Guidance Note 8.04

Thermally sprayed metal coatings

Scope

This Guidance Note describes the process of applying metal coatings by the thermal spray process and explains the properties of the coating system.

Introduction

Thermally sprayed coatings of zinc and aluminium, and more recently zinc-aluminium alloys, have been applied for many years to provide long-term corrosion protection to steel structures exposed to aggressive environments. They are an important component of the duplex (metal coating / paint) systems that are currently specified for steel railway bridges.

However, for highway bridges the protective system Type II using aluminium thermal metal spray was removed from the Specification for Highway Works 1900 Series in August 2014, except for joint material in bolted connections (Protective System Type II Area D). An aluminium metal spray system is still an option for ancillary items such as bearings (protective system Type V), CCTV masts and lighting columns (protective system Type A1)

Thermal metal spray is also commonly used on steel bridge decks on its own or prior to application of surfacing systems.

For railway bridge components, the sprayed metal used for the coatings was historically either aluminium or zinc. Aluminium was normally specified, except for railway bridges likely to be subjected to collision damage, where zinc was recommended due to its sacrificial nature. From the issue of new standards in 2023, thermal metal spray is now specified as a combined Zn/Al system [7].

In atmospheric conditions of exposure, aluminium acts as a barrier coating whilst zinc provides protection by a sacrificial process. The combination of metal and paint in a duplex protective treatment has greater durability in comparison with that of the individual components, and also offers an opportunity to provide an aesthetically attractive finish to the structure by offering a choice of colour.

The total thickness of the selected coating system is usually determined by the required life to first maintenance.

A typical specification for thermally sprayed aluminium and zinc coating thicknesses as part of a multi-coat protection system would be a minimum of 100 µm.

Design for thermal metal spray

The design considerations for thermal metal spray are described in BS EN ISO 2063-1 [2] and BS EN 15520:2007 [9]. One consideration is providing access to apply the coating from the gun as described below. Recesses and deep holes will not be able to be coated easily as the spray cannot be directed near perpendicular towards the surface. Pipes and hollow sections can be coated using special equipment but only before fabrication.

The advantages of thermal spraying compared to metal coating using hot dip galvanizing are:

- Steel components are not heated significantly by the process and this can be advantageous where components are at risk of distorting if heated.
- The application is not limited by the size of the workpiece or component.
- The operation can be carried out in the shop, or on site depending on the spraying process.
- Even geometrically complex components can be coated using the appropriate spray set-up.
- The process with the correct consumables. can provide a slip-resistant surface.

Unlike hot dip galvanizing as described in GN 8.04, it is not possible to apply a metal coating to the internal surfaces of hollow sections, after fabrication.

Coating application

Before the application of the metal coating, it is essential that the surface of the component to be coated is thoroughly cleaned to ensure that all traces of rust and mill scale are removed and to impart a suitable profile and amplitude to provide the necessary mechanical 'key' for adhesion of the coating.

Surface preparation is normally achieved by blasting with a suitable angular abrasive.

It is well established that the performance of any corrosion protection coating system is significantly influenced by the quality of the initial surface preparation. (See GN 8.01).

The metal to be sprayed can be either in powder or wire form. It is first passed through a heat source that melts the material. The hot molten particles are then projected by compressed air towards the surface to be coated. The particles impact on to the surface, flattening and solidifying as overlapping platelets. The equipment used for the melting and spraying process is a hand-held gun that uses either a gas flame system or an electric arc process to provide the necessary heat.

Gas flame spraying

Metal spraying using the gas flame process is a long-established practice that uses powder or wire. However, particular care must be taken to ensure that the surfaces to be treated are properly prepared, especially in areas that have been locally hardened due to flame cutting etc. The process is less tolerant to inadequate preparation than electric arc spraying.

Electric arc spraying

The electric arc process uses twin wire electrodes of the metal to be sprayed that are melted when positioned to form an arc produced by an applied electric current. This process affords many advantages including high speeds of application and improved adhesion to steel substrates, particularly with sprayed aluminium, compared with the gas flame process. Generally, electric arc is not considered as flexible as the gas flame process where intricate articles have to be treated or where access for the equipment is constrained.

Electric arc spraying gives good results on large flat areas, but tends to be relatively rough around web/flange intersections and the corners created by typical stiffener arrangements. This condition is normal and is not detrimental to the performance of the coating.

As successful coating application requires skill and experience, coating applicators should be qualified to BS EN ISO 14918 [4]. Note this is mandatory for railway bridges [7].

Sealer coat

After the application of the metal coating, and except for faying surfaces and abutting surfaces, it is usual to apply a thin 'sealer' coat.

The function of a sealer coat is to impregnate the natural pores in the sprayed metal coating and thus prevent any moisture and oxygen reaching the steel surface. Sealants are therefore usually low-viscosity materials that easily penetrate the coating. They do not add significantly to the coating thickness even where several coats of sealer are applied. There are now many different types of sealers available, including those based on vinyl, phenolic and polyurethane formulations. They are readily obtainable in a wide range of colours.

'Over-thick' application is to be avoided. In the Specification for Highways Works, sealer application is specified in terms of an application rate (between 12 and 20 m2/litre).

It may be noted that sealer manufacturers state that an application rate of 20 m2/litre results in a thickness of 25 μm, which is the Network Rail requirement, but that value relates to thickness on a non-absorbent surface. It is difficult to measure the thickness of sealer after it is applied to metal spray.

Over-application of the epoxy sealer can lead to a smooth glass-like surface and adhesion problems for the first paint coat can result.

As soon as practical, and before the onset of surface deterioration, all thermally sprayed metal surfaces (excluding faying surfaces and abutting surfaces) should be coated with the sealer. Failure to do this may in certain circumstances (i.e. storage in damp or wet conditions) lead to the appearance of dark staining, which is indicative of corrosion of the substrate. In such situations, there is little recourse other than to lightly sweep blast the surface before sealing but this is not an ideal solution.

Life expectancy

Aluminium

The life expectancy of sealed, un-painted, sprayed aluminium will extend over several decades, but it is not easy to predict actual life with accuracy. The protection afforded by aluminium is due to the formation of insoluble salts produced on its surface in corrosive conditions. The inert film accounts for the low corrosion rate of the coating in most environmental conditions.

Zinc

By contrast, the durability of zinc coatings are generally predictable under known local environmental conditions, This is mainly because the coating reacts with the corroding media at a steady rate through the solubility of the zinc corrosion salts that are formed. For this reason, the life of the zinc coating is generally proportional to its thickness. Wetness and contaminants increase the corrosion rate of zinc. At discontinuities in the coating, which may arise due to mechanical damage etc. the zinc provides a measure of protection for the substrate by galvanic action; the zinc behaves in a sacrificial manner.

Zinc-Aluminium

Network Rail now specifies the use of Zn/Al 85/15 i.e., a wire of composition 85% Zinc and 15% aluminium. This provides the benefit of the zinc cathodic protection as described above, and performs better than aluminium in a chloride rich / saline environment.

The N1 system is mandatory on structures that use preloaded bolted splices for railway bridges.

Treatment of faying surfaces at slip-resistant bolted joints

Research has shown that reliable slip factors can be achieved with thermal metal sprayed surfaces. However, sealers should not be applied to the faying surface, except for a small margin (10 – 15 mm) around the edges, as they will significantly reduce slip factors.

If all the steel surfaces of a component are metal sprayed, including the faying surfaces, then masking off for subsequent paint coatings is an easy matter. The steel is in a protected state and the identification and masking of faying surfaces may be done without delay to the finishing process, without undue haste and with no detriment to the eventual protection.

Subsequent paint coats should be kept completely clear of the faying surfaces and stepped back. This latter margin will be properly coated when final painting takes place after the joint is made, in the knowledge that the substrate is well protected. The arrangement of coating and masking for the flange of a bolted splice is shown diagrammatically in Figure 1.

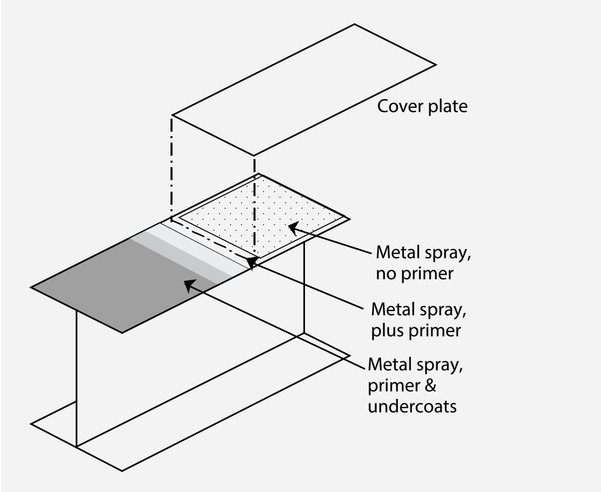

Figure 1 Coating and masking at a bolted splice, with subsequent coats stepped back.

Repair of damaged areas and treatment at site welds

Where the coating has become damaged, and subject to the specification, it is generally acceptable to repair the damage by local blast cleaning followed by the application of more thermal metal spray or by using a zinc rich epoxy paint to either zinc or aluminium thermally sprayed coatings. Similar treatment can be applied at site welded joints. For structures that are to be exposed to high service temperatures, an inorganic zinc silicate repair coating is preferred.

Properties of thermally sprayed coatings

Thermally sprayed metal coatings have several significant properties over paint that make them suitable for application to steel structures;

- Sprayed metal coatings solidify immediately on application and, unlike paints, no drying time is involved.
- They do not sag or run and can be applied to a range of thicknesses in one operation.

- They have good handling, erection and mechanical damage resistance.
- They do not interact or harden before use in hot weather or during prolonged storage.

As a result, metal-coated components can be handled, lifted and transported as soon as required, although they do need to be sealed before exposure to the weather. (This contrasts with painted components, where a curing period is required.)

Coating thickness can be measured as the work proceeds and thin areas rectified at once, although it is preferable for the correct coating thickness to be applied in one operation.

When it is not possible to fully coat a beam that has been blast cleaned, the partially coated section can be protected whilst the remainder is re-blasted and coated, with a feathered edge on the end of the previously applied coating.

The metal coatings also offer protection to areas around slip-resistant bolted connections during the construction period, until final site paint over-coating is completed.

Additionally, the coating materials do not require the addition of hardeners, accelerators or thinners and therefore present no mixing problems. Nor do they contain inflammable solvents. However, the formation of zinc fumes does necessitate the use of personal protective equipment. Refer to the TSSEA Code of Practice [5].

Thermally sprayed coatings are compatible with a wide range of sealers and paints. They do not suffer from degradation or embrittlement due to ultra-violet or thermal effects. Consequently, they can be over-coated with paints, etc. even after long-term exposure. (The only preparation needed is the removal of loosely adherent corrosion products by light wire brushing.)

However, there are a number of aspects that also need careful consideration.

- Thermally sprayed metal coatings in typical multi-coat protective systems are relatively expensive. They require more time and skill to apply, and need a clean surface ideally to Sa3 standard, although Sa2½ is satisfactory for zinc.
- Thermally sprayed coatings need the substrate to have an angular surface profile with a greater amplitude (in the range 75 mm to 100 mm) than other coatings.
- Thermally sprayed coatings are difficult to remove with blast cleaning. (But if the paint coating in a typical duplex system is properly maintained, then removal of the metal coating will not be necessary.)
- Thermally sprayed coatings are best suited to shop application, as the equipment required is bulky and cumbersome. Nevertheless, the process can be used on site for ‘touch-up’ areas on new construction and for large areas on maintenance contracts.
- Inspection and testing of coatings should be undertaken by an inspector trained as a Thermal Metal Spraying Inspector under the scheme provided by The Thermal Spraying and Surface Engineering Association (TSSEA) or equivalent. See also GN 8.06.

Measurement of thickness

The use of modern digital thickness gauges, on well applied and uniformly sprayed metal coatings, tends to give significantly varying readings within small test areas due to a combination of the inherent surface profile of the sprayed metal and the relatively rough grit blasted substrate.

To overcome the variation problem, a method of measurement is set out in BS EN ISO 2063-2 [3], based on averaging a set of individual readings within a test area. However, this method does not take into account the profile of the substrate when determining the coating thickness. One way of achieving a more realistic measurement of coating thickness is to take a set of initial ‘profile’ readings prior to spraying. The averaged value may then be discounted from the final thickness measured using the BS EN ISO 2063 method. Whichever method is used, it is important to appreciate that thickness can only be assessed, rather than directly measured.

Adhesion testing

The Specification for Highway Works [1] and Network Rail standards [7] require regular pull-off testing to confirm the adhesion of the thermally sprayed metal coating. These are carried out on steel test panels representative of the grade of material used in the steelwork being treated. For highway bridges these are carried out to the standard ASTM D4541-Type III and for railway bridges to BS EN ISO 4624 or BS EN ISO 16276-1. If these tests on the test panels fail to meet the required adhesion, further tests will need to be carried out on parent material. Note that the values of required adhesion vary between these specifications.

Certain parts where this test is not suitable will require adhesion to be demonstrated by use of the grid tests described in BS EN ISO 2063-2 [3].

Reference documents

[1] Manual of Contract Documents for Highway Works. Specification for Highway Works, Series 1900: Protection of Steelwork against Corrosion, 2014, TSO.

[2] BS EN ISO 2063-1:2019 Thermal spraying. Zinc, aluminium and their alloys - - Design considerations and quality requirements for corrosion protection systems

[3] BS EN ISO 2063-2:2017 Thermal spraying — Zinc, aluminium and their alloys — Part 2: Execution of corrosion protection systems

[4] BS EN ISO 14918:2018 Thermal spraying – Qualification testing of thermal sprayers.

[5] A Code of Practice for the safe installation, operation and maintenance of Thermal Spraying Equipment Issue 3, July 2014, Thermal Spraying and Surface Engineering Association, Warwickshire.

Other relevant Standards and further reading

[6] NR/L2/CIV/039: Level 2 Specification. Assessment and certification of protective coatings and sealants (Issue 1), Network Rail, June 2023 {formerly NR/L3/CIV/039, now promoted to a Level 2 standard and renumbered}.

[7] NR/L3/CIV/040 Level 3 Work Instruction, Work instruction for the use of protective coatings, June 2023.

[8] 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.

[9] BS EN 15520:2007 Thermal spraying. Recommendations for constructional design of components with thermally sprayed coatings.

[10] Corrosion Tests of Flame-Sprayed Coated Steel 19 Year Report American Welding Society Inc., Miami, Florida 33125.

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