Design and mode of operation for advanced corrosion protection systems

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1 Introduction:

According to a press release from April 2011 by the World Corrosion Organisation, the global economy loses building structures amounting to roughly $ 3.3 trillion every year due to corrosion damage.
The average costs caused by corrosion are, in industrialised countries, approximately three per cent of the annual GDP and increasing up to 5 % GDP at peak times.
However, by simply using existing technologies more effectively, an annual saving of up to $ 990 billion is achievable.
Steel underground pipelines are also affected by this effect. It is for this reason that a primary objective must be to protect these pipelines as best as possible against corrosion and mechanical damage. After damage caused by the influence of third parties, such as damage by excavation equipment, or similar, corrosion damage is the second largest cause of damage.

2 Factory coatings

2.1 Polyethylene coatings:

The use of polyethylene (PE) to coat steel pipes is today recognised as being state- of- the-art.

Advantages:
- Chemical resistance and therefore suited for all aggressive soils
- High mechanical strength
- Significantly larger electrical resistance of the coating, therefore lower protective current density.

3 How the demands on the factory coating have developed:

In the last 20 years, the demands on factory coatings have significantly increased. This can be seen by comparing the requirements from 1991 with those of 2010.
The maximum usage temperature of today's PE coatings is around 10°C (+50°F) higher than it was in 1991, and the required level of peel strength has quadrupled compared to 1991.
The requirements for the resistance to stress cracking under the influence of wetting agents (environmental stress cracking resistance - ESCR test) is new, as well as the oxidative-induction time as a measurement of the thermal stabilisation of the material.

3.1 Field coatings

The biggest difference to factory coatings is the requirement that these materials should be as simple as possible to apply, and are forgiving with errors when used on construction sites. While factory coatings are made under almost ideal conditions in the factory, field coatings must sometimes be applied under extremely difficult and changing local conditions on the construction site. The field coating systems must not have the same degree of mechanical resistance as the factory coatings because most of the sources of possible damage during the transportation and storage of the pipes do not apply to them. An investigation in 2009/2010 undertaken by the International Pipeline and Offshore Contractors Association (IPLOCA) research group for innovative concepts in pipeline construction determined that from leaving the factory until the trenches were filled, the pipes were moved up to 39 times and thus had a correspondingly higher probability of damage to the factory coating. First and foremost the task of field coating systems is to protect the steel from media and corrosive attacks from the outside. When laying the pipeline and later during operation of the pipeline, this coating material must also be able to resist mechanical attacks caused by traffic loads and pipeline movements. Coupled with the sometimes very different climatic and other operating conditions, this produces a very diverse profile of properties which the materials have to meet.

3.2 Main demands on field coatings:

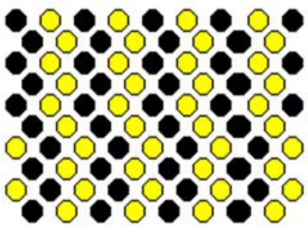
- Easy and safe processing of the coating at construction sites
- Mechanical resistance in terms of the connection of the coating material to the pipe surface – shown through:
  - Peeling values and shear strength
- Mechanical resistance in relation to resistance against damage to the coating – shown through:
  - Indentation resistance
  - Impact resistance
  - Tear resistance
- Ageing resistance (shown through long-term experience on construction sites)
- Chemical resistance (aggressive soils, electrolytes)
- No impairment to the active corrosion protection
- Quality tested in accordance with the highest international standards such as EN, DVGW, ISO etc.
- Quality tests of materials and application on site are mandatory

3.3 Three-ply tape systems

Since the introduction of co-extruded, three-ply tapes with self-amalgamating butyl-rubber layers in the 1970s, these plastic tape systems ensure long-term corrosion protection. Three-ply tapes have proven their excellent technical qualities on countless construction sites across the globe over the last 40 years. Where there are changing weather conditions or in cold or very windy climatic conditions, tape systems are the preferred option, thanks to their wide application range from -40°C (-40°F) to +60°C (+140°F).

The oxygen and moisture ingress found in two-ply tapes due to adhesive fatigue and the subsequent spiral corrosion does not occur when three-ply tapes are used. Partially sealed tape overlaps of two-layer tapes inevitably lead to serious spiral corrosion damage. Most of the little-known negative experiences with tapes are through the use of two-layer tapes being used as corrosion protection as they do not have any self-amalgamating effect. This, as well as the protection of the steel surface without any cavities is due to an essential characteristic of butyl-rubber. From a physical point of view, butyl-rubber is more fluid than a solid substance. The design of the three-ply tapes consists of a carrier film of stabilised polyethylene which is coated on both sides with a butyl-rubber layer. This carried film is produced in a special co-extrusion technique where a substantial and solid unit is ensured by the carrier and the coating material. There is therefore no delamination of the different functional layers which can be seen on laminated tapes. With the spiral winding of three-ply tapes around the pipe, the butyl adhesive layers move into the overlap areas, creating a homogeneous, sleeve-like coating without any separating layer. Where the layers do overlap, the molecules migrate from one butyl-rubber layer to the other. After maximum of five days, this amalgamation process is complete. For this reason, at least the inner layer of a corrosion protection system should consist of a self-amalgamating, co-extruded three-ply tape.
Due to the unique production technology the recognised delamination effect and the risk of permeability of the separating layer between the carrier foil and the coating in the tape structure in the long term, as shown in Figure 1, is avoided.

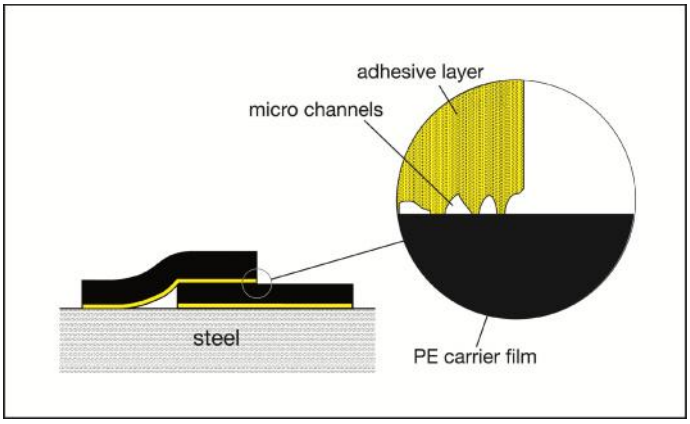
Figure 1 :Self-amalgamation effect in 3-ply tapes



If there is no amalgamation in the overlap area where pure two-ply tapes are used as a corrosion preventing inner wrap, there is a danger of the formation of micro channels, resulting in spiral corrosion.

By using two-ply tapes for the inner wrap, the chances of spiral corrosion occuring on the steel substrate are significantly higher. This effect can be avoided by using co-extruded three-ply tape technology (Figure 2 and Figure 3)

Figure 2 and 3: Spiral corrosion occurring by micro channels



3.4 Shrinking materials:

With high-temperature requirements, current shear-resistant hot-melt adhesives with a defined softening point above the constant operating temperature are used.
With the introduction of DIN EN 12068 in 1999, the possibility of higher temperature classes was established for the first time. The maximum continuous operating temperature is determined solely by the temperature at which the mechanical requirements can still be fully met.

The latest development in the standardisation field is ISO 21809-3.

This deals with shrink systems with PE or PP carrier fabrics, continuous operating temperatures up to +120°C (+248°F) (PE) or + 140°C (+284°F) (PP). However, it should be noted that the processing requires very high pre-warming temperatures for the steel surface in the cut-back area, which in turn brings with it a higher technical effort, and the associated risk of damage to the adjacent factory coating. Without the need for time-consuming inductive pre-warming of the pipe, the required temperatures of up to +190°C (+374°F) cannot be guaranteed.

3.5 PE- coatings:

The ways to apply a PE coating in the field are varied, but technically complex in each case.

Possible procedures include:
– Flame spraying with PE or PP powder
– Injection moulding

– Wrapping and simultaneous welding of extruded belts

These methods have been tried and tested on construction sites, but are complex due to their use of machinery and therefore expensive to use. For this reason, the spread of these procedures has been very limited so far across the globe.

3.6 Visco-elastic materials:

Visco-elastic materials are characterised by good corrosion protection where the steel surface is well wetted, but due to their soft consistency, require additional mechanical protection which is provided in the form of tapes, heat shrinkable sleeves or thermoset plastic systems. Visco-elastic materials may be categorised in terms of their material properties in the load class A 30 of EN 12068, comparable with petrolatum tapes. The application of the manufacturer of these materials to create a new class within ISO 21809-3 will probably not be approved by the technical examination board of the ISO at this current time.

3.7 Petrolatum tapes:

Protection of pipelines started in the 1920s with the use of petrolatum tapes and compounds. The invention of petrolatum coatings by DENSO GmbH by Chemist, Paul Schade, was the first corrosion protection system available on the market and was the starting point for this development. In previous years, the pipes had no corrosion protection at all, or simply a thin bitumen coating had been applied. Petrolatum-based systems still offer excellent corrosion protection thanks to their soft consistency and their very good wetting of the metal surface. Due to this softness, however, these materials are very susceptible to mechanical loads and to higher temperatures. Today, petrolatum tapes are mainly used to protect irregularly shaped components such as flanges or valves. The mechanical stress can be significantly improved by the use of a pipe-protection rock shield, based on a polypropylene non-woven textile. The latest developments are high-temperature resistant petrolatum-based systems which are protected and mechanically very stable by a moisture-curing polyurethane compound during the wrapping process.

3.8 Thermosetting coatings:

For field coating with thermoset plastics (epoxy or polyurethane compounds), the same materials are often used for field coatings as for factory coatings. Processing is done using airless spraying techniques.

These coatings are used world-wide for the renovation of coatings or for rehabilitation measures.

Particular characteristics include:

- Approved for up to + 80°C (+176°F) of continuous operating temperature
- Can be used even with complexly shaped components
- Well suited for applications with higher mechanical loads (e.g. trenchless laying). The application uses an airless hot-spray process at the construction site or in the factory (coating thicknesses minimum 1,500 microns) or as a two-component coating compound which is applied by squeegee or spatula.

3.9 Development and significance of selected requirements:

a) Mechanical resistance to prevent imperfections and defects:

b) Specific electrical coating resistance:

This resistance is a measure of the impermeability of the coating compared to the surrounding soil. The coating must also have a sufficient electrical resistance so that, where a cathodic protection system is used, no current flows through the coating to the pipe surface.

c) Indentation resistance:

This ensures a high degree of safety against damage from stones found in the soil.
A residual layer thickness of at least 0.6 mm is prescribed.

d) Impact resistance:

The impact resistance plays no role in the transportation of the pipes, its role is much more important during pipe laying and filling the trench. With 10 or 30 impacts, the value level can be determined exactly.

e) Peel strength and tensile shear strength:

Demand for sufficient adhesion of the coating, preventing cavities, but also shearing of the coating as a result of longitudinal movements of the pipe or ground movements. The peel strengths are usually determined with a peeling angle of 90° to the steel, or with 180° tape to tape. Requirements (larger than 5 N / cm²)

f) Ageing resistance:

To prevent the deterioration of the mechanical strength, the stability of the coating is tested by heat ageing at a temperature of +20°C (+68°F) above the continuous operating temperature. According to the current standards, the peel strength of a coating can only decrease by a maximum of 25 per cent after 100 days of heat ageing.

g) Cathodic infiltration:

The effect of cathodic disbonding has been observed so far in all coating materials. The infiltration depth is dependent on the pipe-soil potential as well as the chemical nature of the coating materials.

h) Long-term studies: Studies in difficult conditions have shown that the phenomenon of cathodic infiltration is of secondary importance for corrosion protection systems with thermoplastic thick layer coatings. Requirements are still contained in the DIN EN 12068 standard as internationally the effect of cathodic infiltration considered as having a greater degree of importance. In load class C, materials with very low cathodic disbonding values having a low peel strength are found (a minimum requirement of 5 N / cm² is to be met here too). This is part of a way of thinking which allows slight damage to a coating under the condition that this damage is not significantly more pronounced as a result.

4 Long-term experiences

4.1 Long-term investigation E.ON Ruhrgas:

In 2007, E.ON Ruhrgas (known today as Open Grid Europe) published an investigation which showed a representative cross-section of the coating materials used across almost 2,000 km of its overall pipe network. E.ON's overall pipe network is approximately 12,000 km long, and despite its pipeline segments being up to 90 years old, it is in a very good state of preservation. Previous investigations of these pipeline segments were done by intelligent pig testing.

The field coating systems used included petrolatum-based and wax-based systems, various bitumen coatings, two-layer PE tapes and eventually three-ply tapes. In these tests, the self-amalgamating tapes proved to have excellent corrosion protection properties. These tapes, which have been used as the field coating systems of choice construction E.ON´s pipelines, demonstrated no electrical breakdowns, nor a change of their high mechanical strength. This statement by E.ON was based on findings obtained following 25 years of practical experience of the use of these systems for gas pipelines. (Figure 4)

Figure 4: field coating systems used by E.ON

No.	Type	Description	Period of use	Pipeline length evaluated
1	Petrolatum tape	Tape system with 2 to 4 layers of a petrolatum tape. Tape comprising of cotton textile with Vaseline compound on either side.	1927 - 1945	Exemplary sites
2	Cast bitumen	Two layers of bitumen applied to the pipe by the cast method. Comprising a reinforcing carrier (felt or cardboard).	1960 - 1965	156 km
3a	Bitumen tape	System consisting of 1 or 2 layers of a bitumen tape. Tape with glass fibre fleece or textile reinforcement.	1945 - 1980	689 km
3b	Bitumen tape with rock shield	System 3a, combined with a rockshield of e.g. sintered polyethylene pellets.	1945 - 1980	69 km
3c	Bitumen tape with polyethylene adhesive tape	System 3a, combined with a polyethylene adhesive tape for mechanical protection.	1972 - 1974	234 km
4	Polyethylene / butyl rubber composite tape	System usually comprising 2 layers of self amalgamating butyl rubber tape, combined with 2 layers of a mechanically protecting two ply or three ply polyethylene outerwrap tape.	Since 1981	766 km

5 Conclusion

It always pays off to thoroughly check the specific requirements for a project and to select the most suitable coating for the factory and field coating system used. When selecting the field coating materials, it should also be considered that the costs for a high-quality system are around 0.03 per cent of the total project costs at most. The weld seams are, however, the weak points of the pipeline and, if a low-value material is selected, large costs may result from the requirement to perform repairs which are not comparable with the higher costs of using a technically higher-quality system.

A chain is only as strong as its weakest link. It is therefore irresponsible to try to save money for the field coating system by compromising on the quality. There are very good, durable solutions for almost all requirements. A system which covers all the requirements, however, does not currently exist, and probably won‘t for the foreseeable future. Each operator should select the best possible system for his needs.

The three-ply tapes are the best solution thanks to their highly variable use to meet the diverse requirements of areas of use from - 35°C (-31°F) to + 60°C (+140°F).

For higher continuous operating temperatures of up to +80°C (+176°F), special high-temperature tape systems as well as heat-shrinkable sleeves made of polyethylene are available on the market. Heat-shrink sleeves made of polypropylene can be used at temperatures up to +130°C (+266°F). For continuous operating temperatures of up to +80°C (+176°F) and increased mechanical loads, such as those found in the trenchless process with piling and pressing processes, as well as in horizontal direction drilling measures, two-component thermosets based on polyurethane and epoxy materials have proven themselves.

In the long term, in terms of value and longer service life of the pipeline network, it pays to select high-quality and durable materials to coat the pipelines.
Here the approvals of the systems according to internationally-valid standards, such as EN 12068 and DVGW testing, with the associated third-party monitoring of the production processes are to be more highly valued than as yet un-verified guarantee promises made by some manufacturers in the future.

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