Mitigation of Pipe End Coating Disbondment

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Figure 6: No coating disbondment found on these pipe ends preserved with an end cap and a SPVC tape for more than 2 years exposed in an open marine environment (Courtesy of PipeGuardTape.com)

Abstract:

Storage of coated pipes for an extended period without any preservation, especially in some marine and tropical environments which are hot, humid and salty, can lead to deterioration and rusting of pipe ends and pipe end coating disbondment. The issue has been a long term problem of the oil/gas pipeline industry, which affects the integrity of the pipe coating and the pipeline integrity. This paper discusses the mechanism, affecting factors, and corrective and preventative measures of pipe end coating disbondment.

INTRODUCTION

Fusion bonded epoxy (FBE) and threelayer polyolefin (polyethylene 3LPE or polypropylene 3LPP) are the most common external coating systems for new oil and gas pipelines. In addition, multilayer polypropylene coating (MLPP) and other FBE-based coating systems (such as polyurethane or polystyrene) can be several inches thick, providing corrosion and mechanical protection as well as thermal insulation. All these FBE based pipeline coatings have long track records of successful use, but there are occasional challenges and problems that must be addressed as part of the pipe installation process. One of these challenges and problems often met in the pipeline coating industry is pipe end coating disbondment, a delamination normally between the FBE and the steel at the cutback area of the pipe ends. The pipe ends of factory-coated pipes are often un-protected for girth weld joint applications during pipe installation.

Traditionally, it has been believed that for single layer FBE or dual layer FBE (DLFBE) coatings, delamination in the cutback area of the pipe ends is a rare occurrence, but for multilayer systems it is not uncommon[1]. Another belief is that the pipe end coating disbondment is due to very high concentration of residual stresses developed at the cutback interface between the steel and the three or multiple polyolefin coating system, as a result of thermal mismatch between the steel and the coating system. The stress concentration factor (SCF) at the cutback area is a function of cutback angle and polyolefin topcoat thickness. The high shear and peeling stress can disbond the coating system from steel. Normally, a smaller cutback bevel angle (<30o) and thinner polyolefin topcoat can reduce SCF and thus prevent a pipe end from coating disbondment[2]. To further prevent the FBE disbondment, a FBE toe (typically 3-5 mm or longer) is established to shift the high SCF to FBE/copolymeric adhesive layer of the three or multiple polyolefin coating system, to help out to eliminate the pipe end disbondment.

However, many failures of recent oil and gas pipeline projects have suggested that the above believing is not the case. Storage of coated pipes for an extended period without any preservation, especially in some marine and tropical environments which are hot, humid and salty, can still lead to deterioration and rusting of pipe ends and pipe end coating disbondment. The pipe end coating disbondment occurred regardless of whether the pipe coating was just a FBE/DLFBE or a multi-layered system, whether the cutback bevel angle was <30o or not, and whether and what length of a FBE toe was used.

In a pipeline project in South East Asia, pipe end disbondment occurred with well-applied single layer FBE coated pipes after a 6-month storage in an open environment (Figure 1). In an Australian offshore pipeline project, the coating end disbondment issue occurred, after 8 months of exposure to an open environment, on a few MLPP coated pipes with a FBE toe of >20 mm in length which was significantly longer than the typical 3-5 mm, intending to significantly reduce the SCF (Figure 2).

Figure 1: End Disbondment of a FBE pipe coating

Figure 2: End Disbondment of a MLPP coating with a FBE toe (of >20 mm length vs. typically 3-5 mm)

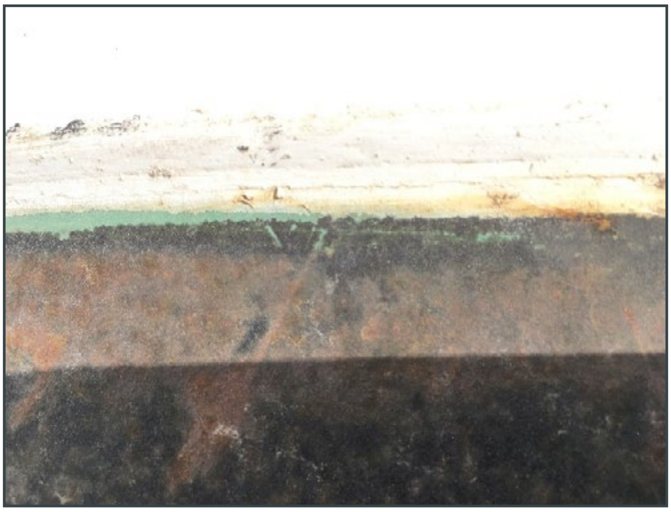

Figure 3a: End disbondment on a pipe with the FBE toe remained

Figure 3b: End disbondment on a pipe with the FBE toe disappeared

In a 3LPP pipeline project in the Middle East, pipe end coating disbondment occurred when the cutback bevel angle was well below <30o (Figure 3a and Figure 3b) and with a 3-5 mm FBE toe. The first pipe (shown in Figure 3a) had some areas showing a 2-5 mm FBE toe remained but coating disbondment still occurred in some areas around the circumference of the pipe, delaminating between the FBE and the steel, after over 1 year exposure in an open environment. The second pipe (shown in Figure 3b) had most FBE toe disappeared, with some traces of FBE left in the toe area. Like the first pipe, the cutback bevel angle of the second pipe was less than 30o, complying with the project specification requirement. Some gouge damage on the cutback and the FBE toe were found from the investigated pipe ends of the first and the second pipe. However, localized end disbondment spots between good FBE toe and rust steel were also evident, suggesting that the use of FBE toes did not provide a sufficient protection to the pipe end from end disbondment when exposed to an open environment, and that the gouge damage on the FBE toes was not the key root-cause of the issue.

MECHANISM

Poorly formulated or applied FBE coating can lose its bond to steel when exposed to moisture. FBE is a semi-permeable membrane, i.e., it absorbs water and allows it to pass through the coating. At room temperature, it absorbs most of the water it will accept within the first two days to a level of less than 1%[3] by weight. FBE coated pipes, if stored prior to installation for months or even for weeks in a hot and high humidity environment, will absorb water into their coating film. More moisture can be absorbed by the FBE in the cutback area with the help of accumulation of dust and debris formed on the unprotected pipe ends.

Water absorbed into the FBE polymer matrix has a plasticizing effect and can lower the glass transition temperature (Tg) of FBE. The moisture absorption along with other environmental aging, such as temperature cycling (day and night), UV degradation, and rusting will degrade the FBE mechanical properties, weakening the bonding of the FBE to the steel substrate. Over time, disbondment can occur.[4-5]

The following mechanism is presented for the development of end disbondment of a FBE based pipeline coating:

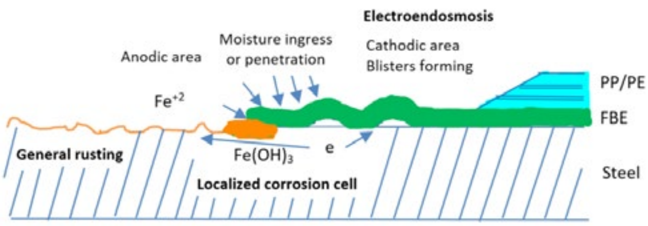

Figure 4 :The mechanism of end disbondment of a FBE/3LPO pipeline coating

Step 1. Rusting occurs along the entire cutback area where the steel was uncoated or unprotected due to the loss of effectiveness of any temporary coating applied over the cutback area for transit. The rust formation of the pipe ends was due to accumulation of moisture, dust and debris on the steel surface.

Step 2. At the cutback area, a localized corrosion electrochemical cell is formed around the steel/coating transition line. On the left, the rusting and unprotected steel is the anode, and on the right the steel protected under the FBE or 3LPO coating is the cathode. The anodic reaction is:

$$Fe \rightarrow Fe^{+2} + 2e^-$$

The cathodic reaction occurs under the FBE/3LPO coating, a very short distance away from the rusting steel (anode):

$$H_2O + ½ O_2 + 2 e^- \rightarrow 2 OH^-$$

Remembering that soluble sodium and chloride ions from the environment do not participate in the reaction, the overall reaction of the electrochemical reaction is

$$Fe + ½ O_2 + + H_2O \rightarrow Fe^{+2} + 2 OH^- \rightarrow Fe(OH)_2 \downarrow$$

Ferrous hydroxide precipitates from solution, however this compound is unstable in oxygenated solutions and is then oxidized to the ferric salt:

$$Fe(OH)_2 + ½ H_2O + ¼ O_2 \rightarrow Fe(OH)_3$$

The final product is the familiar rust. Furthermore, these electrochemical reaction processes are affected by the presence of other ions, such as Na^+, Ca^{2+}, Cl^-, $SO42^-$, from the environment, which serve as an electrolyte, and thus accelerate the rust formation. Over time, at the steel/coating transition line the localized formed corrosion product would absorb more moisture and grow, with its volume taking up a larger volume than the steel. This physically forces the coating off from the substrate. Eventually this would lead a localized edge delamination when the physical force exceeds the adhesive bonding strength of the FBE coating to the substrate (Figure 4).

In addition to the electrochemical reactions above, electroendosmosis also occurs around the steel/coating transition line at the cutback area. The metal steel underneath the localized cathodic area contains an excess of negative electrons, therefore making it a negative surface. Water or moisture then trends to ingress through the FBE coating/steel interface or penetrate from the coating surface through the coating film toward the negatively charged cathode. The end result is the formation of cathodic area blisters of the FBE coating near the steel/coating transition line, very similar to the situation of coating blistering formation during a cathodic disbondment (Figure 1). The osmotic pressure generated in the blaster will eventually break the FBE-steel bonding strength and delaminate the coating from the substrate.

Coating end disbondment is thus caused by the combination of above electrochemical reactions and electroendosmosis blistering. The end disbondment breaks the ligament to link the anode with cathode to widen the rusted steel area. The adjacent steel under the coating without rusting becomes then the new cathode and the same processes repeat to widen the rusted area. It is normally called rust creepage or under film corrosion process. Initially, the disbonded area looks like half of a blister or half of a cathodic disbondment. The semicircle begins at the interface between the FBE and the steel in the cutback area. The shape of the disbonded area implies that there is an initiation point where an electrochemical reaction begins and creates the disbondment (Figure 1). Multiple initiation sites can later result in multiple disbondments growing together and a loss of adhesion around the circumference of the pipe.

CONTRIBUTING FACTORS

Several factors will affect the deterioration of pipe ends and end disbondment of pipe coatings during long term storage:

- Storage environmental conditions of coated pipes prior to pipeline installation: Water absorption and rust formation can occur with coated pipes stored for several weeks or longer periods prior to construction, particularly at a hot, high humidity and salty environment (i.e. tropical and marine). Wet and dry cycles will also accelerate repeated corrosion cells and increased electroendosmosis blistering during disbondment growth, leading larger coating disbondment with often growth rings.1 The degree of rust creepage also depends on the salt content, atmospheric humidity, temperature cycles, and the residual stresses. In Southwest Asia, the Middle East, Australia, and the Gulf of Mexico, the local environments could easily facilitate the coating rust creepage progress and pipe end coating disbondment if no adequate corrosion protection. The need for temporary corrosion protection of external and internal surfaces during storage and transportation shall be considered during design/engineering for later inclusion in fabrication and installation specifications.
- Properties of the coating and adhesive: Properties of different types of coating components affect their ability to withstand deterioration and end disbondment, including: moisture absorption, density, hardness and elasticity, tensile strength, coefficient of thermal expansion, stress relaxation, thermo-oxidation/UV and heat ageing resistance, etc. Only proven coating and adhesive materials shall be used for a pipeline project and new materials shall be evaluated and carefully qualified.
- Thickness and cutback configuration of the mainline coating: At pipe coating cutbacks, stress concentration is related to coating thickness and cutback bevel angle. The higher the pipe coating thickness and more acute cutback bevel angle, the higher the residual stress concentration and thus the easier the pipe end coating disbondment[2]. As moisture and rust weakens the bonding strength of the base coating layer to the steel substrate but the SCF remains unchanged over the environmental aging, over time the coating will disbond at the cutback once the resultant shrinking force from the stress concentration exceeds the adhesive force of the coating-steel interface. Bevel angles of a pipe coating cutback shall

be 30o or less, and the use of 3-5 mm FBE toe is sufficient to reduce the stress concentration.

- Quality of the factory applied coating: End disbondment of a pipe coating can be a result of already poor adhesion due to improper surface preparation or improper decontamination in the plant coating process. Improper surface preparation results in poor angular surface profile and contaminations. Improper coating application results in too high coating porosity, too low application temperature for the FBE, etc. Aside from selection of the coating material which may be specifically required by the client, the other factors are the applicator's responsibility.
- Type of pipe materials: The industry knows rarely about the impact of pipe material types on the factory coating quality and then the pipe end coating disbondment. New pipe materials such as high strength steels (X80/X100 or higher), CRA cladded or lined pipes, stainless steels, etc. pose additional challenges to pipe coating application and pipe coating quality relative to plain carbon steel or lower grade pipes. During the FBE application, a steel pipe undergoes various heating processes and cycles. These new pipe materials would show different characteristics of heat retention and heat soak across the pipe, causing higher fluctuations of temperatures and sometimes cold pipe ends[6]. This phenomenon has posed new challenges, requiring adjustments and additional controls of the coating application processes to ensure good wetting of the FBE powders onto the substrate for good adhesion.

CORRECTIVE AND PREVENTATIVE MEASURES

Corrective and preventative measures can be taken, in order to mitigate the deterioration of pipe ends and end disbondment of pipe coatings. These measures include:

- Design and select a pipe coating system which can be thinner, less absorbent to moisture, more UV and thermal stable, and is less or not constrained by the shrinkage-stress factor.
- Pipe coaters to improve their process capability in order to produce higher quality pipe coatings and to deliver an effective preservation program for long term pipe storage. This is true particularly when the current industry coating standards or project coating specifications have not been specific enough to cover the requirements on coating application of special pipe types, on pipe preservation for long term storage, and on pipe end configuration/protection against end coating disbondment.
- Review and improve related coating application processes for the selected coating system: for examples, to tighten up surface preparation and application temperature control in order to enhance the adhesive strength of the coating to the substrate, to apply multiple layers for thick coating systems rather than in one single coat in order to reduce the stress build-up, and to make correct cutback configuration and FBE toe in order to reduce/minimize the stress concentration.
- Repair localized end disbondment prior to pipe installation: 1) Provide specifications and work instructions to field contractor to repair localized end disbondment prior to pipe installation (Figure 5a and 5b). 2) If the localized end disbondment cannot be repaired, set up a remedial procedure on these pipes to brush back the disbonded coating until sound and tightly adhered coating, and then apply a suitable field joint coating or temporary protective system prior to pipe installation.
- Develop and implement an effective temporary preservation method and program, in order to protect the pipe end cutback and the pipe coating during long term storage. 1) Require a proper preservation system and process on uncoated pipe ends not only for transit but also for long term storage of more than 3 months from the date of completion of the coating application. 2) Add requirements of regular monitoring and inspection of proper preservation of coated pipes to prevent or reduce pipe end disbondment. 3) Set up inspection procedures and criteria to identify those pipes which are to be repaired for localized end disbondment, or to be remediated by brushing the entire cutback, or to be completely stripped and re-coating.

Figure 5a: Surface preparation for repairing a localized spot of coating end disbondment on a 3LPE coated pipe

Figure 5b: Repair a localized spot of coating end disbondment on a 3LPE coated pipe using a primer + adhesive + PE melt stick

TEMPORARY PRESERVATION METHODS

Table 1: Various Pipe End Preservation Methods and Their Effectiveness on Preventing Coating End Disbondment in an Open Environment

	Preservation Method	Pros	Cons	Effectiveness
1	Controlled (no preservation)	No efforts and no costs	Rusting, end disbondment, field joint difficulty and cost	None
2	Tarpaulin cover	Ease of use and removal, internal protection	Need to monitor and change every 3+ months	Good with replaced covers
3	Heat shrinkable sleeve	No rust and easy factory installation, internal protection	Difficulty of removal and re-installation in stockpiling, high cost	Excellent
4	Special End cap	No rust and easy factory installation, internal protection	High cost, potential fitting issues for large diameter pipes and thick coatings	Excellent
5	SPVC End Seal Tape	Little rust and easy factory installation, easy removal	Potential adhesive residues and some tapes contain lead	Good to Excellent
6	Alkyd primer	Ease of use, cheap	Difficulty of removal, Effective less than 6 months	Poor to fair
7	Weld-Through Primer	Ease of use and removal	Effective less than 3 months	Poor to fair
8	Organic phosphate	Ease of use and removal	Effective less than 3 months	Poor to fair
9	VCI impregnated wrap	Ease of use and removal	Ease to be damaged and loss effectiveness	Poor
10	Peelable varnish	Ease of use	Difficulty of removal, Effective less than 3 months	Poor to fair
11	Water displacement oil	Ease of use and removal	Effective less than 3 months	Poor to fair

Outdoor storage of unprotected pipes for a period of up to about a year will not normally cause any significant loss of pipe wall thickness. However, unprotected stockpiles of coated in an open environment shall do nothing good to prevent coating end disbondment. Unpreserved pipe ends may also cause additional surface roughness and blistering of FBE mainline coating which would affect field joint coating application of the pipeline installation. Conditions for storage should be such that water will not accumulate internally, or externally at any supports. Applying conventional temporary preservation paints/products such as a varnish, liquid primer or a rust preservative to the cutback area has recently become common in major international pipeline projects. Over the last decade, various temporary pipe end protective products as directed by clients for their individual pipeline projects have been applied and field tested. In addition, since 2010, an industry initiative has been made in Asia Pacific to investigate and evaluate the effectiveness and efficiency of different alternatives available to mitigate the deterioration of pipe ends and end disbondment of pipe coatings storage over long periods[6]. Table 1 highlights the efficacy as well as pros and cons of various temporary preservation methods used in the industry. The use of a tarpaulin cover can further enhance the performance of any preservation measure for long term pipe storage, but torn tarpaulins shall be replaced or repositioned frequently as required. Without a tarpaulin, the use of heat shrinkable sleeves, special end caps, and SPVC pipe end seal tapes were proven to be quite effective.

SUMMARY

The leading cause of coating disbondment in the cutback area of pipe ends is environmental exposure without any preservation or poorly preserved. The degradation process initiates at a weak or damaged area of the FBE/bare steel interface and a corrosion cell starts. The mechanism includes a combination of electrochemical reactions of the corrosion cell and electroendosmosis blistering. In addition to storage environmental conditions of coated pipes prior to pipeline installation, other contributing factors of pipe end coating disbondment include: properties of the selected coating and adhesive, thickness and cutback configuration of the mainline coating, quality of the factory applied coating and surface preparation prior to the coating application, and the type of steel pipe materials. These additional factors act as intensifiers once the bonding strength of the FBE coating is reduced by the environmental exposure.

Corrective and preventative measures can be taken, in order to mitigate the deterioration of pipe ends and end disbondment of pipe coatings. These measures include: 1) Design and select a pipe coating system which can be thinner, less absorbent to moisture, more UV and thermal stable, and is less or not constrained by the shrinkage-stress factor; 2) Pipe coaters to improve their process capability in order to produce higher quality pipe coatings and to deliver an effective preservation program for long term pipe storage; 3) Review and improve related coating application processes for the selected coating system: for examples, to tighten up surface preparation and application temperature control in order to enhance the adhesive strength of the coating to the substrate, to apply multiple layers for thick coating systems rather than in one single coat in order to reduce the stress build-up, and to make correct cutback configuration and FBE toe in order to reduce/minimize the stress concentration; 4) Repair localized end disbondment prior to pipe installation, or set up a remedial procedure on the unrepairable pipes to bush the entire cutback back to where the coating is intact, and then apply a suitable field joint coating or temporary protective system prior to pipe installation; and 5) more importantly, develop and implement an effective temporary preservation program and use a proper and effective pipe preservation product/method, in order to protect the pipe end cutback and the pipe coating during long term storage.

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