DEVELOPMENT OF A COST EFFECTIVE POWDER COATED MULTI-COMPONENT COATING FOR UNDERGROUND PIPELINES

P.Singh
Shaw Pipe Protection Limited
One of the Bredero-Shaw Group of Companies
1200, 630 3rd Ave. S.W.
Calgary, Alberta T2P 4L4

J.Cox
DuPont Canada Inc.
Calgary, Alberta

ABSTRACT

Pipelines are used globally to transport a variety of materials including gas, crude, petroleum products as well as water. To a great degree, they fulfill a range of demands to provide safe and low cost conduits. Currently, more and more pipelines are being called upon to perform for durations beyond their planned life. In addition, the pipelines are being used for different media being transported under new conditions, not anticipated in the original design. Pipeline coatings are selected on the basis of product cost with little regard given for the impact of coating types on overall project costs or on asset integrity beyond the planned life. In view of this, there has to be some rethinking of the design and selection philosophy regarding pipeline coating. This will lead to an increasing demand for innovative and better performing external corrosion coating systems to ensure pipeline assets are well protected and retain their value even after their planned assignments have been completed. This paper compares conventional Fusion Bonded Epoxy (FBE) coating against an innovative powder coated multi-component coating. Economic benefits of this coating system, particularly in the significant phases of new pipeline installations such as transportation, field storage, construction, and operational service are discussed.

Keywords: powder coated multi-component coating, corrosion, cathodic protection, economic benefit, design, lifetime

INTRODUCTION

Pipelines are designed and constructed with corrosion resistant coating and protected simultaneously with cathodic protection. Over the past decades, a wide variety of organic coatings have been developed and used, ranging from plant applied systems to over the ditch applied tapes. Original coal tars, asphalt enamels and vinyl tapes have given way to more dependable and better performing extruded polyethylene, and Fusion Bonded Epoxy (FBE) coatings. The newest technology being introduced is the multi-component system including the powder coated and extruded three layer polyethylene and polypropylene coatings.

Coated steel pipes are exposed to a variety of conditions in their journey from the coating plant to being buried in the ground and finally being put into operation. The coating is subjected to impact from other pipes and objects, abrasion from being dragged around in contact with sharp objects, high shear stresses, temperature extremes, corrosive mediums, and electrical fields from cathodic protection systems. The results can be coating damage in the form of holidays, disbondment, material deterioration, and weakened coatings that fail prematurely during pipeline operation. Coatings can and do perform under these conditions, however they need to be designed and selected for the required service. In addition to these performance requirements, additional factors must be considered such as: land or offshore usage; design life requirements; anticipated changes in operating conditions, disposal through sale/merger/acquisition; and ability to address current risk related issues such as Stress Corrosion Cracking (SCC), safety and environment.

The economics of selecting a given coating system has to be one of the most significant topic that has received less than its fair share of analysis. Far too often, this is done in a piecemeal manner, with attention paid to selected parts rather than the overall analysis. The coating costs represent only a small part of the project cost. However, it protects a pipeline which has replacement cost, and this in turn protects the viability of much larger assets. The cost of lost production or environmental damage claims from a failed pipeline or one shut down for repairs or maintenance, can far exceed the cost of the coating. Other costs that can be more directly attributable to the coating selection should also be considered. These include unanticipated additional costs due to installation practices, warm/cold weather installation, stock piling/storage, handling/transportation, and carrying out unplanned early maintenance. Examples of these are easy to come by, but they are never factored into the overall cost of the selected system. Thus coating are still selected on a material cost basis with no concerted effort in place to change this to an overall cost evaluation.

A powder coated multi-component is described and then compared to FBE coating on both technical and economic merits, with project examples given. FBE, being the most commonly used coating for larger diameter pipelines, and well known is not described in any details. The technology and application process is well documented and easily found in published literature. In comparisons where data on the powder coated system is lacking, data for three layer systems is considered. The three layer system and the powder coated system are similar in many respects and share performance characteristics.

MULTILAYER COATINGS

Single layer coating systems perform well in a limited set of conditions matched to their characteristic properties, but disappoint when subjected to the full spectrum of conditions that is typically encountered by a pipeline coating. Multi-layer coatings offer a means of countering the weakness of a single layer by combining materials in such a way to create a broader base of advantageous characteristics. Multi-layering is based on two principles which are: (i) optimisation of a coating by multi-layer design which combines the favourable properties of various coating materials, and (ii) functional separation of corrosion protection and protection against mechanical damage, thus individual layers of coating materials satisfy each of these needs entirely.[1] Multi-layering can become very sophisticated, being limited only by process and cost considerations.

Three layer pipeline coatings utilise a primer layer of FBE or liquid applied epoxy, a polyolefin outer layer and an adhesive tie layer. FBE primers are selected because of their excellent adhesion to steel and their cathodic disbondment resistance. This is achieved because of the strongly polar molecular structure, which is also responsible for it high moisture absorption. Polyolefins are very non-polar, and thus have low moisture absorption and good electrical insulation properties. The combination of the polyolefin and FBE materials in layers give greatly improved properties of the system. Interlayer adhesion is attained with a chemically modified polyolefin material with polar end groups, which can form linkages between the non-polar polyolefin and the polar FBE.

There is no consensus on the optimum thickness of individual materials that will produce an effective coating. The thickness of FBE primer has ranged from 100 µm and upwards. The FBE layer can be viewed partly as a corrosion coating and as an adhesion layer for the coating to steel interface. As an adhesion layer, thickness in the range of 50 - 72 µm, have been used [2], however for a corrosion coating, the minimum thickness of 100 – 200 µm is recommended. Polyethylene layer thickness is selected to withstand environmental conditions, especially impact during transportation and laying of pipe. Typical thickness can range from 500 µm to several millimetres. The tendency has been for thickness of up to 3 mm of low density polyethylene based on the results of fairly severe transportation and construction scenarios. However, recommendations are for lower thickness especially with medium and high density polyethylene which have better impact resistance.[3]

POWDER COATED MULTI-COMPONENT COATING

The coating under study (HPCC – High Performance Composite Coating) [(1)] is a powder coated multi-component coating consisting of a FBE primer, a medium density polyethylene outer layer and a tie layer containing a chemically modified polyethylene adhesive, all applied as powders. Figure 1 shows a schematic drawing of the cross-section of the coating.[4] The tie layer is a blend of adhesive and FBE with a gradation of FBE concentration. This mixing produces a physical interlocking of the components with no defined interface. The adhesive and polyethylene are similar to each other and intermingles easily to disperse any interface. The layers are strongly interlocked and behave as a single coating system. This system provides excellent adhesion to the pipe surface with inherent shear resistance properties, impact and cathodic disbondment resistance, and very low moisture permeability. The selected materials allow for operating temperatures up to 85°C and installation temperatures down to -40°C.

In typical three layer systems, the polyethylene layer is applied by side extrusion for large diameter pipes and by cross-head extrusion for smaller diameter pipes. However, the problem with extrusion on large diameter pipes with raised spiral or longitudinal welds is poor coverage of the welds especially where the profile is pronounced. There is the tendency to form voids at the weld neck area, which produces pinholes and entrap water during the cooling stage. Rollers have been used to compress the molten polyethylene around the weld seam with some success in regular welds. There is also a reduction of coating thickness at the top of the weld, which results in increased material usage to achieve the minimum required coating thickness.

Powder coating avoids these problems and provide additional advantages of being able to coat large diameter pipes easily. The powder coated multi-component coating uses a proprietary process for applying all of the components in powder form using electrostatic powder coating techniques. The process provides versatility in customising the thickness of the components of the coating system, as well as produce the structure as described previously. It also uses a proprietary internal quenching process rather than relying solely on spraying or flooding of the pipe exterior. As a result of this process, the coating solidification front moves from the steel-primer interface towards the outer surface. This minimises the formation of voids, which can be formed when the outer surface freezes before the bulk of the material.

Optimization studies have shown that a FBE primer thickness of 150 μm is a good base for corrosion resistance when used in conjunction with the powder polyolefin adhesive and polyethylene topcoat in this powder coated multi-component coating. Higher levels of epoxy, above 250 μm, have been used in three layer coatings on some critical areas especially off-shore pipelines. Coating costs rise considerably as the epoxy thickness trends up and there may be plant process implications as well. The powdered adhesive component is used strictly as a functional "tie-layer" between the epoxy and the top coat and only a small amount of material as necessary to effect good chemical bonding and melt blending of the components to form a composite material is used. Typically about 125-150 μm is used for the powder adhesive tailored for this technology. The polyethylene top layer serves several different functions: chemical and moisture barrier, mechanical protection and weather resistance. A minimum of 500 μm has been found to give adequate protection to normal handling with higher thickness recommended for specialty needs.

Application Process

The application process for the powder coated multi-component coating consists of similar steps as required for FBE coating. The steel pipe is prepared by pre-warming in a hot water rinse, then abrasive blasted to achieve a near white metal finish and a specified anchor pattern. The pipe is then inspected for defects such as slivers, which can be removed by grinding. Acid washing and rinsing is carried out followed by induction heating to the recommended powder application temperature. The three components are applied sequentially to the hot pipe in the same powder booth. After fusing and curing is completed, the pipe is cooled using both internal and external water quench. Finally, the coating is inspected, marked for identification, and tested for quality conformances. Some of the tests and acceptance criteria are listed in Table 1.

Coating Performance

The powder coated multi-component coating cannot be adequately or fairly characterised using qualification tests designed for either single layer FBE or extruded polyethylene coatings. It shares characteristics with FBE especially in properties involving its adhesion to the steel substrate. In through-thickness properties (those affected by the bulk of the materials rather

---

[(1)] HPCC is a proprietary Bredero-Shaw product.

than interfacial characteristics), its characteristics are similar to those of polyethylene based coatings. However, powder coated polyolefin behaves differently from extruded polyolefin. In this respect, the tests and the interpretation of the results for this coating system need to be carefully drawn from the respective FBE and polyethylene coating standards.

The following tests were chosen from the CSA Z245.20 [5] and CSA Z245.21 [6]: cathodic disbondment; hot water immersion; impact resistance; and flexibility. Other tests include electrochemical impedance spectroscopy, electrical resistivity, abrasion and shear scratch.

Cathodic Disbondment tests were carried out according to CAN/CSA Z245.20 at 23, 65 and 95°C, and for exposure time up to 1 year. The test cells were placed in ovens for temperatures other than at ambient. The results illustrated in Figure 2 show that the disbonded radius is quite small, less than 40 mm. for the higher temperature condition, and less than 10mm for the 365 days duration. The disbonded radius increases rapidly with time initially, but shows a levelling off with increasing duration. The higher temperature of 95°C does not show any more deterioration on the disbondment radius compared to the 65°C. In a comparison with FBE in Table 2, the cathodic disbondment results show that the powder coated multi-component coating has significantly better resistance than FBE alone. In the short term, the difference in disbondment radius is small. However, at extended periods at higher temperatures, the difference is quite large.

The TISI gouge resistance and the Taber abrasion results in Table 3 show that the composite coating with its three components provide higher gouge resistance and lower wear in comparison. FBE has fairly poor scratch resistance because of its hard and brittle nature. This is still evident even at higher coating thickness up to 825 µm. The high resistance of the powder coated multi-component coating can be attributed to the tough medium density polyethylene outer layer. This deforms and smears rather than fracture and wears away as do the other harder materials. The interface between the polyethylene and the FBE serves to deflect any crack tip propagation into the coating, thus providing an increased resistance to the formation of any holiday.

The powder coated multi-component coating has a unique structure unlike extruded three-layer systems. The application of all the components in powder form allows for their integration into a single coating with the materials interlocked. A variety of tests were evaluated for suitability in measuring the interlayer bond strength. Peel tests were not be completed because the polyethylene layer could not undergo sustained peel. Shear tests showed no movement even at high temperatures. Shear failure, when it occurs, only does so within the weaker polyethylene outer material and only above its softening point. Elcometer pull-adhesion tests were carried out by gluing aluminium dollies with adhesive materials onto the coating. The dollies were then pulled off at a constant rate using a tensile testing machine. The results were always failure at the dolly adhesive and in rare cases within the outer polyethylene material. The recorded values were approximately 2500psi. In no case was failure at the steel interface evident.

Figure 3 shows the resistivity of the powder coated multi-component coating and FBE in an environment of 0.5% NaCl solution as a function of exposure time at two different temperatures. The resistivity was measured using a Hewlett Packard High Resistance Conductivity /Resistivity meter Model 16008A. The data shows that the powder coated multi-component coating has very high resistivity above 10^{10} ohms/m^2, and this does not deteriorate either with time or with high temperature. Similar results showing the electrical resistance for extruded three layer polyethylene coatings above 10^{10} ohms/m^2 even after immersion in water for long duration and at high temperature have been reported elsewhere.[3] For FBE, the resistivity is at least two orders lower. Below a limiting value of resistivity, reported at 10^6 ohms/cm^2, it is expected that corrosion will occur at the metal coating interface due to ion penetration through the coating.[7] This decreases dramatically at the higher temperature. The implication is that the multicomponent coating will have a low cathodic protective current requirement based on the high resistivity values reported above as well as the higher damage resistance.

Electrochemical Impedance Spectroscopy (EIS) has been shown to be a very useful technique for evaluating the performance of organic coating systems. It is sensitive in predicting the failure of coatings due to corrosion at the metal-organic coating interface. EIS was carried out on the powder coated multi-component coating in comparison with FBE in varying thickness. The coatings coupons were set up for exposure and measurement in EG&G standard flat cell. The coatings were then immersed in a solution of electrolytes (simulating an Alberta Groundwater environment) at a temperature of 65°C over a period of 70 days. The impedance and calculated water absorption are illustrated in Figures 4 and 5 for the selected coatings over exposure duration. The results show that the three-layer coating is virtually unaffected by the exposure condition while FBE shows some decrease in impedance associated with an increase in water absorption.

Repair/Joint Protection

Repair procedures used for the powder coated multi-component coating are no different than those used on conventional three-layer coatings. In the event of minor damage to the outer polyethylene, the area is first cleaned to remove any foreign material and polyethylene is reheated locally and a hot melt stick repair is performed. Where there is damage through to the FBE coating and the diameter of the damage is less than 25mm in diameter, a two-part liquid epoxy primer is applied followed by a hot melt stick or patch material. Where the diameter of the damage is >25mm, a two-part liquid epoxy primer is applied followed by a hot melt stick or heat shrink sleeve. There are currently several methods of completing the coating on the joint after welding has been performed in the field. These include:

- Liquid epoxy coating and a multilayer shrink sleeve;
- an epoxy-urethane liquid coating, and;
- multi-component powder coating.

Each method has its own limitations, which tend to restrict its usage to selected environments and construction conditions. So far, multi-layer shrink sleeves have been used most widely. However multi-component powder coating offers the greatest potential solution in protecting the pipeline in its entirety with a reliable, high performance coating.

Project Experience

Although the powder coated multi-component coating has been recently developed, it has gained a substantial base of experience by being selected for use in a variety of critical environments, where current FBE coating is perceived to be deficient. These include environment with very rocky terrain, acid rock drainage, and wet soil with a hot pipeline. A list of pipeline projects completed using this powder coated multi-component coating is given in Table 4. Prior to commercial sales, a test loop of several joints of 80ft long coated pipes, together with various alternative joint coatings were installed in service by a major gas transmission company. The test area was selected downstream of a compressor station where the pipeline maintained temperatures in the 45C range, and the soil was mixed sand/clay with a high water table. Several years later, the segment of pipeline was dug up and the powder coated multi-component coating was found to be in excellent condition.[8] In 1997, this coating was selected for Enbridge's 540km, 30"OD Athabasca Pipeline.[9] The powder coated multi-component coating was chosen for this challenging project involving moving hot oil at $65^{o}C$ for several reasons including:

- environmental conditions involving muskeg, rock, clay, sand and gravel, and sloughs in which both winter and summer construction had to take place. This required excellent mechanical protection.
- many road and river crossings requiring good abrasion and shear resistance.
- service temperature design of $65^{o}C$ in predominantly wet environment.
- an extremely high percentage of pipe was being bent during both summer and winter construction which required improved coating flexibility.
- better performance in key tests as cathodic disbondment resistance, impact and hot water soak which indicate good field performance trends.
- with extended storage during both winter and summer construction required a coating with good ultra-violet radiation resistance. This was provided by the black polyethylene top coat.

COATING ECONOMICS

The economics of selecting a given coating system has to be given more attention, especially when the product cost represent a small portion of the overall project cost, but its potential impact can be much larger. Based on experience as well as on a pipeline economic survey[10], a summary of coating cost as a percent of pipeline project coat is given in Table 5. The cost of coating is typically in the 3-5% of the overall pipeline project cost. The majority of the costs can be attributed to the steel pipe and to construction. In many cases, the client or end user relies on cost data based solely on the coating costs supplied by the applicator of choice. The applicator is usually physically closest to his project location, the steel source, or along the project routing. This relationship is usually sought because the costs can be lowered by the reduction of freight and handling charges for the bare steel. This up-front cost can be estimated fairly easily and features prominently in decision making. On the other hand, a poor selection of coating can run the risk of increasing construction costs due to more repairs, create delays in project completion, dubious pipeline asset integrity, and eventual premature repairs and early obsolescence. However, these risks are difficult to quantify with no experience or published data to draw upon. As a result, these cost risks are not accounted for and life cycle analysis of the coatings remains elusive.

In this section, the discussion is targeted on the cost of meeting the anti-corrosion requirements of the pipeline project, and the process of getting the coated pipe from the mill to the trench while maintaining the integrity of the coating. This is then combined to produce a total cost picture relating to charges involved in coating materials, handling, repair, installation and cathodic protection. There are numerous studies comparing the performance of various types and even variation in thicknesses of given coatings. Comparisons are made regarding temperature capability, environment resistance, cathodic disbondment, and hot water immersion. These are all based on valid scientific principles and have proven very relevant in ranking or selecting coatings for a given service condition. However, a similar analysis but with an evaluation of cost impacts is never done. There are many areas that should be added to the list for analysis of individual coatings. It is only then that a true comparison on coating can be made covering both the technical as well as the economic aspects.

Corrosion Resistance

The relationship of the various components in a pipeline project are well understood. These include: engineering, design, easements, product contracts, steel purchase/shipment, coating, final shipment to field, installation, inspections, girth welds, line pipe testing and commissioning, then day–to-day operation for " life" and long term asset protection in service. The coating plays a minor role in the scheme relating to the engineering and construction phase, but a major role in the asset integrity/operational phase, and can influence cost greatly on a one time basis at the installation phase. Protection of the value as a pipeline asset by guaranteeing its integrity and safety well beyond its design life is the ultimate function of the coating. The ramification of a corrosion leak involving gas or oil, is that any earlier coating- related savings become secondary and are wiped out immediately in solving the problem. Historically, corrosion leaks on pipelines due to external corrosion do not appear until after several years or decades. Corrosion related problems are not immediately visible as do mechanical related problems. However, problems in mechanical properties can and do lead to serious corrosion failures in time. So protecting the pipeline during handling and installation is key to the integrity and safety of the asset. Table 6 shows the experience of a major petroleum company in one year regarding pipeline incidents.[11] As seen, external corrosion failures account for 13% of the total incidents, which led to property damages of approximately US$7M.

Impact Resistance

The impact resistance properties of coatings are critical in determining the behavior under many of the conditions encountered in handling the pipe from shipping from the plant to being buried on the right of way. These include normal handling practices from:

- Stacking pipes in a stockpile or for transportation. Any sharp object such as stones or nails under or in between the pipes can cause damage. This effect is aggravated when there is relative movement between the pipes.
- Handling. In lifting pipes from stockpiles onto to transportation or vise versa, there is always the risk of contact with other objects. The most common impact scenarios are from pipe ends, dropped end hooks and tools.
- Bending/Welding. Pipes have to be picked up from the right of way and placed into a bending machine. For welding, clamps have to be placed on the pipe ends.
- Burial and Back-filling. In a rocky environment, both the back-fill and ditch may contain rocks that are dropped on the pipe or impinge on the coating during burial.

There are several test methods used to determine the impact resistance of coatings, ranging from falling stones to falling weight involving more precise and controlled impact scenarios. Open for discussion, are the many factors that affect the measured impact resistance values as well as interpretations of results when there is evidence of substantial damage to the coating with no holiday during impact. For a more detailed discussion of this topic, see the following references [12-14].

The powder coated multi-component coating has superior impact resistant properties compared to FBE, thus its is less susceptible to severe damage when stuck by a blunt object such as another pipe during handling or stones during back-filling. Because of this property, the multilayer coating does not need to have rockshield where the back-fill contains rounded stones and gravel. Heavier polyethylene topcoat layer can be selected for increased impact resistance and decreased back-fill costs. Alternatives to this include tape rockshield material which can cost from approximately CAN$40.00/meter for 273.1mm pipe to CAN$80.00/meter for 914mm pipe for materials and field application. As a less likely option, is the trucking in of sand padding, which is estimated at twice the cost of tape rockshield. Depending on the location, the cost can vary tremendously. In addition, there is the cost of trucking out the displaced back-fill material.

Flexibility

The bend or flexibility property of the pipeline coating is one of the more important mechanical properties. It can have significant impact on the cost as well as project schedule. Field bending of the coated pipeline is required to follow the right of way. The coating must withstand the elongation associated with the bend radius and the temperature without undergoing any cracking. Several types of bending tests are available for determining the flexibility property of the coating. An review of the flexibility testing of coating is presented in reference [15].

Some of the factors having various degrees of influence on coating flexibility include: coating thickness; bending radius; temperature; substrate thickness; and the absence of artificial crack initiation sites on the coating sample.

The flexibility tests can be related directly to field experience. The bending limits for steel pipeline are restricted to keep within the yield strength of the steel and thus bends are typically less than 1.5 degrees per pipe diameter. However, because pipeline construction is done in winter in Canada, the bending can be carried out in sub-zero temperatures.

UV Resistance

FBE chalks and loses thickness with exposure to sunlight during prolonged storage. This is a factor that needs to be seriously considered if the project will be delayed and the coated pipe will be stockpiled for an extended period. As a result, stockpiles of FBE coated pipes have to be protected withe the use of tarps or whitewash paint to prevent UV degradation. Whitewash, when used, is washed off the coating by rain, and needs to be reapplied each year to maintain an adequate level of protection. In a typical application, the additional protection from UV degradation can range in cost, from 3-5% of the value of the coating per year. On the other hand, the powder coated multi-component coating was made up of a black polyethylene topcoat formulated with sufficient UV protection to last for several years in outdoor storage.

Handling

As with all coated pipes, handling and transportation from the pipe plant to field storage and to the ditch, must be done carefully so as to protect the integrity of the coating and pipe through best practises. These are all common sense procedures and are well known to contractors who routinely install pipelines. The composite coating should be handled in the same manner as an FBE coating or three layer coating. However, based on contractors and end users comments regarding handling of FBE versus the powder coated multi-component system, it appears that this coating is superior and more resistant to construction damage. The multi-component coating, with its higher thickness (0.75 – 1.0mm) can withstand deeper damage than the FBE coating (0.35mm). A sharp hard object would penetrate the FBE but would damage less than 50% of the composite coating.

In one installation, we have seen less damages with multi-layer coatings compared to FBE single layer coatings by a factor of 10 fold, i.e. 1 holiday in multi-layer versus 10 in FBE under the same environment.[16] We have also seen field installation experience (42 inch diameter) of composite coating where only one holiday occurred per kilometer of coated pipes going into the rocky, rugged terrain.

On a contractor cost comparisons for a recent project in Virginia, U.S.A., in which a three layer coating was used, some key cost details were compared to a FBE thin film system used in similar environments . Observations were that cost savings were seen in key areas of:

- Repair savings of US$ 1.45 per foot - considerably less repairs with three layer coating on handling, storage and transportation as well as much less from bending damages.
- Padding requirements of US$3.75 per foot - no need for sand to be hauled in, instead soil and rock from excavation was used for back-fill.
- Rock shield products were not required, nor was labor to install them - US$1.20 per foot.

From these three areas alone, a total of $ 6.40 per lineal foot was saved, which translates to about US$1.22 per square foot calculated on the 20 inch diameter new gas line. The pipeline did require much less cathodic protection, and as a result only two ground beds were installed at 32 kilometers apart with shallow anodes used at 10-15 feet deep. Cost for some ground beds can approximate US$15 – 20,000 each, or as high as US$87,000 for two on a 9 miles, 144" diameter water pipeline. On the other side, the biggest complaint is always the toughness of getting the coating off when it is necessary to do tie-ins. Productivity is the same but more effort is required to strip the coating area. In this example, no measure of the savings associated with coating integrity and safety, translating into longer service life, was made. The new powder coated multi-component coating system will perform similar to this when compared to FBE thin film coating and offer the same type of cost saving benefits as a conventional three layer polyethylene coating but at less overall costs due to its powder structure mechanism and relatively thinner composition.

Installation

With the knowledge that it can easily cost more than US$1 million per mile to replace a section of poor integrity or prematurely failed pipeline, it becomes very easy to see the potential benefits of carrying out a proper job in coating protection and installation early in the project life. Today, rehab, or recoating of lines is expensive and can run up to US$750,000 per mile which translate to US$15.00 per square foot for a 36 inch diameter line. One can easily justify adding value by selecting a superior coating that will give dependable, economic, safe service over the life of the project and still maintain the pipeline as a viable asset on the company books. Normally, the pipeline is used well beyond its initial service life of 25 – 40 years. Hence, the need for better coating performance when selecting the coating, followed by proper installation procedures for handling in the field so that the integrity remains intact. Several papers have been written on "how to select" plant applied coatings which take into effect the needs of the environment and provides a base checklist to follow.[17,18] Installation procedures will not be any different than the normal procedures for FBE or three layer systems.[9]

Repairs

By far, the most frequent cause for unanticipated costs are repairs to the coating. Coatings can be damaged during transportation from the plant to the right of way. This depends quite strongly on the number of times that the pipe has to be handled in loading and unloading. The length of the journey is almost inconsequential. The coating become subjected to point loading from errant stones and other sharp objects, impact from dropped tools and other objects.

Improper coating selection for the environment can become a cost nightmare. In our experience, one project using FBE thin film coating going into a rocky trench, had repair charges of more than US$ 600,000 or approximately US$ 0.34 per square foot. A second similar project generated additional charges over US$900,000 or approximately US$1.30 per square foot. However, this included a polyethylene rock shield material, which was used to prevent further rock damage to the coating. The cost was not separated. The two mentioned projects were small in size and length with less than 100 km. of pipeline construction. In both situations, these additional costs could have been avoided by selection of a “purpose designed” multi-layer coating system

Cathodic Protection

Cathodic protection costs are derived from current demand of the pipeline which in turn is determined by the coating resistivity as well as a relative percent of bare pipe(holidays, coating breakdown) to coated pipe. The number of groundbeds are installed to provide an adequate coverage to the entire pipeline, and this incurs an initial capital costs. Operating expenses are incurred from the continuous current demand. The implication is that the powder coated system or the three-layer coating, with their high resistivity and low expected damage, will have low protective current requirements and cathodic protection costs compared to other coatings with low resistivity, such as FBE. In a comparison between a three layer polyethylene coating and an asphalt coating, the estimated cost for installed anodes for a 650km, 40" diameter, 50 year design life, was US$10M compared to US$23M for the asphalt coating. The coating breakdown used was 7% for asphalt and 3% for three layer polyethylene, although it was estimated that 0.5% for more realistic for the latter. Although the asphalt coating was less costly at US$29M compared to US$35M for three layer coating, the overall cost including the cathodic protection system was more costly at US$52M compared to US$45M.

CONCLUSION

A new multi-component coating produced by melt fusing all components in powder form, has been developed for the pipeline industry. The use of a completely powder application process provides a unique structure and makes it very versatile where thickness of the components can be adjusted for any special requirements, and raised welds can be coated very efficiently.

The FBE layer provides excellent adhesion to the steel surface while the polyethylene layer provides good damage protection as well as a barrier to the diffusion of corrosive material to the steel surface. The coating has undergone considerable testing, meeting all the requirements of CSA Z245.20 and CSA Z245.21 and exceeding many of the test results for conventional coating systems. The superior mechanical and corrosion resistance properties make it a cost-effective solution for pipeline operators. This coating has been successfully installed on a number of pipeline projects to date, filling a gap where FBE coatings have been determined to be deficient. It has been used in rocky terrains, acid rock drainage areas, and in wet environments with a hot pipeline. Field experience shows that the improved properties translate into substantial overall cost savings during construction as well as in operation.

ACKNOWLEDGEMENTS

The authors wish to thank their respective companies, DuPont Canada Inc., and Shaw Pipe Protection Limited for their support in publishing this paper.

REFERENCES

1. Haimbl, J.G., Geiser, J., Polyethylene coatings in Europe. A look back on 30 years of experience, Prevention of Pipeline Corrosion Conference, Houston, Oct 31 - Nov 2 1995, Pipeline and Gas Industry.
2. Connelly, G., Gaillard, G., Provon, Y., Cavalle, B., Lemaire, C., Locatelli, R., Three layer pipe coatings for elevated temperatures, Pipeline Industry, March 1990, pp53-58.
3. N. Schmitz-Pranghe, W.Von Baeckmann, “Polyethylene Extrusion Coatings for Steel Pipe”, Material Performance, 1978, pp22-32.
4. A.I. Williamson, P.Singh, Development of a High Performance Composite Coating for Pipelines, NACE Northern Region Western Conference, March 1999, Calgary.
5. CSA Z245.20-98, “Fusion Bond Epoxy Coated Steel Pipe”, Canadian Standards Association, Rexdale, Ontario, 1998.
6. CSA Z245.21-98, “External Extruded Polyethylene Coating”, Canadian Standards Association, Rexdale, Ontario, 1998.
7. E. G. & G. Princeton Applied Research, Application Note AC-2, “Evaluation of Organic Coatings by Electrochemical Impedance Measurements”.
8. Shaw Pipe Protection Limited, Internal Report, TR96-58
9. A.Castro, W.Kresic, B.Scott, Corrosion Management and Construction Methodology for the 30” diameter Enbridge Athabasca Pipeline, NACE Northern Area Western Conference, Calgary, March 1999.
10. “Pipeline Economic Study”, Oil & Gas Journal, Nov. 28, 1992.
11. Internal incident report for transmission, gathering, natural gas distribution and liquid pipelines
12. G. Mills, The Role of the Pipe Coating as an Engineered Part of the Cathodic Protection System, Corrosion 88, St. Louis, 1988, Paper number 237.
13. K. Varughese, Understanding mechanical properties critical to project economics, Oil &Gas Journal, Sept 16, 1996, pp40-46.
14. P.Singh, D.Wong, Coating test methods and their relationship with expected performance, NACE Northern Area Western Region Conference, Victoria, February 1998.
15. K. Varughese, Mechanical Properties critical to pipeline project economic, Oil & Gas Journal, Sept 9, 1996, pp 41- 46.
16. J D N “ Multi-Coat , Comparing Benefits of High Density Polyethylene Coatings for Anti-Corrosion Protection of Pipelines using CSA / Canadian standard Z 245.21.
17. Bredero Price, Internal Technical Paper, Update on how to select mill applied pipe coatings.
18. T.A. Pfaff, Designing the Ideal Pipeline Coating.

TABLE 1

QUALITY CONTROL TESTS PERFORMED ON POWDER COATED MULTI-COMPONENT SYSTEM

COATING PROPERTY	TEST	ACCEPTANCE CRITERIA
Adhesion	CSA Z245.20-98 Clause 12.14 - 48 hours at 75^{o}C	Rating of 1 – 2
Cathodic Disbondment	CSA Z245.20-98 Clause 12.8 Condition (b) - 48 hours at 65^{o}C	10mm maximum
Flexibility	CSA Z245.20-98 Clause 12.11 - 2.5^o p.p.d.	No cracking at -30^{o}C
Impact Resistance	CSA Z245.20-98 Clause 12.12	4 J/mm of nominal coating thickness minimum
Interface Contamination	CSA Z245.20-98 Clause 12.15	30% maximum
Delamination	CSA Z245.20-98 Clause 12.11 Bend of 48 hours at –30^{o}C with cut in coating	No delamination between FBE and PE.

TABLE 2

TYPICAL PROPERTIES OF POWDER COATED MULTI-COMPONENT AND FBE COATINGS

COATING PROPERTIES	POWDER COATED MULTI-COMPONENT	FBE
Cathodic Disbondment Radius (mm) 23^{o}C, 28 days 65^{o}C, 48 hours 65^{o}C, 28 days	 2.5 – 4.5 3.0 – 3.5 11 – 20	 5.0 – 10.0 4.0 – 6.0 20 – 30
Hot Water Immersion-adhesion (rating) 75^{o}C, 28 days 95^{o}C, 24 days 95^{o}C, 28 days	 1 1 1 - 2	 2 – 3 1 3 – 4
Impact Resistance (J) At -30^{o}C	7.5 – 11	3 – 5
Flexibility (degrees p.p.d) At -30^{o}C	Greater than 5.5	2 – 4

TABLE 3

COMPARISON OF ABRASION RESISTANCE OF SELECTED COATINGS

COATING TYPE	TISI SHEAR RESISTANCE (Weight Passes - kg)	TABER ABRASION CS-17, 1 KG, 1000 CYCLES (Weight Loss - mg)
FBE 14 mils 20 mils 35 mils	 3 4 10	 20 –100
Dual Powder FBE Overcoat 30 mils 40 mils	 10 – 15 15 – 20	 20 – 100
Urethane Overcoats 30 mils 40 mils	 20 – 25 25 – 30	 30 – 150
Powder coated multi-component 35 mils 60 mils	 20 – 25 40 – 45	 8 –12

TABLE 4

PROJECT EXPERIENCE WITH POWDER COATED MULTI-COMPONENT COATING

COMPANY/PROJECT	YEAR	LENGTH (km)	DIAMETER	LOCATION/ CONDITIONS
Maritimes & Northeast Pipelines	1998	23	NPS 30	Nova Scotia Acid Rock Environment
Enbridge Pipeline Inc. Wild Rose – Athabasca Pipeline	1997-1998	540	NPS 30	Fort MacMurray-ColdLake-Hardisty, AB 65°C operating, muskeg (wet soil)
Enbridge Pipeline Inc.	1997	5	NPS 20	
BC Gas	1997	2	NPS 20	
Westcoast Energy Inc.	1996	2	NPS 42	Savona, BC Rocky terrain
Westcoast Energy Inc.	1995	43	NPS 24	B.C.
TCPL	1992	7 – 80ft joints	NPS 42	Stittsville, ON Field trial 40°C operating, clay with high water table

TABLE 5

ALLOCATION OF PIPELINE PROJECT COSTS ACCORDING TO MAJOR CATEGORIES

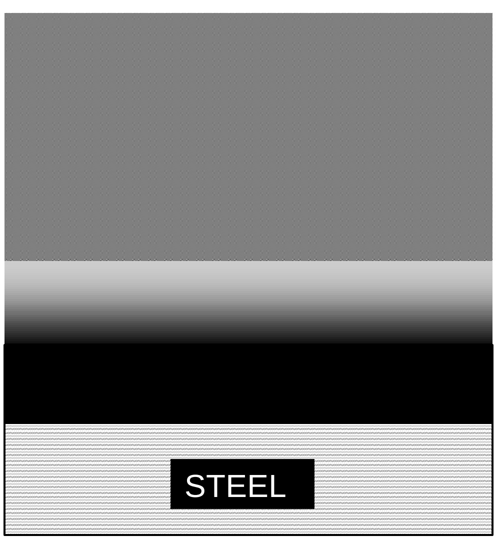
ITEM	(% of Total Cost)
Right of way (survey, clearance, damage)	2 – 5
Materials (other than coating)	35 - 50
Labour	35 – 50
Engineering/Inspection	3 – 5
Taxes/transportation	5 - 8
Pipe Coating	3 – 5
Other (legal, regulatory)	5 – 10

TABLE 6

PIPELINE FAILURE INCIDENTS BY CAUSE

CAUSE	% of Total
Internal Corrosion	6
External Corrosion	13
Damage	33
Construction/Operation related	9
Accidental	7
Other (defective materials)	32

Coating Cross-Section



Material	Standard Thickness µm	(mils)
Polyethylene topcoat	500	(20)
FBE/Adhesive Interlayer	125	(5)
FBE	125	(5)
TOTAL	**750**	**(30)**

Figure 1 – Schematic showing cross-section of powder coated multi-component coating.

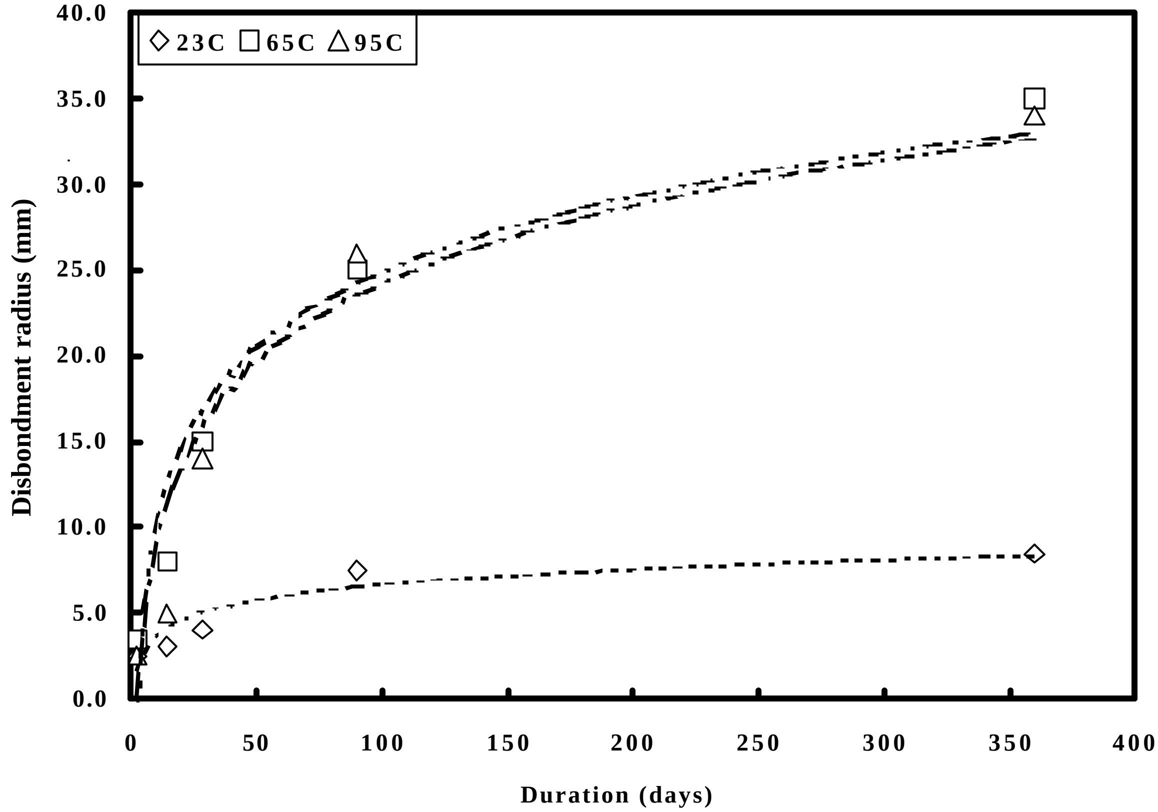


Figure 2: Cathodic Disbondment results

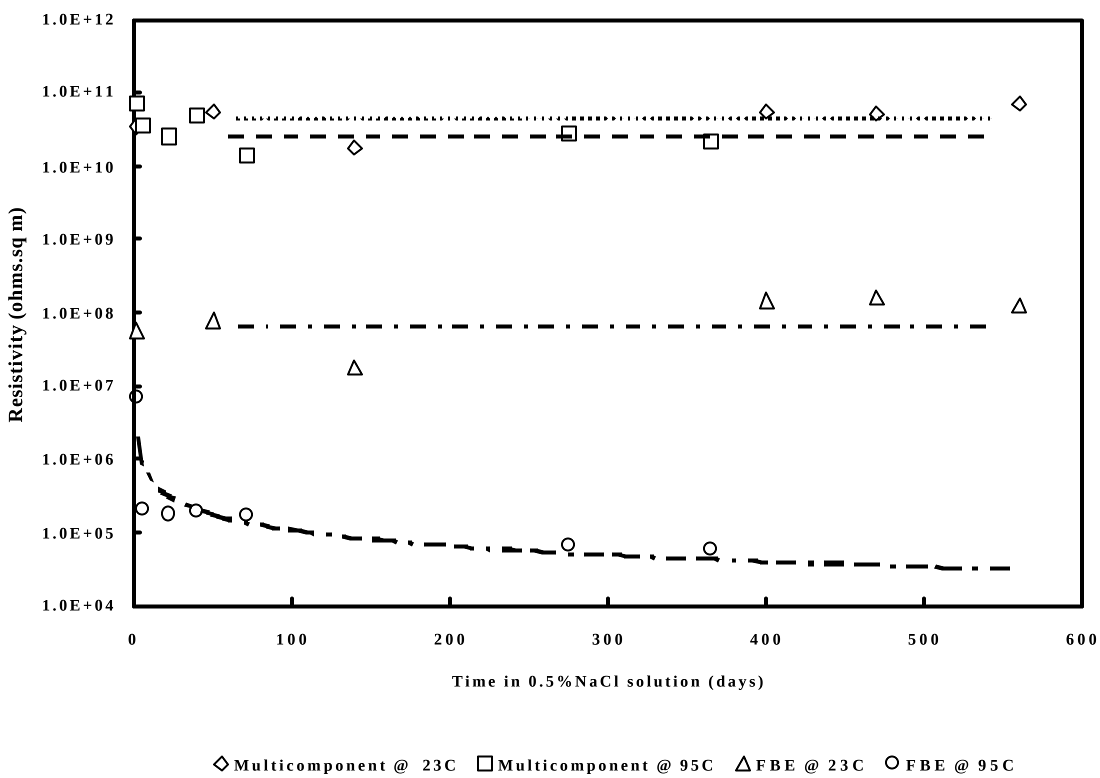


Figure 3: Resistivity of FBE and powder coated multi-component coating versus time and temperature

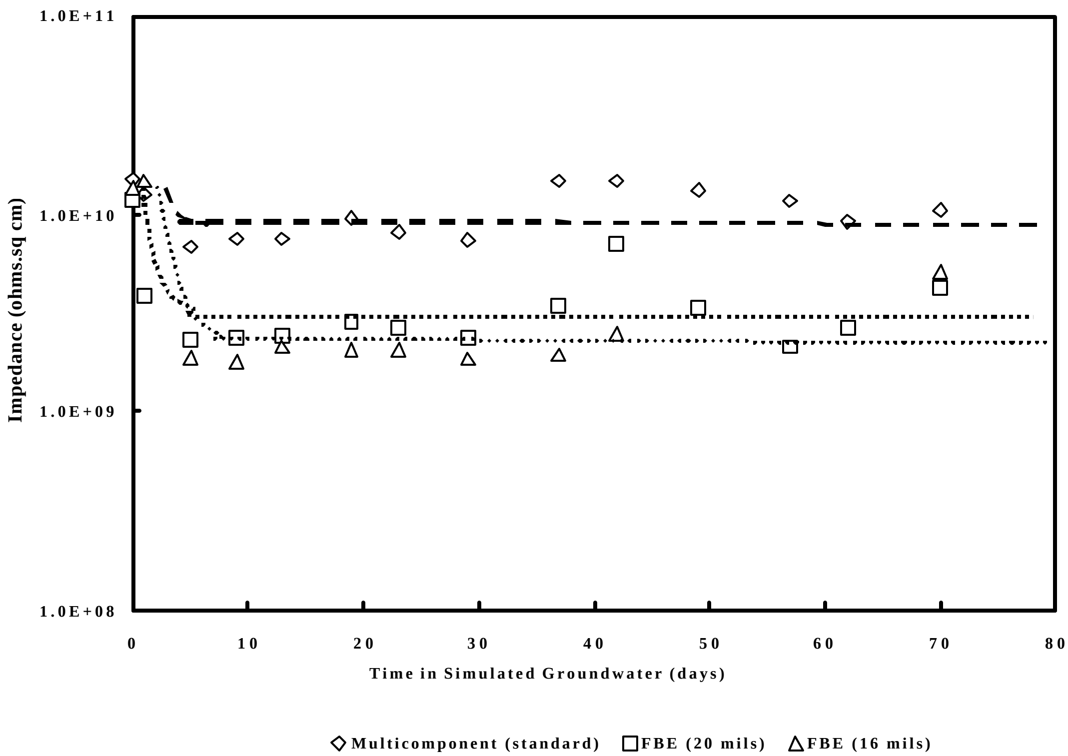


Figure 4: Impedance of powder coated multi-component coating and FBE from EIS measurements

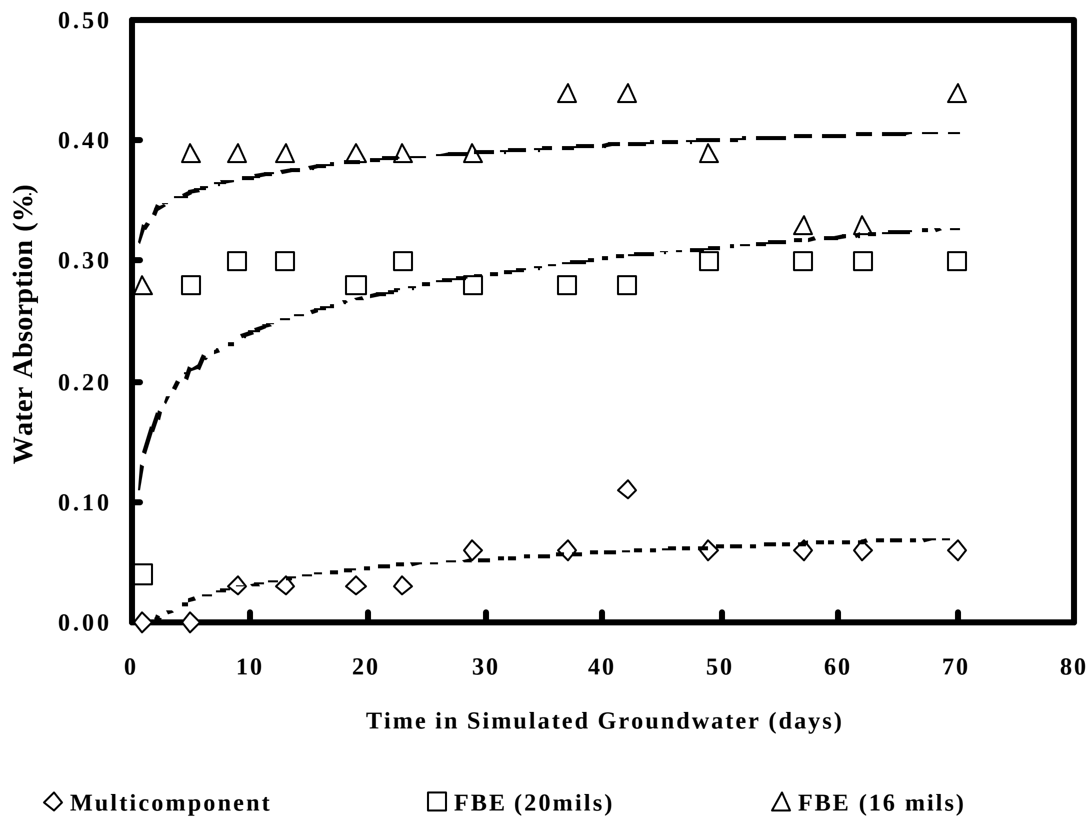


Figure 5: Water absorption of powder coated multi-component coating and FBE coatings from EIS measurements