Polyamide as a reliable coating for steel pipe at Marl Chemical Park

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Innovative material and a wealth of technical know-how are the main ingredients of the new pipeline that has been built on the doorstep of Marl Chemical Park. Starting in 2015, liquid hydrocarbons can now be conveyed safely over 10 km from the Scholven refinery to Marl Chemical Park. The new double pipeline is intended to safeguard jobs and reduce emissions since it will make 25,000 truck journeys per year redundant. For the trenchless sections, Evonik Industries AG and Salzgitter Mannesmann Line Pipe GmbH have broken new ground together by using VESTAMID® NRG, a polyamide (PA) 12, for coating the steel pipes. In doing so, they have drawn on the technical expertise of Köster GmbH.

At Evonik Industries AG, the Zephir project stands for growth at its Marl and Antwerp locations, and also for an innovative material: VESTAMID® NRG is a variant of polyamide 12 for the oil and gas industry that Evonik has developed with buried pipelines in mind. Here the producer of specialty chemicals relied on the Siegen-based pipe manufacturer Salzgitter Mannesmann Line Pipe GmbH (SMLP) and on Köster GmbH as the lead contractor. The pipeline constructor used polyamide 12 for the approximately 10-km route from Ruhr-Oel GmbH's Scholven refinery to Marl Chemical Park, which also involved diverse trenchless techniques. For shorter sections, for example, a pipe jacking technique was used in which a DN 800 steel-in-steel pipe protecting the product pipes inside it was hydraulically rammed through the soil. This technique has been employed in many other projects, such as the crossing underneath the A 52 freeway (***Figure 1***) and other underground road crossings. For longer trenchless sections of over 2 km, the Köster GmbH's pipe-laying experts used the horizontal directional drilling method (HDD drilling), in which the product pipes were pulled directly into the previously drilled bore.

Figure 1*: For the underground crossing of the A 52 freeway, Köster GmbH used a pipe jacking technique in which a DN 800 steel-in-steel pipe to protect the product pipes inside it was hydraulically pushed through the soil*

In all, laying the two roughly 10-km strings (FG 70 and FG 71) of the double pipeline (DN 150/PN 100) took ten months. It was a project with high safety requirements, for the new route runs mostly parallel to high-voltage overhead lines, through the protective strip of an existing pipeline system as well as farmland. To ensure due consideration of the geological features and minimize the impact on nature, the principle of pipeline bundle routing was applied. Because of the many pipelines running parallel to or crossing the route, the route was subdivided into 50 sections. For each of them, three or even four separate approval procedures were required (1 = exploratory shaft, 2 = top soil removal, 3 = pipe trench and water management, 4 = drainage). This meant between 150 and 200 procedures had to be seen through in all before civil engineering work proper could be started.

Steel pipes for buried pipelines have a mill-applied polyethylene (PE) coating for passive corrosion protection. Previously Evonik used to apply an additional top coat of glass-fiber-reinforced plastic (GFRP) to the PE coating for extra mechanical protection during trenchless pipe-laying. Given the positive experience gained in several successful projects as well as the lower pulling forces involved, Evonik and Salzgitter Mannesmann Line Pipe decided to use a multi-layer system comprising a PE coating and a top coat of VESTAMID® NRG for the double pipeline pulled through the three HDD bores. This system is not only cost-efficient

but also provides sustainable safety, which is particularly important in the case of buried pipelines, because these can be subject to high stresses not only during pipe-laying but also under operating conditions. In-situ rock or other obstacles may apply point loads or external pressure to pulled-in sections and cause local damage to the corrosion protection coating.
Before pulling in a pipe string, the pipeline constructors subject it to coating holiday detection (ISOTEST, 15 kV) immediately before admission to the drilled bore (***Figure 2***). For this purpose, the medium pipe is earthed while a current-carrying test spiral is pulled over the coating. The objective of this test is to detect pores, cracks and/or other mechanical damage in both the mill-applied coating and the field coating. The presence of any such damage is indicated by arc-over from the test spiral to the medium pipe and by an acoustic signal. As soon as this happens, the pulling operation is stopped and the holiday is repaired, before the string finally disappears in the pipeline bore.

Figure 2: *Before pulling in a pipe string, the pipeline constructors always subject the coating's quality to a special test*

To prevent coating damage during string pulling, Evonik Industries AG additionally protects polyethylene-coated steel pipes intended for HDD bores with a top coat of polyamide 12, which is particularly resistant to mechanical damage. Also, the shear strength between the polyamide top coat and the corrosion protection coating of polyethylene is excellent.
The pipeline constructors use this multi-layer system in conjunction with HDD drilling, because this process involves higher-than-normal loads on the pipe outside surface due to friction inside the pipeline bore. HDD drilling uses a liquid clay mineral mix – called bentonite – to support the drilled bore (***Figure 3***). However, due to its special consistency, it also acts as a lubricant on the pipe outside surface when the pipe string is pulled into the bore, and it prevents lumps of rock or other obstacles from damaging the passive corrosion protection coating. In some cases, sharp-edged objects may nevertheless come in contact with the pipe, leading to an increase in the pulling forces required to overcome the frictional resistance. To prevent damage to the steel pipe's PE coating under these conditions, an additional polyamide top coat is applied directly at the mill.
To verify the new coating system's suitability, the pipeline constructors agreed with the client and TÜV NORD experts that a pipe section approximately 3 m in length would be welded to the front end of each of the two pipe strings and pulled through all three HDD bores (***Figure 4***). In all, the pipe section was thus pulled through a stretch of about 1,100 m, since the same section was used in all three cases. The pulling operations were monitored by experts from TÜV NORD. After this field test, the PA 12 coat on the test piece only showed minor scratches and was otherwise totally unaffected. In conclusion it can be stated that the new PA 12 m coat has proven effective for the pipe diameter and soil conditions involved in the project (Recklinghausen sandy marl, sandy and silty soils, etc.) and provides good mechanical protection of the underlying PE coating.

Figure 3: *To support HDD bores, a liquid clay mineral mix – bentonite – is used*

Figure 4: *A double HDD pipe string (black polyamide coat) with a test pipe specimen welded to its front end is ready for pulling through the bore. The conventional double pipe string (yellow coating) is ready for lowering into the trench*

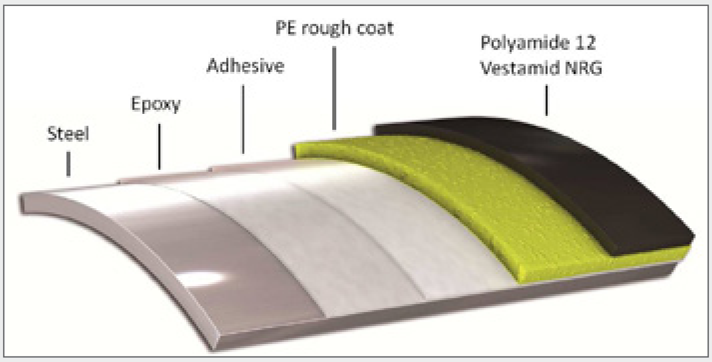

Figure 5: *With a coating combination of polyethylene and polyamide, a so-termed rough coat provides the necessary mechanical interlocking*

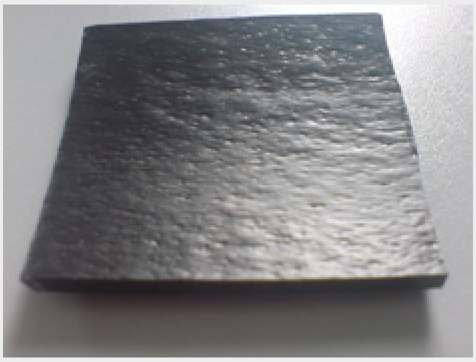

Figure 6: *Fused granules create a rough structure on the lower surface of the polyamide top coat*

A large number of coatings are in use today in trenchless pipe-laying projects. These also include thick-layer coatings based on polyethylene or polypropylene, which have become broadly established particularly in conjunction with flush drilling. Depending on the layer thickness, up to two or even three layers are extruded on top of each other. Damage investigations have shown that the excellent adhesion between the layers proves to be a severe disadvantage, because if cracking occurs it affects all layers of the coating. The cracks thus expose the steel surface to the pipeline environment.

Tests have proven that crack penetration through the thick coating to the steel surface can be avoided if the individual layers of multi-layer extruded coatings do not have to adhere to each other. In the case of the polyamide coat, adhesion is prevented by the combination of the homopolar polyethylene coating and the polar polyamide top coat. The associated separation of the functions of the corrosion protection coating and mechanical protection is also inherent in other systems used in trenchless projects, such as cement mortar coating and the combination of PE and GFRP. Nevertheless, with trenchless pipe-laying techniques measures are required to prevent the stripping of the coat during the pulling operation.

Cement mortar coatings, for instance, are co-extruded with a T-ribbing which provides a firm mechanical bond between the mortar layer and the polyethylene layer. In the case of the GFRP top coat, the required shearing resistance is achieved by brushing the PE surface. With the combination of polyethylene and polyamide, a so-termed rough coat provides the necessary mechanical interlocking (***Figure 5***). The rough surface is achieved by sprinkling PE/PP granules onto a smooth, freshly extruded PE coating. The partial melting of the granules and their fusion with the hot surface causes the subsequently applied polyamide coat to interlock with the PE coating. ***Figure 6*** shows the lower surface of the polyamide top coat and the rough surface structure generated by the fused granules. The advantage of VESTAMID® NRG over conventional polyethylene and polypropylene coatings is its superior mechanical properties. The loads involved in pulling operations are best simulated by the gouge test as per the Canadian CAN CSA Z 245.20-10 standard [1]. This test simulates the effect caused by a sharp-edged rock penetrating the coating surface as the pipe string is pulled into the bore. For this purpose, the coated pipe specimen is pulled underneath a test tip (***Figure 7***), which is weighed down with a load of 50 kg (angle of test tip 20°;

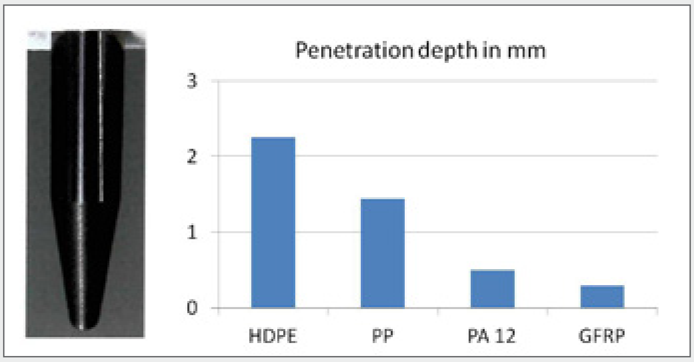

Figure 7: *Mannesmann Salzgitter Line Pipe uses the gouge test to test the mechanical properties of plastic coatings. The maximum penetration depth of a test tip is determined with the aid of a dial gauge*

Figure 8: *In the Zephir project, a combined PE-GFRP system is used for field coating*

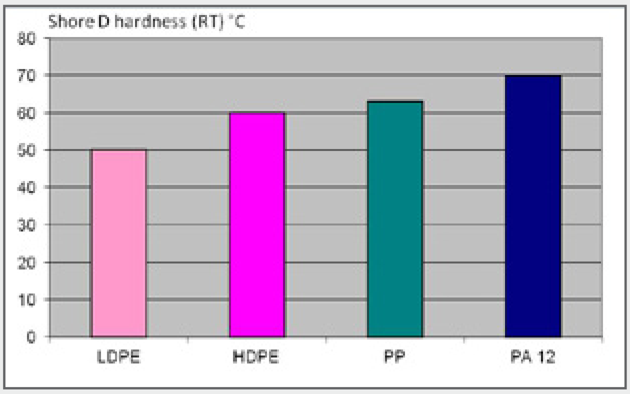

***Figure 9**: A comparison of the Shore D hardness of various coating materials reveals that polyamide 12 is far superior to conventional materials*

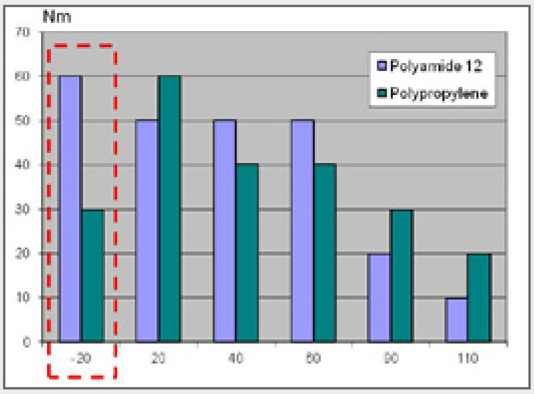

***Figure 10**: Polyamide 12 is clearly superior to polypropylene in terms of its notch toughness at lower temperatures in accordance with DIN ISO 179-1*

diameter of hemisphere 2.5 mm). The coated pipe specimen is pulled at a rate of 200 mm/min. The maximum penetration depth of the tip over a length of 50 mm is determined with the aid of a dial gauge.

Comparative tests revealed a significant difference between the polyamide and GFRP coatings on the one hand and the polyethylene and polypropylene coatings on the other. The gouge resistance of the polyamide coating is almost of the same magnitude as that of the GFRP coating. The test results impressively demonstrate the superior gouge resistance of polyamide coatings over polypropylene and polyethylene (Fig. 7). In terms of cost, a combination of polyamide and polyethylene is less expensive than a polyethylene-GFRP combination.

For the field coating of the girth welds in pipes with a multilayer coating system, a variety of materials are available, including polyurethane as casting material and GFRP-based coating systems (***Figure 8***). The pipe ends are appropriately prepared at Salzgitter Mannesmann Line Pipe's mill, i.e. the polyamide layer is cut back on the polyethylene coating over a length of at least 50 mm. This is long enough to ensure that the overlap of the mill-applied corrosion protection and the field coating can be achieved as specified by the applicable standard.

If short pipes are required, a circumferential cut should be made into the polyamide layer using a specially prepared cutting tool, whose blade only protrudes far enough to penetrate the outer coating to a maximum depth of 2 mm. For a precise circumferential cut, a clamp can be provisionally fitted around the pipe as a guide for the cutter. This procedure is recommendable, since the force needed to cut into the polyamide coating is greater than for polyethylene. The polyethylene coating can then be cut back in the usual way.

The differing properties of polyethylene (or polypropylene) and polyamide are attributable to their respective production processes: polyethylene is produced by polymerization, and polyamide by polycondensation. In simple terms, the linking of the individual components of polyethylene to form a polymer is caused by the "flipping" of bonds, while polyamide, on the other hand, forms through the reaction of an organic acid with an amine by splitting out water molecules. As a result, hydrogen bridges form in the production of polyamide, which contribute towards crystallinity, and this in turn increases strength and chemical resistance and raises the melting point. Compared to other polyamides, polyamide 12 offers the following advantages:

» Minimum water absorption
» Outstanding impact resistance and notch toughness, even at temperatures far below the freezing point
» Good to excellent resistance to greases, oils, fuels, hydraulic liquids, many solvents and salt solutions and other chemicals
» Outstanding resistance to stress corrosion cracking
» Excellent resistance to abrasion
» Low coefficient of sliding friction

As a result of these properties, the application range of polyamide 12 extends from complex piping systems, such as fuel pipes, wire insulation in the cable industry and catheters in medical engineering through to flexible oil production tubing in the offshore sector.

A comparison of the Shore D hardness of various coating materials reveals that polyamide 12 is far superior to conventional polyethylene or polypropylene materials (***Figure 9***). A look at tensile stress measurements also reveals that polyamide 12 has significantly higher tensile strength across the entire temperature range (-40 to +23 °C). Compared to polyethylene (HDPE), it is about twice as high, while polypropylene tends to range between these two materials. Besides, the application range of polypropylene is limited to service temperatures of 0 °C.

Similarly, polyamide 12 is clearly superior to polypropylene in terms of its notch toughness at lower temperatures in accordance with DIN ISO 179 1. In fact, polyamide 12 maintains its ductile fracture behavior down to -40 °C (see ***Figure 10***). The advantages of polyamide at lower tempe-

Table 1:

Pipeline no.	Location, parallel HDD-flush-drilled bore	Length of HDD-flush-drilled bore [m]	Coating resistivity [Ohm*m²]
70	Storchennest	500	1.56 E+10
71	Storchennest	500	6.83 E+09
70	Storchennest, Altendorfer Strasse crossing	420	4.02 E+09
71	Storchennest, Altendorfer Strasse crossing	420	3.78 E+09
70	Dümmerbach	130	6.76 E+10
71	Dümmerbach	130	2.03 E+11

ratures are evident, for example, in an impact test based on DIN 30678 or DIN 30670. Thanks to its more favorable properties, polyamide 12 is an excellent alternative to polypropylene, especially at low temperatures.
Another positive property of polyamide coating is its smooth surface, which is just as round and as smooth as the underlying PE coating. This is a great advantage when automated orbital welding equipment is used. In these processes, the electric arc is continuously guided mechanically through 360 degrees around the pipe or other bodies with a circular circumference. A high-quality weld is only possible when the distance between the welding head and the pipe shell remains largely uniform as the orbital welding machine travels around the pipe.
The most important criterion in quality assurance, besides visual inspection after the pulling operation, was a polarization measurement. Here, a value of better than 10^8 Ωm² was required.

Overview of coating resistances in new pipelines:

» Under laboratory conditions, up to 10^{10} Ωm² can be achieved.
» Accepted limit value for holiday-freedom: 10^8 Ωm²
» Values of 10^7 Ωm² and below indicate a high probability of coating damage.
» From values of 10^5 Ωm² measured on in-situ pipelines, intensive measurement is recommended instead of an IFO measurement.

The following values were in fact measured after the pulling operations, see ***Table 1***.

These are outstanding results showing that the coating integrity has remained unaffected along the pipeline. Neither were noticeable flaws detected during visual inspection – not even in the pipe section that was pulled in three times and thus over a stretch of over 1,100 m. On the basis of this consistently positive record, PA 12 will now be used as standard coating system on pipelines exposed to increased mechanical stresses. This brings us full circle. Now the basic raw material for producing polyamide is being conveyed through a steel pipeline coated with polyamide.

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