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Steels suitable for galvanizing

Most steels can be satisfactorily hot-dip galvanized. However, reactive elements in the steel, silicon (Si) and phosphorus (P), can affect the hot-dip galvanizing process. An appropriate selection of composition can therefore give more consistent quality of coating with regard to appearance, thickness and smoothness. The prior history of the steel (e.g. whether hot rolled or cold rolled) can also affect its reaction with the zinc melt. Where aesthetics is important, or where particular coating thickness or surface smoothness criteria exist, specialist advice on steel selection should be sought prior to fabrication of the article or hot dip galvanizing.

The influence of silicon and phosphorus on steel reactivity

During steel production, silicon or aluminium is added to remove oxygen. These steels are known as “killed steels”. Since the content of silicon (Si) affects the hot dip galvanizing reaction, the silicon content should always be taken into consideration for steels that will be galvanized. Aluminium-killed steels suitable for galvanizing have low silicon content, below 0.03 weight percent. Silicon-killed steels with a silicon content above 0.14 % also works well in galvanizing, but gives a thicker coating than aluminiumkilled steels. The phosphorus content of the steel also influences on the reactivity, especially for cold rolled steels. Other alloying elements in the steel have no major influence on the coating.

The Sandelin range

Steels with a silicon + phosphorus content in the range 0.03-0.14 weight percent are called “Sandelin steels” in galvanizing terminology. These steels should either be avoided or special types of galvanizing baths should be used. In a conventional zinc bath the reaction between this type of steel and zinc is very strong and the coating becomes thick and irregular, often with poor adherence. It is the crystals in the outermost alloy layer, the zeta-phase, that grow as small, thin grains. Molten zinc diffuses rapidly between the grains and the growth of the coating is very fast. If zinc baths with suitable alloy additions not are available, this type of steel should be avoided for hot-dip galvanizing.

Studies performed by FORCE Technology in Denmark have shown that the bottom limit for the Sandelin range is lower than earlier suggested. It has also been shown that the phosphorus content has a large influence on the reactivity for cold rolled steels. For this reason, Nordic Galvanizers now gives the following recommendations:

If the appearance of the galvanized surface is very important, for example in architectural applications, the following expression shall be used for **cold rolled steel:**

Si < 0.03 and Si + 2.5 x P < 0.04 weight percent

For **hot rolled steel** the silicon content is even more critical, but the phosphorus content is of less importance, and the following expression is recommended:

Si < 0.02 and Si + 2.5 x P < 0.09 weight percent

In most cases however, steel with silicon + phosphorus content < 0.03 % is adequate and gives an acceptable surface finish in both the cold rolled and hot rolled conditions.

Aluminium killed steel with lower reactivity than expected

Aluminium killed steels also contain low levels of silicon, which is important for the reactivity. In recent years aluminium killed steel with so-called ultra-low silicon content, below 0.01 %, and aluminium content above 0.035 % ,has become more common. These steels have many positive properties when it comes to cutting and formability, however the low silicon content in combination with the high aluminium content makes the zinc layers thinner than stated in the hot dip galvanizing standard EN ISO 1461.

If galvanizing is performed in a nickel alloy bath, which is common today since nickel is considered to add several positive properties, the reactivity is further decreased, with thinner layers as a result. A deviation from the standard for such steels can be agreed between customer and galvanizer. If a deviation cannot be accepted, this type of steel must be blasted before galvanizing.

Relation between chemical composition of steel and the coating thickness after galvanizing

Since the type of steel, primarily the silicon content, has a large influence on the coating thickness in hot-dip galvanizing, it is very important that the constructor or manufacturer are aware of this in order to get the right result in every individual case.

Aluminum-killed steel, which has a silicon + phosphorus content below 0.03% by weight, gives a shiny coating after galvanizing. Silicon-killed steel can also be used, but its silicon content should then preferably be in the range 0.15-0.22 % silicon.

If the galvanized steel will operate in a more corrosive environment than normal there is a Swedish appendix to EN ISO 1461 that is used in Sweden. This appendix gives advice on how to achieve thicker coatings. The suggested silicon content is > 0. 22 %, and the coating thickness increases with increasing silicon content, fig 1. Even if it is possible to galvanize steels with silicon contents in the range of 0.35-0.40 weight percent, it is important to be aware that these steels are very reactive and give very thick zinc coatings. A thick coating gives good corrosion protection, but these thick coatings are usually brittle and may flake off during handling of the steel. For this reason such high silicon contents are not recommended.

Important information about cold rolled steels

Cold rolled steels are usually annealed after rolling. During this heat treatment silicon near the steel surface may be oxidized. This so called ”internal oxidation” means that the free silicon content, that influence the reactivity during galvanizing, is lower than the mean value of the steel chemical analyses. Annealing steel with a silicon content in the range 0,15-0,21 weight percent can easily decrease the free silicon content so it falls in to the Sandelin range. The steel is then very reactive and get a thick, brittle coating with poor adherence to the steel surface. The depth of the oxidized zone depends on temperature, time and atmosphere during the annealing. The oxidized zone is usually removed during pickling, but in some cases it is deeper, and it may be necessary to blast or grind the steel before galvanizing.

Impact of silicon and phosphorus content on hot and cold rolled steel during galvanizing:

	Cold rolled steel	**Hot rolled steel**
Si+P < 0,03	Acceptable surface finish in most cases. Shiny coating. If the appearance of the galvanized surface is very important, the following expression should be used: Si < 0,03 and Si+2,5P < 0,04	Acceptable surface finish in most cases. Shiny coating. If the appearance of the galvanized surface is very important, the following expression should be used: Si< 0,02 and Si+2,5P < 0,09
0,03 < Si+P ≤ 0,14	Not suitable	Not suitable
0,15 ≤ Si ≤ 0,21	Thicker coatings. Internal oxidation may change reactivity.	Thicker coatings.
0,22 ≤ Si ≤ 0,28	Significant thicker coatings. Grey appearance.	Significant thicker coatings. Grey appearance.
0,29 ≤ Si ≤ 0,35	Thick coatings that may be brittle. Grey appearance.	Thick coatings that may be brittle. Grey appearance.

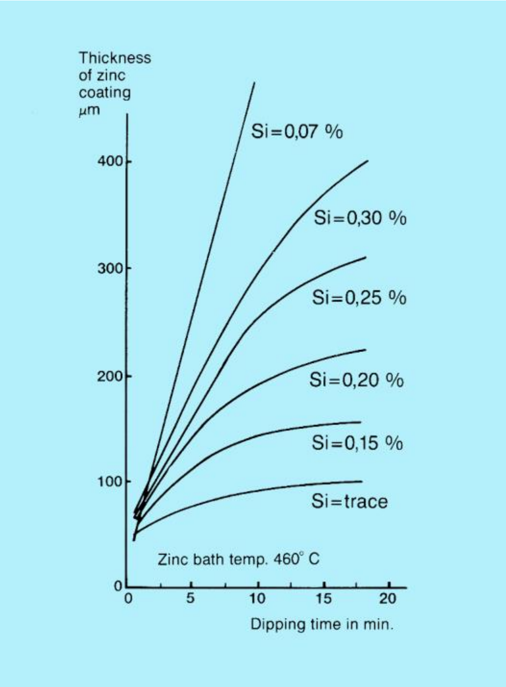

Fig 1. Relationship between dipping time and thickness of zinc coating on steels with different silicon contents. The curves are average curves, based on experiments and practical experience. Significant variations can occur between steels with the same silicon contents, but from different charges.

Galvanizing of other steels

High strength steels

High strength steels are more and more common in constructions that are galvanized. According to Swedish Regulations for Steel Structures, steels with yield strength over 460 MPa are classified as high strength for sheets and wide flat bars. However, there is no official definition of the border to the high strength area. It is up to the steel producer how to describe the product.

Experience has shown that some high strength steels are less reactive than expected during galvanizing, while others instead are very reactive. In the first case that means that the coating thickness requirement according to EN ISO 1461 may be hard to fulfil. In the second case the coating can be very thick and dull grey with poor adherence to the steel surface.

Generally, when choosing steel for galvanizing, the same rules as for low alloyed steels can be applied also to high strength steel. That means that the silicon and phosphorus contents must be taken into consideration. Some high strength steels have a silicon content of 0.10 weight percent, i.e. in the middle of the Sandelin range. These steels are not suitable for galvanizing, but it is often possible to order them with higher silicon content (0.20 weight percent) for galvanizing, at east in larger volumes. Some high strength steels also undergo different types of heat treatments during manufacture, which may cause internal oxidation of silicon and influence on the reactivity of the steel.

There is a lot of research and development in progress to increase the understanding of the high strength steels and their behaviour during galvanizing.

For high strength steels with a yield strength (ReH) > 650 MPa the fatigue strength could be reduced during galvanizing. For steels with a lower yield strength than 650 MPa the reduction in fatigue strength is very low. It should be noted that steels without or with only poor corrosion protection may very quickly develop local corrosion attack (for example pitting corrosion) which dramatically lowers the fatigue strength. This means that the fatigue resistance of the galvanized steel is usually superior in the long term.

High strength steels may under some circumstances have a brittle behaviour during working and/or galvanizing. Because of that there are special guidelines for galvanizing high strength steels. Consult your galvanizing company or contact Nordic Galvanizers for more information.

Steels with higher sulphur levels

Higher sulphur levels — above approx. 0.18 % — like those in certain free-cutting steels, can accelerate the reaction to such an extent that the steel cannot be hot-dip galvanized. The attack from the zinc would be so vigorous that the steel would be ruined.

Stainless steels

Stainless steels, for example AISI 304 or so called acid-proof stainless steels, AISI 316, are sometimes galvanized when stainless parts are welded onto carbon steel. The zinc coating on the stainless parts may be thick with a dull surface finish, depending on the content of silicon, chromium and nickel. There can also be bare spots on the surface, without any coating. Galvanizing of stainless steels may cause zinc brittleness, i.e. zinc penetrating the grain boundaries, if there are stresses in the steel. Such stresses may be created during welding or cold working of the steel.

Hardened or cold worked steels

Hardened or strongly cold worked steels (HRc > 33) may absorb hydrogen during pickling and show hydrogen embrittlement. To avoid this, hydrogen baking for 4 hours at 275 ºC can be performed after pickling, but since these steels also are sensitive to zinc embrittlement they are not suitable for galvanizing.

Coating thickness

The coating thickness on galvanized steel mainly depends on:

• Steel silicon content

• Steel phosphorous content
• Dipping time in zinc melt
• Steel dimension and surface roughness
• Heat treatments of steel during working

In table 1 coating thickness requirements from the EN ISO 1461:2009 standard is shown. In table 2 examples of thicker coatings are given.

Steel thickness in mm	Local coating thickness in µm	Average coating thickness in µm
Steel > 6 mm	70	85
Steel > 3 - ≤ 6 mm	55	70
Steel ≥ 1,5 - ≤ 3 mm	45	55
Steel < 1,5 mm	35	45
Cast iron ≥ 6 mm	70	80
Cast iron < 6 mm	60	70

Table 1. Coating thicknesses according to standard EN ISO 1461:2009. If nothing else is specified in the order, coating thicknesses according to the table above are given.

Steel thickness	Fe/Zn 115		Fe/Zn 165		Fe/Zn 215	
	Min local value	Min middle value	Min local value	Min middle value	Min local value	Min middle value
Steel > 6 mm	100	115	145	165	190	215
Steel > 3 - ≤ 6 mm	85	95	100	120	115	140
Steel ≤ 1 - ≤ 3	60	70	70	95		

Table 2. Examples of thicker coatings. (National appendix NA to standard EN ISO 1461:2009 in Sweden). If the customer requires thicker coatings than in EN ISO 1461: 2009 table 3 (shown in table 1 above), this should be agreed with the galvanizer. To achieve higher coating thicknesses more reactive steel must be chosen, see table 3 below.

Coating thickness (µm)	Optimal silicon level (%)	Silicon range (%)
Fe/Zn 115	0,18	0,15-0,21
Fe/Zn 165	0,25	0,22-0,28
Fe/Zn 215	0,32	0,29-0,35

Table 3. Optimal and range values for silicon when higher coating thicknesses are required.

The surface roughness of the steel largely affects the coating thickness. Studies have shown that sand blasting leads to a large increase in coating thickness on most steels (80-100%). Scratching or local deformation of the steel surface during cold forming also influences the surface roughness, and may lead to significant variations in coating thickness. In these cases, dark grey areas on an otherwise shiny surface can be seen.

Flame-cutting, laser-cutting and plasma-cutting change the steel composition and structure in the zone around the cutted surface, so that the minimum coating thickness may be more difficult to obtain. According to the galvanizing standard EN ISO 1461 thickness measurements shall not be performed on cut surfaces or on surfaces less than 10 mm from edges or corners.

To reach the standardized coating thickness on such surfaces, the oxidized area must be removed before galvanizing. On cut areas, grinding or blasting until the annealing colour is removed is suitable, since this also breaks the cut edges, which improve the coating adherence. Sometimes normal or slightly heavier pickling is enough to remove the heat affected surface zone from the steel. Thus, a mechanical treatment of the surface is usually needed.

Coating appearance

Hot dip galvanizing of steels with low silicon- or phosphorus content gives light and shiny zinc coatings. In outdoor environments, the surface colour changes to dull and light grey after some time.

Steels with silicon content in the range 0.15 to approximately 0.22-0.23 weight percent normally gives light, shiny coatings. Silicon contents around 0.25 weight percent may give grey surfaces or a grey network on an otherwise bright surface. If a nickel alloyed zinc bath is used, the reaction between zinc and iron are reduced, and the coating is usually bright up to 0.22 weight percent silicon.

Steel with higher silicon contents (> 0.25 weight percent) normally gives dull, grey coatings, which gets darker with increasing silicon content. The dark grey colour is only an aesthetic effect, since the corrosion protection is the same, or even better as long as the coating thickness is the same. Dark grey coatings are often thicker than bright coatings, since they usually are coarsed by higher reactivity between iron and zinc, and therefore gives longer corrosion protection. The colour of the coating is determined by the proportion of iron-zinc crystals that are mixed with pure zinc on the outer surface of the coating — the purer zinc, the lighter the surface; the higher the iron-zinc content, the darker the surface.

When a zinc coating with high iron content corrodes, the iron is released and oxidized, which may give the surface a reddish-brown discolouration. The reddish-brown colour will increase when a larger part of the iron-zinc coating corrodes. Thus, a reddish-brown discolouration of the surface does not mean that the zinc coating is gone.

Zinc coatings with an outermost layer of pure metallic zinc and a light appearance may also develop reddish-brown discolouration when the pure zinc layer has corroded away. The time for the reddish-brown discolouration to form is longer in this case, depending on the thickness of the pure zinc layer. On steels with a silicon + phosphorus content < 0,03 % the pure zinc content is usually 30-50 % of total coating thickness.

If there are uncertainties about the silicon content of the steel and thus the appearance of the coating, test galvanizing is to be recommended.

Ordering of steel

To get a proper result after galvanizing it is not enough only to use the steel classification (CEN-standard or commercial name) when ordering and purchasing steel. It is also necessary to specify limitations for the silicon, and in some cases also the phosphorus, content.

Unfortunately, it not always possible gets exactly the desired chemical composition of the steel. When larger volumes of steel are purchased this is often not a problem, but when buying from stock it may be harder to find steel with the desired composition. Early contact with the steel manufacturer increases the possibility to get the right steel specification.

It is also important to be aware of the quality of the steel surface before galvanizing. Construction steels are often delivered pickled and oiled, and after, for example, welding the oil may be bonded to the steel surface and hard to remove during degreasing prior to galvanizing. Since the oil must be removed to avoid problems with black spots on the steel after galvanizing, special cleaning may be necessary.

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