Field Joint Developments and Compatibility Considerations

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ABSTRACT

The selection of appropriate pipeline coatings is carried out by pipeline engineers after careful analysis of parameters such as pipe diameter, grade of steel, operating pressures and temperatures, soil and site conditions, construction techniques, backfill materials and cathodic protection and monitoring programs. New coating products are often considered as part of this design process. Critical to this consideration is the fact that the main pipeline coating and the applied field joint coating are subjected to exactly the same stresses during pipe laying and subsequent in-service conditions. Therefore, the potential use of new technology must consider the need for the field joint to be compatible with the selected mainline coating.

This paper describes new developments and trends in our mainline and field joint coatings industry, and focuses on the important compatibility issues and industry test protocols.

INTRODUCTION

Pipeline coating choices for mainline and field joint protection are diverse. For onshore applications, mainline coatings are usually selected from a range of options including: single and dual layer FBE, 3-layer polyethylene (3LPE) and more recently multi-layer polypropylene coatings. A similarly broad range of field joint coatings exist with the most widely used technologies being FBE, liquid coatings and heat shrink sleeves.

Selecting field joint systems which mirror the mainline coating represent a very logical and proven methodology. Field-applied FBE on FBE coatings and 3-layer Heat Shrink Sleeves on 3LPE systems are prime examples of this approach.

This paper discusses the regional predisposition in coating choices, presents key advantages and disadvantages and highlights compatibility issues when different technologies are forced together. A number of industry studies are referenced which investigate aspects of the compatibility issues such as the fundamental differences in polarity of epoxies and PE which leads to poor adhesion. Further studies simulating construction and in-service considerations of coating compatibility are also referenced.
TRENDS IN MAINLINE COATINGS

The broad range of options can sometimes complicate the mainline coating selection process. Over the past 60 years, pipeline coatings have developed from hot asphalt and coal tar enamels to the highly-engineered polymer coatings of today (Figure 1). Addressing the demanding requirements of current pipeline projects are high performance coatings such as 3-layer polyethylene (3LPE), single and dual-layer FBE and more recently multi-layer polypropylene (MLPP) coatings.

![Mainline Coating Developments 1940 - Present](image)

**Figure 1. Mainline Coating Developments of the Past 60 Years**

Selection of the mainline coating has a definite regional perspective. As an example, in Europe and the Middle East, the dominant coating choice for large diameter pipelines are 3LPE and MLPP systems. In North America and in the UK, FBE continues to be used, however multi-layer systems are gaining acceptance (Figure 2).

Over the past two decades, the pipeline community has been on the move. Mergers and international JVs have resulted in the North American and European pipecoating philosophies to be promoted/pushed/shoved outside their rooted areas. However, general tendencies are to stick within one’s comfort level. For pipelines engineered in Europe or in America, this probably means there’s a preference towards 3LPE or FBE, respectively. On a global basis, multi-layer systems hold a market share advantage over FBE coatings.
Figure 2. Mainline Coating Use by Geography

Are there compatibility issues in switching a region from one coating to another? Most agree that 3LPE coatings are more robust than their FBE cousins. Regions with limited transportation infrastructure, rough handling and construction practices are probably better suited to 3LPE and MLPP coatings. FBE coatings have been used in North America in part because the transportation infrastructure and construction techniques are sufficiently developed to allow the FBE coated pipe to be delivered with minimal damage. Well-informed engineers are cognizant of these issues and most do their best to select coatings which are compatible with the regional norms.

Assuming the selected mainline coating is fit for purpose and is compatible with the regional idiosyncrasies, how does the pipeline engineer select the appropriate field joint coating? Each different supplier will promote the features and benefits of their unique joint solution.

FIELD JOINT COATING DEVELOPMENTS

The field joint coating (FJC) system must not be the weak link in the pipeline chain. As a minimum, it must provide protection that is equal or better than the mainline coating and to that end, it must be fully compatible and similar in behavior with the parent coating. Testing a field joint coating as a stand-alone product is meaningless if the project mainline coating is not also tested as part of a total coating system.

The field joint coating developments have mirrored the advancements in mainline coatings. Acceptance of new mainline coatings technologies can be dependent on the development of a new, cost-effective joint finishing technology. Over the past 10 years, three technologies have been widely used to protect the field joints: Heat-shrink Sleeves, FBE, and Liquids (Figure 3).
Some specifiers favor FBE on the joints of FBE mainline coated pipe. The rationale is quite simple, as in theory; the installed system closely replicates the parent coating. Applying FBE in the field is the main drawback of this system. Expensive equipment operated by skilled labor are required to achieve in-field application. Leading pipe-coaters often use very sophisticated process controls in their plants to produce FBE mainline coatings. However, given the highly variable construction conditions on the right-of-way, there is some question whether field-applied FBE can truly duplicate the quality of the mainline.

Two–component liquid epoxy coatings have gained favor with specifiers who previously preferred field-applied FBE. Recently, liquid epoxies have been formulated in field-friendly formats with performance properties that generally match those of the parent FBE coating. Liquid epoxies grapple with a number of field issues such as: cold weather application, applicator skill, film thickness variability and coating consumption.

On 3LPE coated pipes, the joint coating system selection requires greater engineering consideration. In these systems, long-term success for the joint coating requires that it must be compatible with four quite different substrates: steel, FBE primer, co-polymer adhesive and PE topcoat.

**TESTING FIELD JOINT COATINGS ON 3LPE**

In the two last years, our industry has undertaken a program of tests that carefully examined at various performance characteristics of leading joint protection systems on 3LPE-coated pipe. The joint coatings included were two representative liquid epoxies systems, a liquid coal tar urethane and two heat shrink sleeves (HSS). Independent industry personnel conducted all sample preparation and coating application in accordance with manufacturers written instructions for each coating material.
Elongation testing was conducted per Transco Standard CW6 before and after aging at 75°C for 56 days (Figure 4). In comparing the before and after heat aging results, no significant change in elongation was noted for the HSS or liquid epoxy coatings. The HSS samples maintained their excellent break elongation of 500% while the epoxies maintained their 1.5% elongation. The urethane sample displayed a dramatic drop in elongation from 14.7% initially to 1.2% after 56 days aging. The researchers hypothesized the loss of plasticizers in the coal tar urethane may be the cause of this embrittlement during heat aging.

<table>
<thead>
<tr>
<th>Mean Elongation %</th>
<th>0 days</th>
<th>7 days</th>
<th>14 days</th>
<th>28 days</th>
<th>56 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy #1</td>
<td>1.39</td>
<td>-</td>
<td>1.64</td>
<td>1.95</td>
<td>1.72</td>
</tr>
<tr>
<td>Epoxy #2</td>
<td>1.54</td>
<td>-</td>
<td>2.07</td>
<td>1.84</td>
<td>2.04</td>
</tr>
<tr>
<td>Coal Tar Urethane</td>
<td>14.71</td>
<td>3.8</td>
<td>1.26</td>
<td>1.14</td>
<td>1.20</td>
</tr>
<tr>
<td>HSS Backing</td>
<td>497</td>
<td>-</td>
<td>494</td>
<td>484</td>
<td>497</td>
</tr>
</tbody>
</table>

Source: Advantica R5579 September 2002

Figure 4. Test Results: Effect of Heat Aging on Coating Elongation

Twenty-eight day, 65°C cathodic disbonding tests were conducted per CW6 (Figure 5). The two epoxies had better resistance to cathodic disbonding than the coal tar urethane. The HSS systems, with disbondment of less than 2mm, had displayed significantly better resistance to cathodic disbondment than the liquids.

<table>
<thead>
<tr>
<th>Resistance to Cathodic Disbondment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>48 Hours at 65°C</td>
</tr>
<tr>
<td>Epoxy #1</td>
</tr>
<tr>
<td>Epoxy #2</td>
</tr>
<tr>
<td>Coal Tar Urethane</td>
</tr>
<tr>
<td>HSS #1</td>
</tr>
<tr>
<td>HSS #2</td>
</tr>
</tbody>
</table>

Notes:
1. Tests conducted per Transco CW6
2. Disbonded radius starting from the edge of the pre-damage.

Source: Advantica R5446 August 2002

Figure 5. Test Results: Cathodic Disbondment at 65°C
Flexibility testing at strains of 1.0%, 1.7% and 3.0% was conducted to CW6 at nominal room temperature (Figure 6). The HSS performance was deemed excellent as both sleeves exceeded 3.0% strain and remained firmly adhered to the steel and PE substrate after bending. Because of the brittle nature of the epoxies tested, both epoxies failed at 1.0% strain and the urethane failed at 1.7% strain. In all cases, the liquid coatings failure occurred at the critical transition between the PE and the steel.

<table>
<thead>
<tr>
<th>Epoxy #1</th>
<th>1.0% Strain</th>
<th>1.7% Strain</th>
<th>3.0% Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy #2</td>
<td>Fail</td>
<td>Fail</td>
<td>Fail</td>
</tr>
<tr>
<td>Coal Tar Urethane</td>
<td>Pass</td>
<td>Fail-Pass</td>
<td>Fail</td>
</tr>
<tr>
<td>HSS #1</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>HSS #2</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Notes:
1. All tests carried out at 23+/-3°C temperature
2. Failure confirmed using holiday detector
3. Testing per Transco CW6

*Source: Advantica R 5435 August 2002*

**Figure 6. Test Results: Bend Flexibility**

Another round of testing focussed on adhesion (per CW6) of these systems to PE after 28 day 50°C water soaking (Figure 7). Quoting the testing staff:

“The liquid coatings exhibited fair/poor initial adhesion to the PE substrate in the as-applied condition. After water immersion, the liquid coatings exhibited poor adhesion”

“The HSS exhibited excellent adhesion to the PE substrate in the as-applied condition and after water immersion. Upon prying, the sleeve adhesive layer peeled in a cohesive mode, and the adhesive remained firmly adhered to the entire PE substrate.”
Cross-Cut Adhesion Testing (CW6)

<table>
<thead>
<tr>
<th></th>
<th>Before Immersion</th>
<th>After 28 Day 50°C Water Soak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy #1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Epoxy #2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Coal Tar Urethane</td>
<td>3-4</td>
<td>4-5</td>
</tr>
<tr>
<td>HSS #1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>HSS #2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes:
1. Ratings per CSA Z245.20-98
   • #1 to #3 = Pass
   • #4 & #5 = Fail

Source: Advantica R 5405 July 2002

Figure 7. Test Results: Effect of Water Soaking on Coating Adhesion

From a compatibility stand-point, the adhesion to PE results bear more consideration. As stated earlier, the 3LPE coating system consists of layers of epoxy primer, a co-polymer adhesive and PE topcoat. The epoxy provides primary corrosion protection and the outer PE provides a tough, damage-resistant armor coat. In addition to increasing overall corrosion protection properties, the primary role of the intermediate adhesive layer is to maximize the adhesion between the non-polar PE and the polar epoxy.

SIMULATED LARGE SCALE TESTING

On a 3LPE coated pipeline, an FBE or liquid coating applied on the PE clearly non-compatible. While the primary epoxy layer is a common element, the sealing and mechanical protection offered by the adhesive and the polyethylene is absent.

This non-compatible performance problem has been demonstrated by several studies. Espiner’s paper provides details of a simulated full scale test program carried out to assess the performance of a 3-layer PE coating and FBE with respect to damage endured during:
- Backfilling (Impact Test)
- Static load stresses in buried condition (Penetration Test)
- Pipe movements in buried conditions (Abrasion Test)

The test program was thorough in selecting the backfill and bedding aggregate materials with different hardness and diameters. Four aggregates used were sandstone (softest), limestone, igneous and quartz (hardest), and the diameters were 5mm, 20mm, 40mm and 100mm. The tests were done on 914mm pipe with 12.7mm wall thickness, and were devised to provide practical real-life simulations.
In order to illustrate the differences in behaviors of the two coating types, only the tests conducted using 20mm diameter aggregates are given here:

<table>
<thead>
<tr>
<th>Test</th>
<th>FBE</th>
<th>3LPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Test</td>
<td>Fail</td>
<td>Pass</td>
</tr>
<tr>
<td>Penetration Test</td>
<td>Fail</td>
<td>Pass</td>
</tr>
<tr>
<td>Abrasion Test</td>
<td>Fail</td>
<td>Pass</td>
</tr>
</tbody>
</table>

These results clearly highlights that if the FBE or a similar liquid epoxy was used on a field joint of 3LPE coated line, there would be serious damage at the joints. This might be overcome by the costly practice of using graded backfill aggregates for the joint area.

Espiner’s paper also describes an important observation regarding the impact behavior of epoxies during the backfilling operation. It states that, “from the impact energy values quoted by coating manufacturers, it would have been predicted that the 20mm aggregates (based on weight alone), would not have caused holidays in the FBE coating, when released from the 3m drop height of the impact chute. Because the large-scale test involves many impacts, it was thought that these might result in a reduction in coating thickness either by indentation or abrasion. Thinning of the coating might therefore be expected to result in lower impact energies”. This phenomenon is likely the result of the brittle nature of the epoxies as opposed to the “tough” impact absorbing nature of polyethylenes. When “brittle” materials like epoxies that can get “chipped away” by repeated impacts even by small aggregates are put on a joint alongside a “tough” 3LPE coating, a clear understanding of the consequences is required.

Large scale testing and long-term testing are critical to approval of a field joint system for pipelines designed to have a long service life. While epoxies and HSS have had a proven track record on FBE coated pipelines, the use of stand-alone epoxies on 3LPE is a new concept with limited short-term testing. A tremendous risk is introduced in this scenario. Will the joints meet typical design lifetimes of 30-40 years?

**CONSEQUENCES OF INCOMPATIBLE COATING CHOICES**

The field joint coating must offer compatible performance to that of the selected mainline coating. A thorough engineering evaluation will include construction and in-service factors such as lowering-in forces, backfilling, dynamic and static loadings, coating application limitations, holiday testing and cathodic protection designs.

Heat shrink sleeves have been widely used in freezing ambient temperatures. Although liquid products can work well on warm climate FBE lines, they generally do not cure below 10°C. In North America, techniques have been developed to allow for the application and cure of liquid epoxies on FBE coated lines in sub-freezing temperatures. Essentially this requires the bare steel joint to be pre-heated above 65°C prior to applying the epoxy.

Cold weather application poses unique challenges for epoxies on 3LPE. When the application described above for the FBE is used on 3LPE, the epoxy may cure on the steel portion, however sufficient pre-heat may not transmit through the PE to affect the cure. A secondary process would be needed to cure the epoxy on the PE. Physical property changes
within the epoxy alter the corrosion protection benefits as demonstrated in a laboratory setting.

Another practical consideration of incompatibility involves the holiday test. If a different mainline and field joint coating were used, the holiday detector sweep done along the line would have to be adjusted at each joint. As an example, typical 3LPE holiday detection is conducted at over 10,000 Volts. Epoxy coatings require holiday testing at less than 5,000 Volts. The implication is a re-calibration of the holiday test apparatus at each field joint, a logistics headache which amounts to over 15,000 manual adjustments per 100 kilometers of pipeline. Not only is this impractical, but there is danger of inadvertently subjecting the epoxy coating to high voltage required for the 3LPE, and thus causing damage, particularly at the steel/PE transition.

On lowering-into the ditch, the bend forces must be maintained within the operating limits of the mainline and field joint coatings. As highlighted in earlier flexibility discussions, epoxies and HSS have vastly different flexibilities and elongations. Being less tough, epoxies are more susceptible to damage than HSS.

Another factor to consider during lowering-in is the transition zone stresses. The large differences in thickness between 3LPE and thin epoxy film create sharp transitions where the dynamic forces are intensified. Stresses due to the stinger roller during lowering in, or stresses due to pipe movement during service interacting at these sharp transition zones may damage the coating, particularly the thin brittle epoxy films. Several labs including Heriot-Watt University have capability in performing stinger roller testing which simulates these forces. Given its brittle nature, an epoxy coating may propagate a crack through its cross-section directly to the steel (Figure 8).

Figure 8. Compatibility Considerations of Coatings onto 3LPE
Some corrosion engineers have concerns about the behavior of the CP currents concentrated at the joint and the effects on cathodic disbondment. Mortimore has articulated this concern as follows:

“at normal operating potentials for impressed current systems it is very difficult to push sufficient current down pinholes in 3LPE, only larger areas of exposed steel can be protected. Pinholes in thin films of urethane and epoxy will be protected. However, the CP current will always take the path of least resistance and this can lead to over application of current at damaged areas of these films which in wet ground will lead to the development of the osmotic pump effect, undercut and disbondment.”

**INCOMPATIBILITY OF EPOXY AND POLYETHYLENE**

Epoxy does not have a natural affinity to bond with PE since the epoxy is highly polar, while the PE is non-polar. This fact has substantial pipe coating cost implications. There would be a considerable cost savings resulting from the elimination of the expensive adhesive layer if epoxies did bond to PE. However today, the proven technology does not exist.

The poor adhesion of the epoxy to the PE is now a widely acknowledged problem. Some manufacturers have proposed exposing the epoxy layer (“FBE toe”) of the 3LPE at the cutback and overlapping and bonding the field epoxy onto the exposed epoxy. This option tries to duplicate the epoxy on FBE coated mainline success of North America. However, it does not mitigate the problems of epoxy film on 3LPE described above. Exposing the epoxy in the 3LPE coating plant is significant logistical problem that results in a coating cost surcharge.

While the coated pipe is in storage and during transit, deterioration of the thin FBE toe is a point of concern. Chalking has been observed with most FBE pipe coatings subjected to UV light during outdoor storage. The resulting decrease in thickness may be a substantial portion of the FBE toe thickness and can amount to 50 microns loss per year. Given the thin-film nature of the FBE toe, water ingress and undercutting of the 3LPE system are also possible.

During construction, it is difficult to protect the FBE toe while grit blasting. The FBE toe layer (50 –150 microns) tends to be considerably thinner than the stand-alone FBE (greater than 350 microns) coating thickness. Being so thin, it can easily be removed by the blasting. The biggest danger in following this process is that the edges of PE, the adhesive and potentially the 3LPE epoxy layer could be exposed to the elements in the ground or water, when the joint epoxy comes away from the 3LPE. Corrosion can occur as water has a path of ingress under the 3LPE which would compromise the effective protection of the pipecoating.

There has been extensive research on investigating technologies which may eliminate the adhesive tie-layer in the 3LPE coatings. This has involved some form of surface modification to achieve a long-term, stable bond between the PE and the epoxy. Processes involving heat, light, chemicals and other surface energy alterations have been explored. All of these methods have proved to be inadequate for use in coating plants and in more-variable field conditions. Processing options have included highly toxic chemicals or hazardous practices
that are not suitable beyond a controlled lab environment. To-date, no safe, field-adaptable technology has been demonstrated.

**COMPATIBLE FIELD JOINT COATINGS**

On an FBE coated line, FBE or a liquid coating on the joint provides compatible performance. A suitable 3-layer heat shrink sleeve is also fully compatible since the primary epoxy layer provides the similar corrosion protection, and the sleeve can provide superior mechanical protection to that of the FBE parent coating.

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**Mainline Coating versus Shrink Sleeve Cross Sections**

- **Epoxy Primer**
- **Intermediate Adhesive**
- **Adhesive**
- **Polyolefin Coating**
- **Crosslinked Backing**

Role of Intermediate Adhesive:
To maximize the adhesion between the non-polar polyolefin and polar epoxy.

Role of Adhesive in a Sleeve:
To bond the sleeve to the primed steel and mainline coating while bridging transitions and provide corrosion protection.

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**Figure 9. Cross-sectional Compatibility of 3LPE and Heat-shrink Sleeve**

Heat shrink sleeve construction mirrors the 3LPE system with an epoxy primary layer, adhesive and polyethylene (Figure 9). As a result of their compatibility, ease of application, reliability and proven track record, HSS are the most common type of pipeline joint protection used today.

**CONCLUSIONS:**

1. 3LPE and FBE are dominant coatings and are selected based on pipeline requirements, construction conditions and regional preferences.
2. Long-term compatibility of field joint and mainline coatings is the paramount factor in achieving an effective pipeline coating system.
3. For FBE-coated lines, proven joint protection solutions include liquid epoxies, heat shrink sleeves and field-applied FBE.
4. Heat shrink sleeves are widely used on 3LPE coated pipelines because of their proven compatibility and extensive track-record.
5. Because of dissimilar technologies, compatibility of liquid coatings as a joint solution on 3LPE coatings is in question.
Compatibility of coating systems should be confirmed by conducting long-term adhesion testing to the mainline as well as simulating performance during backfill and burial conditions. Short term tests to qualify coating systems are of limited use.

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