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Preservation of Coated Pipes for Long Term Storage in Tropical Environment

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ABSTRACT

Storage of coated pipe over an extended period, especially in the tropical environment, can lead to deterioration of steel pipe ends and coatings, undercutting or even causing end disbondment of external FBE/3LPE/3LPP/Insulation coating, and general accumulation of dust and debris on internal and external surfaces. Various preservation methods have been investigated to mitigate the negative impact of pipe storage over long periods. Primary attention has been given to reducing the end disbondment that could occur with three layer and multi-layer polyolefin coatings as a result of undercutting corrosion of cutbacks. Among the investigated solutions is the End Seal Tape - a durable tape, featuring a modified pressure-sensitive adhesive which has been developed for water resistance. The method helps maintain integrity of the coating at the cutback, supplementing the performance of other preservation measures. This paper discusses these preservation methods and reviews the development of the End Seal Tape and its successful use in several significant pipeline projects in Asia Pacific and Gulf of Mexico.

Key words: Pipe preservation, long term storage, pipe coating, end disbondment

THE NEED FOR END PRESERVATION OF COATED PIPES

As more and more new oil and gas reserves are developed in more challenging and remote locations, increased transportation difficulties and thus increased long-distance pipeline constructions have been seen. Large pipe volumes are often required on a single pipeline project, and thus pipe coating activities may take place several months or even years before the coated pipes are loaded out for installation. Storage of coated pipes for an extended period, especially in the tropical environment, can lead to deterioration of pipe ends and coatings, undercutting (or corrosion creep) of external anti-corrosion and/or flow assurance coatings, and rust formation of pipe ends due to accumulation of moisture, dust and debris on external and internal surfaces. Moisture and rust weakens the bonding of the anti-corrosion base layer, often being fusion bonded epoxy (FBE), to the steel substrate. Over time, disbondment can occur, particularly at the cutback of thick three layer and multi-layer polyolefin coating or insulation systems due to high residual stress.

The need for end preservation during storage remains the same even with pipes coated with relatively thinner single layer or dual layer FBE coating. 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%[1] 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 detrimental effects of water absorption can be shown during FBE field joint coating. In order to achieve rapid heating of the field joint and hence application of the FBE powder, induction heating coils are employed. Induction heating applied at a high heating rate (>100°C/min) to raise the temperature to approximately 250°C prevents the absorbed water to escape from the film in a controlled manner and will convert the water to steam, resulting in a rapid and large volume expansion. As the temperature is raised, the FBE mainline coating softens and becomes an "elastic film" (a condition when the FBE temperature is above its Tg). The adhesive bond of the FBE mainline coating to the pipe substrate is then put at risk as the cohesive strength of the film becomes greater than the adhesive strength. In consequence, blisters may be formed and observed when the force of water expansion underneath the elastic film exceeds the adhesive strength of the FBE coating film.

FACTORS TO CONSIDER FOR PIPE END PRESERVATION

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

- *Type of 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.
- *Thickness and cutback configuration of the mainline coating:* At pipe coating cutbacks, stress concentration is related to coating thickness and cutback angle. The higher the pipe coating thickness and more acute cutback angle, the higher the residual stress concentration[2]. As moisture and rust weakens the bonding strength of the base coating layer to the steel substrate, 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.
- *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 application resulting in too high interface porosity, coating formulation with too easy to absorb moisture, 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.
- *Storage 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).

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.
- Select pipe coaters who have better demonstrated process capability and track records to produce high quality pipe coatings and to deliver an effective preservation program for long term pipe storage.
- 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 in order to reduce stress build-up, and to make correct cutback configuration and FBE toe in order to reduce/minimize the stress concentration.

- Brushing 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.

Whereas applying conventional temporary preservation paints/products such as a liquid primer or a rust preservative to the cutback area has recently become common in major pipeline projects, there are concerns with the impact of this practice and its associated removal process affecting the schedule, safety, effectiveness, cost and the field joint coating operations, particularly for offshore application. Effective and efficient removal is needed for the factory coating applicator processing extensive stockpiles of coated pipes and for the field joint coating contractor with limited schedule and work space (e.g. on offshore lay barges).

EVALUATION OF DIFFERENT PIPE END PRESERVATION METHODS

Over the last 10 years, we have applied various temporary pipe end protective products as directed by clients for their individual pipeline projects. In addition, since 2010, we have been involved in an industry initiative 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. Primary attention has been given to reducing the end disbondment that could occur with three layer and multi-layer polyolefin coating as a result of undercutting corrosion of cutbacks. The investigated systems were: 1) Control Test Piece (no protection of cutback); 2) Tarpaulin Cover; 3) Special Long End Caps; 4) Alkyd Primer; 5) Weld-Through Primer; 6) Organic Phosphate; 7) Vapor Phase Corrosion Inhibitor (VpCl); 9) Vapor Corrosion Inhibitor (VCI) shrink wrap; 10) Heat Shrinkable Wrap Sleeve (HSS wrap); 11) End Seal Tape; 12) Peelable Varnish; and 13) Water Displacement Oil.

In evaluating the effectiveness and efficiency of these different pipe end preservation methods, the following questions were asked in related to the protective attributes of each method:

- As a rust inhibitor to prevent rust formation?
- As an inhibitor to prevent end creep corrosion/disbondment (ECC)?
- As an inhibitor to prevent blistering of FBE mainline coating during FBE field joint coating application?
- Ease of use (preparation, application, time, labor, HSE, damage…)?
- Ease of removal (cleanness, residue, time, dust, HSE, waste, cost, space…)?
- As an inhibitor to internal corrosion protection?

After application of the end preservation method, all pipe samples were placed in the fog cure area normally used for concrete weight coating application, and were wetted via a water mist spray for 12 hours on and 12 hours off, for a period of 4 weeks. This is to simulate an aggressive corrosion environment. The pipes were then transferred to the long term storage area for a storage period of 3 months (simulating typical short term storage) to 18 months (simulating typical long term storage). The long term storage area was located close to the South China Sea in Kuantan, Malaysia, in order to simulate the worst case storage conditions due to exposure to higher levels of sea-salt particles present in the marine air. Upon completion of the storage periods, the pipes were transferred to a blasting chamber/brushing area. Preserved cutback areas were then blasted and power wire brushed to achieve a cleaning finish of Sa2.5 and St.2 respectively. Visual inspection and salt tests were conducted on the tested pipes. The following parameters were observed and recorded: general visual condition and any damage sign of the preserved cutback prior to cleaning; ease of removal of residual rust/preservative; time required to achieve desired cleanliness; amount of dust generated during cleaning; cleaned surface dust contamination; condition of brush after cleaning; and condition of grit after cleaning. Individual score (1 = not effective; 5 = very effective) and total score (the higher, the better) was then given to each of the preservation method (without or with a Tarpaulin cover) for each evaluation question related to its protection attributes. The results are outlined in Table 1.

Table 1 Protection Attributes of Various Pipe End Preservation Methods

	End Preservation Method	Rust inhibitor	ECC inhibitor	FBE blistering inhibitor	Ease of use	Ease of removal	Internal protection	Total Score
1	Control (no protection)	1	1	1	5	5	1	14
2	Tarpaulin only	3	3	2	3	4	3	18
3	Special End Cap	5	5	3	3	4	5	25
4	Special End Cap with Tarpaulin	5	5	3	1	3	5	22
5	**End Seal Tape**	**5**	**5**	**4**	**4**	**4**	**1**	**23**
6	**End Seal Tape with Tarpaulin**	**5**	**5**	**4**	**2**	**3**	**3**	**22**
7	HSS wrap	5	5	4	3	4	1	22
8	HSS wrap with Tarpaulin	5	5	4	1	3	3	21
9	VpCI	3	3	4	4	1	4	19
10	VpCI with Tarpaulin	3	3	4	2	1	5	18
11	Alkyd primer	3	3	4	4	1	1	16
12	Alkyd primer with Tarpaulin	4	4	4	2	1	3	18
13	Weld-Through Primer	2	2	2	4	5	1	16
14	Weld-Through Primer with Tarpaulin	3	3	2	2	4	3	17
15	Organic phosphate	2	2	2	4	5	1	16
16	Organic phosphate with Tarpaulin	3	3	2	2	4	3	17
17	VpCI impregnated shrink wrap	1	1	1	3	4	1	11
18	VpCI shrink wrap with Tarpaulin	3	3	3	5	3	3	20
19	Peelable varnish	3	3	3	4	1	1	15
20	Peelable varnish with Tarpaulin	3	3	3	2	1	3	15
21	Water displacement oil	1	1	1	4	5	1	13
22	Water displacement oil with Tarpaulin	3	3	2	2	4	3	17

Three systems received the best overall score from this evaluation when a tarpaulin cover was not used, viz., the use of a Special Long End Cap, an End Seal Tape, and a heat shrinkable wrap sleeve. Visual inspection prior to blasting showed only a slight hint of rust formation throughout the whole cutback areas protected by these three systems, after the long term storage under the extreme environment without a tarpaulin cover. Other systems including the control test pipe piece failed to provide adequate protection for the cutback area and significant amounts of rust was formed. The three best systems recorded the lowest time (1 to 3 minutes per pipe end) taken to blast one cutback area. Others recorded the longest time (4-5.5 minutes per pipe end) taken to blast one cutback area. The control test piece recorded an average time (3-5 minutes per pipe end) to complete blasting one cutback area. The three best systems also generated the lowest amount of dust. The requirement of blasting time and dust generation of this evaluation is derived from the need of offshore pipeline installation to achieve a cutback steel surface as clean as possible and ready for heating and welding within the shortest workable time, without generating a source of contamination. Additionally, a good protection system should be non-hazardous and easily contained after removal to prevent the creation of a hazardous waste.

Compared with standard end caps, the Special Long End Cap is customized designed to fit not only the individual pipe size but also the individual cutback length of a pipeline project. The preservation can be achieved as the entire cutback length is covered, however, this customized option is an expensive solution. Should any damage on the special end cap occur during storage and handling, re-installation while the pipe is in a stockpile of coated pipe to assure a perfect fit to the pipe end will be practically difficult. The heat shrinkable wrap sleeve is less expensive than the special long end cap, but will face more difficulties and cause safety concerns due to the heat shrinking process during any re-installation. Therefore, overall the End Seal Tape becomes the most cost effective and workable preservation option.

The use of a tarpaulin cover can further enhance the performance of any preservation measure for long term pipe storage. Tarpaulin covers help to protect bare/coated pipes during storage, against rain, dust, solar radiation and weathering. Storage of pipes over a lengthy period in humid tropical environment may lead to patches of algae accumulating on the surface which is unsightly but has no detrimental effect on the coating. Tarpaulin could also help to reduce the formation and growth of this algae staining. Due to HSE concern, all stacks should be completely covered and secured with weight blocks and cables to mitigate exposure and damage to the tarpaulin when subjected to windy conditions. Torn tarpaulins should be replaced or repositioned as required.

THE DEVELOPMENT OF END SEAL TAPE

During the evaluation program, an End Seal Tape was developed. The End Seal Tape is a durable plasticized PVC tape, featuring a modified pressure-sensitive adhesive. The rubber-based adhesive has been developed for outstanding water resistance. The highly flexible backing has excellent tear and chemical resistance. Table 2 lists the typical property of the End Seal Tape.

Table 2 Physical Properties of the End Seal Tape

Property	Test Method	Unit	Values
Total Tape Thickness	Measurement	Mm (inch)	0.15 ± 10% (0.006 ± 10%)
Adhesion to Steel	ASTM D1000	g/mm (lb/inch)	28.5 ± 10% (27.5 ± 10%)
Tensile Strength	ASTM D1000	g/mm (lb/inch)	260.7 ± 10% (15 ± 10%)
Elongation at Break	ASTM D1000	%	160 ± 10%

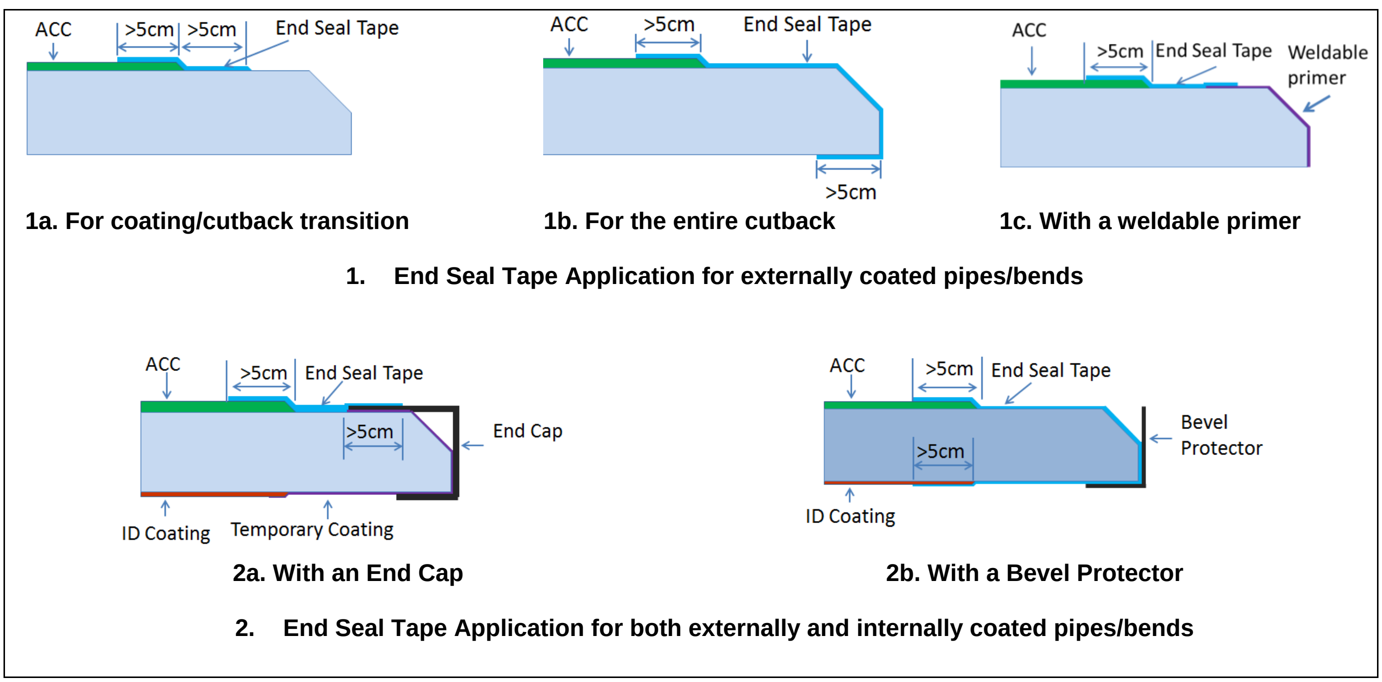

Figure 1: The use of End Seal Tape for different cutback options

The main use of the End Seal Tape is to prevent external anti-corrosion coating (ACC), such as FBE, 2LFBE, 3LPE, 3LPP and thermal insulation systems, such as multilayer PU/PP, from absorbing moisture in the cutback area during an extended storage period. Figure 1 illustrates the configuration of the use of End Seal Tape for different cutback preservation options. To minimize end disbondment of the coating at the cutback area, apply the End Seal Tape starting at least 5 cm (2") from FBE coating cutback (for FBE/DLFBE coated pipes) or from PE/PP chamfer (for 3LPO/MLPP coated pipes) to at least 5 cm (2") beyond the cutback or the FBE toe. Apply 2 full wraps at the start and end, with an overlap of at least 50% at body. If long term protection from pipe end rusting is required, the End Seal Tape can be applied over the entire pipe end and wrapped back into the pipe end internally for at least 5 cm (2"). If an end cap is used, apply the end cap first, then complete the installation as above, and apply 2 full wraps over the end cap / pipe transition to prevent moisture penetration.

The FBE/steel transition area of a FBE coated pipe was power brushed first and then taped with End Seal Tape, immediately after the FBE factory coating application. The pipe was then stored in tropical environment for 1 month, covered with a tarpaulin cover. The End Seal Tape was peeled off at 38 - 40ºC without any cooling, showing no sign of adhesive residues/rust stains and maintaining the original power brushed surface cleanliness (Figure 2). Surface rusting, however, was formed in the un-taped cutback area even underneath the tarpaulin cover.

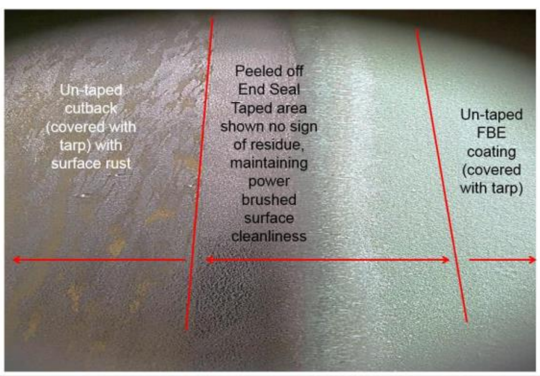

Figure 2: End Seal Tape preserved the transition area of a FBE coated pipe over a month in an tropical environment

Figure 3: A cutback area preserved with End Seal Tape after more than 12 month exposure in a tropical environment

Figure 3 illustrates the application of End Seal Tape onto the entire cutback of a 3LPP coated pipe and the surface conditions of the steel cutback surface before the application and after more than 12 months outside exposure in a tropical environment. The surface was clean with no corrosion products, consistent with the pipe which had just been blasted. No disbondment, uplifting or undercutting was apparent at the steel/coating interface.

An "IR hob" test for FBE blistering assessment was designed, in order to allow the test program to commence before proceeding to full scale FBE coated pipe tests for FBE blistering during a field joint coating application. Four end preservation systems were applied on freshly prepared panels coated with two types of FBE products (within 8 hours after coating application), and were compared with each other and also with unprotected FBE as the control. These four systems are: End Seal Tape, a peelable varnish, VpCI, and VCI with tarpaulin. The protected FBE coated panels were then weathered outside in Kuantan, Malaysia for up to 16 weeks. Coated panels were placed on an IR hob and heated. After the surface temperature had reached 200°C, the panel was removed from the IR hob and cooled to ambient temperature within 4-5 minutes. Then, the surface of coating was observed for blistering and the appearance of the coating surface was documented by photograph. The test results suggested that different FBE products variably resisted blistering during the simulated induction heating test, perhaps due to their different moisture absorption behaviors during the exposure. Among all four different end preservation methods, End Seal Tape was the most effective way of preventing blister formation (Figure 4). Other methods were found less effective, for example, blistering occurred on FBE coated panels preserved with a peelable varnish even after only 6 weeks of weathering exposure.

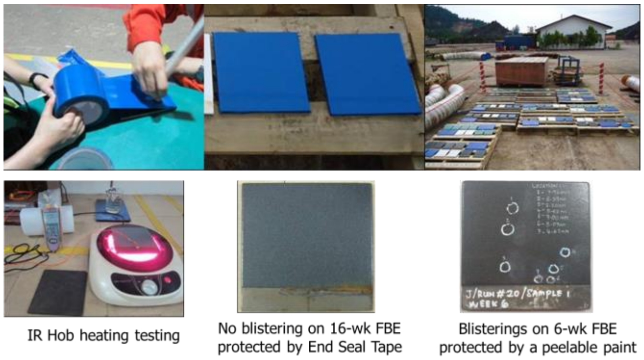

Figure 4: End Seal Tape helped to eliminate FBE blistering during an IR Hob heating test

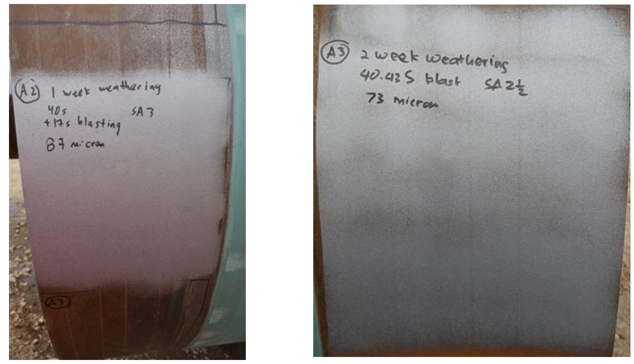

Figure 5: Cutback preserved with End Seal Tape was easily blasted without affecting by residue after 1 and 2 week weathering

One of the major concerns of the use of any adhesive type tape for pipe end preservation is if any adhesive residues left after removal of the tape on previously taped cutbacks would have any significant impact on the surface preparation and cleaning process for field joint coating application and the quality of the field applied FBE coating. The same concern applies to End Seal Tape. To address this concern, numerous laboratory and field trials were conducted. Extensive laboratory test results suggested that no adhesive residues would be left on the pipe surface if the pipe surface temperature is less than 35^{o}C-40^{o}C. Field trials showed that damaged tape left more residue, whether backing was punctured or not, that rapid removal of End Seal Tape left less residue, and that solvents such as acetone or Oxol 100 could effectively remove all adhesive residue even with very heavy deposits. Trials also showed that adhesive residues retained on pipe after End Seal Tape removal degraded or lost tackiness after being left without a tarpaulin cover for a set period of time. In particular, trials showed a 95% reduction in surface areas affected by residues (as detected by touch tackiness or tissue adhesion) in as little as a week of “weathering”. At two week weathering, all residue affected areas were blasted clean to a Sa.2.5 finish within the reference time of 40 seconds (the time used to blast a rusted bare pipe section using a manual pot blasting equipment), as shown in Figure 5. The mechanism of degradation is thought to be a combination of 1) oxidation of the adhesive, 2) UV degradation of the adhesive and 3) low molecular weight components in the adhesive diffusing. All 1-week and 2-week weathering sections passed the coating QC tests (holiday test at 3KV, 48 hour hot water soak and 28 day cathodic disbondment) after FBE coating. Accordingly, the recommendation is to remove all the End Seal Tape prior to load out of the pipe in the coating yard. This will enable all pipes to have a minimum period of 1 week weathering naturally prior to going on the lay vessel. If it is desired to remove the tape in or just prior to firing line operations, it is recommended that the removal is to be done at a pipe surface temperature of less than 35^{o}C-40^{o}C, or the taped steel areas can be wiped with acetone to remove all residues prior to blasting.

CASE HISTORIES

Since 2012, the End Seal Tape has been used on several significant projects in Asia Pacific and Gulf of Mexico as one of the main end preservation methods.

The Chevron Wheatstone Project reported the pipe end conditions after removal of End Seal Tape by the lay contractor as follows: “The steel looks in good condition (bright steel at steel/ FBE interface with light rusting on last 100mm cutback to bevel) and there is minimal residual adhesive left on the steel when the tape is removed at approximately 22 °C. We do see some traces of the adhesive at tape overlap areas but these are readily removed by blasting."

Other pipeline projects using End Seal Tape included Inpex Ichthys Project, Apache's Julimar Project in Australia, and PTT's Nakhon Sawan Project in Thailand.

BP Mad Dog Phase II Project set up a testing program to evaluate the effectiveness of various end preservation methods after more than one year exposure in the Gulf of Mexico. The sample population contained two pipe samples coated with 3LPP with cutbacks protected by End Seal Tape. Both ends of each joint were taped and sealed to monitor corrosion on the cutback and internal surfaces. The performance of the End Seal Tape was impressive, and appeared most likely to survive extensive handling among all preservation methods evaluated. An initial cut was made into the End Seal Tape followed by unwrapping in a reverse method to application. The tape was tightly adhered requiring moderate effort to remove. The tape peeled cleanly with no visible adhesive residue on the coating surface, the tape backing, or the steel cutback. The cutback surface exhibited a very light tackiness from the 11:00 to 1:00 positions. No tackiness was detectable on the sides or bottom of the cutback. On removal of the tape, the appearance of the steel cutback was similar to freshly blasted pipe. The outer surface of the pipe was moderately pitted from seamless manufacturing and the removal of mill scale. Despite this surface, the pits were well defined, consistent with the absence of corrosion. The surface was clean with no corrosion products, consistent with pipe which had just been blasted. No uplifting or undercutting was apparent at the steel/ coating interface.

CONCLUSIONS

Various preservation methods have been investigated to mitigate the negative impact of pipe storage over long periods and the results have been analyzed. Primary attention has been given to reducing the end disbondment that could occur with three layer and multi-layer polyolefin coatings as a result of undercutting corrosion of cutbacks. The best performance was realized with End Seal Tape - a durable tape, featuring a modified pressure-sensitive adhesive which has been developed for water resistance, and ease of application and removal. The method helps maintain integrity of the coating at the cutback, supplementing the performance of other preservation measures.

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REFERENCES

1. A. Kehr, *Fusion-Bonded Epoxy (FBE): A Foundation for Pipeline Corrosion Protection*, NACE International, Houston, TX., 2003, p. 534
2. A. Moosav, B. Chang, and K. Morsi, "Failure Analysis of Three Layer Polypropylene Pipeline Coating", Corrosion/2010, paper no. 10002 (Houston, TX: NACE, 2010), p. 6