A New Concept in Multi-layer Coating

of Steel Pipes

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For trenchless pipe laying a large number of pipe coatings are available and have already proved their worth. These include not only additional coatings for a conventional corrosion protected pipe based on cement mortar or glass fibre reinforced plastic, but, in particular, also thick layer polyethylene or polypropylene coatings. These thick-layer coatings at time are usually produced in several coating steps, with which the best possible adhesion between the layers can be expected. Such a thick-layer coating must not only provide effective protection against corrosion but also adequate mechanical protection. This presentation explains the disadvantages of this concept and offers an interesting solution by way of a new alternative multi layer coating type.

1 Introduction

Over the course of time, methods of trenchless laying of pipes have been growing steadily in importance. There is hardly any major project which does not involve the crossing of roads, railway lines, rivers, or streams, and possibly also protected nature reserves. From the financial point of view, such situations can only be resolved by construction methods which do not involve cutting trenches. Such special construction procedures require independent planning, which sets them apart from conventional pipe-laying situations which can be resolved with standard pipes and pipe coatings.

There are a number of different coating systems available for special construction techniques, but the selection of the coating system is usually determined by the experience of the planners or the company carrying out the work. The use of thick-layer coatings, especially on a polypropylene base, has gained wide acceptance in the jetting technique sector in particular. In the case of cross-head extrusion two or even three production stages are required depending on the polypropylene (PP) layer thickness. A disadvantage with polypropylene is inadequate strength at low temperatures. Experiences with this have been reported in the past [1].

Polypropylene becomes brittle at lower temperatures. Local stress peaks, caused for example by point layering or point loading, are dissipated in the brittle state in the form of cracks, in particular if there is previous damage such as scoring or notching. The damage shows that, if cracks form, the good adhesion between the polypropylene layers represents a serious disadvantage, because the entire layer is affected by the crack formation. This of course also applies to thick-layer coatings which are produced in one step.

For aged 3-layer PP coatings this usually gets even worse. As the coatings become older, the brittleness temperature shifts to higher values in the course of time. The issue of crack formation is therefore a question of time, depending on the load situation and the plastic base. In the case of trenchless pipe laying in particular, a critical combination of scoring and notching, as well as point loading, cannot be excluded. Recent investigations showed crack propagation between coating layers in the case of interlayer adhesion. In the case of missing adhesion between coating layers crack propagation from one layer to another was not observed so far. With trenchless laying methods there is the risk that without strong interlayer adhesion the coating could be peeled off when the pipe is drawn into position. In order to compensate missing interlayer adhesion good shear strength of the coating is required, what seems at the first glance confusing. In the following section we shall therefore take a closer look at these concepts in the context of claddings and coatings of steel pipes.

2 Adhesion and Shear Strength

High peel strength, which means good adhesion, is drawn on as a quality feature for the three-layer polyethylene or polypropylene coatings conventionally used today, consisting of epoxy resin primer, adhesive, and the polyethylene or polypropylene top layer. Technical delivery specifications, such as DIN 30670 [2] or DIN 30678 [3], require for the determination of the peel strength a separation within the adhesive layer (cohesive failure). With a multi-layer structure, separation always occurs in the weakest element. This means that, with a separation inside the adhesive layer, the adhesion of the coating to the steel and the adhesion of the individual components to one another is greater than the strength of the adhesive used. The adhesion of the coating to the steel is determined by the bond of the epoxy resin primer and the steel, and is comparable to a single-layer coating of the epoxy resin. High values for the peel strength with a separation within the adhesive layer are indicative that the three-layer coating has been properly produced, and also of good adhesion of the coating.

Experimental determinations of the adhesion all adopt the same principle: A force takes effect vertically on a defined surface area of the coating. The amount of the force which is required to separate the coating from the steel surface is taken as the measure of adhesion. The adhesion of a single-layer epoxy resin coating is determined, for example, by the pull-off test according to DIN EN ISO 4624 [4]. The measured value then only corresponds to the adhesion if the separation takes place between the coating and the steel (adhesive failure). A separation inside the layer (cohesive failure) in this case also means that the adhesion is greater than the strength of the coating material.

While in the case of adhesion the force imposed vertically to the coating is countered by a resistance, when it comes to the shear strength this resistance takes effect in the longitudinal direction (Figure 1). Forces in the longitudinal direction to the axis of the pipe are to be anticipated in particular with trenchless pipe laying, while the pipe is being drawn in. In this situation, adhesion and shear strength are not necessarily to be equated with one another in the physical sense.

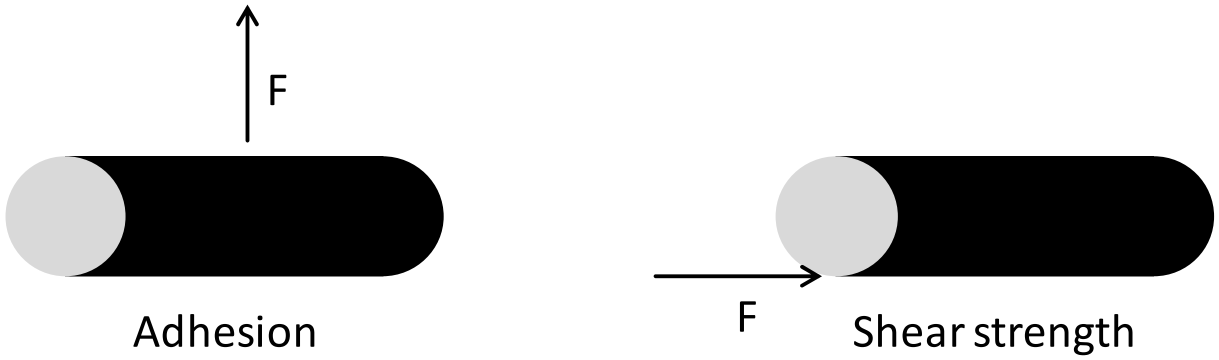
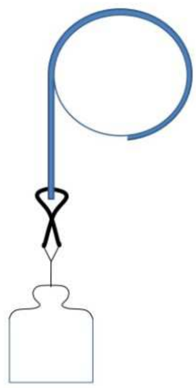
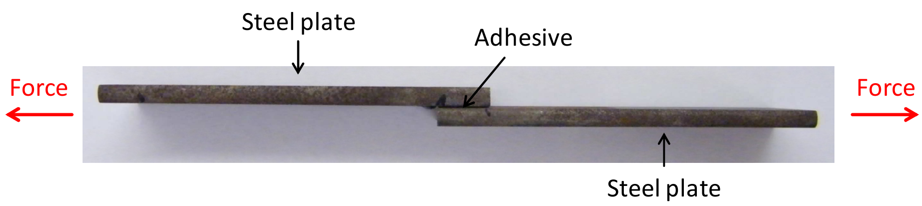


Figure 1: Differences in measurement of adhesion and shear strength

The difference between these two values is particularly clear in the case of AS/NZS 1518 [5], an Australian delivery specification for two-layer HDPE coatings consisting of adhesive and HDPE top layer. Here, the two values are assessed separately. The adhesion is determined by a peel test. To do this, a 25 mm wide strip of the coating is cut into. For the purpose of the test, a 300 g weight is hung on the end of the strip. For the assessment, the peeling speed is determined, which may amount to 100 mm/min at room temperature. The principle of this test is shown in Figure 2.





Figures 2 and 3: Test principle for determining adhesion and shear strength in accordance with AS/NZS 1518 [5]

To determine the shear strength, AS/NZS 1518 makes reference to an American test specification, ASTM D 1002 [6]. For the test, a defined adhesion surface is produced with the adhesive of the two-layer coating between two metal plates. In a tensile test, the force necessary to break the adhesion is then measured (Figure 3). For the shear strength of the adhesive, AS/NZS 1518 requires a minimum value of 34 N/cm². In a similar way, for example, the shear strength of FBE is also determined in accordance with DIN EN 1465 [7].

Another test principle for determining the shear strength is applied in the case of the cement mortar coating of PE or PP sheathed (polyolefin sheathed) pipes. In the case of the special design (Type S) for trenchless laying procedures, a corresponding shear strength of the coating is again required. The technical delivery specification, DVGW* worksheet GW 340, also makes provision in this situation for a component test [8]. In this case, the system of steel base material, coating, and sheathing is not subjected to a tensile load but to a pressure load parallel to the axis of the pipe (Figure 4).

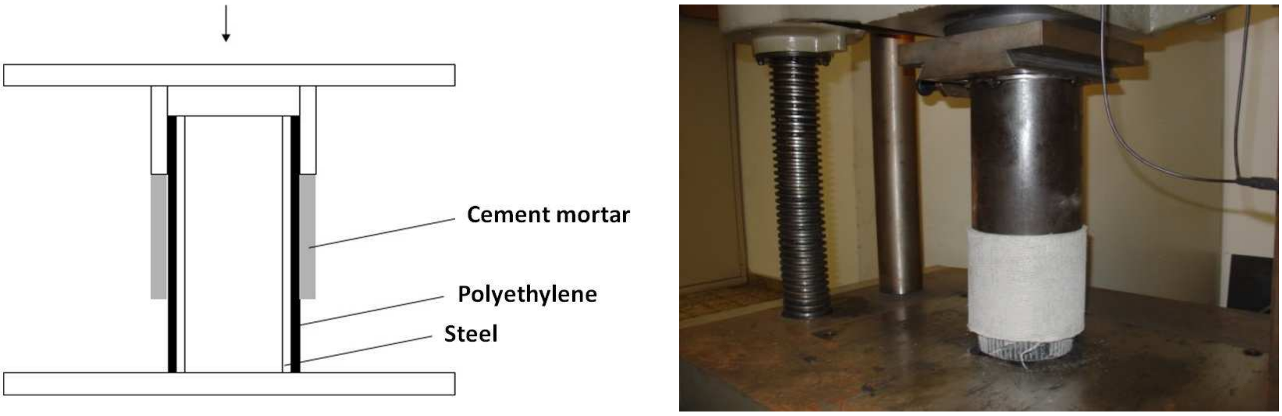


Figure 4: Test arrangement for determining the shear strength in accordance with DVGW* worksheet GW 340

The combination of cement mortar and polyolefin layer in particular demonstrates that an adhesion deficiency does not necessarily also mean a deficiency in shear strength. Naturally, between cement mortar and polyolefin layers there is only the possibility of a mechanical link. In the case of the FCM-S format according to DVGW worksheet GW 340, adhesion and shear strength are achieved by appropriate profiling of the polyethylene coating. In this situation, rough T-shaped webs are extruded, distributed over the circumference, into which the cement mortar coating can engage.

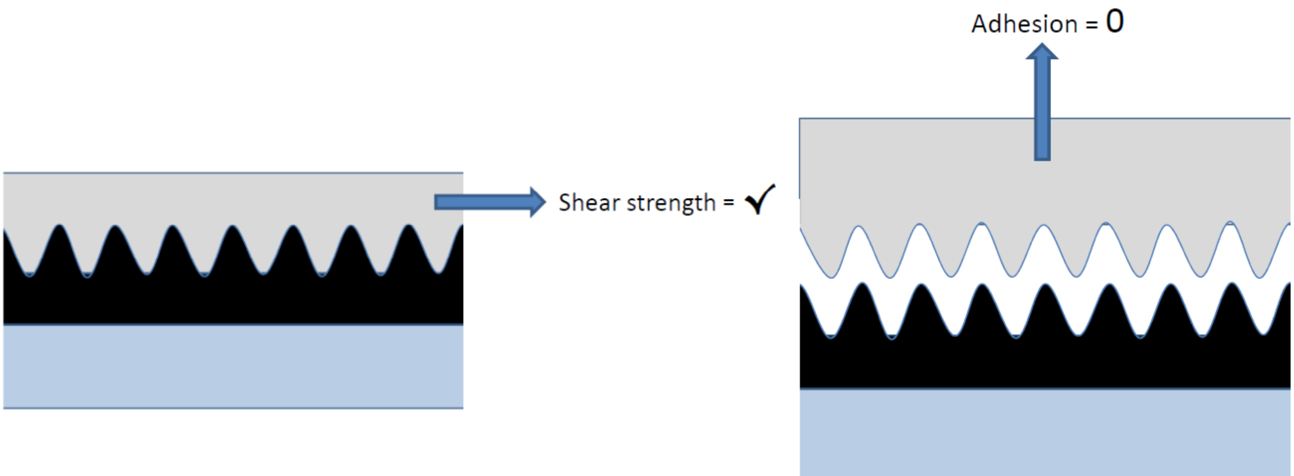


Figure 5: Shear strength and adhesion in the context of a rough surface structure

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*DVGW German Association for Gas and Water

As well as the extrusion of a rough T-profile, which by its nature allows for both adhesion as well as shear strength, the use of what is referred to as a “rough coat” is known. The rough coat arrangement of the polyethylene coating is specifically aimed at increasing the shear strength of a concrete sheathing which is usually reinforced with steel inlays. This coating format is often used for offshore pipe laying. After the extrusion of the polyethylene layer, a fine PE granulate is then sprinkled onto the still hot coating. The granulate melts on, and a rough surface structure is formed. This profiling achieves a perceptible shear resistance by mechanical means (Figure 5). Adhesion is not provided, however. Particular attention was paid to this effect in particular in the development of alternative multi-layer systems for trenchless pipe laying methods.

3 The alternative coating concept

The main idea in the development of an alternative coating system is to apply the top layer without adhesion to the other layers in a multi-layer structure, in order to avoid the propagation of cracks between these layers. The crack formation is accordingly stopped in the area of the boundary surface between two non-adhering layers. In this situation, however, a corresponding shear strength should still be ensured. In principle, this core concept is already provided in the case of cement mortar coatings. Up to now, this formulation has not been considered in the case of 3-layer polyolefin coatings with increased thickness, which are often preferred.

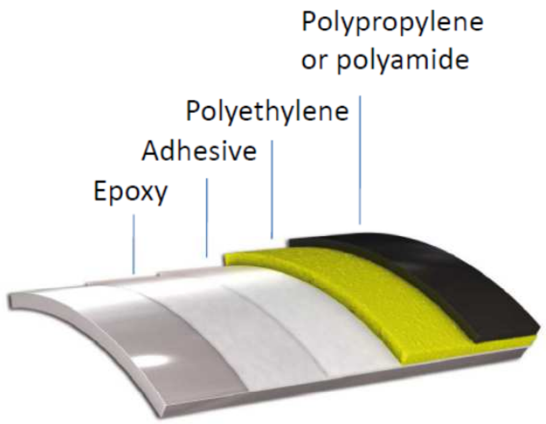

Figure 6: Structure of the multi-layer coating

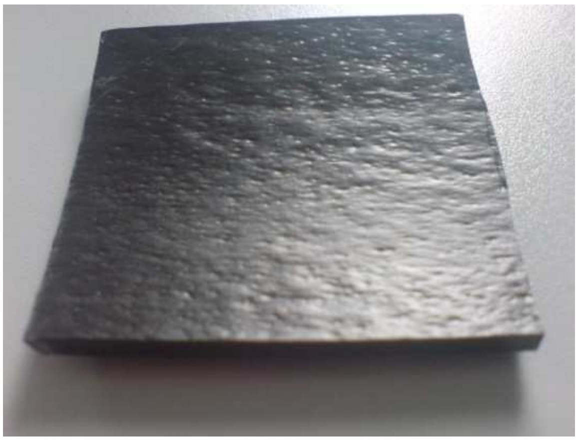

Figure 7: Underside of the polyamide layer

The new coating concept presented here makes use, instead of cement mortar cladding, of an extruded polypropylene or polyamide top layer, which does not adhere to the coating layers below. This can be achieved by extrusion of a polypropylene or polyamide layer on the top of a three-layer polyethylene coating modified by a rough coat, which forms an independent mechanical means of protection (Figures 6 and 7). In the case of a polypropylene top layer, the selection of an appropriate application temperature prevents adhesion to the polyethylene layer. For a polyamide top layer, the combination of non-polar polyethylene layer and polar polyamide top layer prevents the adhesion between both coating layers. In this multi-layer structure, therefore, as in the case of cement mortar, the functional aims of corrosion protection and that of mechanical protection are specifically separated from one another.

4 Properties of the new coating concept

4.1 Shear strength of the coating

The coating combination of polyethylene, rough coat and polyamide or polypropylene top layer was investigated to determine the shear strength on the basis of the GW 340 worksheet [8]. To do this, the protective sheath on the corrosion protection coating was pushed off by a ring segment adapted for the purpose and the force required was recorded (Figure 8).

Figure 8: Set up for testing the shear strength

To test the multilayer system of a 3-layer polyethylene coating with an additional polyamide top layer respectively with an additional polypropylene top layer, pipe segments about 5 cm wide were cut. The top layer was cut on both ends of the pipe segment, so that a ring with a broadness of 25 mm was remaining. On the upper end the coating was removed as far as the polyethylene layer and at the lower end as far as the epoxy resin (Figures 9 and 10).

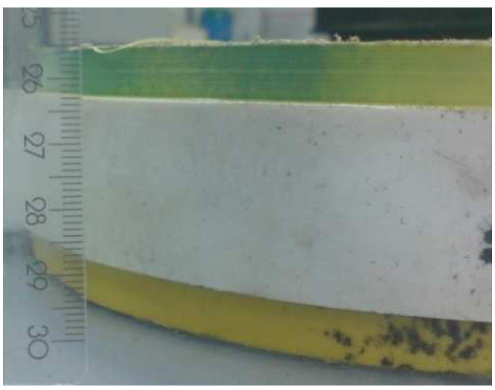

Figure 9: Test specimen, PE/PP combination

Figure 10: Test specimen, PE/PA combination

A steel ring, matched to the outer diameter of steel and polyethylene coating, allows, by its projection, for a shear area of some 5 mm (Figure 8). The principle is adopted that the measurement is ended after the shearing of an area of 5 mm. The specimen and the ring set on it are positioned beneath the testing device, and the force necessary for the shearing is recorded. The combination of polyethylene and polyamide could not be completely pressed off in this situation in the intended test area due to lack of projection of the ring segment. The shear forces determined therefore represent minimum values, which in practice are higher. For the 25 mm wide coating strip, with a test surface of 175 cm², a force of 3.6 tons was nevertheless determined. The shear strength to be demonstrated according to the DVGW worksheet GW 340 therefore reaches at least 200 N/cm².

In the case of the polyethylene and polypropylene combination it was possible to determine the actual shear force with the selected test set-up. Due to the profiling of the PE coating, in the case of non-adhering coating and with the same geometries, a force of just on 6 tons was determined, corresponding to a shear strength demonstrated in accordance with DVGW worksheet GW 340 of 340 N/cm². The minimum shear strength required for cement mortar sheathings of Type S according to DVGW worksheet GW 340, of 50 N/cm², is well exceeded according to these test results, and by both coating variants [8].

Although the shear strength of the new coating system is only attained by mechanical means, it is approximately on the same level as the values published in the literature for three-layer polyethylene coatings. For the three-layer polyethylene coating, at room temperature shear strengths are determined of between 300 and 400 N/cm² [9].

4.2 Crack formation in the multi-layer system

With the aid of an impact test at low temperatures, the crack formation in the multi-layer system was examined in greater detail. Because the PP coating reacts perceptibly more sensitively to cold in comparison with the polyamide, for the test the combination of polyethylene and polypropylene was selected. The impact test takes place in this situation as is formulated, for example, in the delivery specification for polypropylene coatings, under perceptibly more stringent conditions (see DIN 30678 [3]).

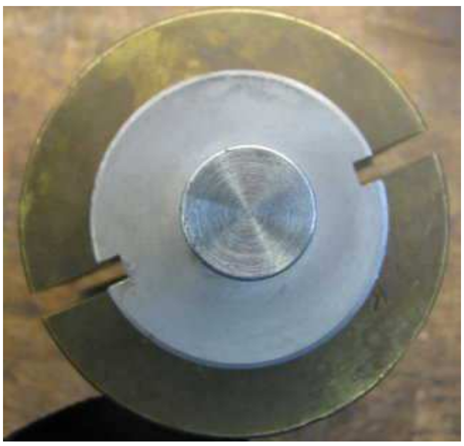

Figure 11: Drop weight

Figure 12: Result of the impact test

The test is carried out with an impact force of 200 Nm (as opposed to 10 Nm according to DIN 30678) at sub-zero temperatures (as opposed to 0°C according to DIN 30678), in order deliberately to provoke cracks. The drop weight in this situation is not a hemisphere as provided for according to DIN 30678. The test surface area has a flattened form, with a diameter of 21 mm (Figure 11).

The aim of this impact test is to clarify the issue of whether, with the multilayer structure, a crack which forms in the outer layer can be transferred over the boundary surface into the polyethylene located beneath. While with the same test arrangement cracks are produced in the pure PP coating as early as at -10°C [1], in the multilayer system they first occur at -60°C, which may possibly be attributable to the buffer effect of the polyethylene coating, which has a tendency to be softer. As anticipated, the polyethylene coating in this layer arrangement remains undamaged. In Figure 12, after the impact test, in the area of the crack only the black rough coat can be seen beneath the detached polypropylene coating. The cracks end, as expected, in the boundary surface of the polyethylene and polypropylene.

4.3 Testing the indentation resistance

For the simulation of the loadings imposed during a draw-in procedure, what is referred to as the gouge test was selected, in accordance with the Canadian Standard CAN CSA Z 245.20-10 [10]. As a model presentation for this test, the effect of a sharp stone was chosen, over which the pipe is pulled as it is being drawn into the bore channel. Accordingly, a sheathed pipe specimen is drawn under a test tip (Figure 13) over a length of 50 mm.

Figure 13: Test tip

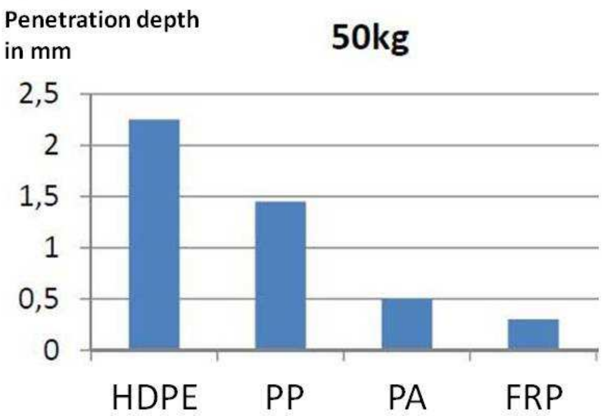

Figure 14: Results of different coatings in the gouge test (Test in accordance with CAN CSA Z 245.20-10 [10])

For this purpose, the test tip is weighted with a weight of 50 kg (angle of the test tip 20°, hemisphere 2.5 mm diameter). The advance of the sheathed pipe specimen was at a rate of 200 mm/min. The penetration depth is determined with the aid of a dial gauge. Figure 14 shows the results of these measurements. The polyamide and glass fibre reinforced plastic layers differ markedly from the polyethylene and polypropylene layers. The indentation resistance of the polyamide coating in this situation is almost at the level of a glass fibre reinforced coating. This test provides impressive proof that the polyamide coating can tolerate perceptibly greater loads in comparison with polypropylene, and confirms the advantages of polyamide already described earlier [11], [12].

5 Practical experiences

5.1 The coating combination of PE and PA in plough laying

As part of a programme of upgrading and extension, the Bavarian Forest Water Board carried out the construction of a mains water pipe to provide the towns and municipalities of the catchment areas south of the Danube with drinking water from the groundwater pumping station at Moos near Plattling in the south of Germany. The pipeline construction project, planned for the period from April to August 2011, covered a trace length of 9.5 km. Because of the condition of the soil, the companies involved had already decided at the planning phase to lay a large part of the whole distance by means of a plough procedure.

Figure 15: The coating combination of polyethylene and polyamide in the plough laying procedure

The plan was for about half of the planned pipeline route to be laid in this manner. This was subdivided into 21 individual sections, with a maximum draw-in length of 760 m. On one part of the line, for the first time, as well as the thick-layer polyethylene coating provided for, over a length of 1200 m a multi-layer system consisting of polyethylene and polyamide was used. The pipes were welded into strings on the trace itself, and mounted on roller stands for drawing in. For the subsequent coating, the connection areas were sand-blasted and provided with shuttering to accommodate a polyurethane casting compound.

For the laying, a 480 h.p. winch with a pulling power of max. 220 tonnes was used (Figure 15). This winch draws the laying plough, which brings the pipe to a laying depth of maximum 2.5 metres. The tip of the plough clears out and shapes both the cavity as well as the bed for the pipe string. Taking account of a curve radius provided for of 190 metres, incurred due to the procedure, the pipe format selected can be subjected to a maximum tensile force of 100 tonnes. These forces, however, were not attained even with a draw-in length of 760 metres. The maximum tensile force never exceeded 60 tonnes. A major part was played in this on the one hand by the amenable soil conditions, but on the other also by the low slide friction of the plastic coating.

5.2 The coating combination of PE and PA in the HDD process

As part of a relaying project to supply a hotel complex in the northern part of the city of Münster, in response to an order by the municipal public works department, a gas pipe with a rated diameter of 200 was laid beneath an area of woodland and the hotel's own tennis court. The jetting process is especially well-suited for situations such as these.

Figure 16: The coating combination of polyethylene and polypropylene in the jetting process

By contrast with the plough method described earlier, laying with the HDD process, or jetting, has been known for a long time (Figure 16). While with ploughing the pipe string is, as a rule, drawn dry into the soil, with the jetting technique a bentonite solution provides, in the ideal situation, for a floating introduction into the ground. The start of the project was in March/April 2013. The pipes, provided with a combination of polyethylene and polypropylene, were welded to form a string.

In order to protect the connection areas, a subsequent coating was provided on a glass fibre reinforced plastic base. The pipe drawing took place in September 2013. The horizontal bore, some 2.5 metres deep, was 60 metres long. The pipe string was then guided under a wall, which was protected as an ancient monument, and then integrated into the existing network.

6 Conclusions

When it comes to trenchless construction procedures, there are a number of different concepts to choose from with regard to coatings and sheathing. Thick-layer coatings frequently used for this purpose are combining corrosion protection and mechanical protection. Experiences in the recent past show that in case of fracture mechanical properties the view cannot remain restricted to the product with as-new values alone; it is essential to take account also of the changes to these materials which are wrought by time. Mechanical loadings, which do not cause any problems for material of new value, can lead in later operation to crack formation. In thick layer systems these cracks extend to the steel base material, so the function of passive corrosion protection is no longer provided.

For polyethylene or polypropylene coated pipes which are additionally sheathed with cement mortar, the function of corrosion protection and of mechanical protection has always been separated from one another. In the event of flexure, for example, which can occur during handling on site, crack formation in the cement mortar sheathing is by no means uncommon. The reinforcement of the sheathing with fibres and fabric strips serves in this situation to bridge the cracks, so the cement mortar is fixed on the pipe surface. Because cement mortar and polyethylene do not enter into a substance combination, cracks in the mortar are of no significance for the function of corrosion protection.

With the new multi-layer coatings presented here, by the specific selection of the coating materials and, as appropriate, the manufacturing parameters, this concept of separation of the functions of corrosion protection and mechanical protection is transferred to pure plastic coating systems. The shear strength required for the application sector of trenchless laying is realized by the rough coat, and the mechanical engagement of the layers associated with this.

Initial experiences with applications show that during laying no impairments can be identified in comparison with the thick-layer systems used hitherto. Advantages in long-term service life are to be anticipated in case of scoring and/or notching, as well as point loadings, which are typical loads for trenchless pipe laying. In the event that, in the course of time, due to age-induced brittleness, forces from point loadings and point layering are dissipated by crack formation in the outer cover layer, the coating will nevertheless remain stable in form due to the soil pressure imposed. The function of corrosion protection of the underlying coating layer will not be impaired. In this situation, the newly-developed multi-layered systems are plainly superior to the thick-layer systems used hitherto, and so expand the product spectrum of special solutions for pipeline construction.

7 Literature

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