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A NEW APPROACH TO HIGH PERFORMANCE POLYOLEFIN COATINGS

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ABSTRACT

This paper discusses two common problems, “weld tenting” and low coating thickness over the external weld, and their causes in traditional three layer polyolefin pipeline coatings. To tackle these problems, a new approach to applying multilayer polyolefin coating to pipes is introduced. The new system consists of side-extruding high density polyethylene over a graded structure polyethylene (GSPE) coating. This study demonstrates that the new coating approach can provide exceptionally uniform coverage of external welds, successfully eliminate “weld tenting”, and significantly reduce residual stresses in the coatings.

Keywords: multi-layer polyolefin coatings, weld geometry, fusion bonded epoxy, polyolefin, cooling method, weld tenting.

INTRODUCTION

The presence of oxygen and water at a steel surface is one of the most common causes of corrosion, but because complete exclusion of either is extremely difficult, the preferred route is to minimize the presence of both. Since access to the steel surface can occur both by diffusion through the coating, and by migration along the steel/coating interface, this involves using materials that are resistant to permeation by moisture and oxygen, which adhere very well to the steel surface, and which are highly resistant to being dislodged by water or cathodic disbondment.

Fusion-bonded epoxy (FBE) combines very low permeability to oxygen with excellent adhesion to properly prepared steel surfaces and excellent resistance to cathodic disbondment. However, it is permeable to moisture, and is easily damaged by mechanical impacts. It is also quite costly and has a tendency to disbond when exposed to hot, wet conditions for long periods of time. It is therefore beneficial to cover the FBE with a relatively thick layer of a polymer that is highly resistant to moisture permeation, and which is both flexible and highly resistant to impact damage. Polyolefin resins, such as polyethylene and polypropylene, are particularly well suited, combining low cost with very low moisture permeability, toughness and, in the case of polyethylene, exceptional low temperature flexibility. Because polyolefins do not bond to FBE, the two layers are bonded together with an adhesive which is typically a polyolefin resin that contains polar groups to interact with, or preferably react with the FBE. Such "3-layer" polyolefin coatings are widely used to protect metal pipelines, especially oil and gas pipelines, from both corrosion and mechanical damage.

In conventional 3-layer polyolefin coatings, the outer polyolefin covering is usually applied by extrusion. When the cross head extrusion process is employed, the polyolefin is extruded onto the pipe surface through an annular die as described in Trzecieski et. al. [1]. However, due to the limitations on the diameters of cross head extrusion dies, this process is limited to pipes with smaller diameters. For larger diameter pipes, the outer polyolefin covering is normally applied by a side-wrap extrusion process wherein a continuous sheet of molten polyolefin is wrapped helically around the exterior circumference of the pipe immediately after the FBE and adhesive have been applied.

Most pipes used in oil and gas transmission pipelines are welded pipes. Pipes with diameters of, 24" (610 mm) or less are commonly welded using electric resistance welding (ERW), resulting in weld seams which are flush with the body of pipes. Therefore, these pipes can be coated without any concern about covering a raised weld. However, the manufacturing processes used to produce pipes with diameter larger than 24"OD (610 mm) produce welds that protrude both above and into the pipe diameter. Figure 1 is a photograph of the cross section of a typical protruding weld on a pipe.

There are two methods for manufacturing large diameter pipes. The most popular one is to bend steel plates from flat into a "U" shape and then further into an "O" shape. The edges are welded together to form a single longitudinal seam weld pipe, commonly referred to as a "long seam" pipe. The second method is to continuously form and weld narrower steel plate in a spiral fashion to create a spiral weld pipe, commonly referred to as "spiral" pipe. Regardless of which procedure is used, current welding techniques produce welds that protrude up from the external surface. Different weld geometries can be found in larger diameter pipes, with the shape and the height of the weld varying from "long seam" to "spiral", and from manufacturer to manufacturer. The terminology used to describe the shape of a weld is shown in Figure 2. Weld geometry is an important factor in coating process, especially when applied by the side-wrap extrusion process. The ideal shape of weld is short and with round top which makes a smooth transition from the pipe body as illustrated in Figure 3(a). However, this configuration is rarely achieved unless the weld seam is ground to shape with an additional step. Generally, weld seams similar to those in Figures 3(b) to (e) are obtained from the pipe manufacturing plants.

In the conventional 3-layer side-wrap extrusion process, soft silicone rubber rollers are used to apply pressure to the extruded sheet to improve contact between the layers, promote adhesion and smoothing of the polyolefin overlaps, and push the molten polymer into to surface irregularities, including the raised weld. The effectiveness of the silicone roller depends largely on the weld geometry. With high raised welds or square welds as shown in Figures 3(b) to (e), molten polymer can be pushed into the weld on the incoming side of the weld as the pipe rotates towards the roller. However, it may not be able to improve the contact on the exit side, resulting in voids at the weld neck (see Figure 4). In particular, it is more difficult to attain uniform coverage over the weld with "spiral" pipes than with "long seam" pipes.

With the traditional side-wrap extrusion application, protruding (raised) weld seams lead to a variety of coating problems. The most common problems are:

- Tenting, in which voids develop at the base of the weld neck, as shown in Figure 5.

- Thinning across the top of the weld, resulting in the thickness of the coating being well below specification at the top of the weld.

Inadequate thickness across the top of the weld is often overcome by applying a greater thickness to the body of the pipe in order to bring the thickness over the weld up to the minimum requirement. This practice decreases output, increases cost, and can lead to seriously high residual stress in the polyolefin jacket. It also becomes less effective as the design thickness of the coating is increased. In principle it should be possible to apply extra material along the seam, and to that end a number of "weld seam compensators" have been designed [2,3]. These tend to be mechanically complicated, challenging to use, and of limited effectiveness in resolving the issue. They are particularly ineffective with spiral-weld pipe, for which weld compensation equipment is very much more difficult to design. Not only is there a much greater length of weld seam to contend with, but there is the periodic cross-welding of plates, forming welds that are at right angles to the spiral weld. Double-jointed pipes have the additional problem that the joints are deliberately offset at the girth weld for both longseam and spiral pipe. All of these factors have confined the use of weld seam compensators largely to single joint longseam pipe.

In addition to weld geometry, water quenching plays an important role in causing "weld tenting" and non-uniform thickness in the side-wrap extruded process [4]. Polyethylene (PE) and polypropylene (PP) exhibit significant volume shrinkage (10-25%) from the melt stage to the solid stage. In the traditional 3LPO coating process, water quenching is applied to the external surface of the pipe in order to solidify the polyolefin sufficiently to prevent damage during further conveying. As the outer surface begins to cool, the PE or PP layer develops hoop stress around the pipe. At the raised weld, this hoop stress attempts to pull the molten polymer into a tangential configuration, causing the thickness to decrease at the top of the weld and increase at the sides and edges. Therefore, voids, separation of layers, or discontinuities often develop around the weld neck as illustrated in Figure 5.

Internally cooling the pipe and coating causes the opposite effect. The adhesive layer is the first to solidify, thereby fixing the outer polyolefin layer, and the outer polyolefin layer recrystallizes and shrinks from the inside out. This causes the polyolefin to contract into the profile of the weld, drawing material in from the main body and resulting in a smooth transition from the body to the top of the weld, with little or no thinning across the top.

As an alternative to extrusion, the polyolefin adhesive and topcoat layers can be applied as powders which fuse into solid layers at the application temperature of approximately 240°C. This method has the particular advantage that it results in very uniform coverage of raised welds and eliminates the need to roll the molten polymer. It also allows the production of lower thickness coatings than is possible with side-extruded 3LPO coatings, which are very difficult to produce on raised weld pipe at thicknesses less than about 2 mm. Because this approach requires the additional step of grinding the polyolefin, an all-powder polyolefin coating is slightly more expensive to produce than extruded polyolefin coatings at equivalent thickness. A more significant downside of using the powdered polyolefin application system is that the rate of production decreases dramatically at thicknesses much greater than about 1.25 mm because the insulating efficiency of the polyolefin reduces the heat transfer necessary to fuse the thermoplastic powder particles.

The High Performance Composite Coating[1] (HPCC)[1] system is not only an example of such an all-powder system, but it is also a "graded structure" polyethylene (GSPE) coating, in which the composition changes continuously from FBE through to polyethylene, in contrast to the sharply defined interfaces typical of 3LPE coatings. This structure avoids the sharp discontinuities across interfaces between materials with vastly different physical properties, causing a smooth transition of properties from the very rigid FBE to the much tougher and compliant polyolefin. The result is the virtual elimination of interlayer adhesion failures.

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[1] "High Performance Composite Coating" and "HPCC" are Trade Marks of ShawCor Ltd.

The ideal situation would be to be able to combine the exceptional ability to provide uniform coverage over raised welds provided by powder-based systems with the relatively lower cost, higher throughput rates and ability to attain thick coatings afforded by extruded polyolefin processes. This has been achieved with the new process, which allows the production of multilayer polyolefin pipe coatings of virtually any thickness with uniform thickness at all points and no tenting along the edges of all but the most severe of welds.

An additional consideration is the increasing usage of high strength steel (X80 or higher) for oil and gas transmission pipes. Recent evidence that the pipe preheat temperatures of conventional FBE (200 - 240°C) can reduce the elongation at yield are causing some pipeline companies to limit preheat temperature to 175-200°C where such steels are being used. The new approach described in this work can be applied in conjunction with the new “Low Application Temperature” graded structure polyolefin coating (LAT-HPCC[2]), which can be applied without having the pipe temperature exceed 200°C at any point in the process. Results [5] demonstrated that this new coating provides performance virtually identical to the standard GSPO product.

EXPERIMENTAL PROCEDURE

Materials

The base coat epoxy used in this study is a new generation FBE designed to be applied at pipe temperatures ranging from 175°C to 200°C. A polyethylene copolymer adhesive in powder form was used as the tie layer. For the conventional 3LPE coating, high density polyethylene (HDPE) was side-extruded onto the copolymer adhesive as the outer covering. For the new approach, a powdered PE was applied after adhesive application, followed by side-wrap extruded HDPE over as the outer covering.

Steel pipes used in this work had an outside diameter of 30” (762 mm) and a wall thickness of 15.7 mm. While there is no inherent restriction on the diameter of pipes that this process will handle, it is most beneficial on pipes having an external weld seam.

Procedures

<u>Surface Preparation.</u> Steel pipes were cleaned with hot water and grit-blasted to meet the SSPC-SP10 standard. Then the blasted pipe surface was acid washed by phosphoric acid and rinsed with deionized water. Cleaned pipes were then preheated to a temperature range 185±10°C with induction coils prior to coating application.

<u>Conventional 3LPO Coating Process.</u> FBE powder was applied with a minimum thickness of 250 µm onto the pipe surface followed by the copolymer adhesive (minimum 125 µm). Both layers were applied by electrostatic spraying. Subsequently, the polyolefin topcoat was side-wrap extruded on the adhesive layer with a minimum thickness of 2.5 mm. This process is shown diagrammatically in Figure 6. Details of such coating process can also be found in [1].

<u>New Approach to Multi-Layer PO Coating.</u> FBE was applied first with a minimum thickness of 250 µm followed by the copolymer adhesive with minimum 125 µm thick, both were applied by electrostatic spraying. Immediately following the adhesive application, polyethylene powders were

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[2] A new Bredero Shaw product: Low Application Temperature – High Performance Composite Coating

then deposited by vibration pans and the thickness of the fused PE layer was 500 μm minimum. This GSPO coating process is described by Wong et. al. [6,7]. A minimum of 2.2 mm thick high density PE was then side-wrap extruded over the GSPO system to build up the thickness which was specified by the customer. The coated pipes were quenched with water internally and then externally [8]. This process is shown diagrammatically in Figure 7.

This new approach of side wrapping HDPE over the GSPO system has been carried out in two different ways:

(1) Extrusion of the HDPE directly in line with the application of the GSPO, with the extrusion die placed sufficiently downstream of the PE powder application to permit fusion of the thermoplastic powder;

(2) Extrusion of the HDPE as a second process. In this case the GSPO-coated pipe was heated mildly with an induction heater, and surface was further heated using an infrared heater to approximately 130°C prior to side-wrap extrusion of the HDPE.

Results presented in this work were obtained from using approach (1).

<u>Bend Test.</u> Polyethylene coated samples were cut to approximately 25.4 mm wide and they were placed in a freezer at -30°C for approximately 3 hours. The cold strips were bent at 4.2° per pipe diameter. The mode of failure for each was recorded.

<u>Rock Impact Test.</u> 22 pounds (9.98 kg) rock with a diameter of 8" (203 mm) was dropped from a height of 2 m and impacted to coated pipes at -40°C. This test was to simulate backfilling in cold winter. Backfilled rocks may be round or sharp, therefore, impact tests were performed with both round and sharp rocks as shown in Figure 8.

RESULTS AND DISCUSSION

Figure 9 shows the comparison of coating coverage at weld area between the traditional 3LPE coating and the new multi-layer PE coating. Voids can be clearly seen in Figure 9(a) at toes of the weld and possibly on the crown. While this is not necessarily representative of a typical 3LPO coating, it is a good example to demonstrate the weld tenting phenomena. It also shows clearly that the thickness of the coating is significantly lower over the top of the weld than in the pipe body. In this example, the thickness on the body of the pipe is about 30 to 40% greater than that at the top of the weld. In extreme cases the thickness difference has been as high as 100%, particularly in the case of 3-layer polypropylene coatings.

By comparison, Figure 9(b) shows a much more uniform thickness over the weld when the new process is used. The thickness on the body is only 6 to 10% greater than in the case of the conventional 3LPE coating shown in Figure 9(a). More importantly, there is absolutely no evidence of tenting or other irregularities at any point of the weld.

Figure 10 shows another weld cross-section using the new coating, but in this example the extruded layer was yellow and the powder-based polyethylene layer was black. This makes it easier to see the interface between the two, and to see how the powder-based multilayer coating provides a more gradual transition for the extruded sheet to cover. Although the results herein are based on GSPE coating, the benefits in regard to thickness uniformity and elimination of tenting should extend to all-powder 3-layer polyolefin coatings in which the layers are discrete.

The difficulty in controlling the coating thickness over the weld avoiding weld tenting using the conventional side-extruded 3LPO process are clearly eliminated with the new approach. More impressively, these results can be achieved with both long seam and spiral welded pipes, as well as "double-jointed" pipe, Photos of longseam and spiral weld pipe coated with the new process are illustrated in Figure 11. Of particular interest are Figure 11(c), which shows the intersection of the longseam weld with the girth weld on double-jointed pipe, and Figure 11(b), which shows how well the coating hugs the profile of the weld.

Residual stress built-up in the polyolefin coating during processing can be a significant contributor to the adhesion loss of thermoplastic coatings [9,10]. In view of this, the new approach has combined the GSPO coating system with internal cooling to minimize the residual stress built-up in the final coating. Unlike the conventional 3LPO coating, the GSPO coating system provides a graded transition of mechanical properties from the hard, stiff, polar FBE layer to the soft, ductile, non-polar polyolefin, which helps to reduce stresses on the FBE interface. Moreover, internal cooling is used to ensure rapid and optimum cooling.

Figure 12 shows the comparison of conventional 3LPE and new multi-layer PE samples after flexibility tests at -30°C with 4.2° per pipe diameter. It shows that with conventional 3LPE coating using the standard coating process, two out of five samples failed. By contrast, there were no failures with the side-wrapped GSPE coating. We believe that the difference is due to less residual stress built-up with the new approach to high performance polyolefin coating.

Finally, rock impact tests were performed to characterize backfilling resistance with these two coating processes. No difference was found between the two coating methods when impacted with a 22 pounds (9.98 kg) ***round*** rock. However, when impacted with a 22 pound (9.98 kg) ***sharp*** **rock**, two out of three samples passed with the new coating process, but all three of the conventional 3LPE coatings failed. We believe that the difference in impact resistance is a combination of lower residual stress combined with the lack of distinct interfaces and the superior impact-absorbing properties of the powder-based polyethylene top coat used as a component of the underlying GSPO.

CONCLUSIONS

A new system consisting of high density polyethylene (HDPE) side-extruded over a graded structure polyethylene (GSPE) coating is introduced in this work. This new approach to the design and production of a high performance polyolefin coating overcomes the drawbacks of the conventional 3LPE coating. The advantages of this new approach are as follows:

1. The new approach provides exceptionally uniform coverage of external welds on both long seam and spiral welded pipes.

2. This new approach successfully eliminates "weld tenting", which is a common problem with the conventional 3LPE coating process. This should reduce or eliminate the need to grind the external weld to reduce its height and provide a more gradual transition.

3. The new approach leads to a coating with significantly reduced residual stresses. This results in superior low temperature flexibility and resistance to sharp impact, and should reduce the incidence of gradual loss of adhesion associated with thick 3LPO coatings.

ACKNOWLEDGMENTS

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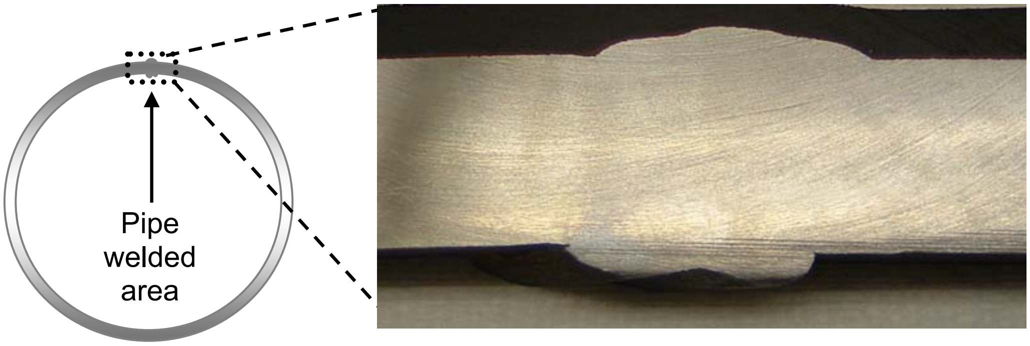


FIGURE 1 – Cross Section of a Typical Weld on a Pipe

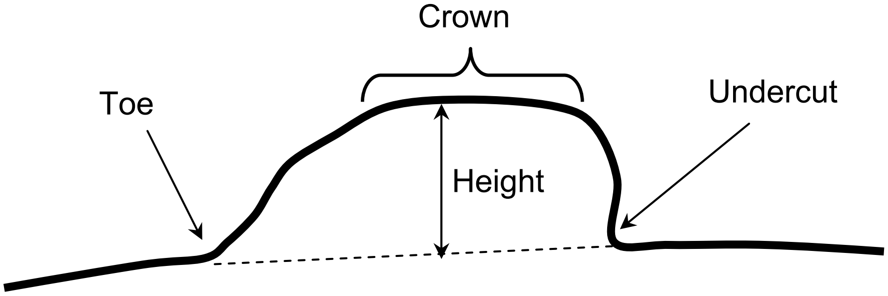
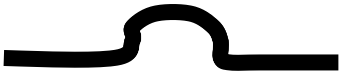
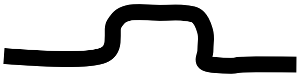


FIGURE 2 – Terminology Used to Describe Weld Geometry

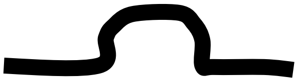
(a) Ideal weld shape



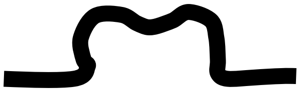
(b) Square edges



(c) Square edges with slight undercut

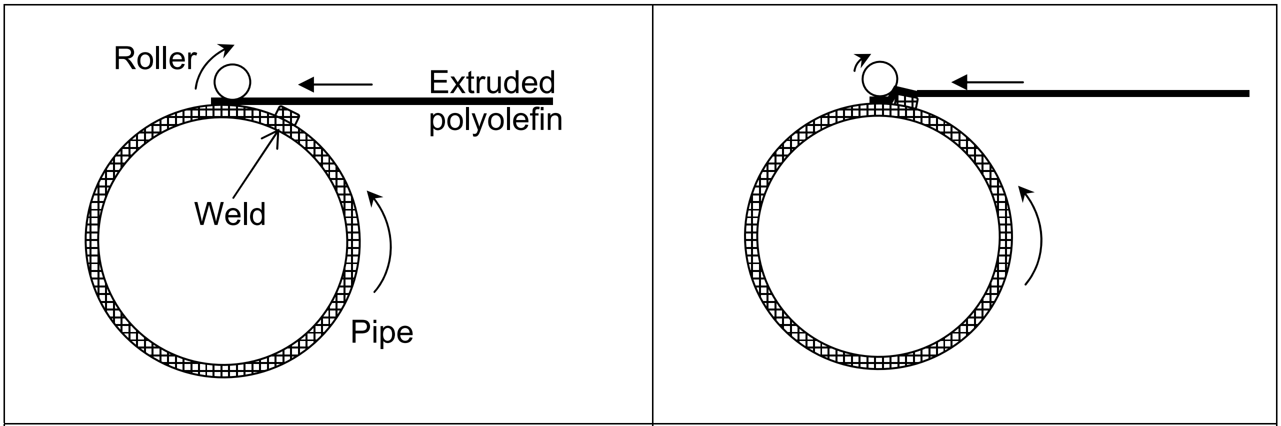


(d) Square edge with severe undercut



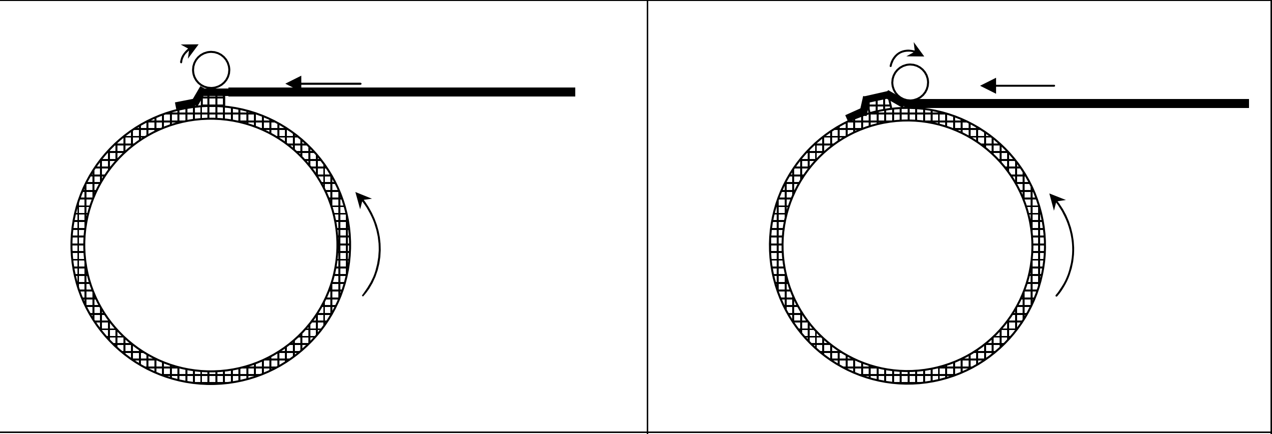
(e) Severe undercuts both sides and recess on top

FIGURE 3 – Different Weld Geometries



(a) Advancing Weld impacts lower surface of molten sheet and pushes up into it.

(b) Roller pushes polyolefin material towards and into the advancing weld.



(c) Roller jumps up onto the weld; full downward force is on narrow top of weld.

(d) Roller drags material away from receding weld, and cannot easily form the polymer into the crotch of the weld.

FIGURE 4 – Conventional Side-Extruded Polyolefin on Pipe with the Aid of a Roller

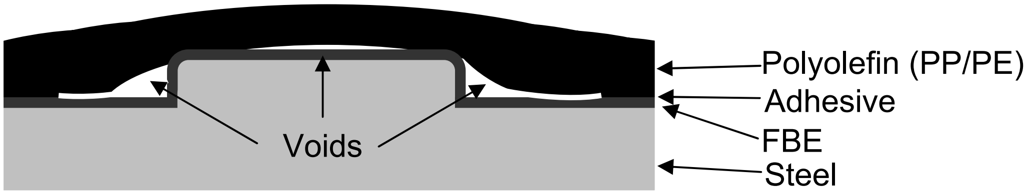


FIGURE 5 – Weld Tenting Phenomena

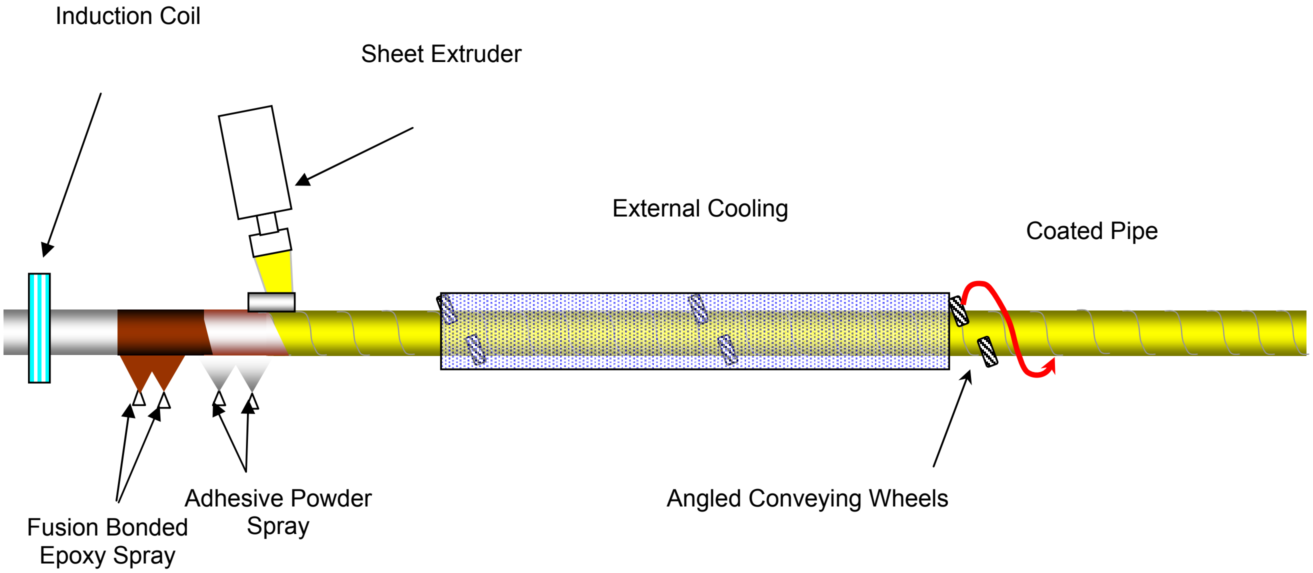


FIGURE 6 – Conventional 3-Layer Polyolefin Coating Process

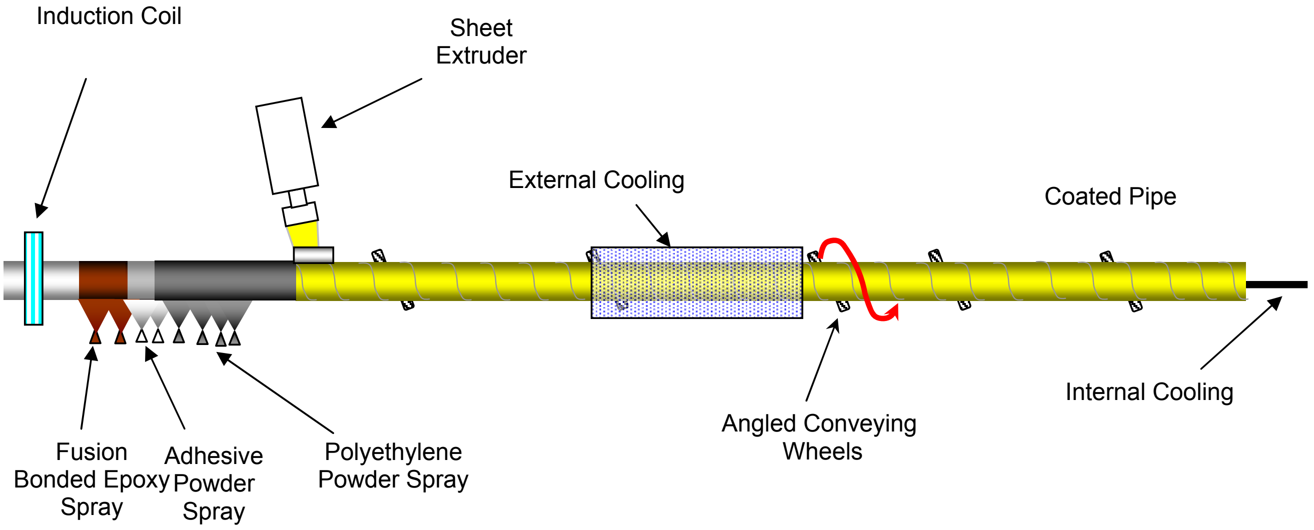


FIGURE 7 – New Side-Wrapped Composite Coating Process

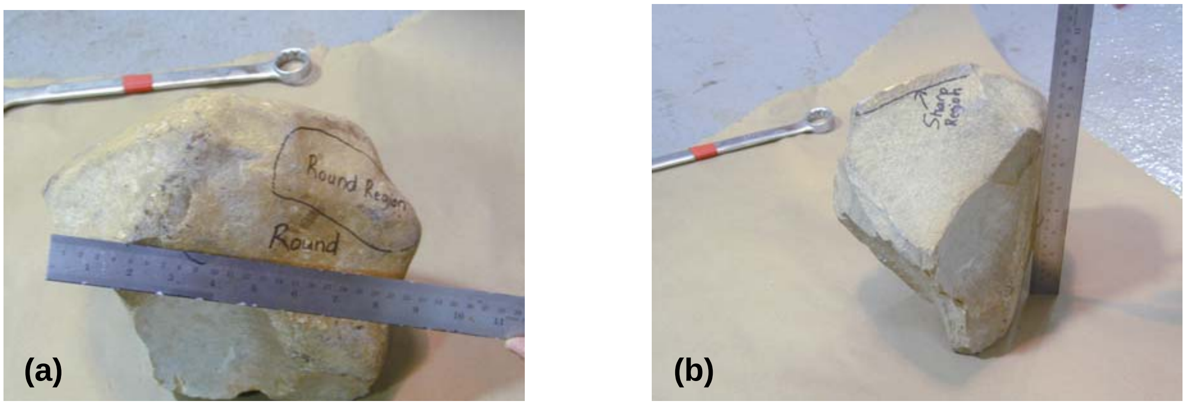
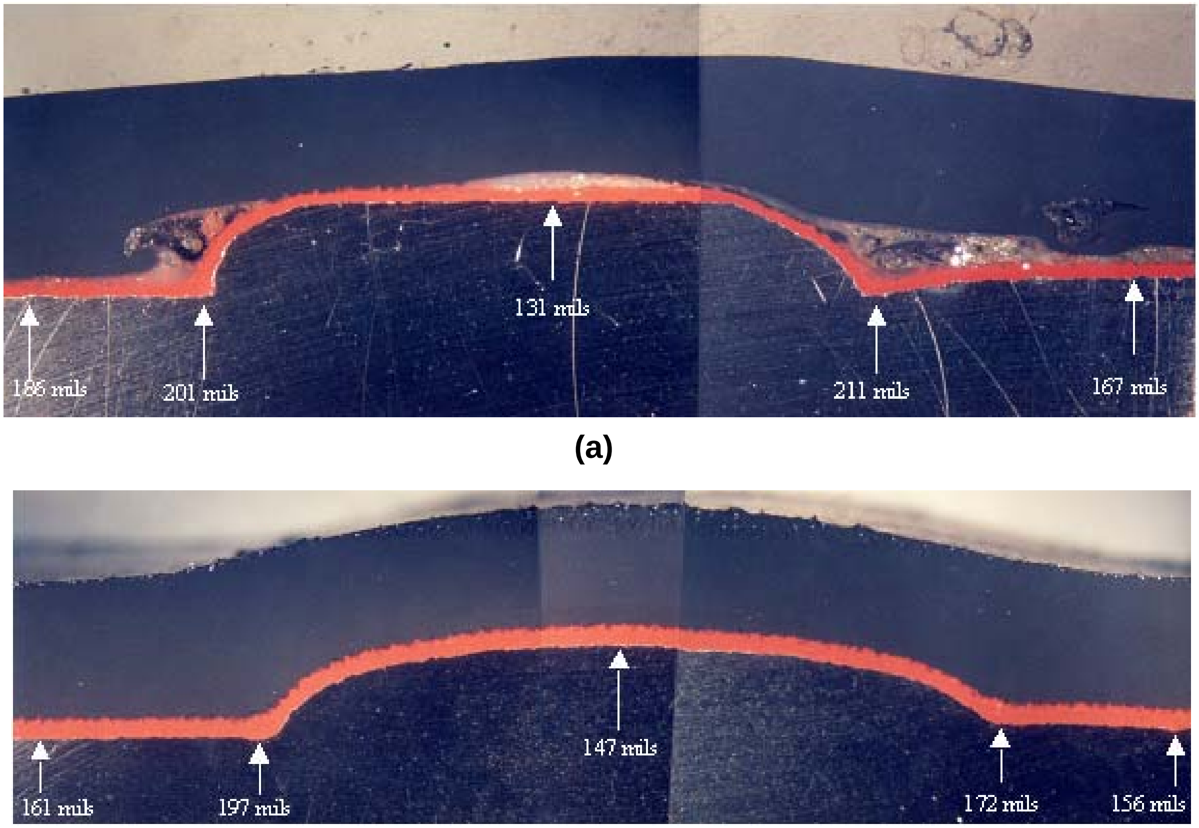


FIGURE 8 – Photographs of the 22 lb (a) Round and (b) Sharp Rock used in Impact Tests at -40°C



(a)

(b)

FIGURE 9 – Cross Section of Weld Seam obtained from (a) Conventional 3LPO Coating Process; (b) New Approach to Multi-Layer PO Coating

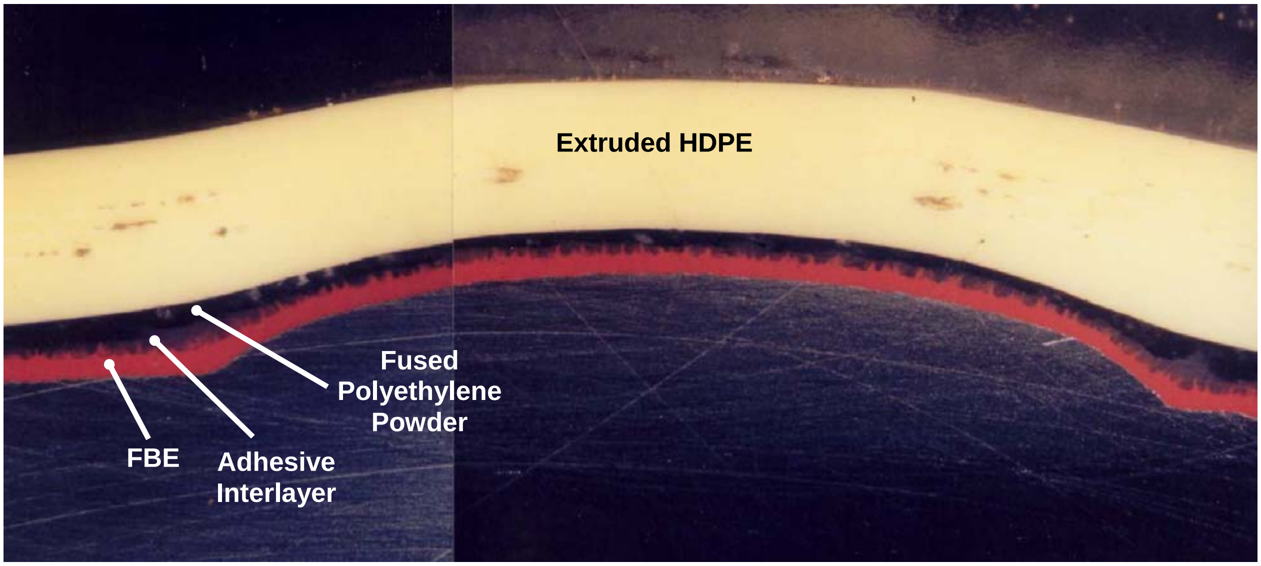
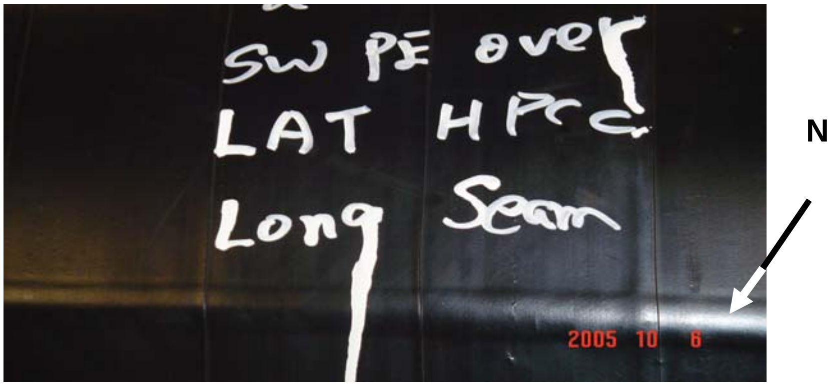


FIGURE 10 – Cross-section of Weld with Black Powdered Polyethylene and Yellow Extruded Polyethylene. Note how the powder-based coating smoothes out the weld profile, making it easier for the extruded layer to conform to it.

(a) Side-Wrapped GSPE on Spiral Weld Pipe (30")



Note how well-defined the weld seam is.

(b) Close-Up Showing Excellent Conformance to the Long Seam Weld

(c) Intersection of the Long Seam and the Girth Weld on Double-Jointed Pipe

FIGURE 11 – Photographs of the New Multi-Layer PE Coating Coated on (a) Spiral Pipe; (b) Long Seam Pipe; and (c) Double-Jointed Pipe.

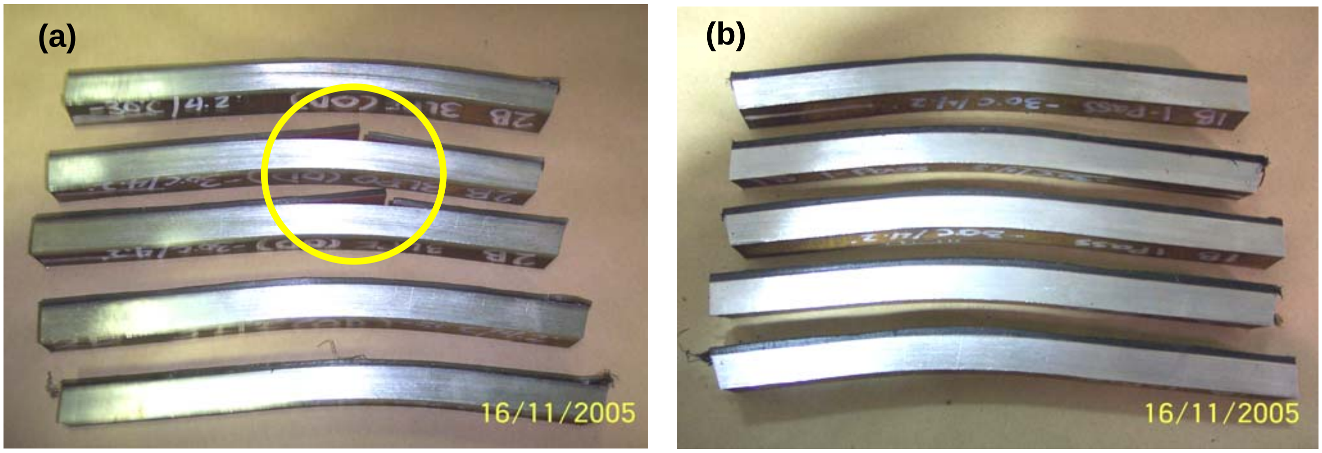


FIGURE 12 – Results of Flexibility Test at -30°C and 4.2° per Pipe Diameter.

(a) Conventional 3LPE Coating;

(b) New Multi-Layer PE Coating (Side-Extruded HDPE over GSPE Coating).