

Investigation of Fusion Bonded Epoxy (FBE), as a Protective Coating for Pipes

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Abstract

Fusion bonded epoxy coating, also known as fusion-bond epoxy powder coating and commonly referred to as FBE coating, is an epoxy based powder coating that is widely used to protect various sizes of steel pipes used in pipeline construction, concrete reinforcing rebars and on a wide variety of piping connections, valves etc. from deterioration due to corrosion. This paper reviews history, chemistry, manufacturing process, surface preparation, application, characteristics for FBE. It is indicated that FBE was introduced as a protective coating early 60's. The coating is applied by manual spraying guns, or fluid-up process, and blast cleaning is the most commonly used method for preparation of steel surfaces. "Induction heating" or "oven heating" are mostly used as heating processes. Advantages of FBE are: ease of application, less waste of material, rapid application, faster production rates compared with the conventional liquid coatings.

Key words: Fusion bonded epoxy (FBE), Properties, Advantages

1- Basics

FBE coatings are thermoset polymer coatings. They come under the category of "protective coatings" in paints and coating nomenclature. The name "fusion-bond epoxy" is derived from the way of resin cross-linking and their method of application which is different from that of a conventional liquid paint. FBE coatings are in the form of dry powder at normal atmospheric temperatures. The resin and hardener parts in the dry powder remain unreacted at normal storage conditions. At typical coating application temperatures, usually in the range of 180 to 250 °C, the contents of the powder melt and transform to a liquid form. The liquid FBE film wets and flows on to the steel surface, on which it is applied, and soon becomes a solid coating by chemical cross-linking, assisted by heat. This process is known as "fusion bonding". The chemical cross-linking reaction taking place in this case is "irreversible", which means once the curing takes place; the coating cannot be converted back into its original form by any means. Application of further heating will not melt the coating and thus it is known as a "thermoset" coating. World's leading FBE manufacturers are Jotun Powder Coatings, 3M, DuPont, Akzo Nobel, BASF and Rohm & Haas [1,2].

2- History

Since their introduction as a protective coating in early 60's, FBE coating formulations had gone through vast improvements and developments. Today, various types of FBE coatings, which are tailor made to meet the varying requirements of the industry are available in the market. Following recent research works by various FBE manufacturers, FBE's are available as stand-alone coatings as well as a part in multi-layers. FBE coatings with different chemical and physical properties are available to suit coating application on the main body of the pipes, internal surface, girth welds as well as on fittings. Similarly, variations are also available to match different ranges of pipeline service conditions (Figs. 1,2) [1,3]. FBE coatings on reinforcing steel have been utilized since 1972 in over one hundred thousand concrete structures in North America alone. 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.



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

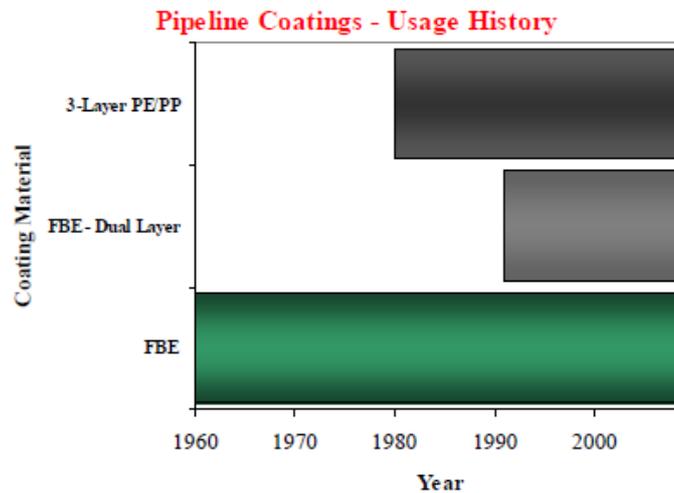


Figure 2. A truncated history of pipeline coatings

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 (Figs 3,4) [1,3].

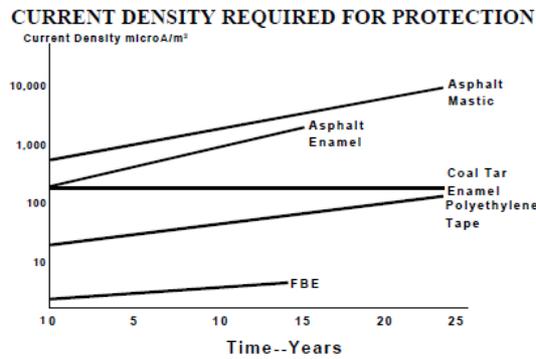


Figure 3. FBE coated pipelines require modest levels of current for cathodic protection.

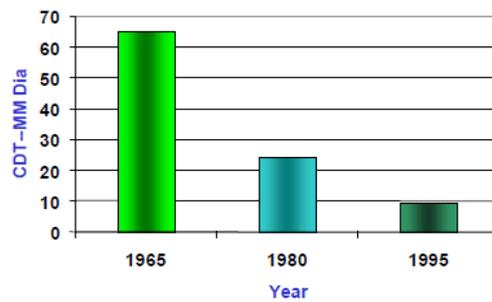


Figure 4. Continuous research and development has resulted in significant product improvements in such characteristics as cathodic disbondment resistance.

3- Chemistry of FBE coatings

Structure of unmodified Bisphenol A type epoxy prepolymer is shown in Fig. 5. Chemical structure of three-layer polyolefin coat is shown in Fig. 6 [3].

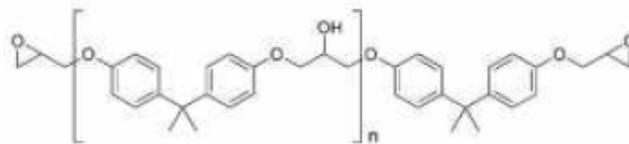


Figure 5. Structure of unmodified Bisphenol A type epoxy prepolymer. n denotes the number of polymerized subunits and is in the range from 0 to about 25.

Essential components of a powder coating are

1. Resin
2. Hardener or curing agent
3. Fillers and extenders
4. Colour pigments

The resin and hardener part together is known as the "Binder". As the name indicates, in Fusion bonded epoxy coatings the resin part is an "epoxy" type resin. "Epoxy" or "Oxirane" structure contains a three membered cyclic ring - one oxygen atom connected to two carbon atoms - in the resin molecule.

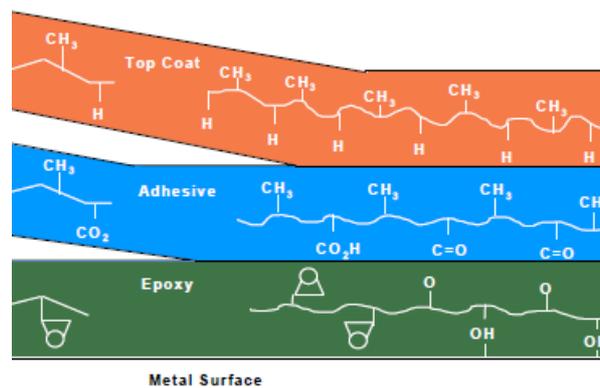


Figure 6. Three-layer polyolefin coating systems utilize FBE as the primary corrosion barrier.

This part is the most reactive group in the epoxy resins. Most commonly used FBE resins are derivatives of bisphenol A and epichlorohydrin. However, other types of resins (for example Bisphenol F type) are also commonly used in FBE formulations to achieve various properties, combinations or additions. Resins are also available in various molecular lengths, to provide unique properties to the final coating [3-5].

The second most important part of FBE coatings is the curing agent or hardener. Curing agents react either with the epoxy ring or with the hydroxyl groups, along the epoxy molecular chain. Various types of curing agents, used in FBE manufacture, include dicyandiamide, aromatic amines, aliphatic

diamines, etc. The selected curing agent determines the nature of the final FBE product, its cross linking density, chemical resistance, brittleness, flexibility etc. The ratio of epoxy resins and curing agents in a formulation is determined by their relative equivalent weights.

In addition to these two major components, FBE coatings include fillers, pigments, extenders and various additives, to provide desired properties. These components control characteristics such as permeability, hardness, color, thickness, gouge resistance etc. All of these components are normally dry solids, even though small quantities of liquid additives may be used in some FBE formulations. If used, these liquid components are sprayed into the formulation mix during pre-blending in the manufacturing process [3-6].

4- FBE powder manufacturing process

Essential parts of a powder coating manufacturing plant are:

1. weighting station,
2. pre-blending station,
3. an extruder, and
4. a classifier or grinding unit

The components of the FBE formulation are accurately weighed and are pre-blended in high speed mixers. The mix is then transferred to a high-shear extruder. FBE extruders incorporate a single or dual screw setup, rotating within a fixed clamshell barrel. A temperature gradient between 50 °C to 100 °C is used within the extruder barrel. This setup compresses the FBE blend, while heating and melting it to a semi-liquid form. During this process, the ingredients of the molten mix get dispersed thoroughly. Because of the fast operation of the extruder and relatively low temperature within the barrel, the epoxy and hardener components will not undergo a significant chemical reaction. The molten extrudate then passes between cold-rollers and becomes a solid, but highly brittle sheet. It further moves to a "Kibbler", which chops it to smaller chips. These chips are ground, using high speed grinders (classifiers) to a particle size of less than 150 micrometers (standard specifications requires 100% pass through in 250 micrometer sieves and maximum 3% retains in 150 micrometer sieve). The final product is packaged in closed containers. Particular care is given to avoid moisture

ingression. Normal storage temperatures of FBE powder coatings are below 25 °C in air-conditioned warehouses [2,3].

5- FBE coating application process

Regardless of the shape and type of steel surface to be coated, the FBE powder coating application has three essential stages:

1. The steel surface is cleaned to a high grade of cleaning,
2. The cleaned metal part is heated to the recommended FBE powder application temperature, and
3. The application and curing stage.

The advantage of pipe and rebar is that their round shape allows continuous linear application over the exterior surface, while the parts are moved in a linear conveyor through the powder application booth. This method ensures high production rates. On

fittings, etc., the coating is applied by manual spraying guns. Another method of application is "fluid-dip" process, in which the heated components are dipped in a fluidized powder bed [1-3,7].

6- Surface preparation - blast cleaning

"Blast cleaning" is the most commonly used method for preparation of steel surfaces. This method removes rust, scale, slats, etc., from the metal surface in an effective manner and produces an industrial grade cleaning and a "rough" surface finish. The roughness of the steel achieved after blasting is referred to as "profile", which is measured in micrometers or mils. Commonly used to profile ranges for FBE coatings are 37 to 100 micrometers (1.5 to 4 mils). Profile increases the effective surface area of the steel. The cleanliness achieved is assessed as NACE grades, or in accordance with Swedish standard (SIS) terminology of white-metal, near white-metal, etc.

It is very important to remove grease or oil contamination prior, to blast cleaning. Solvent cleaning, burn-off, etc., are commonly used for this purpose. In the blast cleaning process, compressed air (90 to 110 psi) is used to force an abrasive onto the surface, to be cleaned. Steel grit, steel shot, garnet, coal slag, etc., are the frequently used abrasives. Another method of

blast cleaning is "centrifugal blast cleaning", which is especially used in cleaning the exterior of the pipes. In this method, abrasive is "thrown" to the rotating pipe body, using a specially designed wheel, which is rotated at high speed, while the abrasive is fed from the centre of the wheel [4-6].

7- Heating and FBE powder application

Heating can be achieved by using several methods, but the most commonly used ones are "induction heating" or "oven heating". The steel part is passed through a high frequency alternating current magnetic field, which heats the metal part to the required FBE coating application temperature. Other methods of heating are "oven heating", "infra-red heating", etc. The FBE powder is placed on a "fluidization bed". In a fluidization bed, the powder particles are suspended in a stream of air, in which the powder will behave like a fluid. Once the air supply is turned off, the powder will remain in its original form. The fluidized powder is sprayed onto the hot substrate using suitable spray guns. An electrostatic spray gun incorporates an ionizer electrode on it, which gives the powder particles a positive electric charge. The steel to be coated is "grounded" through the conveyor. The charged powder particles uniform wraps around the substrate, and melts into a liquid form (Fig. 7). Internal surfaces of pipes are coated using spraying lances, which travel from one end to the other end of the heated pipe at a uniform speed, while the pipe is being rotated in its longitudinal axis (Fig. 8). Standard coating thickness range of stand-alone FBE coatings is between 250 to 500 micrometers, even though lower or higher thickness ranges might be specified, depending on service conditions. The molten powder "flows" into the profile and bonds with the steel. The molten powder will become a solid coating, when the "gel time" is over, which usually occurs within few seconds after coating application. The resin part of coating will undergo cross linking, which is known as "curing" under the hot condition. Complete curing is achieved either by the residual



Figure 7. FBE coated pipe



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

heat on the steel, or by the help of additional heating sources. Depending on the FBE coating system, full cure can be achieved in less than one minute to few minutes in case of long cure FBE's, which are used for internal pipe coating applications [2-6].

Rebars are coated in a similar manner as coating application, on the exterior of pipes (Fig. 9). For FBE coating application on the interior of pipe surface, a lance is used. The lance enters into the preheated pipe, and starts spraying the powder from the opposite end, while the pipe is being rotated on its axis and the lance pulls out in a pre-determined speed [2,3].

On fittings such as tee's, elbows, bends, etc., powder can be sprayed using hand held spray guns. Small sized fittings can also be coated by dipping in a fluidized bed of powder, after heating the steel to the required powder application temperature.

After field welding of the pipe ends, FBE can be applied on the weld area as well. Figure 10 shows the process of FBE coat overally and table 1 includes some FBE projects in the world.



Figure 9. FBE coated rebar under water quenching

Advantages of FBE application over conventional liquid coating application are [2-8]:

- ease of application,
- less waste of material,
- rapid application,
- and cure schedules, which means faster production rates

Finished coated pieces can be moved to the storage area within minutes after the application.

Conclusion

1- FBE coating is an epoxy based, thermoset polymer powder coat, and it applies in the range of 180 to 250 °C. The liquid FBE film wets and flows to the surface.

2- Blast cleaning increases effective surface area and better adhesion of the coating. The commonly used profile for FBE ranges between 37 to 100 micrometers (1.5 to 4 mils).

3- Prior to application of FBE the surface is heated either in an oven or by induction heating. The FBE powder is placed on a Fluidization bed wherein the powder is suspended in a stream of air in which the powder behaves like a fluid.

4- Unlike liquid paints, FBE coatings consist of resin and hardner parts, both of which remain dry and unreacted at ambient temperatures.

5- Advantages of FBE over conventional liquid coatings are: ease of application, less waste of material, rapid application and cure schedules.

6- It can be said that FBE coating is used against protection from physical damage and chemical attack.



FBE FUSION BONDED EPOXY

PRODUCT APPLICATION PROCESS

MORE PROJECTS

Eastern Canada	NPS 30"	530 km
Western Canada	NPS 4"-42"	2000 km
Eastern Canada	NPS 30"	540 km
Western Canada	NPS 36"	100 km
Western Canada	NPS 48"	150 km
Western Canada	NPS 42-48"	95 km
Western Canada	NPS 24"	440 km
USA (Canada)	NPS 30-36"	53 km
Western Canada	NPS 20"	120 km
Western Canada	NPS 48"	50 km

PRODUCT DESCRIPTION

① Powdered Epoxy
② Steel Pipe

APPLICATIONS

- Small diameter pipe
- Large diameter pipe
- Oil and Gas Pipelines

PIPE DIAMETER

Minimum 3 1/2" Maximum 48"

OPERATING TEMPERATURE

Minimum -40°C Maximum 105°C

JOINT PROTECTION

- Field-applied sprayed powder
- 2-part liquid epoxy kits
- Canusa Heat Shrinkable products
- Urethane

PROJECT HIGHLIGHT

SPPL coated 2000 km of NPS 4" - 42" with Fusion Bonded Epoxy for the Alliance Pipeline Systems project.

The Alliance Pipeline System is designed to carry natural gas from Western Canada to the Chicago-area market center for distribution throughout North America.

Figure 10. FBE application process



Table 1. Some F.B.E Projects in the world

Amoco Marlin	240,000 ft. of 10" and 12" OD Fusion Bond Epoxy, Buckle Arrestor Insertion, Anode and Anode Taper Installation
ANR / Coastal Typhoon	94,200' of 12" and 182,920' of 20" OD Fusion Bonded Epoxy, Concrete Weight Coating, Miscellaneous Fabrication Transitions, Flex Head Assemblies, Beveling and ID Boring, TSA Coating, Anode Installation
BP Pompano	50,000 ft. of 8-5/8" .500 wall OD Fusion Bond Epoxy Coating Reeled Pipeline Project
BP Troika	316,120 ft. of 10" and 24" OD Fusion Bond Epoxy coating and Sigma Armorcote
British Borneo Allegheny	152,000 ft of 12", 16" and 20" OD Fusion Bond Epoxy Coating
British Borneo Morpeth	198,000 ft. of 8" and 12" OD Fusion Bond Epoxy, Triple Joint Welding, Buckle Arrestor Insertion, Anode Installation.
ChevronTexaco Gemini	293,000 ft. of 12" OD Fusion Bond Epoxy Coating, Buckle Arrestor Insertion, Anode and Anode Taper Installation
ChevronTexaco Genesis	161,500 ft. of 14" OD Fusion Bond Epoxy Coating, 49 Integral Ring Buckle Arrestor Insertions, 71 Sleeve Buckle Arrestor Insertions
ChevronTexaco Malongo PL	67,100 ft. of 24" OD Fusion Bonded Epoxy, Concrete Weight Coating
ChevronTexaco Venice Gathering Expansion	279,000 ft. of 24" OD Fusion Bonded Epoxy
Conoco Joliet	65,000 ft. of 8" and 12" OD Fusion Bond Epoxy Coating
Delos Marco Polo	
Dow Pipeline Project	150,000 ft. of 8" and 26" OD Fusion Bond Epoxy, Multiple Joint Fabrication, Concrete Weight Coating
Duke Energy Dauphine Island	14,000 ft. of 8" and 200,880 ft. of 12" OD Fusion Bond Epoxy Coating
Duke Energy	118,000 ft. of 24" and 144,720 ft. of 30" OD Fusion Bond Epoxy and Concrete Weight Coating
Duke Maritimes & N.E.	
El Paso Cameron Highway	140 Miles of 24" and 240 Miles of 30" OD Fusion Bond Epoxy and Concrete Weight Coating
Enron Columbia	OD Fusion Bonded Epoxy First major international project where Bayou Coating, LLC was involved in transporting coated pipe to a foreign destination This required special handling.
Enron Florida Gas	221,000 ft. of 30" and 36" OD Fusion Bonded Epoxy and Multiple Joint Fabrication
Enron Florida Gas Ph IV	146,600 ft. of 36" OD Fusion Bonded Epoxy and Multiple Joint Fabrication
Enron Florida Gas Ph V	221,000 ft. of 30" & 36" OD Fusion Bonded Epoxy and Multiple Joint Fabrication
Enron Northern Border	178,000 ft. of 30" OD Fusion Bonded Epoxy, ID Flowliner and Blast and Multiple Joint Fabrication
Enserch Cooper	640,000 ft. of 12" OD Fusion Bond Epoxy Coating First time non slip or rough coat was applied to provide a rough surface for the tensioners to grip.
Enterprise Lou-Tex	500,000 ft. of 12" OD Fusion Bond Epoxy Coating
Enterprise Products	211,000 ft. of 12" OD Fusion Bonded Epoxy and Concrete Weight Coating
Exxon / Southern Nat.Gas Alabaster	375,000' of 20" pipe OD Fusion Bonded Epoxy
Exxon Diana	1,694,000 ft. of 6", 10", 18" and 20" OD Fusion Bond Epoxy Coating, ID Flowliner & Blast, Quad Joint Fabrication (1100 - 6" & 10"), Buckle Arrestor Insertion, Anode & Anode Taper Installation and SCR Fabrication First simultaneous co-development of multiple deepwater fields. In water nearly a mile deep! This project was flawlessly executed with a seven times better than industry average safety record, more than \$100 million under budget, and ahead of schedule. The Hoover-Diana is the world's deepest

References

1. J. Alan Kehr, NACE International, Fusion-Bonded Epoxy (FBE): A Foundation for Pipeline Corrosion Protection, 2000.
2. J. Alan Kehr, 3M USA, FBE Pipeline and Rebar Corrosion Coatings, 2008.
3. J. Alan Kehr, Martin Rau, and Emran Siddiqui, 3M Company, Fusion-Bonded Epoxy (FBE) and Dual-Layer FBE Materials Provide Enhanced Performance for Pipeline Installation, 2009.
4. Shiwei William Guan, Madison Chemical Industries Inc - Canada, Corrosion Protection by Coatings for Water and Wastewater Pipelines, 2001
5. www.kccworld.co.kr/english
6. www.jotun.com
7. www2.dupont.com
8. www.garneau-inc.com