

Technical Paper - "Pipeline Coatings - The Good, The Bad and The Ugly"
Written by David Norman - November 2002 - Presented at the Australasian Corrosion Association's Conference in Adelaide, Australia.

INTRODUCTION

In order to achieve corrosion protection for the design life of a pipeline the corrosion protection system – the combination of coatings and cathodic protection – has to be designed, specified, applied, constructed, maintained and managed correctly.

Case studies of pipeline coating failures, from around the world, are presented.

The key elements in making sure that a pipeline coating is fit for purpose are discussed

CASE STUDIES

The case studies presented are from work undertaken in:

- South America
- North Africa
- India
- The UK

Case Study 1 – South America

- 762mm diameter pipe sourced from Japan and Brazil
- Temporary "protectives", shellac or bitumen, applied at pipe manufacturers
- Pipe stored for 15 months in marine environment, prior to coating
- Fusion bonded epoxy (FBE) coating system applied
- Inadequate coating plant and specification used

Very high daytime temperatures and heavy afternoon precipitation were experienced where the pipe was stored. In addition the atmosphere and the ground both exhibited a high degree of "chloride content".

The temporary "protectives" applied at both the pipe manufacturing works proved to be a major source of problems. The shellac type of material was thin and brittle and tended to loose adhesion to the pipes. However it remained over about 30% of the surface. This caused differential rates of corrosion over the 15 months of storage and consequently problems in the abrasive blast cleaning processes.

The bitumen temporary "protective" softened and flowed to form raised areas on the pipes. A higher degree of corrosion was experienced in these areas.

It was found impossible to effectively blast clean the pipes with bitumen on them. As the bitumen was soft the blast cleaning abrasive would not remove it. In addition the abrasives soon became highly contaminated with salts. A freezer unit was built, immediately prior to the first blast cleaning unit, to try to harden the bitumen. This did not work.

All pipes were covered with a large amount of salts which were not removed prior to entering the first abrasive blast cleaning unit.

During the 15 months of pipe storage the bottom layer of pipes had been stored directly on the ground. Being between the sea and a sea-water estuary this ground was highly contaminated with salts. With the very high daily temperatures and the heavy afternoon rains corrosion rates were high. Initially, no attempt to remove the salts was made. Eventually, every pipe from the bottom layers at the pipe dump was individually treated by hand blast cleaning using a mixture of water and sand. Unfortunately the water was impure and the sand contained a high degree of chlorides!

Pitting corrosion was very prevalent on the bottom layer of pipe. Even so all the pipes were coated with fusion bonded epoxy powder (FBE). A late examination of some of the pipes where pitting had been experienced showed up to a 72% loss in wall thickness.

The coating plant being used had been brought from another location in South America, where it had been built to coat 356mm diameter pipe. Needless to say the coating of 762mm diameter pipe was extremely difficult. No procedure qualification trial had been executed.

Following totally inadequate abrasive blast cleaning chromate solution was applied to all pipes. Even the chromate solution was applied in an inadequate manner – 26 drips of chromate solution encircling the pipes in spirals without any wiper blade to smooth them out into a thin and regular film.

The FBE application booth was totally inadequate, with large volumes of powder exiting to atmosphere, and some “clogging up” the booth. All coated pipes were covered in a layer of virgin, unreacted powder,

Case Study 2 – Africa

- 1219mm diameter pipe sourced from 4 pipe mills in Europe
- 3-layer low density polyethylene (PE) coating system
- Field joints protected with mastic, heat shrink, wrap-around sleeves
- Temperature of operation ambient ground, except downstream of compressor stations >60 deg. C
- 3 years in ground
- Ground conditions varied from sand to damp alluvial soil
- A cathodic protection system was in operation

All pipe was shipped from Europe to Africa, some as deck cargo. Some pipe was stored, beside the sea, for 12 months prior to coating.

The pipe coating specification used was not acceptable. Surface preparation criteria were inadequate. No phosphoric acid washing, or chromate pre-treatment were specified. No procedure qualification trials were undertaken.

The coating specification (3-layer, low density, polyethylene) called for 50 – 75 microns of fusion bonded epoxy powder, ~150 microns of a polyethylene co-polymer adhesive, and an overall total film thickness of 2.3mm using a low density polyethylene (PE). This was for 1219mm diameter pipe.

After only 3 years in-ground the adhesion of the coating to the substrate was seen to have lessened considerably. The low density polyethylene (LDPE) was soft and easy to cut through. The total of the 3-layers of the coating could be removed from the substrate. No fusion bonded epoxy (FBE) remained.

Corrosion products were visible under the coating. Examination of the substrate and underside of the coating showed:

- a rounded, not angular, profile
- an open rather than dense profile
- particles of abrasive material
- dust and detritus
- crystalline salts

As the coating of the pipe in the plant was not seen, only records were available. These confirmed that neither phosphoric acid washing nor chromate pre-treatment had been used. Profiles of the abrasive blast cleaning profile were recorded to be in the required range, but the roundness/angularity/denseness of profile was not recorded.

It is known that low density polyethylene (LDPE) has a higher rate of moisture vapour transmission than Medium DPE or High DPE. It is therefore thought that this is a contributory cause to the failure mode.

Where similarly coated pipe had been stored above ground, under tarpaulins, the adhesion of the coating to the substrate was adequate. Pipe stored above ground in the open exhibited adequate adhesion in the body of the pipe, but a lack of adhesion next to the cut-back areas.

All the mastic, heat shrink wrap-around sleeves examined exhibited wrinkling, where the ground conditions had "grabbed" the sleeves causing the mastic to move.

All patch repairs had been undertaken with heat shrink patches. Many below ground patches had lost adhesion to the pipe/coating and all those viewed above ground were losing adhesion. A lack of surface preparation and poor heating techniques were the contributory cause to the failure of these heat shrink patches.

Case Study 3 - India

- 762mm diameter pipeline
- 3-layer, low density polyethylene (3-LDPE) coating system applied
- Temperature of operation ambient ground except downstream of compressors >50 deg. C
- Ground conditions varied from dry sand, through sharp stone/rock, to very wet clay
- 5 years in ground
- A cathodic protection system was in operation

The coating system specified was ~50 microns fusion bonded epoxy powder (FBE), ~ 150 microns of a co-polymer adhesive and low density polyethylene (LDPE) to a total coating thickness of 3.0 – 3.5mm.

The majority of the features found on the African project were also found in India.

Failure modes were similar to those on the African pipeline.

Heat shrink, wrap-around sleeves were of the "three-layer" type were used on all the joints. No problems were experienced.

Case Study 4 – UK

- Pipe of diameter 304mm to 1066mm from European mills
- Fusion bonded epoxy powder (FBE) coating applied at various European coating plants
- Nominal thickness of FBE was 400 microns
- First FBE coated pipe used in 1977
- Wide ranging ground conditions
- Temperature ambient ground, with excursions to >50 deg. C downstream of compressors

Following extensive research and development work British Gas used their first FBE coated pipe in 1977. 25 years on they are still using FBE coated pipe as their main corrosion protection coating.

From the outset a well thought out specification was used (CW6). In depth liaison was carried out with the pipe/fitting manufacturers, the coating manufacturers, the coating applicators (factory and field), the pipeline contractors etc. Laboratory procedure qualification trials were undertaken on all coating systems. Those coatings that passed this rigorous testing procedure were then procedure qualified at all coating plants utilised – for various pipe diameters and wall thickness combinations. Only pipeline coating plants that had been procedure qualified were used.

Only independent, trained and certified coating inspectors were used, with additional expertise being given by the BG Quality Control, and BG Corrosion Engineers.

In the "early days" of using FBE a number of problems were found and recognized. Some of these are recorded below:

- Poor adhesion on one side of the longitudinal seam weld.
Caused by inadequate surface preparation and/or low temperature of application.
- Pinholes in, or roughening of the coating.
Caused by inadequate surface preparation (salts).
- Craters/blistering of the coating.
Caused by extraneous material (e.g. rubber) trapped in the coating as it gels, or mill scale trapped in the steel and giving off gasses whilst coating is curing.
- Foaming
This can be caused by high levels of moisture in the powder or too high an application temperature.
- Strain lines/cracks in the coating.
Caused by hydrostatic testing at very low temperatures.
- Blisters in the parent coating when induction heating field joints.
Can be caused by moisture uptake, trapped moisture, contamination under the coating, or incorrect temperature profile during coating (cold ends)
- Loss of adhesion at the cut-back.
Can be caused by moisture uptake and/or contamination under the coating.
- Blistering of the coating soon after application over the circumferential weld – joint coating.
Following cellulosic welding techniques hydrogen gas can be evolved.
- Leopard spotting in ground.
Caused by the formation of corrosion products underneath coating that has lost adhesion to the substrate, disbanded or delaminated. This usually occurs at pinholes.

The problematical corrosion control situations that have been highlighted in this paper have been witnessed, in recent years, on pipeline projects around the world. Therefore the question 'What should be done to ensure that a pipe coating, in conjunction with a cathodic protection system, will provide protection for the design life of the pipeline?' needs to be answered.

The key elements in ensuring that the coating on a new pipeline is 'fit for purpose' include:

1. Specifications and qualification
2. Pipe supply
3. Coating plant and inspection
4. Control of coating application
5. Control of site operations

SPECIFICATIONS AND QUALIFICATION

Many of the in-ground coating problems, seen around the world, have resulted from the use of imprecise technical specifications. It is imperative that a coating specification should be "project specific" relating directly to the generic type of coating to be used on the project. Specifications for fittings, field joints and methods of repair should also be project specific.

All coating specifications should be completed and agreed prior to the award of a contract.

All coatings and coating systems should be procedurally qualified against the requirements of the technical specifications. Coating plants should be qualified, preferably before the award of contract. The coatings should be qualified in both a testing laboratory and in the coating plant or field situation.

Procedure qualification activities are necessary to ensure that the coating systems, coating plants and contractors are adequate to meet the requirements for corrosion protection of pipelines. Unfortunately they are not usually an automatic feature of a pipeline coating contract. In recent coating failure investigations the use of low density polyethylene (LDPE) has been brought into question because of the possible formation of corrosion products under 3LPE systems. LDPE has a greater moisture vapour transmission rate than Medium DPE, and High DPE.

In addition the use of normal co-polymer adhesives, rather than the grafted types, and the use of very thin films of fusion bonded epoxy powder (FBE) (~ 50 microns) has compounded the adhesion and corrosion problems. This is particularly the case where surface preparation techniques have been inadequate.

PIPE SUPPLY

During pipe manufacturing processes many chemical solutions may be used. It is possible that the residues from some of these solutions could be present and detrimental to the adhesion of the coating to the steel substrate, even after some cleaning processes have been implemented.

Subsequent to the manufacture of pipe temporary protective coatings e.g. shellac or bitumen have sometimes been applied to pipe and fittings in order to try to prevent corrosion during storage. This is an unacceptable procedure as it is usually extremely difficult to fully remove the temporary coating prior to the main pipe coating procedure. In addition contamination of the abrasive blast cleaning materials usually results.

On some projects bare pipe has been left on salt contaminated ground for lengthy periods. This has resulted in extensive corrosion and severe pitting. All bare pipe and fittings should be stored on suitable wind-rows. The pipe should not be placed on the ground or in point contact with the "sand" wind-row, but polyethylene sheeting, or similar should be used to separate the pipe and the "sand". By this action contamination and corrosion should be minimised, and problems with the coating process should not accrue.

COATING PLANT AND INSPECTION

A thorough survey of the coating application plant that will be used for a project, should be undertaken prior to the award of the contract, but this rarely happens. The applicator's plant/machinery should be assessed; adequate quality assurance and quality control schemes should be in place. Inspection, laboratory facilities and techniques should also be assessed.

Once the contract is placed with the coating applicator there should be an ongoing dialogue between the personnel from the coating plant and the end product user and any other parties involved.

Independent, trained and qualified coating inspectors should be utilised. This can be a cost effective way of achieving the desired coating standards.

On many pipeline coating and pipelining projects the "end product user" uses inadequate, untrained and unqualified coating inspectors. This can result in coating systems that do not have the correct capability for corrosion protection.

CONTROL OF COATING APPLICATION

Surface Preparation

Undoubtedly, surface preparation is one of the areas in the pipe coating regime that is most problematical. Without adequate surface preparation the pipeline protective coating will not adhere correctly to the substrate. It is therefore imperative that all surface preparation processes are undertaken in a controlled manner in order to give a fully cleaned, correctly profiled substrate.

Many pipeline coating failures have occurred directly as a result of incorrectly cleaned substrates. The following list provides an outline of the main requirements in the surface preparation of pipes for coating with an fusion bonded epoxy powder (FBE) or 3-layer polyethylene (3LPE) or 3-layer polypropylene (3LPP) or 2-component liquid system is to be applied:

During the coating of line pipe and fittings all surface preparation and coating work should be undertaken in the same manner as undertaken in the satisfactory procedure qualification trial(s).

1. all grease, soil and detritus should be removed before entry into the first abrasive blast cleaning unit so that the abrasive/machine, and other pipe, are not contaminated.
2. the pipe should be heated in order to drive off all moisture.

3. the first abrasive blast cleaning unit should be adequately run and maintained, particularly in the minimisation of dust.
4. the hardness, size and type of abrasives should be adequate to meet the requirements of the contract (ISO 11124 -1 Chilled iron grit, and ISO 11124 - 2 Cast steel shot and grit).
5. the abrasive mix should be adequately and regularly maintained.
6. the cleanliness, dryness and size of the abrasive should be monitored
7. chemical cleaning with a proprietary brand of phosphoric acid should be undertaken in order to achieve a substrate with the desired (specified) cleanliness.
8. all the points above that apply to the first blast cleaning unit apply to the second unit (when available) as well.
9. the second blast cleaning unit should provide an angular, dense profile of the specified peak to trough height and cleanliness (ISO 8501 - 1 Part A1 Visual Assessment, and ISO 8503 - 1 C1 & C2 Surface Profile Comparators).
Rounded and dished profiles are not acceptable.
10. dust should be removed by a vacuum or clean, dry air lance techniques.
Brushes should not be used as they spread the dust, rather than remove it.
11. the degree of dust remaining on the surface should be measured in accordance with the requirements of ISO 8502-3. The maximum allowable level is 3 or less.
12. following the attainment of a correctly cleaned and profiled substrate a chemical conversion coating, to alter and improve the condition of the substrate e.g. chromate solution, should be applied.
(It may be necessary to put extra heat into the pipes prior to the application of the chemical conversion coating in order to achieve the desired effect.)

Coating Application

Following adequate preparation the coating system must be applied in a manner so as to at least meet the requirements of the technical specification. Some of the important points to consider are:

1. speed of travel and rotation of the pipes.
2. use of the correct type of transport rollers
3. heating techniques and achievement of the temperature window for application of the coating (system).
4. measurement of the temperature of the pipe before coating by an adequate means and with recordable data
5. operation of the fluidised beds and the guns delivering the FBE.
6. complete wetting of the substrate by the coating, and to the correct film thickness.
7. application techniques for the adhesive layer within the correct "window".
8. application techniques for the PE or PP.
9. an adequate and correctly designed water cooling system.
10. repair procedures, where necessary, to achieve the same high class of coating as the parent coating, with an adequate bond to the parent coating.

Inspection and Testing Procedures

On many projects the inspection criteria and personnel, and the testing regimes are inadequate. In order to obtain the required quality of work:

1. all inspection and testing should be undertaken by qualified and trained personnel.
2. all instrumentation should be calibrated regularly, and records of calibration should be maintained.
3. all inspection and test results should be diligently recorded.

CONTROL OF SITE OPERATIONS

All transportation and storage of coated pipe should be undertaken in a safe manner and so as not to damage the coating or the pipe.

The guidelines on specifications, contractual agreements, pre-qualification of materials and procedures and inspection levels apply equally to field coating operations.

CONCLUSIONS

The core message of this paper is that pipeline integrity and protection from corrosion can be achieved with project specific specifications, trained personnel and good procedures. This costs money.

The money, personnel and procedures can be directed at in-service repair or at obtaining a product that is 'fit for purpose' from the outset.

The choice is (y)ours!