Armorgalv Coating Characteristics Compared with Other Zinc-based Metallic Coatings.

Report for Armorgalv (Aust) Pty Ltd

By

John Robinson
Director

Mount Townsend Solutions Pty Ltd

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The term 'galvanizing' is applied to a number of processes that involve the application of zinc-based coatings to steel as a protective coating. This implies that all these coatings are similar in characteristics and performance. This is not so!

Zinc-based coatings are the world's most widely used coatings for the protection of steel from corrosion. These coatings are applied using differing technologies, giving rise to zinc coatings with differing mechanical and durability characteristics.

As the obvious reason for applying protective coatings to steel is to prevent it from corroding for as long as possible in its service environment, it is important that the characteristics of the coatings produced by these diverse processed be understood with respect to their relative durability.

There are 5 basic application processes, each of which is associated with alternative technologies. Each of these processes are best suited to particular classes of steel product and no one process is suitable for all types of steel coating. They are:

Hot dip processes: These involve the immersion of pre-treated steel in molten zinc or zinc alloys.
Chemical processes: These involve the electro-deposition of zinc or zinc alloys from a chemical solution in combination with the application of an electric current.
Applied processes: These involve the application of zinc in the form of zinc dust as a pigment in a paint coating, or as a momentarily molten metal spray using a hot metal spray gun.
Diffusion processes: These involve the heating of the steel to below the melting point of zinc while in close contact with zinc dust.
Mechanical processes: These involve the application of a zinc or zinc alloy coating to the surface of small steel parts by rumbling them in a rotating vessel causing the part-to-part impacts to apply an adherent zinc-based coating to the parts

1. Hot dip processes.

The greatest percentage of steel that is zinc coated is processed immersing the steel in molten zinc or zinc alloy. There are two fundamental types of hot dipping processes; continuous and batch galvanizing.

1.1 Continuous galvanizing processes.

Products such as sheet, wire and tube are commonly continuously galvanized by passing the steel sections through the molten metal during the manufacturing process at relatively high speed – up to 180 metres/minute with some products. Sheet and wire are fed into the galvanizing process from coils and re-coiled after galvanizing. Tube sections are coated externally after forming in straight lengths, or manufactured from steel coil that has previously been galvanized.

This process produces a galvanized coating that has specific characteristics. These are:

a. The coating is relatively thin and usually around 25 microns in thickness.
b. The coating is almost 100% zinc. (See Figure 1)

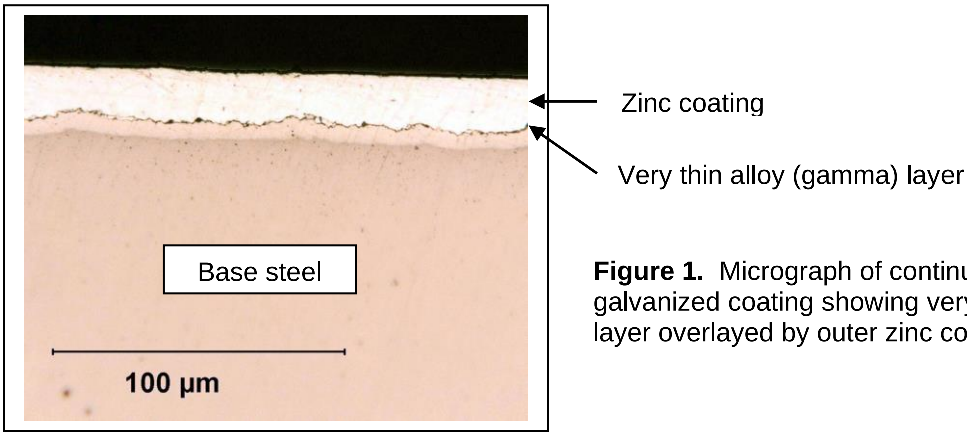


Figure 1. Micrograph of continuously galvanized coating showing very thin alloy layer overlayed by outer zinc coating

c. The alloying of the zinc to the steel is limited by the high speed of the continuous process. This creates a malleable coating that allows the pre-galvanized sections to be roll formed, bent or pressed in subsequent manufacturing operations.

d. The cutting and punching of the sections in manufacture results in all edges being uncoated. The cathodic protection provided by the zinc coating on adjacent surfaces prevents corrosion of these exposed steel areas, but increases the coating's local corrosion rate as a result. (See Figure 2)

Figure 2. Early cut-edge corrosion on these continuously galvanized purlins – the thicker the section, the greater the risk of cut edge corrosion.

1.2 Batch galvanizing processes

Batch galvanizing involves processing the steel after fabrication. For larger fabricated items, these are suspended from chains, jigs or head frames to transport the fabricated steel items through the hot dip galvanizing process.

For small parts such as nails, screws and bolts, perforated baskets are used to transport the work through the process and centrifuge the excess zinc from the items as they exit the molten zinc.

The items being processes are immersed in the molten zinc for several minutes. This creates a galvanized coating with its own set of unique metallurgical characteristics. These are:

a. The coating largely comprised zinc-iron alloys arising from the longer immersion time in the molten zinc. The presence of this alloy layer results in a thicker coating usually no thinner than 50 microns on thin sections to more than 200 microns on heavy structural sections.

b. Because the steel items are immersed in molten zinc after fabrication, all surfaces and edges are coated.

c. The appearance of a batch galvanized coating is less smooth and uniform than that on a continuous galvanized product. The drainage of molten zinc from steel items as they are withdrawn from the galvanizing bath, combined with the surface tension of the zinc at temperatures close to its freezing point, may result in the clogging of threads, and the seizing of moving parts. See Figure 3.

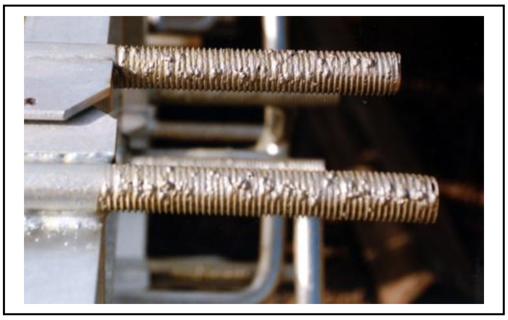


Figure 3

d. The alloy layers are much harder than pure zinc (approx. 4X). This gives the batch galvanized coating excellent abrasion resistance but lower flexibility than continuously galvanized coatings, making it unsuitable for forming after galvanizing.

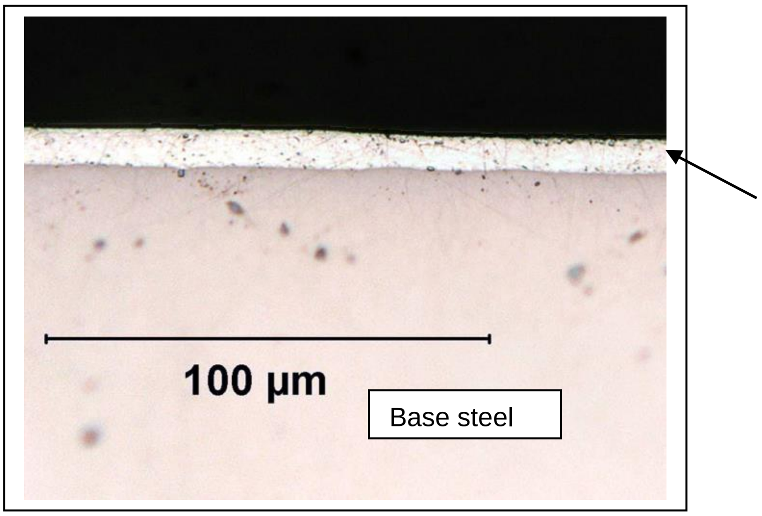
e. The process is not well suited to the coating of high strength steel where the steel strength exceeds 800MPa because of the risk of hydrogen embitterment arising from the acid pickling processes used in the hot dip galvanizing process.

2. Chemical processes

Zinc electroplating is widely used to coat small parts, appliance components and builders hardware. The process involves passing the cleaned steel parts through a zinc-bearing solution containing other chemicals to assist in leveling or brightening the coating.

While some proprietary processes can apply relatively heavy zinc plated coatings to steel components, the majority of zinc-electroplated products have coating thicknesses less than 10 microns, making them unsuitable for exterior use.

Figure 4



Thin pure zinc coating – no alloy layers

The characteristics of an electroplated zinc coating are:

a. The coating is bright and uniform. Some products such as screws may have a heavy chromate coating, giving them a brown/yellow appearance, to improve their corrosion resistance.

b. The coating is pure zinc and is quite soft. There are no alloy layers present in the coating. See Figure 4

c. The coating is relatively thin – usually less than 10 microns, and conforms closely to the surface profile of the steel item, making it suitable for use on small threaded components.

d. Electroplated coatings are not sufficiently durable for external exposure applications

3. Applied processes.

3.1. Zinc-rich paints

Zinc can be applied to steel surfaces as zinc-rich paint, where either organic or inorganic binders are heavily loaded with zinc dust as a pigment. Silicate binders are commonly used for inorganic zinc-rich paints and epoxies are the most common of the organic binders used in these paints.

A high level of steel surface cleanliness is required for best results with such paints, with those having organic binders more tolerant of lower levels of surface condition that the inorganic systems.

Zinc rich paints are well suited to the coating of large structures and for on-site application to structural steelwork of all types.

Like all applied coating systems, the quality and performance of the finished coating is heavily dependent on the quality of each stage of the application and relies on the skill of the operator, rather than process control to achieve reliable performance.

3.2 Zinc metal spraying

Metal sprayed coatings are applied by passing zinc dust or wire through an electric arc or gas flame. (See Figure 5)This melts the metal and deposits the molten metal on the steel's surface. A very high level (Class 3) of steel surface cleanliness is recommended for metal spray applications. Metal sprayed coatings have the following characteristics:

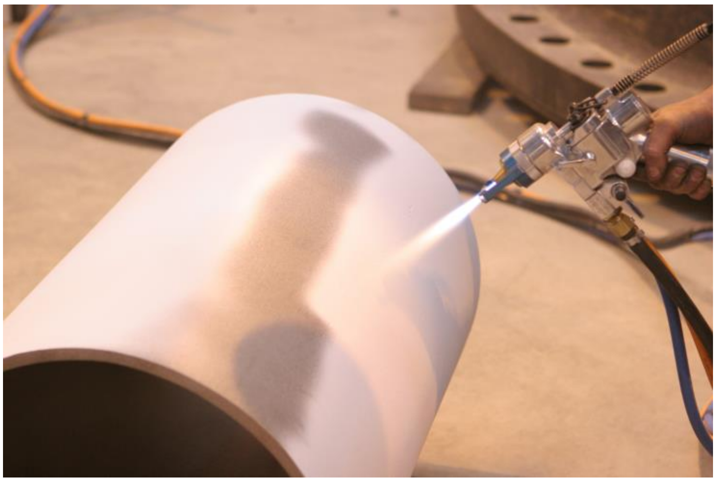


Figure 5

a. The coating consists of flattened droplets of zinc mechanically bonded to the steel surface. Some of the zinc (up to 30%) is converted to zinc oxide during the high temperature application process.
b. Very thick (up to 500 micron) coatings can be applied.
c. The newly applied coating is rough and porous. Sealing of the metal-sprayed coating with a polymer coating is recommended for aggressive environments.
d. Only the external surfaces of fabrications can be readily coated.
e. The zinc dust/wire can be alloyed with other metals such as aluminium to improve corrosion resistance.
f. A metal spray gun can deposit approximately 30 kg of zinc per hour with overspray losses up to 30%, depending on the shape of the fabrication. Typical application rate is around 1 kg/m^2. This is a higher cost process than other zinc coating processes as application is largely manual.

g. Low heat transfer to the steel minimises distortion risks on thin steel sections.

4. Diffusion processes

The process of Sherardizing is a diffusion process, where small parts are tumbled in a zinc/sand mixture at a temperature from around 380^{o}C to over 500 ^{o}C. It is rarely used today because of its low productivity as processing a batch of parts weighing a few hundred kg may take up to 3 hours, with zinc recovery of around 50%

It is well suited to small parts and threaded fasteners, as the coating conforms closely to the surface profile. The items are best cleaned by grit blasting prior to coating. The characteristics of a Sherardized coating are:

a. Coatings applied are typically between 15 and 30 microns in thickness.
b. The coating is 100% alloy layer containing no free zinc. It has a matt gray appearance.
c. The coating is metallurgically bonded to the surface.
d. The coating has good abrasion resistance

5. Mechanical processes

Mechanical plating of zinc and zinc alloys is now widely used for the protective coating of high strength fasteners such as self-drilling TEC screws. Batches of components are cleaned of oxide deposits and organic contamination and loaded into a rotating barrel with a carefully controlled mixture of metal dust and reaction chemicals.

The batch is processed for about 20 minutes. Glass beads are also used to assist in peening the metal particles on to the surface. Because of the autogenous nature of the process, the steel items being mechanically plated need to be manufactured from higher strength steel grades to prevent mechanical deformation during the plating process. Zinc-tin alloys mixtures are commonly used in Australia on roofing fasteners to improve their corrosion resistance.

The process is well suited to automation and large numbers of parts can be mechanically plated efficiently in an automated facility.

The characteristics of a mechanically plated coating are:

a. Applied at room temperature
b. Zinc alloy coatings can be used that are difficult to apply by other methods.
c. The coating conforms closely to the profile of the part.
d. The mechanically plated coatings are relatively thin – usually less than 20 microns.
e. The coating may be thinner on edges and corners due to the mechanical impacts intrinsic to the process.
f. The bond between the coating and the steel is largely mechanical

The characteristic that determined durability of zinc coatings in any given environment is the thickness of the coating. This will be dealt with in detail elsewhere in this manual.

6. The Armorgalv Process

The Armorgalv process is a thermal zinc diffusion process that is based on sheradizing technology but has been developed to provide a higher level of productivity, can process larger steel products with specially developed zinc powder technology using automated batch process control to ensure consistent coating uniformity.

The metallurgy of thermal zinc diffusion coatings is unlike other metallic zinc coating applications, as it is a solid state process. When the activated zinc powder and the steel to be coated are heated to around 300^{o}C, the mobility of the zinc atoms increases considerably, and they react with the iron in the steel to form a solid solution of zinc and α-iron (iron ferrite). As the temperature increases, the α-iron phase becomes saturated and a solid solution of other iron-zinc phases forms on the powder side.

Proprietary mixtures of zinc powder developed for the Armorgalv process and the time at temperature controls determine the metallurgical characteristics of the finished thermal diffusion coating.

Figure 6

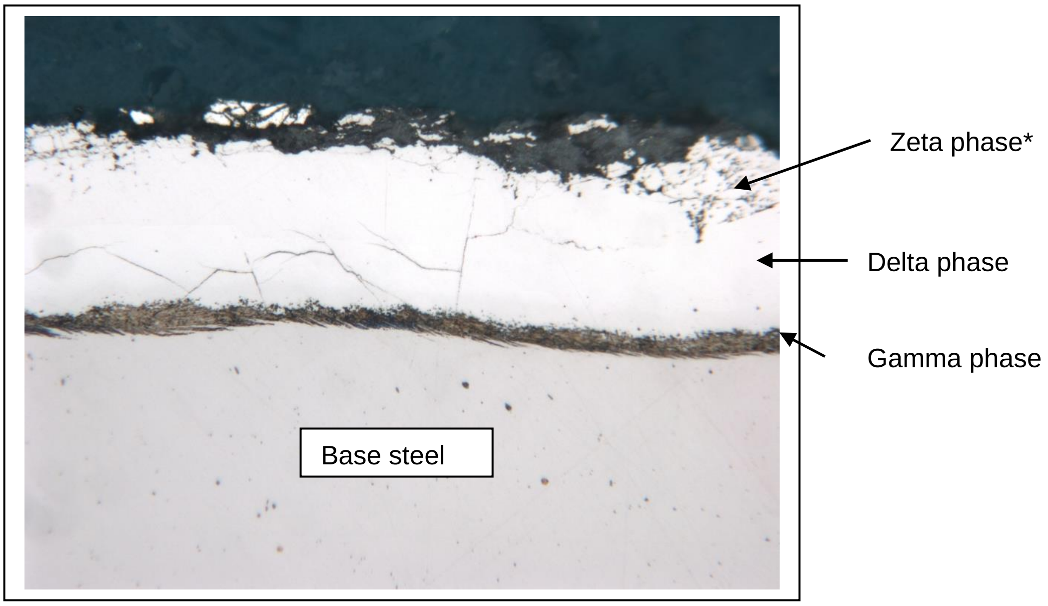


Figure 6 is a micrograph of a typical Armorgalv thermal zinc diffusion coating. The Gamma phase closest to the surface is approximately 50% zinc – 50% iron. The Delta phase comprising the majority of the coating is 25% iron – 75% zinc, while the upper Zeta phase, that is not clearly defined, is 7-10% iron – 90-93% zinc.

A characteristic of thermal zinc diffusion coatings is the uniformity with which they are deposited on the iron or steel's surface. The process controls in the Armorgalv process also allow the coating thickness to be managed to tailor the coating to its application.

ENVIRONMENTAL FACTORS IN ZINC COATING PROCESSES

The environmental factors associated with the application of zinc-based metallic coatings include:

1. Energy use
2. Materials use
3. Effluents and waste products
4. Recyclable residues

1. Energy use.

Structural hot dip galvanizing baths contain 200-400 tonnes of zinc that must be kept molten at 455oC 24/7. In addition, energy is also required to heat caustic degreasing and preflux tanks.

Electroplating and mechanical plating are less energy intensive as they operate at close to ambient temperature.

Thermal diffusion and zinc metal spray processes require energy for application with thermal diffusion processes needing sufficient energy to heat the items being coated in addition to their contents and containment systems.

Metal spray coatings require a high temperature heat source - either oxy acetylene or plasma to melt the wire or powder at the application gun.

2. Materials use.

Hot dip galvanizing processes use ingot zinc and significant quantities if hydrochloric acid and lesser quantities of sodium hydroxide and zinc ammonium chloride. The quantities use are proportional to the tonnages of steel being processed. Zinc usage is typically 5% of steel processed and is the largest cost element in the process.

Metal spray coatings use zinc wire as their main material component at accost typically 2X that of ingot zinc. Other material costs include surface preparation consumables and paint sealers.

Thermal zinc diffusion coatings use proprietary zinc powder mixtures at a cost typically 2X that of ingot zinc. A small amount of additional material is used in the post-coating dip sealing process in the Armorgalv process.

3. Effluents and waste products.

Hot dip galvanizing and electroplating have a large chemical component in their application. Hot dip galvanizing plants use hot caustic solutions for degreasing, hydrochloric acid for rust and oxide removal, hot zinc ammonium chloride for prefluxing and sodium dichromate solutions for post galvanizing passivation and quenching.

The hot dip galvanizing process also produced fumes that are required to be captured in bag-house facilities. These fumes are largely zinc oxide with some residual chlorides.

Electroplating processes use some of these pre-treatment chemicals along with the plating chemicals which may be acid or alkaline and are manufactured specially for the zinc electroplating industry. Other chemicals are used in smaller quantities for post plating treatment.

The chemical waste products arising from each of thee processes are required to be disposed of through licensed waste disposal facilities, with disposal costs exceeding new material costs in some cases. Some waste acid from hot dip galvanizing processes is used for process water treatment in the coal industry and has some limited local commercial value.

There are no significant effluents or waste products arising from zinc metal spraying or thermal diffusion processes.

4. Recyclable residues

The hot dip galvanizing process generates zinc-rich residues that are recyclable and have a value proportional to their zinc content. These residues are zinc oxide (zinc ash) and zinc-iron dross.

Electroplating and zinc metal spraying processes do not produce any significant quantities od residues. The thermal diffusion processes generate zinc–based residues that have a value proportional to its recoverable zinc content.

ANTI-CORROSION PERFORMANCE OF ZINC-BASED METALLIC COATINGS

The performance of zinc in protecting steel is well established, with a large number of laboratory-based controlled investigations, along with case history performance that has been developed for over 100 years.

Most applied coatings (paints) protect the substrate by inserting a barrier between the steel and the external environment. The priming systems used with these coatings may also have a chemical interaction with the steel's surface that assists in inhibiting corrosion, through the use of pigments such as zinc phosphate, zinc dust or other proprietary ingredients.

Metallic coatings used for corrosion prevention are almost all exclusively zinc-based, as either hot dipped or electrolytically applied zinc or zinc alloys. Of these galvanized coatings are the most common; either continuously applied or batch galvanized. Thermal diffusion coatings and zinc metal spraying are also used for specialised anti-corrosion applications. It is the unique characteristics of zinc-based coatings that allow their service life to be estimated with a high degree of confidence.

ZINC CORROSION MECHANISMS.

The major component in hot dip galvanized coatings is zinc. Zinc-based coatings in one form or another, have been used to protect steel from corrosion for more than 150 years. As a result, a great deal of performance data has been accumulated on the performance of zinc-based coatings in a wised range of environments.

The vast majority of galvanized products are used in atmospheric exposures, and in this environment, it is possible to accurately predict the life of a galvanized coating, given that its original coating thickness is know and the environment in which it is exposed is correctly classified.

Unlike most other protective coating systems that fail by other mechanisms, galvanized coatings always fail from the outside, in. This occurs through weathering of the zinc's surface through a range of oxidation reactions that are determined by the variables of the local environment.

In the hierarchy of metals, zinc is relatively reactive, but like aluminium, relies on oxide films that develop on its surface to provide its superior corrosion resistance in atmospheric environments. Zinc is also an amphoteric metal, in that it reacts with both acids and alkalis.

This means that zinc works best as a protective coating in pH conditions that are in and around the neutral range of pH 7.

When steel is freshly galvanized, the zinc coating has not developed any protective oxidation films. Many manufacturing processes, such as hot dip galvanizing, apply a passivation film (usually sodium dichromate based) to the zinc's surface to provide protection from accelerated corrosion in the youth period of the coating.

The type of oxide film formed on the surface will depend on the exposure location and condition. In normal atmospheric exposures, the main reactions are as follows:

1. Initial oxidation $2Zn + O_2 = 2ZnO$ (unstable)

2. Hydration $2Zn + 2H_2O + O_2 = 2Zn(OH)_2$ (unstable)

3. Carbonation $5Zn(OH)_2 + 2CO_2 = 2ZnCO_3.3Zn(OH)_2 + 2H_2O$ (stable)

4. In salty air (unstable) $6Zn + 4CO_2 = 8NaCl + 7O_2 + 6H_2O = 4Zn(OCl)_2 + 2Zn(HCO_3)_2 + 8NaOH$

5. Industrial atmospheres $Zn + O_2 + SO_2 = ZnSO_4$ (unstable)

For these reactions to proceed, moisture must be present. If the surface remains dry, very little oxidation will occur. Thus, the time of wetness of the surface is an important factor in the determination of zinc coating life.

For the carbonation phase of the oxidation to occur, good air circulation is necessary to provide a source of carbon dioxide.

Very rapid corrosion of zinc coatings can occur in their 'youth' period if they are stored in poorly ventilated, damp conditions. The oxidation reaction proceeds to the hydration stage (Point 2 above), and will continue while moisture is present. Nested galvanized products are particularly prone to this form of accelerated corrosion, which is commonly called white rust or white storage stain.

The stable carbonate film, formed on the zinc's surface are relatively thin – usually only a few microns in thickness. Any action that removes these oxide films by abrasion or erosion will accelerate the consumption of the underlying zinc, as more zinc is consumed in the re-formation of the oxide films. The passivation of the Armorgalv coating is done as part of the process using a time-controlled phosphate immersion stage to carbonate the zinc surface prior to applying the dip sealer. This provides additional anti-oxidation protection to the Armorgalv coating is the early stage of its service life.

While sulfates arising from industrial activities can significantly increase the corrosion rate of zinc coatings, the stringent controls on sulfur-based emissions from industry has reduced the levels of sulfur oxides in the atmosphere by more than 90% since the 1970's.

The main drivers of corrosion of zinc coatings are the time the coating is wet and the presence of chlorides. Much of Australia's urban areas are in maritime environments, influenced to a greater of lesser degree by airborne chlorides generated from ocean surf.

CORROSION RATES OF ZINC COATINGS

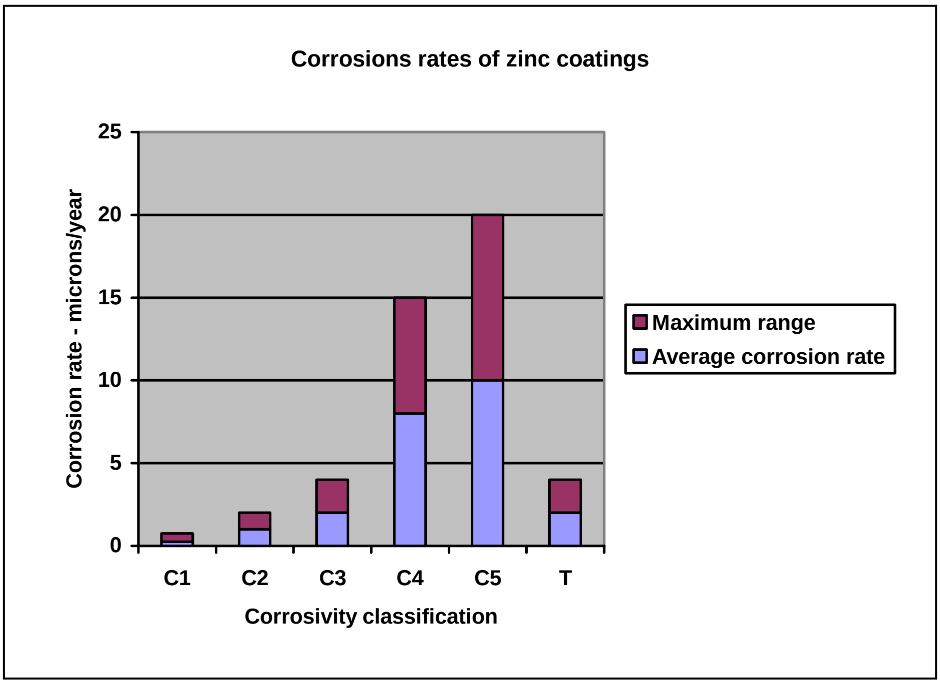
While zinc-based coatings are frequently specified in terms of coating mass (grams per square metre), in practice, coating thickness is used as a measure of the coating's compliance with standards, as it can be readily measures non-destructively.

If zinc-based coatings are exposed to a particular environment, they will corrode at an approximately linear rate over time. One this corrosion rate is established, the expected life of the coating can be calculated with a high degree of confidence.

For example, a typical hot dip galvanized coating on a structural steel section is in the order of 100 microns in thickness. The corrosion rate zinc in the Western Suburbs of Sydney is typically 1-2 microns per year. On that basis, the 100 micron coating in that area should have a maintenance-free life of 50-75 years.

There are a number of Australian Standards that contain information on the classification of the corrosivity of atmospheres. These include AS/NZS 2312 and AS/NZS 2699. (See Appendix I for relevant Standards)

AS/NZS 2699, uses an R0, R1, R2, R3, R4 and R5 rating criteria that is based on airborne salt (chloride) deposition. AS 4312 Corrosivity zones in Australia, uses a C1,C2, C3, C4 and C5 rating system that is consistent with the system used in International (ISO) standards, specifically ISO 9223.



The corrosivity classifications in the above charts are detailed below in condensed form.

C1 Very low – internal and sheltered locations remote from marine influence.
C2 Low – Rural areas, inland towns and cities.
C3 Medium – Most coastal urban areas more than one kilometer from the ocean surf
C4 High - Within one kilometer of ocean surf, depending on prevailing wind direction and topography.
C5 Very high – Ocean front locations subject to ocean surf aerosols.
T Tropical – Northern Australian regions subject to monsoon seasonal conditions.

For any corrosivity categories of C3 or below, galvanized coatings will provide whole-of-life protection for steel against corrosion.

PRACTICAL ASSESSMENT OF GALVANIZED COATING LIFE

In service, zinc-based coatings will often last a lot longer than desktop assessments would indicate. This can be due to micro-environmental factors that reduce the corrosion stress on the coating, or simply that the environment may be much more benign that remote assessment may indicate.

This is particularly true of many coastal locations, that may be classified as marine or severe marine in standards corrosion maps. Topographical features such as coastal orientation, headlands, cliffs, height above sea level and prevailing wind direction will have a significant effect of the corrosivity of the location.

Tropical environments were once considered to be aggressive with respect to metal corrosion, but for galvanized coatings, this is not the case. High temperatures, high humidity and high levels of UV radiation make the tropics a tough place to be for paint coatings, but provide a much happier climate for galvanizing. This is so because the high ambient temperatures and seasonal nature of the rainfall means that the time of wetness is short and metal surfaces remain dry for much longer periods than is the case in temperate regions of Australia.

In addition, most of tropical Australia is not subject to ocean surf because of reefs and islands acting as a barrier, so the level of airborne chlorides is very low compared to the southern regions of the country.

Because galvanized coatings corrode at an approximate linear rate, and they have been used almost everywhere for a very long time, there are few places in Australia that do not have existing galvanized structures in their vicinity.

Such items as sign posts, guard rail, galvanized roofing street lighting poles and fencing will all provide accurate indication of local corrosion rates of galvanized coatings. If the installation date of these items can be determined, simple measurement of the thickness of the zinc coating compared to its time in service will give a good indication of their remaining service life and the local corrosivity classification.

Much of the exposure testing has been done with pure zinc test panels of pre-galvanized panels without recognition of the effects of alloy layers in the galvanized coatings, as the majority of the test panels do not have this characteristic.

Both hot dip galvanized coatings and thermal diffusion coatings such as Armorgalv are made up largely of zinc-iron alloys and the anti-corrosion behavior of this material differs significantly from that of pure zinc.

Some hot dip galvanized coatings that are applied to reactive steel are made up entirely of alloy layers, with no free zinc on the surface of the coating. In this respect, they are similar to thermal diffusion coatings in their characteristics and anti-corrosion performance.

Field testing of these types of coatings on bridge structures (Stewarts River Rail Bridge – Johns River, Northern Coastal NSW) that were installed in 1980 have been monitored for over 25 years, and indicate a corrosion rate of less than 0.5 microns per year or approximately 25% that of a zinc coating in the same location.

This slower rate of corrosion of zinc-iron alloys has also been noted by the CSIRO at its test site in Point Fairy in SE Victoria (on Bass Straight) in testing that is being done in conjunction with the Galvanizers Association of Australia.

OTHER FACTORS AFFECTING COATING LIFE

Time of wetness

Moisture is necessary for the corrosion process to take place. Water can come in contact with steel from precipitation (rainfall) or condensation. Water will condense on steel if the combination of humidity and temperature combine to reduce the temperature to the Dew Point. Moisture films on metal surfaces arising from condensation may be virtually invisible, but never the less, they will be a major driver of corrosion.

This is particularly important where airborne chlorides can accumulate on the surface of steel that is not subject to regular wash-down from rainfall. Small amounts (milligrams/day) of aerosol chlorides deposited in a sheltered surface can lead to very high salt concentrations when thin layers of condensation form on the surface and re-hydrate the sodium chloride crystals.

Where steel surfaces are sheltered from ventilation and sunlight, time of wetness will be prolonged as evaporation of the water will be delayed. For this reason, the underside of a metal roof may corrode more quickly than the upper surface. The classic failure of older galvanized iron roofs, made from many overlapping sheets, is in the overlapping areas. Water caught in the overlaps accelerates the corrosion of the galvanized coating in these areas.

Contact with other metals

Zinc is up near the top of the electrochemical series of metals, will be cathodic to many other metals to which it comes in contact. It is this characteristic that makes it such an anti-corrosion excellent performer on steel. If the galvanized coating is damaged, the zinc will cathodically protect the exposed steel. It is this characteristic that makes the use of pre-galvanized steel products practical.

Many wire, sheet and tube products are continuously galvanized and are cut, punched and formed into the finished product. These manufacturing processes leave all these products with exposed, uncoated edges. Because most are relatively thin, less than 3 mm, the zinc on the adjacent surfaces is close enough to cathodically protect the uncoated steel.

Contact with more noble metals such as stainless steel and copper alloys will produce higher corrosion currents and can lead to rapid consumption of the galvanized coating with which they are in contact. Copper alloys are particularly aggressive to zinc coatings in this respect.

Thermal diffusion coatings such as Armorgalv will be lower on the electrochemical series than zinc because of their high iron component, and while still delivering cathodic protection to exposed steel, will be less susceptible to cathodic corrosion in contact with stainless steel than is the case with zinc coatings.

Because of the high iron levels in the Armorgalv coating, its performance in contact with higher pH environments is superior to that of pure zinc as the iron component has excellent tolerance to alkaline environments and is passivated at pH levels of pH9 and higher.

DETERMINING COATING LIFE - SUMMARY

The thickness of a zinc coating is the main factor that determines its relative durability. The presence of zinc-iron alloys in the coating will add an additional degree of durability as the rate of corrosion will be slower than is the case with pure zinc coatings. Once the environmental conditions have been identified, it is a simple task to calculate the expected life of a galvanized coating of known thickness with a high degree of confidence.

CONCLUSION

In comparison with other zinc-based coatings, Armorgalv thermal zinc diffusion coatings have a number of advantages given the limitations of the size and shape of iron and steel items that are able to be processed in the Armorgalv facilities.

These advantages are:

1. The Armorgalv coating can be applied uniformly to all surfaces of the item being processed making it well suited to threaded components and moving parts.
2. The automated controls in the Armorgalv process allows close control of the coating thickness.
3. The steel strength is not affected by the Armorgalv process and high strength steels (over 800 MPa) can be coated without risk of embrittlement.
4. The metallurgical characteristics of thermal zinc diffusion coatings, including Armorgalv and hot dip galvanizing give the coating improved abrasion resistance due to the zinc-iron alloy components of these coatings. Its average hardness is equal to or exceeds that of standard steel grades. (See Report Appendix II)
5. The corrosion resistance of thermal zinc diffusion coatings is likely to be significantly superior to the unalloyed zinc coatings applied by electroplating or continuous galvanizing processes. The Armorgalv thermal diffusion coatings have additional anti-corrosion treatment with a two stage passivation process involving a dip phosphating treatment followed by the application of a proprietary dip-applied sealer.
6. The Armorgalv process has introduced efficiencies to the thermal zinc diffusion process that has enabled the coating to be supplied cost-competitively.
7. The absence of free zinc and the hardness of the Armorgalv coating gives it very good anti-galling properties and allows accurate torquing of structural bolts.
8. The zinc-iron alloy layers in the Armorgalv coating have a melting point approximately 230^{o}C higher than zinc, and thus have superior heat resistance than unalloyed zinc coatings.
9. The surface micro-texture of the Amorgalv thermal zinc diffusion coating gives it superior adhesion characteristics for the application of paint coatings, powder coatings and rubber linings.
10. The Armorgalv process has zero emissions other than a low level of heat leakage from the heating chambers.

APPENDIX 1

RELEVANT COATING STANDARDS

Australian and international standards have been developed for each of the commonly used zinc-coating processes. These standards define coating thickness with respect to the various product classifications. This can, in turn, be used to determine the appropriate coating for a particular durability or manufacturing requirement.

Standards relating to zinc-based coatings discussed in this document include:

THE ZINC-COATED (GALVANIZED) STEEL STANDARDS.

AS/NZS 4680:2006 – *Hot dip galvanized (zinc) coatings on fabricated ferrous articles*

AS/NZS 4534:2006 – *Zinc and zinc/aluminium coatings on steel wire*

AS/NZS 4791:2006 – *Hot dip galvanized (zinc) coatings on ferrous open sections applied by a continuous or specialised process.*

AS/NZS 4792:2006 – *Hot dip galvanized (zinc) coatings on ferrous hollow sections applied by a continuous or specialised process.*

AS/NZS 4791:2006 – *Hot dip galvanized (zinc) coatings on ferrous open sections applied by a continuous or specialised process*.

AS 1397:2001 – *Steel sheet and strip – Hot dipped zinc coated and aluminium/zinc coated*

AS 4750:2003 – *Electro- galvanized (zinc) coatings on ferrous hollow sections.*

AS 1214:1983 *Hot-dip galvanized coatings on threaded fasteners (ISO Metric coarse thread series)*

AS/NZS 1559:1997 *Hot-dip galvanized steel bolts with associated nuts and washers for tower construction.*

AS/NZS 1252:1996 *High strength steel bolts with associated nuts and washers for structural engineering.*

ASTM A1059/A 1059M – 08 – *Zinc alloy thermal diffusion coatings (TDC) on steel fasteners, hardware and other products.*

BS EN 13811:2003 – *Sherardizing, zinc diffusion coatings on ferrous products – Specification.*

THE ENVIRONMENTAL CLASSIFICATION STANDARDS.

AS/NZS 2312:2002 references a suite of ISO standards that are intended to provide the platform for classification of corrosivity or atmospheres. These standards are:

ISO 9223 - *Corrosivity of atmospheres – Classification*
ISO 9224 – *Corrosivity of atmospheres – Guiding values for corrosivity categories*
ISO 9225 – *Corrosivity of atmospheres – Measurement of pollution*
ISO 9226 – *Corrosivity of atmospheres – Determination of corrosion rate for standard specimens for the evaluation of corrosion.*

AS 4312:2006 - *Corrosivity zones in Australia*

AS/NZS 2699.3:2003 – Built-in components for masonry construction – Lintels and shelf angles – Durability requirements

AS2309:2008 – Durability of galvanized and electro-galvanized zinc coatings for the protection of steel – Atmospheric.

Austpower Engineering
ABN 95 071 415 499

Unit 1, 2 Alhambra Avenue, Cardiff NSW 2285
PO Box 1184, Warners Bay NSW 2282
T: (02)4953 7999 F: (02) 4954 9939
W: www.austpowereng.com.au
E: info@aeng.com.au

METALLURGY INVESTIGATION REPORT

SITE/LOCATION: Armorgalv

CLIENT: Armorgalv

PLANT/SUBJECT: *TZD Coating Hardness and Micrograph*

CONTACT: Wayne Sharman - Business Manager

CONTRACT/WO NO.: n/a **CLAUSE NO.:** -

REPORT NO.: L226-01 **REVISION NO.:** 0

INSPECTED BY: K. Swain

AUTHOR: K. Swain **CHECKED:** K. Gilby

DATE: 21.12.2010

INTRODUCTION

A high tensile bolt that had been coated using the Armorgalv thermal diffusion galvanizing process was submitted to Austpower Engineering for micrographs and hardness testing of the coating.

Figure 1 Bolt as received. Red line indicates cross section taken for examination.

INVESTIGATION Coating Micrographs

A cross section was mounted in resin and polished to a 1 micron finish, and etched in 0.5% Nital. Micrographs were taken at various magnifications both in the etched and unetched conditions. Some micrographs have already been provided and further micrographs with the coating thicknesses are given in appendix 1.

The coating thickness averaged 40 microns with a 10 micron thick layer adjacent the steel which was identified as the gamma layer.

Hardness Testing

A Shimadzu micro Vickers hardness tester with a 15g load was used to give the smallest indentation possible. The indentations were then measured at x100 magnification on an Olympus PMEG 3 microscope.

The small indentations required have resulted in a loss of accuracy, and are indicative only. However they do demonstrate that the gamma layer is much harder that the steel, and that the bulk coating has a hardness comparable with a high tensile steel.

Table 1: Microhardness Results

Location	Hardness Results			Average (HV)
	1	2	3	
Steel	343	329	308	327
Gamma Layer	679	568	568	605
Adjacent Gamma Layer	482	329	315	375
Bulk Coating	376	262	290	309

Micrographs of the coating and hardness location are provided in Appendix IIA.

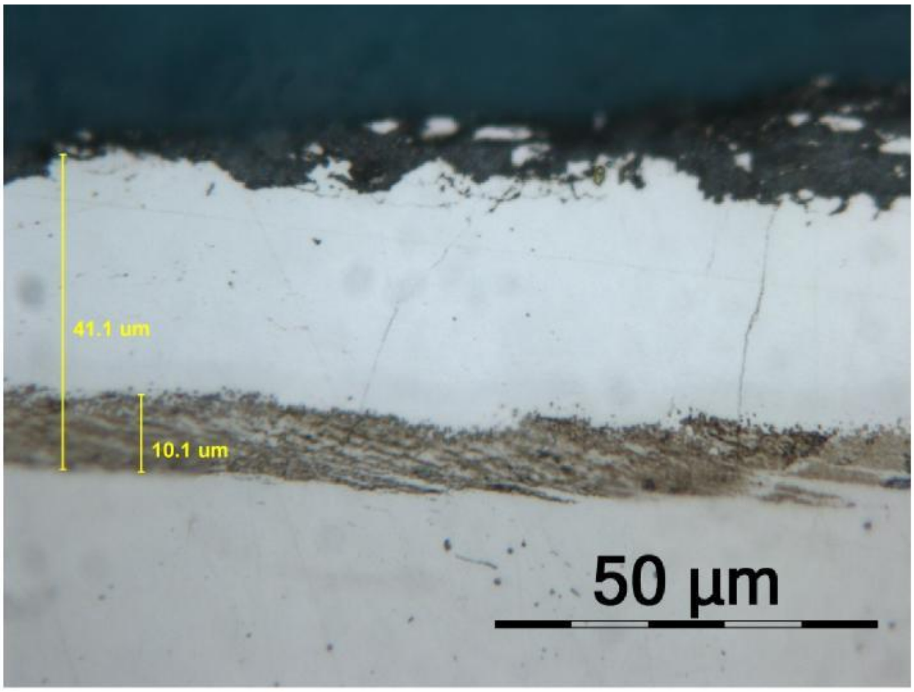
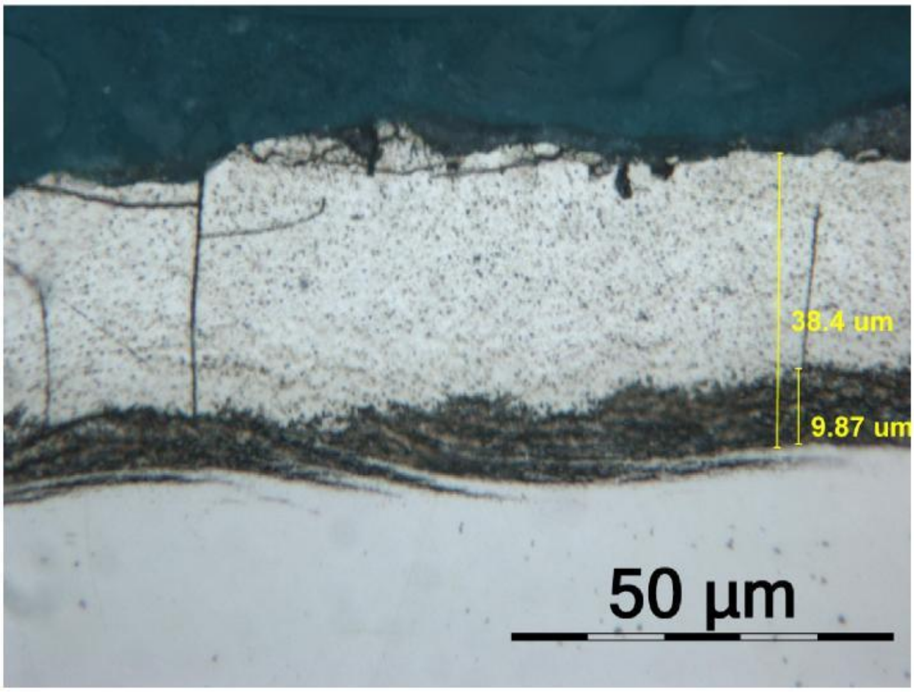


Figure 1: Unetched coating (original magnification x 1000)



Appendix IIA Micrographs

Figure 2: Etched coating (original magnification x 1000)

L226-01 ArmorGalv TDG Coating Micrographs and Hardness

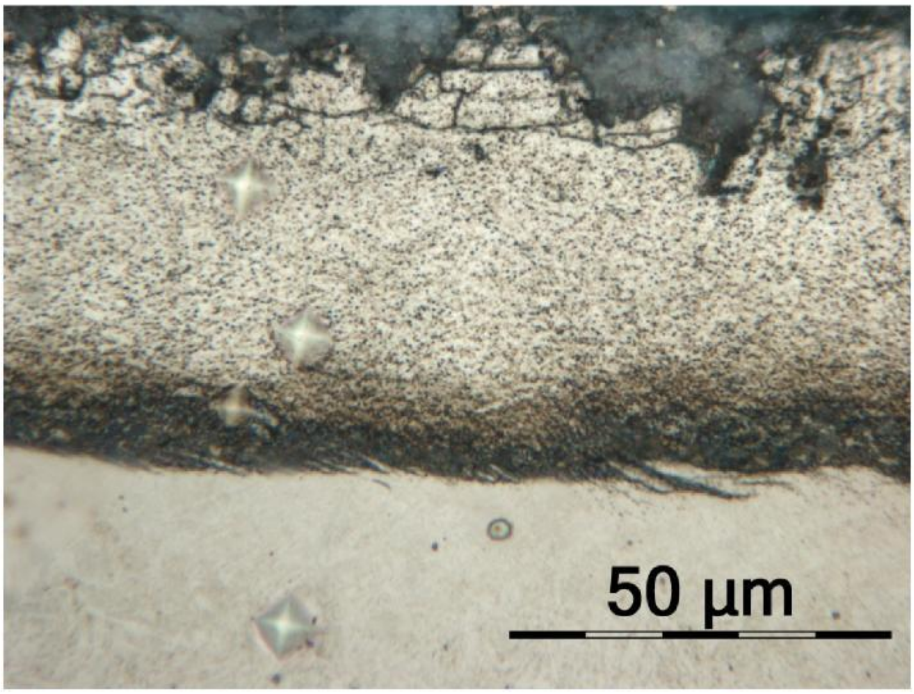


Figure 3: Hardness Indentations at location 1 (original magnification x100).

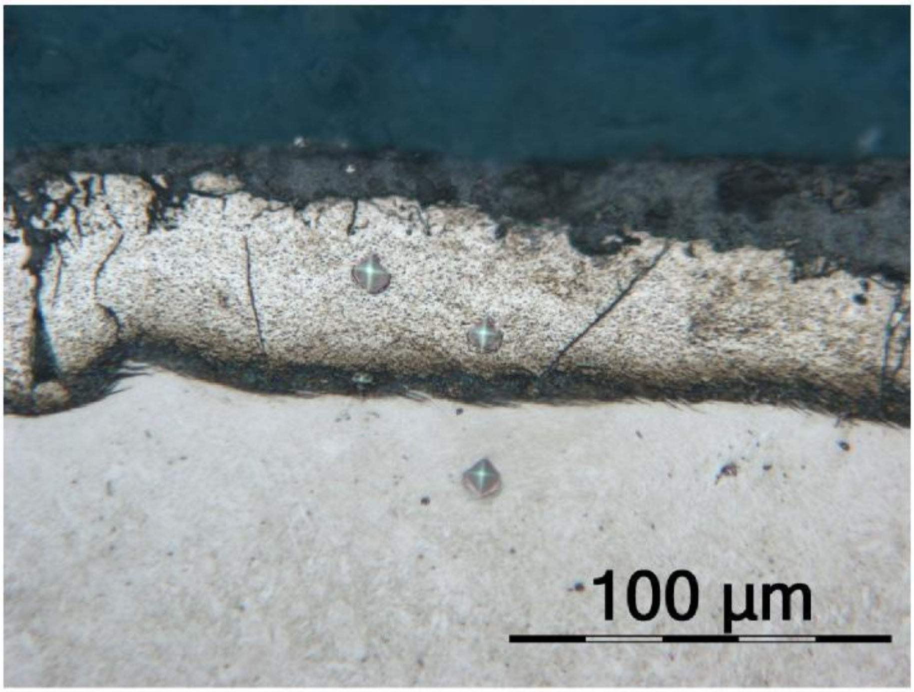


Figure 4: Hardness indentations at location 2 (original magnification x50).