Rehabilitation of Corrosion Protective Coatings on Buried Steel Pipelines

By Michael Schad

Large oil- and gas-pipeline-networks have been installed with diverse coating systems over the last 50 years. The rehabilitation of those pipelines – and their corrosion protective coatings – has now become a topical challenge. Different advanced materials have been used for rehabilitation of pipe coatings since the beginning of 1929. The experiences are as versatile as the products being used – petrolatum, bitumen, coal tar, sintering processes, PE/Butyl tapes, FBE, liquid coatings and shrink sleeves.
In the following a short overview of coating materials to be recently rehabilitated and the respective solution will be presented. Special focus will be laid on the newly designed tape system DENSOLEN® AS50/R20HT by DENSO.

INTRODUCTION

In 1595 the oldest known industrial pipeline in the world was constructed in Austria. It transported saline solution for 40 km from Hallstadt to Ebensee. At that time rehabilitation was a quite simple affair. As the pipeline was made of 13,000 trunks, one simply had to cut down a tree, hollow it and replace the defect section.

The necessity of more light in the streets of Berlin/Germany grew around 1900 with the increasing traffic on the streets. Due to its special design and structure, the existing Berlin Gas Distribution System could also be used as remote switching for the street lighting. The danger of leakage and corrosion grew with the expansion of the Berlin Gas Distribution System, reaching its widest expansion in 1929. At that time, the worldwide first passive corrosion prevention for pipelines was invented by DENSO with the Petrolatum Tape.

Due to the corrosion damages of gas distribution systems and pipelines, rehabilitation during the global industrialisation became a major issue. Over the last decades the quest for the best coating – or rehabilitation material – became more and more complex since the requirements of corrosive and mechanical protection of pipelines increased.

CURRENT COATINGS TO BE REHABILITATED

Due to the technical development of the factory or mill coatings of pipelines over the last decades different types of coating systems have been applied to pipelines. If onshore pipelines are excavated today due to results of ultrasonic inspection, most of the mill and joint coatings are of coal tar, bitumen, two-ply tapes made of PVC with hotmelt or bitumen adhesives or two ply tapes made of PE with hotmelt or butyl

FIGURE 1: **Bitumen coated pipeline**

FIGURE 2: **Bitumen coated storage tank**

TABLE 1: **Environmental stresses and their influence on coating materials**

Loads		Requirements
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

rubber adhesives. Liquid coatings or shrink sleeves are rather new corrosion prevention technologies which have been applied over a shorter period of time and therefore rehabilitation experiences have only just started to contribute to the development of market trends.

Coal Tar and Bitumen Based Coatings

Coal tar and bitumen coatings (see **figure 1** and **figure 2**) are rather old types of coatings, but are still in use in some countries over the world, such as India. Very often these coatings got brittle, resulting in the formation of crevices and cracks and a significant decrease in adhesion to the steel surface. The risk of corrosion increases. Protective current voltages for old coal tar or bituminous coatings often exceed by far values which are acceptable for an economically operated cathodic protection. High protective current voltages result in the formation of H_2 and therefore increase the corrosion.

Two-ply Tape Systems (PVC- and PE-Tapes)

In most of the cases where tape coatings on pipelines have to be rehabilitated two-ply tape systems are involved. Main reasons for their failure are low quality material properties and a general drawback of the coating system most often combined with false application.

Particularly for PVC and bitumen based tapes intrinsic material drawbacks are the main reason for coating failures.

As PVC is a rather brittle material, tapes made of PVC contain to a certain extend plasticizer agents. During the lifetime of a pipe-coating these plasticizers diffuse out of the PVC carrier film. This results in an embrittlement of the carrier film and a decrease of adhesion, when the plasticizers accumulate in the interface of the adhesive to the steel surface. Due to this effect only minor residues of the tape remain on the pipe surface when the pipe is excavated after years of service – the mechanical and corrosive protection is no longer in place.

Also PE and butyl rubber based two-ply tapes, which generally did not suffer from such material drawbacks, failed as well. The reason for an unsuitability of two-ply tapes for corrosion prevention purposes is the very high risk of spiral corrosion.

Corrosion protective coatings have to provide a primary protection, which is achieved by covering the *entire* metal surface with a material that prevents the condensation of water on the steel surface. Suitable materials for covering and sealing the whole surface are permanently plastic compounds (petrolatum, butyl rubber) as well as rigid compounds (polyurethane, epoxy resins), which also prevent the interdiffusion or penetration of water and oxygen.

Two-ply tapes generally contain a carrier film that is coated with an adhesive on only one side. Due to this structure two-ply tapes can provide certain primary protection against corrosion, because of their adhesion to the steel surface, when supported by a primer paint. But 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. This facilitates a possible penetration path for water and oxygen, increasing the probability of corrosion.

Factory or mill coatings are intended to provide a maximum of mechanical and corrosive protection, while the method of application is not under the main focus. The mill coating can be applied independent of environmental influences and human factor. Field coatings are confronted not only with the required mechanical and corrosive protection of at least the same quality as the corresponding mill coating, but also with material properties of easy application and tolerability to application faults under changing conditions on site.

Due to the versatility of application for field coating systems, general worldwide standards for all materials do not exist. German and European Standards for corrosion field coating materials are among the highest in the world and applied in several countries worldwide. The relevant standards 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, up to 50° C, and HT (high temperatures)).

Self-Amalgamating Three-ply Tapes

At first sight it seems contradictory to recommend tape systems for the 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 tapes and real co-extruded self-amalgamating three-ply tapes. The latter one contain a carrier film of stabilised polyethylene, which is coated with a butyl rubber adhesive on both sides. Carrier films of co-extruded 3-ply tapes are manufactured with a 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 3**).

The self-amalgamation process (**figure 4**) and the "free of cavities"-sealing of the steel surface is based on an important property of the butyl rubber: from a 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 each other layer. After a certain period of time the originally existing interface has disappeared (**figure 5**).

A high percentage of negative experiences with two-ply tape coatings in the past originate from the effect of spiral corrosion, which is shown in **figure 6**. In the remaining and clearly defined interface between the layers of a two-ply tape system micro channels exist, which facilitate a possible penetration path for water and oxygen.

After some time of operation of the pipeline, the incompletely sealed tape overlaps inevitably lead to spiral corrosion followed by complete undermining corrosion.

Compared to two-ply tapes, no interface or penetration paths remains in overlapping zones of high-performance co-extruded three-ply tapes. The outstanding feature of co-extruded three-ply tapes and their layer of butyl rubber is its ability of self-amalgamation in the overlap areas, resulting in a completely sealed, impermeable and sleeve-type coating.

Pipeline Rehabilitation "Isarschiene" Germany

In autumn of 2003 segments of a 27 years old pipeline ("Isarschiene", running from Moosburg to Straubing/Germany, owned by Erdgas Südbayern (ESB)) had to be excavated for bypassing. This offered the unique opportunity for assessment of the mill coating and field joint coating performance. The field joints of the polyethylene factory coated pipeline had been wrapped with four layers of co-extruded self-amalgamating three-ply DENSOLEN® tape in 1976. At the time of construction of the pipeline in 1976 this four layer coating system was in accordance with the DVGW-leaflet GW7, which was the valid technical specification for field coatings at that time. When excavated in 2003 all field joint coatings applied in 1976 showed no failure of the coating system and the steel surface presented itself like new. This is by far the best reference for a coating system – 27 years in operation without any mechanical or corrosive impact. Although today's

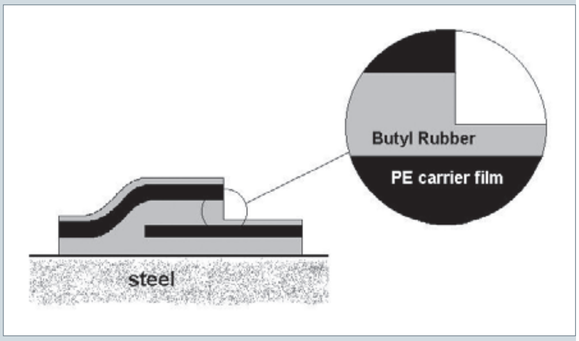


FIGURE 3: **Sealing by self-amalgamation: co-extruded three-ply tapes**

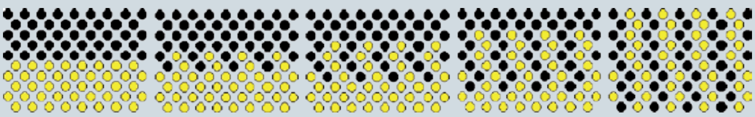


FIGURE 4: **Self-amalgamation process**

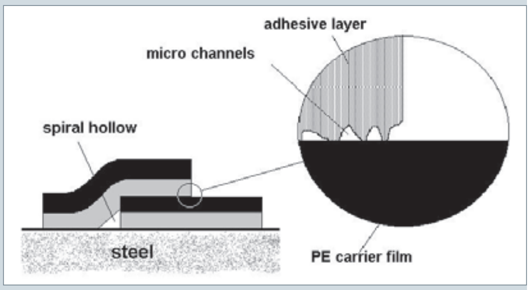


FIGURE 5: **Incompletely sealed tape overlap of two-ply tape wrapping**

TABLE 2: **Standards 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 21809-3	Coatings for transit pipelines	12-2008
EN 10289	Steel pipes and fittings fur burried or immersed pipelines – epoxy coatings	08-2004
EN 10290	Steel pipes and fittings fur burried or immersed pipelines – polyurethane and modified polyurethane coatings	08-2004
EN 10329	Field coatings for welded joints of burried steel pipes	04-2006
EN 12068	Coatings from tapes and heat shrinkable materials (for burried pipes with cathodic protection)	03-1999

TABLE 3: **Stress classes according to EN 12068 [3]**

Stress-class	Petrolatum-Tapes	Bitumen-Tapes	Plastic-Tapes	Heat Shrinkable Materials
A-30	+	+	n.a.	n.a.
B-30	–	+	+	n.a.
B-50	–	n.a.	+	+
C-30	–	–	+	+
C-50	–	–	+	+

\+ well suited
n.a. not applicable
\- not suited

corrosion protection standards and stress-classes had been further developed since 1976, this co-extruded self-amalgamating three-ply tape-system developed in 1976 would even fulfil today's requirements of stress-class C-50 – more than 35 years later.

Tape coating systems for rehabilitation of pipelines should in any case involve at least two layers of a co-extruded 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 mechanical and corrosion protective performance on differently prepared steel surfaces.

As a minimum requirement to avoid spiral corrosion, the inner wrap tape (or corrosion protection tape) should always be of a co-extruded three-ply structure with butyl rubber adhesive layers on both sides of a PE carrier-film. This inner wrap can then be covered with a mechanical protection tape as an outer wrap tape.

Among the above presented structures of 3-ply tapes (**figure 8**), the asymmetrical tape is to be preferred, because its thick inner adhesive layer ensuring better filling of surface irregularities and potential hollows. Furthermore state-of-the-art asymmetrical corrosion prevention tapes like the DENSOLEN®-Tapes AS39P 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 of non-co-extruded tapes, and resulting failure of the protection system, is avoided (**figure 9**).

Pipeline Rehabilitation Case Study South Africa

Sections of one of the major pipelines in South Africa had to undergo a rehabilitation in 2012. Several failures in the factory or mill coating lead to the following definition of the required properties for the new rehabilitation coating:

- Ease of handling and application
- Good adhesion
- UV resistance
- Resistance to cathodic disbondment
- High insulating properties
- High resistance to indentation/penetration
- Resistance to bacterial attack
- Minimum shielding of CP current
- Ease of inspection during application

After investigating and testing of different coating systems, the pipeline operator decided in favour of a new developed cold applied co-extruded tape system according to the standard EN 12068. With a three-ply tape inner layer and a two-ply tape outer layer, 50% overlapping and a total coating thickness of 3.2 mm, the DENSOLEN®/BUTYLEN AS50/R20HT System was chosen. This system is especially suited for rehabilitation purposes.

FIGURE 6: **Spiral corrosion**

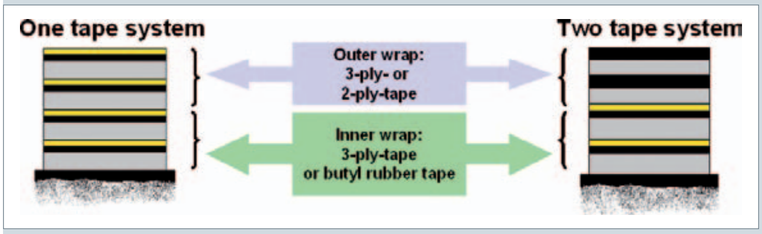
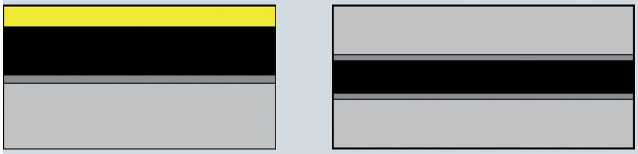


FIGURE 7: **Cross sectional view of a one-tape and a two-tape system**



asymmetrical   symmetrical

FIGURE 8: **Cross sectional view of a 3-ply corrosion prevention tape**

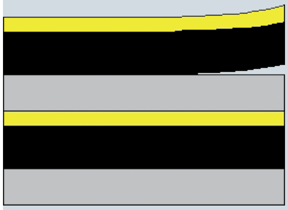


FIGURE 9: **Delamination effect during peel-test of non-co-extruded tapes**

DENSOLEN® AS50 was originally designed for an "in-one-go wrapping". With one wrapping turn, with only an overlap of 50%, the operator will achieve already the stress class B 50.

In combination with the white coloured two-ply outer tape DENSOLEN® R20HT a structure will be applied which will by far exceed even the highest stress class C 50 according to EN 12068.

To ensure a constant tape tension and required tape overlap, the tape wrapping was carried out with hand wrapping machines, suitable to the tape system. By using tape rolls of a length of up to 50 m for the inner wrap and 80 m for the outer wrap, the wrapping machines require a minimum pipe clearance of only 45 cm. At the same time a max-

FIGURE 10: **Blasting of defected areas**

FIGURE 11: **Application of primer HT**

FIGURE 12: **Application of inner wrap AS50**

FIGURE 13: **Application of outer wrap R20H**

imum of roll change intervals is provided, ensuring a safe and economic application. This rehabilitation project was executed in small sections in a bell-hole procedure. For larger sections a DENSOMAT® motor driven application device can be used.

The operator of the pipeline, third party engineers and the contractor were very much satisfied with the performance of this new tape system as it fulfilled all their requests.

CONCLUSION

There are many pipeline rehabilitation systems available in the market of corrosion prevention material and all of them may have there advantages and disadvantages. The evaluation of an appropriate rehabilitation system is depending on many specific circumstances and has to be chosen in coordination with the material and on site requirements. Furthermore it has to be suited for the relevant and unique project conditions, especially taking into account an easy and economic way of applicability of the system.

For standard temperatures up to +50° C state-of-the art real co-extruded three-ply tape systems offer the widest range to meet the diverse conditions on site. Those systems can be applied at ambient temperatures from -35° C to +60° C, even under difficult jobsite conditions.

The new developed system DENSOLEN® AS50/R20HT (see **figure 12** and **figure 13**) is designed to combine an ease of application, economical pricing with excellent mechanical resistance and outstanding corrosion prevention, not only for larger scale rehabilitation projects.

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