Corrosion Protective Coating Technology for Transit Pipelines in Europe

By Th. Rehberg and M. Schad

In the last 50 years large oil- and gas-pipeline-networks have been installed with diverse coating systems. Corrosion protective systems – e.g tapes, shrink sleeves and liquid coatings (polyurethane and epoxy) have been used 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, for USA and all major countries where pipelines are laid, there are numerous standards and guidelines specifing 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. This paper will focus onto the experiences made with so called 3-ply plastic tapes. Due to their self-amalgamating butyl rubber layers they have proven their excellent performance for field coatings for 30 years now.

Introduction

"Pipelines do not fail, unless their coating fails first" to quote Derek Mortimore, one of the leading corrosion experts in the world. This statement is backed by a survey of NACE International, the worlds largest corrosion organisation, and the US Federal Highway Administration made in 2002. More than 7 billion Dollar have to be invested annually in the USA for repairing the costs of corrosion of pipelines in the USA (study available at www.nace.org). The total costs of corrosion in all sectors exceed 276 Billion Dollars per year!

Table 1: Field coating systems overview

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.	1912 – 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

Therefore it should be mandatory to select the appropriate corrosion system with high diligence.

Long term experience and history of corrosion prevention material in Germany

Based on the various requirements on sites numerous coating systems have been developed over the last decades and constantly improved [2]. To get an impression of the performance of different coating systems it is a good reference to have a look at the long term experience of field coating systems of pipelines used at different periods of constructions.

E.ON Ruhrgas, the largest distributor of Natural Gas in Europe, operates approx. 12,000 km of high pressure gas pipelines, which were constructed between 1912 and 2006. **Table 1** gives an overview of the surveyed field joint coatings. With respect to the technical development and the state of the art technology during the year of construction, different types of field joint coating systems were used for these pipelines.

From the results of different pipeline survey methods applied to pipelines from different periods of construction, significant differences in field joint coating corrosion protection performance can be derived.

- Petrolatum tape systems (used between 1912 and 1945) tend to degrade over time thus exposing large bare metal areas to the surrounding medium, where cathodic protection efficiency might be questionable. Interference on neighbouring structures should be considered.
- Cast bitumen comprising a reinforcing carrier implies a likelihood for poor adhesion in the lower segment of the pipe due to poor qualification of this coating system for field application. Cathodic protection is effectively shielded and technically non negligible corrosion rates (i.e. exceeding 0.01 mm/a) shall be expected.
- Bitumen tape systems with glass fibre fleece or textile reinforcement may exhibit

larger coating defects over time leading to questionable cathodic protection effectiveness and also poor adhesion but generally do not tend to shield the steel surface from cp-current. The situation will change dramatically if additional polyethylene tape is applied as outer wrap which leads to a shielding of the cp-current thus technically non negligible corrosion rates (i.e. exceeding 0.01 mm/a) shall be expected.

- Polyethylene/butyl rubber composite tapes show excellent corrosion protection properties. These tapes (which have been the preferred field joint coating system for E.ON-Ruhrgas pipelines since 1981) neither show excessive holidays nor loss of adhesion nor decreasing strength of shape. This assessment is based on pipeline operation experience of over 25 years.

Summarizing these results, it is recommended to select field joint coating systems with respect to their proven long term adhesion and strength of shape. Any additional component of the coating system, e.g. materials preventing the risk of mechanical damages, that may result in shielding the pipeline steel surface from the cathodic protection current should be avoided [2, 4].

General requirements for corrosion protective coatings:

What are the general requirements of materials for pipeline coatings?

These materials have to withstand different stresses during their service life (**Table 2**).

While factory coatings are focussed to reach a maximum of mechanical resistance, the requirements for field coatings are focussed on an easy application and tolerability to application faults under changing conditions on site.

Due to the versatility of application for field coating systems, general requirements for all materials do not exist. 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 4**.

Field coatings do not have to withstand the same mechanical resistance as factory coatings. Especially lap shear resistance of coating materials is mainly temperature dependent. Some of the main sources of originating defects to pipe coatings as transport and loading don't have to be taken into consideration. Therefore, not only due to the better applicability of the field system, it is legitime to choose materials for joints coatings, which show a reduced mechanical resistance. Decoupling rockshields may be suitable to prevent shear forces of the native soil to be exerted on the coating.

Table 2: Environmental stresses and their influence on coating materials

Loads		Requirements for coatings
Corrosion defects are caused by	Water	Vapour impermeability
	Oxygen	Oxygen impermeability
	Electrolyte	Chemical impermeability Impermeability of ions
	Stray electrical current	Electrical isolation
Coating defects caused by	Impact at transport and application	Impact resistance
	Loads at transport and application	Indentation resistance
	Compacting of soil	Indentation resistance Peel strength Lap Shear resistance
	Pipe movement in soil	Lap Shear resistance
	Sunlight	UV-Stability
	Aggressive soil, high levelled operating temperatures	Ageing resistance, Chemical resistance
	Micro-organism Unsuitable application	Microbiological resistance Easy and secure application methods

Table 3: Guidelines for passive corrosion field coating material

Standard	Scope	Issue
DIN 30672	Coatings from **tapes** and **heat shrinkable materials** (for pipes with operating temperatures up to +50°C without cathodic protection)	12-2000
ISO 2 1809 Part 3	Field Joint Coatings for Transport Lines	12-2008
EN 10289	Steel pipes and fittings for buried or immersed pipelines – **epoxy coatings**	08-2004
EN 10290	Steel pipes and fittings for buried or immersed pipelines – **polyurethane** and **modified polyurethane** coatings	08-2004
EN 10329	**Field coatings** for welded joints of buried steel pipes	04-2006
EN 12068	Coatings from **tapes** and **heat shrinkable materials** (for buried pipes with cathodic protection)	03-1999

Table 4: Stress classes according to DIN EN 12068 [3]

Stress-class	Petrolatum-Tapes	Bitumen-Tapes	Plastic-Tapes	Heat-shrinkable materials
A-30	+	+	/	/
B-30	-	+	+	/
B-50	-	/	+	+
C-30	-	-	+	+
C-50	-	-	+	+

+ well suited, / not applicable, – not suited

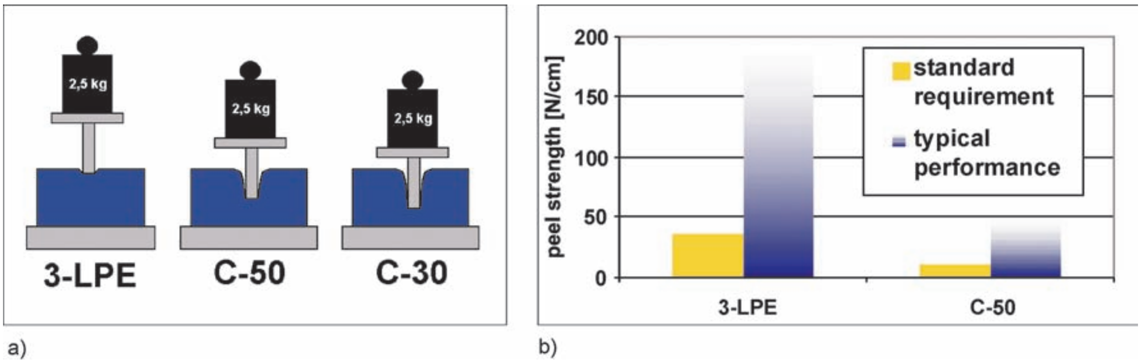


Fig. 1: a)Typical residual thickness after Indentation tests of a three-layer PE coating compared to stress-class C-50 and C-30 tape coatings (at 23 °C) b)Peel Strength of 3-layer PE factory coatings (DIN 30670) and stress class C 50 field coatings (EN 12068) at 23 °C

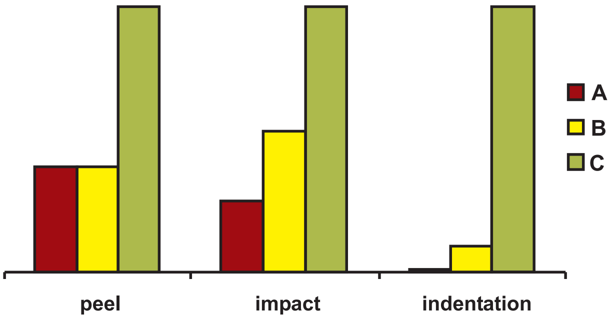


Fig. 2: Differences in requirements for peel strength, impact resistance and indentation resistance of stress-classes A, B and C according to EN 12068

Technical properties of a corrosion protective tape coating are being described in corresponding national and international standards. It should be noticed that frequently employed ASTM-standards contain well suitable test procedures to determine single properties, but they neither define acceptance criteria nor do they assess all properties of a tape coating together.

In contrast material standards like European standard EN 12068 [5], not only describe how to determine the relevant tape and coating properties, by their concept of stress classes they also give a well suitable tool for classification of tape coatings. The mechanical stress classes A, B and C essentially differ concerning requirements for peel strength, impact resistance and indentation resistance. Corresponding ratios are shown in **Figure 2**.

When choosing a corrosion protective tape coating referring to stress classes it has to be considered that the performance level of a standard factory coating, e.g. three layer PE coating, exceeds the performance level of a field coating. It is also apparent that for tape coatings a higher temperature stress class (50 instead of 30) always indicates a higher peel strength or indentation resistance or both at 23° C. [5]

Table 5: Tape systems guideline

Operating temp.	Field of application	Recommended tape system	Mechanical stress	Stress-class
≤ 30 °C	Irregularly shaped objects (e.g. weld-on branch lines)	butyl rubber tape with mechanical protection tape	low/	B-30
			medium/high	C-30
≤ 50 °C	all	one tape system or two tape system	high	C-50

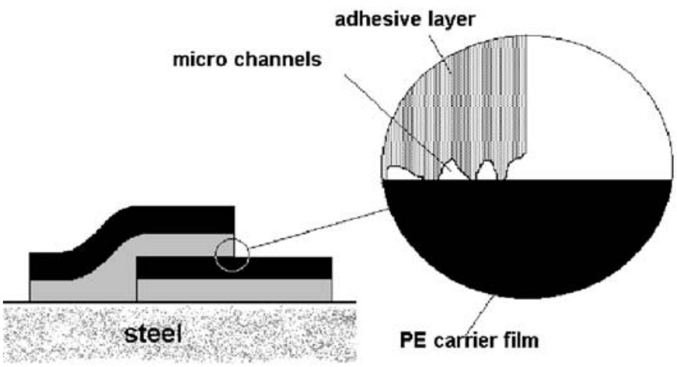


Fig. 3: Two-ply tape with thick layer adhesives

Fig. 4: Spiral corrosion on pipe joint sealing by adhesion only

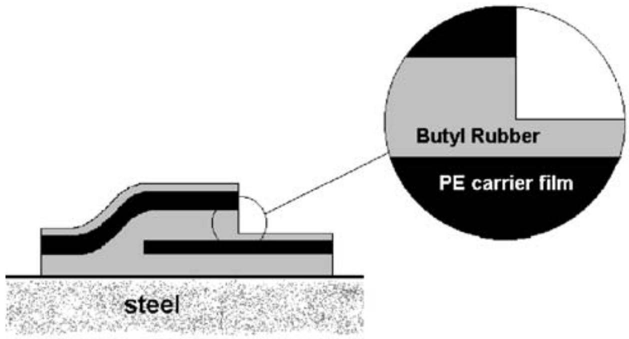
Plastic-Tape systems

In any case where pipelines with tape coatings have to be newly 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 the arabic countries, result in negative experiences made in the 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 reasons 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 digged out after years of service [8].

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.

Fig. 5: Sealing by self-amalgamation: Three-ply tapes



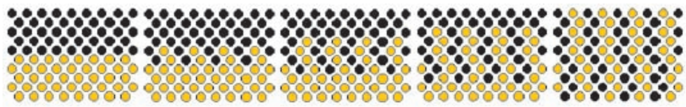


Fig. 6: Self-amalgamation process

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 conden-

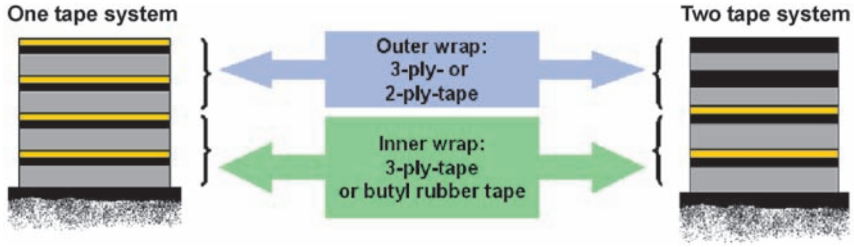


Fig. 7: Cross sectional view of a one tape and a two tape system

sation 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 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 3**) 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 are not able to fill the cavities formed in the overlap area (**Figure 4**).

Self amalgamating three-ply tape

What does "self amalgamation" mean?

At first sight it seems irritating to recommend tape systems for the rehabilitation or new constructions 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-ply tapes. The latter one contain a carrier film from favourably stabilised polyethylene, which is coated with a butyl rubber adhesive on both sides. Carrier films of co-extruded 3-ply tapes are manufactured with 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 (**Figure 5**).

The self-amalgamation process and the sealing of a steel surface without any 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 formerly different layers migrate into other layers. After a certain period of time the originally existing interface has disappeared (**Figure 6**).

Having made the choice for butyl rubber and polyethylene as the material basis, the question of the most suitable tape structure is brought up. Tape coating systems for rehabilitation of pipelines should in any case involve at least two layers of a three-ply tape or butyl rubber 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.

As a minimum requirement the inner wrap tape or corrosion protection tape should always be a three-ply structure with butyl rubber adhesive layers on both sides of a PE carrier-film, than covered with a mechanical protection tape as an outer wrap tape. Long term experience showed, that the best results in protection and adhesion will be fulfilled with a one tape system out of co-extruded 3-ply tape as an inner and outer wrap.

Among these structures of 3-ply tapes, the asymmetrical one is to be preferred, because its thick inner adhesive layer ensures better filling of surface irregularities and potential hollows. Furthermore, state-of-the-art asymmetrical corrosion prevention tapes like the DENSOLEN®-Tapes, AS40 Plus or AS50 have a four-ply structure, containing an additional layer between carrier film and adhesive. This intermediate layer is co-extruded from a blend of butyl rubber and polyethylene and thus ensures a homogenous transition from butyl rubber to PE. Due to the unique production technology of co-extrusion of 3-ply tapes, the well known delamination effect (**Figure 9**) and a potential long term permeability through the interface between carrier film and adhesive is avoided by the tape structure shown in **Figure 11**.

Field Study: OPAL Pipeline 470 km 56“ /DN 1.400

The OPAL (Ostsee-Pipeline-Anbindungs-Leitung – Baltic Sea Pipeline Link) will connect Germany and Europe to the major natural gas reserves in Siberia via the Nord-Stream-Pipeline.

The OPAL will pick up the natural gas in Lubmin near Greifswald from the Nord Stream pipeline and will transport it 470 kilometres south to Olbernhau on the Czech border. The OPAL will not only provide connecting points for discharging the gas into the existing pipeline network, it will also link up the current natural gas transit lines.

The pipeline consists of 14 sections of around 35 km each.

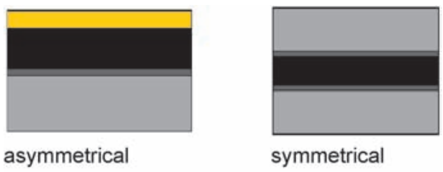


Fig. 8: Cross sectional view of 3-ply corrosion prevention tapes

Fig. 9: Delamination effect during peel-test

Fig. 10: Cohesive peel mode by co-extruded intermediate layer of high-performance tape

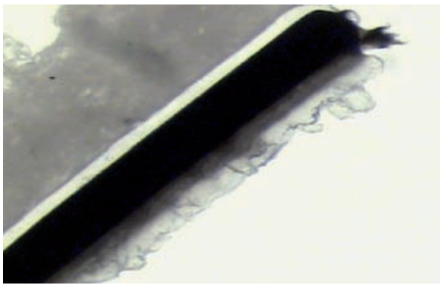


Fig. 11: Microtom cross section of a co-extruded above named 3 ply Tape

Section 1-2 PPS/HABAU, section 3-6 Ghizzoni, section 7-10 Bonatti and section 11-14 Max Streicher/Sicim.

All pipes were supplied by Europipe GmbH, the factory coating was applied by Mülheim Pipecoatings GmbH.

A few facts about OPAL:

Pipe Diameter: 1.420 mm, wall thickness: 22,3 mm, MOP: 100 bar, total length 470 km, length of pipes 18 m, weight of each pipe 15 tons, pipe quantities: 27.000 units

One pipe per truck load = 27.000 transports to the site!

Pipe metal capacity needed: 10 times more than the steel used for the construction of the Titanic.

Due to the tight schedule, construction has to take place over two winter seasons. On 1st July 2011, the pipeline must be ready for the first gas and the commercial start is scheduled for 1st October 2011. More than 2.500 employees are contributing to the construction of OPAL. At each of the 14 sections 8 sidebooms and 25 excavators are in the field.

The OPAL is the most ambitious onshore project under construction in Europe.

There are only two short pipeline sections (12,5 km in total) in Germany which were built in the diameter DN 1400 before. 1 ½ km long pipe section of E.ON Ruhrgas at Waidhaus and approx. 11 km of WINGAS Pipeline from the Polish border to the Wingas compressor station at Mallnow.

Each DN 1400 pipe's weight is 50 % higher than one of DN 1200. This has tremendous effects on the load capacities and requested quantities of sidebooms, excavators and transport facilities.

DENSO GmbH´s contribution to the construction is the supply of corrosion prevention tapes for field-joint coating on all sections of the OPAL and of appropriate application devices for the wrapping process. The tape systems will be applied by the service companies Eupec Pipeline Services GmbH and Peper GmbH.

The tape system used on the OPAL – DENSOLEN Tape System N 60/S20 – was designed a few years ago, based on the special requirements of E.ON Ruhrgas for large pipe diameters, and exceeds the requirements of the highest class of EN 12068 C 50 in significant parameters e.g. excellent peeling strength. Another outstanding feature is the specific electrical insulation resistance of the coating exceeding of > 10^{11} Ohm m^2. As a rule for the cathodic protection a line is considered free of defects at a value of > 10^8 Ohm m^2.

The system comprises of a butyl-rubber based primer, a three-ply self -amalgamating tape for corrosion prevention in 1,2 mm thickness

Fig. 12: Pipeline grid of WINGAS-Map by courtesy of WINGAS

Fig. 13 and 14: Wrapping with engine driven application device-simultaneous application of inner and outer wrap

Fig. 15: Lowering of pipes into trench at OPAL

(N 60) and a three-ply tape in 0,5 mm thickness (S 20) for the mechanical protection.

At the OPAL project, the rolls length are tailor-made per joint, calculated to wrap the innerlayer for corrosion prevention and the outerwrap with the same overlap of 50 % simultaneously.

For pipe diameter exceeding DN 400 the featured use of these special designed two tape system DENSOLEN N60/S20 is mandatory at E.ON Ruhrgas projects and for the bigger diameter at WINGAS projects as well. One reason for that is the complete covering of the distinctive higher weld beads by the thick butyl rubber layer.

State-of-the-art asymmetrical corrosion prevention tapes like DENSOLEN Tape N60/S20 have a four-ply structure, containing an additional layer between carrier film and adhesive. This intermediate layer is co-extruded from a blend of butyl rubber and polyethylene thus ensuring that the well known delamination effect is avoided by this tape structure. These three-ply tapes have proven their impressive long-term behaviour for more than 30 years [2, 7].

The inner- and outerwrap show different colours – grey for the inner- and black for the outerwrap to exclude a mix-up of the tapes by the applicators.

Whenever possible a field coating with properties close to the performance level of the existing line should be chosen. Therefore, a stress-class C 50 should always be used as the higher peel strength and intendation resistance will ensure a higher safety level.

The motor driven application device DENSOMAT 11, engineered and manufactured by DENSO, has been used successfully on several pipeline construction sites with different diameters in Europe before. For the OPAL necessary tailor-made adjustments on the DENSOMAT 11 were invented in order to fit the complex challenges of DN 1400 pipes.

The DENSOMAT 11 has been designed for variable and fast application of corrosion prevention tapes on pipes, especially for long distance pipelines. It can be left on the pipeline while it is transferred from one joint to the subsequent. By opening the ring of the chain guide at the bottom, the machine can be pushed forward along the pipeline with minimal force. Additional advantage is a requested clearance of 50 cm only around the pipe.

The DENSOMAT 11 can apply two tapes simultaneously with constant overlap and tension providing a high-quality coating at constantly high speed.

Technical design and engineering will often not correlate with practical conditions on site.

On large scale construction sites as OPAL permanent responding to unexpected circumstances on site is requested. A lesson DENSO learned early on.

The pipe bedding method of Italian companies, for example, differs from methods being used at most European sites, where the pipes are laid on pipe supports made of timber beams. The Italian companies make the pipe support of sand, embedding the pipes on sandheaps which cover mostly of the pipe´s surface. This has the advantage that the pipe load will be disposed homogeneously and the pipe position is very stable to movements.

For the use of DENSOMAT 11, however, this method was a real challenge as one could not pass these sandheaps on first trials.

DENSO designed a scissor-type jack that will lift the DENSOMAT 11 on both sides of the chain guide ring of approx. 30 cm which will solve the problem of transporting the device to the next joint.

This will not be the last challenge at this project, but DENSO is convinced that it will overcome them in a good co-operation with its construction partners.

Conclusion

One should keep in mind that the value for a field coating system at pipeline projects will amount to a maximum of 0,04 % of total costs of a new construction project, but one may incur incalculable high subsequent damage claims by choosing an inappropriate coating system.

For every application there are high quality corrosion prevention systems available, however, the perfect universal coating for all applications has not been developed yet. There are many good systems available but they all have certain limitations inherent to the systems in their technical performance.

At standard operating temperatures, three-ply self-amalgamating plastics tape systems still offer the widest range of application combined with an experienced high reliability.

References

[1,3,5] EN 12068 "Cathodic protection – External organic coatings for the corrosion protection of buried or immersed steel pipelines used in conjunction with cathodic protection-Tapes and shrinkable materials." (1999-2003).

[2] Ahlers, M., Quast M., Schöneich, H.G.: Long term experiences with corrosion protection performance of field joint coatings, 3R international 46 (2007)

[4,6] Quast, M.: Aspects of corrosion protective tape technology, 3 R internat 1/2006, pages 53-57

[7] Quast, M.: Long term Experiences with DENSOLEN-Tapes. 3 R internat. 43 (2004); No.13, p.69-72.

[8] Schad, M; Zipffel, O.: Aspects of modern corrosion protective coating technology, 3 R International 46 (2007)

Further Literature:

Heim, T: Entwicklung von Korrosionsschutz Nachumhüllungsmaterialien für Stahlrohre, 3 R International 44 (2005) Nr.11 S.624 – 633.

DIN EN 10329 "Steel tubes and fittings for onshore and offshore pipelines – External field joint coatings" (2006)

DIN 30671 „Thermosetting coatings of steel pipelines (1992-06)"

EN 12068 "Cathodic protection- External organic coatings for the corrosion protection of buried or immersed steel pipelines used in conjunction with cathodic protection-Tapes and shrinkable materials." (1999-2003).

EN 12090 Steel Tubes and Fittings for onshore and offshore pipelines. External liquid applied polyurethane and polyurethane modified coatings (2001-2011).

ISO/DIS 21809-3 "Petroleum and Natural Gas Industries – External coatings for buried and submerged pipelines used in pipeline transportation systems – Part 3: Field joint coatings" (2007)

Quast, M: Pipeline Rehabilitation with DENSOLEN Tape System, 3 R international (42) Heft 7, 2003

Schwenk, W.; Heim, G.; Wedekind, B.; Schäfer, T.: Investigation of corrosion protection effect of coatings on steel pipes by long term exposure in soil and water. 3R international 35 (1996) Nr. 12, S. 676-685

Authors:

Thomas Rehberg
Product Manager Pipeline Division
Denso GmbH, Leverkusen, Germany

Tel. +49 214 2602-308
Fax:+49 214 2602 217
E-mail: rehberg@denso.de

Michael Schad
Key Account Manager
Denso GmbH, Leverkusen, Germany

Tel. +49 214 2602 – 260
Fax:+49 214 2602 -217
E-mail: schad@denso.de