Factors influencing coating thickness

The thickness, alloy structure and finish of galvanized coatings are influenced by:

1 Surface condition of steel
2 Composition of the steel

Increasing the period of immersion in the galvanizing bath will not increase coating thickness except in the case of silicon steels, as discussed on this page.

Surface condition of steel

Grit blasting steel before galvanizing roughens the surface and increases its surface area, resulting in higher reactiveness to molten zinc. Greater zinc-iron alloy growth occurs during galvanizing, producing thicker coatings, though at the expense of a rougher surface and poorer appearance.

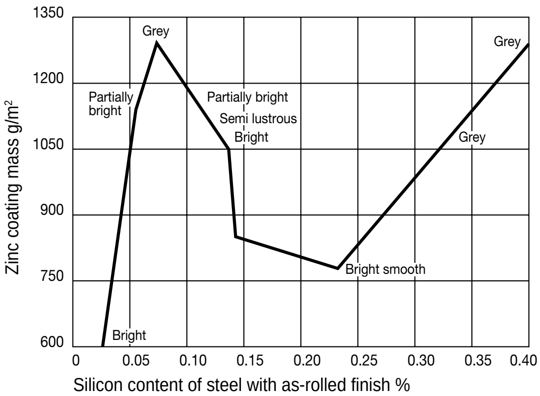
Application of this method of achieving thicker coatings is generally limited by practical and economic considerations. Where increased service life or reduced maintenance is required the use of duplex galvanizing-plus-paint systems is a preferable alternative, as discussed on page 65.

Composition of steel

Both silicon and phosphorous contents can have major effects on the structure, appearance and properties of galvanized coatings. In extreme cases, coatings can be excessively thick, brittle and easily damaged.

Silicon. As shown in the graph below, certain levels of silicon content will result in excessively thick galvanized coatings. These very thick coatings result from the increased reactivity of the steel with molten zinc, and rapid growth of zinc-iron alloy layers on the steel surface. The graph shows that excessive growth in coating thickness takes place on steels with silicon contents in the range 0.04 to 0.14%. Growth rates are less for steels containing between 0.15 and 0.22% silicon, and increase with increasing silicon levels above 0.22%.

Effect of silicon content of steels on galvanized coating mass and appearance



Phosphorous. The presence of phosphorous above a threshold level of approximately 0.05% produces a marked increase in reactivity of steel with molten zinc, and rapid coating growth. When present in combination with silicon, phosphorous can have a disproportionate effect, producing excessively thick galvanized coatings.

Suitability of silicon/phosphorous steels for galvanizing. As a guide to the suitability of silicon and phosphorous containing steels for galvanizing, the following criteria should be applied:

% Si < 0.04%
and
% Si + (2.5 x % P) < 0.09%

Galvanized coatings on silicon steels are usually dull grey or patchy grey in colour with a rough finish, and may be brittle. Coating service life is proportional to the increased thickness and is unaffected by appearance, provided the coating is sound and continuous. In general, the thickness, adherence and appearance of galvanized coatings on silicon and phosphorous steels are outside the control the galvanizer. (See also 'Dull grey coatings', page 42.)

Double dipping or galvanizing a second time will not increase the thickness of a galvanized coating for reasons discussed under "Coating thickness" page 13, and may adversely affect coating appearance.

The terms 'double dipping' and 'double-end dipping' are sometimes confused. Double-end dipping is a method of galvanizing articles too long for the available bath by immersing one end of the work at a time, as described on page 33.

Mechanical properties of galvanized steels

The galvanizing process has no effect on the mechanical properties of the structural steels commonly galvanized.

Strength and ductility

The mechanical properties of 19 structural steels from major industrial areas of the world were investigated before and after galvanizing in a major 4-year research project by the BNF Metals Technology Centre, UK, under the sponsorship of International Lead Zinc Research Organisation. Included were steels to Australian Standard 1511 grade A specification, and British Standard 4360 series steels.

The published BNF report 'Galvanizing of structural steels and their weldments' ILZRO, 1975, concludes that '... the galvanizing process has no effect on the tensile, bend or impact properties of any of the structural steels investigated when these are galvanized in the "as manufactured" condition. Nor do even the highest strength versions exhibit hydrogen embrittlement following a typical pretreatment in inhibited HCl or H_2S0_4.

'Changes in mechanical properties attributable to the galvanizing process were detected only when the steel had been cold worked prior to galvanizing, but then only certain properties were affected. Thus the tensile strength, proof strength and tensile elongation of cold rolled steel were unaffected, except that the tensile elongation of 40% cold rolled steel tended to be increased by galvanizing. 1-t bends in many of the steels were embrittled by galvanizing, but galvanized 2-t and 3-t bends in all steels could be completely straightened without cracking.'

Embrittlement

For steel to be in an embrittled condition after galvanizing is rare. The occurrence of embrittlement depends on a combination of factors. Under certain conditions, some steels can lose their ductile properties and become embrittled. Several types of embrittlement may occur but of these only strain-age embrittlement is aggravated by galvanizing and similar processes. The following information is given as guidance in critical applications.

Susceptibility to strain-age embrittlement. Strain-age embrittlement is caused by cold working of certain steels, mainly low carbon, followed by ageing at temperatures less than 600°C, or by warm working steels below 600°C.

All structural steels may become embrittled to some extent. The extent of embrittlement depends on the amount of strain, time at ageing temperature, and steel composition, particularly nitrogen content. Elements that are known to tie up nitrogen in the form of nitrides are useful in limiting the effects of strain ageing. These elements include aluminium, vanadium, titanium, niobium, and boron.

Cold working such as punching of holes, shearing and bending before galvanizing may lead to embrittlement of susceptible steels. Steels in thicknesses less than 3 mm are unlikely to be significantly affected.

Hydrogen embrittlement. Hydrogen can be absorbed into steel during acid pickling but is expelled rapidly at galvanizing temperatures and is not a problem with components free from internal stresses. Certain steels which have been cold worked and/or stressed during pickling can be affected by hydrogen embrittlement to the extent that cracking may occur before galvanizing.

The galvanizing process involves immersion in a bath of molten zinc at about 450°C. The heat treatment effect of galvanizing can accelerate the onset of strain-age embrittlement in susceptible steels which have been cold worked. No other aspect of the galvanizing process is significant.

Recommendations to minimise embrittlement

Where possible, use a steel with low susceptibility to strain age embrittlement. Where cold working is necessary the following limitations must be observed:

1. **Punching.** The limitations specified in AS 4100 and AS/NZS 4680 on the full-size punching of holes in structural members must be observed.
   Material of any thickness may be punched at least 3 mm undersize and then reamed, or be drilled. Good shop practice in relation to ratios of punched hole diameter to plate thickness, and punch/die diametral clearance to plate thickness should be observed.
   For static loading, holes may be punched full size in material up to $\frac{5600}{Fy}$ mm thick where Fy is material yield stress up to 360MPa.
2. **Shearing.** Edges of steel sections greater than 16 mm thick subject to tensile loads should be machined or machine flame cut. Edges of sections up to 16 mm thick may be cut by shearing.

   Sheared edges to be bent during fabrication should have stress raising features such as burrs and flame gouges removed to a depth of at least 1.5 mm. Before bending, edges should be radiused over the full arc of the bend.
3. **Bending.** Susceptible steels should be bent over a smooth mandrel with a minimum radius 3 times material thickness. Where possible hot work at red heat. Cold bending is unlikely to affect steels less than 3 mm thick.
4. **Critical applications.** It is better to avoid cold work such as punching, shearing and bending of structural steels over 6 mm thick when the item will be galvanized and subsequently subjected to critical tensile stress. If cold working cannot be avoided a practical embrittlement test in accordance with ASTM A143 should be carried out.

   Where the consequences of failure are severe and cold work cannot be avoided, stress relieve at a minimum of 650°C before galvanizing.

   Ideally, in critical applications structural steel should be hot worked above 650°C in accordance with the steelmaker's recommendations.
5. **Edge distances of holes.** In accordance with Australian Standard 4100 'Steel structures' minimum edge distances from the centre of any bolt to the edge of a plate or the flange of a rolled section should be used. See page 39.

Fatigue strength

Research and practical experience shows that the fatigue strength of the steels most commonly galvanized is not significantly affected by galvanizing. The fatigue strength of certain steels, particularly silicon killed steels may be reduced, but any reduction is small when compared with the reductions which can occur from pitting corrosion attack on ungalvanized steels, and with the effects of welds.

For practical purposes, where design life is based on the fatigue strength of welds, the effects of galvanizing can be ignored.

Fatigue strength is reduced by the presence of notches and weld beads, regardless of the effects of processes involving a heating cycle such as galvanizing. Rapid cooling of hot work may induce microcracking, particularly in weld zones, producing a notch effect with consequent reductions in fatigue strength.

In critical applications, specifications for the galvanizing of welded steel fabrications should call for air cooling rather than water quenching after galvanizing to avoid the possibility of microcracking and reductions in fatigue strength.

Other metallic zinc coatings for steel

Zinc plating should not be confused with After-Fabrication galvanizing which applies much heavier coatings providing a correspondingly longer service life. However several grades of plating now exist, ranging up to 100g/m^2 where use in coating systems for automobile and white goods continuous production lines, have become known as electrogalvanizing.

There is in general an economic upper limit to the zinc coating mass which can be applied by electroplating. Zinc plating therefore is normally not recommended for outdoor exposure without supplementary coatings.

Zinc plating is an economic, versatile and effective method of applying a protective coating to small steel components. It is the most widely used method of applying metallic zinc coatings to small fasteners, as described on page 48.

However fasteners used with after-fabrication galvanizing should have comparable coating and composition.

Sherardising is a method of zinc coating small, complex steel parts such as fasteners, springs and chain links, as described on page 48. The dark grey sherardised coating is hard, abrasion resistant and uniform in thickness over the whole surface of the article. The sherardising process is not used in Australia.

Mechanical plating or peen plating is an electroless plating method used to deposit coatings of ductile metals onto metal substrates using mechanical energy. It is used to plate zinc onto steel parts, particularly threaded components and close tolerance items, as discussed on page 48.

Zinc spraying or zinc metallising allows coating of fabricated items which cannot be galvanized because of their size or because coating must be performed on site. Zinc spraying has the advantage that zinc coatings up to 250 µm thick, equivalent to 1500 g/m^2 can be applied, by either manual or mechanised methods. The steel surface must be prepared by grit blasting. The resulting zinc coating provides cathodic protection for the underlying steel in the same way as a galvanized coating.

Zinc rich coatings consist of zinc dust in organic or inorganic vehicle/binders. Surface preparation by abrasive blast cleaning is necessary, and coatings may be applied by brush or spray. Zinc rich coatings are barrier coatings which also provide cathodic protection to small exposed areas of steel, provided the steel surface is properly prepared, and the paint conforms to relevant Australian/New Zealand Standards AS/NZS 3750.15.1998 and AS/NZS 3750.9.1994.

Suitable zinc rich paint coatings provide a useful repair coating for damaged galvanized coatings as discussed on page 45.

Preconstruction primers are relatively thin weldable zinc rich coatings used widely for ship building, storage tanks, and similar steel plate constructions, intended for subsequent top coating.

Continuous galvanizing processes. Steel sheet, pipe and wire are continuously galvanized in specially developed galvanizing processes which allow accurate control of coating thickness, ductility and other characteristics of the zinc coating, producing a wide range of products to suit the varying requirements of subsequent manufacturing operations and end usage. Because of the differing process and wide variety of coatings offered, these products should not be confused with after-fabrication galvanizing. In-line products with thinner coatings often require supplementary coatings for outdoor exposure.