# Rehabilitation of Corrosion Protective Coatings on Burried Steel Pipelines with Self-amalgamating Three-ply Tapes

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**Abstract**
After construction of large oil- and gas-pipeline-networks in the last 50 years, rehabilitation of these pipelines and particularly of their corrosion protective coatings has now become a topical problem. Materials to be refurbished are bitumenous - and coaltar-coatings as well as PVC- and PE-based first generation two-ply-tapes. Reasons for the failure of these sustems are both material properties and intrinsic system drawbacks as well as faults during application. State of the art cold applied three-ply tapes based on polyethylene and butyl rubber afford perfect sealing of the surface to be protected combined with a maximum ageing resistance. Depending on the degree of surface preparation possible for the pipelines to be rehabilitated, differently build-up coating systems, each containing at least two layers of a three-ply tape, are recommended.
Economic efficiency and reliability of the refurbishment-measures could be increased by employing hand- or motor-driven wrapping machines, ensuring constant wrapping tension and tape overlap.

**Introduction**
Rehabilitation of large oil and gas pipelines and particularly of their corrosion protective coatings has become a recent problem. In many cases there is not only one solution for a rehabilitation project. Pipeline owners, contractors and material manufacturers should cooperate to find taylor-made solutions for a certain rehabilitation measure, considering type of old coating, degree of surface preparation possible, financial resources and technical requirements.
Within this paper a number of measures are proposed, each involving tapes from thermoplastic compounds, which have been proven materials for corrosion prevention on steel pipes over a period of more than 30 years. It should not be concealed that first generation tape systems are the coatings to be refurbished now. Differences between this tapes and the high performance corrosion protective tapes proposed in this paper will therefore be clearly pointed out.

**Coatings to be rehabilitated**
Among the pipeline coatings that have to be rehabilitated today one has to distinguish between

- coal tar
- bitumen
- two-ply tapes from PVC with hotmelt or bitumen adhesives
- two-ply tapes from PE with hotmelt or butyl rubber adhesives

**Coal tar and bitumen based caotings**
Coal tar and bitumen coatings are rather old types of coatings and the necessity for rehabilitation sounds reasonable. 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 cunductive 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.

**Tape systems**
In any case where pipelines with tape caotings have to be rehabilitated only two-ply tape systems are involved. 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 digged out after years of service.

Although PE and butyl rubber based two-ply tapes generaly 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 (figure 1 and 2). 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 overlaping 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 1) 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 2).

Figure 1: Two-ply tape with thick layer adhesives, sealing by adhesion only

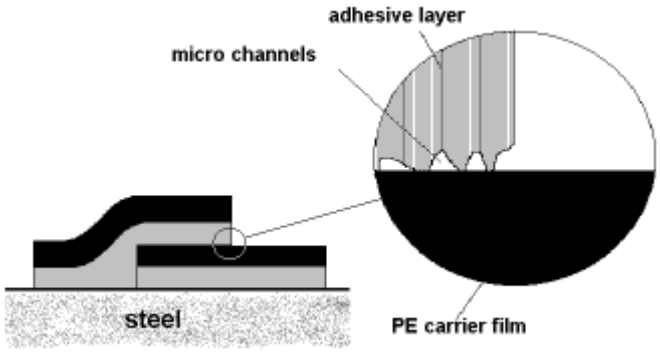
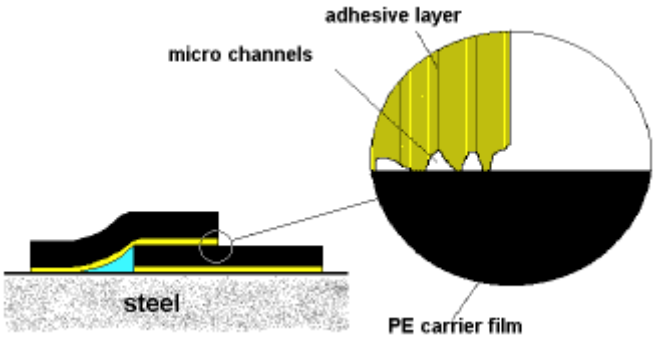


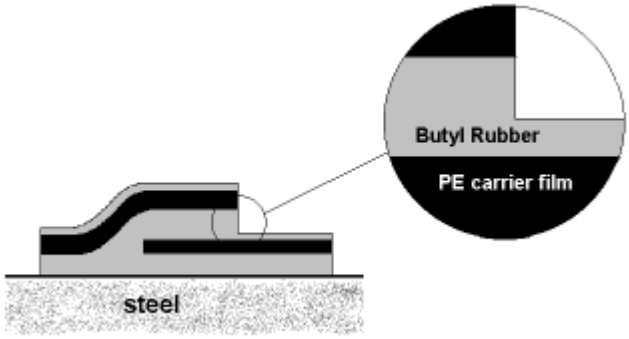

Figure 2: Hotmelt-adhesive two-ply tape, sealing by adhesion only, formation of cavities in the overlap area




In many cases the performance of two-ply tape systems was made even worse if not enough care had been taken of the most important point for tape application, namely wrapping tension. Generally tape systems can only work if the tape is applied with a certain degree of wrapping tension. A value of approximately 2 kg / 10 mm is recommended to obtain enough tension to press the tape tightly onto the metal surface. This forces could not be achieved by hand wrapping of tapes of more than 100 mm width, provided that the carrier film has a thickness large enough to ensure a mechanical resistance in accordance with stress class C-50 of EN 12068, which should be required for the coating of a large diameter pipeline. In the past many tapes of 150 mm width had been wrapped by hand, resulting in low wrapping tension, low adhesion and in the worst case formation of wrinkels within the coating.
Even with motor driven wrapping machines, a tape width of 150 mm should not be exceeded, otherwise the wrapping tension would not be high enough to ensure the functionality of the system. In the past tape width up to 450 mm have been used for over-the-ditch wrapping and are still going to be used today.

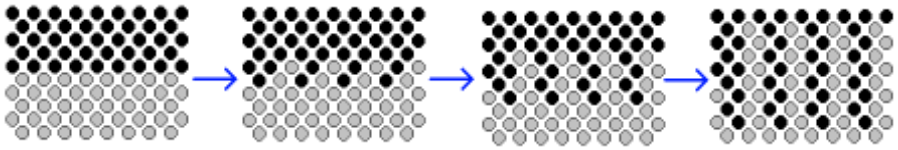
**Materials for pipeline rehabilitation – self-amalgamating three-ply tapes**
At first sight it seams to be quite unusual to recommend tape systems for the rehabilitation of pipeline coatings, when the refurbishment measures have becomme necessary due to the failure of a tape system originally applied 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 stabilized polyethylene, which is coated with a butyl rubber adhesive on both sides. Carrier films of DENSOLEN 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 (figure 3).

Figure 3: Sealing by self-amalgamation: Three-ply tapes




The self-amalgamation process and the a 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 4).

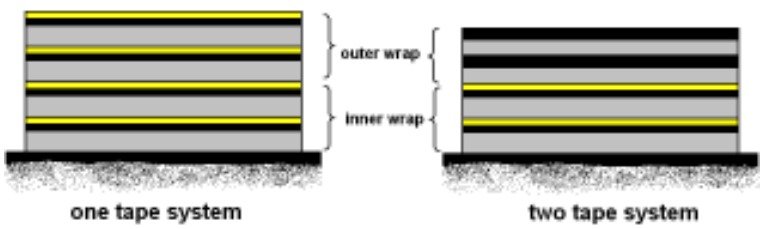
Figure 4: Self-amalgamation process



Tape coating systems for rehabilitation of 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.
The degree of surface preperation required in a refurbishment project should not be generalized. In many rehabilitation projects, especially when only short length of pipe coating are to be repaired, a complete removal would be too cost-intensive and from the technical point of view other surface conditions would be be also sufficient. The employment of permanently plastic DENSOLEN tapes offers a broad variety of combinations for coating system and methods for surface preparation.

**Surface preparation according ST2 or better**
In any case where the surface could easily and cost-efficiently be prepared according to ST2 or better, either by brushing or by sand blasting, standard one tape or two tape systems should be used for coating. 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.

Figure 5: One tape and two tape corrosion protective coatings



**Surface preparation up to a great extend according to ST2 ,residues of old adhesive**
During removal of old tape coatings in some parts of the surface residues of the old adhesive could still show good adhesion to the metal surface. In this areas the old adhesive can remain on the surface as this residues normally do not show undermining corrosion and methods for complete removal are complicated and cost-intensive.
Prior to coating with a high performance one-tape or two-tape system it has to be checked wether the residual adhesive is compatible with the butyl rubber primer paint or not. In the latter case a stabilizing penetration primer has to be applied prior to application of the tape primer. The principle of a penetrating primer, which could also be used on wet surfaces, is described below.
Depending on the amount of old adhesive remaining on the pipe, the employment of a pure butyl rubber moulding tape may be necessary to flatten the surface by filling the uneven surface structures.

**Surface preparation up to a great extend according to ST2 ,residues of old hot applied bitumen coating**
When the origin of the residual adhesive is hot applied bitumen, an incompatibility of the butyl rubber primer with the original bitumen or coal tar coating may exist, which has to be individually checked for every rehabilitation project. In case of incompatibility, the bitumen will get a gelous consistency and adhesion of the butyl rubber adhesive will be very low. Then two diffenrent measures could be taken to improve peel strength and coating performance:

- Employment of a stabilizing penetration primer prior to application of a standard one-tape or two-tape system
- Primary coating of the pipe surface with hot applied bitumen tapes. This method is especially recommended when larger residues of bitumen remain on the steel and a lot of potential hollows would have to be filled. For this the pipe surface is heated up to app. 60°C followed by aplication of a bitumen tape of 4 mm thickness with an overlap of at least 30 mm. In order to completely seal this primary bitumen coating and to improve the mechanical resistance of the system at least 2 layers of a three-ply tape should then be applied onto the bitumenous ground. Again the tape application could be done with or without a butyl rubber based primer, depending on the compatibility of the materials. In case of incompatibility again a stabilizing primer paint could be used. The prefered method should be to apply the tape directly onto the warm bitumen, which would result in peel and lap shear strengths in compliance with stress class B or C according to EN 12068.

**Residues of old bitumen coating and pipeline under operation during rehabilitation**
A very special situation occurs when an originally bitumen coated pipeline has to be refurbished on an only short length, so that cost-intensive cleaning methods should be avoided. Such a rehabilitation problem was solved with very special mesures in 1996 on 300 m of a DN600 gas pipeline (figure 6), whose coating had to be renewed due to crevices and cracks in the old bitumen coating.

Figure 6: DN 600 bitumen coated pipeline to be rehabilitated while in operation

Due to the fact that the pipeline was still in operation, an appropriate application of a bitumen coating as describes in the previous chapter would not have been possible. The insufficient pre-heating of the surface and a steady condensation of water from the torch flame caused by the low operating temperature of the pipe would have resulted in very low adhesion of a bitumen-tape. Rehabilitation was therefore carried out as follows:

The old coating was removed mechanically and by means of high pressure water jets (240 bar, figure 7).

Figure 7: Removal of old coating with high a pressure water jet

Because of the impossibility to dry the surface and to apply a bitumen based coating system, a special measure had to be taken to remove the water from the surface and the crevices within the residual bitumen. A surface sufficiently prepared for application of a DENSOLEN tape system could be achieved by use of a penetrating one component polyurethane primer paint. A primer paint of this type cures when comming in contact with water or air humidity. On surfaces like in the certain rehabilitation project the primer penetrates into the crevices and consumes the remaining water by chemical reaction (figure 8). A stabilized ground suitable for application of polyethylene – butyl rubber tapes results.

Figure 8: Curing of a 1 component polyurethane penetration primer

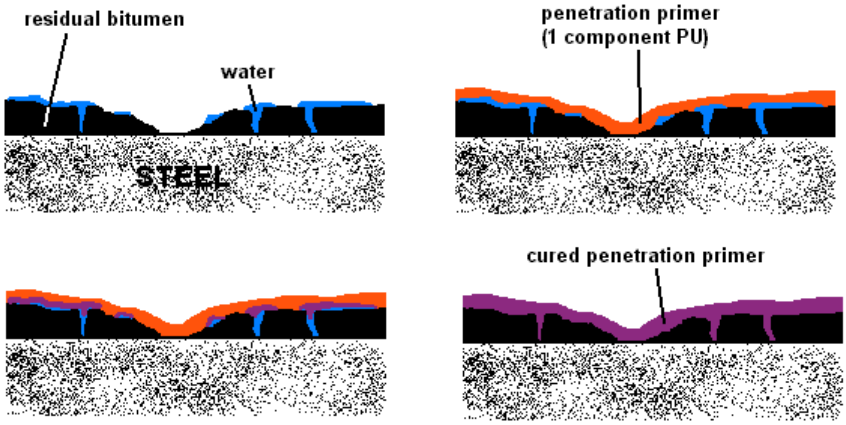



Figure 9: Application of the one component polyurethane primer

After application of a butyl rubber based primer (figure 10) wrapping of a high performance one-tape system was then carried out cost-efficiently by means of a motor driven wrapping machine (DENSOMAT 11), which especially meats the requirements for yard coating of welded joints or full pipe length up to some hundred metres. As apparent in figure 11, the tape width used was limited to 100 mm to ensure an appropriate wrapping tension.

Figure 10: Application of a primer for butyl rubber based tape systems

Figure 11: One step application of inner and outer wrap of a DENSOLEN tape system with DENSOMAT 11 wrapping machine

**Summary**
While tape systems involving only two-ply tapes are condemned to fail as corrosion protective pipeline coatings, self-amalgamating three-ply tapes offer a good possibility for rehabilitation of either bitumen or first generatin tape coatings. Depending on a technically sufficient and economically reasonable degree of surface preparation in a certain rehabilitation project, different coating systems should be used, each containing at least two layers of a three-ply tape. Supplementary products should be employed when surface preparation could not be done completely according to ST2. The following table summarizes the methods for pipe coating refurbishment described in this paper.

Table 1: Rehabilitation measures for pipe coatings involving three-ply tapes and different ways of surface preparation. The use of a filler or moulding tape prior to application of the inner wrap could be necessary in all cases.

| Surface Preparation according to | Supporting Measures | Tape System | | |
|---|---|---|---|---|
| | | Primer | Inner Wrap (two layers) | Outer Wrap (two layers) |
| ST2 or better | none | butyl rubber based | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |
| mainly ST2, residues of old adhesive | none, if old adhesive compatible to butyl rubber primer | butyl rubber based | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |
| | stabilizing 1 component polyurethane primer, | butyl rubber based | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |
| mainly ST2, residues of old hot applied bitumenous adhesive | none, if old adhesive compatible to butyl rubber primer | butyl rubber based | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |
| | stabilizing 1 component polyurethane primer, if only thin layer residues | butyl rubber based | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |
| | ground from heat applied bitumen tape coating | butyl rubber based, if compatible to bitumen coating | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |
| | | none, if incompatible to bitumen coating | three-ply polyethylene – butyl rubber to be applied onto the warm bitumen caoting | three-ply or two-ply polyethylene – butyl rubber |
| worse than ST2, wet residues of old hot applied bitumenous adhesive | 1 component penetrating polyurethane primer | butyl rubber based | three-ply polyethylene – butyl rubber | three-ply or two-ply polyethylene – butyl rubber |