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 coating systems 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 adhesive.

FIGURE 1: Bitumen coated pipeline

FIGURE 2: Bitumen coated storage tank
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 H₂ 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 an 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

<table>
<thead>
<tr>
<th>Corrosion defects are caused by</th>
<th>Loads</th>
<th>Requirements</th>
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</thead>
<tbody>
<tr>
<td>Water</td>
<td>Vapour impermeability</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>Oxygen impermeability</td>
<td></td>
</tr>
<tr>
<td>Electrolyte</td>
<td>Chemical impermeability</td>
<td></td>
</tr>
<tr>
<td>Stray electrical current</td>
<td>Electrical isolation</td>
<td></td>
</tr>
<tr>
<td>Impact at transport and application</td>
<td>Impact resistance</td>
<td></td>
</tr>
<tr>
<td>Loads at transport and application</td>
<td>Indentation resistance</td>
<td></td>
</tr>
<tr>
<td>Compacting of soil</td>
<td>Indentation resistance, Peel strength, Lap shear resistance</td>
<td></td>
</tr>
<tr>
<td>Pipe movement in soil</td>
<td>Lap shear resistance</td>
<td></td>
</tr>
<tr>
<td>Sunlight</td>
<td>UV-Stability</td>
<td></td>
</tr>
<tr>
<td>Aggressive soil, high levelled operating temperatures</td>
<td>Ageing resistance, Chemical resistance</td>
<td></td>
</tr>
<tr>
<td>Micro-organism Unsuitable application</td>
<td>Microbiological resistance, Easy and secure application methods</td>
<td></td>
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</tbody>
</table>

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

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**TABLE 2: Standards for passive corrosion field coating material**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Scope</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN 30672</td>
<td>Coatings from tapes and heat shrinkable materials (for pipes with operating temperatures up to +50 °C without cathodic protection)</td>
<td>12-2000</td>
</tr>
<tr>
<td>ISO 21809-3</td>
<td>Coatings for transit pipelines</td>
<td>12-2008</td>
</tr>
<tr>
<td>EN 10289</td>
<td>Steel pipes and fittings for buried or immersed pipelines – epoxy coatings</td>
<td>08-2004</td>
</tr>
<tr>
<td>EN 10290</td>
<td>Steel pipes and fittings for buried or immersed pipelines – polyurethane and modified polyurethane coatings</td>
<td>08-2004</td>
</tr>
<tr>
<td>EN 10329</td>
<td>Field coatings for welded joints of buried steel pipes</td>
<td>04-2006</td>
</tr>
<tr>
<td>EN 12068</td>
<td>Coatings from tapes and heat shrinkable materials (for buried pipes with cathodic protection)</td>
<td>03-1999</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Stress-class</th>
<th>Petrolatum-Tapes</th>
<th>Bitumen-Tapes</th>
<th>Plastic-Tapes</th>
<th>Heat Shrinkable Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-30</td>
<td>+</td>
<td>+</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>B-30</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>n.a.</td>
</tr>
<tr>
<td>B-50</td>
<td>–</td>
<td>n.a.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>C-30</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>C-50</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+ 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 homogeneous 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.

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-
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.

AUTHOR
Michael Schad
DENSO GmbH, Leverkusen, Germany
Tel. +49 214 2602-260
E-Mail: schad@denso.de