he quality and durability of polyethylene (PE) pipe coating systems have been questioned by some sources recently, and the industry is struggling to provide a definitive answer.

Some high profile pipeline coating failures have been reported by David Norman et al.\textsuperscript{1,10,11,12} These failures put pipelines at risk of corrosion and rupture, which would damage the environment and reduce confidence in the ability of the pipe coating industry to provide durable and “fit for purpose” coating solutions. Photographs showing examples of typical coating problems reported are shown in Figs. 1 and 2.

While many problems and subsequent failures can be attributed to
poor substrate preparation, incorrect coating application, and incorrect material selection, it is also evident that products generally available to applicators can vary considerably in application characteristics and final coating properties. This variation can also affect the quality of the applied coating system and the ultimate durability or service life of the pipeline coatings.

This article looks at the properties of different three-layer PE coatings (topcoat and adhesive) and discusses how the variations among these different coatings might affect ultimate performance and durability. This author intends to open a discussion and will propose some potentially new ideas on how different test methods, some from other pipe applications, might be used or adapted to provide a better estimation of durability and service life.

The test schedule chosen for this study compared various mechanical and physical properties that provide benefits to different members of the pipe coating value chain. The value chain concept (the value each interested party seeks in a product) is one that this author strongly believes in and has recently used in developing products and business opportunities. Pipeline owners and specifiers, for example, may look for coating materials to have long-term durability and low maintenance requirements, whereas applicators may tend to focus on ease of application and the ability of the system to meet specification requirements. Although described as a “chain,” it may be more beneficial if we think of a matrix, with interactions and exchanges of value potential in a non-linear way, rather than a straight line. A typical pipe coating value chain is shown in Fig. 3.

**Materials and Pilot Line**

High density (HD) and medium density (MD) PE topcoats and grafted PE adhesives generally available in the market were selected for testing, obtained in their original, unopened packaging, and taken from stock still in shelf life. References 1 and 2 in the tests are described as bimodal high density compounds. The pipe coatings were applied on the Borealis pilot line in Porvoo, Finland. No special conditions or application parameters were used, and all materi-
als were treated in a similar manner.

The test schedule for this evaluation is shown in Fig. 4.

Other values reported in this article are taken from technical data provided by the manufacturer.

The pilot line (Fig. 5) will coat steel pipe up to 168 mm external diameter and is capable of applying multi-layer coatings (up to five layers by side wrap and four layers by cross head extrusion). The line was prepared to coat in a typical three-layer set-up, with epoxy powder applied by electrostatic spray, and the adhesives and topcoats applied by side extrusion through a flat die.

Pipe preheating was performed by induction coil and was set at 185–195 C (~365–383 F), depending on the material; topcoat extrudate temperature was 220–230 C (~428–446 F).

**Test Results**

One immediate and obvious conclusion is that, for the chosen test conditions, the physical characteristics of the materials vary considerably.

**Extruder Output Test**

The extruder used for the output tests is a Krauss Maffei 45/30D. The same extruder was used for the "neck-in" tests (described below). It is easy to understand that higher output can realize faster application speeds, which can be an important factor for the applicator if his coating line capacity is constrained. On the other hand, higher output can also translate to lower revolutions, resulting in less power consumption at an equivalent output. In this test, the difference between the best and worst output is about 10% (Fig. 6). In theory, it should be possible to convert this to a 10% increase in application speed. In cases where the application equipment was further optimized for temperature profile and screw configuration in the extruder, and then for bimodal HDPE compounds, output improvements of up to 15% have been reported to the author.

**Neck In or Draw Down Test**

The neck in (or draw down) test involves measuring the difference...
between the die width and the molten film width at the pressure roller for different rotational speeds of the pipe. Empirically, the faster the rotational speed, the higher the draw down should be for the same extruder settings. Draw down or “neck-in” is an indication of the melt strength of the molten polyethylene film. This test shows how reliable and stable the molten plastic will be during processing. It also shows if there are any gels or unmelted pellets in the molten mass that may lead to film breakages. More stable and reliable molten films have obvious benefits for applicators.

All compounds but Reference 1 suffered film breaks, with Reference 2 breaking at 15 m/min. rotational speed. Strangely, the neck-in for Reference 4 actually improved until it broke at 20 m/min. (Fig. 7). This indicates some difference in the rheological properties of Reference 4 that may affect application properties adversely.

**VICAT Temperature**

VICAT temperature broadly indicates the upper operating temperature limits of the applied three-layer PE coating, because the higher the VICAT temperature, the higher the softening point of the compound. The topcoat should be matched with a suitable adhesive (and epoxy) to optimize the performance of the system.

Figures 7 and 8 show the variation in measured VICAT temperatures for the tested PE adhesives and PE topcoats. Of the topcoats, References 1 and 2 should offer the best performance, with at least a 10 degrees C (~30 degrees F) difference from Reference 3. Of the adhesives, Reference 3 should offer worse high-temperature performance (Figs. 8 and 9).

**Surface Hardness**

Similarly, surface hardness measurement at various temperatures is an indication of the mechanical properties and upper operating temperature. Density also correlates closely to surface hardness. Here, the tests indicate References 3 and 4 of the topcoats have the lowest densities and Shore D hardness, and would provide the worst mechanical properties at higher temperatures. This correlates well to the VICAT temperature measurements (Fig. 10).

**Peel Force Tests**

Peel force tests are used for quality control in the coating plant and also for prequalification purposes, and it is generally recognized that the higher the peel force, the better. The retention of peel force at higher temperatures will also indicate suitability for higher operating temperatures and possibly longer service life. Adhesion is generally accepted as an indication of the quality.
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of the whole coating system, and specifications are calling for higher values than before. In this test we look at the differences in peel time force for the 3-layer PE system as applied onto pipes coated on the Borealis pilot line.

The main governing factor in determining peel force is the chemical nature of the adhesive. An adhesive with grafted active sites will provide much better performance than, for example, a copolymer type, and the nature and concentration of the grafting should also affect the peel force.\(^9\) (Note: the selection of an epoxy primer with a high enough glass transition temperature \([T_g]\) is also required for higher operating temperatures, especially over 110 C.) In our tests, the adhesives—References 3 and 4—clearly give much lower performance at 80 C (\(~176\) F). Reference 2, strangely, appeared to increase in peel strength at 80 C (\(~176\) F). Reference 1 and Reference 5 appear to offer the best overall performance (Fig. 11).

**Low Temperature Elongation Tests**

This laboratory test, for the topcoat compounds, uses compression-molded plates made from virgin pellets. Tensile elongation is measured at -45 C (\(-49\) F) on 2 mm thick test specimens (“dog bones”), with a pulling speed of 50 mm/min.

This test, taken from the Russian GOST and Gazprom specifications,\(^6\) is particularly useful in determining the low-temperature performance of plastics during mechanical handling, such as field bending or even moving pipes in or to the stock yard or right-of-way, and is important for cold climates such as in parts of Russia, China, and Canada (Fig. 12).

Reference 1 clearly shows much better performance than any of the other compounds tested.

It should be noted that the method of obtaining samples for this test can...
lead to variation in the values. The GOST and Gazprom specifications call for test samples to be taken from actual coated pipes, which will lead to variations in the film thickness and continuity, thus causing variation in elongation and early breakages.

**Discussion**

Although all of the products tested are designed to meet the requirements of various national, international, and company standards and specifications, there is a wide variation in the tested properties of these commercially available and often used topcoat and adhesive compounds. This raises the question, “How might that variation translate to actual field performance and durability or lifetime?” Some suggestions for further tests that could be used to simulate or predict lifetime are given below in blue italics.

The draft ISO 21809-1 for polyolefin coated steel pipes will probably contain a short-term (24-hour) disbondment after a hot water soak test. This is intended for in-plant quality control. Robin John⁴ proposes a 60- or 100-day hot water immersion test as an indicator of long-term durability. A thermal cycling test is included in the approval testing to Russian GOST and Grazprom specifications for 3-layer PE pipe coatings.⁶ Might a long-term hot water soak or thermal cycling test be suitable as a general screening test for durability? If so, for how long, and would it be possible to extrapolate a lifetime to failure?

When pipes are coated with polyethylene by side wrap melt extrusion, stresses are frozen into the polymer and are said to aid adhesion. However, could these stresses also play a part in disbondment? It has been noticed that lifting or detachment at pipe ends sometimes occurs.¹ This lifting might
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The phenomenon of cathodic shielding, or blocking of protective CP current, has been the subject of dozens of technical papers since the mid 1980’s. You can review a cross section of these papers on Polyguard’s website. You can also view a 10 minute explanation of the cathodic shielding process.

Worldwide, we estimate that over half of pipelines are being coated with solid film back coatings, such as shrink sleeves, tapes, and 2 or 3 layer systems. Most of these lines have CP systems. These are the operators who may be wasting their money on CP. Moreover, many install shielding coatings on girth welds, the most vulnerable area for corrosion.

Two corrosion coatings are proven to be non-shielding, and allow passage of protective CP currents. One of these coatings is FBE. The other is Polyguard RD-6.

NACE SP0169-2007 states: “Materials ... that create electrical shielding should not be used on the pipeline”.

49 CFR §192.461 states: “External protective coating ...must ...have properties compatible with any supplemental cathodic protection.”

If you are concerned that your organization is behind this curve, we recommend:

1. Visit polyguardproducts.com/failurescoating.htm and review the large body of information about shielding problems.

2. Talk to operators who have used Polyguard’s RD-6 system. (There are many) Ask them if they knew of any serious corrosion or SCC ever found under RD-6. (We don’t, even after 18 years and thousands of installations).

3. Have someone in your organization attend the NACE course “Coatings in Conjunction with Cathodic Protection”.

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1. NACE SP0169-2007 “Control of External Corrosion on Underground or Submerged Metallic Piping Systems”.
2. 49 CFR Ch.1 (§192.461 see also §195.559)

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be a function of frozen-in stress and/or differential expansion and contraction between the plastic and steel.

Perhaps a test to determine the frozen in stresses might be useful in evaluating lifetime. If so, how might the test be done?

For plastic pressure pipes, it is widely accepted that pressure testing at different temperatures can be extrapolated using regression curves to predict service lives of 50 years or more. Notch and slow crack growth is also widely used in plastic pipes to predict service life and rank for durability.7,8

Environmental Stress Crack Resistance (ESCR) is also used to indicate durability of plastics. Some PE resins for pipe coating have publicized ESCR at 1,000 hours, while others are 5,000 hours.

What could this difference in ESCR mean in terms of lifetime or durability?

Could the tests above or similar tests be used for pipe coating qualification, and where should the threshold be set? Marcel Roche et al.2,4 have called for more cooperation and information sharing about pipeline coatings, and I can only echo that request. Additionally, a cross-industry research program to develop an accelerated durability test or suite of tests would be the best approach to the uncertainty that currently exists. Borealis would certainly be willing to be an active participant in such research.

Conclusion

Three-layer polyethylene coatings for steel pipelines that transport oil and gas are the coatings of choice in many areas of the world. Global energy supply is coming more and more in focus as every nation vies for security of supply. Correctly specified pipeline coatings add to the security of the pipeline, and ensuring the quality and durability of the coating is one important factor. This article has shown that the properties of different polyethylene coatings vary considerably and suggests how this variation in properties might affect performance. Tests to predict durability or service life have yet to be considered, however, and the author hopes that this article will aid in the discussion of this subject in the future.

References

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6. Russian GOST R51164 and Gazprom specifications for 3-layer PE coatings on steel pipe.


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