Polyamide coatings for non-conventional pipe laying methods

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SUMMARY: The use of underground pipes involves considerable stresses being exerted on them. This is not only the case while they are being laid, but also while they are in use. Dynamic stresses result not only from passing traffic but also from weather-related subsidence that takes place in pipe trenches. Such stresses will inevitably lead to point loads or point supports, which can present a local risk for anti-corrosive coatings. For this reason, ordinary polyethylene-based coating must be bedded in stone-free material. For non-conventional laying methods, combinations of polyethylene and fibre cement mortar or an additional GRP jacket may be used. This article will specifically introduce polyamide as a new base material for pipe coating and examine initial experiences from use.

INTRODUCTION

The use of polyethylene coatings has established itself in the last few decades and is an alternative to the use of FBE coating materials in pipeline construction. A wide range of national and international regulations have incorporated requirements on measures to be taken in order to protect such coatings against mechanical damage.

This especially includes the requirement that pipes must be bedded in stone-free material. The literature also describes the use of "soil binders" [1, 2], to protect the coatings. Special solutions have been developed [3, 4] for specific non-conventional laying methods which, as with trenchless laying or sand-bed-free pipe laying, require the use of additional mechanical protection for the polyethylene coating. These include various types of fibre cement mortar coating as per DVGW worksheet GW 340 [5] as well as the profiling of polyethylene coating or the combination with a GRP jacket (**Figure 1**).

When employed each of these special solutions has advantages and disadvantage, and by necessity these will affect the decision to use or not use a given design depending on usage experience. Among this range of possible special solutions, a further alternative to be considered in the future is the use of extruded polyamide coating.

The utilisation of polyamides as coating materials are not new. Polyamides, which are described in DIN EN 10310 (Steel tubes and fittings for onshore and offshore pipelines - Internal and external polyamide powder based coatings) and are applied by means of sintering, have been used as coating materials for pipes for a long time [6]. These coatings, for example, are used for pipelines in surface installations. Many service stations provide relevant examples (**Figure 2**). Sintered polyamide coatings are considered to be an alternative to FBE (fusion-bonded epoxy), a powdered epoxide resin coating.

Combination of polyethylene coating and GRP

Polyethylene and cement mortar coating, as per DVGW worksheet GW 340

FIGURE 1: **Pipe designs for non-conventional laying methods**

Two approaches are possible for the extruded polyamide coating presented here:

- a two-layer system comprising one base coat and the extruded polyamide coating
- a four-layer system comprising three-layer PE coating with epoxide resin primer, adhesive and polyethylene together with the extruded polyamide layer.

For the field joint coating, a polyurethane resin is recommended; this is a system that has been recognised for applications such as this for a long time [7, 8].

The material is applied for example by casting or spraying it onto the previously cleaned and roughened steel surface (**Figure 3**). The requirements of such polyurethane coatings in respect of their anti-corrosion properties are described in DIN EN 10290 [9]. The advantage of this is that it ensures roughly the same mechanical properties in both the polyamide coating and the field joint coating.

POLYAMIDE 12 – A POLYCONDENSATE

The chaining together of different components to form polymers differs with polyamides in respect of the polymerisation of ethylene or propylene to polyethylene or polypropylene usually used as coating materials.

With polyethylene, this chaining (explained simply) is done by folding over bonds (**Figure 4**). With polyamides, an organic acid reacts with an amine when water is split (**Figure 5**). The functional components are an "acid group" -COOH and an amine group $-NH_2$. If each of these reaction partners each has two such functional groups, the splitting of water molecules will produce long chains with carbonamide groups acting as bonds. The resultant polyamide is produced as a result of the process known as "polycondensation".

"Laurinlactam" is used as a component for polyamide 12 (**Figure 6**).

The carbonamide groups (-CO-NH-) produced during the polymerisation process causes hydrogen "bridges" to develop between the individual macromolecule chains (**Figure 7**). These hydrogen bridges contribute to the crystalline nature, increase the hardness, elevate the melting point and improve the substance's chemical resistance.

Of all polyamides currently available, the concentration of these carbonamide groups is the lowest in PA 12. This results in following advantages:

- Lowest water absorption
- Extraordinary impact resistance, even far under freezing temperature
- Good to very good resistance against greases, oils, fuels, hydraulic fluids, many solvents, as well as saline solutions and other chemicals
- Superb resistance to stress cracking
- Superb resistance to abrasion
- Low sliding friction coefficient

These properties make polyamide 12 suitable for use in the most demanding pipeline systems such as fuel pipelines, cable insulation in the cable industry, catheters in medical technology, and precision moulding components such as pump wheels

FIGURE 2: **Polyamide-coated pipelines in a service station for drinking water**

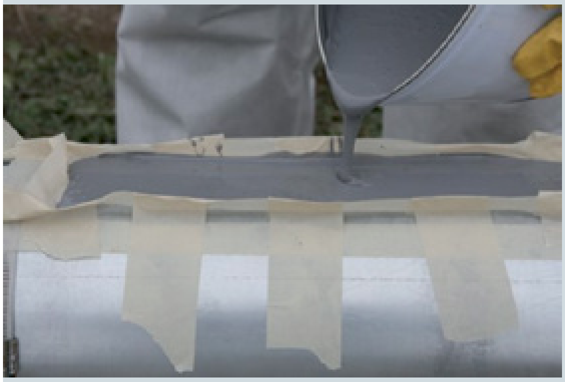

FIGURE 3: **Polyurethane field joint coating (casting)**

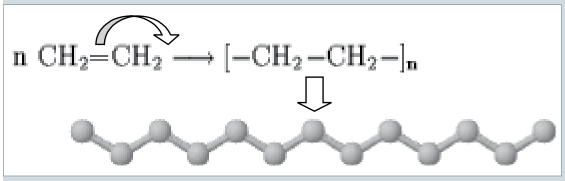

FIGURE 4: **Polymerisation of polyethylene**

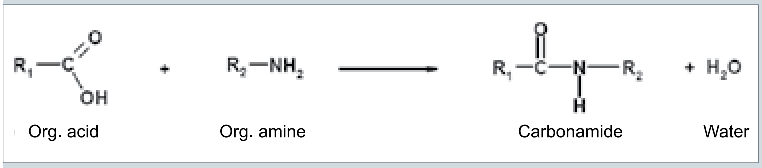

FIGURE 5: **Production of carbonamide groups from the splitting of water molecules**

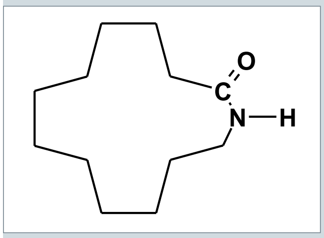

FIGURE 6: **Laurinlactam, monomer (source product) of polyamide 12**

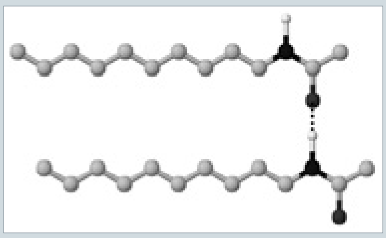

FIGURE 7: **Hydrogen bonds between two polyamide chains**

and switchover valve enclosures used in engineering and machine construction.

In **Figure 8**, the values determined as per DIN EN ISO 868 [10] for the Shore D strength of various coating materials are compared. Polyamide, especially PA 12, achieves a considerably higher shore D Hardness here than the commonly-used polyethylene or polypropylene-based materials.

When examining the yield strength values (**Figure 9**) determined in the course of tensile testing as per ISO 527-3 [11], it is apparent that polyamide 12 exhibits significantly higher values across the entire temperature range (-40 ... +23 °C). When compared with polyethylene (HDPE), the yield strength is around twice as high, while the values for polypropylene generally lie in between. As polypropylene is limited in its application to 0 °C [12], lower temperatures were not included in this testing.

Yield strain (**Figure 10**) progressively falls as temperature drops. It is with that polyamide maintains the greatest flexibility, especially at these lower temperatures. The drop in yield strain is, as expected, particularly marked with polypropylene.

The results confirm that polyamide 12 is an excellent alternative to polypropylene coatings due to its comparatively superior mechanical properties, particularly under lower temperatures. Polypropylene is used in many places where HDPE coat-

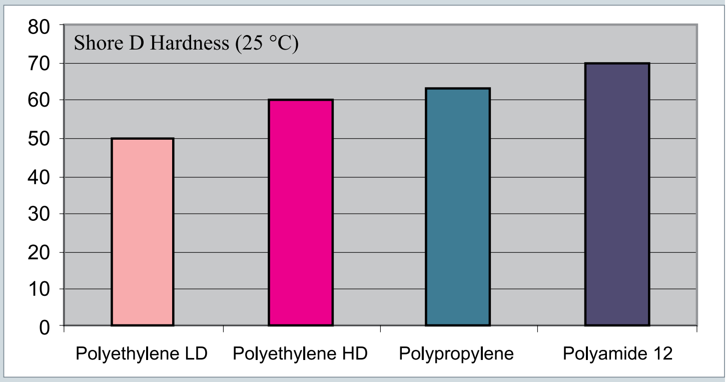

FIGURE 8: **Shore D Hardness as per DIN EN ISO 868 [10]**

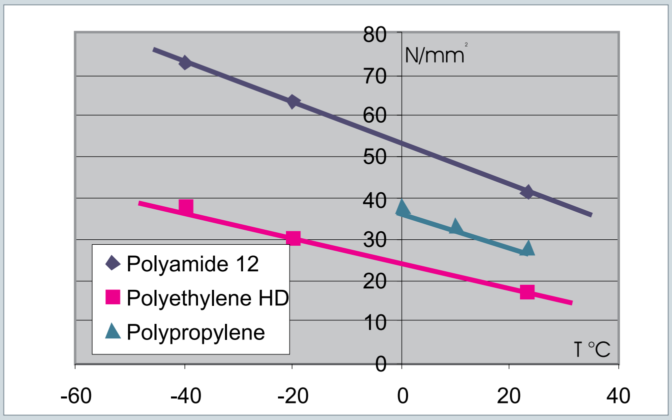

FIGURE 9: **Tensile testing as per ISO 527-3 [11], yield strength**

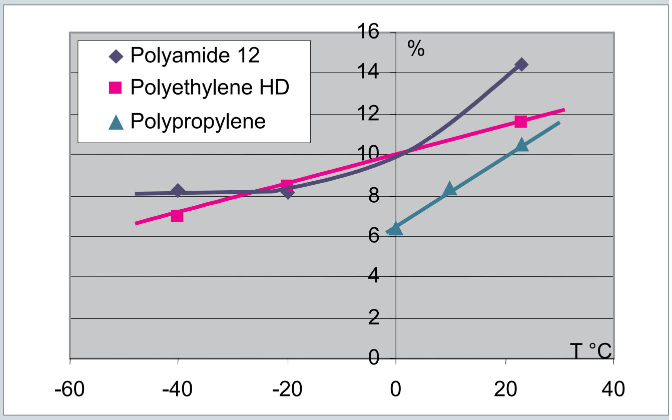

FIGURE 10: **Tensile testing as per ISO 527-3 [11], yield strain**

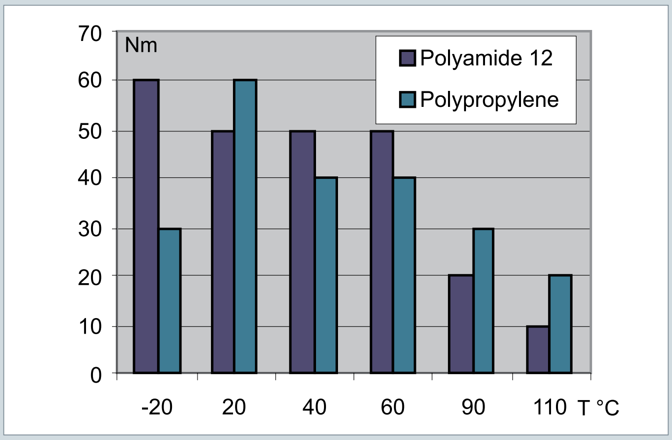

FIGURE 11: **Indentation test, roughly based on DIN 30670/30678**

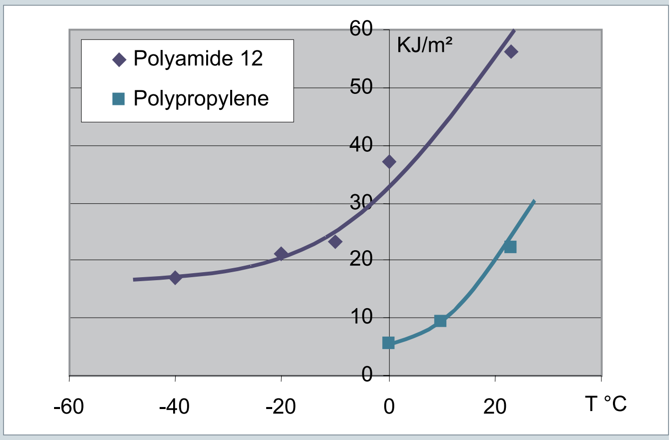

FIGURE 12: **Charpy impact test as per DIN EN ISO 179-1/1eA [14]**

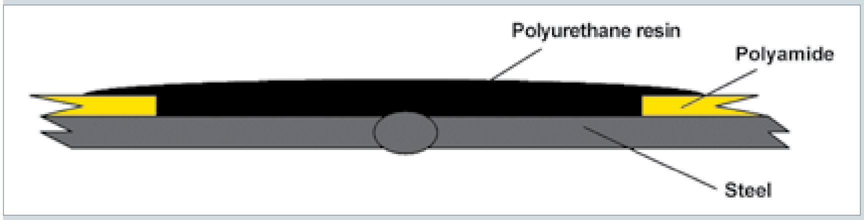

FIGURE 13: **Field joint coating for the pre-trials of polyamide coated steel pipes**

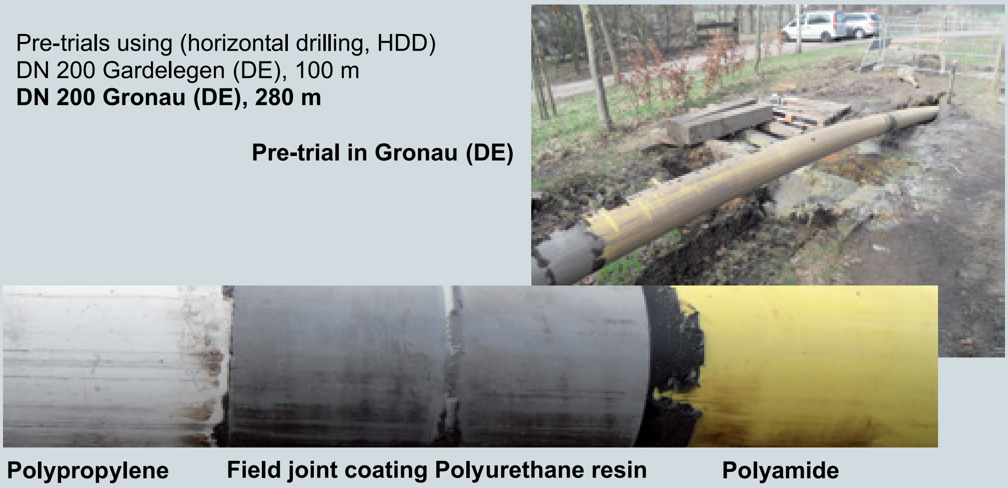

FIGURE 14: **Pre-trials of polypropylene und polyamide coated pipes**

ings is no longer suitable. This applies in particular to non-conventional laying methods such as horizontal drilling for example. The advantages of polyamide against polypropylene at lower temperatures can be demonstrated by means of indentation testing on the basis of DIN 30670 or DIN 30678 [12, 13].

Here, a weight is dropped on the coated pipe surface. The end of the weight is a semi-sphere with a diameter of 25 mm. In contrast to the specified standard, however, testing is performed by progressively increasing the drop height until initial holidays will be detected with an insulation test (25 kV). In **Figure 11**, the indentation impact testing results are plotted against temperature. While impact resistance falls sharply under 0 °C with polypropylene, it continues to rise with polyamide.

Polyamide 12 also demonstrates considerably superior properties when compared to polypropylene with the Charpy impact test performed as per DIN ISO 179-1 [14]. Even at -40 °C, polyamide 12 still provides to be ductile (**Figure 12**). In light of this promising, positive comparison data, a number of initial trial layings have been conducted using extruded polyamide coating.

INITIAL PRACTICAL EXPERIENCE WITH POLYAMIDE CLADDING

Pre-testing

The suitability of polyamide coating for trenchless pipe laying was assessed in pre-trials. Here, test strings were prepared using pipes with polyamide and pipe with polypropylene coatings. The pipe joints were coated with a polyurethane resin (**Figure 13**).

These test strings were pre-welded onto the actual pipe to be laid (in the direction to be pulled) and pulled through completely. The pre-trials were implemented in one project by Eon Avacon over a length of 100 m in Gardelegen (DE), north of Magdeburg (DE), and another in Gronau (DE) over a length of 280 m, this time by the laying company "Gerhard Rode" from Münster (DE). Both cases used DN 200 pipes. The test strings were each inspected visually after pulling, and checked using an insulation test (25 kV). **Figure 14** shows the result of the pre-trial in Gronau (DE). These pre-trials already indicate that the polyamide coating exhibited almost no scratches due to the increased hardness, while the polypropylene-coates pipe had considerable marking.

Laying of polyamide-coated pipes with HDD (Horizontal Directional Drilling)

For the construction of a DN 200 high-pressure gas transmission pipeline under the responsibility of Eon Avacon, specific sections were planned to be laid using HDD. One of these drilling projects, in Algermissen (DE) in the district of Hildesheim (DE), was ideally suited to serve as a pilot project for polyamide coating. Rohr- und Tiefbau Hoya GmbH was the company performing the laying. A canal was dug using HDD on a distance of 260 m. The roughly 300 m long pipe string was entirely pre-assembled. Once the weldings had been checked, the field joint coating, a polyurethane resin, was applied. The joint was first blasted, than sprayed with this rapidly hardening material (**Figure 15**).

A company specialised in recording the path of the drill hole from the starting pit onwards was responsible for the right deviation of the first drilling. This is usually done by following the section while keeping note of the location of the drill bit. Such an approach is not possible if water crosses the drilling, however. The drill hole was widened to 330 mm prior to pulling in the pipe string. The drilling fluid consisted of a mixture of bentonite and a slow-curing cement mortar; this was at the request of the approving authority.

The pipe string pulled in was then evaluated by measuring the polarisation current for the cathodic corrosion protection. The requirements of the regulations underlying the evaluation of the measurement were met; consequently, the coating was undamaged. This could also be confirmed by a visual assessment of the pipe end pulled in. Once the equipment and pipe end had been cleaned, there were hardly any recognisable traces of the pipe pulling process (**Figure 16**).

Blasting the joints

Field joint coating with polyurethane

FIGURE 15: **Field joint coating using a polyurethane resin**

Drilling equipment

Pulling of the pipe string

Pulled pipe end

FIGURE 16: **Pilot project – laying a polyamide-coated pipe by horizontal drilling**

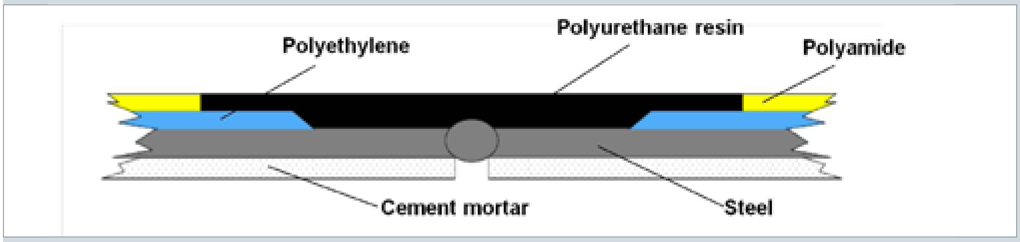

FIGURE 17: **Layer structure of the polyamide-coated pipes**

Laying plough and traction unit

Pulling Head

Widening unit

Ploughing the pipe string

FIGURE 18: **Laying of a water transportation pipeline using the plough technology**

Laying of polyamide-coated pipes using a pipe-laying plough technology

For the first time in Germany, a DN 300 cement mortar-lined steel pipeline was laid using the plough technology for the construction of a water transportation pipeline to supply the Bavarian Forest region with water. A steel pipe with 16 m lengths, lined with cement mortar and polyethylene coated was selected as a base pipe for the planned potable water transportation pipeline. It was a DN 300 pipe with a nominal external diameter of 323.9 mm and a wall thickness of 4.5 mm. With such a wall thickness and a steel grade with a minimum yield strength of 355 N/mm² the pipes can be used at operating pressures of up to 60 bar. The cement mortar lining was prepared at the pipe end for butt welding as per type C3 in accordance with Annex A of DIN EN 10298 (formerly version B of DIN 2614) [15, 16]. The remaining gap in the field joint around measuring 5 to 10 mm is protected by the formation of a passive layer after being in service.

For laying using the plough technology, the cement mortar-lined and polyethylene-coated pipe had an additional polyamide coating applied to protect it against mechanical damage. Taking into consideration the field joint coating with polyurethane resin and the cement mortar lining, the layer structure shown in **Figure 17** is the result. Prior to ploughing the pipes, they were welded together to strings and placed on rolls. On this rolls the joints are blasted and the polyurethane based field joint coating was applied. In this case a casted field joint coating was selected.

A 480 HP winch with a maximum traction of 220 t was used for laying. This winch pulls the laying plough, which brings the pipeline to a laying depth of up to 2.5 m. The pipe is fixed in a widening unit. The plough blade clears and forms the tunnel and prepares the bed for the pipeline (**Figures 18**). The length of the widening unit is used to ensure that the bed is levelled as possible. During the ploughing, the position of the pipe in terms of its laying depth or lateral position and the current traction force are monitored and recorded using a mobile control centre.

For this purpose, the planned route was recorded in advance and the resultant comparison data fed into the measurement and control system. This method ensures that pipes can be laid along the planned route and the planned depth without any problems.

Taking into consideration the maximum permitted bending radius of 190 m, this pipe can be subjected a maximum traction force of 100 t. However, forces of this magnitude were not reached even with a pulling length of 760 m. The maximum value for traction was less than 60 t. The ground conditions, but also the low friction of the polyamide coating contributes fundamentally to this. The surface is restored after the laying by means of a rolling process. Here, the trench is closed on the surface. Over time, the hollow areas left will be filled by seeping rainwater containing fine particles. Measuring the polarisation current for the cathodic corrosion protection showed that the coating has no damages.

PERSPECTIVES AND SUMMARY

This article has examined polyamide as an alternative coating material for use in non-conventional laying techniques. Initial projects and the relevant pre-trials demonstrated the suitability of polyamides for trenchless laying. A fundamental advantage of employing such innovative products is shown by the ability to monitor such projects via the measurement methods of the cathodic corrosion protection, which minimise the risk for the user.

The combination of polyamide and steel should not only be seen as a possible substitute for existing pipe designs, but also this combination of materials will permit methods in both land and off-shore laying that makes currently unused material resources available. This thereby enables a more sustainable use of the resources applied, both from an ecological and economic standpoint. An example of such applications in off-shore technology is the reeling process. The pipes are welded into a string measuring several kilometres on land, rolled up, and then later laid as a string out at sea (**Figure 19**). The steel pipes used with this laying technique are subjected to plastic deformation. Ultimately, the corrosion protection must also be able to withstand the forces incurred in the process.

A further example of the opportunities is a modified ploughing technology which is currently being tested in Canada for the laying of steel pipes [18]. In contrast to the pulling of the pipe strings, the laying plough here is pulled against the prepared pipe string (**Figure 20**). The pipe string will – while being transported on rollers – guided through the plough blade down at the desired laying depth. Here, the plough is also pulled by a winch, which is fitted onto an all-terrain vehicle. At present, the pipeline is only tracted under loads within its permitted elastic bending limits. However, with larger pipe dimensions, a controlled plastic deformation of the coated pipe string with a corresponding rolled-up structure is conceivable, as demonstrated with the reeling process. With this modified ploughing technology the pipe is not subject to any traction loads during the laying process. It is therefore possible to lay an endless pipe string in one work process. These examples demonstrate that polyamide coatings provides a flexible and mechanically resilient system, which in its principle combines the advantages of a flexible polyethylene coating with the mechanical protective effect of an additional cement mortar coating.

FIGURE 19: **Off-shore laying of a "reeled" pipeline**

FIGURE 20: **Ploughing a pipeline**

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