Aspects of modern corrosion protective coating technology

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0. Abstract

Corrosion protective systems - e.g tapes, shrink sleeves and liquid coatings (polyurethane and epoxy) have been used for decades on all types and sizes of buried pipelines.

Results thus obtained are as versatile as the available range of products and systems. The quality of a suitable corrosion protective coating system is an important criterion of the life expectancy of a pipeline and its secure operation. In Europe, USA and all major countries where pipelines are laid, there exists numerous standards and guidelines specifying the properties and functions of these protective coatings e.g. DIN EN 12068 [1].

For choice of a suitable corrosion protective coating system items like project size, intended and/or feasible method of pipe cleaning as well as special pipeline operating conditions have to be considered and are necessarily strongly related to each other. High performance shrink sleeves, tape systems or polyurethane coatings or combinations thereof are both technically powerful and economically suitable material solutions for a variety of project requirements. Recent developments on each named material further improve their hitherto already good performance.

The following paper deals with the material properties and practical experiences of the most common systems to ensure a long term performance of corrosion protection.

The main focus is laid onto the field of passive corrosion protection. While due to the external supply with electrons the cathodic partial reaction of iron corrosion is extremly lowered and suppressed, the anodic partial reaction should be prevented by the isolation of the pipeline. The isolation is executed in form of coating or wrapping with polymeric material, which prevents the ingress of water and oxygen to the metal surface. Besides this isolation the corrosion protective coating shall provide an electrical isolation, to prevent from stray electrical current or galvanic elements.

Each type of corrosion protective coating will cope with its function on a long termed base, if it will withstand all occuring mechanical and other influences in an appropiate manner.
1. Requirements for Corrosion protective coatings are:

- electrical isolation
- impermeability to vapour
- impermeability to oxygen
- impermeability to electrolytes
- chemical resistance (aggressive soil media)
- temperature resistance
- indentation
- peel and shear strength
- ageing resistance

<table>
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<tr>
<th>Loads</th>
<th>Requirements for coatings</th>
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<tr>
<td>Water</td>
<td>Vapour impermeability</td>
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<td>Oxygen</td>
<td>Oxygen impermeability</td>
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<tr>
<td>Electrolyte</td>
<td>Chemical impermeability</td>
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<td>Stray electrical current</td>
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<td>Impact at transport and application</td>
<td>Impact resistance</td>
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<td>Loads at transport and application</td>
<td>Indentation resistance</td>
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<td>Pipe movement in soil</td>
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<td>Aggressive soil, high levelled operating temperatures</td>
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<td>Unsuitable application</td>
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Table 1: Requirements for coating materials
2. Factory coatings

2.1 PE-PP-Factory coatings

State-of-the-art technology coatings are based on thermoplastic compounds (Polyethylene, Polypropylene - if raised mechanical resistance and temperature stability are requested), as they show based on their molecular structure as well excellent impact resistance and indentation resistance. Beside this PE is electrical high isolating and in the used layer thicknesses nearly impermeable to vapour and oxygen. Today mainly three layer coatings based on an epoxy primer are used.

![Figure 1: Two layer PE factory coating](image1.png)

![Figure 2: Three layer PE factory coating](image2.png)

Requirements to PE-Factory coatings are listed in DIN 30670 resp. EN 12085 (in preparation), the standard for PP-coatings is described in DIN 30678. PE-factory coatings are differentiated in maximum operation temperature (standard type N up to 50°C and type S up to 70°C) and minimum layer thickness in correlation to the pipe diameter.

Due to costs aspects and based on its better flexibility to temperature changes, preferably PE-factory coatings are used today.

While thermoplastic compounds like polyethylene can be easily applied to regular shaped objects like steel pipes by extrusion process, the production of equally performing thermoplastic coatings on geometrically complex surfaces are much more complicated to apply. In this event thermosetting coatings have to be preferred.
DIN / EN Standards for Factory Coatings

<table>
<thead>
<tr>
<th>Standard</th>
<th>Scope</th>
<th>issue</th>
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</thead>
<tbody>
<tr>
<td>DIN 30670</td>
<td>Polyethylene coatings for steel pipes</td>
<td>04-1991</td>
</tr>
<tr>
<td>DIN 30671</td>
<td>Polyurethane / Epoxy coatings for steel pipes</td>
<td>06-1992</td>
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<tr>
<td>DIN 30673</td>
<td>Bitumen coatings for pipes and tanks</td>
<td>12-1986</td>
</tr>
<tr>
<td>DIN 30677-2</td>
<td>Exterior coatings (polyurethane / epoxy) for buried valves</td>
<td>02-1991</td>
</tr>
<tr>
<td>DIN 30678</td>
<td>Polypropylene coatings for steel pipes and fittings</td>
<td>10-1992</td>
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<td>prEN 10285</td>
<td>extruded 3 layer PE pipe coatings</td>
<td>draft</td>
</tr>
<tr>
<td>prEN 10286</td>
<td>extruded 3 layer PP pipe coatings</td>
<td>draft</td>
</tr>
<tr>
<td>prEN 10287</td>
<td>PE sinter coatings</td>
<td>draft</td>
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<tr>
<td>prEN 10288</td>
<td>extruded 2 layer PE pipe coatings</td>
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<tr>
<td>EN 10289</td>
<td>Steel pipes and fittings for buried or immersed pipelines - epoxy coatings</td>
<td>12-2001</td>
</tr>
<tr>
<td>EN 10290</td>
<td>Steel pipes and fittings for buried or immersed pipelines - polyurethane and modified polyurethane coatings</td>
<td>12-2001</td>
</tr>
</tbody>
</table>

Table 2: DIN / EN Standards for Factory Coatings

<table>
<thead>
<tr>
<th>Pipe diameter</th>
<th>Minimum thickness [mm] standard (N)</th>
<th>Minimum thickness [mm] reinforced (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to DN100</td>
<td>1,8</td>
<td>2,5</td>
</tr>
<tr>
<td>from DN100 to DN250</td>
<td>2,0</td>
<td>2,7</td>
</tr>
<tr>
<td>from DN250 to DN500</td>
<td>2,2</td>
<td>2,9</td>
</tr>
<tr>
<td>from DN500 to DN800</td>
<td>2,5</td>
<td>3,2</td>
</tr>
<tr>
<td>exceeding DN1000</td>
<td>3,0</td>
<td>3,7</td>
</tr>
</tbody>
</table>

Table 3: PE thickness of Factory coating refering to diameter of pipe
2.1.2 Thermosetting-Factory Coatings

Beside the thermoplastic coating systems duroplast coatings based on polyurethane and epoxy resins are used. During application such thermosetting compounds are more or less viscous fluids, which form the polymeric material only on the objects to be coated by chemical reaction. Therefore these compounds are well suited for irregularly shaped or already installed objects.

Requirements to thermosetting factory coatings are described in DIN 30761 (pipelines) and DIN 30677 (irregularly shaped geometries). In the requirements of DIN 30670 the reduced elasticity compared to PE is expressed in the lowered impact value. European guidelines for PUR and Epoxy-coatings have recently been established (EN 12090 - PUR, EN 12089 - Epoxy resins) [2].

![Figure 3: Polyurethane coating](PUR)

![Figure 4: Glassfibre reinforced epoxy resin](Glassfibre reinforced epoxy resin)

2.1.3 Coal tar and bitumen based coatings

Coal tar and bitumen coatings are rather old types of coatings but still used in some countries e.g India. In most cases the coatings got brittle, resulting in the formation of crevices and cracks and a decrease in adhesion to the steel surface. Protective currents for old coal tar or bitumenous coatings often exceed values that could be accepted for an economically operated cathodic protection system.

The poor electrical insulation resistance of old coal tar or bitumen based coatings could be further reduced by formation of conductive areas within the coating. This areas contain iron sulfide, which is formed by certain bacteria and which penetrates into crevices within the coating.

Additionally for such hot applied coatings faults during application could be the reason for the formation of areas without any adhesion or the presence of hollows that are often filled with water.
3. Field-Coatings

Factory coatings are focused to reach a maximum of mechanical resistance. Regarding the requirements for field coatings an easy application and tolerability to application faults under changing conditions on site must be achieved. For field coatings thermoplastic and thermosetting coating systems are used as well, differentiated in warm and cold applicability.

<table>
<thead>
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<td>Coatings from tapes and heat shrinkable materials</td>
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</tr>
<tr>
<td></td>
<td>(for pipes with operating temperatures up to +50°C without cathodic protection)</td>
<td></td>
</tr>
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<td>prEN 10329</td>
<td><strong>Field coatings</strong> for welded joints of buried steel pipes</td>
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</tr>
<tr>
<td>EN 12068</td>
<td>Coatings from tapes and heat shrinkable materials</td>
<td>03-1999</td>
</tr>
<tr>
<td></td>
<td>(for buried pipes with cathodic protection)</td>
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Table 4: Guidelines for passive corrosion field coating material
Table 5: Cold and warm applied field coating systems

Due to the versatility of application for field coating systems, general requirements for all materials are not existing. The relevant guidelines DIN 30672 and EN 12068 for field coating materials differentiate into three mechanical stress classes (A, B and C) and three operating temperature classes (up to 30°C, resp. up to 50°C and HT -high temperatures-). The classification of these different materials referring to stress classes can be seen in table 6 [3].

The perfect field corrosion protective system for all purposes doesn’t exist yet, but one can choose of the wide range of systems the one, which is best suited for the relevant and unique project conditions, especially taking into account the applicability of the system to be chosen.

Field coatings do not have to withstand the same mechanical resistance as factory coatings. Some of the main sources of originating defects to pipe coatings as transport and loading must not be taken into consideration. Therefore not due to the better applicability of the field
system only, it is legitimate to choose materials for joints coatings, which show a reduced mechanical resistance.

3.1 Cold Applied Systems

All corrosion prevention systems, which need not the supply of warmth e.g. by propane torch, can be defined as cold applicable. For the preparation of the joint surface only, the drying of the metal surface by heating may be necessary.

3.1.1 Petrolatum Tapes

Passive Corrosion started some 80 years ago with petrolatum tapes and mastics. Today’s Petrolatum Tapes provide an excellent corrosion protection due to their soft consistency onto the metal surface, but their resistance against mechanical and thermal stress is clearly limited. Petrolatum tapes therefore are classified into stress class A-30. Today Petrolatum systems are used where the protection of irregularly shaped metal objects request for highly conformable materials e.g. flanges. By use of a rockshield the mechanical stress ability can be increased significantly.

3.1.2 Plastic-Tape systems

In any case where pipelines with tape coatings have to be new laid or rehabilitated caused by corrosion damages, two-ply tape systems are involved only. The negative attitude against tape coatings systems which can be found in numerous countries e.g. of the arabic world, results of negative experiences made in last twenty years are originated from this fact. The main reasons for their failure are material properties and general drawbacks of the coating system as well as unsuitable application procedures.

Particularly for PVC and bitumen based tapes intrinsic material drawbacks are the main reason for coating failure. Because originally PVC is a rather brittle material, tapes from PVC contain a certain extend of softening agents. During the lifetime of a pipe coating these plasticizers diffuse out of the carrier film, which results in an embrittlement of the carrier film and a decrease of adhesion, when the plasticizers accumulate in the interface adhesive - steel surface. Due to this effect very often only minor residues of the tape remain on the pipe surface when the pipe is dug out after years of service [4].

Although PE and butyl rubber based two-ply tapes generally did not suffer from such material drawbacks, they failed as well. This could mainly be explained by the unsuitability of two-ply tapes for primary corrosion protection requirements.
Corrosion protective coatings have to provide a primary protection against corrosion, which is achieved by covering the entire metal surface with a material that prevents the condensation of water on the steel surface. Suitable materials are permanently plastic compounds (petrolatum, butyl rubber) as well as rigid compounds (polyurethane, epoxy resins). As a second function the coating has to seal the surface by preventing interdiffusion or penetration of water and oxygen.

Two-ply tapes contain a carrier film that is coated with an adhesive on only one side. Due to this structure they can of course afford the primary protection against corrosion, because adhesion to the steel surface, when supported by a primer paint, is as good as for three-ply tapes. On the other hand the sealing properties in the overlapping areas of two-ply tape systems can not completely prevent the penetration of corrosive agents. In the remaining and clearly defined interface between the layers of a two-ply tape system micro channels may exist or occur, which represent a possible penetration path for water and oxygen (figure 7). As a result spiral corrosion is found on many pipelines where two-ply tapes are involved, especially when only two layers of tape with an overlap of only 25 mm or less have been employed and hotmelt adhesive coated tapes have been used. In the latter case the thin adhesive layers is not able to fill the cavities formed in the overlap area (figure 8).

**Figure 7:** Two-ply tape with thick layer adhesives, sealing by adhesion only

**Figure 8:** Spiral corrosion on pipe joint

### 3.1.3 Materials for pipeline new construction and rehabilitation –self-amalgamating three-ply tapes

At first sight it seems to be quite unusual to recommend tape systems for the new construction and rehabilitation of pipeline coatings, when the refurbishment measures have become necessary due to the failure of a tape system originally applied to the pipe surface. Yet it has to be clearly distinguished between two-ply and self-amalgamating three-
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Three-ply tapes. The latter one contain a carrier film from favourably stabilized polyethylene, which is coated with a butyl rubber adhesive on both sides. Carrier films of three-ply tapes are manufactured with coextruded intermediate adhesive layers, ensuring that no clearly defined interface remains between carrier film and adhesive layer. When three-ply tapes are wrapped spirally around a pipe, the adhesive layers self-amalgamate in the overlap areas, forming a homogenous sleeve type coating without any remaining interface.

3.1.3.1 Three-ply tapes

The self-amalgamation process and the sealing of a steel surface free of cavities is based on an important property of butyl rubber. From the physical point of view, butyl rubber is more a liquid than a solid. In the overlap area molecules of the different layers migrate into each other layer. After a certain period of time the originally existing interface has disappeared (figure 10).

Tape coating systems for pipelines should in any case involve at least two layers of a three-ply tape to make use of a homogeneous, nearly impermeable layer within the new coating.
This self-amalgamating tape could be combined with several supplementary tapes and primer coatings to obtain a maximum corrosion protective performance on differently prepared steel surfaces.

3.1.3.2 Surface preparation according ST2 or better

One tape systems, consisting of 4 layers of the same three-ply tape, provide a fully self-amalgamated and sealed sleeve type coating, whereas cost-effective two tape systems consist of a fully sealed inner wrap, which is mechanically protected by an outer wrap from a two-ply tape (figure 5). The adhesion to the steel surface is achieved by means of a butyl rubber containing primer paint, which functions as an anchor to the rough steel surface and whose second important function is to enclose residual dust remaining on the surface [5].

![Figure 11: One tape and two tape corrosion protective coatings](image)

3.2 Thermosetting Coatings

New developments show some preferences for no-dig pipe laying (e.g. thrustboring, pipe jacking, linear microtunneling and horizontal directional drilling) [6].

In case of trenchless pipe laying where coating materials of pipes and joints are particularly stressed by abrasion and shear forces, these high levelled requirements will be ensured by choosing two-component thermosetting coating systems based on polyurethane or epoxy resins. Both systems have in common that the system is created by mixing of two components and later curing on site. Thus field coatings are created in alignment with the adjacent factory coating and provide an extremely hard and flexible coatings which are characterized by outstanding high abrasion and shear resistance. Besides coating of pipe joints the repair of defects in factory coatings and coating of air-to-ground-transitions is an important field of application for thermosetting coatings.
To affix warm applied coating materials onto pipes or subjects, warmth have to be supplied e.g. with a propane torch.

### 3.3.1 Bitumen Tapes

The oldest warm applied field coating systems are tapes made of bitumen. Mechanically bitumen tapes show a technical performance on a minor level as plastic tapes or shrink sleeves. They meet at maximum the requirements of DIN EN 12068 stress class B-30°C, but probably A-30°only.

Despite their weakness to withstand mechanical stress, bitumen tapes are still in use for protective coatings of buried or immersed pipeline installations and tanks due to their easy application of coating even at huge areas.

The metal surface has prior to be primed with a bitumen primer. Please note, that primer of plastic tapes and bitumen primer are not compatible.

### 3.3.2 Heat Shrinkable Shrink Sleeves

Another method of PE application onto metals surfaces on site are heat-shrinkable sleeves consisting of radiation cross-linked polyethylene. The later requested shape of coating will be fixed by radiation between the single PE-molecules. In spite of this radiation process the material remains thermoplastic, so that it can be formed in a warmed up state. If a molecular linked material e.g. heat shrinkable sleeve will be stretched by the supply of heat and immediately after this process it will be cooled down again, so that the new shape will be frozen. The material stays under tension and will try to return to its original shape after sufficient warmth will be supplied (as a rule: at temperatures exceeding 100 °C). To adhere the shrinked PE onto the pipe surface, the sleeve backing is coated with a hotmelt, mastic or butyl mastic, which melts instantly, as the PE is shrinking back into its original shape. By
use of high performance shrink sleeve systems, the joint surface will be prior coated with an epoxy-primer. Thus the same layer structure as shown at factory coatings will be obtained.

Heat-Shrinkable Sleeves are a widely used solution for the corrosion prevention of girth welds on buried steel pipes. The sleeves consist of a high density, radiation or thermochemical cross-linked polyethylene, coated with a hotmelt, mastic or butyl adhesive. Two layer systems need no prior priming of the joint. Simple tools of application as hand or electrical power brush, propane torches are needed.

For three layer sleeves blasting of the joint metal surface cleanliness SA 2 ½ is obligatory. Three layer sleeves systems including the prior joint coating with an epoxy primer have excellent resistance to both cathodic disbonding and hot water immersion resistance, even at maximum operating temperature. Specially designed Shrink sleeves (fibreglass reinforced) are used for applications where they have to withstand high mechanical stresses e.g. directional drilling or in off-shore application.

**Figures 16:** Two layer Shrink Sleeve  Three layer wrap around sleeve

**Figure 17:** Application of 3-layer shrink sleeve

### 3.3.3 Sintering process

Besides the „wrapping“ or „shrinking“ the melting of PE on site in the same way as executed in the plant would be desirable. For the application of coating material on site, the extrusion process will be extremly complex and expensive. PE Powder to be molten onto the pipe surface, is used for repairing small defects in factory coatings. For larger areas this process is not practicable, at least at time.
4. Irregularly Shaped geometries

The choice of an appropriate coating system depends significantly from weather and general circumstances on site. High durable liquid coating systems based on polyurethane or epoxy resins react very sensitive to moisture and cold temperature and the application of these materials can start only at an ambient temperature min. 3°C above the dew point.

Irregularly shaped geometries as flanges or valves request for different solutions as standard pipe joints.

4.1 Petroleum Tapes and Compounds

A reliable corrosion prevention coating can be achieved by use of a permanent plastic based petrolatum-based material. A very efficient method is to use a highly conformable Petroleum mastic compound for filling gaps and voids and for achieving a smooth surface of the bolts and nuts. An additional overwrapping with a petrolatum tape will ensure a void – free protection.

High mechanical stress resistance is given by applying a rockshield based on polypropylene fibres which quite often obviates sandbedding.
4.2 Thermosetting coatings

Whereas highly highest corrosive and mechanical stresses at an increased operating temperature up to +80°C should be obtained, reactive resins based on polyurethane or epoxy should be used. For coating of irregularly shaped objects like valves, bends and fittings and as well for rehabilitation purposes, these materials offer decisive advantages for application. Technical requirements for these materials are described in European standard EN 12090. Before the application of thermosetting materials - cleanliness SA 2.5 – blasting of the surface is obligatory.

Airless-hotsprayed applied polyurethane is predominantly used material in fields of application, which demands the corrosion protection of irregularly shaped or geometrically fixed objects with high performance coatings.

Outstanding features of tar and voc free polyurethane 2-component compounds are their extremely low cathodic disbonding and an excellent adhesion even after hot water immersion [7].

5. Testing of coating quality

Even a high performance coating system is only as good as the application executed on site. Besides the requirements of tolerability against application faults, an easy and fast application on site, the quality of the coated pipe section has to be tested on site.

5.1 External test methods

5.1.2 Visual Inspection

The most simple way of testing is the visual inspection. Refering to plastic tape coating the question is: Are there no wrinkles visuable? At Shrink Sleeves. Any hollows or bubbles to be detected, any pores or air enclosures visible at thermo setting coating systems?
5.13 Peeling Test

Peeling tests for tapes and shrink sleeves should be executed on site once a day, a cohesional break in the layer should be achieved.

5.1.4 Holiday Detection

Holiday testing. For shrinkable sleeves and plastic tape systems are the requirements according DIN EN 12068: 5 kV + 5 kV per mm thickness, maximum 20 kV in total.

Liquid coatings will be tested with 8 kV per mm and a maximum of 20 kV.

5.2 Internal Inspection

A new, but interesting and fascinating method to check the quality of coating systems of a buried pipe is the inspection by intelligent pigging-ultrasonic in-line inspection. This inspection offers possibilities to investigate the internal coating as well as on the external side of the steel pipe. While inspection of internal is already matured and can be executed at any time, the inspection of external coating is still in its infancy, but encouraging results have been obtained [8].

Figure 26: Detection of external coating defects by intelligent pigging

6. Conclusions

It pays off to choose the appropriate system for the unique project requirements of every site. It has to be taken into consideration that the percentage of each coating system is around 0.03% of the total project costs only, but due to low quality materials, not suited for the requirements on site or incorrect application, joints are a major source of defects which originates indirect losses and high consequential damages.
Every chain is only as strong as its weakest part. Therefore it is negligent to disdain the value for a coating protection. For nearly all requirements on site there are high-quality long-lasting solutions available worldwide, one only have to choose the appropriate system. For standard temperatures up to + 50 °C state-of-the-art three-ply tapes systems offer the widest range to meet the diverse and many conditions on sites and can be applied at ambient temperatures from –35°C to + 60°C. At exceeded temperature ranges or requested raised mechanical resistance, thermosetting compounds based on polyurethane or epoxy will probably be the best choice.

7. References


DIN30671 „Thermosetting coatings of steel pipelines (1992-06)“.


