Hot dip galvanised steel as a substrate for paint

Characteristics, surface preparation & specifications

Introduction

Galvanising is an effective corrosion protection method for steel in many environments. However, being a metallic coating, galvanised steel may also require additional corrosion protection by paint or coatings in an aggressive environment. In addition, there are other reasons for coating this type of substrate, such as cosmetics, identification and other.
This technical article describes hot dip galvanizing including surface characteristics. The surface characteristics are described together with the necessary surface preparation of galvanized steel before application of paint.
A galvanised steel substrate overcoated with paint is often referred as a “Duplex system”.

Scope

This guideline is valid for most of Hempel epoxy barrier products as well as topcoats. However, of special relevance are the adhesion primers:

- Hempadur 15553
- Hempadur 15554
- Hempel’s epoxy primer HV 15410

Introduction to galvanised steel

Galvanised steel is protected against corrosion by the galvanising itself. Properly selected the galvanising will protect the steel from rusting for years.

Galvanised steel may be painted for different reasons:

- **Enhanced durability**: The durability of duplex systems normally is significantly higher than the sum of the individual durability of the zinc coating and that of the paint coating. One is talking here about a synergism effect. The resulting increase in lifetime is by a factor between 1.2 and 1.5, depending on the system.
- **Colour**: In addition to the metallic zinc coating, it is possible in the case of duplex systems to utilize the full range of colours available by coatings.
- **Signalling/Camouflage**: For certain objects marking by colours for warning and identification purposes is necessary. Using suitable coating materials an adaptation of objects to the surrounding or a camouflage effect can also be achieved.
- The application of suitable coating materials is also then appropriate if, in certain cases, the contamination of the environment by zinc must be avoided.

Galvanised steel is a difficult substrate for paint. Insufficient or incorrect surface preparation, unsuitable binder types, insufficient dry film thickness, and the combination of these factors have caused numerous failures observed - and still today, no one will claim to have found a 100% safe procedure for painting galvanised steel. We can often see these negative consequences in outdoor equipment of everyday life such as traffic signals, boards, sport structures, etc where the existing coatings detach from the galvanised substrate underneath.

The main cause leading to wrong specifications for galvanised steel is that the galvanising coat is considered a “non-corrodible” substrate. This is wrong. The zinc coating does corrode, and the long-time protection that may be offered by uncoated galvanising is due to the formation of a dense, partially insoluble layer of corrosion products, which reduces the corrosion rate of the metallic galvanising layer – just like the oxide layer on aluminium and stainless-steel surfaces. Where such a dense layer of corrosion products is not formed - as in hot or soft water, in acid or alkaline environments - the zinc coating will corrode fast.

Accordingly, when galvanised steel needs corrosion protection by painting, paint systems must be selected, which do not differ much in dry film thickness from a paint system for steel. This is because a too thin paint film may accelerate the break down causing more white rust beneath the paint film, than for an open air exposed galvanised surface having a shorter "wet time".

In addition, it should be noted that flux residues, zinc-ammonium chloride, used during the galvanising process or products like a passivation agent should not be present on the surface when coating the galvanised surface.

Temperature resistance of galvanised coatings

Zinc coated steel is only resistant to temperatures below 200°C/392°F. Above this temperature, the coating will flake, painted or not, due to diffusion processes in the coating.

Types of galvanised steel

Following materials are known as galvanised steel:

- Hot dip galvanised steel
- Continuously galvanised (sheet) steel with
  - Zinc coating
  - Zinc-aluminium coating
- Electrolytically zinc plated steel
- Sherardised steel and mechanically plated steel

Hot dip galvanised steel is the most common type and only hot dip galvanised steel will be described in more detail below.

Hot-dip galvanised steel

The galvanising process is a batch or piece-by-piece process, carried out in small to large galvanising plants.
The process includes:

- Degreasing of steel items
- Removal of mill scale and rust by acid pickling, generally using 10-15% hydrochloric acid
- Fluxing by means of zinc chloride or zinc ammonium chloride: Either by dipping in water solutions of the flux salts before the zinc kettle or by having the flux salts floating as a melt on the molten zinc
- Dipping in a kettle with molten zinc at a temperature of 450-460°C/840-860°F
- Water cooling or “quenching” (optional), not recommended for items to be painted.

Characteristics of hot-dip galvanised coatings
The thickness of the zinc coating ranges from around 50µm to 250µm and occasionally above (thicknesses above 250µm experience significant stress caused during the cooldown process and can lead to flaking of the galvanised layer). The thickness applied depends among other things upon the amount of protection needed and the exposure of the object.

Appearance of hot-dip galvanised coatings
The appearance may range from shiny metallic looking surfaces, often spangled with "zinc flowers", to grey, matt surfaces.

The metallic looking surfaces are mostly found on thinner coatings. They are composed of a so-called iron-zinc alloy layer, formed during reaction of steel with the liquid zinc, and on top of which a solidified layer of pure zinc is formed during withdrawal from the zinc kettle.

The grey, matt coatings are characteristic for heavy steel members, especially when made of silicon-killed steel, which have high reactivity towards zinc. The grey, matt coating is composed almost solely of iron-zinc alloy layers, which are formed partly during dipping in the kettle, partly during withdrawal due to the high reactivity of the steel and/or the heat capacity of heavy steel members. This kind of coating is considered a better substrate for paint than the shiny, metallic looking galvanizing.

Both types of appearance may be seen on one item, generally caused by variations in the steel composition or uneven cooling conditions after withdrawal from the zinc kettle.

Other characteristics of hot dip galvanised coatings

Because of the galvanising fabrication process the galvanised coating may show other characteristics, which may have influence on paint coatings to be applied.

Sags and runs: Liquid zinc may sag just like paint, when the object is withdrawn from the zinc kettle. Sags and runs may be formed due to too high withdrawal speed or a steel design not optimized for the dipping process. If sags and runs are flat without loose zinc, they do not interfere with paint performance - but may still be visible after painting, especially on high gloss finishing coats.

Loose zinc metal: Splashes of zinc and excessive runs may result in loose zinc metal on top of an otherwise intact galvanising. Loose metal must be removed before applying paint.

Burnt-in zinc ash and flux: Zinc ash, which is the thin oxidized layer of zinc on top of the zinc kettle, and flux may be incorporated in the zinc coat, especially in corners and other places, where the free draining of liquid zinc is obstructed during dipping. As zinc ash and flux residues contain salts they must be removed before applying paint.

Zinc drops and spikes: These are like sags and runs created during withdrawal from the zinc kettle and are mostly found on edges. As they generally are sharp as the name implies, they must be removed by grinding before applying paint.

Black spots: Areas, where the molten zinc has not wetted the steel due to insufficient degreasing or pickling, are called black spots. In most galvanising standards, black spots are not allowed or only allowed in limited amount. In cases where black spots are requested to be repaired by paint, the spotted area must be thoroughly cleaned by abrasive (vacuum) blasting or grinding before applying paint (see section Repair of galvanised steel below).

General contamination with galvanising chemicals: As it may be understood from the short description of the galvanising process, there is a risk of general contamination of the galvanised surface with salts. Hydrochloric acid vapours from the pickling bath and flux vapours are typical sources. In modern galvanising plants with effective ventilation the amount of vapour is reduced. Further, from the paint's point of view, the use of a separate flux bath is preferred in comparison with a flux blanket on top of the zinc kettle.

Thickness of zinc coatings

In accordance with EN ISO 1461 the **minimum thickness** of zinc coatings is between 45 µm and 85 µm. In practice the zinc coatings are, however, considerably thicker, depending on composition of the steel, material thickness, time period of dipping and other parameters. Minimum thicknesses are given in table 1.

Table 1: Minimum thickness of zinc coatings (EN ISO 1461)

Material thickness mm	Coating thickness µm
< 1,5	≥ 45
≥1,5 to < 3	≥ 55
≥3 to < 6	≥ 70
≥ 6	≥ 85

In accordance with the specifications in EN ISO 1461 the thickness of the zinc coating must be checked prior to the paint work.

Surface preparation of galvanised steel

Galvanised steel is considered as a much more critical substrate for paint than steel. Proper surface preparation is consequently of the utmost importance.

Contrary to steel on which corrosion products and mill scale are easily distinguishable from the substrate due to a difference in colours, contamination and corrosion products on zinc are more difficult to see. In addition, it should be noted that no flux residues (zinc ammonium chloride) or any passivation agent should be present on the surface when coating the galvanised surface.

Surface preparation methods:

1. **Grinding**

   Purpose:
   Removal of loose metal, burnt-in zinc ash, and burnt-in flux. Removal or rounding to a minimum radius of 2 mm of sags, runs, drops, spikes, and other irregularities which prevent coverage of the paint.

   Procedure:
   Use orbital grinder, cup wheels, abrasives paper, whichever will fit the removal best.
   Take care not to damage the galvanised coating. When removing burnt-in flux, take care that grinding dust is not smeared into the surface.

   Result:
   All loose metal, burnt-in zinc ash, and burnt-in flux is removed. Sags, runners, drops, spikes, and other protruding irregularities are removed or rounded to a minimum radius of 2 mm.

2. **Cleaning**

   Purpose:
   Removal of zinc corrosion products, including white rust, zinc ash and flux. Removal of oil, grease, wet storage stain protective and other general contamination, including dust.

   Procedure:
   Steam cleaning, weakly alkaline
   Use a pure steam or a steam-hot water mixture with an addition of a mild alkaline cleaner. Final cleaning with clean water is necessary immediately after steel cleaning. Dry the surface.
   or
   Emulsifier cleaning
   Use 150-300 bar high pressure freshwater hosing, preferably hot, with a suitable detergent added followed by high pressure freshwater hosing.

   Result:
   All contaminants must be removed.

3. **Abrasive sweep blasting**

   Purpose:
   Removal of zinc corrosion products, including white rust, zinc ash and flux, moreover phosphate and chromate based wet storage stain protective. Establishing a surface profile in the galvanised coating, mandatory before applying most epoxies and other two-component paints (for heavy-duty exposure during service).

   Procedure:
   Use non-metallic abrasive of the grit type. Fine-grained (0.2-0.5 mm) mineral abrasive such as aluminium silicate or corundum as well as various slags, are acceptable, provided they are metal free. Air pressure at the nozzle must be 2.5 to 4 bars. The working distance must be approximately 50 cm/20 inch and with an acute angle of incidence. During surface preparation and until the first paint coat is applied, air humidity must be below 85% RH and the surface temperature must be at least 3°C/5°F above the dew point. Feather (by grinding) any area in the galvanised coating, where the galvanised coating has flaked off.
   As the zinc coating does not show a visible “turning” of the surface as for steel, it is recommended not to leave the surface unprotected longer than an abrasive blasted steel surface, depending on temperature and relative humidity.

   Result:
   The sweep blasted surface must be uniformly matt grey with a dense surface profile.
   No un-swept/blasted area must be visible when inspected at 10 times (x10) magnification.
   The thickness of the galvanised coating is reduced by sweep blasting, an average reduction of about 10 micron/0.4 mils is claimed, but higher values can be seen.

   Comments:
   Abrasive sweep blasting is considered the most safe and productive method for surface preparation of galvanised steel.
   Abrasive sweep blasting must be carried out carefully as there is a risk of flaking of the zinc coating, especially when the coating is thick.
   Abrasive sweep blasting is mandatory before applying epoxy paints and other two-component paints for heavy-duty service (larger areas for service in C5 M/I environments).

   Sequence of surface preparation
   Surface preparation may be carried out in the following sequences:

   Step 1. Removal of surface irregularities, e.g.:

- loose metal
- burnt-in zinc ash
- sags, runners
- drops, spikes
- after-fabrication welding slag

Method(s): Grinding

Step 2. Removal of oil and grease, e.g.:
- wet storage stain protective of oil type
- after fabrication residues

Method(s): Steam cleaning, emulsifier cleaning

Note: After this stage surface preparation is finished for paint systems only requiring "degreasing and washing" as the cleaning methods will also remove step 3 contaminants.

Step 3. Removal of corrosion products and salts, e.g.:
- zinc ash
- flux
- wet storage stain protective, chromate and phosphate based

And creation of an anchor pattern for improved adhesion.

Method(s): Abrasive sweep blasting

Note: Abrasive sweep blasting is mandatory before applying epoxy and other two component paints for heavy duty service (including larger areas for C5 M/I service).

Coating systems for galvanised steel

In general good quality epoxy + polyurethane coatings can be used on galvanised steel provided there is a suitable sharp roughness profile. Alkyds should never be used. Hempel has a wide range of products available. The recommended system build (number of layers and film thicknesses) depends on the service conditions.
There are several international standards related in one way or another to galvanised steel substrates for determination of the quality of the galvanising layer, its characteristics, testing methods, suitable paint systems, etc

However, the most relevant standards related to paint specifications over galvanised steel substrates are:
- **EN ISO 12944-1 to 8 "**Corrosion protection of steel structures by protective paint systems"
- **Norsok M-501, edition 7.** "Surface preparation and protective coating"

EN ISO 12944-1 to 8 Corrosion protection of steel structures by protective paint systems:
EN ISO 12944-5 gives recommended coating systems for various areas including hot-dip galvanized substrates covered in table B.3 of the standard.

The table indicates:
- the generic type of coating products of the coating system (priming coat/topcoat);
- the required number of coats to be applied;
- the total nominal film thickness and
- the expected durability which can be achieved, related to the respective corrosivity category:
  - low (L): 2 to 5 years
  - medium (M): 5 to 15 years and
  - high(H): 15 years to 25 years
  - very high (VH): > 25 years

This expected durability relates to adhesion of the coating on the galvanised surface. See note 3 in table B3 below from ISO 12944-5. The expected corrosion protection of the total system including galvanising is much longer.

Table B.3 – Summary of the minimum number of coats (MNOC) and minimum NDFT of the paint system depending on durability and corrosivity category on hot dip galvanized steel according to ISO 1461 and ISO 2063 (ref. ISO 12944-5:2018)

Durability		Low (l)		Medium (m)		High (h)		Very high (vh)	
Binder base of primer		EP, PUR	AY	EP, PUR	AY	EP, PUR	AY	EP, PUR	AY
Binder base of subsequent coats		EP, PUR, AY	AY	EP, PUR, AY	AY	EP, PUR, AY	AY	EP, PUR, AY	AY
C2	MNOC	a		a		1	1	1	2
	NDFT					80	80	120	160
C3	MNOC	a		1	1	1	2	2	2
	NDFT			80	80	120	160	160	200
C4	MNOC	1	1	1	2	2	2	2	—
	NDFT	80	80	120	160	160	200	200	—
C5	MNOC	1	2	2	2	2	—	2	—
	NDFT	120	160	160	200	200	—	240	—

NOTE 1 The abbreviations are described in Table A.1. For single coats, the binder base of the primer is recommended.

NOTE 2 In addition to polyurethane technology, other coating technologies may be suitable, e.g. polysiloxanes, polyaspartic and fluoropolymer [fluoroethylene/vinyl ether co-polymer (FEVE)].

NOTE 3 The durability is in this case related to the paint system adhesion to the hot dip galvanized surface. In case of damaged paint system, the remaining hot dip galvanized layer delivers further protection to the steel.

[a] If a coating is desired, use a system from a higher corrosivity categories or durability, e.g. C2 high or C3 medium.

Norsok M-501 eds. 7: Surface preparation and protective coating
Galvanised steel is covered in Norsok M501 edition 7 by system 6B.
The recommended specification consist of: 50µm epoxy + epoxy + UV resistant topcoat to a total DFT =225µm.
No prequalification testing is required except that the topcoat has to be prequalified for system 1.
Note that in previous version of Norsok M501 surface preparation by solvent cleaning was suggested. In edition 7 sweep blasting is mandatory.

When sweep blasting is not possible
In some situations, sweep blasting is not necessary or possible. In such cases the best alternative is to use an epoxy primer with chemically enhanced adhesion properties (sometimes called adhesion primers) e.g., Hempadur 15553, Hempadur 15554 or Hempel's epoxy primer HV 15410. A full system can be built by applying one or more layers on top.

In moderately aggressive environments this may offer long durability of the coating system and be a good solution to cover galvanising with the required colour. However, in aggressive environments the absence of a suitable anchor profile created by abrasive blasting will always increase the risk of detachment. While adhesion primers are the best available option for this they can never fully compensate for the missing roughness.

Repair of galvanised steel

It is often required to repair mechanical damages, black spots or welds in the zinc coat with zinc rich paints.
Surface preparation is of utmost importance to secure the quality of repairs. A large damage must be abrasive blasted to Sa 2½ using non-metallic abrasive. Small (coin-size) areas may be abraded to a metallic clean surface (avoid over-polishing the surface) and the edges are to be feathered to give a smooth transition. The intact galvanising surrounding the damaged area, must be light abrasive sweep blasted, alternatively abraded, to secure paint adhesion.

When heavy duty paint systems are to be applied on galvanising it should be considered whether touch-up of damaged spots in the galvanising with zinc rich paint is feasible compared to leaving the protection to the specified paint coating.