SUMMARY: Cost effective reliable corrosion prevention of large plant by the coating of structural steel and peripheral equipment can be difficult to accomplish. However effective reliable corrosion prevention can be accomplished by the systematic application of existing Australian and New Zealand Standards and existing paint approval schemes. This is further enhanced by a simplicity of coating system design, and an awareness that coating application is often the last major task in a project and the lowest priced contractor often wins at the expense of the intent of the project’s desired coating longevity. This paper details the development and practice of cost effective reliable corrosion prevention by coating application over the last twenty years in some heavy industrial Queensland plant and gives trends for the future.

Keywords: painting, protective coating, corrosion prevention, structural steel, Australian New Zealand standards, specification, coating system, cost effective, AS/NZ 2312, coating application, quality control, safe painting temperature

1. INTRODUCTION

This paper presents critical aspects of large industrial plant protective coating specification which has been successfully applied, in part or in whole from about 1982 to present. These plants include:

- Queensland Power Stations; Gladstone 5&6, Tarong, Callide B, Wivenhoe Pump Storage, Stanwell.
- The extension of a large aluminium smelter in Queensland.
- A new significant gold mine in The Independent State of Papua New Guinea, which is situated at/in the caldera of an extinct volcano next to the sea, with some continuing geothermal activity.

Recognition of critical coating aspects and translation of these aspects to appropriate selection and application of protective coatings is illustrated by a case history study of the Kareera Hydroelectric Power Station Penstocks near Tully in Queensland. These penstocks were first painted in 1957 using hot tar enamel, but coating failure was discovered after 6 years. A full re-coat was performed in 1968 and the coating is still performing well today, if beginning to approach its repaint date.

2. WHAT IS CORROSION?

Figure 1 shows diagrammatically what conditions are required for iron/steel to corrode in a normal aqueous or atmospheric environment. As we can see four conditions are required, they are;

- an anodic site.
- a cathodic site.
- an electron path in the metal between the anodic and cathodic sites.
- an ionic pathway in the electrolyte between the anode and the cathode.

Generally speaking corrosion of carbon steel is proportional to the time of wetness of the steel.
surface (that is when an electrolyte exists on the surface).

Shrier (1) has shown that the time of wetness of a metal surface depends on critical Relative Humidity (r.h.) below which corrosion will not significantly occur. In the case of iron and steel 60% Relative Humidity is when rusting commences and proceeds very slowly. In addition there appears to be two further critical humidity levels where corrosion rate undergoes significant step increases. These are at about 75 to 80% r.h. where a capillary condensation of moisture within the rust occurs, and at 90% r.h. which corresponds to vapour pressure of saturated ferrous sulfate solution (from contaminated atmospheres). In addition the surface of a metal will become wet when the dew point is reached and condensation occurs.

In all cases for general corrosion, it is the time of wetness of the steel surface (that is, when there is an electrolyte on the steel surface) that is the principal controlling factor in initiating and propagating corrosion.

3. WHY COAT?

Corrosion can be prevented by the removal or modification of any one of the four conditions for corrosion. Many methods are available to remove one or many of the conditions but the most time proven and cost effective is the prevention of the wetting of the steel surface by the use of a surface coating. Additives or combinations of coating types can greatly enhance system longevity and the time to first rust.

We therefore apply surface coatings to steel to prevent corrosion and enhance the longevity of the structure and its aesthetic appearance.

4. WHAT IS A SURFACE COATING?

A surface coating is a thin layer of inorganic or organic material which forms from a liquid by:

- Solidification from a melt (for example, galvanising, sprayed metal, fluidised bed nylon coatings).
- Electrolytic deposition (for example, zinc, nickel, nicklex, chrome plating).
- Evaporation (ie lacquers, including most water based latex/acrylic paints).
- Evaporation and/or chemical reaction (as in alkyd, epoxy, polyurethane, inorganic zinc paints) forming chemical or adhesive bonds to the substrate to which it has been applied.

This thin layer then prevents corrosion of the substrate material by the breaking of the corrosion cell by any or all of the following:

- exclusion of electrolyte (for example, water on the surface).
- passivation of the substrate surface by chemical reaction with the substrate and forming a passive layer (for example, phosphate anti corrosion additives in anti-corrosion primers).
- providing cathodic protection from the presence of anodic metals (eg Zinc in galvanising or inorganic Zinc coatings). These have the advantages that if slightly damaged, thereby exposing the substrate, galvanic reactions will occur from sacrifice of the zinc coating with cathodic protection of the substrate. If the damage is small enough then the zinc corrosion product (Zinc Hydroxy Carbonates) will seal the damage and shut down the corrosion cell.

It is the self healing effect of zinc coatings that enables a synergistic enhancement of longevity of the coating system when a zinc coating is combined with a top seal coat. The resultant life expectancy is greater than the sum of the life expectancy of the individual treatments.

5. ON THE IMPORTANCE OF SPECIFICATIONS FOR PAINTING

Figure II shows that the choice of a coating can be daunting. If a different coating system is applied to match each service type and coating type, many coating systems will be the result. Some contracts have been observed to have up to 20 to 30 coating systems. This is not the KISS (Keep It Specified Simply) principal. In addition if designers are not astute in key aspects of successful coating system selection, surface preparation, and coating application, a coating ‘disaster’ can result.

It is worth noting that coating application is often one of the last aspects of a construction contract, and at this point pressures on cash flows and overall profitability can force the selection of the lowest cost coating system and its application. If designers are not careful coating system prices can be pushed to the lowest denominator by the exclusion of good contractors, thereby ending up with a cheaper coating system and application which will be incapable of meeting the design life or even last for more than a year or two.

Clear explicit coating specifications that encourage coating application pricing with the initial tender and contract, with defined applicators and material supplies are the best guarantee of a cost effective coating system.
6. SPECIFICATIONS AND THE ‘KISS’ PRINCIPAL

Keeping It Simply Specified (KISS) is the key to a cost effective coating system. The major cost in a coating system is the labour component. Therefore designers can select more expensive coating materials if:

- the number of wet on dry coats can be kept to a minimum (one would be good, but not always practical).
- the coating system requires the minimum number of different prime and top coats to cover the plant material and temperature range.
- surface preparation costs can be kept at the minimum required for the service life designed for.

Designers should select prime and top coats that are universally applicable to the widest chemical and temperature environments, and select a universal priming system and minimal number of top coats. Life expectancy can be increased by simply adding more top coats of the same coating.

In 1982 a KISS coating specification was developed when extensive applicable Australian Standards were not yet present.

The really useful Australian Standard, AS 2312 ‘Guide to the protection of iron and steel against atmospheric corrosion’ first appeared in 1984. About that time coating materials were being controlled to increasing extent by Australian Standards, and more importantly for Government Bodies, by the Government Paint Committee under the GPC approvals scheme. This scheme controlled coatings from the registered recipe level and included many system specifications of which the most useful to atmospheric plant was the GPC-C-27 series. This series was based on coating system performance in actual weathering trials in a number of environments. The ‘teeth’ in the approval scheme, its commercial in confidence nature, the GPC manufacturer auditing scheme, coupled with the very large purchasing power of government bodies, ensured the delivery of verifiable coating product. This scheme, with increased Australian Coating Standards continues today under the authority of the Australian Paint Approval Scheme.

7. SOME ESSENTIAL COATING SYSTEMS SPECIFICATION ELEMENTS

The essential KISS element of atmospheric systems (the majority of the coating requirements) was as follows:

- Prepare the surface well, an AS 1627.4 ‘Abrasive blast cleaning’ to achieve an AS 1627.9 ‘Pictorial surface preparation standards for painting steel surfaces’, Class Sa 3 finish was specified. A Sa2½ finish would suffice if inspection assured it did not drop to Sa 2.
- Alternatively acid pickling as a prelude to galvanising or phosphate passivation would be a good alternative. The market was left to decide.
- Use Zinc in the form of Galvanising, Epoxy Zinc Coating, or Inorganic Zinc Coating as the primer.
- Let the market decide between Galvanising and Inorganic Zinc. Epoxy Zinc was reserved for more corrosive atmospheric areas.
- Use a high build Micaceous Iron Oxide (MIO) two pack epoxy coating for top coats, increasing the number of coats to up life expectancy. The higher the build and the less coats the cheaper the system.
- Only top coat the Galvanising or Inorganic Zinc coatings where needed for life expectancy. For example indoors above two meters steel work need not be top coated. Outdoor areas, including indoor two meters above ground level and indoor plant in corrosive (for example acidic vapour) atmospheres, to be top coated with the MIO epoxy. Inorganic Zinc coatings can be an exception to this in neutral pH atmospheric salt spray environments where they will out perform galvanising (for example off shore platforms). This is because of the special nature of the chemical reaction of the zinc and silicates with the steel substrate and the way the zinc corrosion products form within and seal the pores in the silicon/zinc matrix of the coating.
• Use an epoxy gloss (in the eighties) or a re-coatable polyurethane or acrylic urethane (in the nineties) for colour.

• Coating system success could be enhanced by the following elements;

• Seek input at the design stage so that fabrications are “designed for coating purposes”. This can entail placement of specific clauses in drawings and fabrication specifications. Specific design items can include; design for self draining, radiusing of sharp edges, weld profiling detail. The paint applicator cannot be expected to be involved in the fabrication process.

• Maintain surface cleanliness by appropriate degreasing or removal of surface salts by water blasting followed by dry blasting to Sa3/Sa2½ .

• Ensure the surface is not wet from condensation (which may not be visible) by adherence to safe the painting temperature guidelines of AS/NZS 2312 (refer to Figure III at the end of the paper for details).

• Apply coatings to appropriate Dry Film Thickness (DFT) ensuring drying/curing times and re-coating intervals, as specified by the coating manufacturer, are adhered to.

• Use the same coating manufacturer for all coats unless responsibilities are explicitly agreed to (most coating companies will not guarantee their product in another system).

• Clearly define applicator expertise and experience requirements.

• Ensure a quality standard with traceability is defined and inspect to ensure it is achieved.

• Demonstrate to the contractor your full commitment to the job by maintaining a close involvement (if you don’t care, he won’t either!).

8. COATING SYSTEMS SPECIFICATION AND THEIR COSTS - PAST AND PRESENT

Figure IV Attached at the end of the paper shows the principal coating systems developed in 1982 for Tarong Power Station following their first development at the tail end of the construction of the then Gladstone Power Station 5&6 Units. The ‘KISS’ principal was very much applied and how it eventually lined up with AS/NZS 2312 can be seen from the AS/NZS 2312 system list along the top.

9. THE AUSTRALIAN AND NEW ZEALAND STANDARDS - THE FIRST STEP

The advent of AS 2311 “The Painting of Buildings” in 1993, and its sister standard AS 2312 in 1984, was a significant step in defining surface preparation, coating practice, and coating system selection for the protection of iron and steel in atmospheric structures (AS 2312) and the painting of buildings (AS 2311) in and around Australia and New Zealand. Their use is considered indispensable.

10. THE SPECIFICATION OF QUALITY CONTROL OF MATERIALS AND THEIR APPLICATION - THE SECOND STEP

Coating systems and application procedures can be designed which admirably fulfil the ‘KISS’ principal, but if a substandard coating is applied in a substandard way, then all can be lost. To be assured of the quality of the coating system and its application the best method is to use those coatings and application methods that conform to the relevant Australian and New Zealand Standards and/or the relevant GPC Specifications(1). The following lists some relevant Australian and New Zealand and GPC coating, application, and coating testing specifications:

AS 1214  Hot-Dip Galvanised Coatings on Threaded Fasteners
AS 1345  Identification of the Contents of Piping, Conduits and Ducts
AS 1397  Steel Sheet and Strip - Hot-dipped Zinc-coated or Aluminium/Zinc Coated"
AS 1580  Methods of Test for Paints and Related Materials
AS 1627, Part 1  Cleaning using Liquid Solvents or Alkaline Solutions
AS 1627, Part 2  Power Tool Cleaning
AS 1627, Part 4  Abrasive Blast Cleaning
AS 1627, Part 5  Pickling Steel Surfaces
AS 1627, Part 6  Phosphate Treatment of Iron and Steel Surfaces
AS 1627, Part 9  Pictorial Surface Preparation Standards for Painting Steel Surfaces
AS 1627, Part 10 Cleaning and Preparation of Metal Surfaces using Acid Solutions (Non-immersion)
AS 1650 Hot Dipped Galvanised Coatings on Ferrous Articles
AS 2105 Inorganic Zinc Silicate Paint
AS 2310 Glossary of Paint and Painting Terms
AS 2311 The Painting of Buildings
AS 2312 Guide to the Protection of Iron and Steel Against Atmospheric Corrosion
AS 2700 Colour Standards for General Purposes
AS 3884 Etch Primers (Single Pack and Two Pack) for pretreating Metal Surfaces
AS 3894 Site Testing of Protective Coatings
AS 3894.1 Method 1: Non-conductive coatings - Continuity Testing - High Voltage ('Brush') Method
AS 3894.3 Method 3: Determination of Dry Film Thickness
AS 3894.4 Method 4: Assessment of Degree of Cure
AS 3894.10 Inspection Report - Daily
AS 3894.11 Equipment Report
AS 3894.12 Inspection Report - Coating
AS 4100 Steel Structures
AS 4352 Tests for coating resistance to cathodic disbonding
AS/NZS ISO 9002 Quality Systems - Model for Quality Assurance in Production, Installation and Servicing

Australian Paint Approval Scheme GPC Coating and System Specifications

GPC-U-9 Undercoat for Enamel
GPC-P-13/4 Latex Primer for Galvanised Steel and Zincalume (Buildings)
GPC-E-15/3 Full Gloss Exterior External in MCR (Buildings)
GPC-L-28 Gloss Exterior Latex Paint (Buildings)
GPC-C-29/A Long Life Steelwork Protection System for Atmospheric Use
GPC-C-29/F Long Life Steelwork Protection System for Freshwater Immersion
GPC-C-29/P Long Life Steelwork Protection System for Potable Water
GPC-C-29/S Long Life Steelwork Protection System for Seawater Immersion
GPC-C-29/T Long Life Steelwork Protection System for Tank Lining
GPC-C-29/2A Air Drying Coating for Protection of Steel in the Atmosphere
GPC-C-29/7 Type 1 Product Epoxy Primer
GPC-C-29/7 Type 2 System - Epoxy Enamel or Low Build Epoxy System to 200 micron
GPC-C-29/7 Type 3 System - Solvent Borne Epoxy System to 400 micron Maximum
GPC-C-29/7 Type 4 Product - Solventless Epoxy to 400 micron Maximum
GPC-C-29/7 Type 5 Product - Ultra High Build Epoxy Coating Over 400 micron
GPC-C-29/8A Inorganic Zinc Coating for Steel Protection in the Atmosphere
GPC-C-29/11A Polyurethane Coating for Steel Protection in the Atmosphere
GPC-C-29/16A Organic Zinc Rich Coating for Steel Protection in the Atmosphere
GPC-C-29/18A Powder Coating for Steel Protection in the Atmosphere
GPC-C-29/19A Catalysed Acrylic Coating for Steel Protection in the Atmosphere
GPC-P-155/1 Interior grade Powder Coating (ferrous substrate)
GPC-P-155/2 Exterior grade Powder Coating (ferrous substrate)
11. QUALITY MANAGEMENT OF THE COATING AND ITS APPLICATION - THE FINAL STEP

The best coating systems required, and assured procurement of defined coatings can be achieved by the use of AS/NZS and/or GPC specifications and the appropriate quality control of the coating system applicators by defined Inspection.

As industrial coating application is a skilled operation the need for competent and experienced personnel is very important. With the absence of full certification programmes from TAFE and the like (although this is improving), it is necessary to specify three categories of coating work and the applicator capabilities and experience associated with each class. For example the most stringent category is 1. Category 1 is intended for the most demanding service environment of total and intermittent aqueous immersion. Personnel experience of five years experience in category one work is required. In addition blasting and painting must be carried out under cover, or under approved conditions for site work. The least stringent category is 3 for indoor (covered) Exposure and Indoor decorative finishes. Application personnel must have at least two years experience in Category 3 work.

Inspection and quality control of the coating system application must reside with the application contractor and be carried out using inspection records in accordance with AS 3894.10, AS 3894.11 and As 3894.12.

We have found that a site pre start meeting of all parties, including the coating manufacturer, is often essential to discuss quality control and inspection aspects and reach agreement on issues which can be contentious such as blast profile height, cure time before dry film thickness measurement, assurance of safe painting temperatures.

12. A CASE HISTORY - 1957 TO PRESENT - THE KAREEYA (TULLY) HYDRO-ELECTRIC POWER STATION PENSTOCK

Kareeya Power Station is a 72MW hydro-electric plant which has been part of the Queensland Government’s generation network since commissioning in January 1957. The station consists of:

- Storage Dam (Koombooloomba Dam).
- Intake Works and weir (Tully Falls Weir).
- Horizontal Penstock (675 m @ 2.74 m diameter concrete encased steel).
- Inclined Penstock (995 m @ 1.90m diameter concrete encased steel).
- Distribution Manifold and Branch Pipes.
- 4 X 18MW Turbo-alternators.

The Horizontal Penstock was originally coated with a hot coal tar enamel (typically 3-4mm thick) and the Inclined Penstock with a bituminous paint, Inertol. The later was built up by several thin coats to about 200mm based on the current European practice at that time (the contractors were Swiss). After 6½ years (December 1963) the penstock was drained and the distribution pipes and the horizontal penstock inspected. Severe coating loss and pitting corrosion was found and a decision was made to re-coat (1) once adequate power supply could be assured when Collinsville P.S. came online in 1968.
13. SELECTION OF COATING

The four years lead time provided an excellent opportunity to plan the re-coating project. Coating suppliers were invited to trial products on test panels in the penstock. Approximately forty panels of various systems and preparation methods were trialed for 3 years. The types of coatings trialed were:

- coal tar epoxies.
- vinyls.
- straight epoxies.
- neoprene.
- thixotropic coal tar.

Some good performers such as neoprene were eliminated because of difficult application and solvent fume problems. The best performing group was clearly the coal tar epoxies. In addition, the trials highlighted the special requirements which coating projects in tropical areas face. Both ventilation air and compressed air supply must be dehumidified. Furthermore, work in the penstocks required isolation of blasting grit from coating operations, high application rates and release of little or no toxic fumes.

Having made the decision to use a coal tar epoxy product, approximately 60 candidate formulations were tested between July 1966 to May 1967. During this period, manufacturers revised formulations to try and improve spraying performance, but the breakthrough came when the Shell Epicote Laboratory published its work on the airless spray application of solventless coal tar epoxies. Further exposure trials at Koombooloomba Dam of seven solventless coal tar epoxies allowed a final selection from three satisfactory performers and Carbomastic 12S, a thixotropic product, was chosen to be applied at a nominal 30-40 mil (635-760mm).

13.1 SPECIAL PLANT AND EQUIPMENT

The logistics involved in the preparation and painting of penstocks of this size are daunting. A range of special plant was required to ensure safe access and both technically acceptable and safe working atmospheres.

Purpose-built work trains for both horizontal and inclined penstocks which consisted of a sealed blasting section, a cantilevered paint application structure, an equipment trolley for blast and painting equipment, and a personnel and supply trolley.

Git Blasting Equipment using chilled angular steel grit.

Ventilation and Air Conditioning Plant which was designed to provide air flow through the penstocks at about 1 m/s and to ensure that at least a 5 °F difference between wet and dry bulb temperatures was maintained (this air conditioning effectively prevented any dew point conditions within the tunnel and effectively ensured a safe painting temperature was always present).

Compressed Air Plant with a refrigerated drier used to ensure that the compressed air was dry. Supply was achieved through 100mm aluminium tube.

Haulage Winches with FM communication to operators.

The re-coating work commenced in December 1968 and took 32 days for the horizontal penstock and 43 days for the inclined penstock.

13.2 PERFORMANCE

The penstock operated without inspection until November 1992 when a limited outage and de-water allowed access to the horizontal penstock. Visual inspection was coupled with Dry Film Thickness (DFT) and DC Impedance Measurements in accordance with the technique reported in Bacon, et al (1). The latter technique proved unreliable without baseline data for the new coating.

The DFT results showed that films in the range of 700 to >1000mm (the upper limit of the gauge used) had been achieved. Visual inspection showed that, apart from a small test bed area and some frequent weld margin problems, the coating appeared to be in generally excellent condition. The margins of all site circumferential welds showed extensive pitting - typically 10-25 tuberculated holidays per weld.

Two vital preparation steps were omitted in the 1968 re-coat - dressing of sharp edges and porosity and removal of water soluble contaminants. The extensive planning and trialing had been focussed on either new steel or steel in good condition. In addition, the impact of soluble contaminants on osmotic blistering was not well appreciated at that time. Work by Leidheiser and Funke (1) and others in the early 1980’s has made these mechanisms more widely known and appreciated.
Therefore, the soluble corrosion products associated with the extensive pitting which was uncovered during the blast clean were not removed. Similarly, allowance was not made for dressing dags, porosity, splatter and undercuts associated with the rather rough field welds.

Nonetheless, the coating away from the welds was in excellent condition. The DC Resistance work in 1992 had raised some concerns due to apparent coating saturation. It was decided to more fully inspect the horizontal penstock in late 1993. In addition to the inspection techniques employed previously, some Elcometer (Pull Off) Adhesion Tests were done.

The DC Resistance work was examined in the light of results from other Queensland penstocks and was discarded as being too unreliable. The DFT measurements were more extensive and the results indicated an average of 835mm (sd 86mm). Adhesion results were in the range of 25-40 Kg/cm² with most failures at the Araldite layer or cohesive failure within the coating. Inspection of the distribution pipework also showed coating in good condition. However, here the welds were performed and finished to pressure vessel requirements. Therefore, weld margin breakdown was absent.

At the same outage a full re-coat of the test bed area was undertaken and as many weld margins in the horizontal penstock as could be reached by the contractors equipment were spot repaired.

13.3 LATER STRATEGIES

Subsequently it was decided that there was no technical justification for a full and very expensive re-coat at that time and the recommendation was made to patch repair the incline and distribution pipework.

However, budget estimates for patch painting the incline at a level of defects similar to the horizontal were multi-million figures and a significant percentage of the cost of a full re-coat due to the logistical difficulties involved. It was therefore decided to commission a full inspection of the inclined penstock to assist in the formulation of a management plan. This inspection is occurring in August 1997.

It has been common practice to re-coat immersion surfaces every 15 years. This penstock coating has lasted 29 years. Even if the incline inspection results indicate a re-coat is the most cost effective option, that would not occur for at least 2-3 years giving a life well in excess of 30 years.

NOTES:
1 To determine the dew point, mark in the relative humidity, move up to the Dew Point Line and read the temperature difference. Subtract this figure from the air temperature to obtain the dew point. To determine if conditions are acceptable for painting, mark in the relative humidity on the lower axis, and the air temperature minus the steel temperature on the vertical axis. If the intersection is in the Painting Zone (below the Painting Guide Line), conditions are acceptable. If the intersection is in the No Painting Zone (above the Painting Guide Line), conditions are not acceptable and painting should not proceed.

2 This chart is suitable for field determinations of dew point but should not be used for accurate determinations. An accurate table for dew point determination is given in ISO 8502.4.
COMPARATIVE SYSTEM COSTS
OF FLAT PLATE AT GROUND LEVEL ($/m²) - 8.6.1982

Table and diagram showing the comparative system costs for flat plate at ground level, with costs for 1982 and 1996 presented. The system costs include surface preparation, primer costs, protective coating, and coating systems specification and their costs - past and present. The table compares various coating systems, such as MP6-A, MP1-A, MP5-A, LP2-A, GZ, GZLP-F, GZLP-C, and MP6-A/C, along with their respective costs for different applications and substrates.


GPC Specifications are at present part of the Australian Paint Approvals Scheme (APAS). APAS can be contacted through, The Secretary, Australian Paint Approvals Scheme, 177 Salmon Street, Port Melbourne, Vic, 3207. Phone (03) 9248 4902, Facsimile (03) 9646 5165.


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