Protective treatment of fasteners

No. 8.02

Scope

This note covers the various metal coatings that are applied to bolts used in bridgework, and the practical aspects to be considered.

Why apply metal coatings to bolts?

With the exception of structures of weather resistant steel (WRS), the long-term corrosion protection to bolt groups in bridge structures is given by the full coating system, applied after installation. (For WRS steel structures the bolts, nuts and washers should be of WRS material and are not given any protective treatment, unless the adjacent steelwork is painted for some reason.)

Threaded components are difficult to blast clean effectively after installation, and even more difficult to metal spray effectively, because of the high surface cleanliness required.

Note also that the use of metal spray has recently been removed from HA Specifications, other than for faying surfaces – see Refs 1, 2 and 3.

The normal and recommended approach for fasteners is therefore to procure bolts that are protected by metal coatings during manufacture, in order to avoid or minimise blasting of bolted joints in the assembled steelwork prior to painting.

The metal coating provides primary protection during construction until the rest of the coating system is applied. (For a major structure, this may involve a long period of exposure for the metal coating.) Thereafter, if the metal coating is thick enough, it will contribute to the overall corrosion protection system. Also, in the event that the paint system suffers local breakdown in the longer term, it offers continuing corrosion protection to the concealed surfaces of the bolts.

Note also that where the heads of the bolts can be placed on the more exposed face of the steelwork (or on the external surface for box girders), this may reduce the amount of surface preparation required.

Beware of cadmium coatings

Cadmium plating was frequently specified and used up to the early 1990s. It is now prohibited for health and safety reasons. Cadmium is highly toxic if vaporised; this could happen if a cutting flame or welding arc came into contact with a cadmium-coated surface.

On earlier structures, even when zinc electroplated coatings were specified, it was common for fabricators to seek and be granted a concession to use zinc-plated bolts with cadmium plated nuts, it being well known that such a combination gave lower thread friction and reduced tightening problems.

Extreme caution is therefore necessary when dealing with any bolted connections made before 1995, as cadmium may be present even if the original specification suggests otherwise.

Hydrogen embrittlement

Hydrogen embrittlement (HE) can occur in susceptible microstructures due to ingress of monatomic hydrogen into the steel as part of the manufacturing process or subsequently due to corrosion.

For bolts supplied to EN 14399 (Ref 4) the hardness and the coating method are under the control of the manufacturer.

EN ISO 4042 (Ref 5), which covers the electroplating of bolts, highlights a risk of hydrogen embrittlement in bolts, and similar components, of high strength or hardness. Above a hardness of 320 HV roughly equating to an ultimate tensile strength 1030 N/mm², steel is considered to be at risk of HE.

It must be noted that the hardness of the bolt surface is allowed to be up to 50 HV greater than the core hardness of the bolt as a result of the methods of heat treatment. Hardness limits for each grade of bolt are provided in ISO 898-1 (Ref 6).

Heat treatment, including baking procedures to mitigate against hydrogen ingress and/or to control hardness, can be used, but might not always be reliable. If the microstructure remains susceptible after heat treatment then HE can still occur in service. This can even be exacerbated by the corrosion of cathodic metal coatings such as zinc as such corrosion can promote the production of hydrogen at the bolt surface.

Although the range of hardness for grade 8.8 fasteners from ISO 898-1 extends into the hardnesses where HE is considered possible, it has been found in practice that the risk of HE occurring is small.

However, for property class 10.9 bolt assemblies which can have higher still hardnesses, as a precautionary measure, the Specification for Highway Works (SHW) Series 1800 (Ref 3) rules out the use of electroplating.

For guidance on considerations of HE for tension components, see GN 4.05.

Zinc coatings used in bolt manufacture
There are four common methods of applying zinc or zinc alloy coatings to fasteners:

- Electroplating
- Sherardizing
- Hot dip galvanizing
- Thermo-chemical surface modification

Depending on the thickness of the coating, the female threads of nuts can have a greater clearance tolerance for the coating. This may require nuts to be a higher strength grade than the bolts. This increase in clearance for each coating type is discussed below.

BS EN 14399 does not specify a standard for electroplating or sherardizing and leaves the coatings to be negotiated with the manufacturer.

(1) Electroplated zinc coatings
The coating of zinc is applied by the electrolysis of an aqueous solution of a zinc salt. The minimum local thickness traditionally used in bridge construction is 8 µm.

The thickness of the coating is only sufficient to provide temporary protection and the substrate may need to be blasted down to steel before overcoating. The coating should not be subject to mordant etching treatment ("T-wash") as it is difficult to prevent this treatment from removing the entire thin coating.

The surface of electroplated zinc fasteners, immediately after coating, is a bright metal surface. However, chromate passivation is essential for all zinc electroplated components and this changes the appearance. If no passivation is applied, zinc salts of a powdery appearance will form on the surface very quickly. This is known as white rusting.

Chromate passivation is a process by which the surface of the zinc coating is converted to extend its life. There are four levels of passivation. The use of hexavalent chromate is now prohibited for environmental and safety reasons. Trivalent chromate is now used for passivation.

Passivated surfaces can be clear, pale green or even black due to the formation of zinc chromate. However, the coating colour can also be changed by the use of dyes, so colour is not a complete indicator of the process used.

A basic passivation (designation A, Table B.2 of BS EN ISO 4042) would ensure that the bolt arrives on site in a reasonable condition. Class A is the lowest level of passivation,. The specification for an 8 µm coating would be Fe/Zn 8c1A,

If evidence of passivation remains at the time of painting, then the passivation layer should be removed mechanically, for example by abrading.

The thickness of the coating is such that no special measures are required with respect to thread clearance.

(2) Sherardized coatings
Sherardizing is a diffusion process in which the components are heated in close contact with zinc dust. The process is normally carried out in a slowly rotating and closed container at a temperature in the region of 385°C.

The resulting coating has a matt grey appearance. Orange staining may become apparent on sherardized coatings early in their exposure, but this is not detrimental to their performance.

Sherardizing tends to be used mostly to protect higher tensile steels (greater than 1000 N/mm^2), to avoid the risk of hydrogen embrittlement (which can occur with electroplating). Note that sherardizing is only suitable for protecting higher tensile steels if the method of cleaning the bolts prior to sherardizing is mechanical or alkaline. (For grades 10.9 and above, if the method of cleaning is acid pickling, there is a risk of hydrogen embrittlement.). Note that sherardized coatings may not protect high strength materials from hydrogen embrittlement caused by in-service conditions due to the reasons stated in the discussion of hydrogen embrittlement above.

Sherardized assemblies for preloading must be passivated to remove loose dust from the threads of the bolt and nut; dust could cause problems when tightening to achieve the preload.

The thickness of the coating requires the nut to be over tapped to create sufficient thread clearance (See Section 7 of BS 7371-8, Ref 7, for details.)

For bridgework, Class 30 coatings to BS 7371-8 or Class 30 or Class 45 coatings to BS EN 13811 (Ref 8) would be appropriate. These classes give coatings of minimum thicknesses 30 µm and 45 µm respectively.

(3) Hot dip galvanized coatings
Bolts and nuts are dipped in molten zinc and then centrifuged to remove excess zinc. Such products are commonly referred to as spun galvanized.

Hot dip galvanizing provides the highest level of corrosion protection as it gives a considerably thicker coating than either sherardizing or electroplating. It is also one of the two methods preferred by the Specification for Highway Works.

The galvanizing process does not cause hydrogen embrittlement, but embrittlement can be caused by acid pickling, which is used to clean the bolts prior to galvanizing. There is no problem for bolts up to and including grade 8.8, but for higher grade bolts only mechanical cleaning can be used.

High temperature galvanizing is now available from some manufacturers. The normal galvanizing bath has a temperature of approximately 450°C. However, it has been found that if the temperature is raised to approximately 550°C, a more even coating of zinc is achieved. By careful choice of suitable material and processing, manufacturers can ensure that the high temperature galvanizing process does not have any significant retempering effect on the bolt. This process is covered by BS EN ISO 10684 (Ref 9).

Currently, grades up to and including 10.9 can be obtained in a high temperature galvanized finish, and in sizes up to 24 mm diameter.

The major fastener manufacturers have made considerable investments in developing improved methods of galvanizing. However, extreme caution should always be exercised if galvanized bolts are procured through stockists, especially if the galvanizing is being arranged by the stockist; the process used must be identified reliably.

Passivation is not necessary on a galvanized finish, but the surface needs to be etched, as described below.

Bolts are galvanized after threading. Nuts are over-tapped to create sufficient thread clearance. This is achieved by galvanizing the nuts as blanks and then tapping them over size after galvanizing. Although this approach results in an uncoated female thread, this will be protected by the coating on the male thread when the fastener is assembled.

Hot dip galvanizing to BS EN ISO 10684 is specified for assemblies to BS EN 14399 (Ref 4). The minimum local thickness specified by this standard is 40 µm.

(4) Thermo-chemical surface modification (TCSM)
TCSM is achieved by application of a diffusion sacrificial corrosion-resistant coating of a zinc aluminium polymetallic composition. Typically, for TC bolts (a proprietary form of HRC bolts), the coating is *Greenkote*® (Ref 10), a proprietary product. The thickest coating PM-1 within the range 20 to 100 microns thickness is used for TC Bolts.

In accordance with the Specification for Highway Works Series 1900 (Ref 1) Table 2B has the following requirements for any corrosive protective coating other than hot dip galvanizing to BS EN ISO 10684:

"For such similar alternative surface protection treatments, prior to commencement of the works, the Contractor shall provide to the Overseeing Organisation a copy of the BBA HAPAS Roads and Bridges Certificate or equivalent"

(Note that the zinc electroplated and sherardized coatings are considered as providing temporary corrosion protection and so are not subject to this particular requirement.)

In addition, and as described in Specification for Highway Works Series 1900 (Ref 1) the TCSM coated fasteners must be installed and prepared prior to application of paint in accordance with the requirements of the applicable HAPAS certificate.

The recommendations in this guidance note are based on the HAPAS certificate at the time of writing, the HAPAS certificate current at the time of use should be checked as to all requirements.

Tightening zinc-coated bolts for preloading

Uncoated "self-colour" bolts are generally supplied with a lubricant on the threads of the nut. In the UK, all such bolts manufactured to BS EN 14399 are supplied in a lubricated condition K0.

The tightening of zinc-coated preloaded fasteners (nuts and bolts to BS EN 14399) requires special care. Zinc coated surfaces tend to bind under high interface pressure; this phenomenon is known as galling. Lubrication is essential to avoid a high proportion of bolt breakages in the latter stages of tightening. This situation is exacerbated by some pre-treatments of fasteners as it is necessary to remove all oil and grease to ensure the pre-treatment is effective.

As the use of T-wash prior to assembly will remove/destroy the lubricant, tightening methods that rely on torque should not be used. This is because the friction in the threads will be different from that assumed by the manufacturer from the suitability test for preloading (BS EN 14399-2).

Furthermore, HRC assemblies to BS EN 14399-10 (TC bolts) must not have their lubrication modified in any way, as the coating and spline shear torque together control the preload achieved.

Similarly, any bolting assemblies supplied for use in either of the K-class conditions K1 or K2 must not have their lubrication modified.

The most effective and economic lubricant for bolts for which lubrication is permitted, and especially for T-washed bolts, is tallow, which, for the best results, should be sparingly applied to the leading threads within the nut and the face of the nut that contacts the washer.

Over-application of tallow, for example dipping complete assemblies in molten tallow, gives no advantage and can create additional problems in cleaning prior to painting. Contamination of faying surfaces might occur during installation if there is excess tallow.

The part-turn method of tightening (which is added as an acceptable method of tightening in the SHW Series 1800, Ref 3) is a predominantly strain-control method that takes the bolt beyond its yield point. Consequently the final preload developed is not sensitive to a change in lubricant such as that caused by T-washing or by the application of tallow. However, it may be found that the torque required to tighten unlubricated bolts is sufficient to shear the bolt completely, before the part-turn is achieved.

Similarly the use of direct tension indicators (in accordance with BS EN 14399-9) does not rely on controlled lubrication.

Some specialist bolt suppliers whose products require consistent torque / tension relationships during tightening apply wax-based lubricants to plated nuts under factory conditions. These are often water-soluble and can be readily washed off after installation. Some manufacturers add a dye to the wax coating to distinguish such bolts from untreated items.

Other oils and greases should not be used for the lubrication of preloaded assemblies, as there is a high risk of contaminating faying surfaces and significantly reducing slip factors.

Treating galvanized fasteners and coatings before installation

Sherardized and TCSM coatings do not require etch treatments prior to coating. The surfaces should be clean and dry.

Most paint primers will not satisfactorily adhere directly to electroplated zinc-coated or spun galvanized surfaces, unless they are designed specifically for the substrate.

Three approaches are commonly used to provide a key for paint systems, and a fourth method can be used for high build paint coatings if the main steel members are also hot dipped galvanized.

The first method is to T-wash the bolts before installation to provide an etched surface. The second is to fix the bolts in the structure, as supplied, and then utilise a paint system for the bolted joints that includes, as a first coat, an etch primer. The third approach is to allow the surfaces to weather. The final approach is to use low pressure sweep blasting to produce a mechanical key for painting.

Coatings and treatments for UK highway bridges should be approved under the HAPAS Scheme and applied in accordance with the Specification for Highways Works. Refer to the 1900 Series and associated Notes for Guidance. (Refs 1, 2)

(1) T-wash (mordant etch treatment)

T-wash is a solution containing phosphoric acid and copper carbonate. The phosphoric acid etches the surface of the zinc and the copper carbonate produces a blue/black surface colouration showing that the surface reaction is complete. This discolouration is not absolutely uniform and it is not necessary to try to achieve absolute blue/ blackness, as long as it is clear that the solution has reacted over the whole area. Further application will only remove more zinc than is necessary.

T-wash should not be applied after installation unless on galvanized steelwork as contamination of adjacent surfaces is inevitable and the acid content may damage them and adversely affect subsequent paint application.

The data sheets from most paint manufacturers state that T-wash should be brushed on, but this can be impractical for fasteners; the normal approach is to batch dip. However, care should be taken to remove the items from the solution as soon as they discolour. If the items are left in the solution for too long, the zinc will be stripped. It is also very important to rinse with clean water and then dry the bolts thoroughly before use.

(2) Etch Primers

Some primers, other than etching materials, are now available that will give satisfactory adhesion directly on galvanized surfaces. These provide an attractive alternative to T-wash, the use of which now creates many problems under environmental and health and safety legislation.

Etch primers are also suitable for use on electroplated zinc coatings, provided any passivation layer has been removed by weathering.

However, it is strongly advised that adhesion tests are carried out to verify the performance of such primers prior to their use. Note that, unlike T-wash, the effectiveness of the etching process cannot be checked after application.

Alternative pre-treatments to replace T-Wash are also becoming available. Proper testing should be undertaken before using one of these materials.

(3) Weathering

Where bolted joints have been left for some time after installation, typically at least 12 months, it may be sufficient to let the bolts weather. This may be the best method for non-preloaded connections where the structural steel is also galvanized. Any weathered surfaces should be washed to remove soluble zinc salts and other contaminants, prior to painting in accordance with the paint manufacturers' instructions.

(4) Sweep blasting

Where the steelwork is galvanized, low pressure sweep blasting may be undertaken to provide a mechanical key for painting. This is particularly useful when high build systems are to be applied as part of a duplex system. This method is more widely used in the US than in the UK.

Sweep blasting requires the use of low pressure equipment (less than 2.7 bar 40 psi), suitable soft abrasives such as copper slag or carborundum powder (5 Moh or less) and skilled operation, with an impact angle into the surface of between 30 and 60 degrees. Unless there is previous experience of using this technique, it is advisable to carry out trials to determine all the correct parameters.

Treatment of plated bolts after installation

Normally, the specification of the protective system for slip-resistant bolted joints requires surface preparation of the joint contact surfaces (faying surfaces) by abrasive blast cleaning. This should not be taken to include the bolts, nuts and washers after installation, as they are not 'joint material'.

However, if some blasting of the outer surfaces of the joint material is needed then inevitably some damage to the bolts will occur. Otherwise it is more satisfactory to simply to degrease the fasteners and apply the remainder of the coating system rather than blast off the fasteners' coating and then reapply coatings.

However, if the fasteners have only thin plating and there has been lengthy exposure that results in corrosion, then blast cleaning of the fasteners may be required.

Recommendations

The following table gives an indication of the costs of the various types of zinc coating relative to that of the untreated fastener:

Coating	Cost [1]
Zinc electroplated	20%
Spun galvanized	30%
Sherardized	35%
TCSM	See Note 2

Note 1: The total cost of bolts is usually less than 1% of the cost of the structural steelwork.
Note 2: The cost of the coating for TC bolts, as a proportion of the total cost of the bolt, is not available.

Of the four processes, the two most effective in terms of corrosion protection are spun galvanized and TCSM.

It is recommended that spun galvanized bolts be specified (in accordance with BS EN ISO 10684 (Ref 9) wherever possible for HR bolts and TCSM (such as Greenkote®) is specified for HRC bolts (TC bolts are supplied with Greenkote®).

References

1. Manual of Contract Documents for Highway Works, Volume 1: Specification for Highway Works, Series 1900, Protection of steelwork against corrosion, Aug 2014.
2. Manual of Contract Documents for Highway Works, Volume 2: Notes for Guidance on the Specification for Highway Works, Series NG 1900, Protection of Steelwork against Corrosion, Aug 2014.
3. Manual of Contract Documents for Highway Works, Volume 1: Specification for Highway Works, Series 1800, Structural steelwork, August 2014, TSO.
4. BS EN 14399, High-strength structural bolting assemblies for preloading (in 10 Parts)
5. BS EN ISO 4042:2000, Fasteners. Electroplated coatings
6. BS EN ISO 898-1:2009: Mechanical properties of fasteners made of carbon steel and alloy steel. Part 1: Bolts, screws and studs with specified property classes – Coarse thread and fine pitch thread (ISO 898-1:2009)
7. BS 7371-8:2011 Coatings on metal fasteners. Specification for sherardized coatings.
8. BS EN 13811 Sherardizing. Zinc diffusion coatings on ferrous products. Specification
9. BS EN ISO 10684:2004. Fasteners. Hot dip galvanized coatings
10. Greenkote: Corrosion-Resistant Poly-Metal Diffusion Coatings. Rosenthul, Itzhak, Paint & Coatings Industry; March 2006; 22, 3.

