New developments in high performance coatings

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ABSTRACT

As the demand for oil and gas becomes greater and energy prices increase, the development of gas and oilfields in remote locations becomes more attractive and needed. In North America, pipeline activity is becoming more focused in the Arctic regions. As a result, TransCanada PipeLines Limited and its partners have been involved in demonstration projects to evaluate new technologies in these remote and challenging environments.

The Godin Lake Loop project consisted of 2.0 kilometers of NPS 36 X100 grade pipe and 1.6 kilometers of NPS 36 X120 grade pipe. Bredero Shaw's High Performance Composite Coating (HPCC) was selected for the mainline coating of the construction project to test out proposed Arctic construction materials and practices. HPCC is a homogenous, multi-component coating designed to protect buried oil & gas pipelines in environments where superior corrosion performance and mechanical protection properties are required.

The pipe was coated with HPCC at Bredero Shaw's Camrose, Alberta plant. The process worked smoothly and the plant quality tests gave excellent results. The experience during construction was also very favourable. Very little damage was observed during unloading, stringing and bending even at construction temperatures as low as -45ºC. Field joint systems and repair materials were also applied with favourable results. Canusa's three layer heat shrink sleeve, GTS-65, was applied successfully at very low construction temperature, with adequate productivity and good adhesion properties.

1 INTRODUCTION

As the demand for oil and gas becomes greater and energy prices increase, the development of gas and oilfields in more remote locations becomes more attractive and needed. In North America, pipeline activity is becoming more focused in the Arctic regions. In these remote and challenging environments, pipeline companies are looking at innovative technologies to reduce their risks, lower their costs and to ensure viability of these projects.

Among the challenges are:
- Partnering relationships with innovative companies to introduce new materials including high strength steels and high-integrity coatings,
- Ensuring that the use of new technology meets the higher demands on pipeline integrity, and

- Proving that the materials and any subsequent processes will be able to meet the challenges of working in a harsh and remote environment.

TransCanada is a leading North American energy company with a pipeline network of 41,000 kilometers that transports most of Western Canada's natural gas production to the fastest growing markets in Canada and the United States. It has been involved in a series of technology demonstration projects with its partners to address future pipeline requirements in the Arctic area and provide cost effective solutions. TransCanada's newest demonstration project is the Godin Lake Loop, which was installed in February 2004. The Peerless Lake Project consists of 17.7 kilometers of NPS 24 diameter X70 line pipe near the community of Wabasca, in Northern Alberta. This project was looped with a 3.6 kilometers section of NPS 36 diameter called the Godin Lake Loop.

Bredero Shaw's High Performance Composite Coating (HPCC) was selected for the mainline coating. Bredero Shaw, a ShawCor Company, is a global leader in pipe coating solutions. It has over 27 coating application plants located globally, producing a variety of coatings for onshore and offshore pipelines. With over 40 leading technologies, HPCC represents its most innovative and economical coating solution for major pipeline projects.

2 PROJECT

The main focus of the Godin Lake Loop project was to demonstrate the effectiveness of high strength steels and a high-integrity coating system as an economical solution for pipeline construction and operation in an Arctic environment. JFE Steel Corporation supplied 2 kilometers of NPS 36 diameter by 13.2mm X100 line pipe[1.] Nippon Steel Corporation supplied 1.6 kilometers of NPS 36 diameter X120 line pipe[2], which ExxonMobil has been developing with Nippon Steel since 1993. Bredero Shaw's High Performance Composite Coating (HPCC) was selected as the coating[3]. The Godin Lake Project was located in Northern Alberta and took place in the winter to allow for a wide range of winter construction conditions, expected during construction in an Arctic environment, to be evaluated.

3 COATING SELECTION

TransCanada has extensive experience with the construction of Fusion Bonded Epoxy (FBE) coated pipelines and some experience using dual layer FBE and HPCC coatings. They have recently carried out laboratory and field assessment of in-service pipelines with each type of coating. The HPCC coating was selected for the project based on technical and economic consideration for future projects.

3.1 Coating comparison

The mainline coating selection was based on meeting the stringent requirements of the project, most notably cold weather handling and construction with temperatures in the range of –40°C to –50°C. Also high on the selection criteria was the requirement that the coating have high integrity to provide reliable service during its lifetime. The coating systems under consideration included single layer FBE, dual layer FBE, three-layer polyethylene and HPCC.

Dual layer FBE, often called Dual Powder System (DPS) or Abrasion Resistant Overcoat (ARO), consists of an abrasion resistant FBE overcoat applied over the corrosion resistant

FBE layer. HPCC is a homogenous, multi-component coating designed to protect buried oil and gas pipelines in environments where superior adhesion, impact, water permeation resistance, high temperature performance properties and cathodic disbondment protection are required. Table 1 shows a broad comparison of advantages and disadvantages of each system.

3.2 Coating Experience

HPCC was developed in the early 1990's and has since been used on over 1000 kilometres of pipeline in a variety of critical environments where FBE coating is perceived to be deficient. These include environment with rocky terrain, acid generating rock environment and wet soil environment with a hot pipeline. Prior to commercial sales, a test loop of several joints of 24 meters long coated pipes, together with various alternatives joint coatings were installed in service by TransCanada PipeLines Limited in 1993. The test area was selected downstream of a compressor station where the pipeline maintained temperatures in the 45^{o}C range, and the soil was mixed sand and clay with a high water table. Several years later, the segment of pipeline was dug up and the HPCC coating was found to be in excellent condition[4]. In 2004, after 11 years of service in the ground, TransCanada re-exposed and investigated the HPCC coated pipeline using a combination of laboratory testing and field investigations techniques[5]. In 1997, another major transmission company selected HPCC for a 540 kilometres NPS 30 diameter pipeline used for transporting bitumen.[6]

3.3 Repair/Joint Protection

In challenging and remote environments, the ability to easily repair and protect the field joint is critical in building a high-integrity pipeline. Repair procedures used for HPCC are no different than those used on conventional three-layer coatings. In the event of minor damage to the outer polyethylene, the area is first cleaned to remove any foreign material and then the polyethylene is reheated locally and a hot melt stick repair is performed. Where there is damage through to the FBE coating and the diameter of the damage is less than 25mm, a two-part liquid epoxy primer is applied followed by a hot melt stick or patch material. Where the diameter of the damage is >25mm, a two-part liquid epoxy primer is applied followed by a hot melt stick or heat shrink sleeve.

There are currently several methods of completing the coating on the joint after welding has been performed in the field. These include:

- three-layer heat shrink sleeve (a combination of a liquid epoxy coating and a multi-layer shrink sleeve);
- an epoxy or urethane liquid coating, and;
- multi-component powder coating.

Each method has its own limitations, which tend to restrict its usage to select environments and construction conditions. Ease of application and reduced application risks during construction are prominent selection criteria. Multi-component powder coating offers the greatest potential solution in protecting the pipeline in its entirety with reliable high performance; however mechanized equipment costs and reliability are considerations. Liquid epoxy or urethane coatings are easily applied but special care is required in treating the overlap area to ensure reliable bonding to polyolefin coatings. So far, the three-layer heat shrink sleeve has been used most widely and has the project experience and proven integrity performance required, provided induction heating is used to give adequate and uniform preheating of the girth weld area.

For this pipeline, the majority of field joints were protected using the combination of a liquid epoxy and a multi-layer heat shrink sleeve, Canusa GTS-65[×] field joint system. Approximately 10% of the welds were coated with an all liquid coating system.

4 HPCC COATING

High Performance Composite Coating[+] is a powder-coated, multi-component coating consisting of a FBE layer, a medium density polyethylene outer layer and a tie layer containing a chemically modified polyethylene adhesive. The tie layer is a blend of adhesive and FBE. This blend produces a physical interlocking of the components with no defined interface and single layer coating behaviour. The adhesive and polyethylene are similar to each other and intermingle easily to disperse any interface. This system provides excellent adhesion to the pipe surface with inherent shear resistance properties, impact and cathodic disbondment resistance and very low moisture permeability. The selected materials allow for operating temperatures up to 85^{o}C and installation temperatures down to -50^{o}C.

In typical three-layer systems, the polyethylene layer is applied by side extrusion for large diameter pipes and by crosshead extrusion for smaller diameter pipes. However, the problem with extrusion on large diameter pipes with raised spiral or longitudinal welds is poor coverage of the welds especially where the profile is pronounced. There is the tendency to form voids at the weld neck area which produces pinholes and entraps water during the cooling stage. Rollers have been used to compress the molten polyethylene around the weld seam with some success in longitudinal welds. There is also a reduction of coating thickness at the top of the weld, which results in increased material usage to achieve the minimum required coating thickness. Powder coating avoids these problems. HPCC uses a proprietary process for applying all of the components in powder form using electrostatic powder coating techniques. The process provides versatility in customising the thickness of the components of the coating system, as well as produces the composite system as described previously. It also uses a proprietary internal quenching process rather than relying solely on spraying or flooding of the pipe exterior. As a result of this process, the coating solidification front moves from the steel-primer interface towards the outer surface. This minimises the formation of voids and internal stresses, which can be formed when the outer surface “freezes” before the bulk of the material.

Multi-layer coatings offer a means of countering the weakness of single layer coatings by combining materials in such a way to create a broader base of advantageous characteristics. It is based on two principles which are: (i) optimization by combining favourable properties of different coating materials, and (ii) functional separation of performance such as corrosion protection and protection against mechanical damage[7]. Three layer pipeline coatings utilise a layer of FBE, a polyolefin outer layer and an adhesive tie layer. FBE is selected because of its excellent adhesion to steel and their cathodic disbondment resistance. This is achieved because of the strong polar molecular structure, which is also responsible for its high moisture absorption. Polyolefins are very non-polar, and thus have low moisture absorption and good electrical insulation properties. Interlayer adhesion is attained with a chemically modified polyolefin material with polar end groups, which can form linkages between the non-polar

× GTS-65 is a proprietary CANUSA product.
(+) HPCC is a proprietary Bredero-Shaw product.

polyolefin and the polar FBE. Thus multi-layer systems can offer excellent adhesion and corrosion properties as well as resistance to mechanical damage.

4.1 Composition

There is no consensus on the optimum thickness of individual materials that will produce an effective coating. The thickness of FBE component has ranged from 100μm to 400μm. The FBE layer can be viewed partly as a corrosion coating and partly as an adhesion layer for the coating to steel interface. As an adhesion layer, thicknesses in the range of 50 - 72μm, have been used[8]. However for a corrosion coating, the minimum thickness of 125μm is recommended. Optimization studies[9] (see figure 1) have shown that a FBE primer thickness of 175μm is a good base for corrosion resistance when used in conjunction with the powder polyolefin adhesive and polyethylene topcoat. Higher levels of epoxy, above 250μm, have been used in three layer coatings on some critical areas, especially offshore pipelines. Coating costs will increase considerably as the epoxy thickness trends up and there may be application process implications as well. Higher thickness increases the corrosion performance but this has to be balanced with increasing cost. The powdered adhesive component is used strictly as a functional "tie-layer" between the epoxy and the topcoat, and only a small amount of material is necessary to obtain good chemical bonding and melt blending of the components to form a composite material. Typically about 125-150 μm is used for the powder adhesive tailored for this technology.

Polyethylene layer thickness is selected to withstand environmental conditions, especially impact during transportation and laying of pipe. Typical thickness can range from 500 μm to several millimeters. The polyethylene top layer serves several different functions: chemical and moisture barrier, mechanical protection and weather resistance. Polyethylene thickness plays a role in overall corrosion performance of the coating, with slightly better cathodic disbondment performance with increasing thickness. However, as shown in figure 2, at thicknesses above 1 mm, there is an increase in cathodic disbondment performance but it does not appear to be substantial as in the case of FBE. The tendency has been to use thicknesses of up to 3 mm of low density polyethylene based on the supposition of fairly severe transportation and construction scenarios. However, recommendations are for lower thickness especially with medium and high density polyethylene, which has better impact resistance. Typical impact strength requirements for three-layer polyethylene are in the range of 5–7 J/mm.

4.2 Application Process

The application process for HPCC consists of similar steps as required for FBE coating. The steel pipe is prepared by pre-warming in a hot water rinse, followed by abrasive blasting to achieve a near white metal finish and a specified anchor pattern. The pipe is then inspected for defects such as slivers, which can be removed by grinding. Phosphoric acid washing and deionised water rinsing is carried out followed by induction heating to the recommended powder application temperature. The three components are applied sequentially to the hot pipe in the same powder booth. After fusing and curing is completed, the pipe is cooled using both internal and external water quench. Finally, the coating is inspected, marked for identification, and tested for quality conformances.

4.3 Pre-qualification

HPCC coating cannot be adequately characterized using qualification tests designed for either single layer FBE or extruded polyethylene coatings. Its application of powdered components allows it to share characteristics with FBE, especially in properties involving its adhesion to the steel substrate. In through-thickness properties (those affected by the bulk of the materials rather than interfacial characteristics), its characteristics are similar to those of polyethylene type coatings. However, powder coated polyolefin behaves differently from extruded polyolefin. In this respect, the tests and the interpretation of the results for this coating system need to be carefully drawn from the respective FBE and polyethylene coating standards. A variety of tests were evaluated for suitability in measuring the interlayer bond strength. Peel tests were not completed because the polyethylene layer could not undergo sustained peel. Shear tests showed no movement even at high temperatures. Shear failure, when it occurs, only does so within the weaker polyethylene outer material and only above its softening point. The gluing of aluminium dollies allowed Elcometer pull-off adhesion tests to be carried out. The dollies were then pulled off at a constant rate using a tensile testing machine. The results were always failure at the dolly adhesive. In no case was failure at the FBE-steel interface evident. Shear strengths values in excess of 17 MPa are typically obtained

The external polyethylene component of HPCC does not exhibit the frozen in stresses that are typically seen in three layer systems. In three layer systems, the polyethylene layer is extruded and then wrapped over the pipe. This extrusion and stretching process can induce very high elongational stresses in the top layer that then become frozen in when the material is quenched. During storage and in service, these stresses can then act to produce shrinkage at the cutback area and can even result in disbondment at the FBE-steel interface. The polyethylene powder application in HPCC does not involve any directional forces on the polyethylene material that would result in built in stresses. There is no evidence that HPCC suffers from the same disbondment failures as three layer systems that are becoming more widespread. In integrity digs, as well as pipe that have been stored at the coating plant yards, there are no signs of disbondment at the edges.

Qualification testing was carried out for HPCC and is presented in Table 2. Testing followed CSA methodology, but was modified to cover additional criteria that would be expected in arctic environments. HPCC is covered under the Canadian Standards Association Oil and Gas Standard CSA Z245.20-02 system B2 (coating that consists of a powdered epoxy primer, a powdered copolymer adhesive and a powdered polyethylene outer layer)

5 CONSTRUCTION

The 3.6km of NPS 36 pipe of mostly 12m length joints was coated with HPCC at Bredero Shaw's Camrose, Alberta plant. The coating was comprised of a minimum of 150μm of FBE with 125μm of adhesive and 475μm of medium density polyethylene for a total minimum thickness of 750μm. The specification requirement was CSA Z245.21 system B2 with some additional requirements by TransCanada. The coating application went smoothly. Incoming raw material testing and finished product testing was carried out according to CSA Z245.21, and all quality tests gave excellent results. There were no holidays in the coating at the plant prior to shipping.

5.1 Handling and Bending

The pipe was transported from the plant site to the pipeline right-of-way by truck. During the unloading and stringing process, there was very little damage observed. Field bending can be a cause for substantial coating damage due to a variety of reasons. Some of the possible causes of damage to the coating typically observed in pipeline construction include impact damage from multiple handling and maneuvering of the pipe, abrasion in bending machines with no rubber pads or pads contaminated with gravel, and poor flexibility of the coating especially at colder temperatures. The HPCC coated pipe was successfully bent at temperatures as low as –45°C without damaging the coating. One advantage of using a coating such as HPCC for Arctic construction is the ability to bend the pipe at lower temperatures than an equivalent FBE coated pipe. This is because of the thinner FBE layer in HPCC giving the coating more flexibility in cold weather. FBE flexibility is controlled by thickness. Thinner FBE have greater flexibility but lower impact resistance. HPCC retains its impact resistance with a thin FBE layer due to the very ductile outer layer of polyethylene.

5.2 Girth Weld Coating

Two girth weld systems were used for this project to evaluate competing technologies and in order to maintain flexibility in supply of materials and availability of contractors for future construction[9]. The first system was a three-layer shrink sleeve, while the second system was a full liquid system. System one, which was the Canusa GTS-65 hot melt sleeve with a liquid epoxy primer was used as the primary girth weld coating on 90% of this project.

5.3 Coating Repairs

The average number of holidays requiring repair on an FBE coated pipeline is on the order of 5 to 10 per pipe joint. On this HPCC trial, the number of holidays per pipe joint was approximately 0.1, or 50 to 100 times less than with FBE. Of these holidays, 50% were due to damage caused by positioning the welding shacks on the pipe, 25% were due to the weld band area not being completely covered, 15% were slivers, and 10% were other contact damage[3].
The main concern with the coating during construction was from the joint welding process. Prior to welding, a band was clamped to the end of the pipe to position the welding machine. The welding band had support legs that were placed on top of the coating. Prior to welding, the pipes ends are heated to temperatures in excess of the melting point of polyethylene in order to ensure the welds do not suffer from cracking. This resulted in melting of the polyethylene layer, and flow of the polyethylene underneath the welding band support legs. This material had to be dressed off, thus increasing the amount of weld joint coating materials required to cover the weld affected region.

It is estimated that with additional care in padding and positioning the welding shacks as well as ensuring the weld band damage is properly repaired, 75% of the coating holidays could be eliminated. This would result in an unprecedented level of coating quality and an extremely reduced level of cathodic protection current required to ensure the integrity of the pipeline in the future. The HPCC pipe loop was designed with isolating unions at each end to allow measurement of the cathodic requirement of the pipeline.

6 FUTURE DEVELOPMENT

It has become known that the material properties of high-strength steels may be affected by pipe preheating during coating application. The evidence shows that steel may strengthen and strain harden at preheat temperatures greater than 200°C. This can then influence the outcome of strain based designs. Research and development was performed to apply HPCC coating at reduced preheat pipe temperature. Bredero Shaw has now developed a low application temperature HPCC with pipe preheating limited to 200°C while maintaining the performance characteristics of the product.

7 CONCLUSION

A new high performance coating (HPCC) produced by melt fusing all components in powder form, has been developed for the pipeline industry. It has been successfully installed on a number of pipeline projects to date, filling a gap where FBE coatings have been determined to be deficient. The superior mechanical and corrosion resistance properties can result in many cost savings during construction making it a cost-effective coating solution for pipeline operators[10]. The use of a totally powder application process provides a unique structure and makes it very versatile where thickness of the components can be adjusted for any special requirements, and raised welds can be coated very efficiently. The coating has undergone considerable testing, meeting all the requirements of CSA Z245.21 and exceeding many of the test results for conventional coating systems.

HPCC was selected by TransCanada in the Godin Lake Loop demonstration project to evaluate new technologies in remote and challenging environments for anticipated arctic pipeline construction. The application process and the construction process went exceedingly well with no major problems. Very little damage on the coating was observed during unloading, stringing and bending even at construction temperatures as low as -45ºC. Field joint systems and repair materials were also applied with favourable results.

Table 1 Comparison of coating candidates

COATING	ADVANTAGES	DISADVANTAGES
FBE	• Excellent corrosion resistance. • Does not shield cathodic protection system. • High adhesion limits damaged area.	• Low impact resistance results in considerable field damage. • Sensitive to steel surface preparation and condition. • High moisture absorption and permeation especially at higher temperatures. • Affected by UV during storage.
DPS	• Excellent abrasion and damage resistance. • Excellent corrosion resistance	• Low flexibility • High cost • Sensitive to steel surface preparation and condition • High moisture absorption and permeation especially at higher temperatures. • Affected by UV during storage.
HPCC	• Excellent handling • Excellent corrosion resistance • Excellent low temperature impact resistance and flexibility • Excellent moisture resistance • Excellent raised weld coverage	• Thickness constraints- 1.5 mm • Sensitive to steel surface preparation and condition
3LPE	• Excellent handling • Excellent low temperature flexibility and impact resistance • Excellent corrosion resistance • Excellent moisture resistance	• Prone to thinning across raised weld seams. • Side extrusion prone to delaminations and voids. • High cost due to minimum thickness constraints • Sensitive to steel surface preparation and condition

Table 2 Qualification results for HPCC system[11]

Test	Method	Condition	Results
Thickness (μm)		FBE Total	200 1250 - 1500
Coating Adhesion (Hot water soak)	CSA Z245.20-02 Clause 12.14	48 hrs @ 75°C 14 day @ 75°C 28 day @ 75°C 24 hrs @ 95°C 14 day @ 95°C 28 day @ 95°C	1 1 1 1 1 1
Coating Adhesion (Hot water soak) with Prescribed lines	CSA Z245.20-02 Clause 12.14	48 hrs @ 75°C 14 day @ 75°C 28 day @ 75°C 24 hrs @ 95°C 14 day @ 95°C 28 day @ 95°C	1 1 1 1 1 1
Cathodic Disbondment (mm)	CSA Z245.20-02 Clause 12.8	28 day @ 20°C 14 day @ 50°C 28 day @ 50°C 24 hr @ 65°C 48 hr @ 65°C 14 day@ 65°C 28 day @ 65°C 14 day @ 80°C 28 day @ 80°C	2.1 3.3 10.0 1.5 1.9 5.6 13.0 5.8 9.0
Cathodic Disbondment (mm)	CSA Z245.20-02 Clause 12.8	14 day @ 0°C, 14 day @ -15°C, 14 day @ 15°C (42day)	1.5
Impact Resistance (J)	CSA Z245.20-02 Clause 12.12	-50°C -40°C -30°C -10°C 0°C 20°C 50°C 65°C 80°C	>10 >10 >10 >10 >10 9.75 9.5 8.25 5.5
Coating Flexibility (d.p.p.d.)	CSA Z245.20-02 Clause 12.11	-40°C –30°C	>2.5 >2.5
Hardness (Shore D)	ASTM D2240-86	-50°C -40°C –30°C -10°C 0°C 20°C 50°C 65°C 80°C	70 68 67 64 64 61 55 52 49

Figure 1 Effect of FBE layer thickness on cathodic disbondment radius.

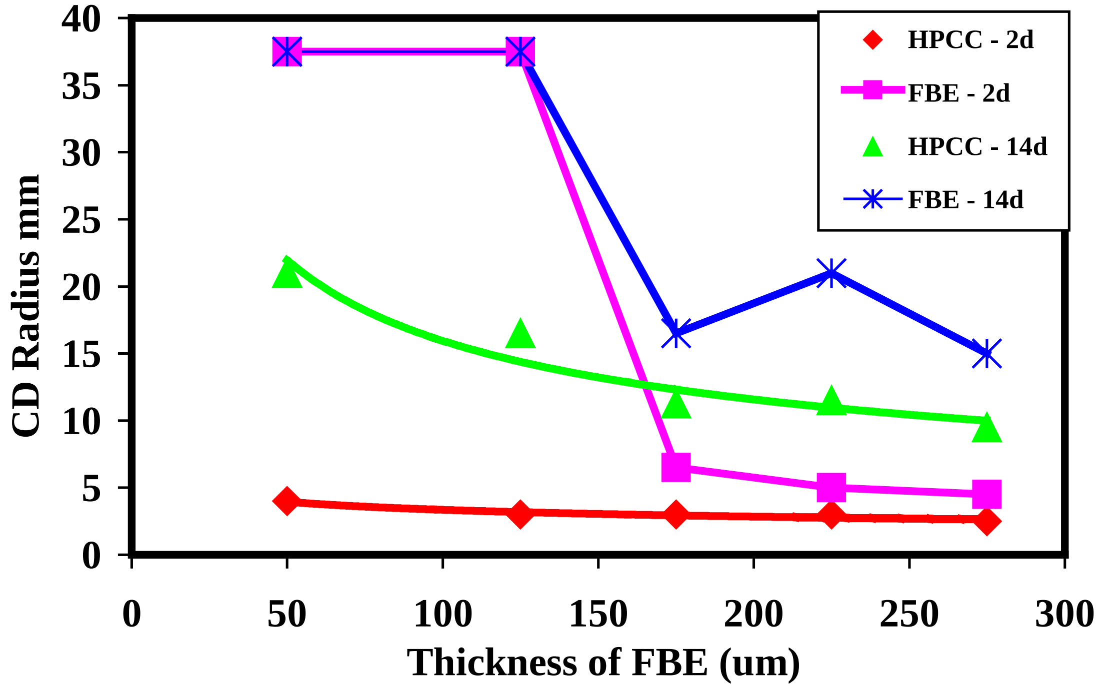

Figure 2 Effect of increasing high density polyethylene thickness

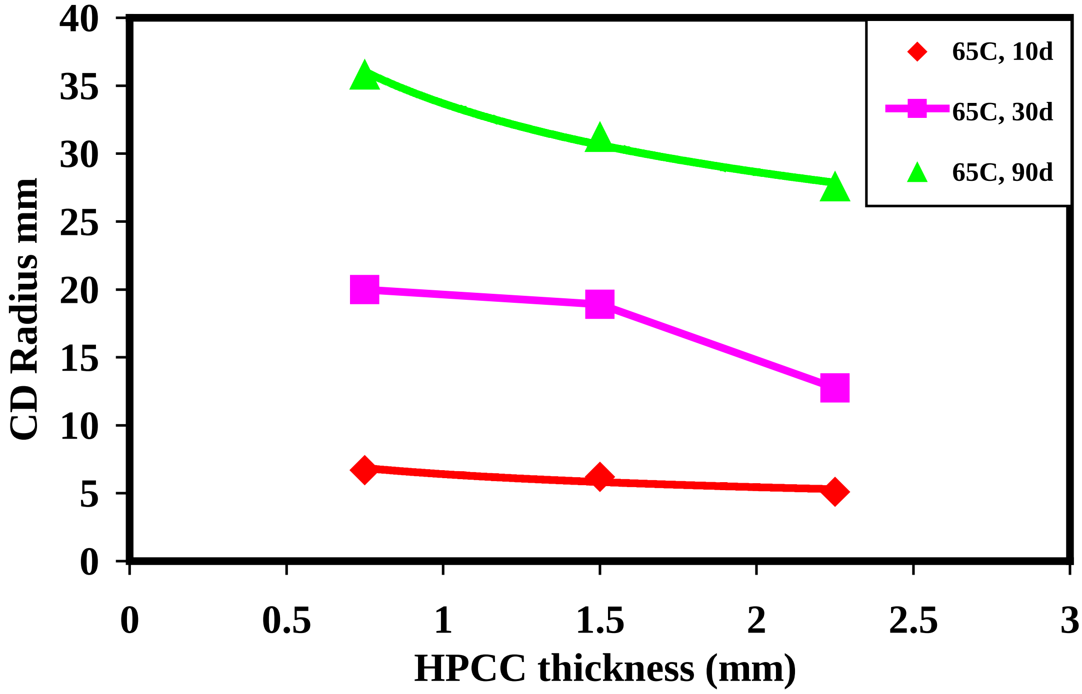

Figure 3 Canusa GTS-65 three layer heat shrink sleeve on a field joint.

Figure 4 Lowering in of pipeline.

Figure 5 Backfilling of pipeline.

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