Are we protecting our assets?

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1 INTRODUCTION

Working as a self-employed Corrosion Engineering Consultant, with many pipeline orientated companies around the world has given a much broader view of pipeline corrosion control than when working with British Gas. The varied ways of how companies approach the subject of pipeline corrosion control provoke the question “Are we protecting our assets?”.

Case studies of major pipeline coating failures from eight countries are presented and analysed.

The key elements in ensuring that a pipeline coating system is fit for purpose are presented.

2 CASE STUDIES

The case studies presented are from work undertaken in:
South America, North Africa, India, the UK, Iran, USA, and Norway.

2.1 Case study 1 – South America

Pipe diameter:	762mm; sourced from Japan and Brazil; temporary protectives applied
Pipe storage:	stored for 15 months in a marine environment
Coating system:	mono-layer FBE
Coating specification:	inadequate, as was the coating plant
Years in ground:	new onshore project
Operation:	new project
CP system:	new project

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 next to 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 and bitumen.
A freezer unit was built, immediately prior to the first blast cleaning unit, to try to harden the bitumen. This did not work. Rotary wire brushing was reverted to. This process gave even worse problems.

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 layer 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 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 pre-treatment 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 spreader 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” in the application booth.
All coated pipes were covered in a layer of virgin, un-reacted powder,

2.2 Case Study 2 – Africa

Pipe diameter:	1219mm sourced from 4 European pipe mills
Pipe storage:	next to the sea
Coating system:	3LPE (low density)
Coating specification:	inadequate
Years in ground:	3

Operation: ambient ground temperatures except near compressor stations
CP system: operative, monitored, but not controlled properly

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 large, 1219mm, diameter pipe.

After only 3 years in-ground the adhesion of the coating to the substrate was seen to have lessened considerably. The LDPE was soft and easy to cut through. The total of the 3-layers of the coating could be removed from the substrate. No FBE remained on the pipe surface.

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 LDPE has a higher rate of moisture vapour transmission than Medium-DPE and High-DPE. The combination of poor surface preparation, and water vapour transmission through the LDPE coating were the main contributory causes to the failure of the coating system.
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 creep.

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 loosing adhesion.
A lack of surface preparation and poor heating techniques were contributory causes to the failure

of the heat shrink patches.

2.3 Case Study 3 – India

Pipe diameter:	762mm
Pipe storage:	mixed rural and near sea environments
Coating system:	LDPE
Coating specification:	reasonable
Years in ground:	5
Operation:	ambient ground temperatures and > 50 deg. C downstream of compressors ground conditions dry sand, sharp stone/rock, wet lay etc.
CP system:	operative, monitored and maintained

The coating system specified was ~50 microns FBE, ~ 150 microns of a co-polymer adhesive and 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 utilising a 2-pack epoxy liquid primer and a crystalline adhesive were used on all the field joints. No problems were seen.

2.4 Case Study 4 – UK

Pipe diameter:	ranging from 304mm to 1066mm, from European mills
Pipe storage:	in the countryside and at by the sea
Coating system:	FBE at various European coating plants, but mainly in the UK
Coating specification:	performance type, with procedure qualification trials for products and processes
Years in ground:	first FBE coated pipe used in 1977
Operation:	mainly ambient ground temperatures; ~50 deg. C at compressors; wide ranging ground conditions
CP system:	operative, monitored and maintained on a thoroughly planned basis

Following extensive research and development work British Gas used their first FBE coated pipe in 1977. 26 years on they are still using FBE coated pipe as their main corrosion protection coating.

From the outset a well engineered performance 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, and inspection companies etc. Laboratory procedure qualification trials were undertaken on all coating systems. Those coatings that passed this rigorous performance testing procedure were then procedure qualified at all coating plants utilised – for various pipe diameters and wall thickness combinations.

The only pipe coatings tat were used in pipeline coating plants were those that had been procedurally qualified.

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:

- 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, or too high a deposition rate.
- 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, foamed parent 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 that tries to escape through the coating film, but forms blisters.
- Leopard spotting in ground.
  Caused by the formation of corrosion products underneath coating that has lost adhesion to the substrate, disbonded or delaminated. This usually occurs at un-repaired pinholes.

2.5 Case Study 5 – Iran

Pipe diameter:	900mm
Pipe storage:	in centre of a land mass
Coating system:	3LPE
Coating specification:	indecisive
Years in ground:	new onshore project
Operation:	new project

CP system: new project

An LDPE system was applied in India and the pipes were transported to Iran. During storage and laying of the pipes it was noticed that the adhesion of the coating system to the substrate was problematical at the ends, near the cut-backs. The adhesion of the coating along the body of the pipes was much better than at the ends, but still intermittently poor.
Examination of the coated pipe showed that:

- Surface preparation, particularly at the ends of the pipes was very poor
- Corrosion products were easily visible under the coating at the ends of pipes
- The FBE first layer had not wetted the substrate properly
- FBE had not been applied under the complete length of the PE, particularly at the ends

2.6 Case Study 6 – USA

Pipe diameter: 100mm, 200mm and 300mm
Pipe storage: beside the sea in a hot and humid environment
Coating system: mono-layer FBE
Coating specification: by major user
Years in ground: new offshore project
Operation: new project
CP system: new project

Whilst induction heating during joint coating operations it was found that the parent FBE coating blistered badly.
Experimentation and investigation showed that the parent coating had foamed, badly in places. The gases trapped in the foamed coating matrix were not able to escape during normal induction heating of the joints and hence blisters were formed.
A very slow build up of heat with an extra induction coil provided a solution in part, and FBE field joint coating was achieved.
However the line-pipe coating remained in a foamed state, through the entire thickness of the coating in places.
It was concluded that the line-pipe FBE coating had been applied at too high a temperature and/or too high a rate of deposition.
Some of the FBE coated pipe was used in a pipe-in-pipe situation. The pipe was wound onto a reel barge for laying.

2.7 Case Study 7 – Norway

Pipe diameter: 750mm
Pipe storage: by sea for short time
Coating system: 3LPP
Coating specification: national spec. with addenda

Years in ground: new onshore and offshore project
Operation: new project
CP system: new project

The pipe was ‘successfully’ coated with a 3LPP system and shipped to Norway, where it was stored for a number of months. During storage it was noticed that the adhesion at the ends of the coating was problematical on some pipes.
During pipe welding procedures it was apparent that the residual heat from the welding process was ‘lifting’ the total 3-layer coating from the substrate.

During induction heating for the joint coating process it was found that the full coating system lost adhesion from the substrate. Trying to cut back to obtain a fully bonded coating was usually unsuccessful.

On-site, laboratory, and coating plant investigations proved that the FBE first layer had been applied at too low a temperature. When examined under high magnification in the laboratory it was found that there was a micro-void between the prepared substrate and the FBE layer of the coating system.

The problematical corrosion control situations that have been highlighted in this paper have been witnessed, in recent years, on pipeline projects around the world. Clearly, the answer to the question “**Are our assets being protected?”**, in the above Case Studies, is no.

How should we ensure that our pipelines are protected?

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

- The use of adequate plant and site coating specifications and processes
- The alignment of the coating specifications with the CP and other standards
- The pre-qualification of materials and processes
- Liaison with the pipe supplier
- Correct storage of pipe and fittings
- The production of a meaningful Quality Plan by both the coating plant and field coating applicators
- The use of independent, trained and knowledgeable coating inspectors
- Total control of the coating application at the plant and at site

3 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, and form part of an overall ‘package’ of coating specifications.

All coating specifications should be completed and agreed prior to the award of a contract.
The new range of ISO and European standards that are being or have been written, will help to provide a common base.

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 and/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 enhanced where surface preparation techniques have been inadequate.

4 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.

5 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.

6 CONTROL OF COATING APPLICATION

6.1 Surface Preparation

Undoubtedly, surface preparation is one of the areas in the pipe coating regime that is most problematical, and/or not receiving enough attention.
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 FBE or 3LPE or 3LPP or 2-component liquid systems.

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 and approved 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. This process removes all soluble salts etc.
8. all the points above that apply to the first abrasive blast cleaning unit also 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 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 should be 3.

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 pre-treatment, 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.)

6.2 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 most 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" of application.
8. correct 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.

6.3 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.

7 CONTROL OF SITE OPERATIONS

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

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

8 CONCLUSIONS

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

The money, personnel and procedures can be directed at expensive in-service repairs or at obtaining a product that is 'fit for purpose' from the outset. Where do your values lie?

”**Are we willing to protect our assets?”**