Fast, Worry Free Pipeline Installation with Dual-Layer FBE Coatings

A Kehr & M Mallozzi

3M Austin Center, USA

Summary: Utilizing two layers of fusion bonded epoxy (FBE) provides great versatility in coatings used for pipeline protection. The first layer has the properties of a standalone FBE coating, including excellent resistance to cathodic disbondment. The top layer provides mechanical damage resistance from impact or gouging during handling, transportation, and construction. The combination provides the contractor faster, worry-free installation and the pipeline owner with improved underground coating performance. This paper reviews single-layer FBE, three-layer polyolefin (3LPO) (polyethylene and polypropylene) coatings, and dual-layer FBE (DLFBE). It also demonstrates the performance characteristics of dual-layer FBE pipeline coating systems through test results and case histories for entire pipeline projects. The review includes application and installation specifics. It also introduces nano-technology for improved dual-layer performance.

Keywords: FBE, DLFBE, 3LPO, 3LPP, 3LPE, flexible, pipe coating, gouge, impact, bend, damage-resistant, non-shielding, shielding

1 INTRODUCTION

FBE and 3LPO are the most commonly used pipeline coatings in the world. Over the last five years, DLFBE coatings have seen more use, combining a coating that is non-shielding to cathodic protection and the low-cost economics of FBE with damage resistance approaching that of 3LPP and 3LPE. Dual-layer FBE coatings have the added advantage of compatible girthweld coating systems. One disadvantage of DLFBE has been reduced flexibility in extreme-bend cases such as offshore installation by reel barge or installation in the cold artic. New technology is now available to provide improved flexibility for those environments with an even more damage resistant DLFBE.

1.1 Brief history of FBE, DLFBE, and 3LPO coatings

1.1.1 Single layer performance, brief history

A New Mexico company coated the first FBE pipeline in 1960. It is now the number one pipeline-coating in North America and has been installed in the ocean, the arctic, in the mountains and in the plains. It is used on pipes, bends, girthwelds, and fittings, and it's used in the oil, gas, and water markets. There are a number of properties that make it the number one choice in North America:

- Excellent adhesion to steel; good chemical resistance
- Non-shielding to CP – fails friendly
- No reported cases of stress-corrosion cracking (SCC) of pipe coated with FBEi
- Resistant to biological, insect, termite, and root attack
- Installation friendly
  - Excellent penetration resistance, good abrasion and gouge resistance
  - Good impact resistance
    - Impact damage is limited to the point of contact
    - Damage is easily seen

  - Damage is easily repaired

- Good flexibility

1.1.2 Dual layer performance, brief history

The first dual-layer FBE (DLFBE), introduced in 1991, was for high-operating temperature pipelines. That was followed in 1998 by the first abrasion resistant outer (ARO) coating for directional drill pipeline installation. In 2002, the first major pipeline was coated with a dual layer coating system from end to end, including the girthwelds. DLFBE maintains the excellent performance and installation characteristics of single-layer FBE, but provides even better damage resistance, with a slight reduction in flexibility that can negatively influence use in reel barge or cold-weather installation.

1.1.3 Three layer performance, brief history

Three-layer polyolefin coatings were introduced about 1980 in Europe. They consist of:

FBE primary coating

Polyolefin-adhesive (or tie) layer

Polyolefin topcoat

In some case, more layers are added to provide thermal insulation, a weight coating, or a frictional coating. The three layers combine the low oxygen permeability of FBE with low-water permeability of polyolefins. The thick layer of relatively damage resistant polyolefin provides a coating friendly to installation under harsh or inexpert conditions. There is a trade off between extra cost for the three layer system and potential savings from such things as reduced use of graded or imported backfill. ii

2 WHY DUAL LAYER?

2.1 Concerns about 3-layer

Going back to 2001, iii there have been numerous presentations and papers about concerns with three-layer coatings in service today. While most of the reported problems have dealt with wholesale loss of adhesion between the FBE and the steel, other problems and concerns have been reported as well:

Potential for SCCiv

Cracking and splitting of the polyolefin coating; loss of bond between FBE and steel and adhesive and FBEv

Adhesion failure and corrosion at the girthweld areavi

Loss of bond between FBE and steel layervii

Shielding from CP and potential for corrosionviii

Disbonding at cutback during storageix

2.2 Concerns about single layer

As with 3-layer coatings, improper cleaning or a contaminated substrate can result in a loss of bond. It can also result in blistering. However, FBE does not shield cathodic protection current and, even with adhesion loss, the pipe can still be protected by CP.x The major concern, especially in countries with inadequate infrastructure and long haulage routes to pipeline installation sites, is transportation and handling damage.

3 COMPARISON DATA DUAL, 3-LAYER, SINGLE LAYER FBE

The purpose of this series of experiments was to compare mechanical properties of typical damage resistant coatings at varying thicknesses. These mechanical properties include impact, gouge/abrasion resistance, flexibility, and cathodic disbondment. The damage resistant coatings tested were a DLFBE, 3-layer polypropylene and 3-layer polyethylene.

3.1 Laboratory testing program

3.1.1 Impact resistance

This test method determines the mean energy required to rupture coatings applied to pipe under specified conditions of impact from a falling weight. The test method was based on a modified version of ASTM G14, substituting coated steel bars with dimensions of 2.5 cm X 20.31 cm X 0.95 cm for the pipe normally used for in this test method.

3.1.2 Gouge

The gouge test is intended to simulate directional-drill pipe installation or pipe handling during installation. The test included a moving stylus moving at 3m/minute at a normal loading of 37.5 kg over a coated specimen. The amount of gouge is measured with a depth gauge.

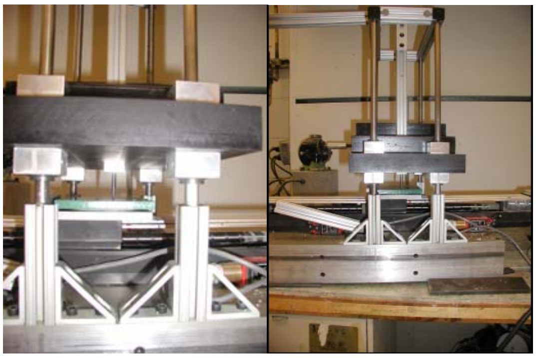

Figure 1:. To evaluate the gouge resistance of a coating system, a coated specimen is placed on moving platform that moves at a rate of 3m/min. A normal force is applied to the coating through a stylus under a weight of 37.5 kg. The amount of gouge is measured with a depth gauge. Photos courtesy of M. Mallozzi

3.1.3 Flexibility/Bend

As a qualification measurement tool, the flexibility test determines the coating's capability to elongate. This translates into the ability to withstand field bending without cracking. The mandrel bend test was used to evaluate the coating's flexibility at -30ºC.

3.1.4 Cathodic disbondment resistance

The cathodic disbondment test is a measure of a coating's adhesion to steel. For this experiment, the effect of the primary corrosion coating thickness vs. cathodic disbondment performance was evaluated. The cathodic disbondment test was run for 28 days at 1.5V at a temperature of 65ºC.

3.2 Test results

3.2.1 Impact

The impact energies for each damage resistant coating are shown below in Figure 2:

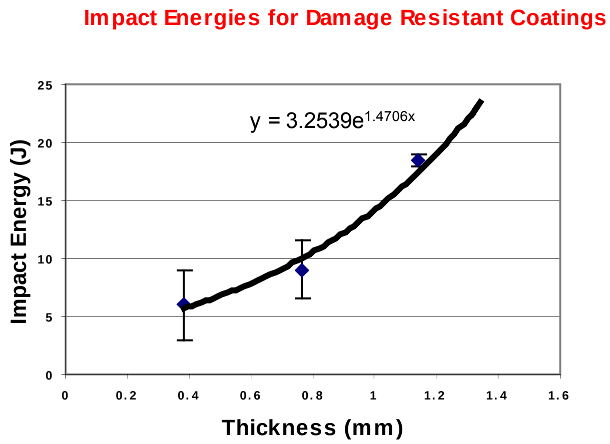

Figure 2: The impact values include the mean failure enery calculated using the statistical equation detailed in ASTM G14. The test results show that increasing DLFBE thicke\ness improves impact resistance.

The mean impact energy of a 0.381mm thick DLFBE is 6 J and increases exponentially to 20 J for a 1.143 mm thick coating. Because of the limited availability of a wide range of 3 layer samples, only a few samples were tested for impact resistance. A 3.5 mm 3LPE sample had an impact energy of at least 18 J. It is assumed that any 3LPE coating applied thicker than 3.5 mm will pass at least 18 J of impact at 23°C. Any 3LPE coating applied less than 3.5 mm will have to be tested for impact resistance. Similarly, a 2 mm 3LPP sample has at least 18 J of impact resistance at 23°C.

3.2.2 Gouge

After each coating was tested for gouge resistance, the gouge depth was measured. The results are shown below Figure 3:

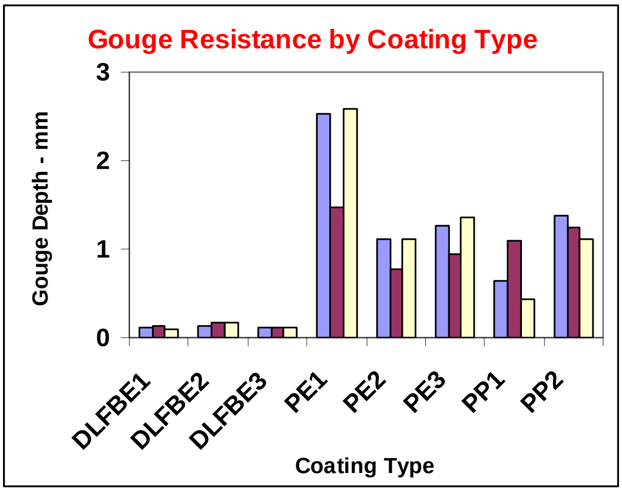

Figure 3: To evaluate the effect of coating type on damage resistance, a gouge test was performed with 37.5 kg of normal force. Several offerings of DLFBE showed small levels of gouge – ranging from an average of 0.16 mm to 0.35 mm, depending on formulation. PE ranged from an average of 1 mm to 2.2 mm and PP from 0.73 to 1.25.

With a normal force of 37.5 kg, a gouge test was performed on several DLFBE offerings and PP and PE. The results ranged from an average of 0.16 mm to 0.35 mm, depending on coating source. PE ranged from an average of 1 mm to 2.2 mm and PP from 0.73 to 1.25.

To assess which system has better gouge resistance, a DLFBE and a 3-layer polyethylene were tested at the same thickness of 0.762 mm. The DLFBE had a gouge depth of 0.177 mm leaving 78% of the initial coating while the 3-layer polyethylene coating penetrated all the way to the steel. The gouge results can be seen below in Figure 4.

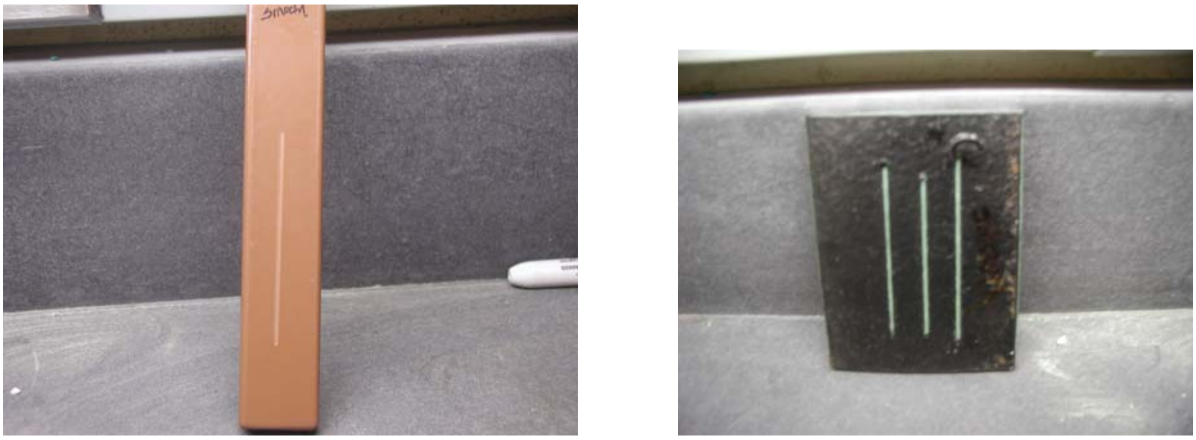

Figure 4: A DLFBE and a 3LPE coating was tested for gouge resistance both at thicknesses of 0.762 mm. The DLFBE retained 77% of the coating thickness while the 3LPE penetrated all the way to the steel. DLFBE has better gouge resistance then the 3LPE system. Photo courtesy of M. Mallozzi

From the test results illustrated in Figure iv, it can be seen that the DLFBE has better gouge resistance then the 3LPE system at the same thickness. Therefore, to have to the same gouge resistance needed for a particular terrain, such as rocky mountains or sharp objects, more 3LPE coating is needed than for a well-designed dual layer coating.

3.2.3 Flexibility/Bend

DLFBE coating thickness does affect flexibility as can be seen from the bend results at – 30ºC seen in Figure 5:

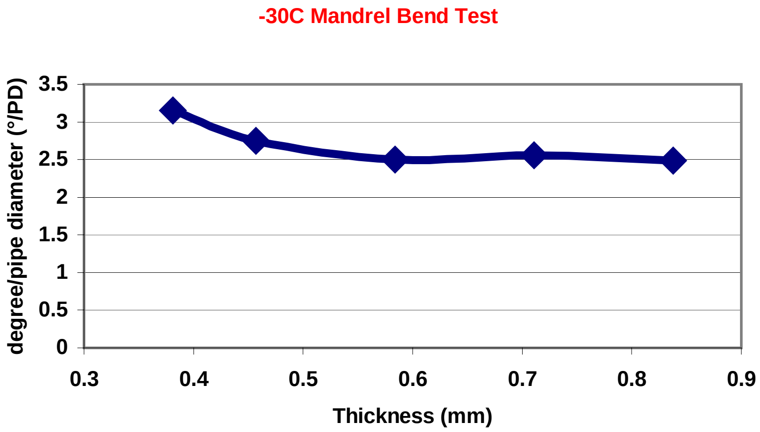

Figure 5: As thickness of a DLFBE coating increases the flexibility slightly decreases reaching a minimum flexibility of about 2.5°/pipe diameter when coated at 0.8 mm. In each case, thickness of the primer corrosion coating was 0.2 mm

A DLFBE has a flexibility range from 3.2°/Pipe Diameter to 2.5°/Pipe Diameter when coated at a thickness range of 0.381 to 0.838 mm respectively. Both 3-layer polyolefin systems have good flexibility at greater then 4 °/Pipe Diameter.

3.2.4 Cathodic disbondment resistance

The cathodic disbondment resistance of a DLFBE system depends on the properties of the corrosion coating in contact with the steel. Beyond 150 µm of thickness of the primary coating, there does not seem to be an advantage of increasing thickness. See Figure 6. Other studies have shown that increasing the total thickness of the protective coating does improve cathodic disbondment resistance. 10

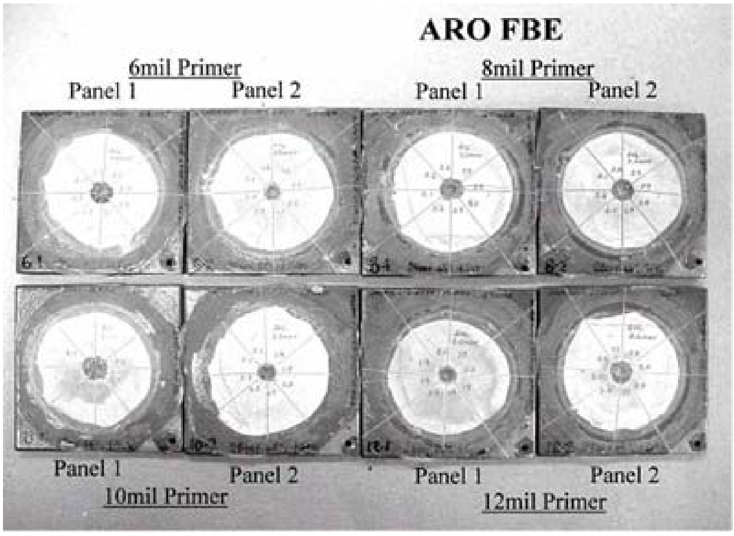

Figure 6: To evaluate the effect of primary coating thickness of a DLFBE abrasion resistant outer-coat (ARO) system, a 65°C, 28 Day, -1.5 V, 3% NaCl cathodic-disbondment test was performed. With a total thickness of 525 µm, the primer thickness did not show an effect on cathodic-disbondment performance over the range of 150 to 300 µm. Photo courtesy of M. Dabiri

3.3 Laboratory test program summary

In terms of mechanical resistance, all three damage resistant coatings – DLFBE, 3LPE, and 3LPE – performed well. Impact energies were at least 18 J for both 3LPO systems when the coating was applied at least 2 mm thick. The impact energy for a dual-layer ARO system was 18 J when the total system was 1.2 mm thick. Polyolefin's are more flexible then dual layer systems, although the DLFBE systems meet the requirements for all but the most stringent installation conditions. Gouge resistance at a given thickness is greater in a dual layer system then a 3 layer polyolefin system.

In order to achieve a worry free installation (acceptable impact, gouge, and flexibility) a dual layer coated should be applied at a minimum thickness of 0.5 mm while, based on the gouge tests, a 3-layer polyolefin system should have a minimum thickness of 3 – 4 mm. As pipe diameter increases, most specifications require a greater 3LPO thickness. The coating thickness for a dual-layer system requires less thickness than a 3-layer system to achieve the same damage resistance. The cost difference associated with this increase in pipe diameter and coating thickness is described below in section 4.

3.4 Backfill performance of FBE, DLFBE, and 3LPO

A 2005 study using large diameter pipe simulated the environment of the pipe-laying installation process. xi It evaluated impact, abrasion, and penetration. It found that 3-layer polyethylene at 2.5 mm to 3 mm performed well in those parameters. Epoxy-urethane and heat-shrink sleeve girthweld coatings did not do as well. FBE at 0.35 to 0.45 performed adequately in the simulated backfill studies as long as the backfill-particle size was less than 6 mm. Dual layer at 0.75 to 1 mm performed nearly as well as 3-layer PE. It had the added advantage of the capability of the same material on the girthweld as on the rest of the pipe. The study indicated that soil with aggregate less than 20 mm in size could be used with both DLFBE and 3LPE without further processing. Backfill with 20 to 40 mm materials should be screened, and above that size should be crushed and screened. See Figure 7.

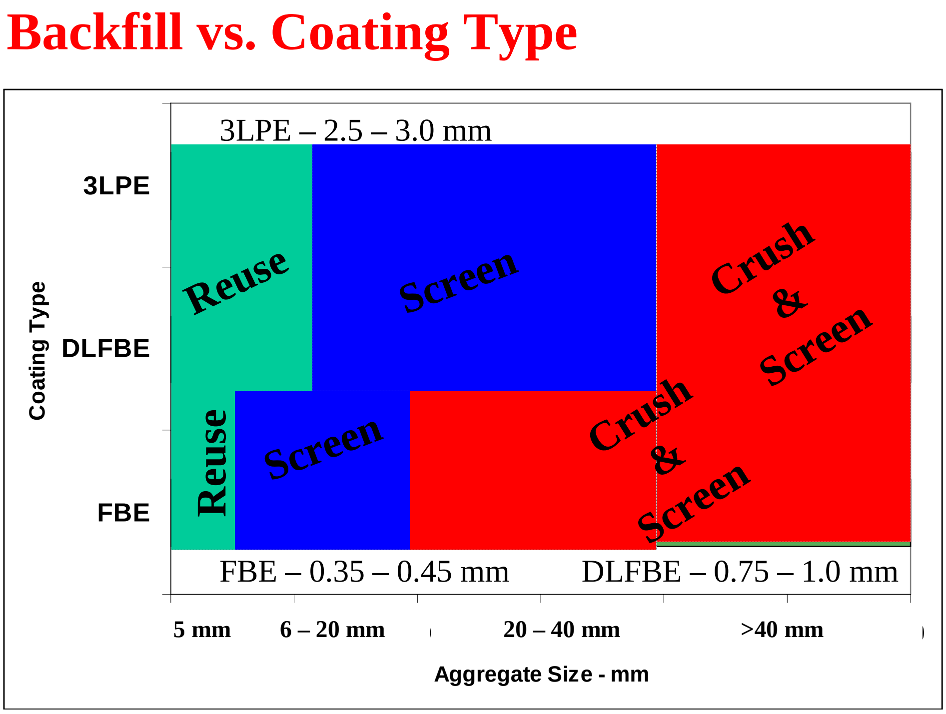

Figure 7: A 2005 study for PRCI that included testing on large diameter pipe, as well as laboratory studies, showed that DLFBE was nearly as effective in resisting backfill damage as 3LPE. DLFBE can be applied to the girthweld in the field, which provides even greater protection during the installation process. The study suggested that FBE is suitable for use with backfill aggregate up to 6 mm in size. From 6 to 20 mm, the large particles should be removed by screening. Above that, the fill should be crushed and then screened. DLFBE and 3LPE needed screened backfill if the aggregate size exceeded 20 mm. Above 40 mm, it should be crushed and screened.

3.5 Field problems with 3LPO

There are many thousands of kilometres of 3LPO performing very well. There are also several thousand kilometres of 3LPO with significant problems. They range from corrosion at the girthwelds, to cracking of the topcoat, to delamination between the FBE and the steel. There are also occasional issues with delamination of the coating from the steel at the cutback area after above ground storage. This can result in extensive rework in the field and construction delays.

Figure 8: There have been numerous cases of disbondment with 3-layer polyolefin coating systems. That is significant because the high electrical resistance of polyolefins means that they shield the pipe surface from cathodic protection. There have also been cases of cracking after a few years of service.5,7 Photos courtesy of D. Norman and A. Moosavi.

3.6 Case histories: Dual layer FBE

While DLFBE is well known and often used for directional drill installation, it is more frequently being accepted as the mainline coating as mentioned in section 1.1.2. For purposes of illustration, two case histories are presented.

3.6.1 Koyali-Ratlam Pipeline Project, India, 2006 – 2007

At the time of this report, a 60 km section of the 262 km X 16” pipeline was in the ditch. The applicator reported holidays on two to three percent of of the joints during each day’s production, with normally one to two holidays in each case.xii Those holidays were repaired and the pipe transported to holding areas. At that point, the contractor found holidays on three to five percent of the pipe, usually from one to three in number.xiii Those were repaired. The pipe was in storage for several months through the rainy season, transported to the right of way, welded and ready for installation. Another holiday measurement was taken. Two to three percent of the pipe joints had holidays usually two to three in number.

Figure 9: The Koyali-Ratlam Pipeline Project in India shows that a robust DLFBE coating system and well defined pipe handling guidelines can result in minimal coating damage even in areas with underdeveloped roads and infrastructure. Photos courtesy of J. A. Kehr.

Reasons given for utilizing DLFBE included xiv improved handling capabilities and in-ground performance, including freedom from cathodic shielding. Also, lower cost of materials and higher application output, which reduces the potential for construction delays and increased costs. Another factor in the low level of damage, in addition to the robustness of the coating itself, was the use of well defined guidelines for handling the coated pipe.

3.6.2 Kern River Expansion Project, USA, 2003

This project looped an existing pipeline and was connected to the same rectifier system. While anecdotal evidence suggested that there was significantly less coating damage than normally expected for FBE during installation, statistical records are not available. However, a pipe-to-soil potential survey after the new pipe was in the ground showed that it was not necessary to adjust the output of the rectifiers to compensate for essentially doubling the size of the cathodically protected area.xv This shows that little damage to the coating occurred. Figure 12 shows that the terrain was rugged and there was a significant amount or required bending.

Figure 10: The 1150 km 36" and 42" Kern River Expansion Project was the first to utilize DLFBE for the entire corrosion coating including girthwelds. Photos courtesy of M. Dabiri.

4 DUAL LAYER FBE: PRACTIAL CONSIDERATIONS

4.1 4.1Cost comparisons

The relative cost between single-layer FBE, dual layer FBE, and three-layer polyolefin coating systems depend on many variables, such as: commodity (solid epoxy, PE) costs that affect coating materials, applicator plant productivity, coating thickness specifications. Those costs will also vary from region to region and applicator to applicator. Pipe diameter and wall thickness can play a role because most specifications call for increased polyolefin thickness as pipe diameter goes up. See Figure 13.

Another factor is application plant productivity. This is very plant specific, but frequently throughput for DLFBE is 10% to 15% or even higher compared to 3-layer polyolefin application.

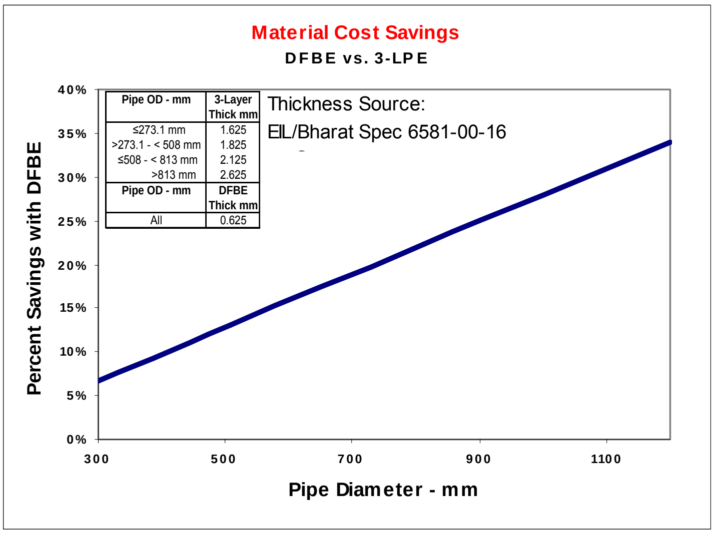

Figure 11: Material costs of DLFBE and 3-layer coatings depend on pipe diameter. This is an example from India showing that the larger PE thickness required for larger diameter pipe significantly affects cost.

4.2 Specifications and handling guildelines

Without reasonable handling practices, even the most robust coating systems like DLFBE and 3LPO can sustain damage. See Figure xiii. Conversely, well written specifications, training, and guidelines can significantly reduce the chance for coating damage. See Figures xii and xiv.

Figure 12: Use of plastic covered sand berms, sandbags, and padded hooks help prevent coating damage. Photos courtesy of J. A. Kehr.

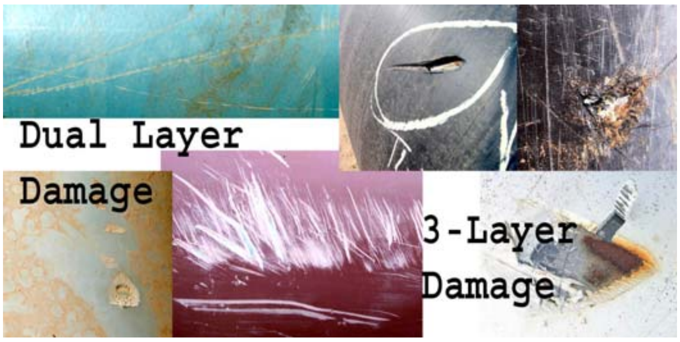

Figure 13: Properly non-motivated construction people can cause damage to either DLFBE or 3-layer pipeline coatings. Photos courtesy of J. A. Kehr, D. Norman, M. Dabiri.

Figure 14: A well written specification requiring the use of separators, padded or non-damaging strapping, and correctly sized and padded dunnage will reduce the potential for coating damage. Photos courtesy of J. A. Kehr.

5 FLEXIBILITY IN ARCTIC AND REEL BARGE

There have been several attempts to make FBE coatings more resistant to mechanical damage. Typically, the thickness of the overall coating is increased to provide added impact and abrasion resistance. However, as the thickness of the coating increases, the flexibility of the coating decreases. Another conventional approach to increasing the damage resistance of coatings is to increase the filler loading. However, similar to the problem with thicker coatings, higher filler loadings can dramatically decrease the flexibility of the FBE coating. As previously mentioned, the cold temperature flexibility of the coating is very important during arctic installation, and the coating must be tolerant to bending. The damage resistant dual layer coatings currently available require a compromise between toughness and flexibility.

A new concept addresses this compromise between damage resistance and flexibility with nanotechnology (See Figure xv). This improved dual-layer coating has cold temperature flexibility close to that of a single-layer FBE even at high thickness without sacrificing impact and gouge resistance or reduced filler loading.

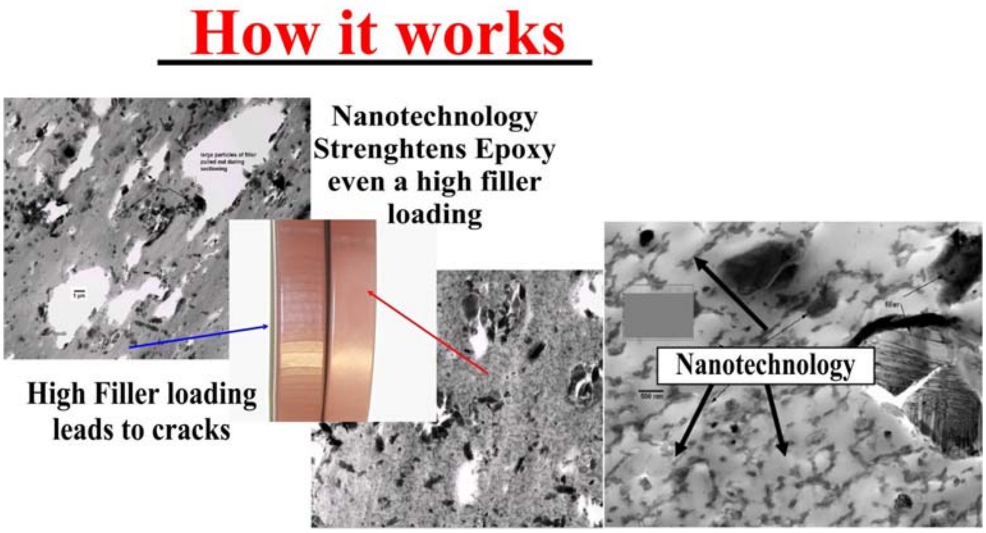

Figure 15: DLFBEs have been known to have reduced flexibility at colder temperatures. One practice in the industry to get better flexibility is to decrease filler loading. Decreasing filler loading decreases damage resistance (gouge and impact). Using nanotechnology has addressed the compromise between damage resistance and flexibility without decreasing filler loading. Nanotechnology strengthens epoxy even at high filler loading. Photos courtesy of M. Mallozzi

A flexibility comparison of the improved nano-dual layer coating and a DLFBE can be seen in Figure xvi, and a comparison of the gouge and impact resistance can be seen in Figure xvii.

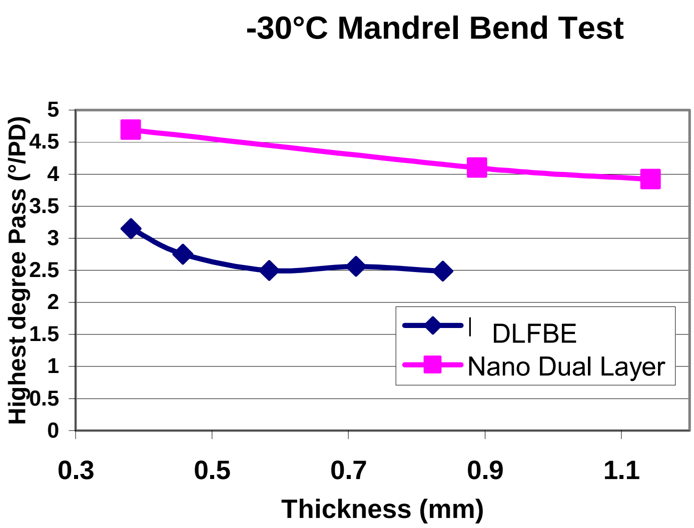

Figure 16: Nanotechnology has allowed a DLFBE to reach 4º/PD at -30C even at high thickness. This higher thickness can lead to more damage resistance without sacrificing flexibility

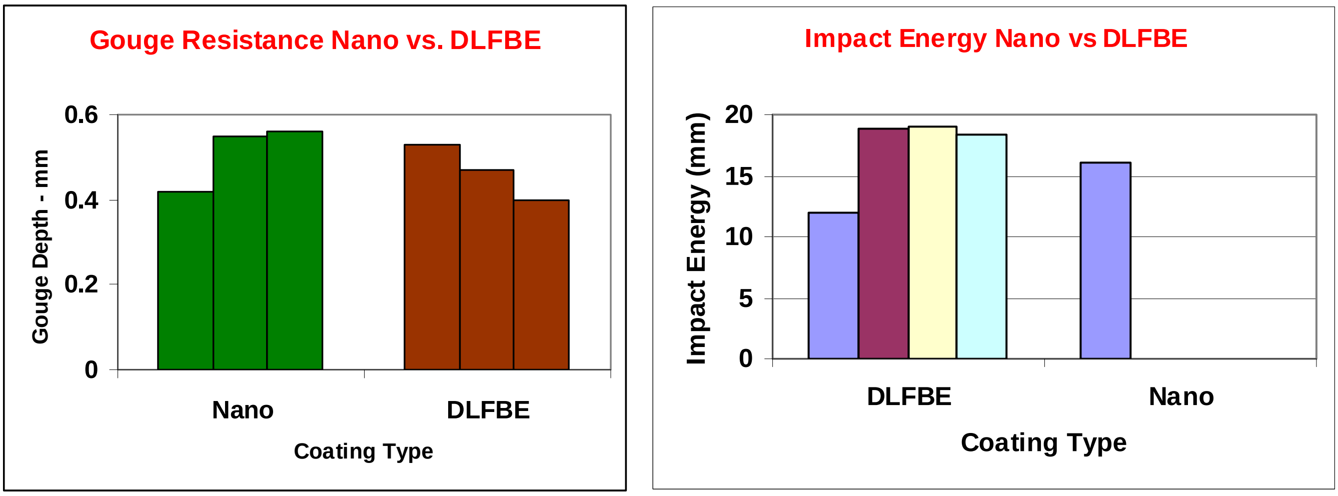

Figure 17: Gouge and Impact Resistance of Nano DLFBE is similar to a standard DLFBE

The improved dual-layer coating gives the pipeline end user another solution to protect their pipeline in adverse geotechnical conditions. Such areas include the arctic or reel barges.

Figure 18: Winter construction and reel-barge installation requires greater coating flexibility. Photos courtesy of M. Dabiri and Pipeline and Gas Journal.

6 CONCLUSIONS

FBE and 3LPO systems have a long track record as effective pipeline coatings. They are often selected based on the construction practices and installation environment of the specific pipeline project. DLFBE provides pipeline owners with an economically attractive, damage-resistant, and non-shielding coating system that can be used from one end of the pipeline to the other, eliminating incompatibility of the girthweld coating system. Nanotechnology will provide an even more versatile DLFBE in the future.

7 REFERENCES

---

1. J. Banach, "FBE: An End-User's Perspective," NACE TechEdge Program, Using Fusion Bonded Powder Coating in the Pipeline Industry, Houston, June 1997.

2. R. Espiner, I. Thompson, J. Barnett, "Optimization of Pipeline Coating and Backfill Selection," Corrosion/03, Paper No. 03046, (Houston, TX: NACE, 2003)

3. K. K. Tandon, G. V. Swamy, G. Saha, "Performance of Three Layer Polyethylene Coating on a Cross Country Pipeline – a Case Study," BHR 14th International Conference on Pipeline Protection, ed. J. Duncan, (BHR Group: London, 2001).

4. S. B. Hardy, J. E. Marr, M. Wilmott, D. Norman, and A. Khera, "Addressing Stress Corrosion Cracking on Multi Layer Pipeline Coating Systems," Petromin Pipeliner, February 2006.

5. A. N. Moosavi, “Limitations of 3-layer Polypropylene Pipeline Coatings,” 5th ADCO International Corrosion Conference, Abu Dhabi, 2006.

6. M. Roche, D. Melot, G. Paugam, “Recent Experience with Pipeline Coating Failures,” Pipeline Protection, BHR 16th International Conference on Pipeline Protection, (BHR Group: London, 2005).

7. D, Norman, “Pipeline Protective Coatings – Failures and Solutions,” NACE Corcon 2004 (New Delhi, India: NACE, 2004).

8. M. Roche, “Disbonding of Pipeline External Coatings: Detection, Causes and Consequences on Corrosion,” 5th ADCO International Corrosion Conference, Abu Dhabi, 2006.

9. D. Norman, “Three Layer Polyolefin Coatings: Where are We Now?” 5th ADCO International Corrosion Conference, Abu Dhabi, 2006.

10. A. Kehr, Fusion-Bonded Epoxy (FBE): A Foundation for Pipeline Corrosion Protection, (Houston, TX: NACE, 2003).

11. I. Thompson, “Coating and Backfill System Optimization,” Catalog No. L52208, (Arlington, VA: PRCI, July 2005).

12. R. Singh, Case history letter, Welspun, Bhurach, India, June 2007.

13. Anon., Case history letter, Gammon India Limited, Mumbai, India, June 2007.

14. Y. Kapur, “Bonding for the Future,” World Pipeliner, November 2006.

15. B. Schow and K Nicholas, “CP System Commissioning Aided by Use of Data Software, Field Computers, Remote Monitoring,” Pipeline and gas journal, March 2006.