FBE PIPELINE AND REBAR CORROSION COATINGS

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Synopsis

The key to a successful pipeline or rebar anti-corrosion program is the coating system. The successful coating system comprises proven high-quality coating materials and consistent, reliable application of the coating materials. Fusion-bonded epoxy (FBE) has proven to be reliable in these markets and new and improved materials are now available for specific corrosion conditions.

Introduction

Corrosion costs an estimated three to four percent of gross national product for direct and indirect costs in the developed countries of the world (1). Selection of the most economically effective technique for minimizing the effects of corrosion is a critical design decision. This paper will review fusion-bonded-epoxy (FBE) coating solutions for corrosion mitigation of pipeline systems, including internal, external, and 3-layer, and for reinforcing steel.

Figure 1. FBE coatings have been in use for underground and undersea pipeline protection for nearly forty years.

The protection of pipelines, valves, fittings, and steel in concrete from corrosion is necessary to ensure long-term operation, minimize maintenance, and prevent costly service disruption, loss of life, and injury. Protective measures are extremely important; yet, they represent a small fraction of the overall cost of a pipeline system or concrete structure.

Background, History, and Advantages of FBE Coating Systems

A fusion-bonded epoxy is a one part, heat curable, thermosetting epoxy resin powder that utilizes heat to melt and adhere to a metal substrate. It provides a coating with excellent adhesion, a tough, smooth finish resistant to abrasion and chemicals and does not entrap solvents. FBE coatings have been used for

Figure 2. Specially designed FBE coatings on reinforcing steel have been installed in more than 100,000 structures in the US alone.

pipeline corrosion mitigation since 1960 on over one hundred thousand kilometers of coated pipe installed around the world. FBE coatings on reinforcing steel have been utilized since 1972 in over one hundred thousand concrete structures in North America alone.

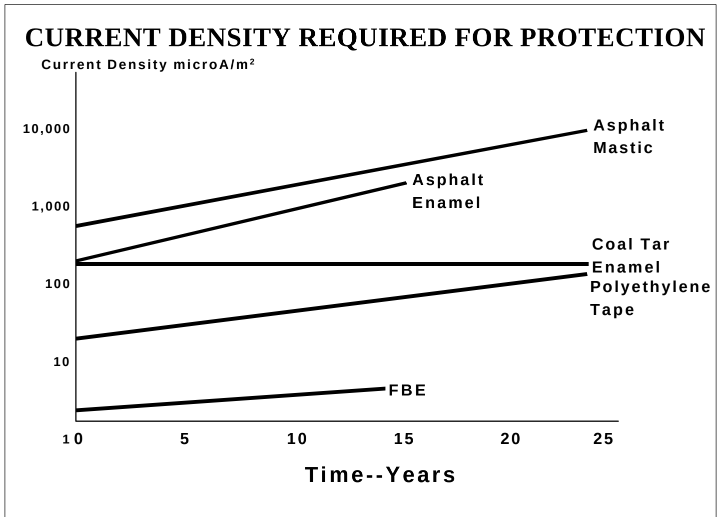

Figure 3. FBE coated pipelines require modest levels of current for cathodic protection (2).

EXTERNAL PIPE COATING

There are a number of factors to consider when selecting an external pipeline coating (2, 3) including:

- Physical and chemical stability.
- Resistance to soil stress.
- Adhesion and resistance to impact.
- Resistance to cathodic disbonding.

FBE AS MONOLITHIC COATING: Fusion-bonded-epoxy coatings have good chemical resistance, do not shield the pipe from cathodic protection, and there are no known cases of stress-corrosion cracking (SCC) of pipe coated with FBE. Although the coating is tough, when installation damage occurs, it is readily detected and repaired. Field application of FBE coating on girth welds provides the same level of performance quality as the plant-applied materials—the pipeline can be protected with the same coating from end to end.

3M introduced the first fusion-bonded-epoxy coating for pipeline corrosion protection in 1960. Typically, coatings have been single-coat materials applied in a thickness range of 300 µm to 450 µm. To enhance specific performance properties, pipeline owners sometime specify increased coating thickness—as high as1000 µm. This thickness increase improves high-temperature cathodic-disbondment and damage resistance.

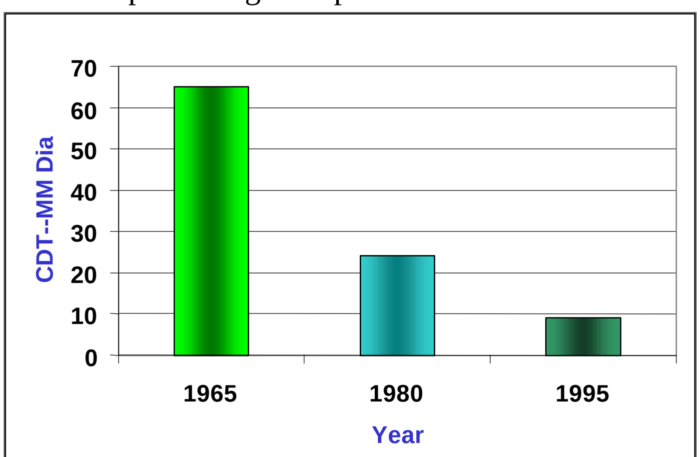

Figure 4. Continuous research and development has resulted in significant product improvements in such characteristics as cathodic disbondment resistance.

FBE standalone coatings are an excellent choice when good construction and installation practices are in use, the backfill is non-rocky, and the operating temperature is below 65°C.

FBE AS DUAL COATING: Two-layer FBE systems utilize the application of a second coating on top of the base coating; the top FBE coating material is applied during the melt stage (pre-gelation) of the first coating. This produces an intimate chemical bond between the layers. Each layer can be designed to impart specific characteristics that combine to produce performance results that significantly exceed those of a single coating.

An example is a topcoat incorporating a closed-cell structure that acts as an impact absorber and imparts damage resistance to protect the primary corrosion coating from perforation and ensuing cathodic disbondment. Flexibility for field bending is also maintained. This system passes 3-layer specification requirements for impact resistance.

A significant advantage of multilayer technology is that unique characteristics can be developed by selection of different coating layers. That means the system performance can be greatly modified depending on the chemistry, characteristics and variations of the primary and secondary coatings.

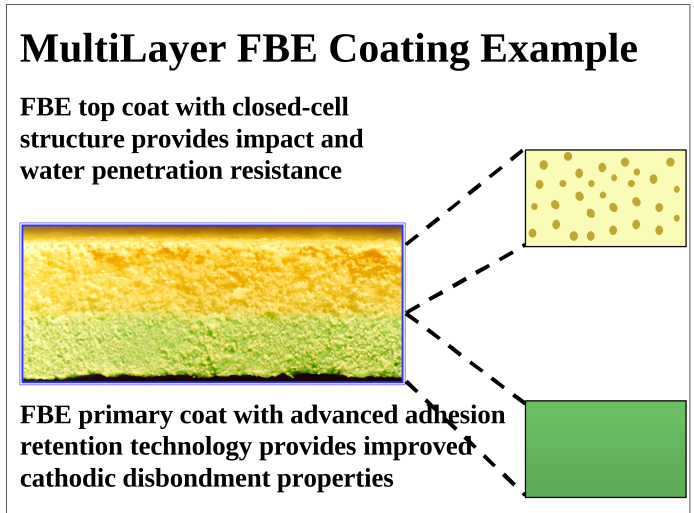

Figure 5. Use of two or more layers of FBE creates the opportunity to significantly enhance performance characteristics.

Using specifically designed coating layers combined with increased coating thickness can dramatically improve cathodic-disbondment performance, especially at high operating temperatures. A combination utilizing an adhesion-enhanced basecoat with a thick layer of closed cell topcoat provides high temperature performance with significantly improved cathodic disbondment and impact resistance. Other systems are designed to improve abrasion and gouge resistance. Another provides a rough surface for improved friction.

Abrasion resistant dual-layer FBE systems make good choices when pipe will be installed via a boring operation or if rough construction practices and terrain will be detrimental to the coating. A friction reducing coating can be employed if concrete is used to provide negative buoyancy. Other dual coating systems can be used to for operating temperature up to 110°C.

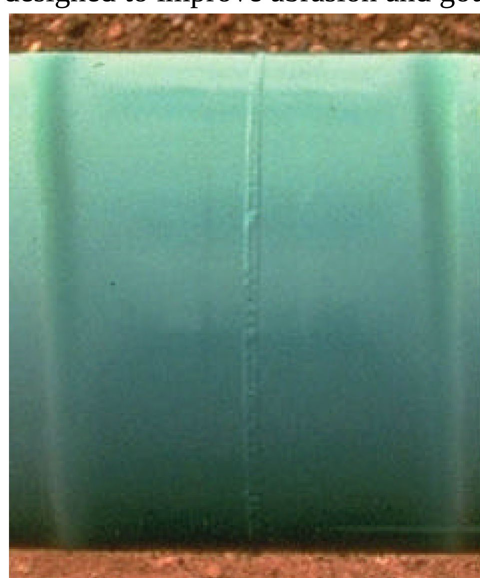

Figure 6. A significant advantage of FBE coating systems is that the same materials can be used on the girthweld as on the rest of the pipe.

FBE AS PRIMARY COATING FOR 3-LAYER SYSTEM: Fusion-bonded epoxy coating is well established as a cost-effective solution to pipeline corrosion protection. High internal strength and excellent adhesion to steel ensures good cathodic-disbondment resistance. One drawback is that excessive damage during installation may result in higher repair and cathodic-protection costs. Polyolefins provide excellent impact damage resistance. They also have low water permeation properties that are useful at high operating temperatures. Polypropylene, with its high softening point, is especially beneficial for high-temperature pipelines.

Three-layer external pipe-coating systems utilize FBE as the primary corrosion coating. Polyolefins have no polarity to 'wet' and do not adhere to steel. Combining the 'polar' epoxy with the 'non-polar' polyolefin combines the positive properties of both materials. An intermediate adhesive layer of modified polyolefin bonds the epoxy to the polyolefin. This adhesive contains polar groups grafted onto the carbon-bond spine of the polyolefin. The polar groups react with the epoxy. The polyolefin is compatible and bonds to the unmodified polyolefin topcoat.

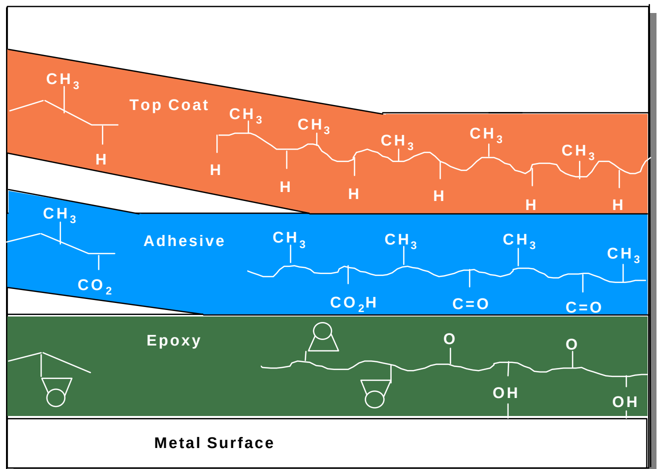

Figure 7. Three-layer polyolefin coating systems utilize FBE as the primary corrosion barrier.

Three-layer polyolefin coatings are good choices when extraordinary coating damage is probable. A polypropylene 3-layer system is a good selection if the operating temperature is expected to be above 110°C.

FBE AS INTERNAL PIPE COATING

Internal plastic coatings have been used in downhole tubulars for almost fifty years (4). New technology is improving the operating temperature and chemical resistance windows for FBE coatings. For best performance, the thickness is normally in the four hundred microns and above range. The coating is applied in one operation. A key factor for the increasing use of FBEs as internal pipe coatings is that they have no solvents (VOCs).

FBE is currently specified in the oil, gas, and water pipeline industries. It has been used as an internal coating in desalination plants in Australia and in the Middle East and on gas transmission lines. FBE has been used in high-sand-content seawater cooling pipework for ten years and is still in excellent condition. It has been applied to valves and pipework handling seawater for the US Trident Submarine program and has a twenty-year history in the pump manufacturing industry effectively protecting against cavitation and slurry damage.

Figure 8. FBE internal pipe coatings provide corrosion protection as well as improved fluid flow.

The use of internal coatings provides additional advantages besides corrosion protection to the pipeline system (5). Several are:

- improved fluid flow characteristics—reduced energy requirements,

- improved pipe inspection prior to installation,
- corrosion prevention during storage,
- easy pipeline cleaning and water disposal after hydrostatic testing.

There are reports of six to eighteen percent flow efficiency improvements when using FBE internal coated pipe as opposed to bare steel pipe (5). Using the six percent figure, on a thirteen-hundred kilometer, DN 750 pipeline with a discharge pressure of 6.6 million Pascals and a compressor station every one-hundred-thirty kilometers, the potential savings are over four million US dollars in compressor equipment cost and an annual energy savings of about a million dollars.

In the water industry, FBE provides a thin coating compared to concrete. This feature allows the use of smaller pipe sizes and reduced bulk and weight during handling and pipe installation. The smooth, hard coating provides reduced friction compared to uncoated or concrete-lined pipe. This translates to more efficient flow, reduced energy costs, and lower installed pump or compressor investment.

To be effective, an internal coating system must cover the entire inside of the pipeline, including the girthweld. Novel mechanical couplings are available to provide one-hundred-percent coverage across the joint. Coating equipment is also available to coat the internal girth weld with fusion-bonded epoxy.

Systems are available for a range of performance requirements from potable to water to the high H_2S and CO_2 chemical environments downhole tubing to coatings that resist wire-line damage.

FBE AS REBAR COATING

Corrosion of steel in concrete has become one of the more costly problems in the world over the last twenty-five years (1). As an example, approximately half of the nearly six hundred thousand bridges in the US Federal Highway system have structural deficiencies or are functionally outmoded. According to US Federal Highway Administration (FHWA) estimates, a quarter of US bridge decks are badly deteriorated. The widespread application of road-salt has caused expensive repairs often required within five to ten years.

It's a worldwide problem. Research indicates that the service life of buildings in the Arabian Gulf may be as short as five to fifteen years due to premature rebar corrosion. In some cases, rebar corrosion problems occur before construction is complete. In Japan, reinforced concrete bridges near the seashore show rapid deterioration within ten years of construction. Eleven viaducts in the UK built in 1972 began to decay within two years of construction due to the application of road deicing salt (2). Parking structures are the most vulnerable of all because

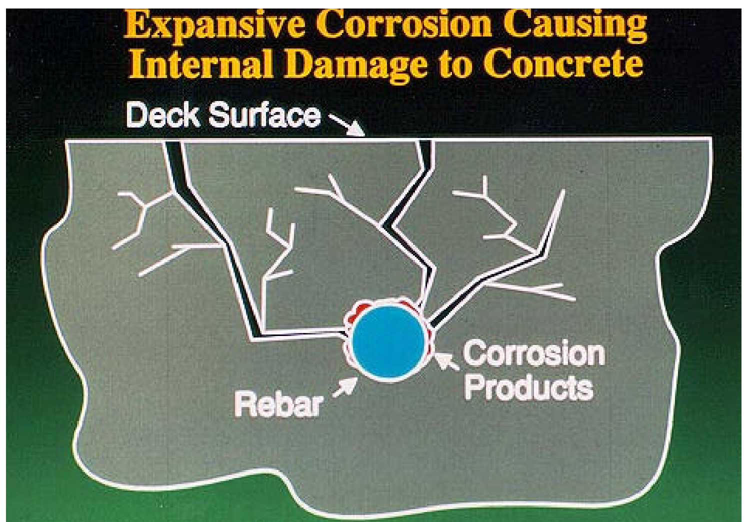

Figure 9. Concrete structural damage occurs when the reinforcing steel corrodes.

automobiles bring in salt, but the deck is not rinsed by rain (3).

The corrosion problems discussed above are caused primarily by chloride-induced corrosion of steel in concrete. Chloride penetrates the concrete from sources such as road de-icing salts or sea exposure. It can also be built in through the use of salt-contaminated aggregate, seawater in the concrete or chloride-based admixtures. Upon achieving a sufficiently large concentration, the chloride causes the depassivation and subsequent rapid corrosion of the steel. The resulting corrosion products occupy a much greater volume than the iron that they replace, and, as such, cause tremendous internal pressure within the concrete. This internal pressure, in turn, causes the concrete to crack and spall, allowing greater access of corrodents to the steel, further accelerating the deterioration of the structure (2).

Figure 10. FBE coated rebar helps prevent corrosion and damage to concrete structures.

Fusion bonded epoxy coated rebar (FBECR) has been in use in concrete structures for over twenty-five years. Evaluations of hundreds of structures in many different environments have shown that epoxy-coated rebar *is* performing to reduce the corrosion that damages concrete structures. Over the last ten years many studies have shown the way to provide even improved FBECR corrosion performance. These studies have resulted in significantly improved standards (6, 7) and application processes that should provide even better performance in the future.

FBECR is a sound choice if the reinforcing steel in the concrete will be exposed to corrosive agents such as salt. Life cycle cost analyses produced by the Concrete Reinforcing Steel Institute (8) show FBECR is a cost-effective solution even if structure life is extended only 1-2 years.

Summary

Fusion-bonded epoxy coatings have a very successful track record for protecting pipelines and reinforcing steel against corrosion all over the world. These coatings have proven themselves from the highly aggressive environment of the Middle East region to the arctic. New coatings are now available as new technologies and new standards developed in the unending quest for improved lifetime benefits of corrosion control.

[1] Islam, Moavin, “Condition Evaluation of Reinforced Concrete Structures: A Case Study,” Paper No. 521, NACE National Corrosion Conference, Corrosion ‘95.
[2] Banach, James L., “Pipeline Coatings—Evaluation, Repair, and Impact on Corrosion Protection Design and Cost,” Paper number 29, NACE Annual Conference, 1997.
[3] Norman, David, and Gray, David, “Ten Years Experience of Fusion Bonded Powder Coatings,” Paper number 367, NACE Annual Conference, 1992.
[4] Davis, Robert H., “The Use of Internal Plastic Coatings to Mitigate CO_2 Corrosion in Downhole Tubulers,” NACE National Corrosion Conference, 1994.
[5] “Corrosion Control Report: Internal Pipe Coatings are a Wise Investment,” Pipeline and Gas Journal, March 1993, pp. 67-69.
[6] “Standard Specification for Epoxy-Coated Steel Reinforcing Bars,” ASTM A 775/A 775M-97, American Society of Testing and Materials, 1997.
[7] “Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars,” ASTM A 934/A 934M-97, American Society of Testing and Materials, 1997.
[8] “Epoxy-Coated Rebar Delivers Cost Effective Value,” CRSI publication, Chicago, 1997.