DEVELOPMENT OF A LOW APPLICATION TEMPERATURE FBE COATING

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ABSTRACT

Fusion bonded epoxy (FBE) coatings have been used on pipelines as protection against corrosion for over 40 years. They have been used as a stand-alone product in single layer systems and as a primer in dual and three layer systems. To achieve optimal performance, current FBE products require application temperatures in excess of 230°C for single layer systems and 200°C for three layer systems. The introduction of high strength steels such as X80, X100 and X120 for use in pipeline construction has presented a challenge to the industry in terms of the availability of suitable coating systems. High strength steels (particularly grades X100 and greater) cannot withstand pre-heat temperatures in excess of 200°C. Exposure to the high heat required when coating with a typical FBE product results in the degradation of some of the key properties of these high strength steels.

This paper will discuss the development and performance of a new generation FBE coating that can be applied at temperatures as low as 180°C for single layer systems and as low as 150°C for multi-layer systems. Performance of this new product will be compared to one of the best performing commercially available FBE products applied at 240°C.

Key Words: fusion-bonded epoxy, FBE, pипecoating, low temperature application, low temperature cure, high strength steel, cathodic disbondment

INTRODUCTION

Fusion bonded epoxy (FBE) is a one part powdered epoxy coating that is sprayed onto the hot pipe where it melts, flows and cures to give a corrosion resistant coating. The first pipe coated with FBE was placed into service in 1960.1 Since that time, FBE coatings have become the most commonly used coating for new pipeline construction in North America. FBE coatings are also used as a primer in the multilayer coatings which predominate as the coating of choice for new pipeline construction in Europe and many other parts of the world. The application temperature is critical for achieving sufficient wetting of the substrate as well as assuring that the powder is sufficiently cured to give a coating of optimal performance. Conventional FBE coating systems require the pipe to be heated to at least 220°C, preferably 240°C, to give optimal performance.
As the demand for natural gas increases, pipelines using thin walled, high strength steel grades (X80, X100, X120) provide the potential for significant cost savings in the construction of large diameter pipelines. Evaluation of the influence of a coating application on the stress-strain curve suggests that this type of heat treatment leads to a significant increase in the tensile yield strength and a slight decrease in the elongation at yield. As a result, it has been recommended that high strength steel grades (particularly grades X100 and greater) avoid exposure to temperatures above 200°C. This restriction prohibits the use of conventional FBE coating systems and has prompted the development of an FBE coating system that is capable of being applied at temperatures as low as 180°C. This paper describes the performance characteristics of a new generation FBE that can apply at temperatures as low as 180°C in comparison to the performance of a conventional FBE applied at 240°C.

EXPERIMENTAL PROCEDURE

Materials

Materials tested included a standard commercially available FBE product designed to be applied at pipe temperatures in the range of 240°C and an experimental FBE product designed to be applied at pipe temperatures in the range of 180°C.

Panels for Cathodic Disbondment Testing (CDT) and Hot Water Adhesion Testing (HWT) of lab applied coating were hot rolled steel with dimensions of 3.5 inch x 3.5 inch x 3/8 inch unless otherwise noted. Bars for flexibility testing of lab applied coating were hot rolled steel with dimensions of 1 inch x 8 inch x 3/8 inch unless otherwise noted.

Sodium chloride was reagent grade and used without further purification.

General Procedures

The laboratory-coated test specimens used for all of the testing reported in this paper were prepared as follows:

1. The steel specimens were solvent washed (in accordance with SSPC-SP1) with methylethylketone followed by an isopropanol rinse.
2. The dry steel surface was grit-blasted to a near-white finish in accordance with NACE No. 2/SSPC-SP10 1508501-5A2.5.
3. The steel specimens were pre-heated in an oven set at the desired application temperature (325°F to 480°F) for approximately one hour.
4. The steel specimens were dipped into a fluid bed for an appropriate length of time so as to give a coating thickness between 14 and 16 mils.
5. The coated specimens were placed in a post-cure oven (set at the same temperature as the pre-heat oven) for 2 minutes (unless otherwise noted).
6. The coated specimens were then air-cooled for 1 minute.
7. The coated specimens were then quenched in a water bath for 2 minutes.

CDT testing was carried out according to the following procedure per CSA Z245.20-06 Section 12.8 (The dimensions of the test specimens used was slightly different than the size called out in the CSA procedure - 3.5 inch x 3.5 inch x 3/8 inch unless otherwise noted):

1. A 0.125 inch (3.2 mm) diameter holiday was drilled into the center of the panel.
2. The test cell, constructed using a clear polycarbonate tube 3” OD x 1/4” wall x 6” long, was attached to the FBE surface using 3M Brand Super Silicone #08663 or equivalent.
3. 3% sodium chloride in deionized water was used as the electrolyte in each cell.
4. The platinum wire used as the anode was inserted through a hole in the top of the cell and a potential difference of -1.5 VDC was applied.
5. The samples were placed in an air circulating oven at the designated temperature.
6. The actual potential difference and the level of the electrolyte were checked periodically and adjusted as necessary.
7. At the end of the test period, adhesion near the holiday was evaluated within one hour by making eight radial cuts and using a utility knife with leveraging action to chip off the coating. The disbondment was measured from the edge of the holiday along the radial cuts and the results were averaged.
8. All values reported are the average of the results obtained on 3 test panels unless otherwise noted.

Flexibility testing was carried out according to the following procedure per CSA Z245.20-06 Section 12.11 (The dimensions of the test specimens used was slightly different than the size called out in the CSA procedure - 1 inch x 8 inch x 3/8 inch unless otherwise noted. In addition, different mandrel sizes were used to give an estimate of the failure point – the highest °/pipe diameter that passed was confirmed by testing 3 specimens at that °/PD):
   1. The test bar was placed in a freezer set at -30°C for a minimum of 1 hour.
   2. The test bar was bent using the mandrel specified to give the desired °/PD. A failure was any visual failure. Any cracks within the top ½” of the coating were disregarded.

HWT testing was carried out according to the following procedure per CSA Z245.20-06 Section 12.14 (The dimensions of the test specimens used was slightly different than the size called out in the CSA procedure - 3.5 inch x 3.5 inch x 3/8 inch unless otherwise noted):
   1. Fresh tap water was preheated to the temperature specified prior to immersion of the test specimens.
   2. The test specimens were placed in the preheated water and submerge fully.
   3. The test specimens were kept submerged for the length of time specified (typically 28 days).
   4. Upon removal of the specimen and while the test specimen was still warm, a utility knife was used to scribe an approximately 30 × 15 mm rectangle through the coating to the substrate.
   5. The test specimen was air-cooled to 20 ± 3 °C.
   6. Within 1 hour after removal from heat, the tip of the utility knife was inserted under the coating at a corner of the scribed rectangle.
   7. A levering action was used to remove the coating. This process was continued until either all of the coating in the rectangle was removed or the coating demonstrated a definite resistance to the levering action.
   8. The adhesion of the coating within the rectangle was assigned a rating as follows:
      Rating 1 — coating cannot be removed cleanly.
      Rating 2 — less than 50% of the coating can be removed.
      Rating 3 — more than 50% of the coating can be removed, but the coating demonstrates a definite resistance to the levering action.
      Rating 4 — the coating can be easily removed in strips or large chips.
      Rating 5 — the coating can be completely removed as a single piece.
   9. All values reported are the average of the results obtained on 3 test panels unless otherwise noted.

RESULTS AND DISCUSSION

It is well accepted in the industry that application temperatures above 220°C are required for conventional FBE coatings in order to give optimal performance. To validate this assumption and to understand how the performance characteristics are related to the level of cure and/or the wetting ability at the given application temperature, the performance of a conventional FBE coating was evaluated at various application temperatures in the range of 350°F to 480°F (177°C to 249°C). The first step in this evaluation was to determine the amount of time required at each temperature for complete cure. Samples were then prepared as described in the General Procedures section of this paper with the exception of post cure time. The post cure time used at each temperature was based on the amount of time required for complete cure as given in Table 1. The performance of the
conventional FBE coating applied using each set of coating conditions was evaluated using CDT, HWT and flexibility. The results of this evaluation are shown in Figures 1-3.

TABLE 1
CURE TIME OF CONVENTIONAL FBE COATING AT VARIOUS APPLICATION TEMPERATURES

<table>
<thead>
<tr>
<th>Application Temperature</th>
<th>Cure time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>350°F (177°C)</td>
<td>15</td>
</tr>
<tr>
<td>390°F (199°C)</td>
<td>10</td>
</tr>
<tr>
<td>410°F (210°C)</td>
<td>7</td>
</tr>
<tr>
<td>430°F (221°C)</td>
<td>5</td>
</tr>
<tr>
<td>450°F (323°C)</td>
<td>2</td>
</tr>
<tr>
<td>480°F (249°C)</td>
<td>2</td>
</tr>
</tbody>
</table>

The results suggest that using a conventional FBE coating at lower application temperatures would require a significant reduction in productivity due to the increase in the time required for a sufficient level cure. The conventional FBE coating also showed poorer performance when applied at lower temperatures even when fully cured. This decrease in performance is presumably due to the inability of these materials to provide sufficient wetting of the substrate at these lower temperatures.

FIGURE 1 – Cathodic Disbondment verses Application Temperature
In order to develop an FBE that could be applied at a target application temperature of 350°F (177°C), a wide variety of technologies and numerous lab formulations were evaluated using a series of designed experiments. A formulation was selected for scale-up based on its flexibility and CD performance at an application temperature of 350°F (177°C). The formulation selected, LTA FBE 1, was designed to provide optimal wetting of the substrate (resulting in good adhesion to the metal surface) as well as sufficient level of cure at the target application temperature to provide optimal
performance. Basic properties of LTA FBE 1 are given in Table 2. The performance of LTA FBE 1 was evaluated over a range of application temperatures in comparison with a conventional FBE applied at 465°F (240°C). The results from this evaluation are shown in Table 3.

### TABLE 2

**EPoxy Powder Properties – LTA FBE 1**

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Test Method</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gel Time at 205°C</td>
<td>CSA Z245.20-06 Clause 12.2</td>
<td>4.9 seconds</td>
</tr>
<tr>
<td>Gel Time at 177°C</td>
<td>CSA Z245.20-06 Clause 12.2</td>
<td>12.3 seconds</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>CSA Z245.20-06 Clause 12.4</td>
<td>0.12%</td>
</tr>
<tr>
<td>Density</td>
<td>CSA Z245.20-06 Clause 12.6</td>
<td>1.43 g/mL</td>
</tr>
<tr>
<td>Thermal Characteristics/DSC</td>
<td>CSA Z245.20-06 Clause 12.7</td>
<td>Onset Tg1: 50.60°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Onset Tg2: 100.74°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delta H: 90.57 J/g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Peak Exotherm: 144.19°C</td>
</tr>
</tbody>
</table>

### TABLE 3

**Performance of Lab Applied LTA FBE Coating**

<table>
<thead>
<tr>
<th>Test Description</th>
<th>LTA FBE 1 applied @ 177°C (350°F)</th>
<th>LTA FBE 1 applied @ 190°C (375°F)</th>
<th>Conventional FBE applied @ 240°C (465°F)</th>
<th>CSA Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility (-30°C Bend to Failure)</td>
<td>3.2 °/PD</td>
<td>3.2 °/PD</td>
<td>4.0°/PD</td>
<td>Pass 3.0 °/PD</td>
</tr>
<tr>
<td>CDT @ 65°C for 24 hours (3.0 V, 3.2 mm holiday, 3% NaCl)</td>
<td>2.03 mm radius</td>
<td>2.04 mm radius</td>
<td>1.53 mm radius</td>
<td>6.5 mm Max.</td>
</tr>
<tr>
<td>CDT @ 65°C for 28 days (1.5 V, 3.2 mm holiday, 3% NaCl)</td>
<td>5.20 mm radius</td>
<td>4.70 mm radius</td>
<td>3.98 mm radius</td>
<td>20.0 mm Max.</td>
</tr>
<tr>
<td>CDT @ room temp for 28 days (1.5 V, 3.2 mm holiday, 3% NaCl)</td>
<td>5.39 mm radius</td>
<td>4.66 mm radius</td>
<td>2.54 mm radius</td>
<td>8.5 mm Max.</td>
</tr>
<tr>
<td>Hot Water Adhesion @ 75°C for 24 hours</td>
<td>2 rating</td>
<td>2 rating</td>
<td>2 rating</td>
<td>Rating 1-3</td>
</tr>
<tr>
<td>Hot Water Adhesion @ 75°C for 28 days</td>
<td>2 rating</td>
<td>2 rating</td>
<td>2 rating</td>
<td>Rating 1-3</td>
</tr>
</tbody>
</table>

These results suggest that the adhesion performance of LTA FBE 1 applied over a range of application temperatures is fairly similar to the performance of the conventional FBE applied at 240°C within experimental error. The CD performance of LTA FBE 1 is well below the CSA requirement for these test conditions (maximum disbondment of 20 mm radius). There is a slight reduction in the flexibility performance of the LTA FBE 1 verses the conventional FBE applied at 240°C; however, the LTA FBE 1 does meet the CSA standard flexibility requirement of 3°/PD.

Additional optimization of the formula in the lab resulted in improvements in both CD performance and increased flexibility. These results are shown in Table 4. LTA FBE 2 shows a slight improvement in
CD performance. LTA FBE 3 shows a significant improvement in flexibility but a reduction in the CD performance. LTA FBE 4 shows improvement in both CD performance and flexibility.

### TABLE 4

**PERFORMANCE OF LAB APPLIED OPTIMIZED LTA FBE COATINGS**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>LTA FBE 1 applied at 177°C (350°F)</th>
<th>LTA FBE 2 applied at 177°C (350°F)</th>
<th>LTA FBE 3 applied at 177°C (350°F)</th>
<th>LTA FBE 4 applied at 177°C (350°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexibility (-30°C Bend to Failure)</td>
<td>3.2</td>
<td>3.2</td>
<td>4.1</td>
<td>3.7</td>
</tr>
<tr>
<td>CDT @ 65°C for 28 days (1.5 V, 3.2 mm holiday, 3% NaCl)</td>
<td>5.2</td>
<td>7.8</td>
<td>13.0</td>
<td>5.9</td>
</tr>
<tr>
<td>CDT @ 80°C for 28 days (1.5 V, 3.2 mm holiday, 3% NaCl)</td>
<td>16.7</td>
<td>7.4</td>
<td>14.6</td>
<td>11.6</td>
</tr>
<tr>
<td>CDT @ 95°C for 28 days (1.5 V, 3.2 mm holiday, 3% NaCl)</td>
<td>14.1</td>
<td>NA</td>
<td>NA</td>
<td>10.4</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

A new generation of Low Temperature Application Fusion Bonded Epoxy (LTA FBE) coatings has been developed. When applied in the range of 180 to 200°C, this coating provides similar performance characteristics to conventional FBE coatings applied at 240°C. This material provides a coating solution for pipelines using high strength steels (X80, X100, X120) that cannot withstand pre-heat temperatures in excess of 200°C. Additional benefits include enhanced line speeds, energy savings during application and the potential for cost reduction and process improvement when used as a primer in the three layer market.

### REFERENCES


