# Coatings and Cathodic Disbondment - The True Story

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## Abstract:

Damage to pipe coating is almost unavoidable during transportation and construction and damage or holidays in pipe coatings may expose the pipe to possible corrosion. Cathodic protection systems are installed to act as a back-up for coating imperfections. However, cathodic protection systems interact with the coating by chemical and physical phenomena, which can lead to cathodic disbondment of the coating. Corrosion may occur underneath the disbonded coating, which is a risk for pipeline owners.

Testing for cathodic disbondment of all types of “conventional coatings” often reveal disbondment to a certain extent. Contrary to this, Properly formulated visco-elastic polymer coating systems do not show any disbondment at all, due to the unique self-healing effect of small defects.

Testing for cathodic disbondment is always done on newly applied coatings and are only tested for a short period of time, e.g. 30 days. Lifetime expectancy of pipelines however are much longer, typically 30 years or more. During its operating lifetime a coating will age and lose essential properties such as adhesive strength. This can be simulated by Hot Water Immersion testing followed by peel-testing. Results obtained with cathodic disbondment testing do not make much sense if over time the coating spontaneously disbonds because of the coating’s ageing processes.

Stopaq visco-elastic coating systems have proved not to be vulnerable to ageing in Hot Water Immersion tests; values obtained with peel testing after Hot Water Immersion at Tmax + 20°C for 100 days were similar to values obtained with non-aged test specimens and the self-healing effect - a typical property of Stopaq coating systems – still completed within the expected period of time.

## 1. Introduction

Oil and gas transport pipelines are mostly constructed of carbon steel, which mainly consists of iron. This is by far the favourite material for these kind of pipelines, because it has many advantages over other types of materials. However, carbon steel is vulnerable to several types corrosion, caused by all kind of influences from the environment and the product being transported.

## 2. Steel pipelines - Prevention of corrosion

The most common type of iron corrosion is atmospheric corrosion. This is an electrochemical process in which a few dozens of chemical reactions have been identified [(1)]. In these reactions two other molecules are involved: water and oxygen.

To prevent corrosion, different types of measures can be taken. The two most used measures are:
1) Coating of the steel substrate and
2) Cathodic protection (with underground pipelines); these are often used in combination with each other. But how does this all work?

The function of the coating is to prevent corrosion. This can only be achieved by preventing water and oxygen from reaching the steel substrate. When these molecules are not present, corrosion of iron cannot happen. To achieve this the coatings should be impermeable for water and oxygen. Special attention should also be given to the application of the coating. Improper application may leave parts of the steel surface uncovered and when water and oxygen can reach the steel, e.g. through voids in the coating, corrosion will occur.

Cathodic protection is a method in which the potential of a system is forced towards less corrosive values, thereby reducing or preventing the electrochemical corrosion reactions from occurring. This is often accomplished by applying current from an external electrical power source (impressed current) or sometimes by using a sacrificial anode.

## 3. Coating defects and CP

Damage to pipe coating is almost unavoidable during transportation and construction [(2)] due to the often heavy loads involved, machinery and equipment used, and - sometimes - bad handling and installation practices in the field. Some of the coating defects encountered are poor surface cleaning, inclusions in the coating, poor application, mechanical damages, damages caused by soil loading, and loss of adhesion over time [(3)].

Breaks or holidays in pipe coatings may expose the pipe to possible corrosion, since after a pipe has been installed underground, the surrounding earth will be more or less moisture-bearing and it constitutes an effective electrolyte, which will allow the transportation of ions. This is where the cathodic protection systems comes into action; it acts like a back-up for coating imperfections.

## 4. Interaction of coatings and CP

The CP-current causes several chemical reactions to occur at the bare steel. These chemical reactions can affect the properties of the coating surrounding the coating defect. The major chemical reaction is:

$$\mathbf{2\ H_2O + 2\ e^- \rightarrow 2\ OH^- + H_{2(g)}}$$

This chemical reaction causes interaction with the coating:
1) Formation of hydrogen gas bubbles near or under the edge of the coating causing lifting of the coating, and
2) formation of hydroxyl-ions causing leaching of the coating and/or adhesive of the coating, thereby changing properties of the coating that are essential for proper adhesion to steel.

Over time this will lead to disbondment of the coating to a certain extent, which is called cathodic disbondment. The disbonded coating will act as an electrically insulating shield on top of the steel underneath and this part of the steel surface is not protected by the CP-current because the current cannot reach the steel; this is called cathodic shielding. Soils and electrolytes can enter the void between the disbonded coating and the steel and may cause corrosion underneath the disbonded coating.

Corrosion is a risk for pipeline owners; they like to minimize risks and, if any, like to have the risks “in control”. Therefore it is of major importance that they know to what extent a coating is resistant to cathodic disbondment.

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## 5. Testing of cathodic disbondment

For testing of resistance to cathodic disbondment, a few dozen different standards are available, see e.g. NACE paper no. 07022 . They are published by several institutes all over the world, e.g. ASTM [2, 4, 5, 6], CEN (Europe) [7], CSA [8], ISO [9, 10], and many others. Furthermore, several standards are modified by oil and gas companies for specific applications.
Selecting an appropriate standard depends on a lot of variables. They mainly differ in applied potential, temperature, electrolyte used, dimension of the artificial damage, test duration, and - of course – specific circumstances in the field. Besides that, many of the standards available are used to compare coatings mutually but do not state requirements on maximum allowed cathodic disbondment. Contrary to this, ISO 21809-3 and EN 12068 list requirements for several types of coatings. Furthermore, selecting an appropriate standard implies considerations about several aspects, e.g. :

- most of the standards have a test duration varying between 28 and 90 days. However, life expectancy of most pipelines in operation is longer than that; 30 years is rather short, examples of 50 years or even 70 years are known.
- ASTM-G8 quote: *“the test methods are intended for use with samples of coated pipe taken from commercial production.”* Laboratory tests should thus be done on pipes as used at construction site and not on laboratory samples like flat panels of steel…
- ASTM-G8 quote: *“Apparently loosened coating and cathodic holidays may not result in corrosion.”* What are we testing for then... Corrosion is a risk, disbondment is not…
- ASTM-G8 quote: *“all dielectric type coatings now in common use will disbond to some degree.”* Choosing an alternative coating may not solve the problem then. However, Stopaq is different…

Tests are carried out according to the selected test method, which prescribes
1) the scope,
2) significance and use,
3) apparatus used,
4)type of reagents,
5) materials used,
6) test specimen including dimensions and preparation,
7) the test method and
8) reporting.

In all tests an artificial damage is made in the coating all the way to the bare steel; the dimension of this defect depends on the standard used. The bare steel in the damage is brought into contact with the electrolyte, either by immersing the test specimen into the electrolyte or by attaching a cell containing the electrolyte over the damaged spot. An inert counter electrode (anode) and a reference electrode are also immersed in the electrolyte. The test specimen and the counter electrode are connected to an adjustable power supply. The power supply is switched on and adjusted until the potential measured between the reference electrode and the test specimen reaches the required value. Adjusting of the applied potential must be done frequently and the current must be recorded also. Note that ISO 21809-3 recommends the use of a potentiostat, such equipment being capable of controlling the applied voltage continuously and recording the current at specified intervals.

Immediately after switching on the power supply, chemical reactions will occur. At the damaged spot of the test specimen, the same reaction takes place as in cathodic protection:

$$2\ H_2O + 2\ e^- \rightarrow 2\ OH^- + H_{2(g)}$$

At the anode two counter reactions will occur:

$$2\ H_2O + \rightarrow 4\ e^- + 4\ H^+ + O_{2(g)}$$

$$2\ Cl^- \rightarrow 2\ e^- + Cl_{2(aq)}$$

The aqueous chlorine molecules will diffuse towards the cathode, where another chemical reaction will occur:

$$2\ OH^- + Cl_{2(aq)} \rightarrow ClO^- + Cl^- + H_2O$$

Chlorine and hypochlorite-ions are known for their oxidative properties towards various kinds of organic materials. Most coating materials contain a significant percentage of organic materials and contact with these oxidizing agents may lead to deterioration and loss of essential properties of the coating, thereby worsening the results of cathodic disbondment testing. In real practice, the anode of a cathodic protection system is placed far away from the object to be protected, often at least a few hundreds of meters. It is therefore very unlikely that the generated chlorine molecules will diffuse towards damaged spots on the pipe; deterioration of the coating by chlorine/hypochlorite is also unlikely to happen in real practice. Nevertheless, it can be assumed that results obtained with test methods using chloride salt solutions differ from situations with cathodic disbondment in practice.

The test is terminated after the prescribed period of time. The test specimen is then disconnected and disbondment of the coating is visually inspected by making radial cuts in the coating surrounding the damaged spot, followed by gentle lifting of the coating. The area of disbondment is measured and recorded.

Requirements for maximum allowed disbondment as stated in e.g. ISO 21809-3 varies per type of coating, e.g. hot applied bituminous tapes and petrolatum tapes ≤ 20 mm, polymeric tapes ≤ 15 mm, PE-backed heat shrinkable coating without primer (type 2A-1) ≤ 10 mm, , liquid epoxy ≤ 8 mm, liquid polyurethanes ≤ 8 mm, and elastomeric coatings ≤ 7 mm.

## 6. Stopaq Coating Systems

Stopaq coating systems consist of at least two layers with different functions. The first layer is a corrosion preventing material that is applied directly onto the bare steel of the object to be coated, e.g. Stopaq Wrappingband (various types). The second layer is a flexible mechanical protective material applied on top of Stopaq Wrappingband, e.g. Stopaq High Impact Shield or Stopaq Outerwrap (various types). This material is applied with tension, thereby generating some pressure on the layer of Stopaq Wrappingband.

Stopaq Wrappingband is based on pure polyisobutene, which has properties that are beneficial in coating applications:

- Polyisobutene (and the Wrappingband compound made thereof) is a liquid with high viscosity and glass transition temperature of -67°C, giving it cold-flow properties, beneficial for 100% coverage of bare steel surfaces.
- Very low permeability for water and oxygen; beneficial for preventing corrosion reactions of iron.
- No reactive chemical groups; resulting in excellent chemical resistance and supreme resistance to ageing and weathering.
- Adhesion by van der Waals-forces; resulting in excellent adhesion to various types of substrates like steel, PE, PP, FBE and others. Due to this, surface preparation is less critical than with all types of other coatings.

Results in cathodic disbondment testing of Stopaq coating systems as described above differ significantly from “conventional coatings”. In execution of the test, an artificial defect is made in the coating system. Due to the liquid nature of the Stopaq Wrappingband compound and the compressing action of the flexible mechanical protective layer on top of it, self-healing of the defect will occur. The liquid-like compound of Wrappingband is pushed towards the defect, thereby sealing the opening within a short period of time. Completion of the self-healing effect depends on temperature; at a temperature of 20°C self-healing of a coating system comprising Wrappingband CZH and Outerwrap PVC takes less than a day, but at 70°C it is completed within an hour. After completion, the current consumed in the cathodic disbondment test will drop to zero, the chemical reactions will stop and the cathodic disbondment process is ceased also. Inspection after termination of the test shows cathodic disbondment is 0 mm or - actually - a negative figure since the compound has covered the area of the initial defect also.
Therefore, Stopaq coating systems distinguish in a positive way from “conventional coatings”. The result of cathodic disbondment testing is 0 mm, caused by occurrence of self-healing effect.

## 7. Ageing of coatings

All coatings are vulnerable to ageing, caused by a variety of influences such as thermal stress (fluctuations in operational temperatures), mechanical stress (vibrations), exposure to ambient conditions (wet / dry cycles, freeze / thaw cycles). The effects caused are changes in compositions and loss of essential properties.

Standards are available for evaluation of coating properties after ageing (9). A method that is often used is adhesion testing after Hot Water Immersion. A test specimen is placed in water for a determined period of time at an elevated temperature, often at or above maximum service temperature of the coating. After this ageing period the adhesion is tested using an appropriate method.

It is a well-known fact that with testing of several types of coating, adhesion properties will have deteriorated significantly after Hot Water Immersion testing (11). Below are some examples of peel test values, compared to initial values of non-aged samples (100%):

- FBE coating (unknown type) tested @ 95°C: after 60 days only 40% of adhesion / peel force was left and after 120 days only 29% of adhesion / peel force was left.
- 3 layer Heat Shrinkable Sleeve (unknown type) tested @ 80°C: after 60 days adhesion / peel force had increased to 124% was left, but after 120 days only 56% of adhesion / peel force was left.
- 2LPE pipeline coating (unknown type) tested @ 60°C: after 60 days the coating had fallen off (0% left) and same result was found after 120 days.
- PE tape with pressure sensitive adhesive (unknown type) tested @ 60°C: after 60 days 80% of adhesion / peel force was left and after 120 days only 40% of adhesion / peel force was left.

A test specimen coated with a Stopaq coating system comprising Wrappingband CZH and Outerwrap PVC was also subjected to Hot Water Immersion testing. It was aged for 100 days @ 90°C (=$T_{max}$ + 20°C) and subsequently adhesion / peel force was tested. The obtained value was the same as found with non-aged samples: 100%! Furthermore, occurrence of self-healing was tested also after Hot Water Immersion 100 days @ 90°C. This was completed within the expected period of time for this coating system.

## 8. Conclusion: coating ageing related to cathodic disbondment

Coatings are subjected to Cathodic Disbondment tests to evaluate the risks for pipeline owners. These tests are often conducted with new applied coatings and the duration of such tests is far less than the life expectancy of a pipeline. All coatings are vulnerable to ageing and Hot Water Immersion testing is a way to simulate the behavior of coatings over time. However, results obtained with cathodic disbondment testing do not make much sense if over time the coating spontaneously disbonds by ageing processes.

Stopaq coating systems comprising Wrappingband and a flexible mechanical protective layer distinguish in a positive way from conventional types of coating. Cathodic disbondment of such coating systems is 0 mm, caused by the self-healing effect. After Hot Water Immersion test of 100 days at 90°C the adhesion properties are not influenced and the self-healing effect is still present.

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