order, it is passed through a passivation stage. This is usually sodium dichromate, which is necessary to prevent the incidence of wet storage stain on the galvanized wire.

The coating thickness is related to the thickness of steel being processed. The thicker the coating the longer it will last in a given environment.

Two specifications cover wire galvanizing in South Africa. They are **SANS 675** and **SANS 935:2007**, the former specification was amended in 1993 to include only one class of coating. The latter specification includes three classes of which only the class 1 is equivalent in coating thickness to **SANS 675** *(table 11).*

Fencing material failures are not always due to the failure of the zinc coating and frequently occur when wire of unsuitable tensile strength is selected *(table 14)*. Damage to the coating may also arise during erection and result in localised corrosion and rust staining if unsuitable tools are used.

Wire complying with these standards will in time exhibit changes in mechanical properties if it is compared with newly zinc-coated wire. The changes due to strain aging or strain-age hardening generally result in an increase in tensile strength and a decrease in elongation (ductility).

### Adhesion of zinc coating

Test the adhesion of the zinc coating by wrapping a suitable length of wire at least six close turns round a cylindrical mandrel. Choose the ratio of mandrel diameter to wire diameter in accordance with *table 12*.

When tested in accordance with the above, the coating shall remain firmly adhered to the underlying steel wire and shall not crack or flake to such an extent that any flakes of coating can be removed by rubbing with the bare fingers. Loosening or detachment of superficial, small particles of zinc during the test, formed by mechanical polishing of the surface of the zinc-coated wire, shall not be considered cause for rejection. Small particles of zinc, formed as globules on the surface during zinc coating, may loosen or become detached during the test. These shall not be considered cause for rejection either, provided that no bare spots (exposed steel) are present.

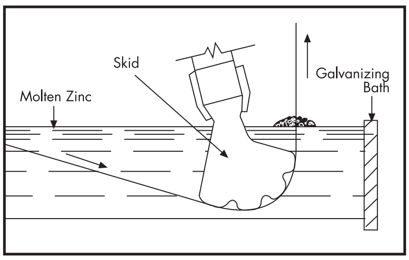



*Figure 22. Section through the plant showing the mounting and positioning of the skid.*

### Diameter of zinc-coated wire

Except in the case of oval wire the cross section of the wire shall be circular. The nominal diameter(s) of the zinc-coated wire shall be in the range given in column 1 of *table 13*, as required. The actual (measured) value(s) of the diameter(s) shall equal the nominal value(s), subject to the appropriate tolerance given in column 2 of *table 13*.

## 6.2 PRACTICAL ASPECTS

### Types of wire

Approximately 50% of the material cost of a fence is in the wire component. Consequently, it is important to select the correct type of wire for a given application, at the most economical cost.

There are two basic types of wire available in South Africa, namely:

1. Soft or plain wire
2. High strain steel wire

These wires differ in that they have different chemical composition and different physical properties and performance in a fence.

### Breaking load

The breaking load is the maximum load that a wire can sustain before breaking. Breaking load is expressed in kN (kilonewton) one kN is equal to a force of 101,793kg.

### Elasticity

A fence wire behaves elastically up to a certain load. It can stretch when a load is applied, then return to it's original length when the load is relaxed.

### Elastic limit

After a certain load has been applied to the wire, the wire will reach a point where it will not return to it's original length. (i.e. it has been stretched)

This load limit is referred to as the yield point or elastic limit. The yield point of any wire can be regarded as approximately 75% of the breaking load.

The amount of elongation produced by the same load will depend on the diameter of the wire. As such, a thinner wire will elongate more than a thicker one and is said to have a higher elasticity.

This also means that a thinner wire will lose less tension than a thicker one.

**Length of strain**
The length of strain has a direct effect on the amount of tension that will be retained in a wire once it is strained. The longer the strain the less tension will be lost. As a guide for fences strained to a similar tension under similar conditions, if one is twice as long as the other, the loss of tension will be halved. Similarly for a fence half the length, the loss of tension will be doubled.

**Effect of temperature on fence wire**
Wire is affected by temperature variations. As the temperature drops, wire will contract, increasing the tension in the wire, and as temperature rises, the wire will expand, decreasing the tension. The change in length is similar for all types and thickness of wire, however, the resultant change in tension depends on the wire's elongation and will therefore differ with wires of different diameters.

It is the increase in tension, due to cold weather, that causes major problems in a fence.

During cold temperatures the fence will contract and this will increase tension in the wire and also on the straining posts. This could result in strainer post movement and when temperatures increase the wires will slacken further.

If these factors are taken into account, then allowance can be made for temperature variations if necessary. As the thinner wires have a higher elongation rate, they will not be effected to the same degree as a thicker wire.

For each 5 degrees C above or below 15 degrees C, subtract or add the following tensions when straining a fence.

4,00mm - 200 Newtons

3,15mm - 100 Newtons

2,50mm - 50 Newtons

**Protective coatings**
All fencing wires are hot dip galvanized. Zinc withstands corrosion better than steel, and in fact corrodes in preference to the steel under natural conditions. This process is known as sacrificial corrosion.

In this process, the zinc corrodes completely before steel corrosion commences; thus the life of the wire can be divided into two separate components, the life of the zinc coating and that of steel.

Corrosion rates vary considerably. Coastal areas can be much more corrosive than inland areas, in turn the atmosphere in industrial areas can be more aggressive than coastal areas.

The service life of the zinc coating is directly proportional to the thickness of the coating, irrespective of the thickness of the wire. *Refer to Chapter 12.*

Most wire galvanizers supply two types of galvanized coatings to prevent corrosion:

- Lightly Galvanized
- Heavy Galvanized

The heavy galvanized wire has more than three times the weight of zinc compared with lightly galvanized products. Therefore, heavy galvanized products will have a much longer life than lightly galvanized products. Heavy galvanized coatings are frequently specified for high strain steel wire, as the wire is finer and there is a smaller mass of steel.

Heavy galvanized coatings should always be specified for areas where corrosion is known to be a problem in abnormally corrosive situations such as marine conditions or in areas where ground salts are prevalent, such as gabions, etc., even heavy galvanized wire may have a relatively short life.

**Expected life span**
The expected life span of galvanized wire is affected by many factors, one of them being coating thickness. *See also Chapter 12.*

**Fire damage to wire**
When comparing the performance of different wires in the field, it is important that circumstances are similar in every respect.

International studies carried out in these conditions indicate that:

- Temperature, tension and wire diameters are the main factors involved.
- Fire temperatures less than 400 degrees C do not affect the performance of any wire.
- Failure in thicker soft wire could be expected to be fewer, because tensions will probably be lower.
- Tension of any wire should not exceed 1.3kN (132kg) in high fire risk areas.
- High strain steel wire, being finer, requires less heat to raise it's temperature to critical levels.

To reduce the risk of fire damage to fences, keep vegetation off the fence and grade or clear tracks along each side of the fence. This also makes fences more accessible for maintenance and checking.

| 1 | 2 | 3 |
|---|---|---|
| Nominal diameter of zinc coated wire mm | Minimum mass per unit area of zinc coating $g/m^2$ | Approximate equivalent average thickness µm |
| 1,20 - 1,50 | 215 | 30 |
| 1,51 - 1,80 | 230 | 32 |
| 1,81 - 2,20 | 245 | 34 |
| 2,21 - 2,50 | 260 | 36 |
| 2,51 - 3,50 | 275 | 38 |
| 3,51 - 5,00 | 290 | 40 |

*Table 11 - Mass per unit area of the zinc coating for SANS 675 and SANS 935 class 1. (Heavy galvanized wire.*

| Dimensions in millimetres | | |
|---|---|---|
| 1 | 2 | 3 |
| Wire diameter *d* | | Mandrel diameter |
| Over | Up to and including | |
| - | 3,8 | 4*d* |
| 3,8 | 5,0 | 5*d* |

*Table 12 - Mandrel diameter.*

| Dimensions in millimetres | |
|---|---|
| 1 | 2 |
| Diameter Range | Tolerance |
| up to 1,80 | ± 0,05 |
| 1,81 - 3,00 | ± 0,08 |
| 3,01 - 5,00 | ± 0,10 |

*Table 13 - Tolerance on diameter.*

| 1 | 2 |
|---|---|
| Grade of Steel | Tensile Strength MPa |
| Mild (M) | 350 - 575 |
| High Tensile (HT) | 1 050 min. |
| Very High Tensile (VHT) | 1 400 min. |

*Table 14 - Tensile strength of galvanized wire.*

# The Reactions Between Iron & Zinc

A hot dip galvanized coating is formed by interaction between iron and molten zinc with the formation of a series of iron/zinc alloys which bond the coating metallurgically to the substrate. These alloys are normally over coated with a layer of relatively pure zinc which displays the silver appearance associated with a hot dip galvanized coating. Although in most instances, suitably cleaned steel dipped into molten zinc will display this silver appearance, there are instances when reactive steels produce coatings that are thicker than normal and aesthetically less appealing. *Figure 23* shows a micrograph of the typical structure of a thick hot dip galvanized coating.

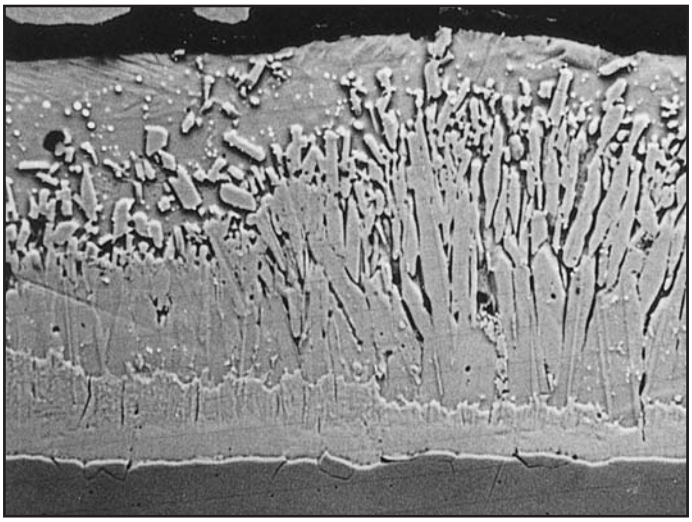



*Figure 23. Cross-section of the zinc layer formed by hot dip galvanizing on a relatively reactive steel. Eta layer with 0.03% Fe; Zeta layer with 5.8 - 6.7% Fe; Delta layer with 7 - 11.5% Fe; Gamma layer with 21 - 28% Fe.*

**Factors which influence the thickness and metallurgical structure of a hot dip galvanized coating**

The factors which determine the overall thickness and metallurgical properties of a hot dip galvanized coating are; *the composition and metallurgy of the steel, zinc temperature, immersion time, alloying additions to the zinc, withdrawal rate of article from the molten zinc, surface condition and thickness of the steel.*

## 7.1 COMPOSITION AND THE METALLURGY OF THE STEEL

High reactivity during galvanizing of carbon steels has been observed for more than half a century. Due to changes in steel making practice and particularly with the introduction of continuous casting, this phenomenon now occurs more frequently. With the continuous casting process, either silicon or aluminium is added to the steel as de-oxidising agents. These steels are respectively known as aluminium-killed and silicon-killed steels. While aluminium additions to steel have no effect on the structure and thickness of a galvanized coating, the same cannot be said for silicon which has for many years been well documented as a major cause of increased alloy layer growth during hot dip galvanizing.

**Aluminium-killed steels**

When aluminium killed steel is immersed in molten zinc, the initial iron/zinc alloy produced is such as to impede growth of further alloy layers. Thinner coatings are therefore produced *(figure 26)*.

When the zinc in the outermost layer solidifies, the surface becomes smooth and takes on a slightly bluish metallic lustre. In some cases, especially that of thin sheet, the zinc can solidify in the form of randomly pointed crystals, which give the surface a distinct "spangle" finish.

The spangle finish, is just a particular form of crystal formation, which depends on factors such as the solidification rate. It gives no indication of good or bad quality hot dip galvanizing. Further, the spangle finish is of no significance to the corrosion resistance of the zinc coating.

In continuous hot dip galvanizing of sheet, the size of the spangle can be controlled *(Chapter 5)*. This is not possible in general hot dip galvanizing.

**Silicon-killed steels**

The constituent of steel, which has the most powerful influence on the reaction between iron and zinc is silicon (Si). In the making of steel, silicon is

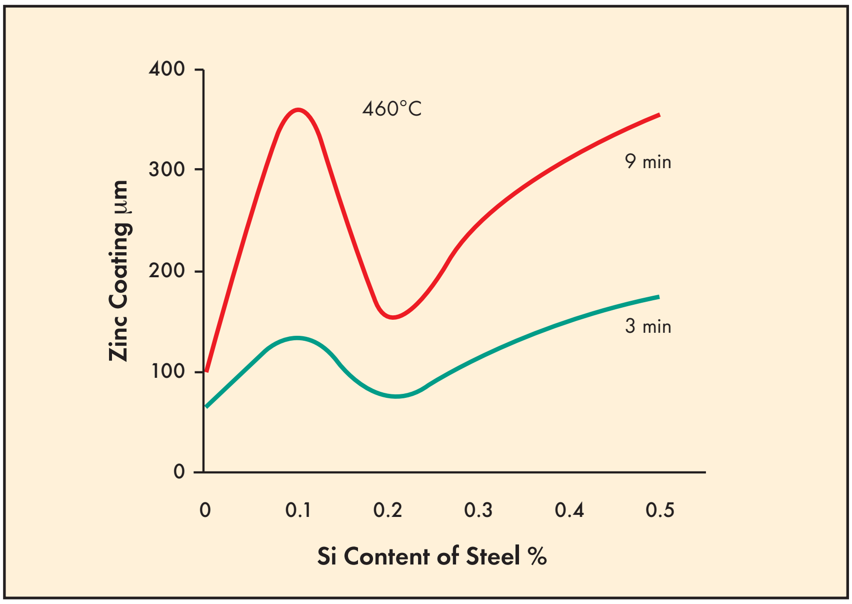



*Figure 24. Relationship between silicon content of steel and thickness of zinc coating for a dipping time of 3 and 9 minutes at 460°C. The curve is an average curve. Significant variations can occur between steels with the same Si content, but from different charges. The high reactivity is between 0.05 and 0.15% Si. This called the Sandelin Effect.*

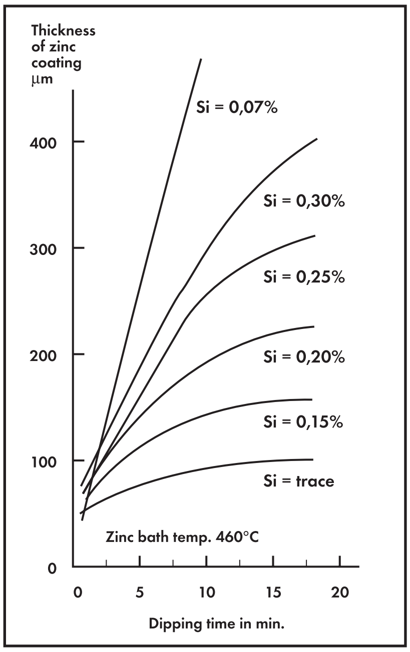



*Figure 25. Relationship between dipping time and thickness of zinc coating in steels with different silicon contents. The curves are average curves, based on experiments and practical experience. Significant variations can occur between steels with the same silicon contents, but from different charges.*

added during the process to remove oxygen.

Silicon influences the reaction between zinc and iron in such a way that the crystals in the outermost alloy layer (the zeta phase) are formed either as small grains *(figure 27)* or as long stem-like crystals *(figure 28)*.

Zinc from the bath is able to penetrate nearly all the way down to the steel surface. The reaction is not retarded, but remains rapid throughout the period during which the object is immersed in the zinc. The thickness of the coating therefore increases considerably with increased immersion time *(see Relationship between dipping time and thickness of zinc coating in steels with different silicon contents – figure 25)* and the coating generally becomes relatively thick.

It should be noted that the structure of the alloy layer described above does not mean that the coating will be "porous", or full of cavities. The space between the alloy crystals is always filled with pure zinc. With silicon-killed steels, therefore, the same compact metallic coating is obtained throughout as with aluminium-killed steels.

However, the influence of silicon does not increase linearly with increasing concentration, but follows the curves shown in *figure 24* which gives only typical values.

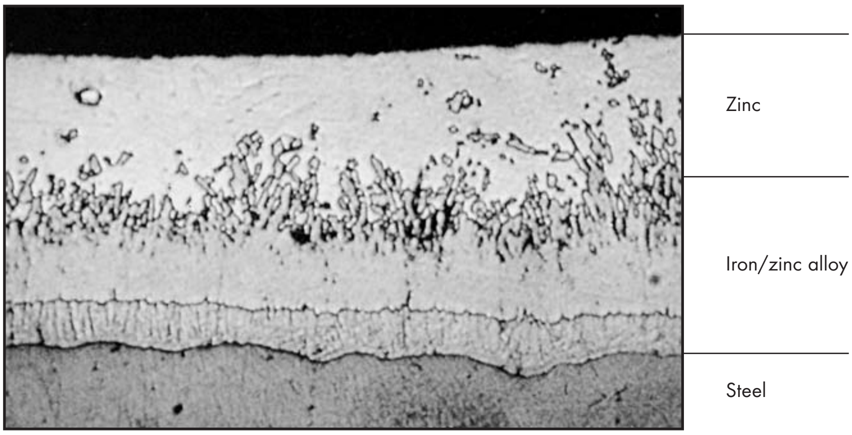



*Figure 26. Cross-section through zinc coating on aluminium-killed steel.*

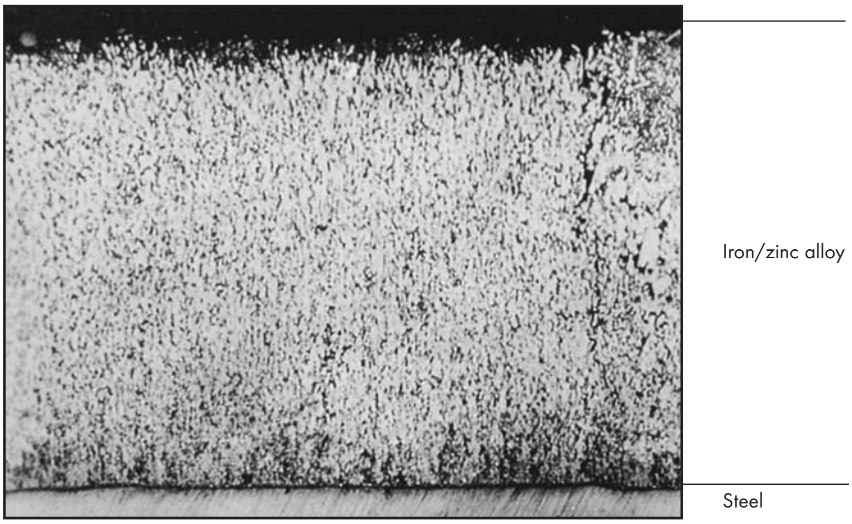



*Figure 27. Cross-section through zinc coating on silicon-killed steel with 0.06% Si. Hot dip galvanizing carried out at 460°C.*

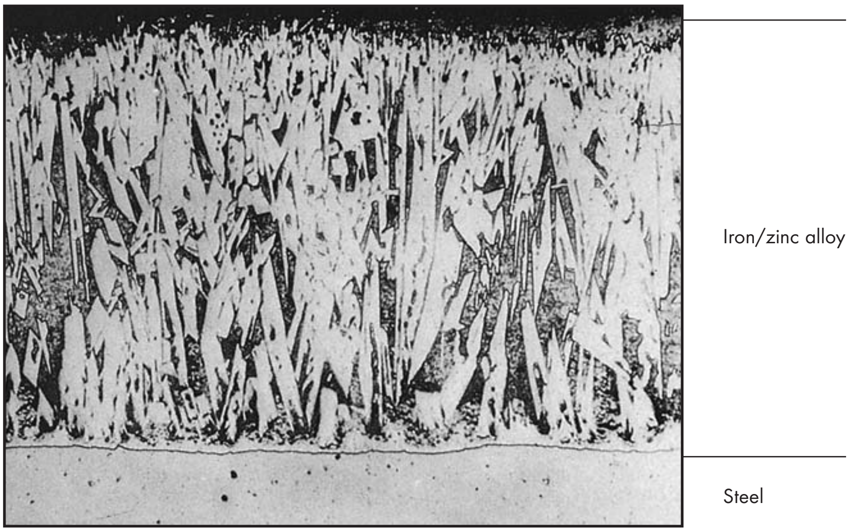



*Figure 28. Cross-section of a coating on a silicon-killed steel with 0.26% Si. Hot dip galvanizing carried out at 460°C.*

The Sandelin curve has been misinterpreted by some to indicate that high reactivity in galvanizing results from the presence of silicon alone with a reactive peak between 0.05 - 0.15% Si.

More recently, the important role played by phosphorus has been recognised either in combination with silicon or alone. It has been said that the influence of phosphorus as an accelerator, is of equal importance to silicon in the iron zinc reaction.

It would seem that phosphorus suppresses delta layer formation but

| CLASSIFICATION | SILICON CONTENT (mass %) | PHOSPHORUS CONTENT (mass %) | STEEL REACTIVITY | COATING APPEARANCE |
|---|---|---|---|---|
| 1 *(figure 36)* | 0 – 0.035 | 0 – 0.025 | Generally normal but occasionally low | Few defects. Occasional thin coatings that are below specification. |
| 2 *(figures 37 and 38)* | 0 – 0.04 | 0.025 – 0.035 | Generally normal. | Localised defects due to outbursts of zeta alloy. (eg 'pimples' or 'tree bark' effect, particularly on tubular and curved sections) |
| 3 *(figure 39)* | 0 – 0.04 | >0.035 | High, especially with high phosphorus content | Pronounced surface defects high tendency to flake |
| 4a (low phosphorus) *(figure 40)* | 0.04 – 0.135 | <0.01 | Moderate, increasing with silicon content | May appear normal with few defects |
| 4b (high phosphorus) *(figure 41)* | 0.04 – 0.135 | 0.01 to 0,03 | High | Generally few defects |
| 5a (low phosphorus) | 0.135 – 0.35 | <0.03 | High, but generally thinner coatings than on class 5b | May appear normal with few defects |
| 5b (high phosphorus) | 0.135 – 0.35 | >0.03 | High | Tendency to flake, especially with high phosphorus content |
| 6 *(figure 42)* | >0.35 | >0 | High, and increasing with silicon content | Tendency to flake, increasing with phosphorus content |

*Table 15. Reactivity classification for steels. Coating appearance can be misleading. When specifying steel for specific applications eg. architectural features, the information under the heading "Steel Reactivity" must be taken into consideration, ie. high reactivity may be regarded as aesthetically less acceptable.*

encourages zeta phase growth while the gamma layer becomes discontinuous. This observation is confirmed by practical studies, which have shown that an excessively thick and brittle coating caused by a high phosphorus content in the steel (>0.02%), is prone to delamination in its entirety from the steel substrate. In contrast, coatings which are prone to flaking, due mainly to reactive silicon content of steel, are partially detached in the vicinity of the zeta/delta interface with the result that the steel substrate is not exposed. The remaining adherent coating can vary in thickness from about 15µm to as much as 40µm.

Upon withdrawal of the article from the zinc bath, a layer of zinc adheres to the alloy layer, even on silicon-killed steels. However, the reaction speed in these steels can be so high that the pure zinc layer is transformed completely to iron/zinc alloys before the hot article has had time to cool down. The reaction does not cease until the temperature of the article has dropped below 300°C.

***It is for this reason that galvanizers who are processing thick reactive steel, can to a degree, avoid the possibility of a total iron/zinc alloy coating forming, by immediate water quenching. It must, however, be borne in mind that immediate quenching can increase distortion in articles that have a propensity for that condition.***

The iron/zinc alloy formation can therefore extend to the surface of the coating, which would then be matt, rough and light to dark grey in colour. The colour is determined by the proportion of iron/zinc crystals that are mixed with pure zinc on the outer surface of the coating - the more pure zinc, the lighter the surface; the higher the iron/zinc content, the darker the surface.

Welding of non-reactive steel to reactive steel, can result in two different coating thicknesses, when the article is hot dip galvanized *(figure 29)*. For coating uniformity, both in appearance and in coating thickness and hence corrosion resistance, similar steels should be selected for the same fabrication.

**Weathered hot dip galvanized coatings**

Where iron/zinc alloy crystals are exposed, the outer surface of the coating sometimes shows signs of rust staining after a few years in service. This is not necessarily an indication that the coating has corroded away. Invariably adequate protection of the underlying steel exists, *(see figures 30 and 31, Reddish-Brown Discoloration)*.

Often a hot dip galvanized surface is not uniformly grey, but has a blotchy appearance with a mixture of matt grey and shiny areas. The reasons for this can be many - the concentration of silicon (primarily), phosphorous and sulphur or other elements in the steel surface; stresses in the steel surface; the heat treatment and structure of the steel - all such factors influence the sequence of reactions. Even the cooling process of the steel after galvanizing influences its appearance.

Zeta crystals have a tendency to grow out at right angles from the steel surface. On flat and convex surfaces, therefore, the crystals grow without disturbing each other. The molten metal is able to penetrate between the crystals and promote growth. On concave surfaces, dips and depressions, however, the crystals block each other and inhibit growth.

It is important to emphasise that continuous sheet and wire processes differ radically from the general galvanizing process, particularly with respect to immersion time. Immersion time plays a significant role in determining the ultimate structure and thickness of the coating.

Arising from research carried out by the International Lead Zinc Research Organisation (ILZRO), reactivity classifications shown in *table 15* have been established. The classes in the table demonstrate the separate and combined influences of both silicon and phosphorus in the mechanism by which a hot dip galvanized coating is formed. Six classes have been identified. The conclusions reached are based on varying immersion times at a zinc temperature of 455°C.

**Class 1.** This class is the recommended steel for hot dip galvanizing when aesthetic appearance is important, eg. Architectural applications and highly visible structures such as lighting masts and street furniture. These steels are also the most suitable for structures, which of necessity, require long immersion periods in the zinc *(figure 36)*.

**Class 2.** This class will provide coatings with a reasonable appearance provided the immersion periods are not extended. The class may show frequent local outbursts of reactive coating - either pimples, striation or tree bark effect, giving localised coating thickness up to 500µm thick. Tubular or curved sections show these effects at lower Si and P contents *(figures 37 and 38)*.

**Class 3.** This class will provide thick and rough coatings with little or no eta (pure zinc) layer. Poor adhesion will result when extended immersion times pertain. Frequent surface defects; poor appearance and easily damaged. At phosphorus levels greater than 0,02%, an acceptable coating is not possible to achieve at normal immersion times *(figure 39)*.

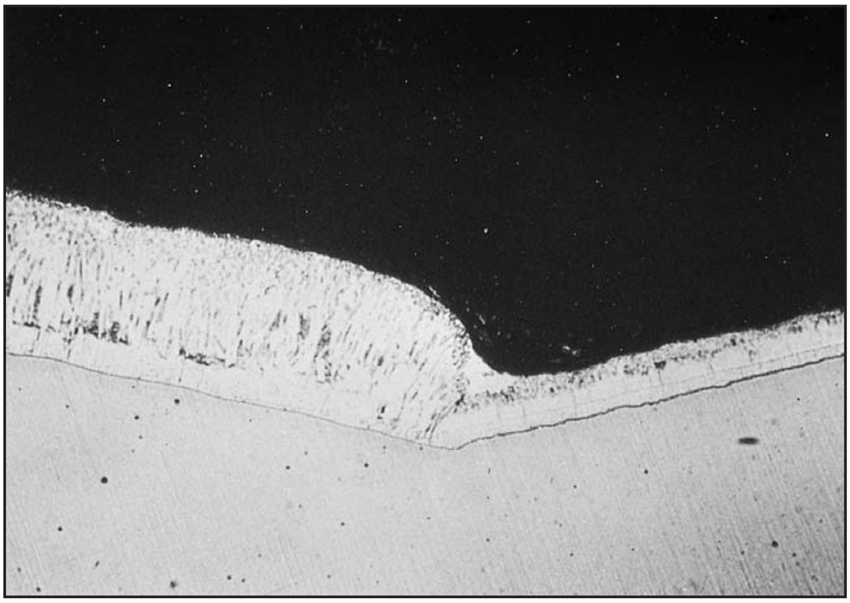


*Figure 29. Micrograph showing the hot dip galvanized coating thickness of two different steels welded together.*



*Figures 30 and 31. The galvanized coating is sometimes not uniformly grey but has a blotchy appearance with a mixture of matt, grey and shiny areas. Signs of red rust staining after several years in service is not necessarily an indication that the coating has corroded away.*

**Classes 4a, 4b and 5a.** These classes are suitable for heavy-duty coatings (coating thickness greater than 105µm). Coatings in these classes may develop a tendency to be brittle and flake when damaged, if steel contact with the molten zinc exceeds about five minutes *(figures 40 and 41)*.

**Classes 5b and 6.** These classes are not recommended for hot dip galvanizing except where immersion periods can be kept down to two or three minutes. This is frequently not practical in a production line *(figure 42)*.

Some other conclusions reached from this research which dispel previous misconceptions are as follows:

- Silicon and phosphorus contents are jointly the most important factors in influencing high reactivity in hot dip galvanizing.
- Other elements in commercial grade steels have a lesser influence on the formation of a hot dip galvanized coating.
- The bulk analysis of steel can be used reliably to predict the type and thickness of a hot dip galvanized coating.
- There is no evidence that high reactivity is caused by segregation of elements at the steel surface.
- Neither prolonged pickling, stripping and regalvanizing or abrasive blast cleaning will alter coating structure but these factors may increase coating thickness.

## 7.2 ZINC TEMPERATURE

The reaction between iron and molten zinc is influenced by zinc temperature. Iron is dissolved by diffusion and this results in the growth of alloy layers on the steel surface. The formation of the alloys creates a barrier between the zinc and iron and this has the effect of retarding the diffusion rate.

With increasing temperature up to about 485°C, diffusion accelerates slowly, causing a slow but constant increase in coating thickness, following a parabolic time law. Above 485°C and up to about 530°C, coating growth is more or less linear with time (regardless of steel composition) after which the reaction reverts to a parabolic time law *(figure 32)*.

At a zinc temperature in the vicinity of 510°C, the reaction between liquid zinc and steel is so severe that a steel galvanizing bath manufactured from 50mm thick plate will perforate within the space of about sixty days. The normal life of a bath at temperatures below 460°C is six or seven years.

Normal galvanizing is carried out at temperatures below 460°C. Hot dip galvanizing at temperatures in excess of 470°C is not recommended.

At the normal galvanizing temperature range (440°C to 460°C), a reduction in alloy layer growth can be achieved for a given immersion time by galvanizing at the lowest possible temperature when reactive steels are encountered. *Figure 33* illustrates the effect of temperature on coating thickness in relation to the Sandelin reactivity curve. Galvanizing at temperatures below about 438°C is not practical since this is too close to the melting point of zinc (419.5°C).

## 7.3 IMMERSION TIME

The degree to which immersion time influences coating growth at normal galvanizing temperatures, is determined by steel composition. At higher temperatures (>485°C) all steels react more or less in a similar manner. In the case of aluminium killed steels with low Silicon and Phosphorus contents, extended periods of immersion at normal galvanizing temperatures result in only a slight increase in ultimate coating thickness, eg. If a coating thickness of 85µm is achieved at a given zinc temperature in 5 minutes, doubling immersion time to 10 minutes is

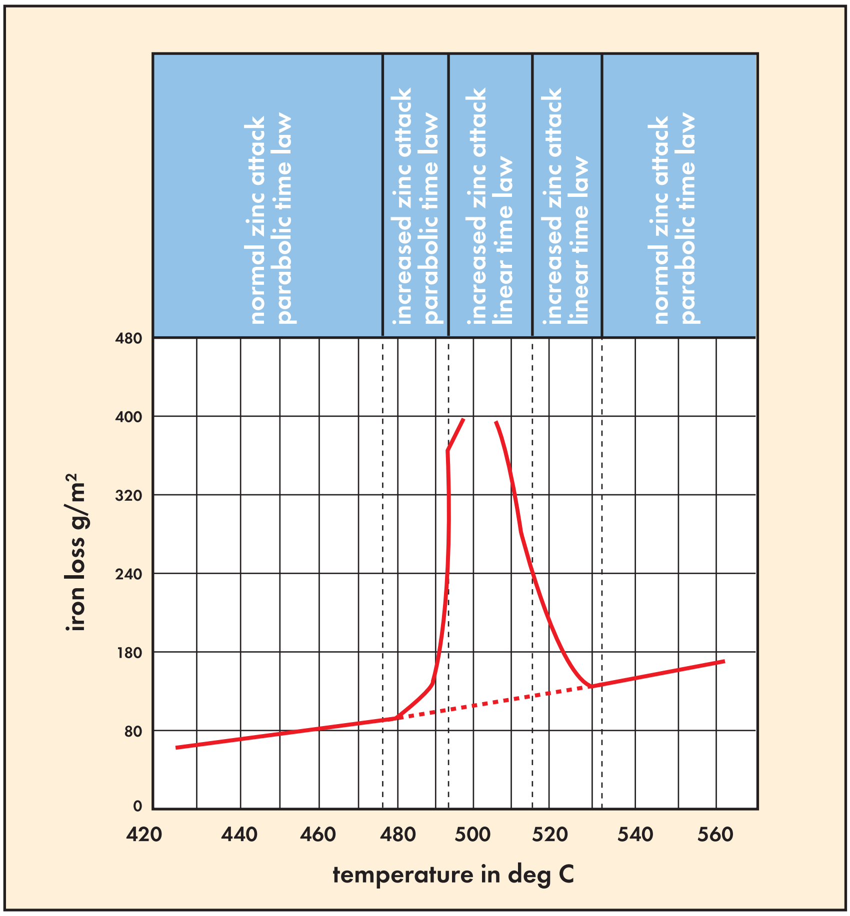



*Figure 32. The influence of temperature on diffusion of iron in molten zinc.*

unlikely to increase the coating thickness by more than about 10μm. In contrast, with steels prone to high reactivity galvanizing (reactive levels of Si and/or P), the ultimate coating thickness can well increase by 50 to 100% over similar dipping periods.

When feasible, reducing immersion time remains the most practical method available to galvanizers for avoiding excessive coating growth. The main difficulty arises with structures where the configuration necessitates manipulation while under the molten zinc, particularly in the case of tubular components where zinc is required to penetrate and coat internal surfaces and then be allowed to drain out of the product on withdrawal. It is recommended that optimum sized fill and drainage holes be used when fabricating a tubular structure. Failure to comply with this requirement frequently renders extended immersion periods to be unavoidable.

## 7.4 ALLOYING ADDITIONS TO THE MOLTEN ZINC

**Aluminium**
The presence of aluminium in the molten zinc retards the initial formation of Fe/Zn alloys, even at low concentrations (0.007%). When extended immersion cycles are unavoidable, the influence of aluminium on coating growth is not effective, although it may improve surface appearance.

Aluminium additives have impacted positively in the galvanizing of continuous strip. Thin sheet with aluminium alloyed coatings have been commercially available under various trade names for a number of years. They contain different levels of aluminium and other additives. Similar coatings applied by the general galvanizing process, require special fluxing agents and have to date had limited success.

**Nickel**
Additions of 0.06% nickel can retard excessive alloy formation but nickel is only a partial solution. While it controls coating structure and thickness for steels containing less than 0.2% Si, it fails to control alloy growth for steels with a higher silicon content *(figure 34)*. The nickel-zinc concept can also result in thicknesses below the specified minimum in the case of coatings applied to less reactive steels.

It would seem that nickel does not retard the zinc iron reaction but rather that alloy is released into the molten zinc as it forms. This results in an increase in dross formation in the galvanizing bath.

**Vanadium and titanium**
Recent research has shown that additions of vanadium and titanium to the molten zinc in the galvanizing bath can overcome the problem of reactive steel galvanizing. The coatings produced consist of uniform layered microstructures similar to those found in coatings on non-reactive steels.

Negative aspects of this development are an increase of approximately 25% in metal cost (which could be offset to a degree by lower overall zinc consumption) and a substantial increase in oxide formation on the surface of the molten zinc in the galvanizing bath.

## 7.5 THE WITHDRAWAL RATE OF THE ARTICLE FROM THE MOLTEN ZINC

The principle of good galvanizing is rapid immersion and slow withdrawal. For instance, if an article is withdrawn at 3,0m/minute as opposed to 1,0m/minute the resultant coating thickness will be greater by about 30%, as molten zinc is dragged out of the bath.

## 7.6 SURFACE CONDITION

Varying surface roughness of the steel leads to variations in thickness of the coating. The rougher the surface of the steel, the thicker the coating. Depending on the type of steel and the surface profile, preparation treatment such as abrasive blasting can result in a 15 to 25% thicker coating. Steel that has been severely attacked by rust, or pickled without inhibitors, also results in increased coating thickness.

## 7.7 THICKNESS OF THE STEEL

The thickness of the steel influences the coating thickness - the thinner the steel, the thinner the coating. This applies especially to silicon-killed steels. One reason for this is that articles fabricated from thinner steels, generally require shorter immersion times. It is for this reason that when reactive thinner steels are welded to non-reactive thicker steels, inordinately thicker coatings may result on the thinner steel. This thicker coating may be aesthetically less acceptable and prone to brittleness and therefore potential damage, particularly on edges. Working, rolling and heat treatment of the steel can vary, leading to different reactions in the zinc bath.

The composition of the zinc bath cannot be varied in ordinary hot dip galva-

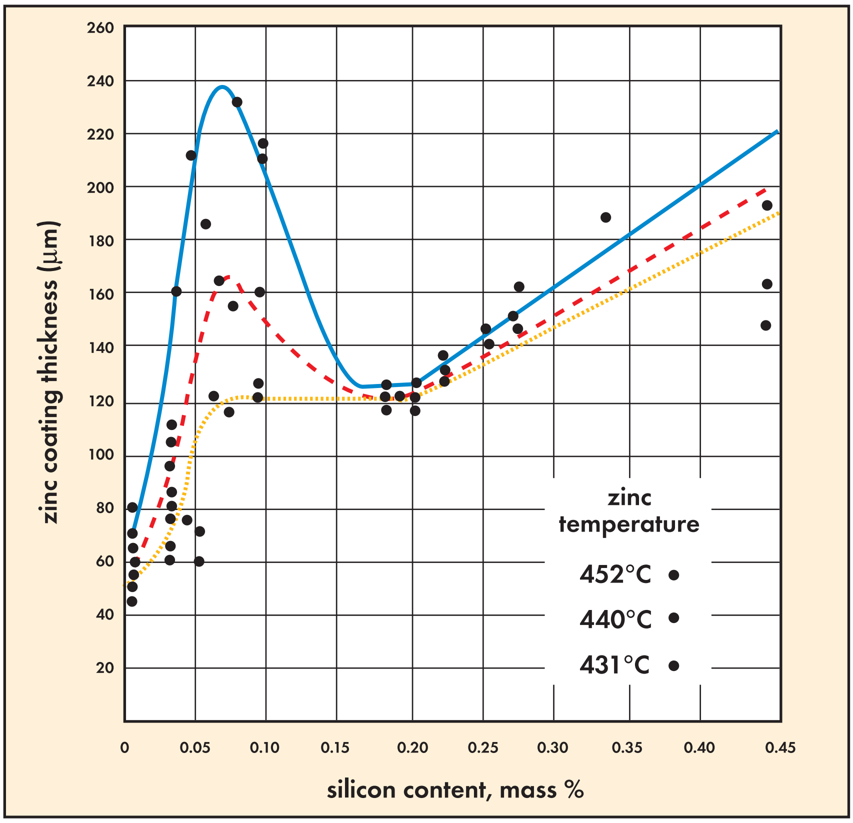



*Figure 33. Bath temperature effect on the Traditional Sandelin Curve.*

nizing. Zinc used for hot dip galvanizing usually contains a minimum of 98,5% zinc. Zn2 with a purity of 99,95% is also often used. When high purity zinc is used, a little lead (max 1%) and aluminium (max 0,007%) is added to the bath for technical reasons. *Refer to **SANS 20** and **ISO 752.***

**Of all the precautions that a galvanizer can implement to avoid excessive alloy layer growth on high reactivity steels, the shortest possible exposure to the liquid zinc, coupled with a low zinc temperature (440°C), are the most effective.**

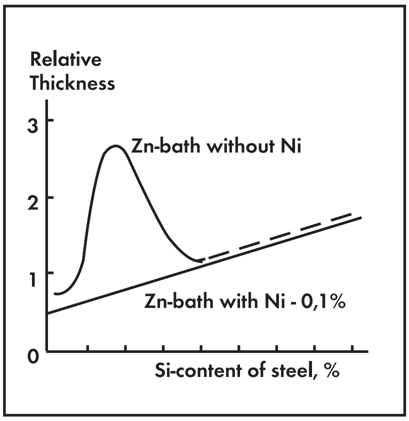



*Figure 34. Relationship between the silicon content of steel and thickness of zinc coating when hot dip galvanizing in alloyed zinc (0.1% Ni) (Traditional Sandelin Curve).*

## 7.8 THE IRON / ZINC REACTION IN CONTINUOUS GALVANIZING

In continuous hot dip galvanizing of sheet, the stock material consists of cold-rolled steel strip of a composition suited to the process. The immersion time is very short, and the temperature is kept within narrow limits. The zinc bath is alloyed with a small amount of aluminium (approx. 0.2%), which has the effect of retarding the iron/zinc reaction at short immersion times. The alloy layer will be thin, approx. 1 - 2µm, with the remainder of the coating consisting of pure zinc *(figure 35).*

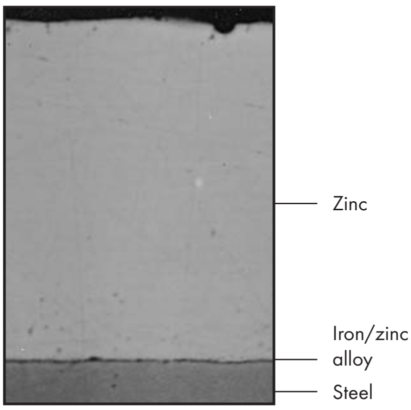



*Figure 35. Micrograph showing zinc coating on continuously coated sheet.*

The iron/zinc alloys are relatively hard and brittle. However, since they have to a large extent been replaced by soft zinc, continuously hot dip galvanized sheet can be bent, curved, folded, press-formed and even deep-drawn without the coating cracking or flaking.

Thin sheet can even be coated with aluminium-alloyed zinc, which gives somewhat better protection against corrosion in severe environments. Some common brand names include Galfan (5% aluminium), and Aluzink, Galvalume or Zincalume (55% aluminium).

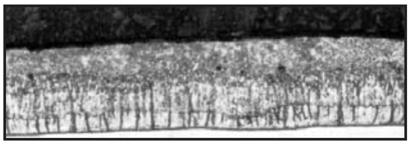


*Figure 36. Reactivity classification 1.*

*Figure 37. Reactivity classification 2.*

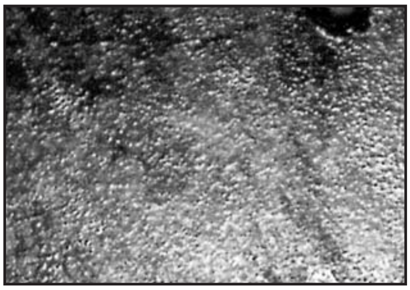


*Figure 38. Surface appearance of a steel showing the outbursts illustrated in figure 37.*

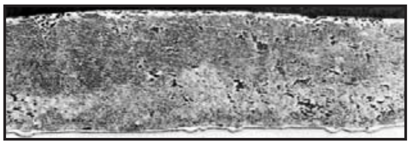


*Figure 39. Reactivity classification 3.*

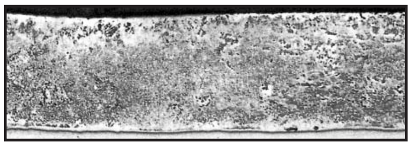


*Figure 40. Reactivity classification 4a.*

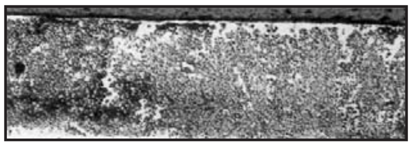


*Figure 41. Reactivity classification 4b.*

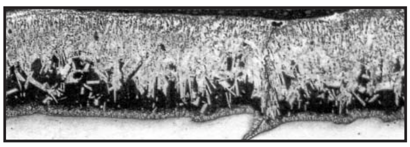


*Figure 42. Reactivity classification 6.*

# Mechanical Properties of Hot Dip Galvanized Steels

The hot dip galvanizing process has no effect on the mechanical properties of structural steel.

## 8.1 STRENGTH AND DUCTILITY

The published BNF report 'Galvanizing of structural steels and their weldments' ILZRO, 1975, concludes that ***'...the galvanizing process has no effect on the tensile, bend or impact properties of any of the structural steels investigated when these are hot dip galvanized in the "as manufactured" condition. Nor do even the highest strength versions exhibit hydrogen embrittlement following a typical pretreatment in inhibited HCl or $H_2SO_4$.'***

Changes in mechanical properties attributable to the hot dip galvanizing process were detected only when the steel had been cold worked prior to galvanizing but then only certain properties were affected. Thus the tensile strength, proof strength and tensile elongation of cold rolled steel was unaffected, except that the tensile elongation of 40% cold rolled steel tended to be increased by hot dip galvanizing. 1T bends in many of the steels were embrittled by galvanizing, but galvanized 2T and 3T bends in all steels could be completely straightened without cracking.

## 8.2 EMBRITTLEMENT

For steel to be in an embrittled condition after hot dip galvanizing is rare. The occurrence of embrittlement depends on a combination of factors. Under certain conditions, some steels can lose their ductile properties and become embrittled. Several types of embrittlement may occur but of these only strain-age embrittlement is aggravated by hot dip galvanizing and similar processes. The following information is given as guidance in critical applications.

***Critical applications.***
It is better to avoid cold work such as punching, shearing and bending of structural steels over 6mm thick when the item will be galvanized and subsequently subjected to critical tensile stress. If cold working cannot be avoided a practical embrittlement test in accordance with **ASTM A143** should be carried out.

Where the consequences of failure are severe and cold work cannot be avoided, stress relieve at a minimum temperature of 650°C before hot dip galvanizing.

Ideally, in critical applications structural steel should be hot worked above 650°C in accordance with the steelmaker's recommendations.

***Susceptibility to strain-age embrittlement***
Strain-age embrittlement is caused by cold working of certain steels, mainly low carbon, followed by ageing at temperatures less than 600°C, or by warm working steels below 600°C.

All structural steels may become embrittled to some extent. The extent of embrittlement depends on the amount of strain, time at ageing temperature and steel composition, particularly nitrogen content. Elements that are known to tie up nitrogen in the form of nitrides are useful in limiting the effects of strain ageing. These elements include aluminium, vanadium, titanium, niobium, and boron.

***Cold working***
Cold working such as punching of holes, shearing and bending before galvanizing may lead to embrittlement of susceptible steels. Steels in thicknesses less than 3mm are unlikely to be significantly affected.

***Hydrogen embrittlement***
Hydrogen can be absorbed into steel during acid pickling but is expelled rapidly at galvanizing temperatures and is not a problem with components free from internal stresses. Certain steels which have been cold worked and/or stressed during pickling can be affected by hydrogen embrittlement to the extent that cracking may occur before galvanizing (see *also chapter 13, point 13.8).*

***The galvanizing process***
The galvanizing process involves immersion in a bath of molten zinc at about 450°C. The heat treatment effect of galvanizing can accelerate the onset of strain-age embrittlement in susceptible steels which have been cold worked. No other aspect of the galvanizing process is significant.

***Recommendations to minimise embrittlement***
Where possible, use a steel with low susceptibility to strain-age embrittlement. Where cold working is necessary limitations of punching, shearing and flame cutting, bending, edge distances and critical applications must be observed. *Refer to Chapter 9.*

## 8.3 FATIGUE STRENGTH

Research and practical experience shows that the fatigue strength of the steels most commonly galvanized is not significantly affected by galvanizing. The fatigue strength of certain steels, particularly silicon-killed steels may be reduced, but any reduction is small when compared with the reductions which can occur from pitting corrosion attack on ungalvanized steels and with the effects of welds.

For practical purposes, where design life is based on the fatigue strength of welds, the effects of galvanizing can be ignored.

Fatigue strength is reduced by the presence of notches and weld beads, regardless of the effects of processes involving a heating cycle such as galvanizing. Rapid cooling of hot work may induce microcracking, particularly in weld zones, producing a notch effect with consequent reductions in fatigue strength.

In critical applications, specifications for the galvanizing of welded steel fabrications should call for air cooling rather than water quenching after galvanizing to avoid the possibility of microcracking and reductions in fatigue strength.

# Design for Hot Dip Galvanizing

**(For convenience purposes the content of this chapter is also available on a wall chart)**

## 9.1 INTRODUCTION

When designing a structure which is to be hot dip galvanized, it must be borne in mind that articles are immersed into and withdrawn from a bath of molten zinc heated to a temperature of 450°C. Design and fabrication is required to conform to acceptable standards which apply, regardless of whether a galvanized or a painted coating is to be applied. In the case of hot dip galvanizing, some additional requirements which aid access and drainage of molten zinc, will improve the quality of the coating and also reduce costs.

With certain fabrications, holes which are present for other purposes may fulfil the requirements of venting of air and draining of zinc; in other cases it may be necessary to provide extra holes for this purpose.

For complete protection, molten zinc must be able to flow freely to all parts of the surfaces of a fabrication. With hollow sections or where there are internal compartments, the galvanizing of the internal surfaces eliminates any danger of hidden corrosion occurring in service.

In addition to using the correct specifications in terms of coating requirements, the steel chemistry should be of a quality suitable for galvanizing *(Chapter 7)*.

**Some general principles for guidance are:**

- Holes both for venting and draining should be as large as possible. The absolute minimum hole sizes are given in *table 16*.
- Holes for venting and draining should be diagonally opposite one another at the high point and low point of the fabrication as it is suspended for galvanizing *(figure 43)*.
- With hollow sections sealed at the ends, holes should be provided, again diagonally opposite one another, as near as possible to the ends of the hollow member *(figure 44 and photos 1 & 2)*. In some cases it may be more economical to provide "V" or "U" shaped notches *(figure 45)* in the ends of the tubes, or to grind corners off rectangular hollow sections. These procedures will provide ideal means for venting and draining.
- Where holes are provided in end plates or capping pieces, they should be placed diagonally opposite to one another, off centre and as near as possible to the wall of the member to which the end plate is connected *(figure 46)*.
- Internal and external stiffeners, baffles, diaphragms, gussets etc., should have the corners cropped and angle bracings should if possible be stopped short of the main boom flange to aid the flow of

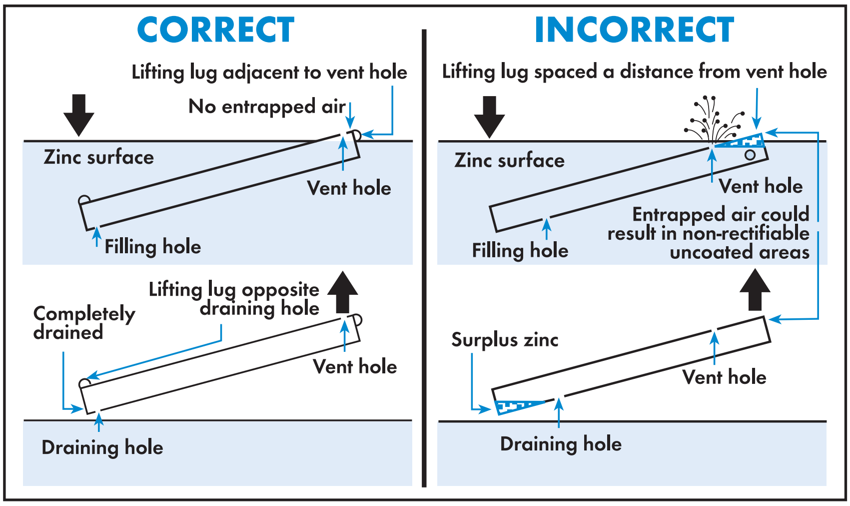



*Figure 43.*

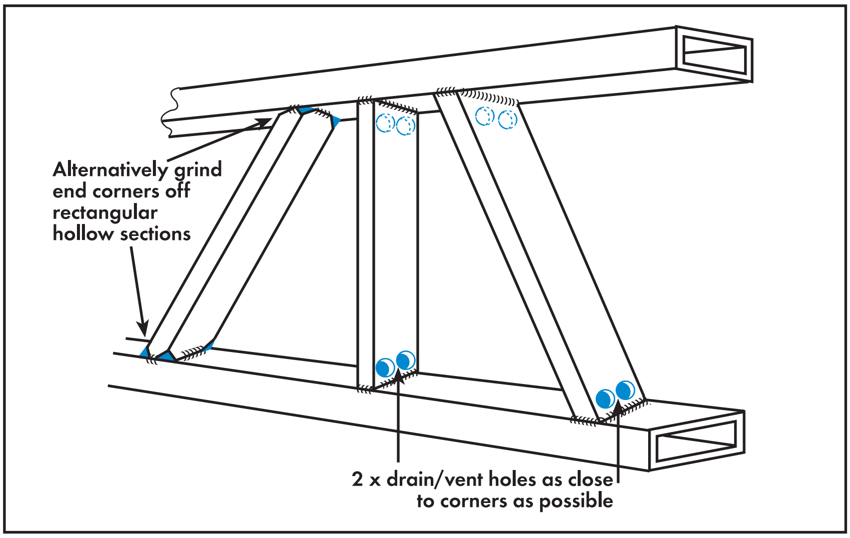



*Figure 44.*

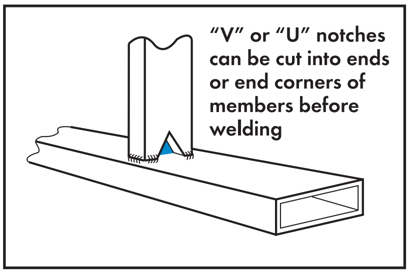



*Figure 45.*

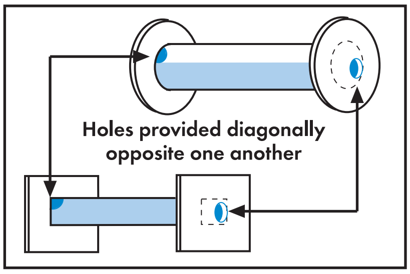



*Figure 46.*

| GUIDELINES FOR MINIMUM VENT FILL AND DRAINAGE HOLE SIZES - REQUIRED BY SECTION LENGTH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Tube Dia | ″ 50 | 60 - 76 | 89 | 102 - 114 | 127 - 152 | 165 | 219 | 245 | 273 | 324 | 355 |
| RHS Sizes (mm) | 50 x 30 | 80 x 40 | 80 x 80 | 90 x 90 | 160 x 80 | 200 x 100 | 180 x 180 | 200 x 200 | 300 x 200 | 400 x 200 | 300 x 300 |
| | 60 x 40 | 70 x 70 | 120 x 60 | 120 x 80 | 120 x 120 | 150 x 150 | 250 x 150 | 220 x 220 | 250 x 250 | | 450 x 250 |
| | 50 x 50 | 100 x 50 | | 100 x 100 | 150 x 100 | | | | 340 x 200 | | |
| | 60 x 60 | 76 x 76 | | | 140 x 140 | | | | | | |
| Length (m) | Hole size (mm) | | | | | | | | | | |
| 1 | 10 (12) | 10 (12) | 10 (12) | 12 (2x10) | 16 (2x12) | 20 (2x16) | 25 (2x20) | 30 (2x25) | 30 (2x25) | 40 (2x30) | 40 (2x30) |
| 2 | 10 (12) | 10 (12) | 12 (2x10) | 12 (2x10) | 16 (2x12) | 20 (2x16) | 25 (2x20) | 30 (2x25) | 30 (2x25) | 40 (2x30) | 50 (2x40) |
| 3 | 10 (12) | 12 (2x10) | 12 (2x10) | 12 (2x10) | 16 (2x12) | 20 (2x16) | 25 (2x20) | 30 (2x25) | 40 (2x30) | 50 (2x40) | 50 (2x40) |
| 4 | 12 (2x10) | 12 (2x10) | 16 (2x12) | 16 (2x12) | 16 (2x12) | 25 (2x20) | 25 (2x20) | 30 (2x25) | 40 (2x30) | 50 (2x40) | 2x50 (3x40) |
| 5 | 12 (2x10) | 16 (2x12) | 16 (2x12) | 16 (2x12) | 25 (2x20) | 25 (2x20) | 30 (2x25) | 30 (2x25) | 50 (2x40) | 50 (2x40) | 2x50 (3x40) |
| 6 | 12 (2x10) | 16 (2x12) | 20 (2x16) | 20 (2x16) | 25 (2x20) | 25 (2x20) | 50 (2x30) | 50 (2x40) | 50 (2x40) | 2x50 (3x40) | 2x50 (3x40) |
| 7 | 16 (2x12) | 16 (2x12) | 20 (2x16) | 20 (2x16) | 25 (2x20) | 25 (2x20) | 50 (2x30) | 50 (2x40) | 50 (2x40) | 2x50 (3x40) | 2x50 (3x40) |
| 8 | 16 (2x12) | 16 (2x12) | 20 (2x16) | 25 (2x20) | 25 (2x20) | 2x25 (3x20) | 50 (2x30) | 50 (2x40) | 2x50 (3x40) | 2x50 (3x40) | 2x50 (3x40) |
| 9 | 16 (2x12) | 16 (2x12) | 25 (2x20) | 25 (2x20) | 2x25 (3x20) | 2x25 (3x20) | 50 (2x30) | 2x50 (3x40) | 2x50 (3x40) | 2x50 (3x40) | 2x50 (3x40) |
| 10+ | 20 (2x16) | 25 (2x16) | 25 (2x20) | 25 (2x20) | 2x25 (3x20) | 2x25 (3x20) | 50 (2x30) | 2x50 (3x40) | 2x50 (3x40) | 2x50 (3x40) | 2x50 (3x40) |
| **Note:** The hole sizes specified above may be substituted with a larger number of smaller holes. (minimum ø 10mm for vent and ø 12mm for fill/drain hole) | | | | | | | | | | | |

*Table 16.*

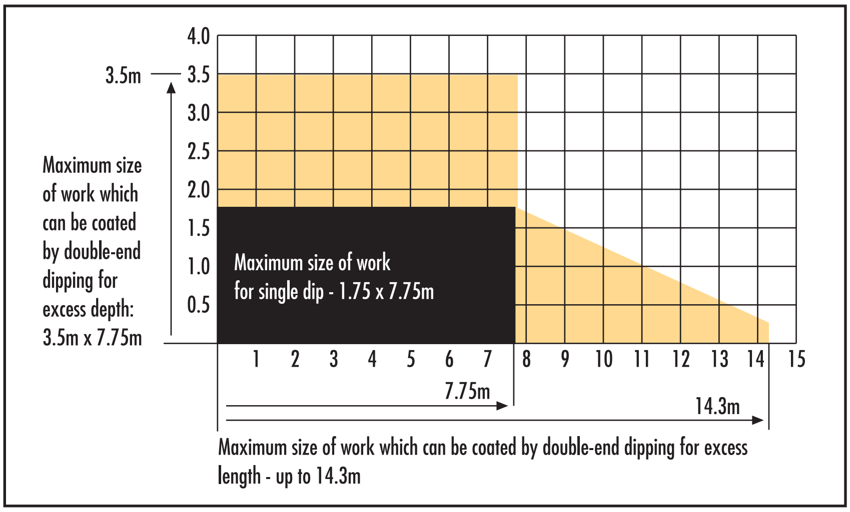



*Table 17. Schematic indication of double-end dipping capacity of a galvanizing bath 8 metres long x 2 metres deep.*

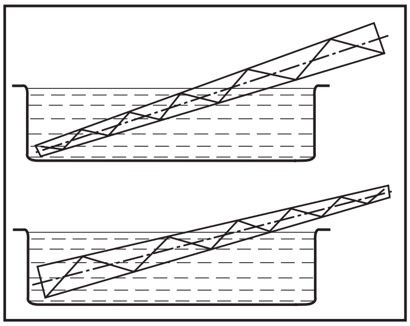


*Figure 47.*

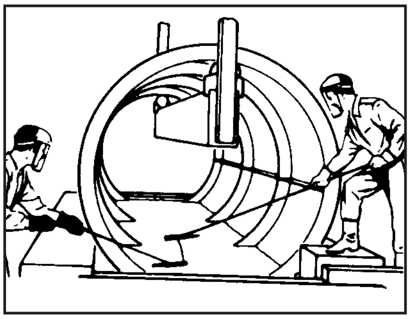


*Figure 48. Progressive dipping.*

molten zinc and to prevent air entrapment *(figures 49, 50, 51 and 52)*.

- Bolted joints are best made after hot dip galvanizing.

**Hot dip galvanizing oversize objects**

Facilities exist to hot dip galvanize articles of virtually any size and shape. (See list of members with bath sizes - refer to www.hdgasa.org.za. When an article is too big for single immersion in the largest bath available it may be possible to galvanize it by double-end dipping *(figure 47 and table 17)*, depending on the handling facilities and layout of the galvanizing plant (check with the galvanizer). Note: The cost of double end dipping can be higher than the standard cost of hot dip galvanizing. Large cylindrical objects can often be galvanized by progressive immersion *(figure 48)*.

These processes increase the potential for distortion as they introduce uneven heating into the object. The area immersed in the bath is raised to the full galvanizing temperature and therefore expands more than the portion remaining outside of the kettle. This is more pronounced during the first dip when the object is raised from room temperature. It is the differential heating and the resulting difference in expansion that may cause the product to distort. Dipping the second part of the fabrication will not remove any distortion that has already occurred.

This problem will be aggravated if vent and drain holes are undersized as this will require longer galvanizing times while the object fills with zinc and drains while removing. This increased

*Photo 1.*

*Photo 2.*

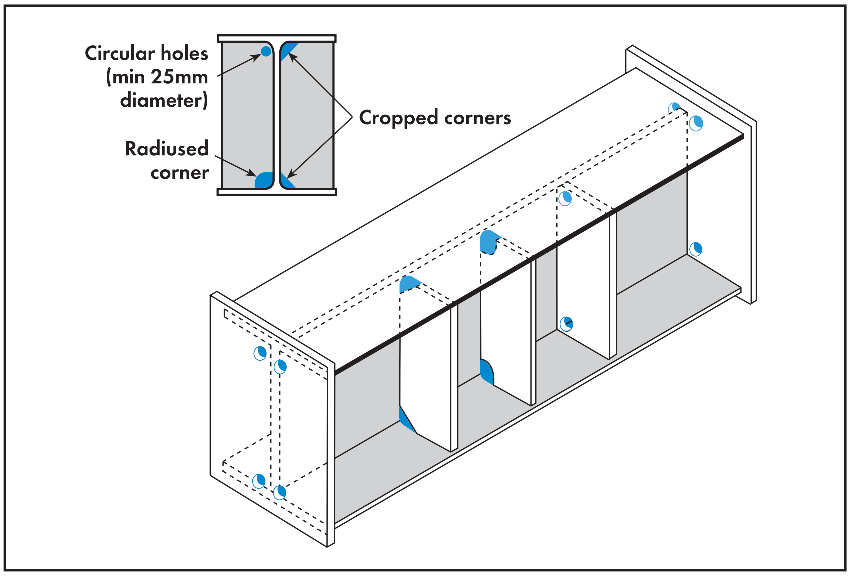



*Figure 49.*

*Photos 3 & 4 above.*

time exaggerates the differential expansion along the steel and hence the possibility of distortion.

These problems can be overcome or reduced by:

- Large structures are also hot dip galvanized by designing in modules for later assembly by bolting or welding. Modular design techniques often produce economics in manufacture and assembly through simplified handling and transport.
- Ensuring that vent and drain holes are adequately sized to enable rapid immersion and withdrawal of the object *(table 16)*.
- Allowing for linear expansion in the design so that any distortion is plastic and not constrained by cross bracing.
- Utilise the longest bath available for the galvanizing.

These problems are rarely experienced in simple pipes, poles or thin spiral sections because of their symmetry and simple design.

**Steel grade**

It is possible to hot dip galvanize all structural steels and the ultimate coating thickness achieved is determined by steel analysis, immersion time and to a lesser degree, zinc temperature. It is for this reason that hot dip galvanizing specifications provide for minimum coating thickness and no maximum limit is set *(see NOTE 1 in Chapter 10)*. Reactive levels of silicon in steel and excessively high phosphorus even at relatively low silicon levels can result in thicker coatings. Thicker coatings provide extended corrosion protection but can occasionally be prone to brittleness. The resultant coating could be aesthetically less pleasing sometimes displaying dull grey to black surface patches. *(Chapter 7)*.

**Fabrication**

***Bending***

Steels that are susceptible to embrittlement and fatigue failure should be bent over a smooth mandrel with a minimum radius 2 to 3 times material thickness. Where possible hot work at red heat. Cold bending is unlikely to affect steels less than 3mm thick. Before bending, edges should be radiused over the full arc of the bend.

**Bending and forming after hot dip galvanizing**

Components which have been hot dip galvanized should not be bent or formed by applying heat above the melting temperature of zinc as this can cause embrittlement due to intergranular liquid zinc penetration between steel crystal boundaries.

***Burrs***

Unlike a paint coating, burrs will be

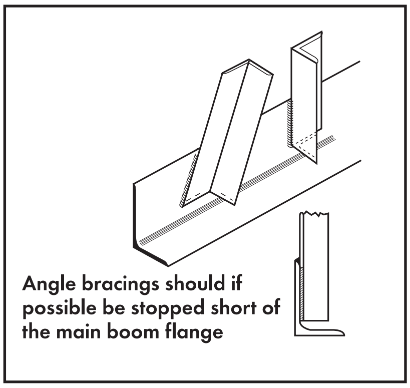



*Figure 50.*

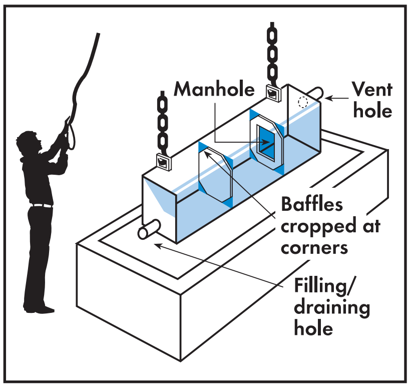



*Figure 51.*

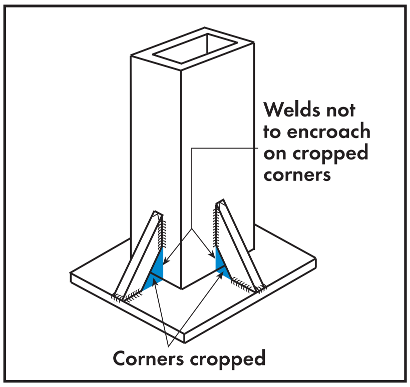



*Figure 52.*

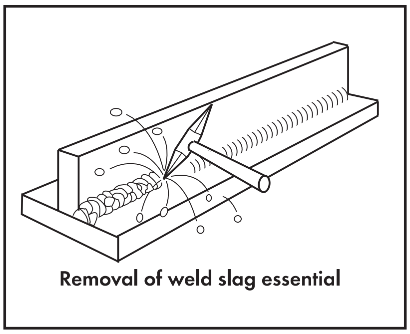



*Figure 53.*

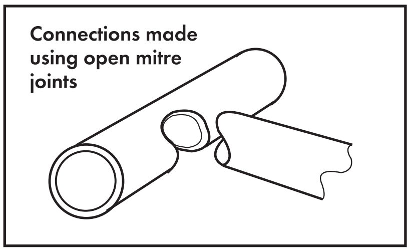



*Figure 54.*

overcoated by hot dip galvanizing but the removal of a burr after galvanizing may result in the presence of a small uncoated surface and for this reason, burrs must be removed prior to galvanizing.

***Edges***

Because a hot dip galvanized coating is formed by metallurgical reaction between molten zinc and steel, the coating thickness on edges and corners is thicker than that on flat surfaces. Thus the rounding of sharp edges, as required for paint coatings, is not necessary. If subsequent painting is required, sharp edges should be rounded during fabrication to a radius of 3mm or 50% of steel thickness.

***Edge distances.*** In accordance with SANS 10162 Clause 22.3.2, which defines edge distance as *"the minimum distance from the centre of a bolt to any edge shall be in accordance with table 8".*

***Punching.*** Full size punching of holes is permitted when (amongst other requirements such as distortion free, burr free, not subject to fatigue), according to Clause 4.3.6.3.c of SANS 2001-CS1, *"the thickness of the material is not greater than the hole diameter plus 3mm; nor greater than 12mm".*

Clause 4.3.6.4 Punching and reaming eads: *"Punching is permitted without the conditions of 4.3.6.3 provided the holes are punched at least 2mm less in diameter than the required size and the hole is subsequently reamed to the full diameter."*

Material of any thickness may be punched at least 3mm undersize and then reamed, or be drilled. Good shop practice in relation to ratios of punched hole diameter to plate thickness, and punch/die diametral clearance to plate thickness should be observed.

For static loading, holes may be punched full size in material up to $\frac{4500}{F_y}$ mm thick where Fy is material yield stress up to 360MPa.

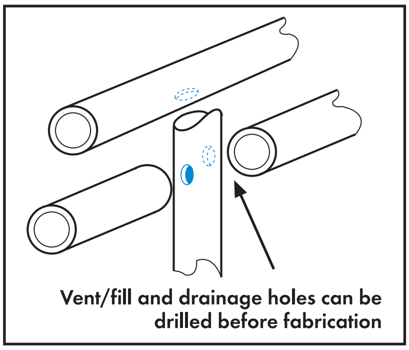



*Figure 55.*

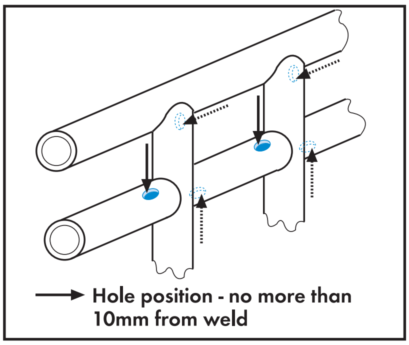



*Figure 56.*

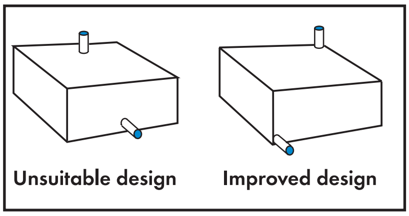



*Figure 57.*

***Shearing and flame cutting***

Edges of steel sections greater than 16mm thick subject to tensile loads should be machined or machine flame cut. Edges of sections up to 16mm thick may be cut by shearing.

Sheared edges to be bent during fabrication should have stress raising features such as burrs and flame gouges removed to a depth of at least 1.5mm.

Temperatures associated with flame cutting alter the surface properties of steel and if such surfaces are not thoroughly ground, a thinner galvanized coating will be formed (usually below the specified minimum).

***Welding and weld slag***

Welds should be continuous and free from excessive pin-holing and porosity. Weld slag, normally associated with stick welding, is not readily removed by acid cleaning and such slag must be removed by abrasive blast cleaning, chipping, grinding, flame cleaning or a pneumatic needle gun, prior to hot dip galvanizing. Shielded arc welding is preferred since this method does not result in the presence of tightly adhering slag *(figure 53 and Chapter 14).*

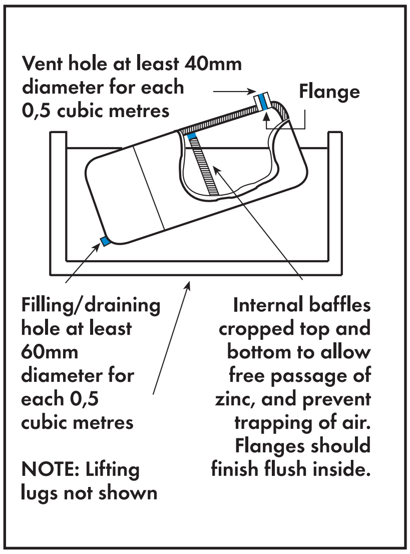



*Figure 58.*

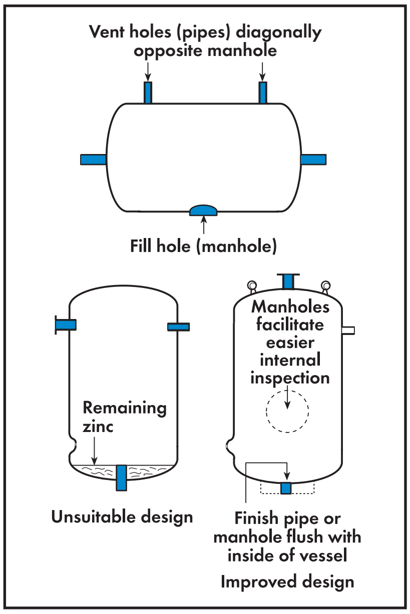



*Figure 59.*

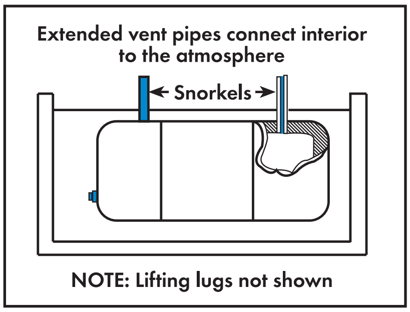



*Figure 60.*

In order that the weld seals and continues at the end of a double sided fillet weld, consider chamfering the long edges and do a full penetration weldment along both sides with runouts on each end to ensure full seal welds *(figure 16).*

***Weld spatter***

Weld spatter does not reduce the protective properties of a hot dip galva-

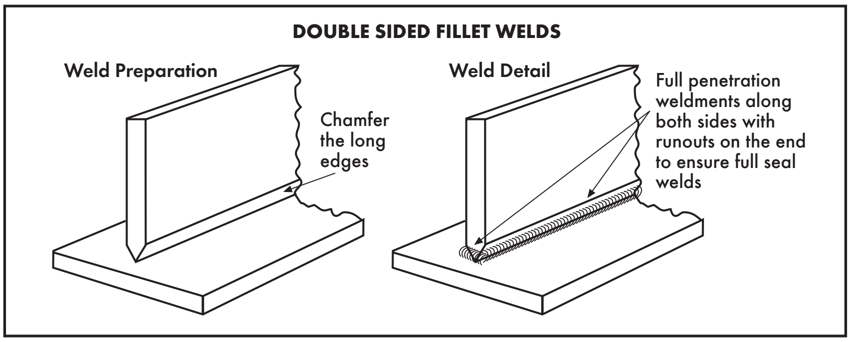



Figure 61.

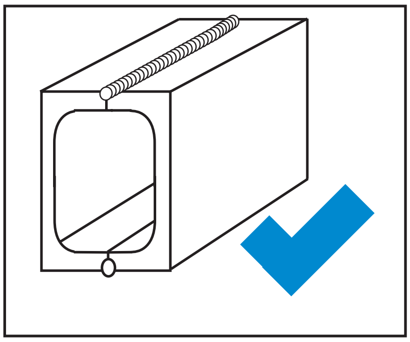


Figure 62.

nized coating to the same extent as with a paint coating, but it is recommended practice to remove spatter prior to hot dip galvanizing.

## 9.2 VENTING, FILLING AND DRAINAGE

External stiffeners, welded gussets and webs on columns and beams and gussets in channel sections should have cropped corners. The gaps created should be as large as possible without compromising structural strength. If welding is required around the edge created, a radiused corner is desirable to facilitate continuity of the weld around the cut end to the other side. Circular holes are less effective: if used, they should be as close to corners and edges as practical. Where more convenient, the cropped corners or holes may be in the main beam. Consultation with the galvanizer, regarding the appropriate vent and drainage hole sizes is recommended *(figure 49 and table 16)*.

**Welded pipe sections**
Closed sections must never be incorporated in a fabrication. Sections should be interconnected using open mitred joints as illustrated in *figure 54*, or interconnecting holes should be drilled before fabrication as in *figure 55*.

Alternatively external holes may be positioned as in *figure 56*, a method which is often preferred by the galvanizer, since quick visual inspection shows that the work is safe to hot dip galvanize.

Pipe ends can be left open, or provided with removable plugs. *(See unwanted vent holes)*.

**Unwanted vent holes**
These may be closed by hammering in lead or aluminium plugs after galvanizing and filing off flush with surrounding surfaces.

**Small tubular fabrications**
Small tubular fabrications must be vented, preferably with holes not less than 10mm diameter *(table 16)*.

**Tubular fabrications / hollow structurals**
Drain/vent hole sizes should preferably be 25% of internal diameter or diagonal dimension for components with a maximum cross sectional area of 180cm$^2$. This percentage can be influenced by the shape of the fabrication. Consultation with the galvanizer at the design stage is recommended.

**Tubular fabrication after hot dip galvanizing**
The requirement for bending tubes after hot dip galvanizing, ie. for the fabrication of gates etc. must be carried out according to the method set out in the Bend Test (galvanized tube). *See 11.6 Testing for Adhesion and Note 2, regarding coating thickness, page 37.*

**Tanks and closed vessels**
When both internal and external surfaces are to be hot dip galvanized at least one filling and draining hole must be provided, with a vent hole diagonally opposite to allow the exit of air during immersion *(figure 57)*. For each 0,5 cubic metres of volume, provide at least one fill/drain hole of minimum size ø60mm and vent hole of minimum size ø40mm or both at ø60mm *(figure 58)*.

Internal baffles should be cropped as illustrated *(figure 51 and 58)*. Man-holes or pipes should finish flush inside to prevent trapping excess zinc *(figure 59)*.

Lifting lugs should be provided opposite the biggest and most accessible filling / draining holes and adjacent to the vent hole on the opposite end *(figure 43)*. The lugs must be designed to accommodate the excess mass of molten zinc within the cylinder / pipe on withdrawal.

| Shaft or spindle size | Minimum radial clearance |
|---|---|
| Up to 30mm diameter | 2,0mm |
| Over 30mm diameter | 2,0 - 2,5mm |

Table 18.

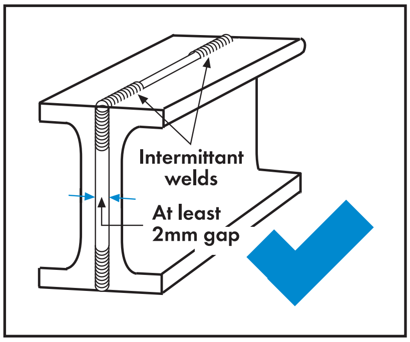



Figure 63.

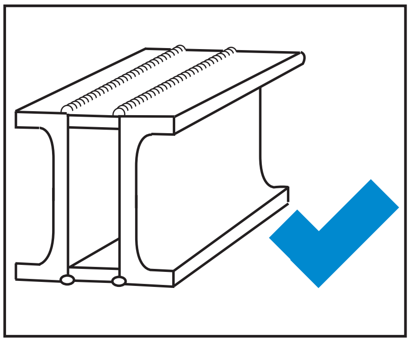


Figure 64.

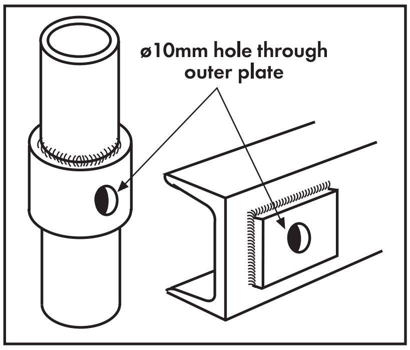



Figure 65.

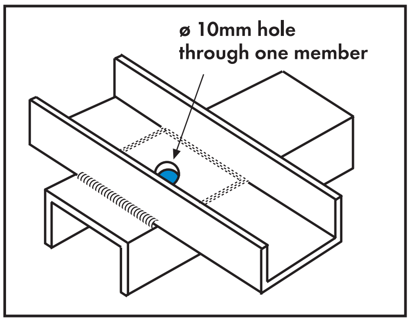



Figure 66.

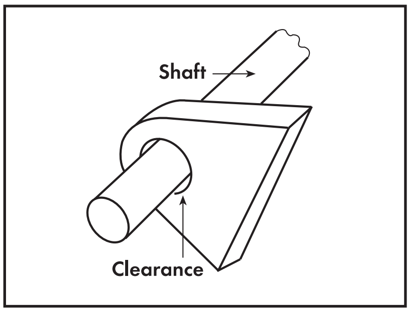



*Figure 67.*

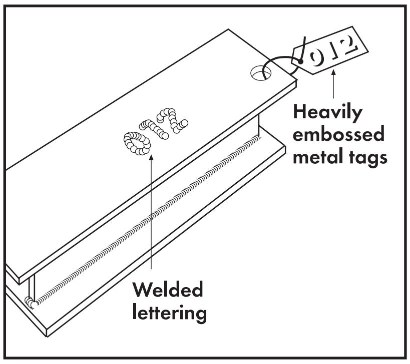



*Figure 68.*

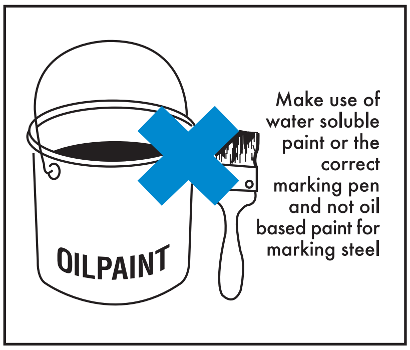



*Figure 69.*

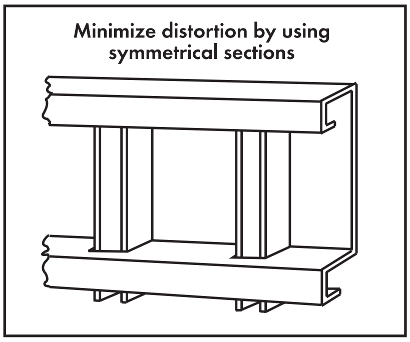



*Figure 70.*

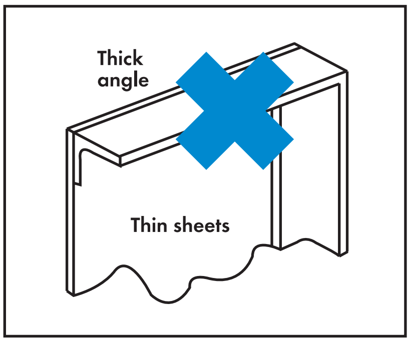



*Figure 71.*

Large vessels require an appropriate size manhole in the baffle.

When vessels and heat exchangers etc., are not to be galvanized internal, 'snorkels' or extended vent pipes must be fitted to allow air or steam to exit above the level of molten zinc in the galvanizing bath *(figure 60)*.

## 9.3 MASKING, WELDING, HANDLING, CLEARANCE FOR MOVING PARTS AND IDENTIFICATION

**Masking**

Masking materials have been developed, which if applied prior to hot dip galvanizing, will prevent the formation of the galvanized coating on surfaces where it is not required.

**Combinations of ferrous surfaces**

Fabrications containing a combination of castings and steels, or rusted and mill scaled surfaces must be abrasive blast cleaned before hot dip galvanizing.

**Provision for handling**

Work not suitable for handling with chains, baskets, hooks or jigs must be provided with suspension holes or lifting lugs *(figure 43)*. If in doubt, consult the galvanizer.

**Materials suitable for hot dip galvanizing**

All ferrous materials are suitable, including sound stress-free castings.

Brazed assemblies may be hot dip galvanized but first consult the galvanizer. Assemblies soft soldered or aluminium rivetted cannot be hot dip galvanized.

**Overlapping surfaces**

A minimum gap of at least 2mm between overlapping surfaces and back-to-back angles and channels, must be provided *(figures 62, 63 and 64)*.

When small overlaps are unavoidable, seal edges by welding.

In circumstances where seal welding is not practical, a degree of temporary surface staining at crevices may be apparent after hot dip galvanizing and quenching. This is often incorrectly described as acid staining. Clean with a bristle brush and mild detergent if necessary. If necessary crevices of this nature can be sealed after hot dip galvanizing with an appropriate sealant.

**Larger overlapping surfaces**

If contacting surfaces cannot be avoided, one 10mm diameter hole should be provided in one of the members for every 100cm$^2$ of overlap surface. The perimeter of the contacting surface can be continuously welded. This requirement is of particular importance when using thin sections. Vent hole sizes for thicker steels >10mm thick and overlap areas > 300cm$^2$ should be agreed upon by the galvanizer prior to fabrication *(figures 65 and 66)*. A vent hole in one member will ensure the safety of galvanizing personnel and prevent damage to the article. Alternatively provide at least a 2mm gap between members.

**Strengthening gussets and webs**

Welded strengthening gussets and webs on columns and beams, and strengthening gussets in members fabricated from channel or I-beam sections should have corners cropped or holed *(figures 49, 52 and photos 3 & 4)*,

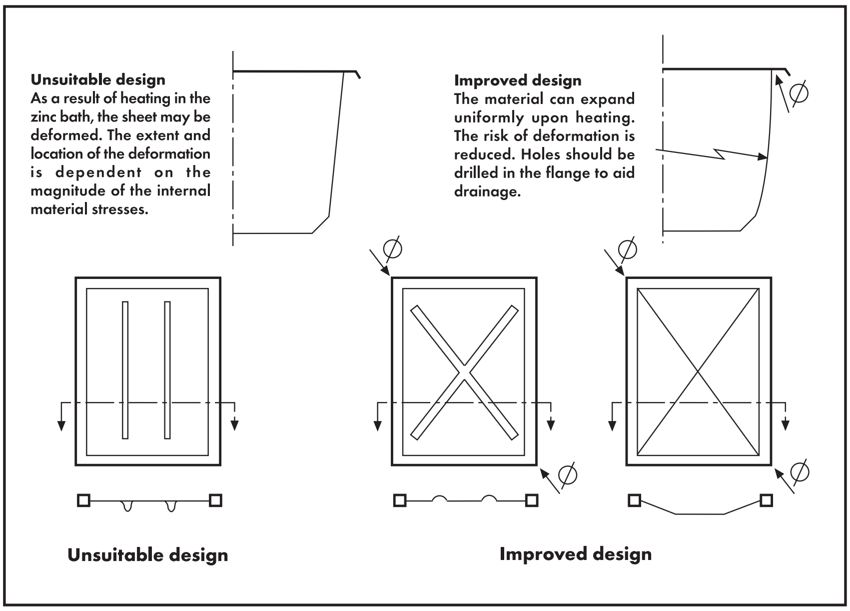



*Figure 72.*

- to prevent the entrapment of air in pockets and corners allowing complete access of pickle acids and molten zinc to the entire surface of the product, and

- to facilitate drainage during withdrawal from degreaser, acid solutions, rinsewater, flux and molten zinc.

**Clearance for moving parts**
Drop handles, hinges, shackles, shafts and spindles require a radial clearance, to allow for the thickness of the hot dip galvanized coating *(figure 67 and table 18)*.

**Identification markings**
For permanent identification use heavily embossed, punched or welded lettering *(figure 68)*. For temporary identification use heavily embossed metal tags wired to the work, water soluble paint or an appropriate marking pen.

Do not use paints, adhesive labels or any other product that cannot be readily removed by degreasing or pickling *(figure 69)*. If present, these coatings require to be removed by paint stripper or abrasive blasting prior to pickling and hot dip galvanizing.

**Hot dip galvanized fasteners**
Hot dip galvanized fasteners are recommended for use with hot dip galvanized or painted structures, but if **SANS 121/ISO 1461** is not specified, there is every likelihood that thinner zinc electro plated coatings will be supplied. *(Chapter 13)*.

## 9.4 PREVENTING DISTORTION

**Distortion**
Distortion can be minimised by:

- Use of symmetrical designs *(figure 70)*.
- Use of sections of a similar thickness *(figure 71)*.
- Use of stiffened sections, particularly when steel is unsupported and of less than 3 - 4mm thick *(figure 72 & photo 5)*.
- Use of preformed members with the correct minimum bend radius to minimise stress.
- Use of balanced or sequence welding techniques to minimise stresses.
- Large open fabrications, thin walled trough sections and rectangular tanks may require temporary cross stays to prevent distortion during hot dip galvanizing *(figure 75 and photos 6 & 7)*.
- Maximise fill, drain and vent hole sizes and optimize their relative positions *(table 16)*.

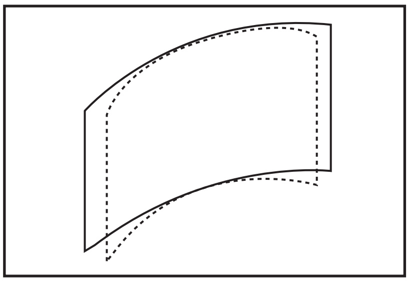


*Figure 73*

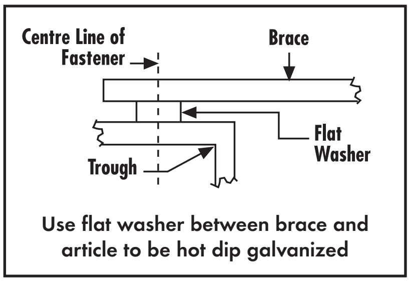



*Figure 74.*

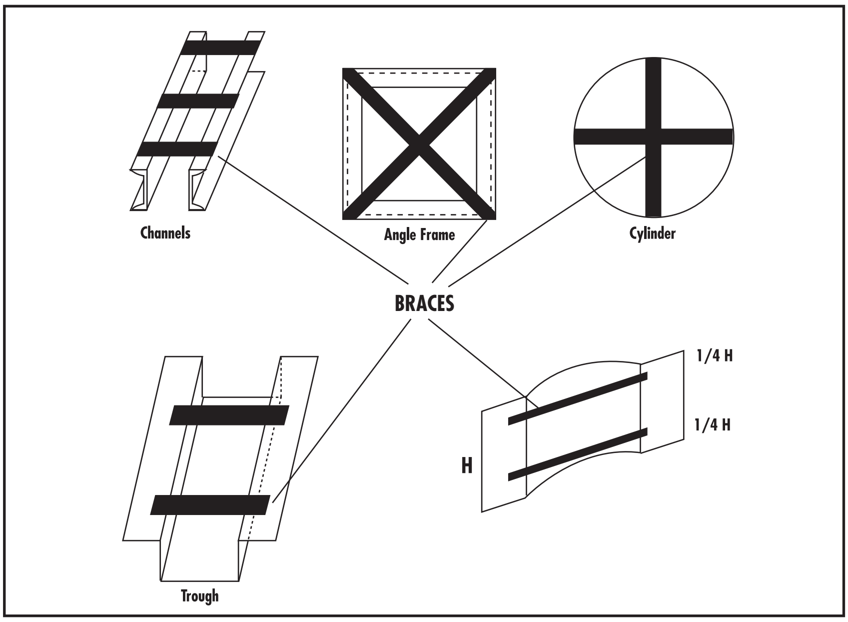



*Figure 75.*

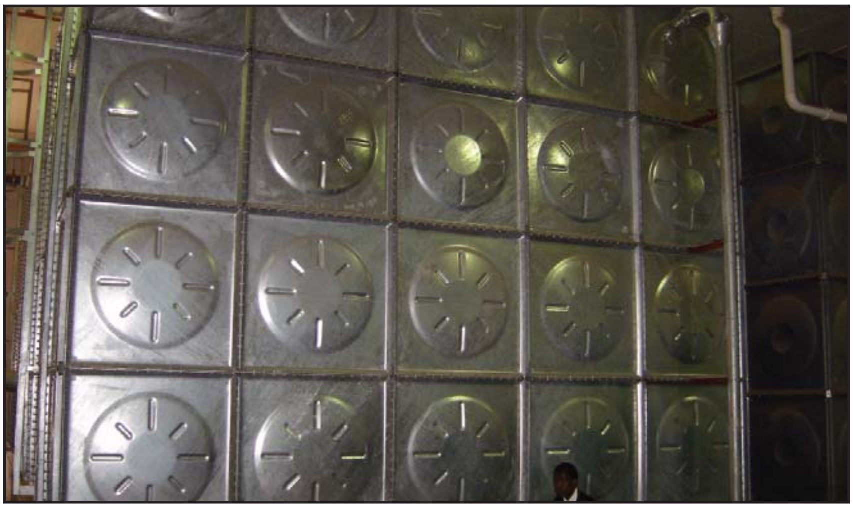


*Photo 5.*

*Photo 6.*

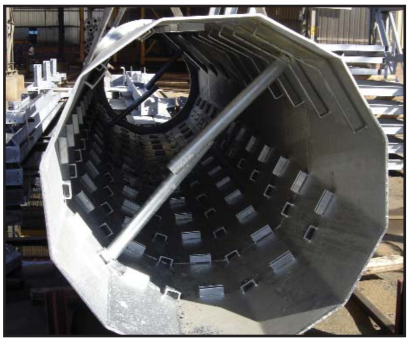


*Photo 7.*

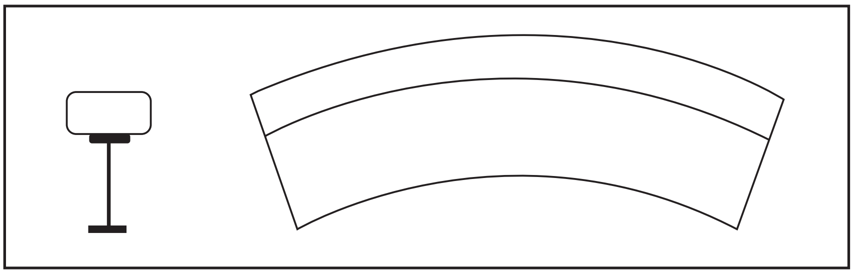


Figure 76.

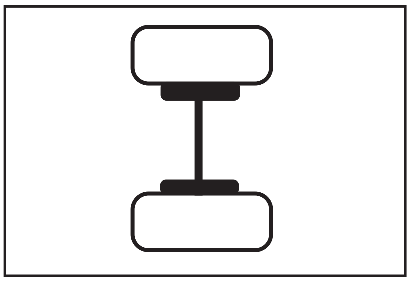


Figure 77.

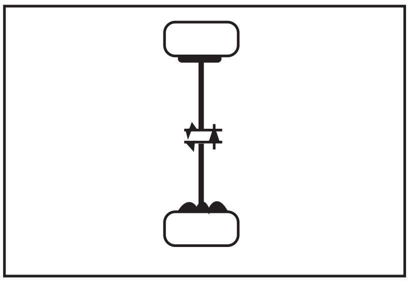


Figure 78.

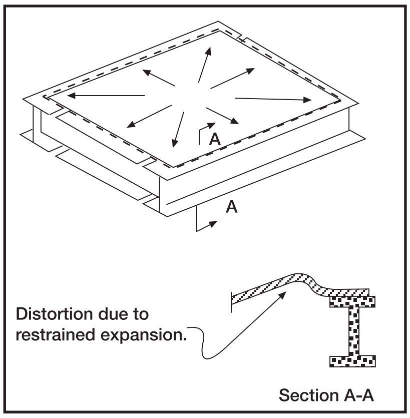



Figure 79.

- Complete and rapid immersion of the item in the galvanizing bath i.e. avoid double end dipping if possible.
- Air cooling after hot dip galvanizing in preference to water quenching.

Use of symmetrical sections minimises distortion during hot dip galvanizing.

**Products shaped by bending**

Many items are formed by bending them to the correct shape at the fabricating stage. This process induces stress into the product, which may be relieved during the hot dip galvanizing operation. This occurs as the molten zinc temperature of around 450°C is at the lower end of the stress relieving temperature for steel. Consequently the stresses used to shape the product may be released giving a resultant change in shape or dimension of the product.

Consider the case of a plate rolled to form part of a circle. During hot dip galvanizing, the release of stress will cause the radius of the circle to increase, and so the final fabricated circle pieces may not meet up *(figure 73).*

These difficulties can be overcome by installing temporary braces across the section to ensure that the object retains its desired shape. The braces would be either welded or bolted in position, with a size proportional to the size and thickness of the plate they are retaining. If bolted, a flat washer may be used as a spacer between the brace and article to be hot dip galvanized, *see figure 74*. The smaller the spacer the smaller the final repair area.

The braces should be located at least at quarter points of the structure. Similar results can be obtained with bent troughs, angle frames or with channels *(figure 75 and photos 6 & 7)).*

It will be necessary to repair the area where the braces have been removed using an approved repair material.

**Welding or fabrication induced stress**

It has been said that the internal stresses due to welding play the greatest part in creating distortion. Because the steel is heated to 450°C during galvanizing, the stresses introduced by welding are released and this may occasionally give rise to distortion. Welding, however, plays an essential part in creating the fabrications which are to be hot dip galvanized. It is therefore important to understand how these forces are generated and to minimise them during the fabrication to obtain a satisfactory product after hot dip galvanizing.

Fortunately, by following a few simple rules it is possible to get much improved results. These basic rules are:

- Avoid overwelding, welds should be no larger than is essential for the structural integrity of the fabrication.
- Welding should be as symmetrical as possible in order to ensure the stresses are balanced. This can be done by placing welds near the neutral axis or by balancing them around this axis.
- Use a well planned, balanced welding sequence. With large structures extra care should be taken that stresses are minimised by preparing and working to a welding plan.
- Weld seams which significantly reinforce the structural strength should as far as possible be welded last so that do not hinder the contraction of other welds.
- Use as few weld passes as possible and reduce the welding time to control the heat input.
- Make weld shrinkage forces work in the desired direction or balance shrinkage forces with opposing forces.
- Use backstep welding or staggered welding to minimise stresses.

If a steel fabrication distorts either after welding and before or after hot dip galvanizing due to these stresses, it is possible to restraighten the item. Best results are obtained by hot straightening either before or after hot dip galvanizing. Preference should be given to hot straightening before as the time required is less and the possibility of damage to the zinc coating is avoided. Tests confirm that hot straightened components which were within tolerance before hot

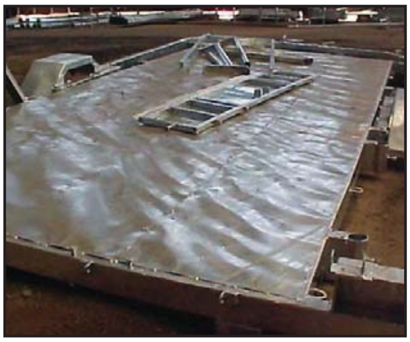


Photo 8.

Photo 9.

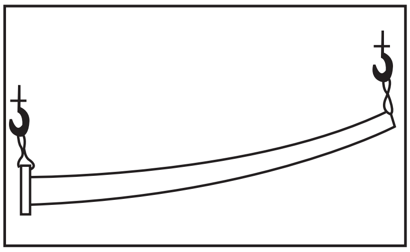


Figure 80.

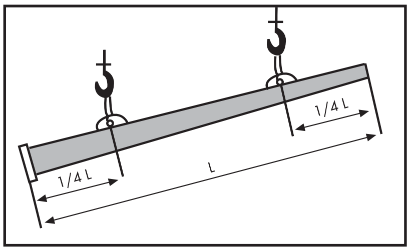



Figure 81.

dip galvanizing do not distort again during the galvanizing process as the stresses have already been relieved.

**Fabrications that lack symmetry**
When fabrications are substantially symmetrical in both the horizontal and vertical planes, they have a much lower potential to distort at galvanizing temperatures. Under these conditions, the expansion forces are balanced and the product does not suffer any distortion. This condition exists with tubes, I-beams, RHS and other similar sections. When these sections are combined in a fabrication, it is possible to remove this symmetry.

Consider the case where a piece of thin walled RHS is welded to the top of an I-beam section. In this situation, the geometric shape is no longer symmetrical, even though the two individual components are.

The thinner walled tube will reach the galvanizing temperature sooner than the thicker flange at the bottom. As a result, the RHS will expand faster than the bottom flange, causing the section to experience an upwards bow *(figure 76)*.

Sections which are not symmetrical, such as Channels and Angles will experience similar problems because of their inbuilt asymmetry. In the case of channels, the section will bow with the toes pointing outwards.

There are three recommended ways to overcome this type of problem.

- Redesign the fabrication to make the design symmetrical. This will enable the forces to balance each other and prevent distortion.
- Fabricate and galvanize the individual components as separate pieces, then weld them together after hot dip galvanizing. The welds can be touched up with a suitable galvanizing repair material.
- When multiple pieces are available they can be hot dip galvanized back to back by using bolts with pipe spacers to separate the pieces.The assembly would be separated after cooling completely and the spacer contact area repaired with a suitable galvanizing repair material *(figures 77 and 78)*.

**Using thick and thin material in an assembly**
When thin material is heated during galvanizing, it expands faster than any thick material heated at the same time. this is because the thinner material takes less time to be fully heated to the galvanizing temperature. The thinner material will therefore distort if its expansion is restrained by thicker material.

Consider the common case where a thin steel sheet is welded to the frame of a trailer to form a tray. This sheet is generally securely attached by welds around its perimeter. If, for example, the sheet is only half as thick as the material used in the frame, it quickly reaches the galvanizing temperature of around 450°C and so has reached the point where maximum expansion will occur.

The frame being made of thicker material will not yet have reached the same temperature and so will not have expanded as much as the thinner sheet. Because of the restraints from the welds around the perimeter, the sheet cannot push its growth outwards at the edges, and so the increase in size causes buckles to occur in the sheet surface *(figures 71, 79 and photo 9)*.

There are two recommended methods of overcoming this problem:

- Hot dip galvanize the sheet and frame separately and then join them after galvanizing. This may be done using mechanical fasteners such as screws or bolts. If welding is used then the welds will need to be touched up with galvanizing repair material.
- Use the same thickness of material for both the frame and the sheet.

In some cases this buckling of the surface may be acceptable *(photo 8)*, as the material is fully protected against corrosion, however once this type of distortion occurs, it cannot be readily corrected after galvanizing.

**Long thin objects**
Long thin objects include poles, tubes and larger RHS sections. Generally these objects will not distort due to their symmetrical nature, however if they are lifted at both ends, they may take on a characteristically bowed shape following the galvanizing process *(figure 80)*.

This bowing is caused when the steel is heated to the galvanizing temperature of 450°C. When withdrawing from the galvanizing kettle, the products own weight may exceed the yield strength of the steel at this temperature, causing the object to bow. This bowing becomes permanent as the steel cools.

If the product has not been designed with sufficiently large vent and drain holes, the problem can be aggravated by additional zinc being trapped inside the object when it is lifted. Further problems are created by this as the time taken for the zinc to drain allows the deformation of the steel to continue for a longer period and the bowing to become worse.

There are two recommended ways to reduce this problem:

- Lifting lugs or holes should be provided at the quarter points of these products so that they do not need to be lifted at the ends *(figure 81)*.
- Vent and drain holes should be placed and sized to maximise the rate of drainage and minimise the retention of zinc inside the section *(figure 43 and table 16)*.

## 9.5 PACKAGING AND TRANSPORTING OF HOT DIP GALVANIZED STEEL

Even though the hot dip galvanized coating is capable of withstanding fairly rough treatment it should be handled with care during storage and transportation. In the case of long sections, simple packaging and binding into bundles not only prevents handling damage but it often facilitates transportation itself. Packaging and binding should be done in such a way as to avoid the risk of wet storage stain. Spacers should be used to facilitate air circulation between components *(see photo 10)*.

Photo 10.

# Specifying Hot Dip Galvanizing

**The galvanizer acts as a sub-contractor to a steel fabricator and as such, his contractual relationship is normally with the fabricator, not with the ultimate user or specifier. It is important, therefore, that the users' or specifiers' requirements for hot dip galvanizing are made clear to the fabricator and that all instructions are channelled via the fabricator to the galvanizer.**

**When specifying hot dip galvanizing it is essential to demand a coating applied in accordance with the requirements of SANS 121/ISO 1461 or SANS 32/EN 10240 where applicable. This will avoid confusion with zinc rich painting often referred to as cold galvanizing and zinc electro-plating referred to as electrogalvanizing.**

**To ensure the best quality and technical support, a galvanizer who is a member of The Hot Dip Galvanizers Association Southern Africa is recommended.**

**When hot dip galvanizing is applied, the steel substrate is completely covered with a relatively uniform coating of zinc. The minimum coating thickness required is related to the thickness of the steel being hot dip galvanized, *as shown in table 19 & 20.***

## 10.1 HOT DIP GALVANIZING SPECIFICATIONS

**SANS 121/ ISO 1461**
Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods.

**SANS 32/EN 10240**
Internal and/or external protective coatings for steel tubes - Specification for hot dip galvanized coatings applied in automatic plants *(table 23)*.

*Note: The above specifications supercede **SABS 763**.*

**SANS 763:1997**
Hot dip (galvanized) zinc coatings (other than on continuously zinc coated sheet and wire).

**SANS 14713/ISO 14713**
Protection against corrosion of iron and steel in structures - Zinc and aluminium coatings - Guidelines.

*Note: The above specification supersedes **SABS 0214.***

**SANS 4998/ISO 4998**
Continuous hot dip zinc coated carbon steel sheet of structural quality.

**SANS 3575/ISO 3575**
Continuous hot dip zinc coated carbon steel sheet of commercial, lock forming and drawing grades.

*Note: The above two specifications supersede **SABS 934.***

**SANS 675:1997**
Zinc coated fencing wire.

**SANS 935:1993**
Hot dip (galvanized) zinc coatings on steel wire.

General hot dip galvanizing specifications state the local (minimum) and the (mean) coating thicknesses. The thickness actually achieved, varies with steel composition and this can range from the minimum up to at least 50% greater. As life expectancy predictions are normally based on the minimum coating thickness, they are usually conservative.

***NOTE 1:** The specification does not stipulate a maximum upper coating thickness limitation, however, excessively thick coatings on threaded articles are undesirable. In order to ensure effective tensioning, the coating thickness on fasteners should not exceed a maximum of 65µm, this applies particularly to high strength bolts and nuts.*

In South Africa, the South African Bureau of Standards (SABS) has adapted **ISO 1461, EN 10240** and **ISO 14713.** The specifications are therefore published by the SABS as **SANS 121/ISO 1461, SANS 32/EN 10240** and **SANS ISO 14713/ISO 14713.**

## 10.2 LEAD TIMES

As a general guide, most articles can be hot dip galvanized and returned to the fabricator within 3 to 7 days after receipt.

**In the case of large contracts, the galvanizer should be involved at the programming stage with the fabricator and the end user. Hot dip galvanizing is normally the final process after fabrication prior to delivery and erection. If insufficient time for hot dip galvanizing and inspection is provided in the overall programme, costly delays may occur at the erection stage.**

**MINIMUM COATING THICKNESS ON ARTICLES THAT ARE NOT CENTRIFUGED**

| | SANS 121/ ISO 1461:1999 | SANS 121/ISO 1461:2009 | | |
|---|---|---|---|---|
| | Category and thickness (t) mm | Category and thickness (t) mm | Local coating thickness (minimum) µm* | Mean coating thickness (minimum) µm* |
| PROFILES | t ≥ 6 | t > 6 | 70 | 85 |
| | t ≥ 3 to < 6 | t > 3 to ≤ 6 | 55 | 70 |
| | t ≥ 1.5 to < 3 | t ≥ 1.5 to ≤ 3 | 45 | 55 |
| | t < 1.5 | t < 1.5 | 35 | 45 |
| CASTINGS | t ≥ 6 | | 70 | 80 |
| | t < 6 | | 60 | 70 |

■ Thickness legend - 3mm > t ≤ 6mm - thickness greater than 3mm but equal to and less than 6mm.

*Table 19.*

**MINIMUM COATING THICKNESS ON ARTICLES THAT ARE CENTRIFUGED**

| | SANS 121/ ISO 1461:1999 | SANS 121/ISO 1461:2009 | | | | |
|---|---|---|---|---|---|---|
| | Category and thickness/ diameter (t) or (ø) mm | Article and its diameter (ø) or thickness (t) mm | Local coating thickness (minimum) µm* | | Mean coating thickness (minimum) µm* | |
| FASTENERS | ø ≥ 20 | ø > 6 | 45 | 40 | 55 | 50 |
| | 6 ≤ ø < 20 | ø ≤ 6 | 35 | 20 | 45 | 25 |
| | ø < 6 | | 20 | | 25 | |
| OTHER ARTICLES (INCLUDING CASTINGS) | t ≥ 3 | t ≥ 3 | 45 | | 55 | |
| | t < 3 | t < 3 | 35 | | 45 | |

■ Thickness legend - ø > 6 = diameter greater than 6mm.

*Table 20.*

**NOTES**

* Local coating thickness is defined as the mean of the measurements taken within a specified reference area. Mean coating thickness is the control sample number average of the local coating thickness values from each reference area.

- Where only one reference area is required according to size of the article, the mean coating thickness within that reference area shall be equal to the mean coating thickness given in the above tables.
- **Deviation from standard coating thickness.** A requirement for a thicker coating (25% greater than the standard in ***table 19*** can be requested for components not centrifuged, without affecting specification conformity).

  Where steel composition does not induce moderate to high reactivity, thicker coatings are not always easily achieved.
- Refer to Chapter 13.8 "Bolted Connections; High Strength Fasteners" for information on the hot dip galvanizing of High Strength Fasteners

# Quality - Inspection Before & After Hot Dip Galvanizing

## 11.1 INSPECTION BEFORE HOT DIP GALVANIZING

Good quality hot dip galvanized coatings on fabricated articles are more likely to be achieved if correct fabrication techniques have been adhered to. Inspection of fabricated assemblies, castings and other components for hot dip galvanizing, should be carried out before despatch to the galvanizer *(table 21)* in order to ensure conformity to the design requirements detailed in *Chapter 9*. This may avoid costly rectification and unnecessary delays at the galvanizers premises.

## 11.2 INSPECTION AFTER HOT DIP GALVANIZING

As a final step in the process, the hot dip galvanized coating is inspected for compliance with relevant specifications. Interpretation of inspection results should be made with a clear knowledge of the causes of various conditions which may be encountered and their potential influence on the ultimate objective of providing long term corrosion protection.

Inspectors should remember that the ***purpose of hot dip galvanizing is to protect steel from corrosion.*** The length of time that this protection can be expected to last, is called its "service life or time to first maintenance". This is defined as the time taken for the appearance on an article of 5% surface rust. **The service life of a hot dip galvanized coating is directly related to the thickness of the protective zinc coating. Corrosion protection is greatest when the coating is thickest. Thus coating thickness is the single most important quality check.**

**Coating thickness is only one inspection aspect. Other checks must include continuity, coating adhesion and appearance. Embrittlement and defects, which arise from specific materials, design and fabrication, must also be considered when inspecting susceptible items.**

While minimum standards must be satisfied in all these considerations, their relative importance varies according to the end use of the finished product. For example, the aesthetic appearance of hot dip galvanized structural steel in an industrial application is less important than when a structure is destined for use in a decorative application. Understanding of the specific requirements as well as the limits to what can be achieved by hot dip galvanizing is essential for effective inspection.

## 11.3 THICKNESS TESTING

Several methods are used to determine the thickness of the zinc coating on a hot dip galvanized article. The size, shape and number of pieces to be tested, will dictate the method to be used. Specified test methods are either destructive or non-destructive. These are detailed in **SANS 121/ISO 1461** and in **SANS 32/EN 10240**. The most practical test is the non-destructive method utilising the electromagnetic principle for determining coating thickness *(figure 82)*.

Threaded articles must fit their mating parts and, in the case of assemblies that contain both externally and internally threaded articles, it shall be possible to screw mating parts together by hand.

For small items, particularly those with complex geometries, **ISO 1460** provides for gravimetric measurements aimed at determining mass of coating per unit area as opposed to thickness. This is a destructive test method.

*Figure 82. Using a digital instrument to measure zinc coating thickness.*

## 11.4 APPEARANCE

The ability of a hot dip galvanized coating to meet its primary objective which is to provide corrosion protection, should be the chief criterion when evaluating coating acceptability.

The specified requirements for a hot dip galvanized coating are that it be:

- continuous,
- relatively smooth,
- free from gross imperfections,
- free from sharp points (that can cause injury), and
- free from uncoated areas

To be essentially free from uncoated areas was best described in **SABS 763** 4.3.2 b. This reads as follows:
*"The area of an individual bare spot or thin area shall not exceed 5mm². The combined area of bare spots or thin areas shall not exceed 25mm² per metre of length or per square metre of surface of an article.".*

*Note: **SABS 763** is obsolete but for practical purposes the above clause has been retained for galvanizing inspectors.*

The above requirements are of particular importance when a subsequent organic paint coating is to be applied onto a galvanized surface. Smoothness and absence of roughness achieved on mechanically wiped products, such as continuously galvanized sheeting or wire, are not to be used as the criteria for accessing surface finish on general hot dip galvanized products. Roughness and smoothness are relative terms. The end use of the product must be the determining factor in setting standards.

In order to provide optimum corrosion protection, the hot dip galvanized coating should be continuous. Handling techniques for hot dip galvanized articles may entail the use of chain slings or other holding devices if suitable lifting fixtures are not attached to the item. In exceptional circumstances, chains and special jigs may leave a contact touch mark on the hot dip galvanized item. These marks are not always detrimental and a reason for rejection. Should these marks, be greater than 5mm² with bare steel exposed, suitable repairs should be carried out using the method described in **SANS 121/ISO 1461.** *Refer to Chapter 15 - Reconditioning Damaged or Site Modified Hot Dip Galvanized Coatings.*

Differences in the lustre and colour of hot dip galvanized coatings do not affect corrosion resistance and the presence or absence of spangle has no effect on coating perfor-

| CHECK LIST PRIOR TO SENDING GOODS FOR HOT DIP GALVANIZING |
| --- |
| **Size and Shape**<br>Check that work is suitably sized and if necessary, lugs have been provided for the handling and galvanizing facilities of the selected galvanizer. It may be too late to make changes to the design, but it is costly to despatch work which the galvanizer cannot process. |
| **Structural Steel**<br>Check that bending, punching and shearing have been carried out in conformity with the recommendations in Chapter 9. |
| **Satisfactory Hot Dip Galvanizing**<br>Observance of the points listed below and described in more detail in Chapter 9 will ensure optimum galvanized product quality and minimise extra costs or delays.<br>1. Check that closed vessels and hollow structures are adequately vented for safety and optimal fill and drain holes have been provided to ensure satisfactory hot dip galvanizing.<br>2. Check that all welding slag has been adequately removed.<br>3. Check that assemblies comprising castings and steels of widely differing surface conditions have been abrasive blast cleaned to minimise differences in galvanized finish.<br>4. Check that castings are abrasive blast cleaned before despatch unless otherwise arranged. Check that large grey iron castings have been normalised.<br>5. Check that appropriate temporary or permanent markings are provided. |

*Table 21.*

mance. The well-known spangle effect found on some hot dip galvanized surfaces is a factor of primary crystallisation. It is chiefly dependant upon the zinc bath chemistry, the rate of cooling, the method of pickling, the steel chemistry, and the thickness of the coating. In fact, dull grey or patchy matte grey hot dip galvanized coatings give service lives equal to or greater than bright or spangled coatings. Variations in coating appearance or finish are important only to the extent that they will affect corrosion performance or the intended use of the article. The primary function of a hot dip galvanized coating is corrosion protection. Specific requirements beyond the standard set out in **SANS 121/ISO 1461**, (eg. aesthetic appearance) should be communicated to the galvanizer in writing or negotiated at the contract review stage.

In order to comply with additional requirements, the following information may be requested by the galvanizer:-

a) Steel composition.
b) Identification of significant surfaces which require special care.

*A significant surface can be defined as a surface which impacts on the performance of that article..*

c) A visual standard should be established if a special finish is required.
d) Any particular special treatments that are required before or after hot dip galvanizing. Special treatment can include painting after hot dip galvanizing, where any renovation requirement and material should be discussed before galvanizing. *Refer Chapter 15.*
e) Deviation from standard coating thickness. See information below *table 20.*

| DEGREE OF FLATTENING FOR TESTING COATING ADHERENCE FOR TUBES | |
| --- | --- |
| **Tube type** | **Distance between platens** |
| Square | 75% of side |
| Rectangular tube | 75% of shorter side |
| Round ≤ 21.3mm | 85% of outside diameter |
| Round > 21.3 ≤ 48.3mm | 80% of outside diameter |
| Round > 48.3 ≤ 76.1mm | 75% of outside diameter |
| Round > 76.1 ≤ 114.3mm | 70% of outside diameter |
| Round > 114.3mm | 65% of outside diameter |

*Table 22.*

f) The presence of flame, laser or plasma cut surfaces.
g) Where fabrications include internal cavities, provide written evidence that adequate venting has been provided.
h) Coating inspection arrangements.
i) Whether a certificate of conformance is required.

For ensuring optimum appearance of the hot dip galvanized coating after installation, *refer to Installation Do's and Don'ts, figure 106 on page 48.*

## 11.5 ADHESION OF THE COATING

Acceptable adhesion is related to the practical conditions pertaining during transportation, erection and service. Hot dip galvanized coatings should be sufficiently adherent to withstand normal handling without peeling or flaking regardless of the nature and thickness of the coating. Bending or forming, other than straightening by the galvanizer after hot dip galvanizing, is not considered to be normal handling.

When reactive grades of steel or very thick sections are hot dip galvanized, coatings which are thicker than usual may occur. The galvanizer has limited control over the formation of thicker coatings, since this is a function of the chemical composition of the steel. Extended immersion time also plays a role. Heavy hot dip galvanized coatings greater than 250μm thick, may have brittle tendencies. Interpretation of the standard adhesion tests must take this into consideration. The requirements for careful transportation, handling and erection should be evaluated against the additional corrosion protection afforded by these thicker coatings.

## 11.6 TESTING FOR ADHESION

Testing for adhesion is not necessarily a true measure of the adhesive strength of the metallurgical bond between the hot dip galvanized coating and the base steel, but it does serve as an indicator of the adhesion properties of the coating.

**Paring test**
This simple but effective test is conducted by cutting or prying the hot dip galvanized coating with a sharp knife. Considerable pressure is exerted in a manner tending to remove a portion of the coating. Adherence is considered satisfactory when it is possible to remove only small particles of the coating. It should not be possible to peel any portion of the coating in the form of a layer so as to expose the underlying iron or steel in advance of the knife. Although not mentioned in **SANS 121/ISO 1461**, this test has shown practical significance as a test for adhesion.

**Cold flattening test (galvanized tube)**
For compliance with **SANS 32/EN 10240**, the most popular test is cold flattening in accordance with **SANS 8492/ISO 8492.** Test pieces not less than 40mm in length are flattened between parallel flat platens as shown in *table 22.* No cracking or flaking of the coating shall occur on the surface away from the cut surface.

**Bend test (galvanized tube)**
The bend test shall be carried out using a tube bending machine, and the test piece shall be bent through 90° round a former having a radius at the bottom of the groove equal to eight times the outside diameter of the tube.

***Note 2:*** *Should the above requirement of bending be implemented for the fabrication of gates, etc. after hot dip galvanizing, the maximum coating thickness should be no greater than 40% more than the minimum required in table 23.*

| MINIMUM COATING THICKNESS ON STEEL TUBES TO SANS 32/EN 10240 | | | | |
| --- | --- | --- | --- | --- |
| | COATING QUALITY | A1 | A2 | A3 |
| **Mandatory** | Minimum local coating thickness on the inside surface except at the weld bead | 55μm | 55μm | 45μm |
| | Minimum local coating thickness on the inside surface at the weld bead | 28μm | 1) | 1) |
| **Options** | Minimum local coating thickness on the outside surface | 2) | 2) | 2) |
| | COATING QUALITY | B1 | B2 | B3 |
| **Mandatory** | Minimum local coating thickness on the outside surface | 55μm 3) | 40μm | 25μm |
| 1) This requirement does not apply | | | | |
| 2) This requirement applies when the purchaser specifies Option 1 | | | | |
| 3) Option 3 specified (if >55μm required, purchaser to specify according to SANS121/ISO 1461) | | | | |
| Coating qualities 'A' and 'B' refer to end application with quality 'A' being for gas and water installations and 'B' for other applications. The number following the quality letter refers to specific requirements in terms of coating thickness. ***NOTE:*** In South Africa, **SANS 32/EN 10240** to quality A1 replaces the previous **SABS 763,** B4 coating. | | | | |

*Table 23.*

# Corrosion Resistance of Hot Dip Galvanized Coatings

***The life of a hot dip galvanized coating is more or less proportional to its thickness in a given environment. (Table 2).***

Hot dip galvanized coatings on steel protect against corrosion in two ways:

1 - Barrier protection is provided by a virtually non-porous film which isolates the steel substrate from corrosion inducing substances in the surrounding environment.

2 - Cathodic or sacrificial protection is provided at small uncoated surfaces while corrosion creep under the surrounding coating cannot occur.

The corrosion rate of zinc is low in most environments. This is due to the natural formation of a stable protective film of zinc conversion products which develops on the surface of the coating.

## 12.1 THE CORROSION TEST

**Summary**

The selection of coatings for corrosion resistance is a process which normally combines practical experience and scientific knowhow. One aid in the process is the corrosion test.

Testing the corrosion resistance of materials is necessary in order to identify materials, coatings, and designs that will help prevent corrosion damage. However, these tests can be confusing and even misleading if they are not understood and conducted properly.

*Figure 83. Exposed surface of a hot dip galvanized coating with outer layer of pure zinc. The shiny surface disappears to be replaced by grey corrosion products (sometimes called zinc patina).*

**USED BY THE HDGASA TO DETERMINE SERVICE LIFE OF HOT DIP GALVANIZED STEEL EXPOSED TO VARIOUS ATMOSPHERIC ENVIRONMENTS**

**Reference Source: ISO 9223:1992**

| Category | Corrosivity | Description of Typical Corrosive Atmosphere |
|---|---|---|
| C 1 | Very Low | Interior: dry |
| C 2 | Low | Interior: occasional condensation<br>Exterior: exposed rural inland |
| C 3 | Medium | Interior: high humidity, some air pollution<br>Exterior: urban inland or mild coastal |
| C 4 | High | Interior: swimming pools, chemical plant, etc.<br>Exterior: industrial inland or urban coastal |
| C 5 | Very High | Exterior: industrial with high humidity or high salinity coastal |

*Table 24: Description of categories of atmospheric corrosivity.*

The typical descriptions detailed in *Table 24* are intended as a general guide and it is recommended that a review of actual site conditions should be undertaken before finalising the applicable corrosive category. A general review of existing hot dip galvanized structures is an ideal method used to establish the corrosive conditions in the general area of a particular site.

| Corrosivity Category | Corrosion Rates ($r_{corr}$) of Hot Dip Galvanized Coated Steel (Ref ISO 1461:2009) | | | | |
|---|---|---|---|---|---|
| | Units | Zinc | 55µm for steel ≥ 1.5mm to ≤ 3mm | 70µm for steel > 3mm to ≤ 6mm | 85µm for steel > 6mm |
| C 1 | µm/a | $r_{corr} \leq 0.1$ | > 100 years | > 100 years | > 100 years |
| C 2 | µm/a | $0.1 < r_{corr} \leq 0.7$ | ≤ 78.5 years | > 100 years | > 100 years |
| C 3 | µm/a | $0.7 < r_{corr} \leq 2.1$ | 26 to ≤ 78.5 years | 33 to ≤ 100 years | 40 to > 100 years |
| C 4 | µm/a | $2.1 < r_{corr} \leq 4.2$ | 13 to ≤ 26 years | 16 to ≤ 33 years | 20 to ≤ 40 years |
| C 5 | µm/a | $4.2 < r_{corr} \leq 8.4$ | 6.5 to ≤ 13 years | 8.3 to ≤ 16 years | 10 to ≤ 20 years |

*Table 25: Estimated Service Life for Hot Dip Galvanized Steel complying with SANS 121 (ISO 1461:2009) and subjected to Atmospheric Environments Classified in terms of ISO 9223:1992.*

The figures for service life estimated in *table 25* are intended as a general guide and it is recommended that a more detailed assessment of the actual site environmental conditions should be conducted in order to define longevity expectations for hot dip galvanized coated steel.

It is worthwhile noting that general hot dip galvanizing specifications state the local (minimum) and the mean coating thicknesses *(see tables 19 and 20)*. The coating thickness actually achieved in practice, varies with steel composition and this can range from the minimum up to at least 50% greater. As life expectancy predictions in *table 25* are based on the minimum coating thickness, they are conservative.

**Standardised tests**

Many types of corrosion tests have been developed. Some are standardised tests spelled out by associations such as ASTM or the National Association of Corrosion Engineers (NACE). Others are in-house tests designed to simulate actual field conditions.

Standardised tests have the advantages of reproducibility and general acceptance. These tests have usually been evaluated in a number of locations (round-robin testing) to verify that results are not affected by local conditions.

*Figure 84. Discoloured surface on lighting column. Coating consists mainly of an iron/zinc alloy that grows out to the surface. Iron is freed during corrosion, which leads to rust formation. It is only surface rust and is of aesthetic significance only. The bracket for the traffic sign has a coating of pure zinc as an outer layer.*

So many factors affect corrosion, however, that these standardised tests may not adequately simulate field conditions. For example, one of the most commonly used tests for corrosion resistance is the ASTM-B117 salt spray test. Results of this test are still frequently quoted in automotive product specifications, although the test has virtually been dismissed by auto manufacturers, primarily because it shows that zinc coated steel does not perform as well in an automotive environment as plain cold-rolled steel. Field experience has proven the opposite to be true.

Electrochemical tests are appealing because of their precision. By immersing electrodes made of the materials being evaluated in the electrolyte that the materials will be exposed to in service, a galvanic cell is created similar to that in a battery. Because corrosion is an electrochemical process, the measured potential and current flow between electrodes can be correlated with corrosion rates. However, these tests do not necessarily reflect actual service conditions, such as when the materials are alternately wetted and dried. Without valid parameters, results from electrochemical tests can be misleading as any other corrosion test.

Another common mistake in corrosion testing is to try to extrapolate long-term data from short-term tests, or to rely on data from a single sample. If the corrosion process does not reach steady state during the test, then results can be misleading. Use of several specimens is also recommended to get a good statistical sampling.

## 12.2 CORROSION RESISTANCE IN THE ATMOSPHERE

When a hot dip galvanized article is withdrawn from the molten zinc, the coating surface immediately reacts with oxygen and moisture to form combinations of both zinc oxide and zinc hydroxide. Carbon dioxide in the atmosphere rapidly converts these surface conversion products into a stable, tightly adhering, basic zinc carbonate film with very low solubility. This ensures that further attack of the underlying zinc is prevented. The initial shiny surface with a metallic lustre disappears to be replaced by a matt, light grey appearance *(figure 83)*.

The atmosphere contains greater or lesser corrosive substances such as chlorides, in marine environments and sulphur dioxide associated with industrial pollution. Humidity levels, rain patterns and condensation all influence the degree of corrosion. The different factors can occur in favourable or unfavourable sequences, one after another, alternately, or in combination with each other.

It is normal to differentiate between corrosion rates in:

1. rural environments
2. marine (coastal) environments
3. urban environments
4. industrial environments

*(See tables 24 and 25).*

The atmosphere in cities and industrial areas contains various pollutants. These are able to attack the stable zinc carbonate film producing more soluble products which can be washed away. Consequently the corrosion rate of galvanized steel will accelerate. Modern environmental controls are resulting in lower pollution levels and hot dip galvanizing offers good protection in locations where previously limited coating life was experienced.

In marine environments the corrosion of zinc is influenced by the salt content of the air. However, marine air contains small quantities of magnesium salts, with good passivating influences. Corrosion is therefore not as great as may be expected. The salt content of the air usually diminishes rapidly away from the coastline ie. by 80% over the first 800m from the high water mark.

The colour of zinc corrosion products varies according to the environment in which they are formed. Marine environments give somewhat whiter corrosion products compared with rural and urban environments. Corrosion products are usually darkest in urban environments.

The corrosion of zinc is influenced by many factors. This means that a generally applicable formula for corrosion rates can not be given.

The ubiquitous nature of hot dip galvanizing means that there is always a product such as a lamp post or fence near a proposed future site that can be used to predict future performance.

The Hot Dip Galvanizers Association have frequently been involved in the assessment of the corrosive conditions prevailing at a particular site, prior to the selection of the final coating specifications. Knowledge about the corrosion of zinc, and corrosion rates in different environments, is therefore extensive.

**Reddish-brown discolouration**

Some hot dip galvanized steel can adopt a reddish-brown colour after a period of exposure. After prolonged exposure, particularly in sulphur-rich atmospheres, this discolouration can gradually turn black. The discolouration occurs mainly on coat-

*Figure 85. Wet storage stain that has formed between tightly packed angles.*

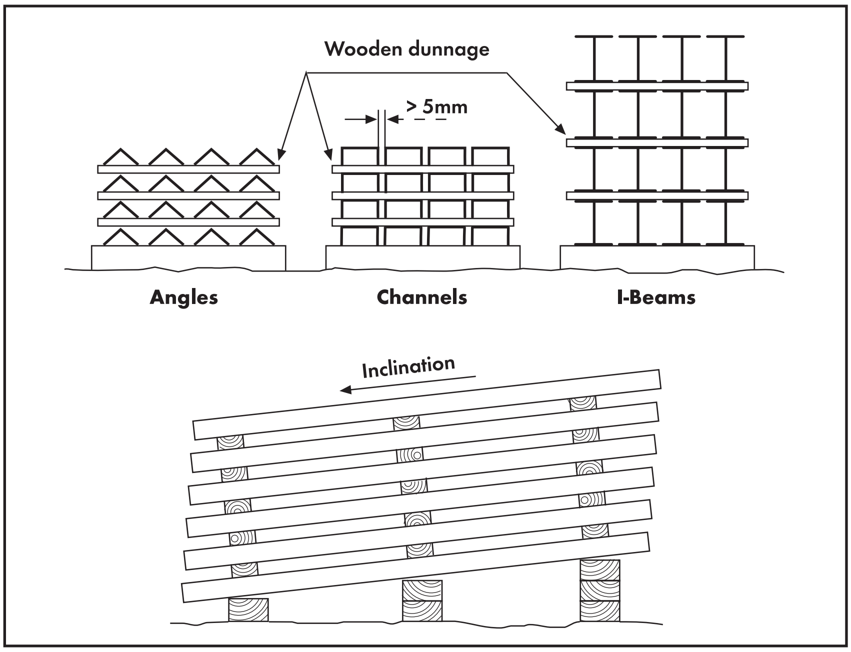



*Figure 86. In order to avoid the formation of wet storage stain on newly galvanized surfaces, profiled steel, beams and structures should be packed at an angle and turned to prevent the accumulation of water. Spacers are placed so as to avoid narrow crevices between the zinc surfaces.*

| | |
|---|---|
| Electro-positive end – more noble metals ↑ | Gold |
| | Silver |
| | Stainless steel (304) |
| | Nickel |
| | Monel |
| | Aluminium bronze (95% Cu, 5% Al) |
| | Copper |
| | Brass |
| | Tin |
| | Lead |
| Electro-negative end – more reactive metals ↓ | CAST IRON, unalloyed |
| | CARBON STEEL |
| | Cadmium |
| | Aluminium |
| | ZINC |
| | Magnesium |

*Table 26. Electrochemical potential scale in sea water at +25°C.*

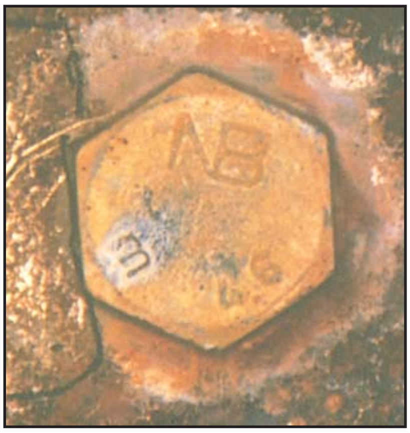


*Figure 87. Galvanized bolt in contact with 3CR12 plate after 10 cycle SO2 test. Note the cathodic protection provided by the galvanized bolt head to the surrounding steel.*

ings consisting largely of iron/zinc alloy on silicon-killed steels.

The source of discolouration is the corrosion of Fe/Zn alloy to form rust in the presence of humid air or rain water. Rust has a great ability to stain, and even small amounts can cause considerable discolouration.

Sometimes when discolouration is severe it is natural to conclude that rust protection has been greatly reduced, or completely destroyed. However, this is seldom the case. The iron/zinc alloys give better protection (in most environments up to 30-40% greater) to the underlying steel than pure zinc.

If appearance is important, discoloured surfaces can be painted *(figures 30, 31 and 84).*

## 12.3 WET STORAGE STAIN

Sometimes a white, floury and voluminous coating called wet storage stain, or white rust, appears on galvanized surfaces *(figure 85).*

The deposit forms on freshly galvanized, shiny surfaces and particularly between closely packed sheets, angles and similar products. A pre-requisite is that the material is exposed to condensate or rain water in conditions where the moisture cannot evaporate quickly. Zinc surfaces that have already formed a normal protective layer of conversion products are seldom attacked.

When freshly galvanized surfaces are exposed to the atmosphere, soluble zinc oxide and zinc hydroxide are formed. Under the influence of carbon dioxide in the air basic zinc carbonate is formed. If air access to the zinc surface is restricted, as in narrow crevices, then the area receives insufficient carbon dioxide to enable the normal layer of zinc carbonate to form.

The wet storage stain deposit is voluminous and porous, and attached only loosely to the zinc surface. As a result, protection against continued attack does not exist. Corrosion can therefore continue as long as moisture remains on the surfaces. When wet storage stain has occurred the object should be stacked to enable the surfaces to dry quickly. This will stop the attack and, with free access to air, the normal protective layer will be formed. The wet storage stain is gradually washed away and the coating acquires an appear-

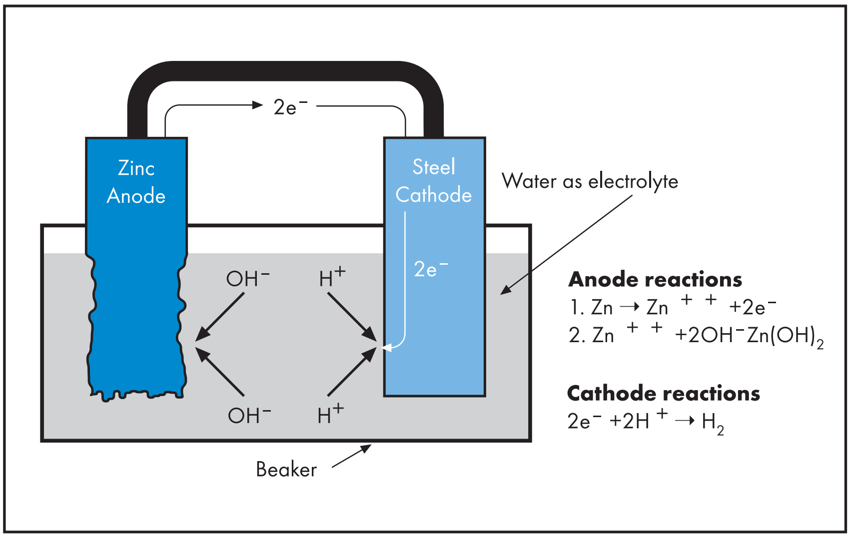



*Figure 88. Galvanic corrosion of zinc in contact with steel in water.*

Figure 89. After 20 years of marine exposure, this site cut unrepaired hot dip galvanized steel grating still offers cathodic protection at the cut ends.

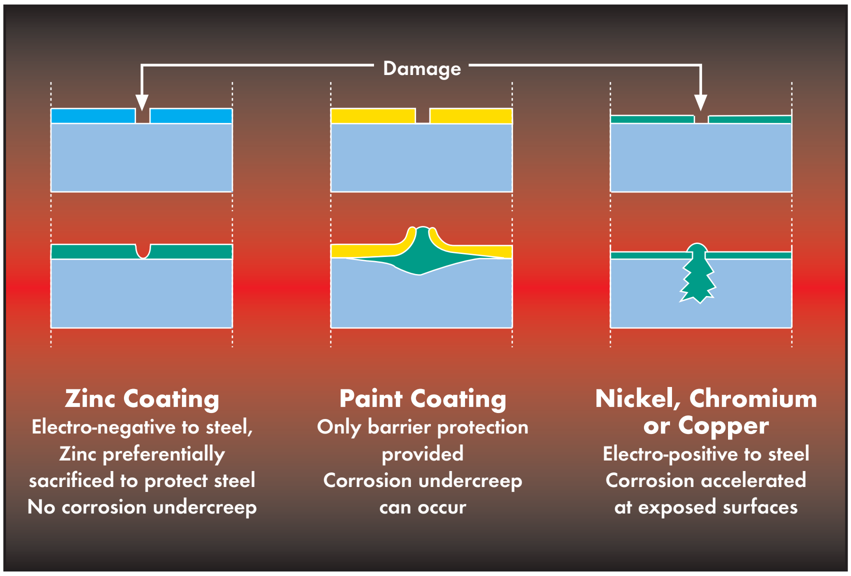



Figure 90. Schematic diagram to illustrate the consequences of damage to different types of coatings offering corrosion protection.

ance that is normal for exposed, hot dip galvanized steel.

Since the product of wet storage stain is very bulky (about 4.5 times the solid volume of zinc from which it is formed), an attack can appear to be serious. However, wet storage stain often has little or no significant impact on the service life of the coating but in the case of very thin coatings a severe attack of wet storage stain can be significant.

Wet storage stain is best avoided by preventing closely packed galvanized surfaces from coming into contact with rain or condensate. Freshly galvanized material which is exposed to the elements should be stacked in a manner that ensures free air circulation *(figure 86)*. Temporary protection against wet-storage stain is obtained through chromating or phosphating.

Wet storage stain which has already formed can be removed completely or partially by moderate mechanical or chemical treatment. *See "Removal of Wet Storage Stain" page 16.*

## 12.4 GALVANIC, BIMETALLIC AND CREVICE CORROSION

Corrosion can be defined as an electrochemical process. Galvanic or bimetallic corrosion occurs when two different metals or alloys in the presence of an electrolyte, are in direct electrical contact with each other. Basis corrosion theory states that for corrosion to take place, there are four essential requirements, i.e. an anode, a cathode, an electrolyte and

Figure 91. Stainless steel fasteners attached to hot dip galvanized plate in immersed conditions, note the sacrificial attack of the zinc coating surrounding uninsulated fasteners compared with the insulated fastener where no attack of the surrounding zinc has taken place.

an electrical circuit. If one of these is absent, corrosion ceases *(figure 88)*. Different metals possess different electrochemical potentials as shown in *table 26*. The electronegative and more reactive metals will corrode in preference to a more electropositive metal when the two are in direct electrical contact, i.e. the anode is attacked whereas the cathode is protected. The electrical potential scale of some metals may vary, depending on the electrolyte but the information contained in *table 26* which relates to sea water is typical for most liquids.

If hot dip galvanizing is in direct contact with 3CR12, stainless steel or brass, it constitutes the anode and it will be preferentially attacked *(figures 87, 91 and 92)*. On the other hand, if steel is coupled to cadmium, aluminium, zinc or magnesium, it will constitute the cathode and be protected, while the anodic material is consumed.

A hot dip galvanized coating primarily provides barrier protection since in most environments it corrodes at a substantially slower rate than steel. The second line of defense is however the cathodic or sacrificial protection at small uncoated

Figure 92. Brass bolt in hot dip galvanized steel on a parking deck.

surfaces which is provided by the electronegative potential of zinc in relation to carbon steel.

Zinc coatings on steel are unusual, since a fairly large area of damage to the coating does not cause catastrophic corrosion *(figures 89 and 90)*. The range of cathodic protection is dependent on coating thickness and the nature of the electrolyte that creates the cell. For structures in normal atmospheres it is usual to expect protective action over several millimetres. However, in sea water significantly greater distances can be expected.

The impact of bimetallic corrosion can be prevented by the provision of a paint or other insulating material between the dissimilar metals.

The concept of sacrificial protection is harnessed to provide cathodic protection to structures subjected to severe corrosive conditions such as immersion in aggressive water or corrosive soils. Zinc or magnesium anodes are attached to steel components to provide protection to the steel. These sacrificial anodes are replaced once they have been consumed.

Hot dip galvanized components in contact with aluminium conductors may require the use of an electrical conducting compound at joint faces to repel moisture and inhibit corrosion.

Crevice corrosion can occur in conditions of high humidity at overlapping hot dip galvanized surfaces. This can be prevented by the application of an inhibitive jointing compound in accordance with SANS 1305. Alternatively a suitable paint may be used. Hot dip galvanized surfaces in contact with other materials also require insulation.

## 12.5 CORROSION RESISTANCE OF HOT DIP GALVANIZED COATINGS IN AQUEOUS CONDITIONS

**General**

Zinc carbonate, the protective film formed over a hot dip galvanized coating, is relatively insoluble in water. However, this stability is restricted to an acid/alkali pH range of 6 to 12,5. Zinc is amphoteric in nature; that is, it forms soluble salts at low and high pH values. This is clearly shown in *figure 93*.

Notwithstanding the above, water contains numerous dissolved salts as well as carbon dioxide and oxygen in solution. Organic matter can be picked up by water as it passes over vegetation. This can also be a major contributor to corrosion in some instances. The effects of water quality on the corrosion rate are summarized in *figure 94*.

In soft waters, zinc corrosion is accelerated. Also, the tolerance for chloride salts is reduced. A reserve alkalinity level is required to stabilize the zinc carbonate film. This is generally assumed to be of the order of 50 - 75mg/l (as $CaCO_3$). In hard waters, high chloride levels (>2000mg/l) can be tolerated. Sulphates, nitrates and phosphates are generally considered to be protective towards hot dip galvanizing. However, when combined with ammonia compounds (such as with fertilizers) soluble zinc compounds may be formed and acid conditions can arise causing attack of hot dip galvanized steel. Organic compounds such as tannins will arrest the corrosion of hot dip galvanized steel but the settling of solids can create conditions for crevice corrosion. Similarly, slime build-up should be avoided as microbially induced corrosion (MIC) can occur, leading to rapid attack.

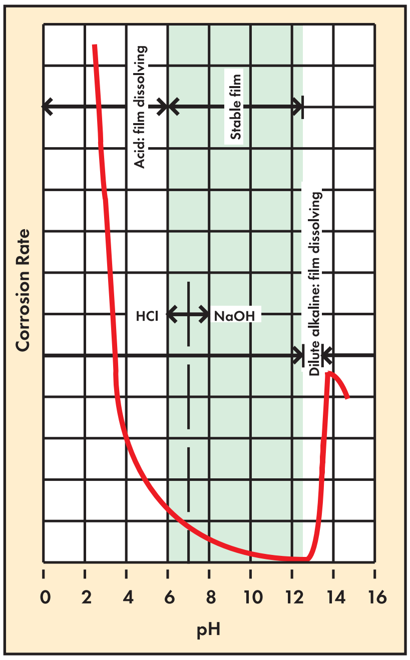



*Figure 93. The influence of pH on the corrosion rate of zinc in aerated ($CO^2$ free) solutions. (Dilute HCl and NaOH at 30°C). Note: The curve only applies for continuous exposure under the specific conditions. For other conditions it can be used as a guide. In hard/scale forming waters protective layers are formed which greatly alter the curve.*

Flow rates should be maintained at sufficiently high levels to ensure that all debris is held in suspension rather than allowed to settle. It should be considered "good practice" to flush systems on a regular basis. This should be carried out on all fire protection systems although, as the water entering these systems is generally of good quality, corrosion rates tend to be low provided that MIC does not occur. In all instances, the corrosion performance of galvanized piping in fire protection systems is far superior to that of bare steel. Crevice or under deposit corrosion is likely to occur where sediment becomes dense and compacted. This may result in the provision of anaerobic sites suitable for the start of MIC.

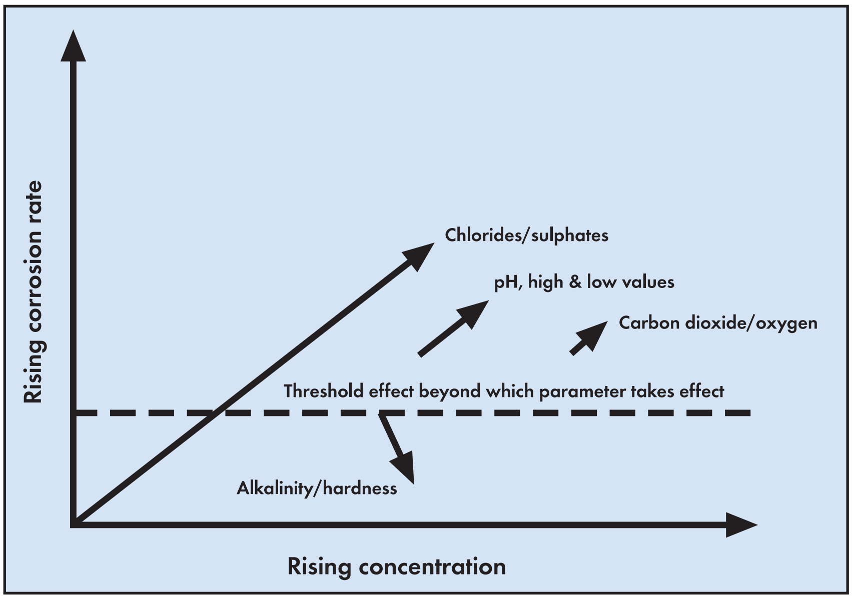



*Figure 94. Effects of water quality on the corrosion rate of a hot dip galvanized coating.*

Under normal circumstances the amount of dissolved oxygen in a water would be sufficient to ensure that no deleterious effects occur. However, anaerobic or septic conditions can affect hot dip galvanized piping adversely as is the case with other metals. For drinking water purposes some form of chlorination is generally applied. Therefore, in normal distribution systems anaerobic conditions giving rise to MIC, should not occur. It is important when testing water lines that clean water be used **and the system drained if it is to be left unused for some time.** Chlorination has no effect upon the protective properties of galvanizing. High oxygen levels accelerate the corrosion rate of zinc. Similarly, high carbon dioxide levels tend to pro-

| No. | Aggressiveness | Soil Condition | Resistivity in ohm | Method of protection |
|---|---|---|---|---|
| 1 | low | dry | >100 | Hot dip galvanizing > 200µm |
| 2 | low | moist | >450 | Hot dip galvanizing > 200µm |
| 3 | moderate | dry | <100 | Hot dip galvanizing > 200µm plus a rust allowance on the basis material of 0.5mm on each side. |
| 4 | moderate | moist | 150-450 | Same as for 3 |
| 5 | high | moist | 50-150 | Hot dip galvanizing > 200µm and rust allowance of 1mm on each side. |
| 6 | very high | moist (In certain cases $H_2SO_4$ can form) | <50-100 | Same as for 5 but rust allowance of 1.5mm on each side |

*Table 27. Soil aggressiveness at different resistivity levels with hot dip galvanized coatings.*

| Soil type | Aggressiveness |
|---|---|
| Lime, calcareous marl, moraine, sand marl | Low |
| Sand, gravel | Moderate |
| Clay, peat, bog, humus-rich soils | High |

*Table 28. Corrosivity of different soil types.*

| VALUE | PARAMETER | UNIT | RATING |
|---|---|---|---|
| **CONDITION OF WATER** | | | |
| A | Flowing | | 2 |
| | Standing | | 1 |
| | Anaerobic | | -5 |
| **CORROSIVITY INDEX *** | | | |
| B | <1 | | 0 |
| | ≥1, <2 | | -1 |
| | ≥2, <5 | | -2 |
| | ≥5 | | -4 |
| **TOTAL ALKALINITY** | | | |
| C | <50 | ppm as (CaCo3) | -1 |
| | ≥50, <200 | | 1 |
| | ≥200, ≤300 | | 0 |
| | >300 | | -1 |
| **CALCIUM HARDNESS** | | | |
| D | <50 | ppm as (CaCo3) | -1 |
| | ≥50, <200 | | 2 |
| | ≥200 | | 3 |
| **pH** | | | |
| E | <5.5 | | -6 |
| | ≥5.5, <6.5 | | -4 |
| | ≥6.5, ≤7 | | -1 |
| | >7 | | 1 |
| **CALCIUM CARBONATE PRECIPITATION INDEX** | | | |
| F | <-2 | | -2 |
| | ≥-2, <0 | | -1 |
| | 0 | | 0 |
| | >0, ≤6 | | 1 |
| | >6 | | 0 |
| **Probability = Sum (A to F)** | | | |
| Result | | Performance | |
| Greater than 1 | | Satisfactory (+25 years) | |
| 1 to -1 | | Fair | |
| -3 to -5 | | Unsatisfactory | |
| * Corrosivity index (B) can be calculated by - (Cl x 0,03) + ($SO_4$ x 0,04) | | | |

*Table 29. Probability of performance.*

duce acid conditions, which can accelerate corrosion in flowing systems.

**Effect of water temperature**
Hot dip galvanized piping has been used for hot water supplies with no deleterious effects in many applications. However, when used above 65°C the zinc is no longer protective to exposed steel. It is therefore recommended that hot dip galvanized systems not be used above 65°C.

The electricity supply commission (Eskom), advise that with proper pipe insulation, the maximum temperature for hot water cylinders be 60°C. For practical purposes therefore, hot dip galvanized piping is acceptable for use in both hot and cold water systems.

In domestic systems copper should only be used downstream of hot dip galvanized piping. This will avoid the possibility of pitting corrosion.

**Effect of sea water**
Hot dip galvanized coatings perform relatively well in submerged seawater conditions which are severely corrosive to most protective systems. Dissolved salts present in seawater react with zinc to form a protective layer minimizing corrosive action. The pH of seawater tends to be constant worldwide as a result of the buffering action of the hydrogen-carbonate salts present. The presence of pollutants is equally not detrimental provided that levels are within internationally acceptable norms.

A simple nomogram *(table 29)* has been produced to allow the specifier to determine the suitability of hot dip galvanizing for the protection of steel piping in water. This provides guidance based upon the water quality and general operating conditions likely to be encountered. More detailed information is contained in **ARP 060:** *Guidance on the use and application of hot dip galvanized steel piping for the transportation of potable water in South Africa.*

## 12.6 CORROSION RESISTANCE OF HOT DIP GALVANIZED COATINGS IN SOIL CONDITIONS

Soil can contain weathered products, free or bound salts, acids and alkalis, mixtures of organic substances, oxidizing or reducing fungi, micro-organisms, etc.. Depending on its structure, soil has different degrees of permeability to air and moisture. Normally, the oxygen content is less than in the air, while the carbon dioxide content is higher. The corrosion conditions in soil are therefore very complicated and variations can be great between different locations, even those in close proximity to each other.

Southern African soils vary from highly corrosive in some regions to moderately corrosive in others.

One method of determining the corrosivity of a soil is to measure its resistivity. Recommendations are given in *table 27.*

If the resistivity of the soil cannot be determined, the rule-of-thumb method listed in *table 28* can give a measure of guidance. Where the exposure of metals to soil is concerned, it is advisable to seek expert advice from suitably qualified sources.

## 12.7 HOT DIP GALVANIZED STEEL IN CONTACT WITH BUILDING MATERIALS

**Mortar, plaster and wood**
Damp mortar and plaster attack zinc. The attack ceases when the material dries out. Dry or moderately damp wood, both impregnated and unimpregnated, can be nailed with hot dip galvanized nails to good effect. However, in the case of nails or threaded unions that are constantly exposed to water an acid-resistant material is preferred. Other dry building materials, such as mineral wool, do not attack zinc.

Wood with acidic properties should not come into contact with galvanized steel.

**Concrete**
Unprotected reinforcement can corrode in certain environments when moisture penetrates the concrete through cracks and pores. Since rust has a greater volume than the steel from which it was formed, the covering layer over the reinforcement can crack and spall *(figure 96).*

Steel components such as bolts and edge guards that have been partly grouted in are often poorly protected against rust. Apart from crack formation and scaling, a problem occurs with unsightly rust staining on the concrete surfaces below.

*Figure 95. Hot dip galvanized reinforcing bars prior to casting concrete, marine conditions.*

This kind of damage can be avoided if the reinforcing steel is hot dip galvanized *(figure 95)*. Hot dip galvanized reinforcing steel or mesh can therefore be used in grouted facade sections. One of the advantages of this is that there is no risk of rust runs discolouring the facade.

According to the Building Research Establishment in the UK, the average adhesion for smooth reinforcement steel in concrete is as follows:

| | |
|---|---|
| hot dip galvanized steel | 3.3-3.6 MPa |
| black steel | 1.3-4.8 MPa |

Local pull out tests confirm these results.

The large range for black steel stems from different degrees of rust and compositions of oxide scale.

According to work done in Finland, the stress for 0,1 mm of slip in reinforcement bars in concrete is approximately as follows:

| | |
|---|---|
| black steel | 150 MPa |
| hot dip galvanized steel | 160 MPa |
| hot dip galvanized and chromated steel | 190 MPa |

When concrete is cast its pH value is around 13. At this high pH, fresh zinc is attacked and hydrogen is produced, which could give rise to poor adhesion. However, the attack ceases as soon as the concrete has hardened and any residual pores are not harmful.

In order to avoid fresh zinc surfaces coming into direct contact with wet concrete it is advisable to allow the galvanized steel to age for several weeks. The cover layer of basic carbonates which then appears will minimize both attack and the production of gas, and will also promote adhesion. Another common way of limiting a reaction from fresh concrete is to chromate the galvanized steel. A further alternative is to add about 40ppm (by mass) of chromates, to the water when concrete is mixed.

### 12.8 ABRASION RESISTANCE OF HOT DIP GALVANIZED COATINGS

Pure zinc is a soft metal, even though it is harder than most organic coating materials. The iron/zinc alloys produced in hot dip galvanized coatings are, however, very hard. In fact, they are harder than ordinary structural steel *(figure 97)*.

The alloys are therefore more resistant to abrasion than pure zinc and experiments have shown that the alloy layer has a resistance to abrasion 4-5 times that of pure zinc.

Hot dip galvanized articles are often used when the surface is to be subjected to abrasion. Examples of this include stairs, floor hatches, hand railings, grid flooring and walkways *(figure 5)*.

### 12.9 HOT DIP GALVANIZED COATINGS EXPOSED TO ELEVATED TEMPERATURES

Conventional zinc coatings can be exposed continuously to temperatures up to about 200°C and non-continuously to temperatures of up to 350°C.

At sustained temperatures in excess of 200°C a diffusion reaction begins inside the coating and causes the outer layer to split-off from the underlying iron/zinc layer. However, the iron/zinc layer has a very good resistance to corrosion and can, depending on its thickness, protect the steel from rust for a very long time.

Aluminium-alloyed zinc layers on thin sheet can resist even higher temperatures. Aluzinc and galvalume for instance, can withstand sustained temperatures up to 315°C.

*Figure 96. Spalling of the concrete layer on reinforcing steel on the underside of a concrete bridge.*

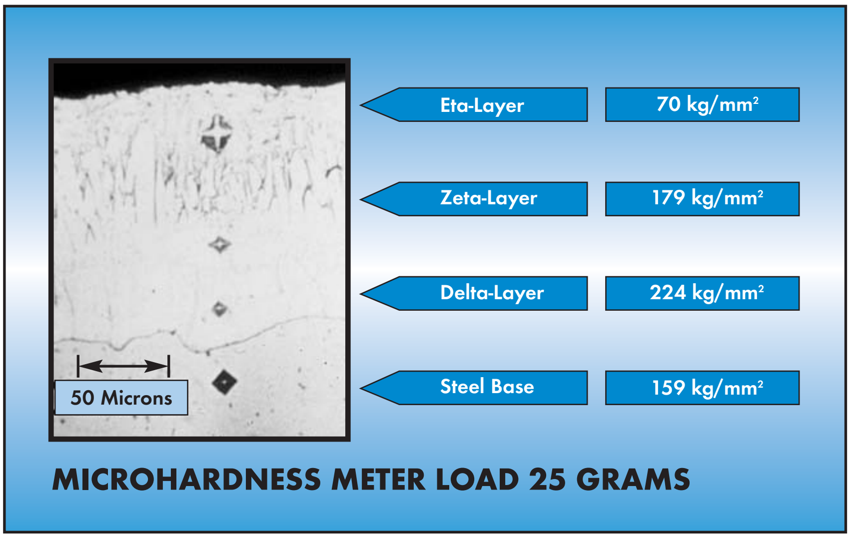



*Figure 97. Microsection of a hot dip galvanized coating showing variations in hardness through the coating.*

# Bolted Connections

Bolted connections are one of the most widely used, versatile and reliable methods for joining structural steel members. Some of the advantages of bolting over methods such as welding and rivetting are:

- Economy, speed and ease of erection;
- Reliability of service;
- Ease of inspection
- Fewer, and less highly skilled operators required;
- Reliable performance under fluctuating stresses;
- No pre-heating of high strength steels;
- No weld cracking or induced internal stresses;
- No lamellor tearing of plates;
- No heat damage to the coating on hot dip galvanized or painted structures.

## 13.1 TYPE OF STRUCTURAL BOLTS AND FASTENING DEVICES

Low carbon steel bolts, generally known as class 4.8, have been in use for many years. Continuing development has produced high strength structural bolts for use in high strength bearing type joints and high strength friction type joints, which are referred to as class 8.8 and 10.9. These newer strength bolting methods have greatly increased the scope of structural bolting.

In terms of the **SANS 1700-7-7; SANS 1700-7-8; SANS 1700-14-8; SANS 1700-14-9; SANS 1700-14-10**, strength of structural bolts is specified in terms of the tensile strength of the threaded fasteners. Two numbers separated by a full stop are stamped on the bolt head. The first number represents one hundredth of the nominal tensile strength and the second number represents one tenth of the ratio between nominal yield stress and nominal tensile strength expressed as a percentage. For example, a grade 4.8 bolt has:

- Tensile strength of 4 x 100 = 400MPa;
- Yield strength of 0,8 x 400 = 320MPa.

A large variety of fastening devices, other than bolts and nuts, are used throughout industry and these include components such as spring clips where permanent retention of clamping force is essential.

## 13.2 CORROSION PREVENTION

While the mechanical properties of fastener assemblies are structurally dependable and cost effective, the durability of such connections will be influenced by the degree of corrosion encountered in service. Deterioration brought about by rusting can lead to the seizure of fasteners and premature failure, in the form of corrosion fatigue. Adequate corrosion protection of fasteners is, therefore of paramount importance if the overall integrity of a structure is to be retained throughout its life *(figures 98, 99 and 100)*.

*Figure 98. An assortment of zinc coated bolts showing the importance of coating thickness in a particular environment.*

*Figures 99 (left) and 100 (right). Corrosion protection of holding down bolts should be equal to that provided for main structures.*

In bolted steel structures the bolts and nuts are critical items on which the integrity of the entire structure depends. Protection from corrosion is provided by using corrosion resistant materials or by providing a protective coating, either before or after installation.

## 13.3 CORROSION RESISTANT METALS

The use of fasteners, manufactured from corrosion resistant metal alloys, frequently provides the most cost effective method of avoiding degradation by corrosion in very aggressive environments. Contact between dissimilar metals can result in galvanic corrosion, particularly where a large cathode is in electrolytic contact with a small anode. Austenitic stainless steel fasteners are used with success in many applications where there is contact with metals such as zinc and in mild to moderately corrosive environments, hot dip galvanized fasteners have proved successful for connecting components manufactured from Corten steel. The use of an organic coating over one or both metal coating interfaces of a joint prior to fastening, or the sealing of that joint after bolting, in an aggressive atmosphere will substantially increase the corrosion resistance of that joint.

*Table 30* provides a guide to the compatibility of various metals and alloys in contact in building applications. For example, it will be observed from the table that a zinc coated fastener (anode) connected to 300 series stainless steel (cathode) is unacceptable in a corrosive environment whereas zinc coated steel connected with 300 series stainless steel is acceptable.

## 13.4 PROTECTIVE COATINGS

A coating applied to fasteners must, of necessity, be tightly adhering and resistant to damage during and after assembly. For this reason, metal coatings applied, prior to assembly, are preferred. Additional protection, after assembly by means of a paint coating, is beneficial in aggressive environments, particularly when these metal coatings have been applied.

Coating metals used include zinc and noble metals such as nickel and tin. In the case of the more reactive metals, such as zinc, coating thickness is of paramount importance with corrosion life being more or less proportional to the coating thickness. Where metals, such as nickel and tin are used, thinner coatings will usually provide long term protection provided that these coatings are free from imperfections and not subjected to mechanical damage which, in corrosive conditions, will lead to accelerated corrosion of exposed underlying steel. The cost of providing protection by means of the more noble metals is high and this has restricted the general use of these coatings for the corrosion protection of fasteners in the structural steel industry.

## 13.5 HOT DIP GALVANIZING OF FASTENERS

Hot dip galvanizing of fasteners is a specialised process and the products should, therefore, be purchased via an SABS approved bolt manufacturer who will ensure that the correct manufacturing and galvanizing procedures, including oversize tolerances, etc., are adhered to.

*Hot dip galvanized fasteners in various forms are available as ex stock items from bolt stockists countrywide. Contact the Association for further information.*

**Oversize tapping allowance for hot dip galvanized nuts**

The zinc coating on external threads shall be free from lumps and shall not have been subjected to a cutting, rolling or finishing operation that could damage the zinc coating. The zinc coating of an external standard metric thread that has not been undercut shall be such as to enable the threaded part to fit an oversized tapped nut *(figure 101)* in accordance with the allowances given in *table 31 below.*

On bolts greater than M24, undercutting of bolt threads is frequently preferred to only oversizing of nut threads.

*Refer to **Note 1** in Chapter 10.*

**Influence of galvanized coatings on thread stripping strength**

In high strength bolting, correct tightening is essential, and the oversize tapping of galvanized nuts does not necessitate a reduction in the level of minimum tension which applies to uncoated fasteners. To meet this requirement, galvanized high strength nuts have a higher specified hardness than that demanded in the case of ungalvanized nuts.

**Bolt relaxation**

The possible effect of bolt relaxation, caused by the relatively soft outer zinc

| | CONTACT MATERIAL (FASTENER/WASHER) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aluminium and aluminium alloys | | Copper and copper alloys | | 300 series stainless steels | | Zinc coated steel and zinc | | Aluminium/zinc coated steel | | Lead | |
| Sheeting material | Industrial & marine | Rural | Industrial & marine | Rural | Industrial & marine | Rural | Industrial & marine | Rural | Industrial & marine | Rural | Industrial & marine | Rural |
| Aluminium and aluminium alloys | A | A | C | C | B | B | B | A | A | A | C | C |
| Copper and copper alloys | C | C | A | A | B | B | C | C | C | C | B | B |
| 300 series Stainless Steels | C | B | B | B | A | A | C | C | C | B | B | B |
| Zinc coated steel and Zinc | A | A | C | C | B | B | A | A | A | A | B | A |
| Aluminium/Zinc coated steel | A | A | C | C | B | B | B | A | A | A | C | C |
| Lead | C | C | A | A | A | A | B | A | C | C | A | A |

*Legend:*
*A = Acceptable. Increase in the corrosion rate of the sheeting or contact material will be zero or slight.*
*B = Acceptable, but increase in the corrosion rate of the sheeting or contact material can occur.*
*C = Do not use. Accelerated corrosion will occur, or the difference in the lives of the two materials is too great, or both.*

*Table 30. Metals and alloys between which direct contact is acceptable.*

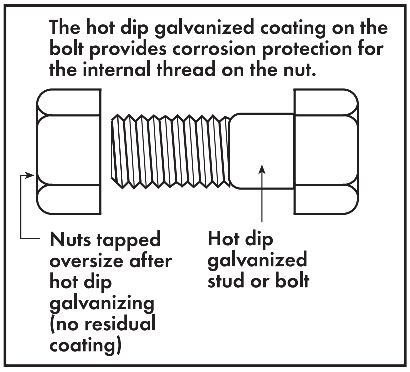



*Figure 101.*

| OVERSIZE TAPPING ALLOWANCE FOR HOT DIP GALVANIZED NUTS | |
|---|---|
| **Nominal Size of Thread** | **Allowance (mm)** |
| M8 to M12 | 0.33 |
| M16 to M24 | 0.38 |
| >M24 = M27 | 0.43 |
| >M27 = M30 | 0.47 |
| >M30 = M36 | 0.57 |
| >M36 = M48 | 0.76 |
| >M48 = M64 | 1.0 |

*Table 31. Recommended oversize tapping allowance.*

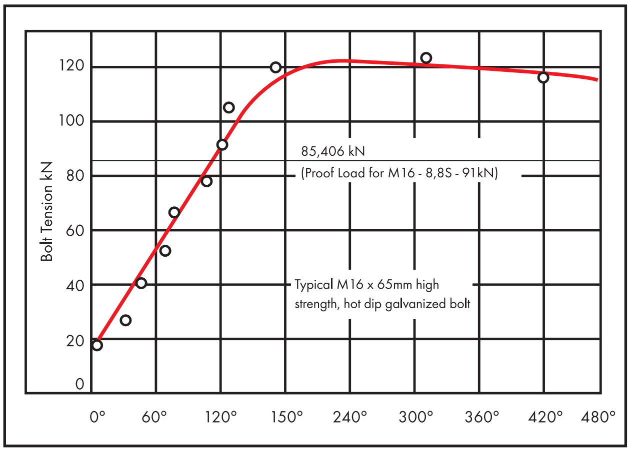



*Figure 102. Demonstration of tensioning results obtained by the turn of the nut method.*

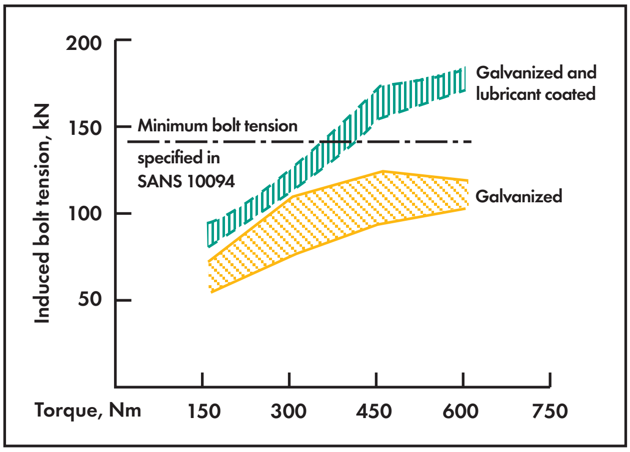



*Figure 103. Torque/induced tension-relation for M20 high strength structural bolts, only galvanized and galvanized and lubricant coated.*

| | Length of bolt, mm | |
|---|---|---|
| Nominal bolt diameter | Nut rotation 1/2 turn with 60° tolerance over no tolerance under | Nut rotation 3/4 turn with 60° tolerance over no tolerance under |
| M16 | up to 120mm | 120 up to 240mm |
| M20 | up to 120mm | 120 up to 240mm |
| M24 | up to 160mm | 160 up to 350mm |
| M30 | up to 160mm | 160 up to 350mm |
| M36 | up to 160mm | 160 up to 350mm |

*Table 32. Nut Rotation from the snug-tight condition. Refer to SANS 10094.*

layer of the galvanized coating on mating surfaces has been investigated. Tests carried out by the Hot Dip Galvanizers Association and the SABS have revealed no substantial relaxation and this confirms international studies which show that a maximum loss of bolt load of 6,5% for galvanized plates and bolts can arise, as opposed to 2,5% for uncoated bolts and members. This loss occurs within about five days and little further loss is recorded. This loss can be allowed for indesign and is readily accommodated.

**Slip factor effecting mating surfaces in friction type joints**

In the case of galvanized friction grip joints the galvanized coating behaves initially as a lubricant and the co-efficient of friction is normally less than 0,2. After the first few cycles, under alternating stress, the galvanized surfaces tend to lock up and further slip, under alternating stress, is negligible *(figure 104)*. If initial slip is undesirable, the application of a zinc silicate paint, to mating surfaces prior to assembly, will provide a slip factor in excess of 0,4 and, this enables hot dip galvanized assemblies to be designed for performance which is similar to that of uncoated steel.

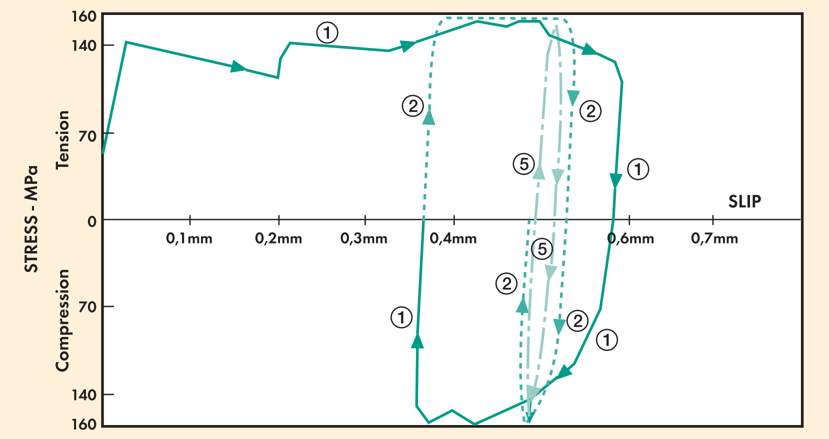
Zinc metal spraying or alternatively light abrasive blasting of mating surfaces will also provide acceptable slip factors.

**Lubrication of threads**

For high strength galvanized fasteners to be tensioned to the required level, thread lubrication, by means of molybdenum disulphide based lubricant or alternatively a wax such as beeswax, is essential *(figure 102)*.

## 13.6 BOLT AND NUT ASSEMBLIES

Hot dip galvanized bolts and nuts should ideally be supplied in the nutted-up condition. This ensures that bolts and nuts have been matched and supplied by the same manufacturer while the possibility of bolts being supplied with clogged threads is avoided.




**Stress versus slip for fatigue specimen subjected to alternating stress of 160MPa. Hot dip galvanized members and bolts. First, second and fifth stress cycles. W.H. Munse 'Structural Behaviour of hot galvanized bolted connections'. Proceedings 6th International Conference on Hot Dip Galvanizing 1968.**

*Figure 104.*

| Threaded Articles Class 10.9 Fastener Diameter | Local Coating Thickness (min.) µm or gms/m² | Mean Coating Thickness (min.) µm or gms/m² | Maximum Coating Thickness (min.) µm or gms/m² |
|---|---|---|---|
| ø > 6mm | 40 (285) | 50 (360) | 65 (465) |
| **Note:** Excessively thick hot dip galvanized coatings (i.e. zinc immersion time of longer than 2 minutes), results in excessive growth of the hard Fe / Zn alloy layers and possible fatigue failure from crack propagation at stress raisers. Excessively thick coatings on threads will interfere with thread tolerances. | | | |
| Threads are to be clearly defined and free from excess solidified zinc, allowing for ease of nut fitting and tensioning. | | | |

*Table 33.*

## 13.7 WASHERS

High strength washers are required to be through hardened prior to hot dip galvanizing.

## 13.8 HIGH STRENGTH FASTENERS – CLASS 10.9 (Refer to SANS 10094)

Class 10.9 fasteners may be hot dip galvanized, provided that a certificate of compliance is issued by the galvanizer, stating that the hot dip galvanizing has been carried out in accordance with **SANS 10094:2005**.

**Procedure for hot dip galvanizing of class 10.9 fasteners**

1. All pretreatment cleaning is achieved by lightly wheelabrating for less than 5 minutes instead of acid pickling. This is preferred in order to eliminate the liberation of hydrogen ions ($H^{+1}$) and remove the potential for hydrogen embrittlement.

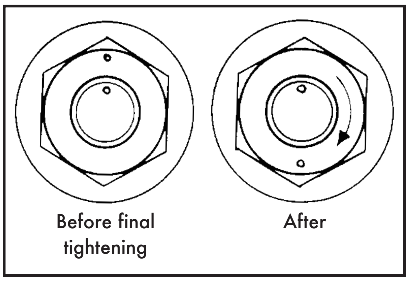



*Figure 105. Where accurate tensioning is critical, permanent indication of the extent of part turn tightening can be identified by match marking.*

2. Thick hot dip galvanized coatings are avoided by limiting the immersion times to less than 2 minutes, agitating in the molten zinc and ensuring that all components are immersed for similar periods of time followed by efficient centrifuging *(table 33)*.
3. **No stripping and re-galvanizing of rejected sub-quality coating is allowed.**
4. No uncoated areas are acceptable.

*Note: Users of fasteners shall be aware of dangers during tightening procedures if they are not applied correctly.*

## 13.9 BOLT TENSIONING PROCEDURES

Extensive tests have been carried out in order to arrive at the most effective method of tensioning hot dip galvanized fasteners while ensuring that this can be performed in a reliable fashion by semi skilled personnel. The torque required to tension hot dip galvanized fasteners, even after lubrication, can vary substantially from one fastener to another and, while this fact also applies to uncoated fasteners, the scatter is greater in the case of galvanized fasteners. It is recommended that reliable tensioning of high strength hot dip galvanized fasteners should not be based on torque/tension values, particularly in the case of friction grip connections. This recommendation is in line with results obtained in countries elsewhere and, for this reason, torque control tensioning is not encouraged either for coated or uncoated high strength fasteners.

**Recommended method of tensioning (turn of the nut method)**

If hot dip galvanized fasteners are to be used, it is recommended that the turn of the nut method of tensioning should be adopted. This method has proved to be reliable and slight variations in the degree of final nut turning do not significantly influence the ultimate bolt tension *(figure 102).* The procedure is simple and does not entail the use of specialised equipment. Nuts are tightened to a snug tight position and variations in tightness at this stage do not significantly influence the final result. Snug tight is defined in many specifications as the full effort of a man on a standard podger spanner or the point at which there is a change in the note or speed of rotation when a pneumatic impact wrench begins impacting solidly. Podger spanners are graded in length, in relation to bolt size and strength and, for example, a spanner of some 450mm in length is regarded as appropriate for an M20 high strength structural bolt. It must be repeated that the clamping force supplied by snug tight is highly variable but this is not significant when bolts are subsequently fully tightened. The bolt tension/bolt elongation curve is relatively flat once the proof load is exceeded and, hence, variations in the snug tight condition result in only small variations in the final bolt tension.

For final tightening the standards in *table 32* are recommended. The table provides for rotation up to 60° in excess of the recommended nut rotation or a total of 240° in the case of M16 and M20 fasteners up to a length of 120mm. This level of tension is well within the capacity of high strength fasteners as laid down in **SANS 1700-7-7; SANS 1700-7-8; SANS 1700-14-8; SANS 1700-14-9; SANS 1700-14-10** (SABS 1282 is to be replaced by specific parts of SABS 1700) where, for test purposes, fasteners of this length are required to be tensioned by nut rotation after snug tightening to a minimum of 300° without fracture or the stripping of threads.

Where accurate tensioning is critical such as in the case of friction grip connections, permanent indication of the extent of part turn tightening can be identified by match marking the bolt end and nut, at the snug tightening stage, before final tightening *(figure 105)*.

**Part torque - part turn method**

This procedure entails the use of a torque wrench to induce a snug tight condition to all bolts prior to applying full tension by turn of the nut procedures.

**Alternative methods of tensioning hot dip galvanized fasteners**

The use of load indicator washers provides effective tensioning but this entails the use of specially manufactured washers with protrusions which are flattened as tension increases and a reduction of the gap by a specified amount, indicates that minimum bolt tension has been reached.

Hydraulic tensioning equipment, which stresses the bolt to the required extent prior to nut tightening, is also available. These alternative methods entail the use of specialised equipment and for this reason the use of the uncomplicated and reliable turn of the nut method is recommended.

## 13.10 THE EFFECT OF HOT DIP GALVANIZING ON STRENGTH PROPERTIES OF FASTENERS

The hot dip galvanizing process does not adversely effect the mechanical properties of high strength fastener steel or even material such as spring steel. Hardened steels <1000MPa yield strength, are not considered to be prone to hydrogen embrittlement as a result of pickling, prior to galvanizing, and any absorbed hydrogen would be diffused during immersion in the molten zinc at 450°C.

In the case of high strength grade 10,9 fasteners as well as products manufactured from spring steel, excessively thick galvanized coatings (>65μm) should be avoided since excessive growth of the hard Fe/Zn alloy layers can result in fatigue failure due to crack propagation from these layers into the substrate where a potential stress raiser may be present. In any case, excessively thick coatings on threads is undesirable as this will interfere with thread tolerance and may also result in gauling during tensioning. Ideally a maximum coating thickness of 65μm should apply to all male threaded components.

The use of hot dip galvanized Class 10.9 bolts and nuts is permitted provided that a certificate of compliance is issued by the galvanizer that the fasteners have been processed in terms of **SANS 10094**.

### INSTALLATION DO'S

- **Do** Wash off any cement splashes with clean water as soon as possible.
- **Do** Remove wet storage stain (white rust) if necessary with the aid of a bristle brush and water (not a wire brush). More stubborn stains can be removed in accordance with the methods given in *Chapter 5.*
- **Do** Avoid direct contact with dissimilar metals. If in doubt, insulate with some organic material or overcoat both at the interface.
- **Do** Use hot dip galvanized fasteners with properly oversized nuts, in preference to zinc electroplated fasteners on hot dip galvanized structures.
- **Do** Seal the crevices formed between two bolted zinc coated mating surfaces in moist corrosive conditions.
- **Do** Use a hot flame, flexible grinding pads or abrasive paper when removing minor zinc protuberances left by the galvanizer.
- **Do** Use an approved lubricant on galvanized high strength steel bolts prior to bolt tensioning, e.g. molybdenum disulfied (Molyslip) or beeswax.
- **Do** Use a bristle brush and industrial abrasive (vim) with water to remove superficial rust stains (iron fillings, etc.) that have adhered to the coating surface. Should this method not be effective, replace the bristle brush with a 'scotchbrite' pad (abrasive pad). Should the stain still remain, ascertain by means of an electro-magnetic thickness gauge the residual coating thickness.

### INSTALLATION DON'TS

- **Don't** Use electro-plated fasteners for fixing hot dip galvanized components. If hot dip galvanized fasteners are not available, overcoat suitably cleaned electro-plated fasteners with a reputable organic coating such as "Zincfix" *(Chapter 15 and 17).*
- **Don't** Unnecessarily disturb the matt grey zinc carbonate surface film by wire brushing.
- **Don't** Abuse hot dip galvanized articles by aggressive unloading, unnecessary hammering or banging when aligning two components. In spite of the excellent abrasion resistant properties offered by the coating, thicker coatings can be brittle and easily damaged.
- **Don't** Allow hot dip galvanized articles to be installed in aggressive acidic environments or allow liquids with a pH of less than 6,0 or greater than 12,5 to be conveyed in hot dip galvanized pipes.
- **Don't** Bend articles excessively after hot dip galvanizing for alignment or fitting.
- **Don't** Use steel files or inflexible grinding pads with inexperienced personnel to remove protuberances left by the galvanizer.

*Should any difficulty be experienced with the above, contact the Hot Dip Galvanizers Association Southern Africa.*

*Figure 106.*

# Welding of Zinc-Coated Steel

Coating by hot dip galvanizing is usually carried out after fabrication is complete. This provides a continuous corrosion resistant barrier to the component so that a reasonable service life can be achieved.

Modular lengths of components smaller than available bath sizes are recommended since single dipping of the component will generally achieve a better overall coating quality. Components are occasionally double end dipped if joining is appropriate and the available bath size is inadequate for a single dip. Components that have been designed in modular lengths appropriate to the available bath sizes occasionally have to be joined on site. This can be achieved by bolting or welding. When welding is preferred certain precautions are required to achieve quality joints. The most common welding processes with their respective effects on the welded joint are provided below.

## 14.1 SHIELDED METAL ARC WELDING (SMAW)

Welding conditions are similar to those used on uncoated steel, except that the root opening is increased in certain cases to give full penetration and allow for drainage.

The welding arc should be advanced on to the zinc coating by a weaving action ahead of the molten weld pool to melt and vapourise the coating from the steel.

**T-Joints using SMAW**
The same basic welding technique used for welding butt joints should be employed; that is, a slower travel speed than normal and a slight whipping action of the electrode. Undercut is the most prevalent defect found in fillet welds deposited in the horizontal and vertical positions with either rutile or basic covered electrodes.

With general galvanizing, the zinc coating is thicker than that deposited on continuously galvanized sheet. This extra zinc may cause trouble in the vertical position, because when it is molten it tends to run down into the weld pool and make the slag difficult to control. This can be minimised, and often prevented, by maintaining as short an arc length as possible.

## 14.2 GAS METAL ARC WELDING (GMAW)

**Conditions for welding general hot dip galvanized steel**
The short-circuiting transfer mode produces less distortion and damage to the zinc coating than the spray transfer mode.

**GMAW spatter formation**
With the carbon dioxide GMAW process, each short circuit during the transfer of metal causes a momentary rapid rise in current followed by extinguishing the arc. Re-ignition is accompanied by the ejection of small particles of molten metal in the form of spatter. When either carbon dioxide or 80% argon, 20% carbon dioxide shielding gas is used, spatter is increased when welding hot dip galvanized steel compared with uncoated steel.

if the spatter particles adhering to the workpiece are unsightly, the problem can be minimised by spraying an anti-spatter compound on to the workpiece before welding. Available anti-spatter products are based on silicone, petroleum or graphite compounds. Applying one of these products will allow the spatter particles to be brushed off easily.

Spatter formation increases with the thickness of the zinc coating and, is therefore greater on general galvanized steel than continuously galvanized sheet. When general hot dip galvanized steel is welded in a T-joint, in a flat position, spatter particles tend to roll into the corner of the joint causing difficult welding. Spatter formation is also troublesome when welding in the overhead position, as spatter particles are apt to fall into the gas nozzle of the welding gun. Spatter formation is reduced by reducing the diameter of the welding wire.

## 14.3 GAS TUNGSTEN ARC WELDING (GTAW)

Gas tungsten arc welding of general galvanized steel is *not* recommended unless the zinc coating is first removed. The zinc vapour may contaminate the electrode which in turn will cause erratic arc operation and poor weld quality. If the zinc coating is removed, the bare steel is welded using procedures suitable for uncoated steel. Gas tungsten arc braze welding with its attendant lower temperatures, can be carried out with less joint preparation.

## 14.4 FLUXED CORED ARC WELDING (FCAW)

Hot dip galvanized steels may be arc welded with flux cored electrodes. Slag systems have been developed for carbon dioxide shielding as well as for gas-free applications. The self-shielded electrodes are favoured for fabricating sheet metal because of the low penetration and high travel speeds that are possible. The recommendations of the electrode manufacturer should be followed and the welding procedure should be qualified by appropriate tests.

## 14.5 SUBMERGED ARC WELDING (SAW)

**Butt joints**
Butt joints can be welded using hot dip galvanized steel using the same edge preparation as for uncoated steel.

Low travel speed can reduce or eliminate porosity. By supporting the plates free from the welding bench, so that zinc vapour can escape from above as well as below the joint, thicker general hot dip galvanized coatings can normally be welded without porosity.

**T-Joints**
Submerged arc twin-fillet welds, in which both sides of a T-joint are welded simultaneously can be deposited on hot dip galvanized steel.

## 14.6 OXYFUEL GAS WELDING (OGW)

Hot dip galvanized steel may be oxyfuel gas welded using copper-coated mild steel filler rods. Preparation for welding is similar to that used for welding uncoated steel; jigs and clamps are used to prevent distortion caused by heat buildup and any grease or dirt is removed from the weld area. A neutral flame should be used, and the size of the tip should be the same as that used for welding uncoated steel or similar thickness.

With oxyfuel welding, because of the low travel speed used, the zinc coating is volatilised and completely removed for at least 7mm on each side of the weld. For an additional 7mm or so on each side, partial volatilisation occurs. These changes result in a reduction in corrosion resistance. Beyond this depleted region, for up to 19mm, the appearance of the zinc coating may be degraded; however, this matted region has been observed to have no deterioration in corrosion resistance.

## 14.7 BRAZING AND BRAZE WELDING

**Brazing**

High-frequency induction brazing can be performed on general galvanized sheet with very good results using filler alloys of silicon bronze or 60% copper – 40% zinc. Careful control of heating rates can result in sound joints with very little damage to the zinc coating.

**Braze welding**

Braze welds are made at a lower temperature than fusion welds. The base metal is not melted and there is less loss of the zinc coating from the steel. Use of suitable brazing alloys produces strong corrosion resistant welds.

## 14.8 SOLDERING

Hot dip galvanized steel can be soldered using either an acid or an organic flux. Zinc chloride- and ammonium chloride-based fluxes are usually adequate when using tin-lead solders containing 20 to 50% tin. The most popular solder composition is 40% tin – 60% lead. The recommended heat source is a soldering iron. A caustic treatment prior to soldering helps to improve wettability.

Sodium dichromate passivation, used to prevent wet storage staining, may interfere with solder flow. Sodium dichromate should be removed *(see Chemical Cleaning - Chapter 17)* prior to soldering.

Hot dip galvanized coatings that have been phosphated are difficult to solder. The phosphate films must be removed prior to soldering.

## 14.9 EMBRITTLEMENT OF STEEL BY LIQUID ZINC DURING ARC AND OXYFUEL GAS WELDING

Welding general galvanized steel joints using carbon-steel electrodes can be prone to cracking. This cracking is caused by intergranular penetration of zinc into the weld metal. It occurs most often along the throat of a fillet weld, in the weld root and is also observed in the base metal in the heat-affected zone.

Properly designed welded joints using the procedures which follow can minimise the occurrence of such embrittlement and the residual tensile stresses which exaggerate the problem. Selecting an electrode containing silicon below 0.4% is also advisable.

The likelihood of cracking occurring in fillet welds depends upon several key factors:

- the thickness of the hot dip galvanized coating;
- the method of hot dip galvanizing;
- the thickness of the hot dip galvanized steel;
- the width of the joint root opening;
- the method of joint restraint;
- the welding process; and
- the electrode classification.

Weld cracking is influenced by coating thickness. For this reason, cracking occurs most often when thick coatings are applied by general galvanizing. Cracking may not develop at all with thin, electrodeposited coatings. Cracking tends to be less prevalent with low-penetrating shielded metal arc welding and more prevalent with gas metal arc welding and more prevalent with gas metal arc welding, especially with carbon dioxide shielding gas. The higher heat input and slower welding speed with shielded metal arc welding allows more zinc to volatilise ahead of the molten weld pool.

Methods for minimising fillet weld cracking on hot dip galvanized steel, due to zinc penetration fall into four categories;

- use correct root opening between the plates, about 1,6mm is recommended;
- correct choice of consumable, with the GMAW process low silicon E70S-3 electrodes are better than the high silicon E70S-6 electrodes, also rutile E6012/13 are better than low hydrogen E7015/16 types;
- selection of the galvanized base metal by suitable procedure tests; and
- preparation of the base plate to reduce the available zinc by burning the zinc off by oxy-gas torch, grinding or abrasive blasting or preplanning by applying a mask prior to hot dip galvanizing.

## 14.10 RESISTANCE WELDING

Resistance welding or spot welding is commonly used to join steel sections thinner than 5mm thick if the coating is lighter than 300g/m$^2$ (43µm thick). Coatings up to 450g/m$^2$ (65µm thick) have been successfully welded, although the life of the copper electrode is much shorter than with lighter coatings. On heavy coatings, it is necessary to frequently redress or replace worn electrodes, due to the build up of zinc on the electrode.

Coating damage by resistance welding is usually of minor significance, requiring very little or no repair. If the galvanized coatings are thick, resistance welding is impractical.

Resistance seam welding is not recommended due to zinc contamination of the electrode wheel but projection welding is possible without serious difficulty.

## 14.11 SAFE HEALTH PRACTICES

Fumes are always generated during the welding of uncoated steel. They contain varying amounts of iron oxide, ozone, hydrogen, carbon monoxides, nitrous oxides and fluorides. Zinc oxide is generated when welding or cutting zinc coated steel. Zinc oxide is a white compound that is clearly visible in the welding fumes, unlike the gases mentioned above.

**Health effects of zinc oxide**

The inhalation of newly formed zinc oxide can cause a condition known as zinc fever, or zinc shivers. The symptoms are similar to those of influenza, i.e. fever, fits of shivering, increased salivary secretion, head-aches and, in more serious cases, nausea and vomiting.

Zinc is not however, retained in the body in the same way as lead, cadmium, and other heavy metals, but is excreted in urine and faeces. The symptoms of zinc fever usually disappear within a few hours and long term effects are thought to be minimal. Temperature, however, does not seem to exceed 39°C and complete recovery usually occurs within 24 - 28 hours. A suggested Threshold Limit Value (TLV) of 5mg/m$^3$, has been laid down for American practice. A worker may be exposed to this level for a period of eight hours without harmful effects.

**Protection from welding fumes**

By taking elementary precautions, particularly in confined spaces, the effects of zinc fume can be minimised as follows:

- provide positive ventilation such as a suction hose;
- use suction tube gun nozzles on gas metal arc and flux cored arc welding equipment;
- use face masks and respirators;
- weld out of doors if practicable;
- use copper chill bars if practicable, to absorb the heat of welding;
- welders should position themselves so as not to be overexposed to fume; and
- ensure that areas to be rewelded / repaired are cleaned of remaining zinc. Grinding is considered to be the most effective way of removing such coatings.

***Additional technical information on welding of hot dip galvanized steel can be obtained from the South African Institute of Welding or the Hot Dip Galvanizers Association Southern Africa.***

# Reconditioning Damaged Coatings Or Site Modified Hot Dip Galvanized Components

## 15.1 COATING REPAIR PROCEDURE BY THE GALVANIZER

In terms of **SANS 121/ISO 1461:2009** a galvanizer may repair a coating by either zinc thermal spraying, zinc rich epoxy or paint, suitable zinc flake or zinc paste products. The use of a zinc alloy stick is also acceptable. Zinc rich epoxy or paint must conform to certain requirements in the specification.

The total uncoated areas for renovation by the galvanizer shall not exceed 0,5% of the total area of the component.

For articles equal to an area of $2m^2$; 0,5% represents a maximum area of $100cm^2$ or 100mm x 100mm. For articles equal to an area of 10 $000mm^2$; 0,5% represents a maximum area of $50mm^2$ or 7mm x 7mm. No individual repair area shall exceed $10cm^2$ or 10mm x 100mm.

If uncoated areas are greater than 0,5%, the article shall be regalvanized, unless otherwise agreed between the purchaser and the galvanizer.

**Zinc thermal sprayed coatings**

The preferred method of repair is by zinc metal spraying. Repair at the galvanizer will only be necessary if bare spots are present, usually caused by inadequate cleaning, air entrapment or if mechanical damage has occurred *(figure 107)*.

***Method***

The damaged area is to be lightly blasted using preferably a pencil blasting nozzle or the surrounding coating should be masked in order to limit damage.

A zinc thermal sprayed coating is then applied to a lightly blasted surface to a minimum coating thickness of 100µm, unless the purchaser advises the galvanizer otherwise, for example, when the galvanized surface is to be painted and the coating thickness for renovated areas is to be the same as for the hot dip galvanized coating thickness. The repaired area is then wire brushed (preferably stainless steel) to remove loosely adhering over sprayed zinc. Wire brushing provides the added benefit of sealing the pores that may be present in the sprayed coating.

**Zinc rich epoxy or suitable zinc rich paint**

***Method***

The defective area shall be blasted as above or abraded with abrasive paper

*Figure 107. Zinc metal spray applied to a small uncoated area on a pipe section, adjacent to the flange.*

*Figure 108. Site welded joint on hot dip galvanized highway sign gantry - repaired by "Zincfix".*

(roughness 80 grit) or wire brushed thoroughly. All dust and debris must be completely removed. In the event of moisture being present, all surfaces are to be properly dried.

A zinc rich paint or epoxy containing not less than 80% of zinc in the dry film (53% by volume), should be applied to a minimum coating thickness of 100µm, unless the purchaser advises the galvanizer otherwise, for example, when the galvanized surface is to be painted and the coating thickness for renovated areas is to be the same as for the hot dip galvanized coating thickness. The paint coating should overlap the surrounding zinc by at least 5mm *(figure 108)*.

The preferred product is a two or three component zinc rich epoxy.

## 15.2 SITE REPAIRS

The preferred method of repair is by zinc metal spraying. Due to the remoteness of most sites, however, and the unavailability of metal spraying equipment, repairs by zinc rich epoxy or zinc rich paint have to date generally been more popular.

Site repairs should be limited to small coating defects and areas that have been cut or welded on site.

Should excessive amounts of grease or oil be present at the affected area, it shall be removed by means of an approved solvent. As far as possible, all residues are to be thoroughly removed by washing with clean water.

The affected area shall then be abraded with abrasive paper (roughness 80 grit) or alternatively thoroughly cleaned using, preferably a stainless steel brush. All dust and debris shall be completely removed.

Repair can now be carried out using an approved product.

Single pack zinc rich paints are good materials and can easily be applied. They, however, require several coats to achieve the required dry film thickness in terms of **SANS 121/ISO 1461**. Multiple coats will necessitate longer drying times between coats.

**Site repairs by "Zincfix"**

Until recently, the approved products for repair were only available in large containers. Due to the large quantities involved and short pot life when mixed, the products proved to be expensive and wasteful.

A product is now available in a two component, solvent free form, packed for convenience in handy, easy to use squish packs. The repair product is called "Zincfix" and is approved by and available from the Hot Dip Galvanizers Association of Southern Africa and all of its members.

The product has been tested against a number of reputable products and has performed exceptionally well.

The packs are available in 100gm or 400gm sizes. The quantity will coat an area greater than $0,25m^2$ and $1,0m^2$ respectively, to a DFT (Dry film thickness) of 100 to 150µm in a single application.

The contents are easily mixed in accurate proportions.

# The Cost Effectiveness of Hot Dip Galvanizing

The choice of rust prevention system is often made only on the basis of purchase price. However, the purchase price says little about the overall economy of the different rust prevention systems.

The maintenance costs of one system can be considerably higher than those of another. This is especially true if access to the structure is difficult; if maintenance causes operational disruptions; if products and machines have to be covered, or if scaffolding has to be erected.

Unfortunately, it is not practical to give a universally applicable answer to the cost of hot dip galvanizing or other surface treatments. Structures and components vary in size, which affects the ease with which they can be handled and therefore the cost of galvanizing.

The price of hot dip galvanizing is based on the mass of the goods, whereas the price of painting is usually based on the surface area *(figure 111)*. The relationships between average material thickness and surface in m²/tonne are given in *figure 109.*

The initial costs are often generally lower for hot dip galvanizing than for heavy duty painting *(figure 110)* because painting is more labour-intensive than hot dip galvanizing.

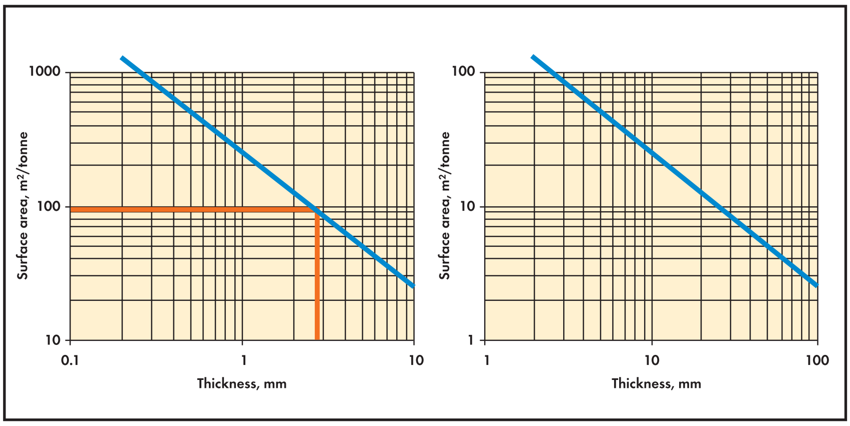



*Figure 109. Diagram for re-calculation of material thickness in mm to material surface in m² per tonne. (According to H-J Böttcher and J P Kleingarn)*

When the total costs of different rust prevention systems are to be compared, a number of complications become evident, since intervals between individual maintenance requirements can vary. The cost situations at each such interval can also vary. However, the long service life given by zinc coatings, together with the reduced risk of minor damage leading to a significant reduction in protection against corrosion, almost always makes hot dip galvanizing cheaper than other methods of surface treatment in the long run.

Total lifetime costs of corrosion prevention systems vary because of different service intervals, different labour contents, the complexity of the maintenance task access costs and discount rates used in present value calculations. The first cost of galvanizing will often be higher than the first cost of short life paint systems but lower than long life paint systems. The cost of hot dip galvanizing complicated shapes and fabrications with high surface to weight ratio will usually be more competitive than the cost of painting. Hot dip galvanizing will also offer short turn round times with no danger of costly site delays. These factors, plus long service life, will usually lead to corrosion protection by hot dip galvanizing being an extremely competitive engineering solution.

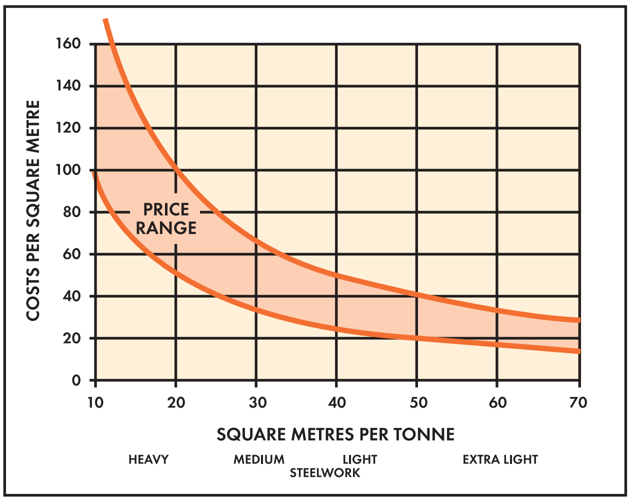



*Figure 110. Comparison between relative initial costs of hot dip galvanizing and a typical heavy duty paint system. The graph takes into account the thickness of hot dip galvanized coating for various profile thicknesses.*

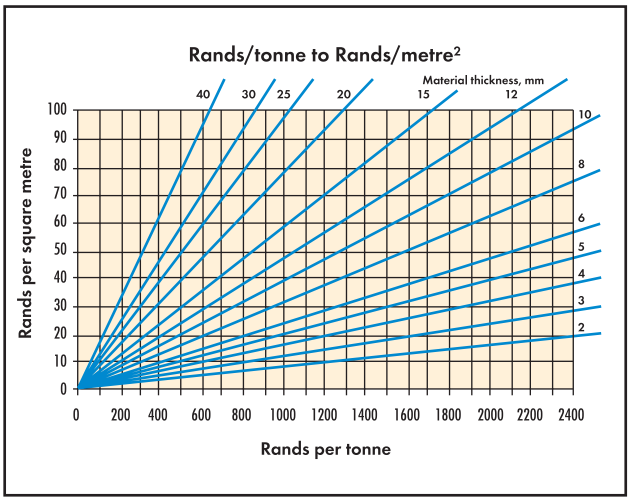



*Figure 111. Converting from a mass based to an area based price.*

# Painting of Hot Dip Galvanized Steel - Duplex Coating Systems

"Duplex Coating" is a term first introduced by JFH van Eijnsbergen, the eminent corrosion expert, in the early fifties. It describes the protection of steel by a layer of zinc which is overcoated by a non-metallic coating. The purpose is to provide additional corrosion resistance especially when required or when a pleasing appearance is necessary. The corrosion resisting life of a properly applied duplex coating is normally greater than the sum of the lives of the two individual coatings. Typically, in a severely aggressive climate, the increase factor is 1,8 to 2,0. In sea water it is 1,3 to 1,6 and in non-aggressive climates the factor is 2,0 to 2,7.

Effective protection by a duplex system is only possible if long term inter-coat adhesion is obtained by means of a paint coating which will not react chemically with the zinc substrate. Inadequate preparation and cleaning of the zinc surface, prior to the application of a compatible paint system or powder coating, is the main cause of premature failure.

Because paint films are pervious, to a lesser or greater degree, water can penetrate, over a period of time, to the zinc surface and may react with the zinc. The solid corrosion products of zinc are approximately 20% greater in volume than the zinc from which they arise, whereas steel corrosion products have about twice the volume of the steel from which they are formed. In the case of duplex coatings, this can be beneficial since defects in the organic coating can be partially sealed and undercreep retarded. However, excessive attack at the interface will result in peeling or blistering, but usually to a lesser extent than when the more voluminous corrosion products of steel are produced.

Hot dip galvanized coatings on silicon killed steel are easier to paint than pure zinc coatings on continuouly galvanized sheets due to the presence of iron/zinc alloy layers. With thermally sprayed zinc coatings it is advisable to apply an initial sealer coat to prevent the absorption of the paint media into the pores of the zinc coating thus leaving a pigment-rich layer which will be prone to disintegration. Powder coating with polyesters, epoxy polyesters or epoxies is common practice.

## 17.1 WHEN TO PAINT HOT DIP GALVANIZED STEEL STRUCTURES

**Existing structures**

Maintenance painting on a cleaned, weathered galvanized surface is normally more effective than when such painting is carried out on a rusted steel surface. This is because zinc corrosion products are easier to remove thus providing a more stable substrate. As with ungalvanized steel, maintenance painting is rarely up to the standard of an original paint coat. Epoxies, which have been specifically formulated for the maintenance painting of steel, will usually also be effective on weathered, but cleaned, galvanized surfaces. With the necessary foresight, however, costly maintenance painting could be avoided, or deferred, by applying a duplex coating in the first place. Frequently, maintenance painting of galvanized structural steel is carried out unnecessarily, due to the mistaken belief that surface "rust stains" present on the coating emanate from the steel substrate. It is important to appreciate that the iron/zinc alloys make up a large proportion of the overall coating. As gradual weathering takes place, rust staining, from these alloys is often observed, particularly in cases where extremely thick coatings, associated with the galvanizing of reactive silicon killed steel are present. The only conclusive test is to determine the actual thickness of the remaining coating by means of an electro magnetic thickness gauge. *(Refer also to Chapter 11).*

**New structures**

By far the most satisfactory duplexing results are obtained by applying the paint system as soon as possible after galvanizing. Weathered galvanizing, which is suitably cleaned, can provide a satisfactory surface on which to apply paint but this should only be considered if material is situated on a site where corrosion is relatively mild and a stable weathered zinc surface has developed. Under no circumstances should the painting of freshly galvanized structures be deferred in a marine environment where the need to remove unstable zinc corrosion products, prior to painting, will render the system less effective. In the case of bolted structures, painting prior to erection provides a distinct benefit in that mating surfaces receive added protection while metal to metal contact is also prevented.

An alternative to applying the entire paint system immediately after galvanizing is to apply a suitable primer at this stage, followed by a compatible top coat on site. The final coat should, however, be applied as soon as possible if primed material is delivered to a corrosive site.

Ideally, material should be fully painted at, or near to, the galvanizer's works where strict quality control procedures can be enforced. Transit damage to painted material is mainly the result of poor stacking and rough handling. The use of plastic spacers, or similar material, as well as nylon slings, for loading and off-loading, usually results in minimal damage to a correctly applied paint coating. The use of re-coatable paint products is recommended so that any coating damage that may occur during transit is readily repairable on site, either before or after erection.

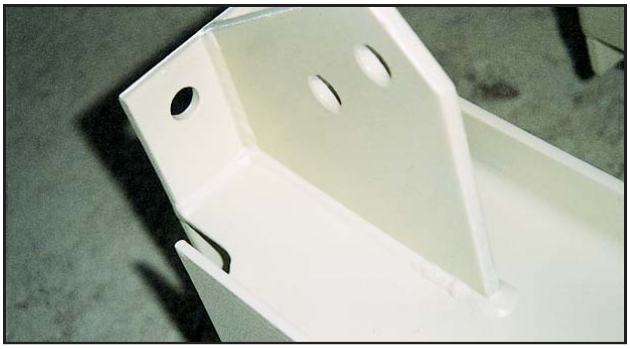


*Figure 112. Sweep blasted hot dip galvanized coating followed by an appropriate paint system.*

## 17.2 SURFACE PREPARATION FOR DUPLEX COATING

A zinc surface totally free from contaminants is an essential pre-requisite for the satisfactory painting of galvanized steel. Nearly all failures occur because of inadequate preparation of the surface or re-contamination, after cleaning and prior to painting, of the reactive zinc surface. **Failure to inform the galvanizer that subsequent painting is to take place will usually result in the provision of a coating which has been passivated and this may adversely influence paint adhesion. When painting is to be followed *(see new structures)* some time after the hot dip galvanized components are exposed to an aggressive marine environment, passivation after hot dip galvanizing is to be encouraged. Like-wise, zinc protuberances and lumps, which may be acceptable on galvanized surfaces, will not be removed if the galvanizer is unaware of the requirement to paint.**

**Surface Roughness of Zinc Coating**
As in the case with a paint coating applied directly onto steel, weld spatter, slag and steel surface defects will be apparent after hot dip galvanizing if prior removal is not carried out.

**Irregularities in the surface of a galvanized coating may consist of small dross particles, zinc oxide, surface flux deposits and stains from unsealed interstitial spaces. Localised lumps may occur where drainage of excess zinc, during withdrawal from the galvanizing bath, was incomplete. Generally, these features do not reduce corrosion resistance of the galvanized coating but, if duplex systems are to be applied, they will appear more prominent after painting and may locally reduce paint coating thickness.**

A locally thinner paint film over a small dross particle, or a zinc droplet, is less critical than a thin paint film on a protuberance on steel since the zinc corrosion products, formed after the thin paint area has corroded away, will prevent accelerated corrosion provided good adhesion of the overall paint film is maintained. This has been demonstrated, for example, in the case of powder coatings where the presence of pinholes had no influence on the corrosion resistance of the duplex system upon atmospheric exposure. In severely corrosive immersed conditions, however, thinner localised paint films should not be tolerated.

**Sweep blasting**
Sweep blasting is a method often used for preparing galvanized surfaces for painting. There is no doubt that, if this process is carried out correctly, excellent adhesion can be obtained. The use of an ultra-fine non-metallic grit and low nozzle pressure are essential but, if contaminated or powdery abrasive material is used, sweep blasting can do more harm than good. High nozzle blasting pressure and the use of unsuitable abrasives can result in the delamination of the iron/zinc alloy layers particularly when heavy zinc coatings, associated with the galvanizing of silicon killed steel, are present. The process is less effective for products such as grid flooring where inaccessible surfaces are under blasted while exposed edges are inclined to be overblasted. Sweep blasting should only be used for the surface preparation of galvanized steel if the correct equipment and materials are available and operated by trained personnel *(figure 112).*

**Chemical cleaning**
Zinc has a tendency to attract contaminants, such as oil and dust. All contaminants should be removed by cleaning with an approved solvent detergent degreaser. Failure to do this is the main cause of duplex failures. Galvanized cleaners, which contain abrasives, have been shown to be effective provided scrubbing is adequate. Abrasive components tend to settle out in containers which have been standing and thorough mixing, prior to use, is recommended. After degreasing, bristle brushing and thorough washing and rinsing with running potable water is essential in order to remove all traces of the cleaning chemicals. The zinc surface should then be "water break free" and once this stage is reached, and the zinc surface is dry, painting should commence as soon as possible.

**Chemical conversion coatings**
Chemical pre-treatment is designed to provide a strong, durable and long lasting bond between metallic and non-metallic coatings and also to prevent or retard undesirable chemical or physical action between the two coatings. The most widely used pre-treatment chemicals are phosphates and chromates and these are used extensively for the painting of sheet and also for powder coating. Certain products have been developed which contain a small addition of copper salts which give the zinc coating a dark grey colour. The advantage of these formulations is that it is possible to establish that all surfaces have been treated merely by visual inspection. These formulations have been shown to promote excellent adhesion, although it can be argued that copper salts are theoretically harmful when in contact with a zinc coating. Experience in the United Kingdom has shown that this only applies if the subsequent organic coating deteriorates or has been applied to a surface where the pre-treatment chemical is continuing to react.

## 17.3 SYSTEM SELECTION

In selecting a suitable system it is recommended that all products, wherever possible, are purchased from the same paint manufacturer. This will ensure compatibility. Certain paint formulae should not be applied directly onto zinc surfaces. Amongst others, alkyds may result in saponification with the formation of formic acid which will attack the zinc substrate and result in long-term adhesion failure. Some paints applied onto suitably cleaned zinc surfaces will provide good adhesion between the zinc coating and the paint without the application of a primer. This is particularly true if zinc surfaces are correctly sweep blasted prior to painting. Excellent adhesion of certain specially formulated high build epoxy and polyurethane coatings can now be achieved without the use of a primer or tie coat.

**Primers**
Primers which are applied onto suitably cleaned galvanized surfaces and which have proved extremely successful in providing the required long term adhesion between the organic coating and the zinc substrate include:

- Twin component, solvent carried, epoxy amine primer containing zinc oxides and silicates.
- Single pack water borne modified acrylic copolymer primers. Such primers should not be used where permanent saturation, in service, is anticipated.

**Finishing coats**
The material to be used will be determined by the conditions to be encountered in service. Polyamide cured high-build epoxy coatings have been used successfully in the corrosive mining industry but problems associated with abrasion and age embrittlement have been encountered with certain products. High-build, high volume solids, twin pack, aluminium filled epoxies are successfully applied to primed galvanized surfaces. These products can be supplied with micacious iron oxide (m.i.o.) pigments, or straight colour pigments, if chalking is not a disadvantage. They are also used successfully for maintenance painting. Polyurethanes are becoming popular in situations where bright colour and gloss retention is a requirement. Over-coating with chlorinated rubber has been successful but this product is, in many cases, being superseded by high-build vinyl coatings. Considerable success has been achieved with specially formulated epoxy tars which, when applied to suitably prepared zinc surfaces, can provide long-term maintenance free protection even in situations of permanent saturation. For more detailed information contact the Association and refer to the publications, Code of Practice For Surface Preparation and Application of Organic Coatings HDGASA 01-1990, Specification for the Performance Requirements of Coating Systems HDGASA 02-1990 and Hot Dip Galvanizing and Duplex Corrosion Protection, including – Quality Surveillance, Handling, Loading, Unloading, Stacking and Site Repair. HDGASA 03-2006. For continuously coated galvanized sheet, r*efer to Chapter 5.*

# Proven Coating Performance – CASE HISTORIES

Corrosion engineering is the specialist discipline of applying scientific knowledge, natural laws and physical resources in order to design and implement materials, structures, devices, systems and procedures to manage the natural phenomenon known as RUST.

While some efforts to reduce corrosion merely redirect the damage into less visible and predictable forms, controlled corrosion treatments such as hot dip galvanizing and duplex coatings, will increase a material's corrosion resistance but will also allow service life predictions to be established.

This predictable performance is significantly highlighted by the following three recorded case histories.

Eskom has for many years relied on hot dip galvanizing to protect their assets amongst other things such as the steelwork required for power stations, pylon structures and sub-station steelwork that are exposed to the many environmental conditions throughout South Africa.

Hot dip galvanizing is normally specified primarily for corrosion protection. For this reason, the two most important inspection criteria of the coating taken at any time during the life of the coating are coating thickness and coating continuity.

As life of a zinc coating, no matter how applied is more or less proportional to its thickness in a given environment, a thicker coating will provide a substantially longer life than a thinner coating.

## 18.1 PENTRICH SUB-STATION – MKONDENI , PIETERMARITZBURG

The sub-station was built around 1967 and exposed to the atmosphere of Mkondeni. According to ISO 9223 – Corrosion of Metals and Alloys – Corrosivity of Atmospheres – Classification (see Chapter 12), suggests that this part of Pietermaritzburg is a C2 or at worse a C3 environment.

**Our findings**

The hot dip galvanized coating thickness on several components within the sub-station was scrapped clean of atmospheric contaminants, measured using a calibrated electromagnetic coating thickness gauge and the results tabulated below.

Although SABS 763 was the hot dip galvanizing specification at the time of installation, coating thickness requirements are similar to SANS 121 (ISO 1461), the current specification. See Chapter 10.

In spite of the atmospheric conditions the hot dip galvanized coating has corroded very little in the 40 years of exposure.

The holding down nuts and bolts of all the structures from the coating thickness readings taken, seemed to have been originally zinc electroplated and were breaking down. The holding down bolts have subsequently been over coated using some zinc rich paint, which was scrapped off to measure the residual metallic zinc coating thickness. Although because of their size and the local atmospheric corrosion conditions, corrosion of these bolts in the medium term would never really compromise the life of the structure, they however should be repaired using an appropriate material.

**Sub-conclusion**

The residual hot dip galvanized coating on the structural steel after 40 years of exposure to the atmosphere of Mkondeni, Pietermaritzburg, is in a sound condition and will not require any refurbishment for another 40 years.



*Photos 12 & 13: Residual coating thickness readings of 90 and 85µm, taken on the 132/88kV terminal tower and two of the isolator supports.*

| COATING THICKNESS (µm) | | | | |
|---|---|---|---|---|
| **Georgedale / Pentrich 3 – 132/88kV Terminal Tower** | | | | |
| | Mean | Max | Min | No. of readings |
| 90 x 90 x 8mm L | 95 | 114 | 83 | 9 |
| 30 x 30 x 3mm L | 134 | 161 | 114 | 11 |
| M12 Hex Nut | 78 | 141 | 55 | 10 |
| M12 Hex Bolt | 97 | 132 | 65 | 12 |
| **132/88kV Isolator Support** | | | | |
| 50 x 50 x 6mm L | 88 | 109 | 61 | 22 |
| 150 x 75 Channel | 123 | 179 | 89 | 18 |
| 70 x 70 x 12 L | 155 | 162 | 145 | 14 |
| M16 Hex Nut | 73 | 88 | 59 | 4 |

*Hot dip galvanized coating thickness readings taken on various exposed components at Pentrich Sub-Station.*

## 18.2 BLOUWATER SUB-STATION – SALDANHA BAY

Blouwater Sub-Station is situated approximately 130km north west of Cape Town. The area is routinely subjected to early morning mists that last well into mid-morning. The location of the site selected is well within 20km of the coast with the prevailing winds being either South Easterly or North Westerly. Steel structures exposed to these conditions are therefore subjected to high levels of moisture as well as coastal saline atmospheres. It was built in 1970.

**Our findings**

In general, the coating is in remarkably good condition despite misleading surface

*Photo 11: General photo of Pentrich Sub-Station.*

contamination. Interestingly, some of the bolts and nuts showed signs of distress. This appeared to be limited to fastener assemblies underneath the lower end of the inverted diagonal angle bracings. The reason for this is due to an extended period of accumulated wetness and being shielded from the sunlight.

The use of zinc-electroplated fasteners (electro-galvanizing) is unacceptable due to the extremely thin zinc coating.

**Sub-conclusion**

After approximately 35 years of service, the hot dip galvanized coatings on steel components installed at the Blouwater sub-station will continue to provide adequate and effective corrosion protection for at least another 35 years.

There is no doubt that hot dip galvanizing can and does provide a cost effective solution to the vexed question of steel corrosion protection, not only within 20km of the coast, but also in the more aggressive areas experienced within Southern Africa.

It is interesting to note that even where the hot dip galvanized steel appears to exhibit "red rust", once the contaminated surface has been cleaned a substantial amount of zinc and zinc iron alloys remain. It is an established fact that the zinc iron alloy layers provide approximately 30% greater corrosion protection than that of pure zinc on its own. However, as the zinc iron alloys corrode, speckles of red rust appear due to the iron content within the alloys. This is sometimes seen as representing a potential failure of the structure, but in reality the steel remains unaffected and capable of performing the functions for which it was originally designed.

## 18.3 ELECTRICAL TRANSMISSION TOWERS

South Africa is known for its many severe corrosive atmospheric conditions. These environmental conditions are not only restricted to the coastal regions, but include many inland industrial areas as well.

**Selected sites and our findings**

The three sites, range across the full spectrum of climatic conditions.

***Site No. 1***

- Relatively Benign Conditions.
- 53kV DC line from Cabora Basa to Eskom's Apollo Sub-Station South of Pretoria installed 1973.
- After removing the "apparent" rust discolouration, the underlying zinc hot dip galvanized coating thickness measured 65.4µm.

***Site No. 2***

- Inland Industrial site selected for its relatively severe corrosive conditions. This site is located within Germiston Industrial area.
- The specific tower is believed to have been in service for the past 40 years.
- After the removal of the discolouration, i.e. corrosion products, a measurement of the remaining hot dip galvanized coating revealed 119µm.


*Photos 14 & 15: Site No. 1 – After removing "apparent" rust discoloration, the underlying hot dip galvanized coating measured 65.4µm.*

***Site No. 3***

- Severe Marine Coastal Conditions
- Buffalo-Port Rex Transmission Line situated in East London. At the time of the inspection, the towers had been in service for 25 years.
- General condition of the tower after 25 years of service, was found to be such that an over coating of a paint system was recommended in order to extend the service life of the structure.
- The site selected for the severe marine conditions consists of transmission towers on the Buffalo-Port Rex Transmission Lines situated in East London.
- The tower that was inspected is situated approximately 3km from the ocean next to the Buffalo River salt-water estuary, as well as alongside a city dump. At the time of the inspection the tower had been in service for 25 years. The initial corrosion protection comprised hot dip galvanizing and had never been over coated with an organic coating system. Severe corrosion with subsequent metal loss was observed on some of the structural members. In one isolated instance the degree of metal loss was so severe that it had resulted in the perforation of the member. The nuts and bolts of these corroded members were also severely rusted. The most severe corrosion was mainly located on the inner surfaces of the members. The members that showed severe signs of corrosion were either perforated or the degree of metal loss was in the 1 to 2mm range. The outer surfaces of these members were only superficially corroded and the hot dip galvanized thickness readings ranged from 87 and 104µm.

*Photo 16: Severe marine coastal conditions. Buffalo-Port Rex Transmission Line situated in East London. At the time of the coating inspection, the towers had been in service for about 25 years.*

**Conclusion**

Hot dip galvanized structures in numerous applications have been shown to exhibit outstanding performance over the full spectrum of environmental conditions. Where severe environmental conditions are encountered, Duplex coatings (hot dip galvanizing plus a top paint coating) should be considered.

We acknowledge and thank Eskom for their input in the above case histories.


*Photos 17 & 18: Despite the apparent "rust" contamination of the galvanized surface, once removed the galvanized coating measured 126µm.*

# RELIABILITY

The hot dip galvanized coating is formed by a metallurgical reaction between suitably cleaned steel and molten zinc. This results in the formation of a series of iron/zinc alloys which are overcoated with relatively pure zinc. The process entails total immersion of components in both pretreatment chemicals and molten zinc. This ensures uniform protection and coating reliability even on surfaces which would be inaccessible for coating by other methods.

# DEPENDABILITY

Ease of inspection and dependability in service are beneficial features of a hot dip galvanized coating. The cathodic protection of steel by zinc ensures that corrosion of the underlying steel cannot occur as long as zinc is present. Even at discontinuities on the coating, corrosion creep under the surrounding zinc is not possible.

# PREDICTABILITY

The durability of a hot dip galvanized coating is determined by the degree of corrosion of zinc in a specific environment and the thickness of the coating. Corrosion of zinc is normally uniform, thus durability of a hot dip galvanized coating is predictable in most applications.

MEMBER'S LABEL

**HOT DIP GALVANIZING HAS BEEN USED TO PROTECT STEEL FROM CORROSION FOR MORE THAN 170 YEARS. APPLICATIONS FOR WHICH HOT DIP GALVANIZING IS SUITABLE ARE NUMEROUS AND VARIED AND THE DEMAND CONTINUES TO INCREASE.**

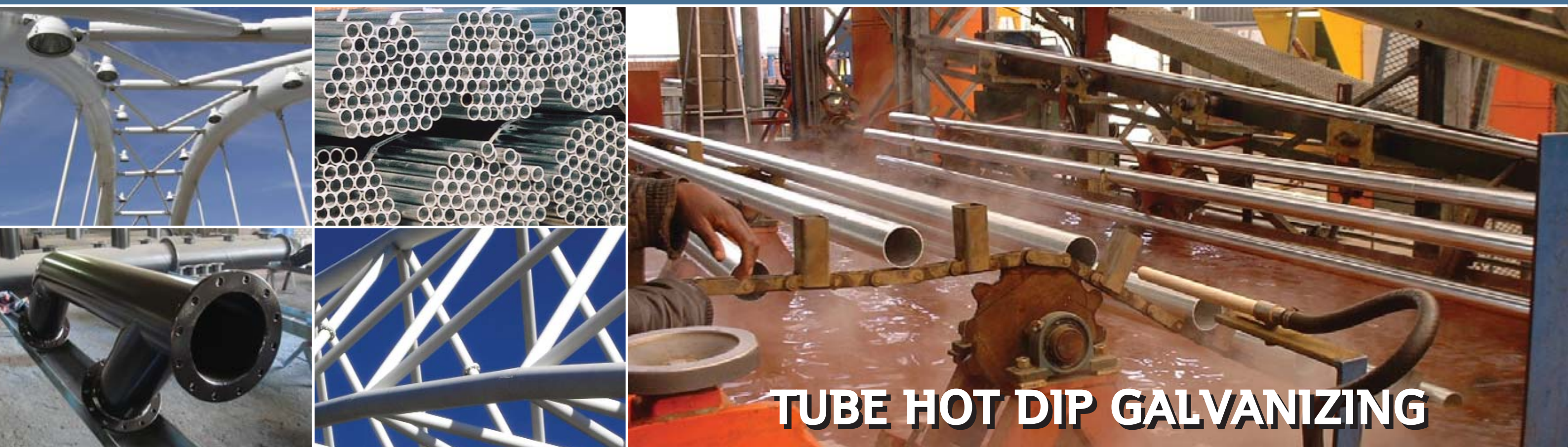
ISSUE DATE: SEPTEMBER 2009



# PUBLICATIONS AVAILABLE FROM THE ASSOCIATION

- Association Journal – Hot Dip Galvanizing Today.
- Steel Protection by Hot Dip Galvanizing and Duplex Systems.
- Practical Guidelines for the Inspection and Repair of Hot Dip Galvanized Coatings.
- Specification for the Performance Requirements of Duplex Coating Systems.
- Code of Practice for Surface Preparation and Application of Organic Coatings Applied to New Unweathered Hot Dip Galvanized Steel.
- Guidelines for the Use of Hot Dip Galvanized Products in the Mining Industry.
- Wall Chart - Design for Hot Dip Galvanizing.


SHEET HOT DIP GALVANIZING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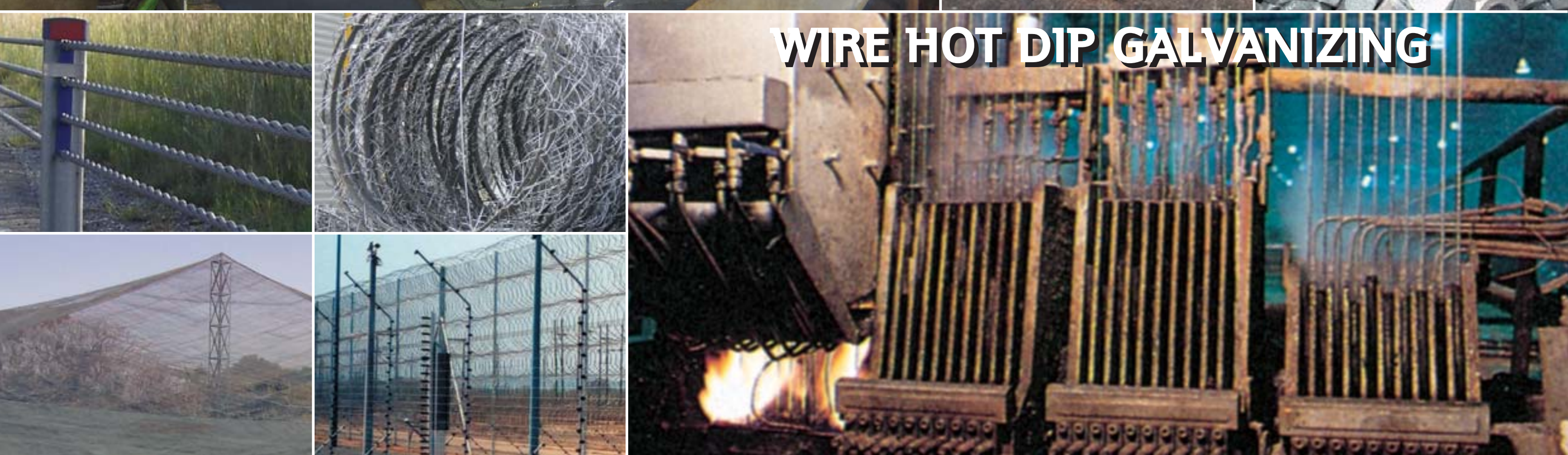
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