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Liquid epoxy coatings for today's pipeline coating challenges

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ABSTRACT

Pipeline coatings have undergone dramatic technological changes over the past two decades. Coatings now must perform at higher in-service operating temperatures, must not be damaged in handling during construction or in operation by soil stress or soil movement, and must provide exceptional corrosion protection. Coatings also must be user friendly and must be able to be applied in a mill or in the field.

Liquid epoxies have been developed to provide protection for pipelines operating at temperatures up to 150°C. Additionally, advances to epoxy technology allow epoxy to be applied on wet surfaces and to bond to polyethylene coating systems.

This paper examines the role of liquid epoxy coatings for pipeline protection, and how these coatings meet the performance challenges of today's pipelines as supported by laboratory data and case histories.

1. INTRODUCTION

Pipe manufacturing has evolved over the last 30 years such that steel chemistry has allowed the development of high strength steels for use as line pipe. Line pipe used for transmission systems has increased in strength from X52 to X80 with ongoing research into the use of X100 and X120. This increase in strength allows the use of thinner wall pipe which reduces cost. However, since corrosion rates are more dependent on environmental factors and pipeline operating conditions than on pipe steel chemistry, corrosion protection, for the thinner wall pipe, increases in importance to secure ones investment.

Coatings are the primary means of corrosion protection for a buried pipeline whether for new construction or for pipeline rehabilitation. Although cathodic protection is applied, it is considered the second line of defense against corrosion. Therefore, today's coatings must provide better protection than their predecessors, continue to function under severe operating conditions, and be applied under less than ideal conditions.

The epoxies discussed here are used primary for girth welds, fittings, valves, short sections of piping for compressor station and pumping station yards, and for coating rehabilitation. This paper centers on the development and use of epoxies for high temperature service, for use on operating pipelines, and for use with three-layer polyethylene coating.

2. PIPELINE OPERATING CONDITIONS

2.1 Preamble

In North and South America, coatings offered for pipeline service must meet performance requirements based on Canadian Standards Association (CSA) Z245.20-02 External Fusion Bond Coating for Steel Pipe, as well as ASTM and NACE testing standards. The ASTM, NACE, and CSA performance tests are used as a guide for qualification of FBE and liquid coatings.

Epoxies offered for high temperature pipeline service and surface tolerant epoxies used on pipelines must also meet the performance requirements for a line pipe coating. The most essential tests that are used to evaluate a coating are flexibility, impact resistance, wet adhesion, and resistance to cathodic disbonding.

These tests are discussed in the following Sections under High Temperature Service and Wet Surfaces.

2.2 High Temperature Service

A novalac-epoxy coating formulated for use on pipelines operating at temperatures up to 150ºC was developed and evaluated for a large North American transmission company. Performance testing and a field application are discussed hereunder. For coating performance evaluation for the high temperature epoxy, test panels and strips were blast cleaned to SA2½ and coated to an average thickness of 800 microns.

2.2.1 Flexibility

Coating flexibility is of utmost importance for line pipe when bending to the allowed maximum of 1.5º/PDL (pipe diameter length). It is of less importance for coating used for girth welds, valves, fittings, and slip bore or directional drilling. Typically line pipe would not experience more than 0.25°/PDL during handling and when used for directional drilling.

The flexibility test was conducted to CSA Z245.20-02 Section 12.11. The test was modified using a fixed radius mandrel to determine failure point. Coated samples were bent over a mandrel for a 10 second time period at three different temperatures.

Figure 1 shows the bend test results at 0ºC. The coating showed no cracks as a result of being bent to an average value of 1.03º/PDL. Cracks occurred (shown by arrows) as a result of bending to an average value of 1.52º/PDL (arrows). All samples were taken to their failure point and the degree of bending was calculated for each one. The results for each series of tests are given in Table 1. At room temperature, the coating would meet the requirements for line pipe flexibility of 1.5°/PDL.

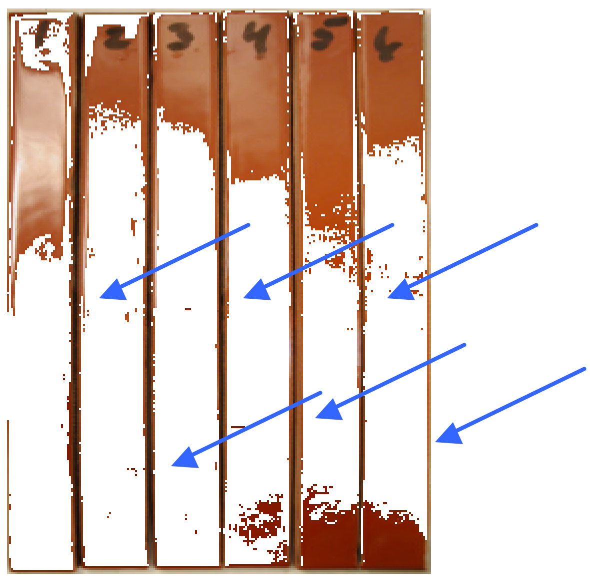

Figure 1. Flexibility test, 0ºC

2.2.2 Wet Adhesion Test

Water can be a most detrimental environment to a coating system. Water molecules that penetrate through the coating to the pipe surface can cause blistering, loss of adhesion, and result in coating failure. The Hot Water Soak Test or Wet Adhesion Test examines a coating's ability to adequately protect steel pipe in immersion conditions.

The Wet Adhesion Test was conducted according to CSA Z245.20-02 Section 12.14. Coated panels were immersed in water at 95C for up to 28 days. At the end of the test period, a rectangle approximately 30 mm x 15 mm was cut in the center of each sample. A knife was inserted under the coating to attempt to remove it from the substrate.

Figure 2 shows the adhesion results before and after immersion of the tested panels at 95ºC. The coating exhibited a definite resistance to the applied levering action and maintained excellent adhesion. No blistering, changing of colour or gloss was observed as a result of testing. Test results given in Table 1 show a rating of 1 for a 28-day test. The pass criterion is a rating of 1 to 3 for 24 hours.

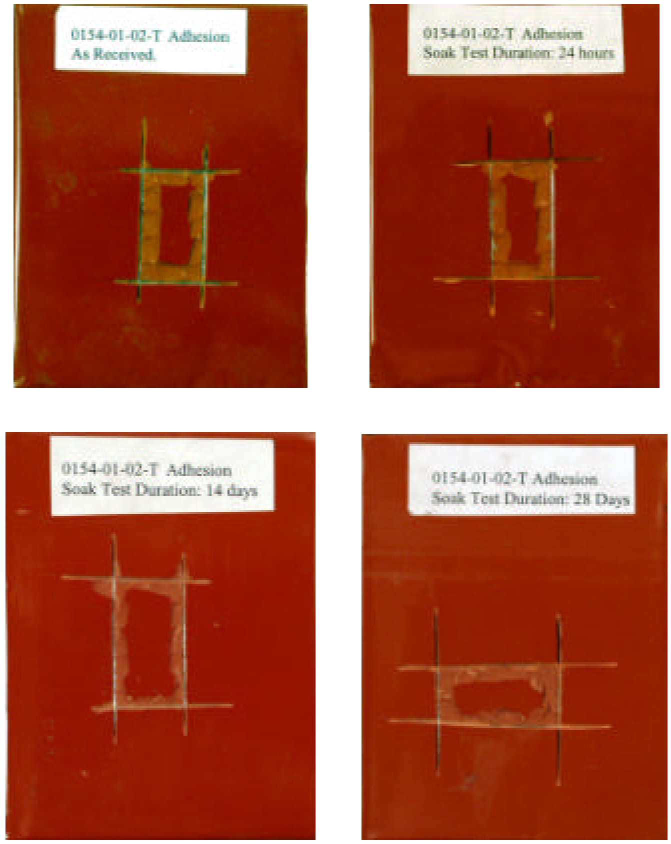

Figure 2. Wet adhesion test

2.2.3 Impact Testing

To protect steel from corrosion, a coating film must be continuous. Breaks in the coating will allow the environment to permeate to the steel substrate and initiate corrosive degradation. The Impact Test was performed by dropping a known weight from a calculated height onto the coating. Failure is the point at which holidays were observed. A Hot Spark or Holiday Test is then used to determine if the coating has been damaged or broken.

The objective of this test is to evaluate the resistance of the coating to damage from impact by a blunt ended object.

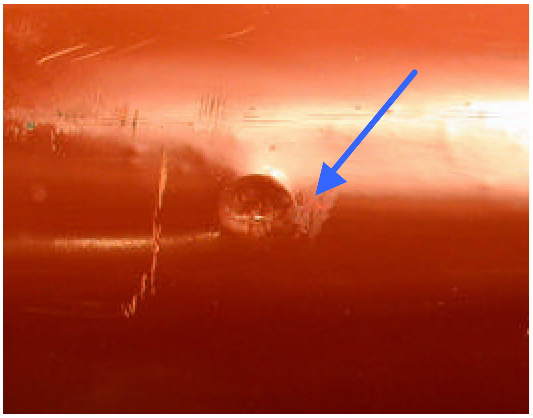

Figure 3. Impact test

Figure 3 shows the panel that was impact tested at 0°C. The arrow indicates the location of where the sample was impacted. The coating exceeded 1.5 joules (pass criterion) for all temperatures tested. Results are given in Table 1.

2.2.4 Cathodic Disbonding

Cathodic protection is a technique used to prevent the corrosion of a metal surface (usually steel). It is accomplished by providing enough cathodic current to mitigate anodic dissolution or corrosion of the metal surface. While preserving the steel, this technique can be detrimental to the performance of the coating applied. Anodic areas develop at breaks and defects in the coating film (holidays). An aggressive, caustic environment at the substrate/coating interface develops on the edge of the holiday (the cathode) as a result of the application of cathodic protection. Coating disbonding is initiated and propagates around the holiday due to the increase in pH in the immediate environment. The phenomenon is commonly referred to as “cathodic disbonding”.

All coatings are tested for their resistance to cathodic disbonding. The test should be carried out at the maximum temperature rating of the coating under test.

The Cathodic Disbonding Test was conducted according to CSA Z245.20-02, Section 12.8. Tests were conducted in a 3% NaCl solution with an impressed voltage of -1.5 VDC at 95ºC, 120ºC, and 150ºC for up to 28 days. The 120ºC and 150ºC tests were conducted in an autoclave.

Figure 4 shows one of the samples that were tested for 28 days at 150ºC. The disbondment radius is 9 mm. The CSA pass criterion for disbonding radius is 8.5 mm for 28 days at 21ºC. Results for all cathodic disbonding tests are given in Table 1.

Figure 4. Cathodic disbonding test result

Table 1. Performance testing summary for high temperature epoxy.

TEST & CONDITIONS	STANDARD METHOD	SUMMARY OF TEST RESULTS
Flexibility @ 21°C	CSA Z245.20-02 Section 12.11 ASTM D522 - 01	The coating passed 1.74°/PDL.
Flexibility @ 0°C	CSA Z245.20-02 Section 12.11 ASTM D522 - 01	The coating passed 1.03°/PDL.
Flexibility @ -30°C	CSA Z245.20-02 Section 12.11 ASTM D522 - 01	The coating passed .7°/PDL.
Impact Resistance @ 21ºC	CSA Z245.20-02 Section 12.12 ASTM G14 - 88	Passed 1.5 Joules.
Impact Resistance @ 0ºC	CSA Z245.20-02 Section 12.12 ASTM G14 - 88	Passed 1.5 Joules.
Impact Resistance @ -30ºC	CSA Z245.20-02 Section 12.12 ASTM G14 - 88	Passed 1.5 Joules.
Wet Adhesion as received.	CSA Z245.20-02 Section 12.14 NACE RP0394-94 (Section N)	Rating 1.
Wet Adhesion @ 95°C, 24 hr	CSA Z245.20-02 Section 12.14 NACE RP0394-94 (Section N)	Rating 1.
Wet Adhesion @ 95°C, 7 days.	CSA Z245.20-02 Section 12.14 NACE RP0394-94 (Section N)	Rating 1.
Wet Adhesion @ 95°C, 14 days.	CSA Z245.20-02 Section 12.14 NACE RP0394-94 (Section N)	Rating 1.
Wet Adhesion @ 95°C, 28 days.	CSA Z245.20-02 Section 12.14 NACE RP0394-94 (Section N)	Rating 1.
Cathodic Disbonding, 14 days @ 95°C	CSA Z245.20-02 Section 12.8 ASTM G95 – 87, Modified (Section N)	Average disbonding radius 2.70 mm.
Cathodic Disbonding, 28 days @ 95°C	CSA Z245.20-02 Section 12.8 ASTM G95 – 87, Modified (Section N)	Average disbonding radius 4.30 mm.
Cathodic Disbonding, 28 days @ 120°C	CSA Z245.20-02 Section 12.8 ASTM G95 – 87, Modified	Average disbonding radius 4.7 mm.
Cathodic Disbondment, 28 days @ 150°C	CSA Z245.20-02 Section 12.8 ASTM G95 – 87, Modified	Average disbonding radius 9.17 mm.

Note:

1. CSA and ASTM or NACE equivalent test method listed.
2. Tensile adhesion for this high temperature epoxy exceeds 3000psi. This is not a CSA performance test

2.2.5 Field Application

In addition to meeting performance requirements, an epoxy coating must be user friendly e.g. one must be able to apply it in the field under a wide variety conditions. High temperature epoxies have been formulated for both brush and spray application. They can be applied over a wide range of ambient temperatures but require heating of the pipe when ambient temperature is less than 10ºC.

Figure 5 shows a high temperature epoxy applied to a girth weld on a pipe with a surface temperature of 0ºC. The pipe surface was blast cleaned and heated to 90ºC prior to application of the epoxy coating. The pipeline was designed to operate at 110ºC.

Figure 5. Girth weld coating using high temperature epoxy

2.3 Wet Surfaces

Often coatings must be applied in-situ on operating pipelines. With product flowing in a pipeline to be coated, condensation can form on the exterior surface of the pipe. Most epoxies require a near white blast-cleaned surface, a minimum surface profile of 50 microns, and a dry surface with no contaminants. An epoxy has been developed that can be applied over damp or wet steel surfaces.

As with other pipeline coatings, the surface tolerant epoxy must possess the necessary attributes that are required of a pipeline coating. Again it must meet impact requirements, resist cathodic disbonding, meet requirements for wet adhesion, and have some flexibility.

For coating performance evaluation of the surface tolerant epoxy, test panels and strips were blast cleaned to SA2½, sprayed with tap water, and coated to an average thickness of 800 microns. Testing for flexibility, impact resistance, wet adhesion, and resistance to cathodic disbonding is discussed hereunder. Table 2 gives the summary of the performance testing that was conducted for the surface tolerant epoxy.

2.3.1 Flexibility

Flexibility tests were conducted at 21°C, 0°C, and at -30°C. Test results are summarized in Table 2.

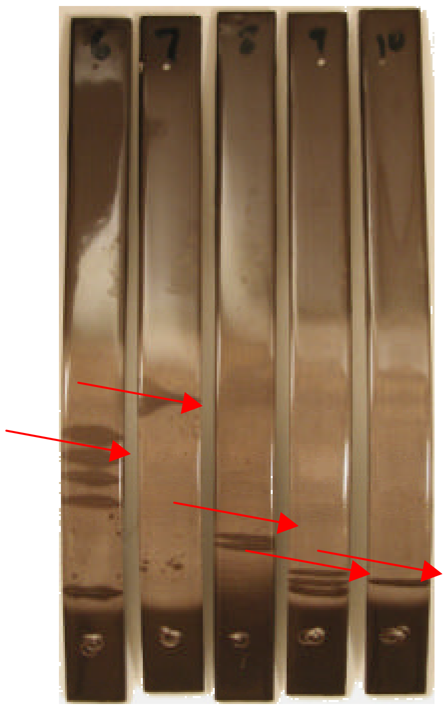

Figure 6. Flexibility 0°C

Figure 6 shows the flexibility test at 0°C. All samples were taken to failure (arrows) and degree of bending was calculated for each one.

2.3.2 Impact Test

As with the high temperature epoxy, the surface tolerant epoxy was tested for impact resistance. Impacts were conducted at 21°C, 0°C, and –30°C. The coating passed 1.5 joules at all temperatures tested.

Tested at -30ºC/-22ºF

Tested at 21°C | Tested at 0°C | Tested at -30°C

Figure 7. Impact tests

Figure 7 shows some of the tested samples at each temperature. The arrows indicate some of the locations of where the sample was impacted. No cracks or other noticeable defects were observed as a result of testing.

2.3.3 Wet adhesion

Figure 8. Adhesion test

Figure 8 shows the wet adhesion results on one panel before and after the immersion tests conducted at 75ºC for 28 days. The coating exhibited a definite resistance to the levering acting applied and maintained excellent adhesion. No blistering occurred as a result of the testing. The test results are given in Table 2.

2.3.4 Cathodic disbonding tests

Cathodic disbonding tests were conducted at 65°C and 80°C for 28 days. Figure 9 shows one of the panels tested at 80°C. The surface tolerant epoxy showed excellent resistance to cathodic disbonding at 65°C and 80°C. The results are given in Table 2.

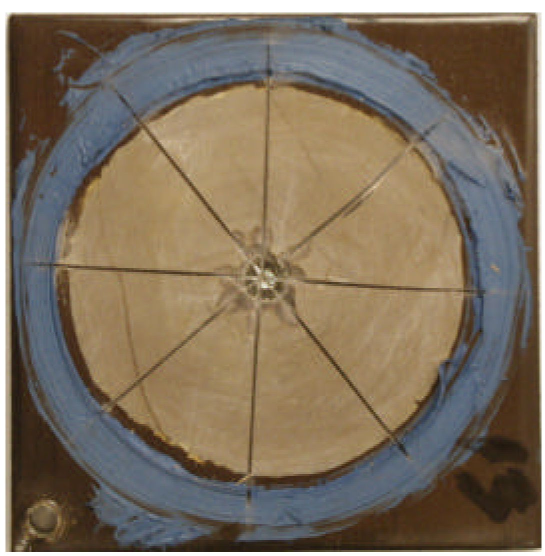

Figure 9. Cathodic disbondment at 80°C

Table 2. Performance testing summary for surface tolerant epoxy.

TEST & CONDITIONS	STANDARD METHOD	SUMMARY OF TEST RESULTS
Flexibility @ 21°C	CSA Z245.20-02 Section 12.11 ASTM D522 - 01	The coating passed 2.93°/PDL.
Flexibility @ 0°C	CSA Z245.20-02 Section 12.11 ASTM D522 - 01	The coating passed 1.96°/PDL.
Flexibility @ -30°C	CSA Z245.20-02 Section 12.11 ASTM D522 - 01	The coating passed .54 PDL.
Impact Resistance @ 25ºC	CSA Z245.20-02 Section 12.12 ASTM G14 - 88	Passed 1.5 Joules
Impact Resistance @ 0ºC	CSA Z245.20-02 Section 12.12 ASTM G14 - 88	Passed 1.5 Joules
Impact Resistance @-30ºC	CSA Z245.20-02 Section 12.12 ASTM G14 - 88	Passed 1.5 Joules
Wet Adhesion @ 95°C, 28 days.	CSA Z245.20-02 Section 12.14 NACE RP0394-94 (Section N)	Rating 1.
Cathodic Disbonding, 28 days @ 65°C	CSA Z245.20-02 Section 12.8 ASTM G95 – 87, Modified (Section N)	Average disbonding radius 4.4 mm.
Cathodic Disbonding, 28 days @ 80°C	CSA Z245.20-02 Section 12.8 ASTM G95 – 87, Modified	Average disbonding radius 3.4 mm.

Note:

1. CSA and ASTM or NACE equivalent test method listed.
2. Tensile adhesion to steel is greater than 2800 psi. This is not a CSA performance test.

3. BONDING OF EPOXY TO POLYETHYLENE

3.1 Preamble

Three-layer polyethylene coating systems for pipelines have gained wide use in Europe, Asia, South America and Africa. Typically, tapes or shrink sleeves have been used for field girth weld coatings for three-layer polyethylene. Recently, epoxies have been tested and approved for use as a girth weld coating. Although, epoxies have superior corrosion protection performance when compared to tapes and shrink sleeves, bonding to polyethylene has been a major concern.

3.2 Polyethylene Surface Treatment

Polyethylene has a chemically inert and non-polar surface. Therefore a surface treatment is required to enhance the bond to polyethylene. The surface of polyethylene can be transformed from non-polar to polar by chemical treatment, electrical method, and by flame treating thereby increasing bond strengths. For polyethylene coatings used on pipelines, flame treatment is the most practical and economical method.

3.2.1 Flame treatment

With flame treatment, the combustion action of a hydrocarbon gas releases free radicals during formation of the flame. These free radicals penetrate the polyethylene and modify its surface wettability (increase in surface energy). The surface to be treated must be free of contaminants and an oxidizing flame used to achieve optimum surface energy.

Figure 10 shows a type of burner used for flame treatment.

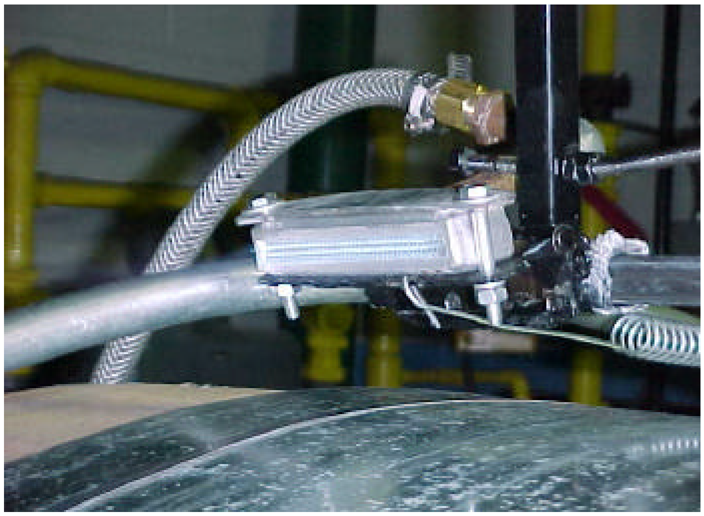

Figure 10. Flame treatment burner

Optimum flame treatment requires a gas flow meter capable of delivering the volumes of gas required for the burner rating, an air flow meter capable of delivering 15% to 25% greater volume of air than is required for normal combustion and a burner designed to give adequate flame pattern for treatment. Prior to flame treatment, the surface energy of the polyethylene should be measure and compared to its surface energy after treatment. Polyethylene has a surface energy of 30 to 40 dynes/cm prior to treatment as measured in accordance with ASTM D 2578-94, Standard Test Method for Wetting Tension of Polyethylene and Polypropylene Films. Optimum surface energy after treatment is 60 to 70 dynes/cm.

Table 3 compares the bond strengths of epoxy to polyethylene for polyethylene that is untreated, sweep blast cleaned and flame treated. A series of tests were conducted for each treatment and the bond values averaged. Surface energy of the polyethylene after treatment was measure as 60 dynes/cm. As shown, flame treatment greatly improves the PE to epoxy bond.

Table 3. Polyethylene to epoxy bond strengths

PE Treatment	Bond strength
Untreated	no bond
Sweep blasted	500 psi

Flame treatment	1100 psi

3.3 Liquid Primer

The bond of liquid epoxy to flame treated polyethylene can also be improved using primers that wet the surface of the polyethylene. Tests were conducted on panels using an epoxy primer that was applied to three-layer polyethylene after flame treatment and prior to the epoxy topcoat.

To simulate the effect of expansion and contraction on the epoxy to polyethylene bond, each test panel was subjected to a 10-day cyclic test prior to undergoing pull adhesion tests. Each cycle consisted of 12 hours immersion in 3ºC water then 12 hours immersion in 65ºC water. The cycle ended on the 65ºC cycle and the pull-off adhesion test was performed within 60 minutes after the hot cycle. Pull-off stubs were affixed to each test plate prior to the start of the test.

The epoxy to polyethylene bond strength increased to over 2500 psi.

4. CONCLUSIONS

Epoxy coatings have been formulated for high temperature service and for surface tolerant applications as shown in laboratory testing and field applications. Additionally, these coatings should excellent results when tested to line pipe requirements.

Epoxy coating coatings are now being used with three-layer polyethylene systems. The concern with the epoxy to polyethylene bond has been addressed by flame treating the polyethylene and applying an epoxy primer.

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