

Guidance Note 8.03

Hot dip galvanizing

Scope

This Guidance Note provides general information on hot dip galvanizing, its characteristics and properties, and highlights the issues designers should consider when specifying hot dip galvanizing for corrosion protection of structural steelwork.

General

An appreciation of the galvanizing process, and the way the coating is formed, is beneficial in terms of understanding the coating's unique characteristics, and how to use hot dip galvanizing.

Zinc coatings protect structural steel by weathering at a slow rate, giving a long and predictable life. In addition, should any small areas of steel be exposed, the coating provides cathodic (sacrificial) protection and corrodes preferentially. If large areas of steel are exposed, the sacrificial protection prevents sideways creep of rust.

Galvanizing is an effective and economic means of corrosion protection, and has many applications for steel bridges including:

- Small components subject to wear and corrosion, especially when chunky and not vulnerable to distortion.
- Bearings
- Bolts & fittings
- Barriers and Parapets
- Lighting columns, CCTV masts and other bridge furniture
- Facing panels (not stiffened)
- Expansion joints
- Standard unit bridge components for overseas transit.

Process and coating

The hot dip galvanizing process principally involves the formation of an impermeable layer of zinc, which via an iron-zinc alloy layer is chemically attached to the steel substrate. This is achieved by the immersion of steel articles in a bath of molten zinc.

Specification for Highway Works (SHW) Clause 1909 [1] provides additional requirements.

Preparation

The galvanizing reaction between zinc and the iron in the steel article will only occur on a chemically clean surface. Most preparation work is done with this in mind. Contamination is removed by a variety of processes. However, welding slag, spatter, paint and heavy grease will not be removed by these cleaning steps and should be removed before the work is sent to the galvanizer.

At the galvanizer common practice is to degrease using an alkaline or acidic degreasing solution into which the component is dipped. The article is then rinsed and then dipped in inhibited hydrochloric acid at ambient temperature or heated inhibited sulphuric acid to remove rust and mill scale.

After further rinsing, the components will then commonly undergo a fluxing procedure. This procedure normally involves dipping the article into a flux bath. Alternatively, some galvanizing plants use a flux blanket on top of the galvanizing bath. The fluxing operation removes the last traces of oxide from the steel surface and allows the molten zinc to wet the steel.

The galvanizing reaction

When the clean iron or steel component is dipped into the molten zinc (at about 450°C) a series of zinc-iron alloy layers are formed by a metallurgical

reaction between the iron and zinc. The rate of reaction between iron and zinc is normally parabolic with time. The initial rate of reaction is very rapid and considerable agitation can be seen in the zinc bath. The main thickness of coating is formed during this period. Then the reaction slows and the coating thickness is not increased significantly - even if the article is in the bath for a longer period. A typical immersion time is about 4 or 5 minutes but it can be longer for heavy articles that have high thermal inertia or where the zinc has to penetrate internal spaces. On withdrawal from the galvanizing bath a layer of molten zinc will be taken out on top of the alloy layer. This cools and solidifies to exhibit the bright shiny appearance associated with galvanized products.

Products larger than the galvanizing bath can be dipped to coat most of the steel component and then turned round and dipped again to coat the remainder. This is called 'double dipping'. This is covered in more detail under design for galvanizing.

Conditions in the galvanizing plant such as temperature, humidity and air quality do not affect the quality of the galvanized coating.

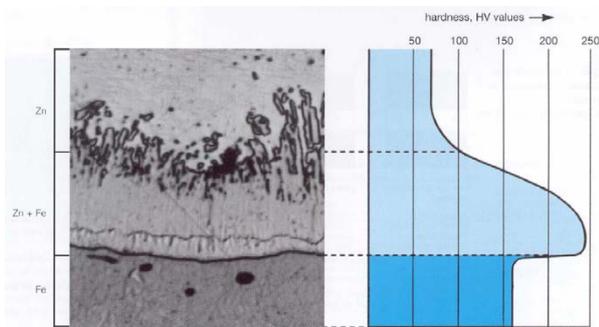


Figure 1 Microsection of hot dip galvanized coating and diagram of hardness through coating

Steel specification

Structural steel that is to be hot dip galvanized should be clearly specified, by invoking the appropriate options in the material technical delivery standards, i.e.:

- BS EN 10 025 - Option 5 (Parts 1, 2, 3, 4, 6)
- BS EN 10 210-1 - Option 1.4

These options require control of the silicon and phosphorus levels. Silicon levels are discussed further below.

The coating

When the reaction between the iron and zinc has virtually ceased, and the article has been taken out of the galvanizing bath complete with its outer coating of zinc, the process is complete. In reality there is no demarcation between steel and zinc but a gradual transition through the series of alloy layers, which provide the metallurgical bond.

Coating thickness

The coating thicknesses achieved are normally determined by the steel thickness and are set out in BS EN ISO 1461. The typical minimum average coating thickness for bridge girders is 85 μm .

Thicker coatings may be produced by one of the following:

(i) Thicker coatings by surface roughening

This is the most common method of achieving thicker coatings. Grit blasting the steel surface to medium to coarse profile Grade Sa 2½ prior to immersion, using chilled angular iron grit of size G24, roughens and increases the surface area of steel in contact with the molten zinc. This generally increases the weight per unit area of a hot dip galvanized coating by up to 50%. For normal structural steelwork this would provide a coating of about 140 microns. Thicker coatings than those required by BS EN ISO 1461 should only be specified following consultation with the galvanizer or the Galvanizers' Association.

(ii) Using reactive steels

A thicker zinc coating will be obtained if the article to be galvanized is manufactured from a more reactive steel. The constituents in steel that have the greatest influence on the iron/zinc reaction are silicon, and phosphorus. Silicon changes the composition of the zinc-iron alloy layers so that they continue to grow with time and the rate of growth does not slow down as the layer becomes thicker.

Such steels are not readily available in structural plates and sections. In addition, according to the American Galvanisers Association [5], steel components with silicon content in excess of 0.22% can produce more brittle, thicker coatings of over 250 microns thickness that can be more easily chipped or damaged.

Note also that weld consumables that create weld metal with higher silicon content can also cause local thickening of the galvanized coating.

Physical performance

The nature of the galvanizing process provides a tough and abrasion resistant coating, which means less risk of mechanical damage at site and speedy erection of structures.

Cohesion

Unlike most coatings, which rely solely on preparation of the steel to obtain good adhesion, hot dip galvanizing produces a coating bonded metallurgically to the steel. In other words, the iron and zinc react together to form a series of alloys that make the coating an integral part of the steel surface with excellent cohesion.

Toughness

Resistance to mechanical damage of protective coatings during handling, storage, transport and erection is very important if the cost of 'touching up' on site is to be avoided. The outer layer of pure zinc is relatively soft and absorbs much of the shock of an initial impact during handling. The alloy layers beneath are much harder, often harder than the base steel itself. This combination provides a tough and abrasion resistant coating.

Hot dip galvanized fasteners

Generally, nuts, bolts and washers down to 8 mm diameter can be galvanized and a wide range of threaded components can now be processed using special equipment. For ISO metric fasteners, the galvanizing of one thread, either internal or external, requires an extra clearance of four times the coating thickness. In practice, it is normal for standard bolts from stock to be fully galvanized but for nuts to be galvanized as blanks and then tapped up to 0.4 mm oversize and the threads then lightly oiled. When assembled, the nut thread is protected by contact with the coating on the bolt. Even after many years of service, galvanized nuts on galvanized bolts can readily be unfastened even though the threads have never been galvanized.

Note that hot dip galvanizing of Grade 10.9 bolts is not permitted by the Specification for Highway Works unless cleaning is carried out mechanically. This is due to the risk of hydrogen embrittlement from acid cleaning.

Slip factors for slip-resistant bolted connections

Initially, the coefficient of friction with galvanized contact surfaces is low - an average of about 0.19. As slip commences, however, friction rapidly builds up and 'lock-up' occurs due to cold welding between the coated surfaces. If a small amount of slip can be tolerated it is therefore unnecessary to treat the surfaces, but if all slip must be avoided, the coefficient of friction can be raised by roughening the surface of the galvanized coating. Wire brushing will raise it to 0.35 and a figure of up to 0.5 has been achieved by a sweep blast as below or by roughening with a pneumatic chisel hammer or needle gun.

Sweep or flash blast cleaning

The standard grit blasting process for cleaning steel, fires grit perpendicular to the surface of the steel component and uses about 7.5 bar (110psi) pressure. This process would remove most, if not all, of the galvanized coating.

Historically sweep or flash blast cleaning, also called sweep blasting and brush-off blasting, has been used more extensively in the US than in the UK, but sweep or flash blast cleaning is now specified in Series 1900 of the *Specification for Highway Works* [1], [2] and in Network Rail standards [3], [4].

Sweep blasting requires the use of low pressure equipment (less than 2.7 bar or 40 psi), suitable soft abrasives (5 Moh or less) and skilled operation. article size should be in the range of 200 to 500 microns. The impact angle onto the surface needs to be between 30 and 60 degrees.

Suitable abrasives include copper slag, carborundum powder, aluminium or magnesium silicate, soft mineral sands or organic media, such as processed walnut shells, or stone materials such as carborundum powder or limestone.

More guidance is also available in ASTM D6386 and The Association for Materials Protection and Performance (formerly The Society for Protective Coatings) Surface Preparation Standard SSPC-SP 16.

Unless there is previous experience of using this technique, it is advisable to carry out trials to

determine all the correct parameters as successful sweep blasting is dependent upon the skill of the operator. The process should be subject to trials to demonstrate the zinc can be roughened by deformation without significant removal of zinc.

Welding of galvanized steel

Tests at The Welding Institute sponsored by the International Lead Zinc Research Organisation (ILZRO) have established that satisfactory high quality welds can be made on hot dip galvanized steel and that the tensile, bend and fatigue properties of such welds can be virtually identical to those of similar welds made on uncoated steel.

However, it is always best to remove the zinc from at least 50 mm from the fusion faces, and only consider welding galvanized steel without zinc being removed as a last resort.

While zinc is a necessary trace element in the human diet and it does not accumulate in the human body, the inhalation of freshly formed zinc oxide fumes can cause a transient 'metal fume fever' with symptoms similar to influenza. To maintain fume levels within acceptable levels, extraction should be provided when welding galvanized steel in confined areas, as indeed it should when welding uncoated steel.

Painting galvanized coatings

For many applications, hot dip galvanizing is used without further protection. However, to provide extra durability, or where there is a decorative requirement, paint coatings may be applied. The combination of metal and paint coatings is usually referred to as a 'duplex' coating.

When applying paints to new unweathered galvanized coatings, special surface preparation treatments should be used to ensure good adhesion. These include sweepblast cleaning as above to roughen the surface and to provide a mechanical key or the application of special etching treatments.

Sweep blasting cleaning is now included in SHW Series 1900 for certain HAPAS approved paint systems onto galvanizing for ancillary items such as parapets, lighting columns, CCTV masts, etc.. Where sweep blast cleaning is the chosen method of adhesion promotion, it shall be undertaken in accordance with

BS EN ISO 12944-4 to surface roughness 'fine' in accordance with BS EN ISO 8503-2.

Alternatively etching treatments can be via paints such as etch primers designed for direct application to galvanizing or by pretreating surfaces using 'T' wash adhesion promoter before application of paint. 'T' wash is a phosphoric acid mordant solution with 1% copper carbonate, the solution is designed to react with the etched surface to darken the surface and so to provide a visual indication of effectiveness. The registered item description under the Assurance Scheme for Paints [2] is Item 155.

Renovating damaged coatings

Small areas of the coating may be damaged during construction and by operations such as cutting or welding after galvanizing. Adequate corrosion protection will be achieved at any damaged area if a repair coating is applied with a minimum thickness of 100 µm. (A lesser thickness might be acceptable when the galvanized surface is to be over-coated to provide a duplex system.)

Coatings should be chosen to provide about 90% or more zinc content within the dried film.

Follow guidance provided in BS EN ISO 1461 and datasheet 13 available from the Galvanizers Association. More prescriptive requirements are given in the SHW, Series 1900, Clause 1907 [1].

The 'zinc Corrosion Map'

The environments in most corrosion guides are necessarily general. Specific corrosivity values in the UK have been mapped in the past by the Agricultural Development Advisory Service (ADAS). The information was based on data obtained from exposure of zinc reference samples at National Grid Reference points in a large number of 10 km square reference areas of the UK.

The results indicated varying rates of corrosion for zinc in different exterior locations in the UK. The Galvanizers Association sponsored the revision of the last map, to provide specifiers with the very latest information on zinc corrosion.

Comparison of data obtained from this latest zinc corrosion rate mapping exercise with results from

previous mapping programmes (1982 and 1991) show a clear, and very significant, drop in the corrosion rate for zinc for most atmospheric exposures across the UK and the Republic of Ireland. Many inland areas now have a corrosion rate of 1.5 microns per annum or less. This improvement is considered primarily due to the reduction in sulphur dioxide levels due to coal fired power station flue gas desulphurisation and closures.

The zinc Corrosion Map online results show that a standard 85 µm galvanized coating may now achieve a coating life of more than 50 years in most environments. Similarly, a thicker 140 µm galvanized coating, often produced on heavier sections of structural steel, may achieve a coating life of over 100 years

Designing articles for galvanizing

Good design requires providing:

- A means for the access to and drainage from surfaces of acid / molten zinc.
- A means for venting air for internal compartments.

This latter point cannot be over-stressed. The danger of not providing adequate ventilation for hollow items is that components may explode, and any explosion is likely to be in the bath of molten zinc. If in doubt, contact the Galvanizers Association.

Size and shape

In recent years, the size and capacity of galvanizing plants has increased significantly. The longest tank in the UK is currently 21 m in length, the maximum double-dip dimension is 28 m, and the maximum lift weight is 20 tonnes. Reference should be made to the GA Directory of General Galvanizers for more details of the bath sizes available, and maximum lift weights, in the UK and Republic of Ireland.

Double-dipping is a special technique which may be employed to facilitate dipping when the length or depth of the item exceeds the size of the bath. However, items which have to be dipped twice are more likely to distort during the galvanizing process. Hence, if the designer is considering such techniques, then the galvanizer should be consulted, and an indication of the maximum component size should be given.

Galvanized components in composite construction

For small spans, using rolled section beams with relatively little welded fabrication, galvanizing may well be the preferred protective treatment. Shear stud connectors on such beams should be welded before galvanizing; the galvanized coating does not impair their structural performance at SLS or ULS.

Distortion

If steel fabrications distort during galvanizing, this is usually due to in-built stresses being released, as the steel is heated to galvanizing temperature. Stresses may be inherent in the steel but they can also be introduced by welding, cold forming, hole punching, and flattening.

Efforts can be made at the design stage and elsewhere to minimize residual stresses, for example:

- Avoiding designs of thin plates with stiffeners.
- Arranging weld seams symmetrically. The size of weld seams should be kept to a minimum.
- Avoid large changes in structural cross-section that might increase distortion and thermal stress in the galvanizing process.
- Use a staggered/balanced welding procedure.
- Ensure that work is single dipped where practicable.
- Use a symmetrical design where possible.

Intermittent welds have many advantages on galvanised structures; reducing distortion, reducing the potential for unvented voids, allowing the zinc to coat all surfaces and increasing protection.

Potential problems, post galvanizing

Hydrogen embrittlement and strain-age embrittlement

In the past, some problems were experienced with embrittlement of galvanized steel, from trapped hydrogen or from strain ageing. The causes of such problems are now well understood and advice is available on the avoidance of these incidents (see the information sheets referred to at the end of this Note).

Liquid metal assisted cracking

For some time it has been recognised that there are occasional incidences of cracking from welds or other details of structural steel members either during or immediately following hot dip galvanizing.

The occurrence of this form of cracking, known as liquid metal assisted cracking (LMAC) depends on a complex interplay of stresses, potential initiation sites, and local material conditions (e.g. hardness) when exposed to the liquid zinc. Although the phenomenon is understood in qualitative terms, since the factors that might contribute to LMAC are each subject to significant variation, the occurrence of cracks in any situation is probably best regarded in statistical terms (i.e. in what circumstances is there a significant risk).

In bridge steelwork, LMAC is rare, but the possibility of it occurring should not be entirely discounted.

Advice on the likelihood of LMAC may be sought from those with experience of the phenomenon. Advice about LMAC is also available from the Galvanizers Association.

As a minimum, it is recommended that a post-galvanizing inspection requirement be included in the project specification. Visual inspection will suffice in most cases, although MPI may be appropriate for critical details.

Finally, if LMAC occurs it may be repairable by gouging and rewelding to an approved procedure, with appropriate post weld testing. Stripping and re-galvanising after repair is not essential; the steel is not permanently embrittled. On some occasions, it may be impractical or uneconomic to carry out a repair. This could cause problems for unique components that are on the critical path for the construction programme.

Further Information

Guidance on the mechanism and avoidance of LMAC is available in *Galvanizing structural steelwork – An approach to the management of liquid metal assisted cracking* (published 2005). This publication is available from the BCSA and the Galvanizers Association.

The BCSA and Galvanizers Association (GA) also provide advice on galvanizing fabricated steelwork including bridges via their helpline facilities:

BCSA 020 7839 8566
GA 0121 355 8838

Relevant Standards

- BS EN ISO 1461: 2022, Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods.
- BS EN ISO 3882: 2024 Metallic and other inorganic coatings. Review of methods of measurement of thickness
- BS EN ISO 14713-1:2017. Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures – General principles of design and corrosion resistance
- BS EN ISO 14713-2:2020. Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures – Hot dip galvanizing
- BS 7371-6:1998+A1:2011, Coatings on metal fasteners. Specification for hot dipped galvanized coatings.
- BS EN 10244-2:2023 Steel wire and wire products. Non-ferrous metallic coatings on steel wire. Zinc or zinc alloy coatings.
- BS EN 10346:2015 Continuously hot-dip coated steel flat products for cold forming. Technical delivery conditions.
- BS 3083:1988. Specification for hot-dip zinc coated and hot-dip aluminium/zinc coated corrugated steel sheets for general purposes.
- BS EN 10025 Hot rolled products of non-alloy structural steels. (Parts 1 to 6 give technical delivery conditions for the different types of steels.), 2004 - 2019.
- BS EN 10210-1: 2006, Hot finished structural hollow sections of non-alloy and fine grain steels. Technical delivery requirements.
- BS EN ISO 12944-4 Paints and varnishes - Corrosion protection of steel structures by protective paint systems. Part 4: Types of surface and surface preparation
- BS EN ISO 8503-2 Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates. Method for the grading of surface

profile of abrasive blast-cleaned steel - Comparator procedure

Other standards (for reference)

- ASTM D6386 Standard Practice for Preparation of Zinc (Hot-Dip Galvanized) Coated Iron and Steel Product and Hardware Surfaces for Painting
- Surface Preparation Standard SSPC-SP 16 Brush-Off Blast Cleaning of Coated and Uncoated Galvanized Steel, Stainless Steels, and Non-Ferrous Metals

Galvanizers Association publications:

Detailed information is available from the Galvanizers Association. Their publications include:

- The Engineers and Architects' Guide: Hot Dip Galvanizing
- The Engineers & Architects' Guide to Hot Dip Galvanized Nuts and Bolts
- Design for Galvanizing Wall Chart
- Galvanized Steel and Sustainable Construction: Solutions for a Circular Economy
- Directory of General Galvanizers
- Corrosion Map (online)
- Galvanizing & Sustainable Construction: A Specifiers Guide
- Individual Datasheets
 - 1: Corrosion Protection Using Zinc
 - 2: The Hot Dip Galvanizing Process
 - 3: Hot Dip Galvanizing of Small Components*
 - 4a: Specifying Hot Dip Galvanized Steel*
 - 4b: Galvanizing to Standard BS EN ISO 1461*
 - 5: Considerations Before Galvanizing – Steel Composition*
 - 6: Considerations Before Galvanizing – Steel Condition
 - 7: Considerations Before Galvanizing – Handling During the Process
 - 8: Welding Before and After Hot Dip Galvanizing
 - 9: Avoiding Distortion During Hot Dip Galvanizing
 - 10: Bimetallic Corrosion
 - 11: Wet Storage Stain
 - 12: Hot Dip Galvanized Castings
 - 13: Renovation of Hot Dip Galvanized Steel
 - 14: Masking and Prevention of Hot Dip

Galvanized Coating

- 15: Painting and Powder Coating on Hot Dip Galvanizing
- 16: Staining and Discolouration of Hot Dip Galvanized Steel
- 17: Batch Galvanized versus Pre-galvanized Products
- Case histories on performance of galvanizing

Other references

- [1] Manual of Contract Documents for Highway Works, Volume 1: Specification for Highway Works, Series 1900, TSO, 2014.
- [2] Design Manual for Roads and Bridges, CG 303 - Quality assurance scheme for paints and similar protective coatings, Feb 2019.
- [3] Network Rail Standard NR/L2/CIV/039, Level 2 Specification, Assessment and certification of protective coatings, Issue 1, June 2023 {formerly NR/L3/CIV/039 promoted to a Level 1 standard}.
- [4] Network Rail Standard NR/L3/CIV/040, Level 3, Work Instruction for the use of protective coatings, June 2023.
- [5] American Galvanizers Association: Design Guide – The design of products to be hot-dip galvanized after fabrication, 2023

Acknowledgement: this Guidance Note was originally prepared with the assistance of the Galvanizers Association, who may be contacted on 0121 355 8838 (<https://galvanizing.org.uk>).