Fusion Bonded Epoxy –
A Field Proven Fail Safe Coating System

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ABSTRACT

After forty years of use, many end users do not recognize one very important benefit of Fusion Bonded Epoxy (FBE) pipeline coating it is "Fail Safe". As with all pipeline coatings, FBE coatings have failed while in service, but rarely is there corrosion on the pipe under the failed coating. When adequate cathodic protection is available, FBE is "Fail Safe" because it does not shield CP current when disbondment occurs. Those who are responsible for selecting pipeline coatings should consider the use of "Fail Safe" coatings, so that when the coating fails, the pipe will be protected by the CP.

Key Words – Fail Safe; Fusion Bonded Epoxy; FBE; cathodic protection; cathodic protection shielding; disbondment; pipeline coating; blistering.

Introduction

Fusion Bond Epoxy (FBE) coatings offer the end user with a pipeline coating that will allow (adequate) cathodic protection to actually protect the pipe steel under any failed or disbonded coating. This is a "Fail Safe" pipeline coating system**.** A "Fail Safe" coating system is defined as one that will allow cathodic protection (CP) current to pass through it to protect the substrate – not shield CP – should the coating bond fail and adequate CP is available.[1] This is not a 100% claim, but this phenomenon has been witnessed and documented on many in-service pipelines coated with FBE. When FBE fails, corrosion is rarely present under the failed FBE when adequate CP is available.

There are many parameters that must be considered when selecting pipeline coating systems. One of the parameters many engineers fail to include in the coating selection criteria, is "What will happen if and when the coating fails?" A key consideration should be "Will the coating shield CP if the bond fails?"[2] However, all coatings experience some disbondment and, therefore, the behavior of a disbonded coating is important in the overall performance of a coating system.[3] Even with adequate cathodic protection (CP), corrosion can occur under most disbonded coatings.[4] With adequate CP, fusion bonded epoxies (FBE) do not totally shield CP currents[5]; therefore corrosion is not a major problem.

Another very important factor about FBE pipeline coatings is that stress corrosion cracking (SCC) has never been found under disbonded FBE coatings. It is believed that the high permeability of FBE coating to water is the reason for the apparently "transparent" nature of FBE coating to the cathodic protection.[6] Stress corrosion cracking has been studied extensively and has never been observed on FBE coated pipelines in over thirty years.[7] So the "Fail Safe" properties of allowing CP current and creating a high pH also extend to help prevent SCC on pipelines coated with FBE.

FAILURE MODES OF COATINGS

All coatings can and will fail. There are many reasons why a coating fails. These failure modes have been well documented [3,4,6,7,8,9,10,11] so they will be briefly discussed in this paper.

Surface Preparations

Improper surface preparation is the reason for most coating failures. Contaminants, such as ionic salts will mix with water to cause disbondment and blistering. Hydrocarbons will not allow proper adhesion. FBE requires a well prepared and clean surface (near white) with a profile of 1.5 to 3.0 mils of anchor pattern.

Application Techniques

Application processes can be a critical problem for all pipeline coatings. Application temperature is the most critical for the proper application of FBE.

Soil Stress

Soil stress can damage many types of coating systems as documented in many articles. When the coating strength is less than the stresses introduced by the soil, the coating will fail.[8] FBE is rarely affected by soil stress, but most other coating systems can be damaged easily by soil stress.

Selection Criterion

Many times coatings are selected for reasons that do not take into account all the possible failure modes and the resulting consequences when they do fail. All coatings will and do fail. All coatings have openings, pinholes, micro-fissures and other methods of allowing water, oxygen and other corrosion causing compounds to migrate through at different rates. FBE for example allows some water to penetrate as mentioned in the book "Fusion-Bonded Epoxy (FBE)" by J. Alan Kehr. However, FBE maintains its insulating properties in the presences of moisture and cathodic protection current.[9]

Operating Temperature

Operating temperature is always a critical factor in choosing a proper coating system. Many coatings, including FBE, are affected by the operating temperature of the pipeline. Higher or lower than specified temperatures can cause coatings to deteriorate, crack, lose adhesion or gravity flow of the coating on the pipe. Higher and lower temperature FBE coatings have been developed. The higher the operating temperature the more rapidly water will penetrate.

There are many other parameters that affect the performance of a pipeline coating, but these are some of the more critical ones. We must consider all the factors for each particular exposure and service when choosing a coating type.

TYPICAL FBE FAILURE MODES

FBE can fail like any other coating. Though coating manufacturers do not admit their particular coatings will fail, those of us in industry know better. In most cases the failure is not the fault of the coating or its formulation, but of the application techniques, selection criteria, or surface preparation.

Cathodic Disbondment and Blistering

Cathodic protection can affect all coatings. The alkaline conditions that develop at the cathode will deteriorate some types of coatings and cause others to disbond. Formation of hydrogen and hydrogen evolution has been debated and studied as another possible cause of coating disbondment. Laboratory tests indicate that the presence of hydrogen bubbles plays little or no role in the rate of disbondment.[10]

Various "ON" or "polarized" potentials have been used through the years by different companies in an effort to establish a potential at which to operate their CP system when using FBE. This author has been involved in FBE systems that operate at "ON" potentials more negative than -6 volts for several years with no detrimental affects to the FBE. Other systems have blistering or failed at "ON" potentials of -1.00 volt or less negative. This seems to point to the fact that many of the FBE failures are related to causes other than over voltage. CP will cause the water to penetrate more rapidly. The water that penetrates is relatively pure, but will mix with surface salts to cause blistering if the areas of contamination are small. Larger areas of contamination may cause the FBE to fail in large, disbonded sheets. Pinholes or holidays may be present but are not necessary for this disbondment to occur because the water penetrates through the coating.

Blistering of FBE will occur when water penetrates and combines with the surface salts to cause the disbondment and the subsequent blistering. Blistering from cathodic protection is the result of the alkaline environment that develops at the cathode. Areas where the wetting out of the surface by the coating was not sufficient or contaminants were present leave small areas of little or no adhesion. These become areas where water can be reduced. As water migrates to these areas, electron transfer takes place creating hydroxyl ions, starting the blistering process.

Loss of Adhesion

FBE has the best overall adhesion of any pipeline coating system when properly applied. If large areas of adhesion failure occur, the cause may be inadequate profile, large areas of surface contamination or application temperature problems.

Excessive Holidays

Excessive holidays are commonly caused from overheating heating during the application process, slivers in the pipe steel, contaminants on the pipe or in the coating material, or mishandling during the coating process or construction. The coating applicator has the responsibility of checking for and repairing holidays during the coating inspection process at the plant. The contractor has the responsibility of inspecting for and repairing holidays during construction.

If holidays are found during dig inspections, the cause for the holidays will typically be backfill related. Of course, if these were not properly inspected or repaired they could be from the problems mentioned above. The blistering mentioned above could also have pin holes or holidays develop during the blistering process. The holiday was not necessarily present before the blistering occurred.

Excessive Operating Temperature

If the operating temperature of the FBE is exceeded, then the coating can deteriorate. The FBE may become soft or grainy and can be easily removed with a knife, etc**.** Fusion bonded epoxy (FBE) coatings can absorb more water than normal at higher temperatures, but do not flow or move on the structure.[11] Glass transition temperatures can be exceeded however changes in physical properties can be expected, may not change the long term performance.

Chalking and Disbondment

Polymer degradation (chalking) from ultra-violet exposure will cause FBE to be grainy in appearance and surface chalking of 2 to 3 mils can be easily removed. There is a discoloration and change in appearance. This damage will typically be a few mils of thickness. If FBE coated pipe is stored where sunlight and air borne elements such as dust, rain, snow and other air borne pollutants contact the coated pipe, FBE is damaged, leading to failure of the coating. For this reason, if FBE is stored, it should be protected from the elements as much as possible. Tarps, covered sheds, and other techniques can be used to shield it from ultra-violet rays and other environmental damage.

FAIL SAFE CHARACTERISTICS OF FBE

FBE coatings have very effective electrical insulation when originally installed and continues to provide effective insulation even as the coating begins to absorb water. FBE continues to have low cathodic protection current requirements many years after installation if it remains well bonded. Even if blistering and small areas of disbondment occurs, the current requirement increases are minimal**.** However, the electrical resistance is low enough to allow cathodic protection to prevent corrosion on the pipe with disbonded or blistering coating – FBE is non-shielding.[7]

The amount of oxygen available at the cathodic will control the rate of the corrosion process under disbonded coatings. FBE has an advantage over many other coatings because it is a good barrier to oxygen. "…, while FBE is a good barrier to O_2, and CO_2, and HDPE to H_2O."[12]

All (organic) coatings are permeable, and have micro-pores and fissures that eventually permit water vapor to reach the substrate.[13] The rate and type of water allowed to permeate are important to coating failures. With FBE the rate may be somewhat faster than for some coatings, but the water that does penetrate is relatively pure, therefore the water has a minimal effect on the corrosion rate. If the water mixes with ionic salts on the pipe surface, the blistering or disbondment process begins. Cathodic protection accelerates the rate at which water penetrates all coatings. The cathodic process (reduction) creates H_2O, OH^- and H at the cathode surface; therefore water is available for transport to the substrate. (Osmosis or electro-osmosis) Electron transfer takes place at the metal electrolyte interface.

This concept becomes very import when evaluating any coating failures. Taking the pH reading of any water under a blister or disbondment will validate the effectiveness of the FBE to allow CP currents to protect the substrate. OH^- ions are being created at the pipe surface; therefore the pH becomes alkaline indicating the CP is providing protection to the steel. The corrosion rate for steel is greatly reduced or is nil in alkaline pH environments (typically from 9 to 13). If the pH is 8 or less, the CP may not be adequate or is shielded by the coating or some other material.

The pipe surface may have some discoloration under the failed FBE, but the important issue is that there is usually no corrosion under the FBE, proving that it is "FAIL SAFE"!

As mentioned earlier, there has to be adequate cathodic protection for this phenomenon to take place. Compared to all other pipeline coating systems, less or no corrosion is found on FBE coated pipe lines when using internal inspection tools. FBE may not be 100% "Fail Safe", but experience has shown that if adequate CP is available and no shielding is present, there is no corrosion.

Another interesting advantage of FBE is that when FBE fails these areas can be found more easily with direct current voltage gradient (DCVG) surveys. Since more current is allowed through FBE at these areas of failure, they can be detected and may show up as small holidays. The owner has the option of repairing the damaged coating or waiting because it is "Fail Safe" and the pipe will not likely have corrosion problems if CP is adequate.

WHAT TO DO IF CORROSION IS DISCOVERED UNDER FBE

If corrosion is found on pipelines coated with FBE, a careful evaluation must be made to determine when and how the corrosion developed. Do not assume if corrosion is present that FBE disbonded and shielded the pipe from CP. Some questions that must be asked and answered are:

- Was there always adequate cathodic protection on this pipeline system? (Some companies wait one year or longer after construction before CP is installed. Even after it is installed it may not have been adequate or monitored properly.)
- Was the corrosion caused from interference from a foreign impressed CP system? (There have been cases where a company lays a new pipeline system and do not monitor the foreign crossings. If they wait to install their CP system, corrosion may develop rapidly on the newly coated pipe system because of these interference problems.)
- Is the pipe at that location being shielded from receiving adequate CP by some object such as plastic items, over-coats on the FBE, rock shield, road casing, or a large metal structure adjacent to the pipe? Everything in the ditch is important.
- If all the corrosion is located at girthwelds, what is the girthweld coating? Did it shield the CP?
- Remember to take the pH under any failed coating. This will tell you if the pipe is receiving adequate CP at that time.

GIRTHWELD AND REPAIR COATINGS

A dilemma when using FBE coatings is what to use for the girthweld coatings and repairs. Since FBE is "Fail Safe", why use a coating on the girthweld that is not? Most corrosion on FBE coated pipelines occur at the girthwelds coated with materials that are not "Fail Safe". FBE can be applied to the girthwelds by using heat induction coils and flocking equipment. The FBE on the girthweld provides the end user with a coating system that is equivalent to the main line pipe when properly applied.

The second choice would be to use other proven “Fail Safe” coating systems such as the geo-textile mesh backed tape system discussed in reference 1. Two part epoxies are also a choice that will provide a coating that is similar to FBE, but may not always be “Fail Safe”. The two part epoxies have not been totally proven to be “Fail Safe”, but if not applied too thick, seem to provide this characteristic. These epoxies bond well to FBE coatings when the surface preparation and application are performed properly. For these reasons, two part epoxies are very good repair materials for FBE coated pipelines.

Solid film backed tapes, shrink sleeves and many other coating systems provide a shield to cathodic protection current if they disbond and water penetrates between the coating and the pipe. One must consider the end results if the coating fails.

CASE HISTORIES

Case History #1

Though rare, corrosion has been found on FBE coated pipelines. A significant pit was found at the 12:00 o’clock position from an internal line inspection tool run in 1992. When the area was excavated a very large boulder (1 to 2 tons) was removed from the top of the pipe. There were several blisters on the pipe in this area. The one pit was directly under the boulder which had apparently shielded the CP from the pipe. No corrosion was found under any of the other blistered FBE in the area.

The pipe was a 12” diameter coated with 22 mils of FBE and had been in service since the early 1980’s. The operating temperature was approximately 180° F. The “On” potential was -1160 mV_{cse}. There was also a large waste management pond just above the pipeline and there were significant bacteria in the oily water (from the leaking disposal pond?) in the area around the pipe.

Case History #2

FBE coated 16” diameter pipe laid in 1985 and internally inspected in 1999. All indications from the internal inspection tool run in 1999 were for internal corrosion. This validates the use of the FBE coating since the overall coating condition is excellent. One area exposed for verification had some blistering, but no external corrosion.

Case History #3

Case History 970721[7]

FBE coated NPS 42 pipe was examined after eight years of service at ambient temperature. Several blisters were observed after excavation. Blisters were rated as such: Medium to large, with no holidays, with bright steel under the coating; Medium to large with darkened steel; Small with liquid under the coating.

The excavated pipe was left exposed to the atmosphere for sometime before the coating was evaluated. This may be the reason there was not water under the large blisters. Deionized water was used to wash the surfaces under the larger blisters so an analysis could be made of the wash. The analysis of the water from the blisters with the darken metal showed about three times the amount of sodium, with some chloride and sulfate as the blisters with the bright steel. The pH of the water under the small blisters was > 13 indicating that CP was providing protection.

ARE WE JEOPARDIZING "FAIL SAFE" CHARACTERISTICS OF FBE?

Are we making a mistake by using thicker FBE or over-coating it with a variety of other coating materials? We are always seeking the perfect pipeline coating system. Even though we have had very good success with the typical 12 to 16 mil FBE coating systems, we strive for more. We use overcoats to protect FBE coating during directional drilling or rocky terrain. We use thicker FBE for higher temperatures or for handling reasons. Are these strategies taking away part or all of the proven "Fail Safe" characteristics of this coating system? If polyolefin and other shielding overcoats are used over FBE, one must understand that if the coating loses adhesion to the pipe substrate and water penetrates, CP will be shielded and corrosion can occur.

CONCLUSIONS

After approximately 40 years of use, FBE has proven to be a very good pipeline coating with the advantage of also being "Fail Safe". FBE has and will fail as with all other coatings. There are many ways a coating can fail, but with FBE the end user has the opportunity to continue to protect the pipe with cathodic protection. Corrosion has rarely been a problem with FBE coated pipelines when adequate cathodic protection is available and the areas are not shielded by some other material.

When blistering or failure does occur always check the pH of any liquid under the coating. If CP is effective the pH will usually be between 9 and 13. Not all coatings are "Fail Safe". Checking the pH is a very effective way to determine if the CP is adequate beneath the coating or if it is being shielded. If you find corrosion, the pH is typically in the 5 to 8 pH range. As mentioned above, always try to find out the cause of the corrosion under any coating, but especially those that have been proven to be "Fail Safe".

The end user must consider all options when selecting a pipeline coating. Many do not understand the importance of selecting a coating that is "Fail Safe". Remember one question we must answer is, "Will the coating shield CP if the bond fails?".[2] However, all coatings experience some disbondment and, therefore, the behavior of a disbonded coating is important.[4] Girthwelds and repair coatings should also be selected for their "Fail Safe" characteristics. For those concerned with pipeline integrity, FBE offers an excellent option when used with girthweld coatings that are also "Fail Safe".

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