Hot dip galvanizing

No. 8.03

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
- Parapets
- 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 is firmly alloyed to the steel substrate. This is achieved by the immersion of iron or steel articles in a bath of molten zinc.

Preparation

The galvanizing reaction 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, paint and heavy grease will not be removed by these cleaning steps and should be removed before the work is sent to 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 hydrochloric acid at ambient temperature to remove rust and mill scale.

After further rinsing, the components will then commonly undergo a fluxing procedure. This procedure normally involves dipping in a flux. 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 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 to exhibit the bright shiny appearance associated with galvanized products.

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

The coating

When the reaction between iron and zinc has virtually ceased, and the article 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.

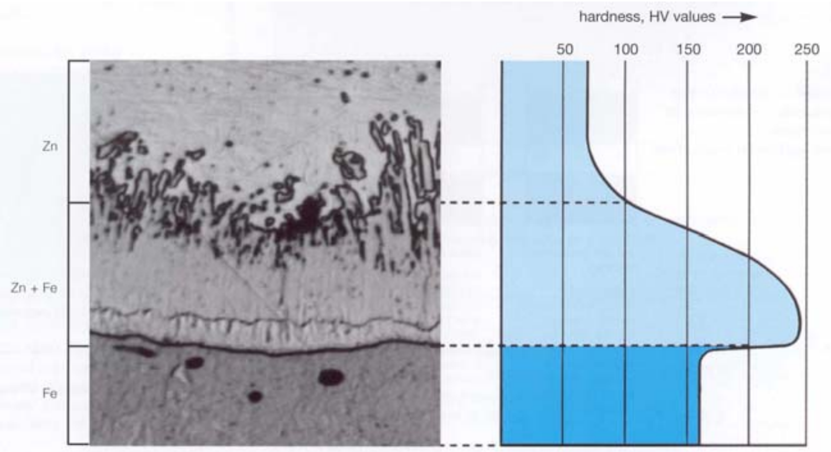

Figure 1 *Microsection of hot dip galvanised coating and diagram of hardness through coating*

Coating thickness
Coating thicknesses are normally determined by the steel thickness and are set out in 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 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%. Thicker coatings than those required by 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 reactive steel. The constituents in steel that have the greatest influence on the iron/zinc reaction are silicon, and phosphorous. 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.

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

Cohesion
Unlike most coatings, which rely solely on preparation of the steel to obtain 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.

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 light grit blasting or by roughening with a pneumatic chisel hammer or needle gun

Welding 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 the fusion faces, and only consider welding galvanized steel 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 galvanized coatings, special surface preparation treatments should be used to ensure good adhesion. These include light blast cleaning to roughen the surface and to provide a mechanical key, and the application of special etch primers or 'T' wash. (T wash is an acidified solution designed to react with the surface and provide a visual indication of effectiveness.)

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.) Follow guidance provided in EN ISO 1461 and datasheets available from the Galvanizers Association. More prescriptive requirements are given in the SHW, Series 1900, Clause 1907 (Ref 1).

The 'Zinc Millennium Map'

The environments in most corrosion guides are necessarily general. Specific corrosivity values in the UK have been mapped 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.

The Zinc Millennium Map 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 structural steel, may achieve a coating life of over 100 years

Designing articles for galvanizing
Good design requires providing:

- A means for the access and drainage of molten zinc.
- A means for venting 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 28m, and the maximum lift weight is 16 T. Reference should be made to the 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.

Steel specification
Structural steel that is to be hot dip galvanized should be clearly specified, by invoking the appropriate options in the material standards, i.e.:
EN 10025 - Option 5 (Parts 1, 2, 3, 4, 6)
EN 10210-1 - Option 1.4
These options require control of the silicon and phosphorous levels.

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:

- Avoid thin plate with stiffeners.
- Arrange 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.
- Consider the use of intermittent welds.
- 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 also provide advice on galvanizing fabricated steelwork including bridges via their helpline facilities:

BCSA 020 7839 8566
GA 0121 355 8838

Relevant Standards

- EN ISO 1461: 2009, Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods.
- EN ISO 14713:2009. Zinc coatings. Guidelines and recommendations for the protection against corrosion of iron and steel in structures
- BS 7371-6:1998+A1:2011, Coatings on metal fasteners. Specification for hot dipped galvanized coatings.
- EN 10244-2:2009 Steel wire and wire products. Non-ferrous metallic coatings on steel wire. Zinc or zinc alloy coatings.
- EN 10346:2009 Continuously hot-dip coated steel flat products. Technical delivery conditions.
- BS 3083:1988. Specification for hot-dip zinc coated and hot-dip aluminium/zinc coated corrugated steel sheets for general purposes.
- 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.
- EN 10210-1: 2006, Hot finished structural hollow sections of non-alloy and fine grain structural steels. Technical delivery requirements.

Galvanizers Association publications:

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

- The Engineers & Architects' Guide to Hot Dip Galvanizing
- The Engineers & Architects' Guide to Hot Dip Galvanized Nuts and Bolts
- Directory of General Galvanizers
- Zinc Millennium Map results
- Galvanizing & Sustainable Construction: A Specifiers Guide
- 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.

Acknowledgement: this Guidance Note has been prepared with the assistance of the Galvanizers Association, who may be contacted on 0121 355 8838 (web site www.galvanizersassociation.com).

