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CORROSION UNDER DISBONDED COATINGS OF CATHODICALLY PROTECTED PIPELINES.

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Abstract :

The literature survey addresses two types of corrosion that occurred under disbonded coatings of cathodically protected buried pipelines. The data analysed refer mostly to the chemical and electrochemical conditions in the crevice at disbonding. The important points of this survey is the idea that anodically polarised zones can be found under disbonded coatings, in spite of the cathodic protection. Geometry of the crevice (length to gap ratio, stagnation or flow) and permeability of the coating to oxygen are important parameters. Oxygen permeable coatings (such as polyethylene) and multiple holidays are capable of producing large corrosion rate at disbonding of a certain geometry.

On the basis of a literature survey and of numerous field observations, an experimental set up was developed to provide a better access to local data on potentials, current densities, pH, local chemistry, corrosion rates and corrosion products inside the crevice formed by a disbonded coating. Some parameters considered in this study are : organic coating impermeable (polyester) and permeable (polyethylene) to oxygen, resistive and conductive bulk solution, purging or establishing a flow of solution in the crevice. Corrosion rate was measured by sensitive electrical resistance probes that gave quasi-instantaneous corrosion rate and by weight loss (cumulated corrosion rate). The test set-up allowed direct visual examination, sampling of small volumes of local solution for pH and chemical analyses and electrochemical measurements (local potential and current densities).
The major result is the detrimental effects of coatings permeable to oxygen (such as polyethylene which as extensively used for buried pipelines at a time) and the renewal of the solution in the disbonded crevice (by purging or by a continuous flow). In those circumstances, corrosion rates in the range of 0.5 mm/y were measured in out tests.

1. Introduction

The subject of corrosion under disbonded coatings of buried pipes with cathodic protection received much attention since 1965, when a gas transmission pipe failed in Natchitoches, Louisiana, USA. More failures occurred since, in Canada after 1977, in France (in 1997 and somewhat before) and also in Italy, Holland, Australia, Iran, Iraq, Pakistan, Saoudi Arabia and in the former USSR. In the USA, external corrosion accounted for 12% of pipeline failures between 1970 and 1993 [1], distributed as 9.5% on gas lines and 15.7% on liquids lines. Both SCC and dissolution corrosion under disbonded coating are included in these figures.

This work was conducted in Belgium where some cases of dissolution corrosion (without cracking) occurred, mostly at field welded joints. The pipelines were installed during the seventies and have been protected cathodically from the beginning. There has always been a tradition of quality for cathodic protection in Belgium because of the need to overcome significant stray currents. All records show that cathodic protection was correct. Again due to the stray currents, the trend is to slightly overprotect instead of applying a minimum protection.

The present work contains an analysis of the related literature, inspection in the field and an experimental study in the laboratory. A great deal of attention was given to inspection in the field : measurements (pH, potential) and sampling (soil, groundwater, crevice water, corrosion products) were made without disturbing the soil and the CP current distribution. Pigging identified the corroded zones. Digging out the pipe was made progressively, following the instructions of the examiners on-site. The results of a large number of field observations were presented previously [2].

2. Literature survey

Most of the studies on the conditions under disbonded coatings under cathodic protection relate to SCC accidents that occurred in Canada, USA and other countries. The major cause mentioned for these cracking accidents is the lack of cathodic protection underneath disbonding.
On other lines, similar lack of CP led to local dissolution (broad open pits), without cracking. The factors that determine dissolution or cracking are critical in terms of risk assessment. However, they are little known and need to be addressed.

Field observations and good data on the conditions underneath disbonding are scarce. One reason is that inspection is mostly made after accidents (explosion, fire, leaks) that, together with the digging-out operations, brought severe modifications to the local conditions.

In some cases, corroded spots were identified by pigging and the excavation and observation work could be conducted with minimum disturbance [2].

In some studies, simulated crevices reproduced the recess under disbonding (figure 1). Rather large geometry (30 to 55 cm length) was found necessary to reproduce a lack of CP.

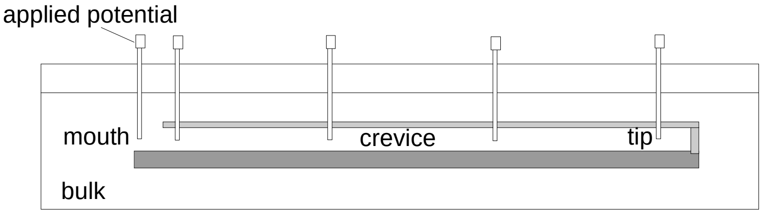

Figure 1: Schematic representation of a crevice at a coating disbonding

Microelectrodes were used for pH (sometimes also pH paper was used) and for potential. Few observations were made on corrosion products and corrosion patterns. One study attempted to use physically separated steel plots for measuring corrosion rates at different depth of the crevice [3].

Most of the recent studies are based on models, with the idea of studying the role of a large number of parameters such as disbonding geometry, groundwater composition, CP level, effect of time over long periods (10 years and more) and ranking of the most or less important factors.
The quality of the models and of their hypotheses is critical. Some inputs and assumptions are :
- a series of reactions are considered : mostly corrosion of iron, reduction of oxygen and reduction of water (with hydrogen evolution). In some models, the CO_2/bicarbonate/carbonate reactions and precipitation reactions (of $FeCO_3$, of ferric oxides) are also considered. The presence or absence of Na^+ or Ca^{++} ions in the groundwater is not addressed.
- often, the oxygen reduction is assumed to be controlled by diffusion, thus independent of potential. Conversely, the potential is not really dictated by the CP current.
- such a simplifying hypothesis cannot be made for hydrogen evolution, when present. But for simplification, the hydrogen production rate is also assumed at a given, empirical value, not dependent of the potential [1].
- the Butler-Volmer equations are used to compute currents from local potentials and from exchange current density data for the local environment, temperature, surface conditions etc.
- conversely, the Laplace equation provides the potential distribution, with the assumption that the concentrations are known. In some models, the concentrations and diffusion coefficients are assumed constant, which is certainly a serious oversimplification. More recent work attempts to introduce various and local concentration and diffusion data.
- CP is applied at different current densities and crevice-mouth potentials.
- a more recent model [4] was adapted to select a larger number of chemical species, with their thermodynamic data and their concentration.
- precipitation and hydrolysis reactions with their effect on pH are introduced in the model,
- reaction rate data can be introduced,
- transport in 1, 2 or 3 dimensions is analysed,
- an important factor is the permeability of the coating to oxygen. This is considered (still rather crudely) in one model [5].

In one study, models were used to determine the local chemistry in the very long term (10 years and more), trying to explain the occurrence of stress cracking [1]. To do that, the rates of reaction (corrosion, hydrogen evolution, oxygen reduction) are assumed at fixed values, which is questionable.

The discussion below in models is arranged first on potentials, then pH, role of CO_2, role of mill scale and corrosion rates.

Potential in crevice

The general understanding is that there is a lack of CP (due to « shielding ») in the crevice. The potential is less and less negative along the depth of the crevice. This is especially true in dilute, non-conductive solutions [5]. In such solutions, CO_2 has no effect at a crevice depth of 25 cm even for $-1.5\ V_{sce}$ applied potential [5].

In high conductivity solutions in the crevice, the potential gradient in the crevice is less pronounced and is probably negligible. This is true as long as the applied potential (on a bare surface at the mouth of the crevice) is not more negative than –1000 mV_{sce} [6].

Some papers suggest that the potential tends to a limit with increasing distance from the mouth of the crevice, and remains constant at the free corrosion potential, at greater distance [5,6,7]. Other factors that influence the potential gradient are the crevice gap, pH, local chemistry and the reactivity of surface [7].

Interesting peculiarities are :
Potentials in the crevice may in some case be locally lower (more negative) than the applied potential. This surprising fact may be due to a polarisation at high pH and without oxygen. This was reported in conductive environment (seawater) [6]. The limiting potential in the crevice may be the zero current potential for the local oxygen free solution.
As a consequence, anodic and cathodic reactions are thought to occur under CP at different locations in the crevice, depending on the local chemistry and potential [4].
When oxygen enters the crevice only from one coating defect, the crevice is divided in two regions : near the mouth the surface is cathodically protected but, deeper in the crevice, the potential is less negative due to a lower CP current, and due to some oxygen diffusion from the mouth. Even deeper into the crevice, oxygen is completely absent and the surface is polarised anodically by the adjacent surfaces (at less negative potentials). The maximum corrosion current is near the border of the two latter regions between the mid-distance and the tip of the crevice [8].

The permeation of oxygen through the coating has been considered [8]. When oxygen diffuses through the coating, the potential in the crevice is higher (here, about 80 mV higher than with no oxygen permeation). And the corrosion current is 20 mA/m^2, 10 times more than without oxygen [8].
Under CP, the oxygen penetrating at the holiday is reduced completely (at the holiday). But oxygen can permeate through some coatings (polyethylene is one of those) and its concentration at the tip of the crevice is higher compared to no permeation. In this case, the potential deep in the crevice is higher than at mouth. For that reason, long crevices (length/gap > 44) produce higher potential at tip than short crevices. This higher potential may be responsible for the higher corrosion current (10 times more than when there is no oxygen permeation) [8].

pH in crevice

All kinds of pH changes are mentioned in literature : acid or alkaline [4]. Often, experimental values are lower than from models [4]. One opinion is that pH is near neutral far away from the mouth due to little CP effect. However, it is inferred that near neutral pH in crevice cannot be sustained for long times [4].

Some consider that the final pH in crevice is independent on the gap/length ratio, at least for less negative applied CP potentials [4]. For the rest, smaller gaps seem to give higher pH [4]. But a more detailed analysis indicates that the crevice gap may influence each reaction differently and therefore the resultant pH may vary. For example in small gaps, if a limiting current controls water reduction, the pH increases faster in a smaller volume. Similarly, oxygen is quickly reduced, but iron corrosion is increased if potential is not low enough (which is likely with small gaps) and acidification by hydrolysis is faster [4].

pH changes result from a competition between hydrolysis (acid forming) when corrosion is possible and reduction of oxygen and of water (with alkalisation) [4].

pH in crevice is influenced by the applied potential but not much by conductivity if there is a reserve of bulk solution [4]. The constancy of bulk solution is important on the results. Wetness of the soils, drain effects, movement of water table is important in that respect [4].

Some maximum pH values measured or computed at the tip of deep crevices are 12.5. Other values are up to more than 13, at applied potentials of –1000 to –1100 mV_{sce}. pH values are however scattered : for example pH 12 is observed at applied potentials of –850 as well as at –1110 mV_{sce} [6]. pH increases not so much near the mouth because the bulk solution diffuses in the crevice. But if the bulk solution is stagnant (related to little moist soils), pH increases faster [6].

Along the crevice depth, pH increases quickly, iron increases regularly, oxygen decreases quickly, hydrogen increases progressively [6].

Role of CO_2

Abundant CO_2 bubbling and $FeCO_3$ as corrosion product is observed under disbonding in some field cases. The total CO_2 content (H_2CO_3, HCO_3^-, $CO3^{--}$) in the crevice solution is orders of magnitude higher than in the groundwater.
The various forms of CO_2 (carbonic acid, bicarbonate, carbonate) have a significant buffer effect. Their influence on the actual pH in the crevice is certain.
The presence of CO_2 decreases the pH at short times. But pH increases again after a few thousand hours. The opinion is that p_{CO2} higher than 3.6 10^{-1} bar (which is 1000 times more than in atmosphere) may keep the pH near neutral for long times, before pH eventually increases [4].

Role of mill scale

Mill scale was probably present on many pipes installed until the early seventies. Mill scale is detrimental because it counteracts the decrease of potential at the steel surface until the mill scale oxide (FeO_x) is completely reduced [6,7].

Corrosion rate

Models clearly show that the corrosion rate in the crevice under a disbonded coating is much influenced by whether or not oxygen can permeate through the coating. In a particular case modelled, the potential at the tip with permeation is about 80 mV higher than with a similar situation without oxygen permeation. In this case, the model predicts a corrosion current of 20 mA/m², which is 10 times more than without oxygen [8]. This figure seems enormous and should be re-examined. Given the Faraday law, 1 mA/cm² corresponds to 11 mm/yr.

From an experimental study conducted at GdF, the corrosion rate in 60 cm long crevices is 0,1 mm/yr when there is no flow of solution in the crevice (crevice with one single opening) and it is higher (up to 0,45 mm/yr) with a flow [3].
However, there are clear signs of highly scattered corrosion rates even with the well-controlled geometry of the simulated crevice. This work suggests 3 zones : one just at the

mouth of the crevice, another a little further but near the mouth (where there is corrosion due to remaining oxygen, but without CP current due to shielding) and another one still further down the crevice, where there is no corrosion due to a complete lack of oxygen. Alkalisation was not observed even without flow, this being attributed to ferrous ion hydrolysis [3].

Quality of coating

Interesting comments can be found in [3] on the degradation processes of coatings : incompatibility between coaltar and bitumen, effects of too high temperatures during application and storage, ingress of water along interfaces between different types of coating or along glass fibres.

3. Experimental study. Materials and methods.

Disbonding of coatings was simulated by assembling sheets of heat-sealing polymer materials and sheets of carbon steel. The size, gaps and types of the defects reproduced those observed during the field investigations: with or without renewal of the solution, with regular purges and with permanent circulation through two holidays.
The distance between the mouth and the tip of the crevice under the disbonded coating was between 30 and 60 cm, which is mentioned in the literature as the most sensitive to corrosion.
The gap between the steel and the disbonded coating was variable, from 0 to 2 mm. This corresponds to many defects observed on site.
The metal exposed in the crevice is divided into 12 squares of 50 x 50 mm x 25 µm which are interconnected by exterior connections to allow for local current densities between adjacent zones or from the exterior anode. The currents were measured by microammeters with zero resistance.
Potentials were measured at different depths in the crevice by three capillary junctions ending in the crevice near its mouth (zone A, 0 to 20 cm from the mouth), at middle length (zone B, 20 to 40 cm) and near the tip (zone C 40 to 60 cm).
Potentials were measured with the CP current “on” and “off”. The capillary junctions allow the “on” potentials to correctly indicate the local potentials as influenced by CP. The “off” potentials were measured for confirmation.

The capillary junctions were also used to sample local crevice solutions for pH and other measurements.
Three of the 12 interconnected sheets of carbon steel are electrical resistance probes, made of a 25 µm thick sheet and positioned at the mouth, at middle length and at the tip. Thus, corrosion rate was measured by electrical resistance during the test and at the end of the tests by weight loss. The sensitivity of the electrical resistance probe is high and the results can be considered as instantaneous rates.

A series of specific precautions was taken to expose only one side of the steel plates, to allow an easy optical examination during the test, to allow verification of the corrosion rates measurements by weight loss without error due to electrical connections and to avoid chloride pollution from the reference electrodes and entry of oxygen through the capillary junctions.

The simulated disbonding was put in a 15 l glass container and connected to a 40 cm^2 steel surface, which is under cathodic control at –1100 to –1200 mV_{sce} by means of a potentiostat.

One opening in the form of 5 cm long slits represents the mouth of the creviced coating defect. A second similar opening allows, at will, to purge the crevice (renew the volume of solution) or to install a permanent flow of solution through the crevice, as it may happen in reality.

Figure 2 is a schematic representation of the experimental set-up.

Different polymer materials were used to investigate the effect of permeability to oxygen:

- a high oxygen permeability material :

low density polyethylene, thickness 80 µm, oxygen permeability 2.2 10^{-13} $cm^3.cm.cm^{-2}.s^{-1}.Pa^{-1}$
volumic electrical resistance 10^{15} to 10^{18} ohm.cm

- a low oxygen permeability material :

polyester, thickness 205 µm, oxygen permeability 0.015 to 0.04 10^{-13} $cm^3.cm.cm^{-2}.s^{-1}.Pa^{-1}$, volumic electrical resistance > 10^{14} ohm.cm.

Bulk test solutions:

- One low-conductive solution:

$NaHCO_3$ 5.10^{-4} M + $CaCl_2$ 5.10^{-4} M + $Ca_3(PO_4)_2$ 5.10^{-4} M

- One conductive solution (NS4, reference solution used in Canadian studies):

KCl $1{,}64.10^{-3}$ M + $NaHCO_3$ $5.75.10^{-3}$ M + $CaCl_2.2H_2O$ $1.23.10^{-3}$ M + $MgSO_4.7H_2O$ $0.26.10^{-3}$ M, pH brought to 7 by addition of HCl.

4. Experimental study. Results

Tests were conducted in three typical conditions :

- a low oxygen permeability coating and a low conductive solution,
- the same low permeable coating and a conductive solution
- a coating permeable to oxygen and a conductive solution.

4.1 Low oxygen permeability coating in a low conductive solution

The potentials decrease rapidly and stabilise after one day at –850 mV_{sce} at about 50 mm of the mouth and at –700 mV_{sce} at middle length and at the tip (the end) of the crevice (figure 3). A correction for the ohmic drop is necessary for the sufaces near the mouth, which receive the current. Without this correction, the apparent potential measured near the mouth is too low. The current density received near the mouth of the crevice (on the first 50 mm long sample) is definitely and significantly cathodic (50 to 90 µA/cm²). But already at 100 mm of the mouth, the cathodic current density is much lower (0.2 to 1.0 µA/cm²) and eventually changes occasionally to anodic. The anodic polarisation inside the crevice is enhanced by a flow of solution in the crevice. The same is observed further down into the crevice (figure 4).
The pH at the mouth of crevice inceases rapidly to 12-12.5. At mid-length and at the tip of the crevice, pH decreases first to 5-5.5, then increases slowly (more slowly at tip). When CP is interrupted, the pH at mouth decreases to 9.5 after 5 days. When the crevice is purged or when there is a flow inside the crevice, pH becomes similar to that of the bulk solution.
The metal in the depth of the crevice is slightly black. Corrosion is insignificant in the whole crevice, with the exception of periods of purges or flow in the crevice. A flow established after 27 days immediately led to corrosion rates up to 0.4 mm/y at mid-length.

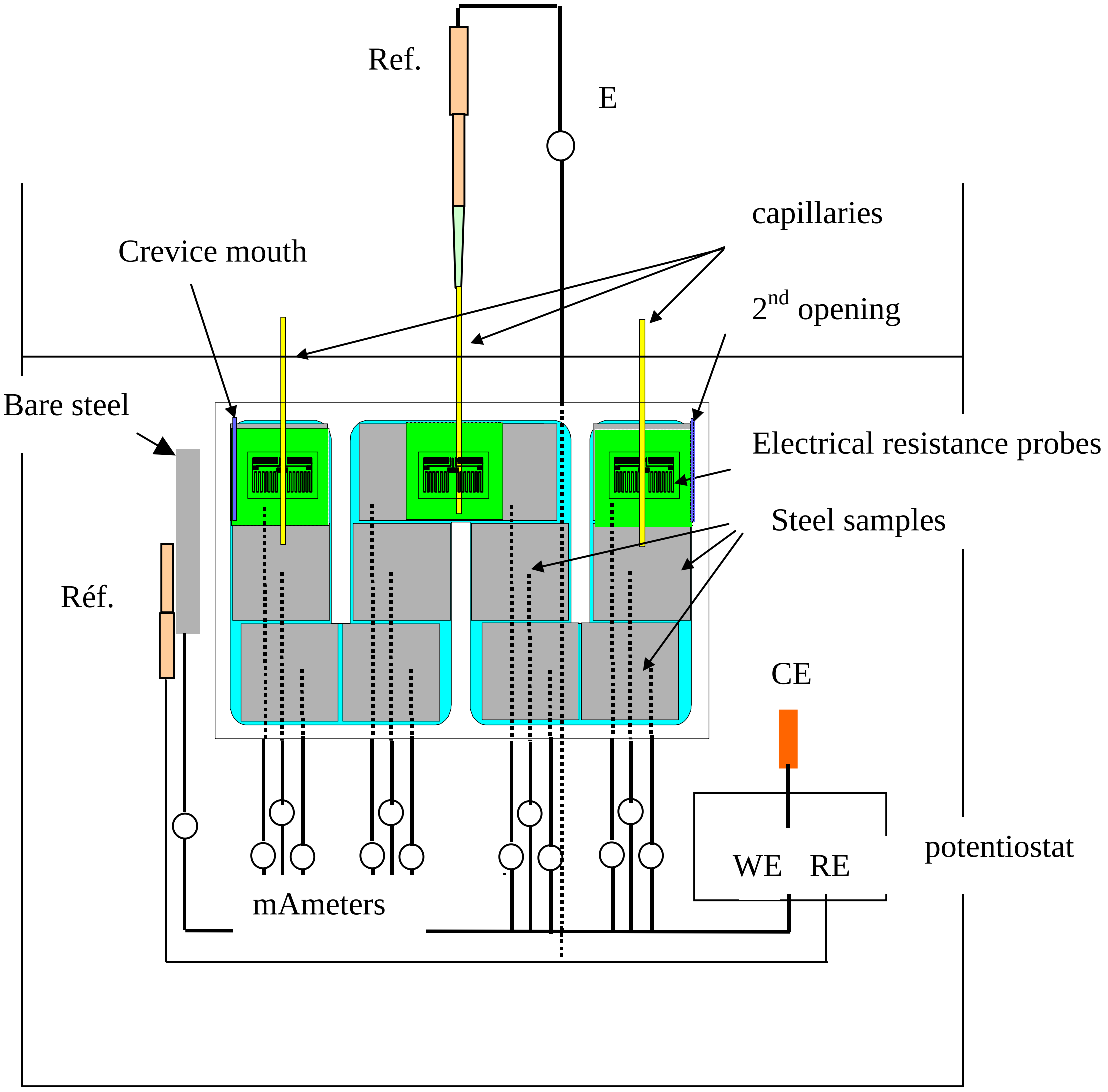

Figure 2: Schematic representation of the experimental set-up

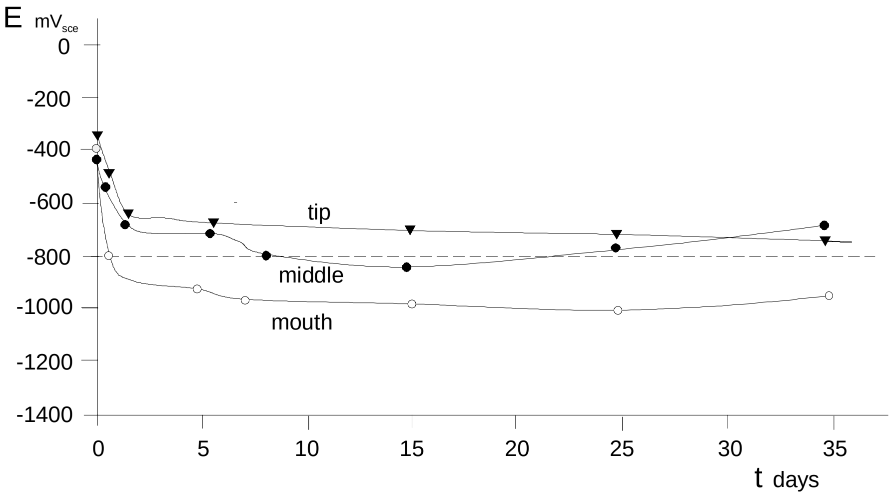

Figure 3: Potentials near the mouth, at middle length and at the tip of the disbonding as a function of time, under CP. Low oxygen permeability coating in a low conductive solution.

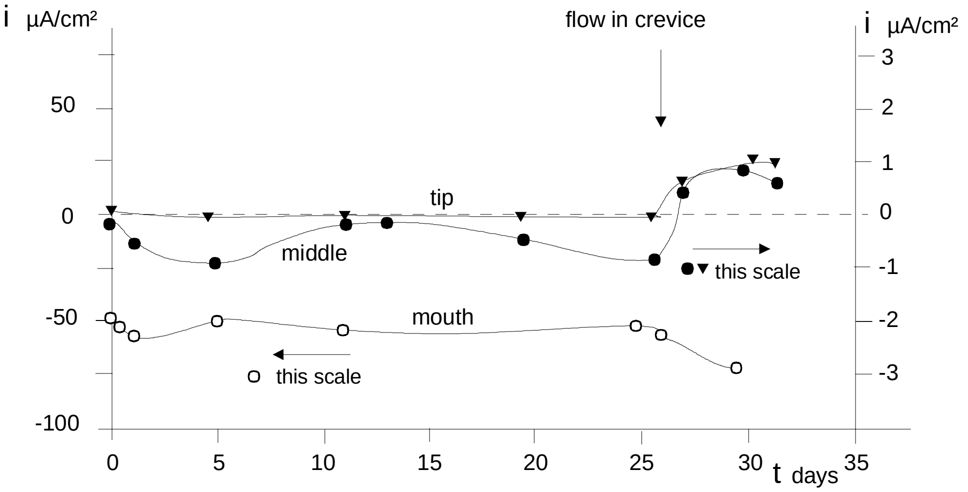

Figure 4: Current density at different distances in the crevice as a function of time
Effect of a flow in the crevice

4.2 Low oxygen permeability coating in a conductive solution

The potentials on the three zones of the crevice decrease below –800 mV$_{sce}$ (after 7 days for the middle and 14 days for the tip of the crevice), figure 5.
The current densities are larger and definitely cathodic near the mouth (up to 120 µA/cm²). At 10 cm of the mouth the current is still cathodic but smaller (1 to 3 µA/cm²). Further down the crevice, the current density is even smaller and of changing polarity (cathodic and anodic) during 10 to 15 days, after which it stabilises at a low cathodic value (figure 6).

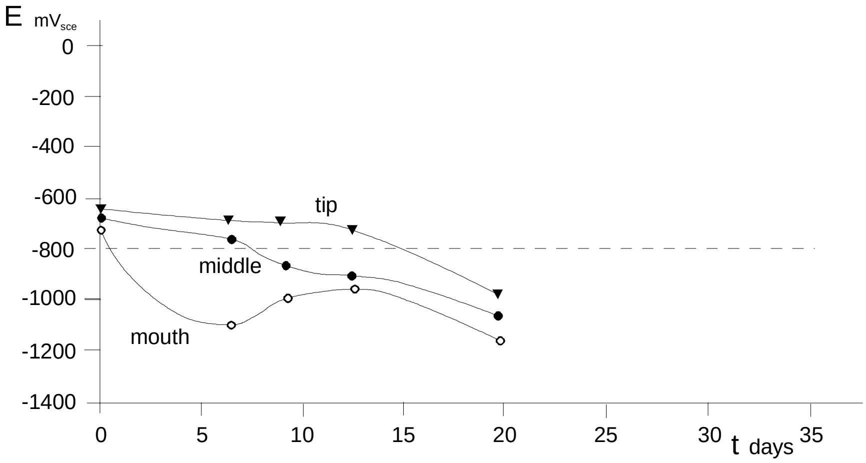

Figure 5: Potentials near the mouth, at middle length and at the tip of the disbonding as a function of time, under CP. Low oxygen permeability coating in a conductive solution.

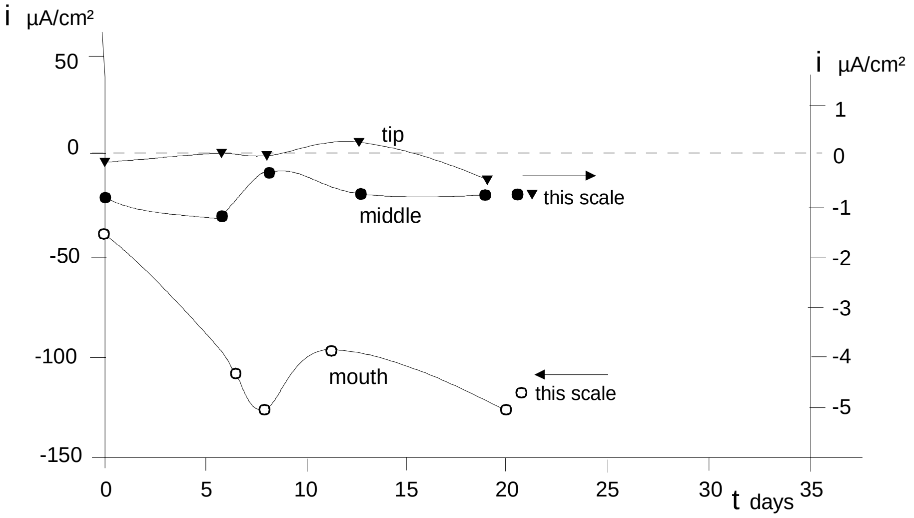

Figure 6: Current density at different distances in the crevice as a function of time. Low oxygen permeability coating in a conductive solution.

The measurements of the instantaneous corrosion rate show zero for the zone A near the mouth, 200 µm/y at beginning for zone B (middle) falling down to 10 µm/y after a few days, and the same for zone C but more slowly.
The pH changes with time are similar to the previous test in less conductive solution: pH increases rapidly at the mouth when CP is applied (to pH 13), pH decreases first to 6.5 then increases to 13 after 20 days in the middle of the crevice and decreases to 6 and increases more slowly at the tip (11.5 after 29 days).
The steel surface showed a few black spots from the beginning of the test but no or negligible corrosion after 20 days.

4.3 Coating permeable to oxygen and a conductive solution.

Near the mouth, the potentials decrease slowly (stabilise at -870 mV_{sce} after 10 days, while the potentials outside the crevice is –1100 to –1200 mV_{sce}). Further away from the crevice opening, the potential never reach the protection potential (stabilises at –600 to –700 mV_{sce}). The current density for the steel near the mouth is similar to that in conductive solution with a non-permeable coating (cathodic, up to 120 µA/cm²). The current densities further down in the crevice are much chaotic and mostly cathodic up to 15 cm into the crevice and also chaotic but often markedly anodic at a greater distance from the mouth. The variations in current density and polarity is often rapid (figure 7).

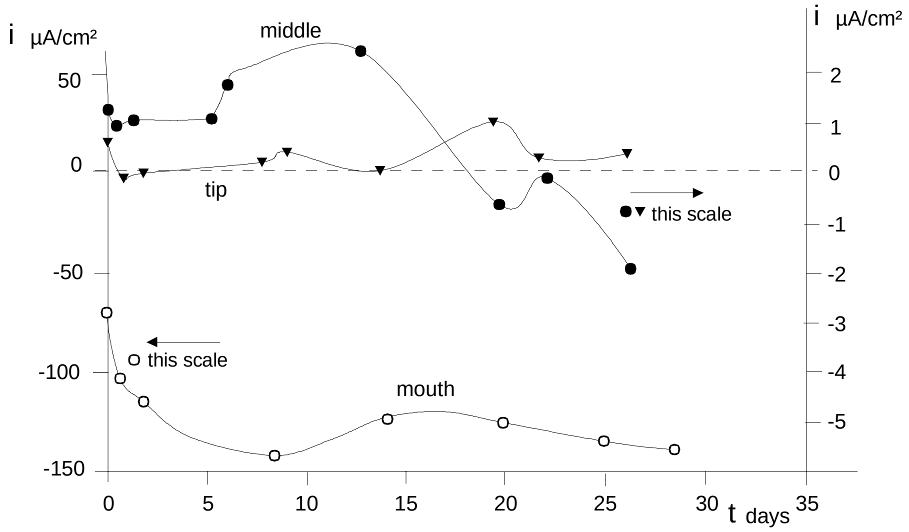

Figure 7: Current density at different distances in the crevice as a function of time. High oxygen permeable coating in a conductive solution.

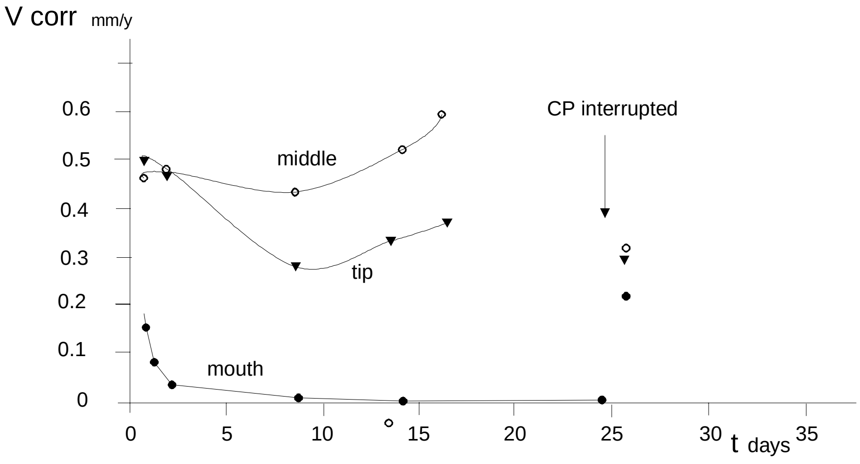

Figure 8: Corrosion rates in the crevice as a function of time. High oxygen permeable coating in a conductive solution.

The corrosion rate near the mouth decreases to very low values (30 µm/y after 2 days and 0 at 10 days). But the corrosion rate further down in the crevice are large at the beginning (450 to 500 µm/y), decrease and increase again with time (400 and 600 µm/y after 15 days). The highest corrosion rate was observed at mid-length. The corrosion rate at the tip of the crevice, although important, was generally lower than at mid-length (figure 8).

pH increased rapidly up to 13 near the mouth but remained low (pH 6) deeper in the crevice, during the whole test duration.

Red-brown corrosion products were visible from the beginning of the test. After 28 days, the test set-up was opened and perforation was observed locally on the 25 µm thick samples, at distances from the mouth equal or greater than 10 cm.

At the end of this test (after 28 days), 0.5 ml was sampled in each zone of the crevice and was analysed for pH, carbonate and bicarbonate equivalent and compared with the bulk solution.

The results are :

	Bulk	Mouth	Mid-length	Tip
pH	7	>13	6	6
OH^- (mg/l)	0	24	0	0
CO_3^{--} (mg/l)	0	258	0	0
HCO_3^- (mg/l)	183	0	366	396

5. Discussion

The tests with a coating impermeable to oxygen showed that in disbonded areas where the coating is an obstacle to cathodic protection and when the solution is not circulating, the corrosion eventually comes to a stop, even very far away from the opening of the crevice. During a transitory period, some surfaces deep into the crevice are polarised slightly anodically, because of the absence of oxygen and consequently low potentials, while at a smaller distance from the mouth, potentials are slightly higher because CP is ineffective and because there is some oxygen brought in by diffusion from the bulk.

With time, all oxygen is consumed (by corrosion, with precipitated corrosion products forming an obstacle to the oxygen diffusion), the pH increases in the whole crevice by diffusion of alkaline solution from the mouth and corrosion stops. Before that, it is probable that the precipitation of corrosion products produces a slight pH decrease (by hydrolysis of soluble iron), which is progressively neutralised by diffusion of the alkaline mouth solution. In our tests, these modifications took a few hours for a little conductive bulk solution and about 20 days for a more conductive solution.

When the crevice is purged or when there is a flow of solution, corrosion is more important. This was observed also in the field : no corrosion was observed on a factory coating disbonded over a large area with a gap of 1 mm, filled with stagnant water. But on the same pipe, a few dm away, under a disbonded field joint coating open to a flow of solution, serious corrosion was observed with local pH around 6 [9].

The test with an electrically insulating coating which is permeable to oxygen, indicated that the potentials hardly decrease in the immunity region even rather close to the crevice opening. Further down in the crevice, immunity is not attained, no alkalinisation is observed and corrosion remains important during the course of time. Only the surface close to the mouth (5 cm) received a large protection current density (120 µA/cm²). Already at 10 cm, the cathodic current density is smaller than 5 µA/cm². Anodic zones were identified at different distances from the mouth (for example 20, 30 and 60 cm). Corrosion rates there decreased when CP was interrupted. Cathodic zones existed at intermediate distances (for example 34, 45 and 55 cm). In addition, several of these zones changed polarity during the test (anodic to cathodic or vice-versa) while the potentials were rather constant. These changes are attributed to local differences in oxygen availability and to hydrolysis and precipitation of corrosion products with local pH changes. The correlation between potentials, current density, pH and analysis of solution and corrosion products needs to be further clarified. The same type of experimental set-up could serve this purpose.

A flow of solution under the disbonded coating produce large corrosion rates. In this study, the potentials attained with a flow of aerated solution were much higher (-400 to –200 mV_{sce}) than the potentials under a disbonded coating permeable to oxygen (-700 mV_{sce}).
However, the corrosion rates measured are in the same range whether corrosion is due to oxygen permeation (0.3 to 0.5 mm/y) or to a flow of solution (up to 0.4 mm/y). These figures are similar to other data or defects with a flow [3].

The corrosion we observed under disbonded coatings was never homogeneous, but local with the shape of craters or corroded patches. A number of factors may explain this: crevice gap, local flow, concentration of corrosion products, precipitation and the resulting local pH, local currents etc.

The data collected in this study could be used in models to assess corrosion rate in the longer-term [4].

6. Conclusion and future work

With the conditions selected for the tests performed, it was possible to simulate correctly situations encountered on site. The results provided detailed information. The experimental set-up proved convenient.

If the coating is impermeable to oxygen, and if there is no circulation of solution, corrosion under long disbonding defects in the coating eventually comes to a stop after some time, even very far away from the opening of the defect.
This is attributed to two major factors : the progressive consumption of all the oxygen present due to the penetration of the CP and to diffusion of oxygen from the crevice tip, and the progressive alkalinisation of all the solution under the disbonding due to diffusion of the alkaline solution near the mouth. In our tests, this took a certain time (up to 20 days depending on the conductivity of the solution). Before stabilisation, local corrosion events can occur temporarily, because of local pH changes due to hydrolysis and precipitation of corrosion products, obstacles to oxygen diffusion, local anodic polarisation etc.

When there is circulation or frequent purges of the solution in the defect, high instantaneous corrosion rates are immediately observed. Figures of the order of 0.4 mm/y were measured. These figures are similar to other data from the literature [3].

If the coating is permeable to oxygen and makes an obstacle to cathodic protection, significant corrosion was observed. Only the zone close to the disbonding opening was finally protected and saw its pH rise after about fifteen days. Further down into the crevice, the potentials never reached the typical protection level of –800 mV_{sce}. In addition, sizeable anodic coupling current densities were measured which caused local corrosion in the range of 0.3 to 0.5 mm/y in the conditions of our tests.

The definite importance of the nature of the polymer coating is underlined. Polyethylene is typically permeable to oxygen. Unfortunately, polyethylene was extensively used at a time (between 1954 and 1995 [10]) for factory coating and as tape for repair at the girth welds. It is only recently that these tapes were modified for lower oxygen permeability.

Tracing the use of oxygen permeable tapes and coatings is one tool for managing the problem of corrosion at disbondings of buried pipelines under cathodic protection. Measurement of oxygen permeability is now part of our routine for on-site examination procedure.

More work is needed to clarify the significance of the often observed ferrous carbonate deposits and of modifications of the local chemistry under disbonded coatings.
More work is also necessary to clarify the reasons and sequences of local anodic polarisation on some zones inside the disbonded crevice. More experiments using basically the same test set up could help for this.

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