Simulation of cathodic disbonding of protective coatings. Review

S. O. Osadchuk*, L. I. Nyrkova

E.O. Paton Electric Welding Institute of National Academy of Sciences of Ukraine;
11, Kazymyr Malevych Str., Kyiv-150, 03150, Ukraine

Abstract

A review of the literature on the modeling of cathodic disbondment of protective coatings, which is an important characteristic of coatings, as well as methods of its study, is carried out. To study the disbondment mechanism of coatings in real conditions, models of installations have been developed, in which the influence of various factors in the electrolyte volume are taken into account, such as environment (with different pH, oxygen and carbon dioxide containing), the level of cathodic polarization, configuration, and size of an artificial defect, etc. Modeling of the conditions of thin-film corrosion under disbonded coating, typical for underground pipelines with complex protection, is promising.

Keywords: *cathodic disbondment modeling, cathodic polarization, coating degradation, protective potential.*

Introduction

Currently, corrosion under protective coatings remains one of the main causes affecting the integrity of underground pipelines [1] and requiring their protection through the integrated use of new technologies and materials, scientific research, and the development of new engineering solutions [2]. Comprehensive protection using cathodic polarization and coatings is recommended for inhibiting external corrosion of underground pipelines and structures. However, during operation, the coatings can disbond off from the pipe surface, which is accompanied by the formation of a gap between the coating and the pipe [3].

For pipelines with a protective coating under cathodic protection conditions, disbondment is recognized as the main cause of coating degradation affecting the safe operation of the pipeline. An in-depth understanding of the mechanism of cathodic disbonding, a reliable assessment of the resistance of the coating to disbonding, as well as adequate control of the level of cathodic protection will minimize its negative impact and ensure the long-term integrity of the pipeline [4]. The destruction of the coatings of underground pipelines usually occurs at defects [5].

The ability to resist degradation is the main operational property of coatings that affects the corrosion state of pipelines [6].

Based on the results of surface diagnostics, it has been established that corrosion or stress corrosion cracking (SCC) can occur under a disbonding coating

with effective cathodic protection of the pipeline. Insufficient coating stability is a major factor contributing to the susceptibility of an underground pipeline to corrosion and SCC. NACE RP-0169 lists the recommended characteristics of coatings, including the ability to resist the development of defects and maintain a constant resistance over time [6].

A significant part of external corrosion and stress corrosion cracking is observed precisely under disbonded coatings. When choosing the type of coating used for repairs, one should take into account the typical mechanisms of their destruction in various environmental conditions, as well as the compatibility of various types with cathodic protection [7], which is especially important in extreme operating conditions [8], in particular, in mountainous and seismic conditions. The pipe industry uses different types of steel, such as high-strength X80 to X120, which can behave differently under coatings compared to conventional low-carbon steels. In addition, there is evidence [9] that sandblasting of different types of steel leads to different base profiles, which will also affect cathodic disbondment.

The disbonding of the coating promotes the penetration of the corrosive environment to the steel surface, as a result of which the cathodic protection currents do not reach the surface under the coating. Therefore, the control of degradation of the coatings of cathodically protected pipelines is decisive for ensuring their durability [1]. To study the mechanism of cathodic disbondment of coatings and corrosion processes under the coating, the understanding of the physicochemical foundations of the process of cathodic disbondment is relevant. Therefore, the purpose of the work was to review and analyze modern methods for modeling the cathodic disbondment of protective coatings for main pipelines.

* Corresponding author:
 svetlanaosadchuk@meta.ua

Control of cathodic disbondment of protective coatings

Variations of the cathodic disbondment method have been developed over the past two decades to provide guidance on the selection of coating systems for pipelines [4]. The cathodic disbondment test provides information on the susceptibility of the coating to loss of adhesion due to cathodic polarization [10]. The most widely used standard laboratory test method is to evaluate the resistance of coatings to cathodic disbondment. However, this test is an ex situ laboratory test method that has a limitation in accurately predicting the behavior of cathodic disbondment in the field due to human error and uncertainty in testing conditions and parameters.

Electrochemical impedance spectroscopy is an electrochemical method for studying the coating/metal interface, but is not effective for monitoring long-term cathodic disbondment. Local electrochemical impedance spectroscopy, scanning Kelvin probe and scanning acoustic microscopy can provide information about the state of the coating/metal interface at a local point, as well as quantify the characteristics of the metal surface under the protective coating at that location. However, these methods have limitations when measuring the cathodic disbondment of thick coatings. The method of scanning acoustic microscopy allows visualizing the area of disbondment both in situ and ex situ, but is used only to study thin coatings. It should also be noted that all scanning methods are more suitable for laboratory measurements than for field measurements. A new approach is known based on in situ electrochemical measurements (current, potential and impedance) and monitoring of cathodic disbondment of various thicknesses coatings during cathodic protection using a multi-electrode sensor, the electrodes of which are pressed into the polymer matrix of wires. The use of a cassette of several plates as a working electrode facilitated the collection of data and recognition of information about the non-disbonded coating and defects, which suggests the prospects for its practical application for field monitoring [1].

It is reported [7] that the improvement of the electromagnetic acoustic transducer in the technology of monitoring the linear part of pipelines made it possible to find places of coatings` disbondment without pitting and assess their condition. Based on the joint analysis of information received from the operating organization and the organization conducting the survey, it is possible to clarify the type of coating, as well as the conditions of application (field, repair, etc.).

Therefore, these methods are used to assess the state of coatings in modeling processes under a disbonded coating.

Standard requirements for test conditions

One of the requirements for the outer coatings is resistance to disbondment from the effects of cathodic polarization. Cathodic disbondment is the loss of adhesion between the coating and the surface caused by cathodic reaction products (NASE SP0169-2007, section 2) [11]. If there is a defect in the protective coating, the unprotected surface is affected by the environment (NASE SP0169-2007, section 2) [11]. During operation, it is not recommended to use polarization potentials more negative than -850 mV for the cathodic polarization of pipelines during operation under pressure and under conditions conducive to stress corrosion cracking (NASE SP0169-2007, clause 6.2.2.3.2) [11]. It is also noted that excessive polarization potentials should be avoided to minimize cathodic disbondment of the coating (NASE SP0169-2007, clause 6.2.2.3.3) [11]. Unfortunately, today there is no generally accepted standard for testing for cathodic disbondment [12].

The paper [13] analyzes the conditions that are used when testing for cathodic disbondment and are used in the USA, the European Union, France, Germany, Saudi Arabia, China, Canada, Australia, New Zealand and other countries, as well as in Ukraine, Table 1.

For example, a basic cathodic disbondment test of coatings at 65 °C for 28 days based on liquid two-component epoxy materials with a thickness of 800 and 900 microns, respectively, showed that under the same temperature conditions and duration, the results differ: when tested according to the Australian AS/NZS 4352 disbondment radius is approximately 15-20 % smaller than when tested according to ASTM G95 and ISO 15711 due to different testing approaches (Table 1). Consequently, the requirements of the standards differ in their approaches to the level of cathodic polarization, test duration, and sample holding temperature.

**Methods for studying cathodic disbondment**

Modeling of cathodic disbondment is associated with modeling of environmental conditions, the level of cathodic polarization, the size of an artificial defect in a coating on a steel base, and other parameters.

To study the cathodic disbondment of coatings in laboratory conditions there are used cells with a solution of 3 % NaCl or with a model ground electrolyte, and an artificial metal defect is performed in the coating. The scheme of such a cell is shown in Fig. 1 [12].

The paper [23] describes the cathodic disbondment of a polyester coating at room temperature according to ASTM G95. In this work, we considered a defect formed in the coating after impact testing instead of an artificially made defect by drilling. The polarization potential was -3.0 V relative to the calomel reference electrode. Cells for cathodic disbondment of the coating are shown in Fig. 2, *a*, and the appearance of the coating to disbondment – in Fig. 2 *b*. Evidence of degradation of the polyester matrix, including outside the impact area, is illustrated in Fig. 2, *c*. After exposure to cathodic polarization for 30 days, there were formed defects in the carbon fiber of the matrix (Fig. 2, *e*). The tested composites showed the susceptibility of the polymer matrix to cathodic disbondment and its degradation in an alkaline medium. Carbon fiber is electrically conductive, and carbon fiber composites, if they are not sufficiently isolated from the metal surface, are subject to degradation on the entire surface in contact with the solution [23].

Table 1 – Test conditions by the method of cathodic disbondment [13]

Standard	Potential, V	Current, mA	Temperature, °C	Test solution	Duration, day
CSA-Z245.20 [14]	-1.5 to -3.5	–	Depending on the conditions of use	3 % NaCl	Depending on the conditions of use
ASTM G8 [15]	-1.5	–	Room temperature	1 % NaCl, 1 % Na_2SO_4, 1 % Na_2CO_3	Depending on the conditions of use
ASTM G42 [16]	-1.5	–	Depending on the conditions of use	1 % NaCl, 1 % Na_2SO_4, 1 % Na_2CO_3	30
ASTM G80 [17]	-1.5	–	Room temperature	1 % NaCl, 1 % Na_2SO_4, 1 % Na_2CO_3	60
ASTM G95 [18]	-3.0	–	Room temperature	3 % NaCl	90
ISO 15711 [19]	-1.05	–	Room temperature	Sea water	182
AS 3862 [20]	-	3	Depending on the conditions of use	3 % NaCl	Depending on the conditions of use
NF A 49-711 [21]	-1.5	–	Depending on the conditions of use	3 % NaCl	Depending on the conditions of use
DSTU 2419 [22]	-1.5	–	Room and maximum operating temperature	3 % NaCl	30
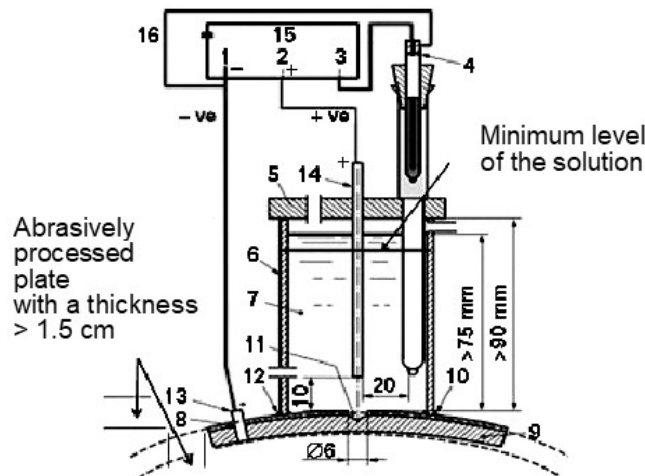
*1 – terminal for connecting the operating electrode; 2 – terminal for anode connection;
3 – terminal for connecting the reference electrode; 4 – reference electrode; 5 – plastic coating;
6 – plastic pipe with a diameter of at least 75 mm; 7 – electrolyte with a volume of at least 300 ml;
8 – coating; 9 – steel base; 10, 12 – sealant; 11 – artificial defect in the coating; 14 – platinum electrode
with a diameter of 0.8 to 1.0 mm; 15 – DC rectifier; 16 – power supply [12]*

Figure 1 – Scheme of a cell for cathodic disbondment

To study the disbondment of a polyethylene coating and control the properties of the medium under the disbonded coating, the authors of [24] proposed an installation, the scheme of which is shown in Fig. 3.

In the simulated gap between the steel surface of the pipe and a plate of polymethyl methacrylate, which simulates the disbondment of pipeline coatings under cathodic protection (Fig. 4), a new combined microelectrode based on an iridium pH microelectrode and a silver chloride concentration electrode was developed for simultaneous control of steel potential, pH and chlorine concentration. The results showed that under cathodic polarization, the local environment under the non-disbonded coating was characterized by a
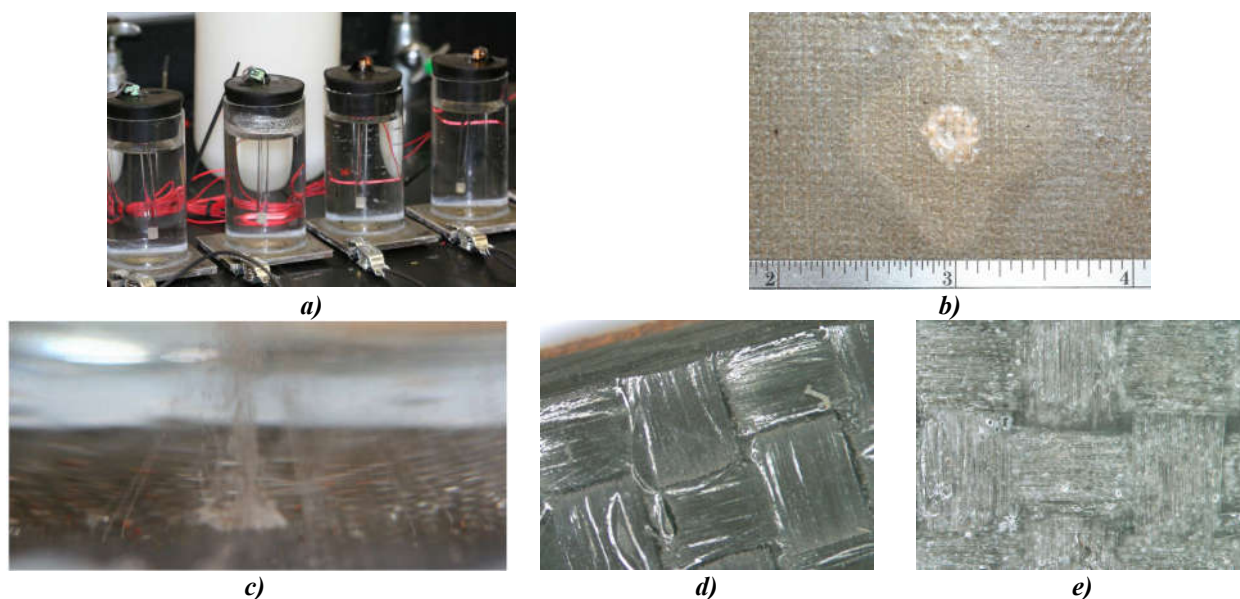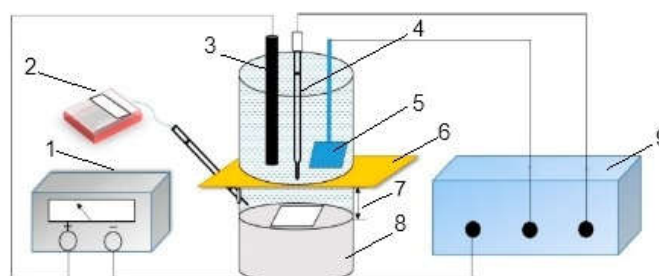
Figure 2 – Photo of cells for cathodic disbondment of a polyester coating (*a*), appearance of the coating for testing (*b*), degradation of the polyester matrix during cathodic polarization (*c*), appearance of carbon fiber before (*d*) and after (*e*) exposure to cathodic polarization within 30 days [23]


1 – power supply; 2 – micro pH meter; 3 – graphite electrode; 4 – silver chloride reference electrode;
5 – platinum electrode; 6 – coating; 7 – disbondment area; 8 – working electrode (steel base); 9 – potentiostat [24]

Figure 3 – Schematic diagram of the experimental setup for cathodic disbondment of coatings and control of the solution under the coating
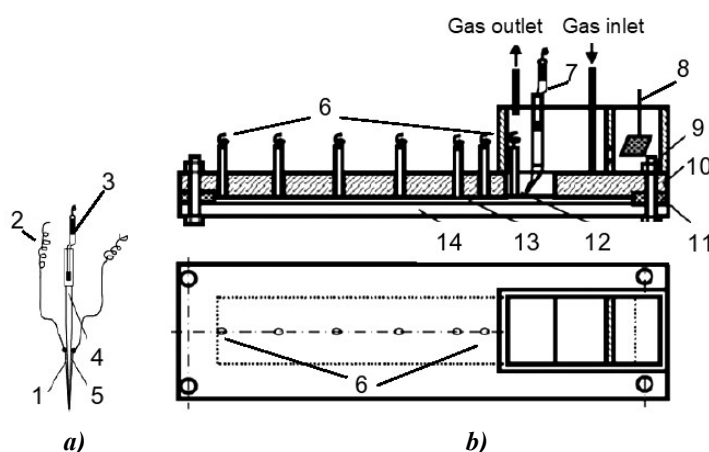
1 – iridium electrode for measuring pH; 2 – connecting wires of electrodes; 3, 5, 7 – silver chloride reference electrode; 4 – the Luggin capillary; 6 – holes for measurement; 8 – auxiliary platinum electrode; 9 – bolted connection; 10 – coating; 11 – sealant; 12 – hole; 13 – gap; 14 – steel plate [3]

Figure 4 – Schemes of a combined microelectrode for the simultaneous determination of the steel potential, pH and Cl$_2$ concentration (a) and an electrochemical cell simulating a gap under a disbondment coating on pipe steel (b)
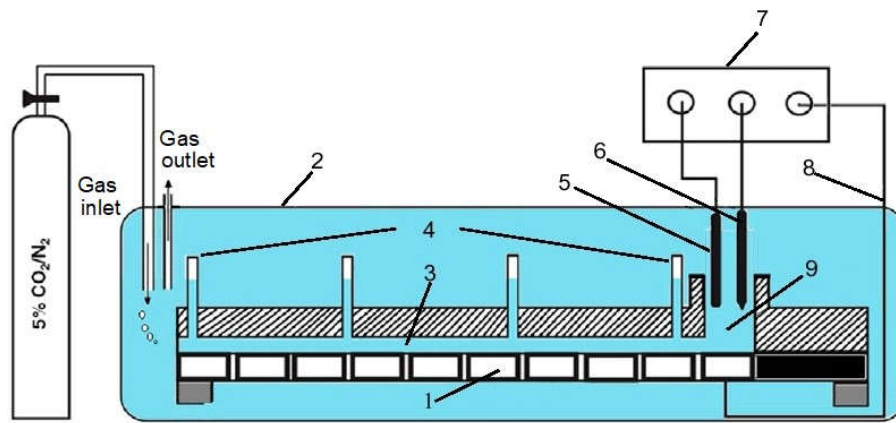
1 – corrosion coupons; 2 – container; 3 – the area of modeling the disbondment of the coating;
4 – holes for measurement; 5 – auxiliary electrode; 6 – silver chloride reference electrode;
7 – rectifier; 8 – insulated wire; 9 – the mouth of the gap [25]

Figure 5 – Scheme of a cell for studying corrosion under a simulated disbondment coating

high pH value and the presence of Cl_2. The local current at the far end of the slot was only 5 % of the current at the open surface. According to the authors of [3], cathodic polarization contributed to a change in the composition of the local medium under the disbondment coating: pH increased and the concentration of chloride ions decreased, which led to a decrease in the corrosion rate and passivation of the pipeline surface. In the cell, the local medium retained its properties for a certain time after the cathodic polarization was turned off [3].

To simulate the disbonding of the coating, a cell was used in which 10 corrosion coupons were placed (Fig. 5). To maintain an anaerobic environment, the coupons were immersed in a simulated soil solution, through which a mixture of 5 % CO_2 + 95 % N_2 was blown and the cathodic polarization of -0.87 V relative to the calomel reference electrode was brought [25]. This made it possible to study corrosion under a simulated disbonded coating of dissimilar joints welded by the method of manual shielded metal arc welding with a consumable electrode (SMAW) of pipelines made of X42 steel and steel designated as grade B [25]. It is shown that by reducing the heat input from 0.74 to 0.61 kJ/mm, the corrosion rate on the weld fusion line has increased. This was explained by the formation of phases, the presence of which contributes to an increase in the corrosion rate (for example, Widmanstätten and acicular ferrite). It was also noted that the corrosion rate decreased in the series: weld → heat-affected zone → base metal. With such heat input during welding, the corrosion rate of welded *dissimilar* joints made of X42 steel and grade B was higher than that of welded specimens from *homogeneous* metals, which is possibly due to a slight galvanic effect between X42 steel and grade B steel.

The test setup [26], which makes it possible to investigate the synergistic effects of strip coating disbondment, cathodic protection, and low-cycle loading, is used to determine the effect of oxygen in a solution with neutral pH on the development of a corrosion crack (Fig. 6).
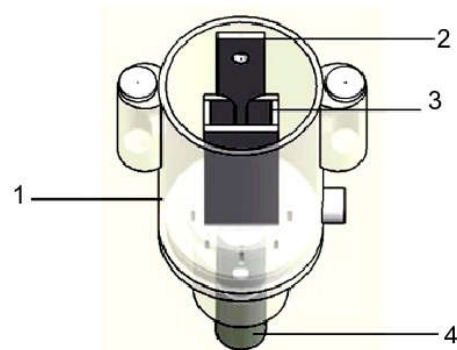
1 – cell containing a model solution; 2 – specimen;
3 – internal cell simulating the disbondment of the coating;
4 – fastening of the specimen to the machine [26]

Figure 6 – Scheme of a test setup for studying the disbondment of a strip coating under conditions of cathodic protection and low-cycle loading

It is shown in [26] that after low-cycle tests for corrosion fatigue in a solution of the composition $MgSO_4 \cdot 7H_2O$ – 0.0274 g/l; $CaCl_2$ – 0.0255 g/l; KCl – 0.0035 g/l; $NaHCO_3$ – 0.0195 g/l; $CaCO_3$ – 0.0606 g/l surface microcracks occur in areas under the simulated disbondment of the band coating in the area with insufficient cathodic polarization, and not in remote areas to which cathodic polarization does not reach, as it is commonly believed. The presence of 1 % oxygen in the composition of the gas has a double effect on the initiation of a crack during simulated disbonding of the band coating. On the one hand, this increases the size of surface microcracks that start on the steel surface in places with insufficient cathodic polarization, and on the other hand, it reduces the number of surface microcracks in areas where cathodic polarization does not reach at all due to an increase in the surface area of the metal affected by general corrosion [26].

The influence of the size of the gap under the disbonded coating on corrosion and the electrochemical state of the pipeline made of X52 steel under cathodic protection was studied [27]. Disbondment of the coating

was simulated with gap sizes of 5, 3, and 1 mm, as well as a gap with a slope coefficient of 5/1 (5 mm at the open mouth and 1 mm at the far end). Different levels of cathodic polarization of the base metal during the simulated disbondment of the coating were carried out using a three-electrode circuit. pH and potential were recorded under the disbonded coating at different distances and at different time intervals. The results showed that in the area of disbondment, depending on the level of the cathodic polarization potential and the size of the gap, the corrosion and electrochemical conditions on the surface of the pipeline can change. In a smaller gap, a lower pH level and a higher cathodic polarization were observed. However, with a gap width of less than 1.6 mm, despite effective cathodic protection, acceleration of corrosion was noted, which was due to the gap effect.

It is noted that over the past 20 years, many studies have been carried out with the aim of reproducing stress corrosion cracking in high-strength low-alloy pipe steel in laboratory conditions. Most of these studies were carried out in solutions. However, such studies do not take into account the features of a thin-layer electrolyte under a non-disbonded coating, which is recognized as one of the main factors in a corrosive environment that affects stress corrosion cracking [28]. Paper [28] studied stress corrosion cracking of API X80 pipe steel under a non-disbonded coating with a defect in an acidic ground solution. The imitation of the coating disbondment was carried out in a specially designed chamber in the form of a slot, into which there were simultaneously placed several specimens fixed on the frame. To control the local electrochemical process during disbonding, there was used electrochemical impedance spectroscopy. The local parameters of the medium (potential and pH) were controlled by microelectrodes. The surface morphology of the specimens indicated that the corrosion intensity of X80 steel decreased as it was separated from the defect. Intense anodic dissolution and initiation of microcracks dominated in the region of defect opening, while corrosion was noticeably slowed down under a non-disbonded coating. It was proposed to determine the CO_2 gradient [28] as one of the SCC factors when studying the mechanisms of corrosion during coating disbonding.

The results of study of the cathode current efficiency on a stand simulating a disbonded coating are presented in [29]. A cylindrical specimens was used to simulate the surface of a disbonded pipe under the coating. Heterogeneity was artificially created on the specimen surface by means of milled grooves and galvanic pairs created by pressing dissimilar metals into the specimen surface. A steel specimen was placed in a polymer shell made of a polyethylene pipe with a simulated underfilm electrolyte (3 % KCl). The shell provides a place for the cathodic protection current to flow into the shell cavity, in which a semi-permeable membrane is installed, impervious to a corrosive environment, but permeable to electric current through capillaries. The measurement of the polarization potential under the surface of the shell was carried out according to the scheme shown in Fig. 7. Potentials were measured with respect to a silver chloride reference electrode 1 sequentially transferred to measuring cells 4. A steel specimen was connected to a controlled DC source and cathodically polarized in a 1 % NaCl solution relative to the steel anode.
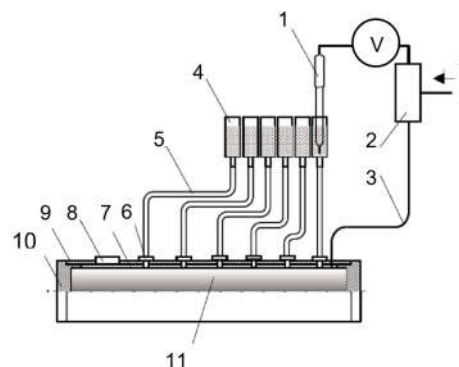
1 – reference electrode; 2 – switching block; 3 – power wire; 4 – measuring cell; 5 – salt bridge; 6 – capillary; 7 – corrosive environment; 8 – plug; 9 – polymer shell; 10 – coating; 11 – steel specimen

Figure 7 – Scheme for measuring the polarization potential under the surface of the polymer shell [29]

Increasing the cathode current step by step, there was measured the potential at points located at different distances from the defect. Based on the obtained results, charts were built illustrating the distribution of the polarization potential in the simulated disbondment defect. There is proposed the distribution law of the polarization potential under the insulating coating:

$$U_n = (a\, L_n(L)+b)I +U ,$$

where *a* and *b* are experimentally determined coefficients for specific conditions; *L* is the distance between the through defect in the insulating coating and the measurement point in the defect zone, m; *I* is the supplied current mA; *U* is the potential of the pipeline, V.

The paper [30] presents the results of laboratory tests of the state of a cathodically protected steel surface, polarized from an external current source, in a cell under a disbonded coating. For this, laboratory cells were used, in which there were reproduced the conditions of an underground steel pipeline. The cells were filled with ground water with a resistivity of 3.05 to 4.4 ohm·cm. The steel potential and pH were measured during the experiment at different points of the gap under the disbonded coating under cathodic polarization conditions. The advantages of using pulsed current compared to direct current were studied. It was shown that the use of low voltage did not allow sufficient polarization of the steel surface in the cell, since an increase in voltage accelerated the release of hydrogen, which blocked the penetration of the cathode current into the slot. Optimum polarization modes were chosen: a) pulsed current with a frequency of 1 Hz and at a controlled voltage from 15 to 20 V; b) direct current at a voltage of 15 V to 20 V. The use of both modes provided satisfactory protection of the steel pipe in the model soil. To provide cathodic protection in the conductive medium in the cell, a protective potential

was determined that satisfied the protection against corrosion, but in this case, the solution was depleted of oxygen in the depth of the cell, the pH in the cell increased, and steel was passivated in an alkaline medium [30].

Since stress corrosion cracking is initiated in a thin layer of electrolyte under a disbonded coating under cathodic protection, the change in the properties of this electrolyte (potential, pH, etc.) was studied in [31]. Studies were carried out on pipe steel under disbonded coatings using a microelectrode in a simulated cell at different levels of cathodic polarization and different concentrations of CO_2 and O_2 [31]. The results showed that the pH of the electrolyte ranged from almost neutral to 12 depending on the cathodic polarization current and CO_2 content. With cathodic polarization, pH rises, but at high CO_2 content, areas with almost neutral pH can exist under the coating. The efficiency of cathodic polarization and the protective effect can be indirectly estimated from the pH level in a thin electrolyte film under disbonded coatings [31].

Also of interest is the original model of a base with a coating in the form of a ball [32], which is implemented for laboratory conditions, the advantage of which is that the potential at each point is almost the same under cathodic polarization. On the basis of the model, there were carried out long-term studies of the bitumen coating under the influence of cathodic polarization.

To test the coating for cathodic disbonding at elevated temperatures, there was proposed a cell with separated anode and cathode spaces, with electrolyte reduction or circulation [33]. A steel plate with a heated coating is the base of the cell. An epoxy coating of various thicknesses applied to steel after shot blasting of the surface and the formation of a conversion sublayer was tested at temperatures of 20, 45, 65 and 85 °C for 7-35 days at a cathodic polarization of -1.5 V relative to NCE (normal calomel electrode), in different electrolytes. It has been found that disbonding accelerates with an increase in temperature and duration of tests, a decrease in the thickness of the coating, and also in the absence of a conversion sublayer. An assumption is made about the effect of diffusion of solution components through the coating. It has been noted that cathodic disbonding at elevated temperatures cannot be unambiguously judged on the basis of data obtained at room temperature.

In [34], it is indicated that models that reproduce the conditions under the coating usually have drawbacks. For example, one of them considers a series of reactions: corrosion of iron, reduction of oxygen, and reduction of water with evolution of hydrogen. Some models consider CO_2/bicarbonate/carbonate reactions and precipitation reactions ($FeCO_3$, iron oxides), but the presence or absence of Na^+ or Ca^{2+} ions in groundwater is not discussed. The reduction of oxygen in neutral solutions with free access of oxygen is controlled by its diffusion and does not depend on the potential. In some models, concentrations and diffusion coefficients are assumed to be constant, which is a simplification. More recent studies attempt to apply variable and local oxygen concentrations. Cathodic protection is studied at different current densities and potentials at the mouth of the slot. Newer models are adapted to select a large number of components with their thermodynamic parameters and concentrations.

The models can take into account precipitation and hydrolysis reactions, their effect on pH, data on corrosion rates, analysis of ion transport in all directions, as well as oxygen permeability through the coating. In one of the researches, to explain stress corrosion cracking, there were used models in which local metal damage was determined for a sufficiently long time (10 years or more). For this, the rates of reactions (corrosion, reduction of hydrogen, reduction of oxygen) were considered constant contradictory values.

It is noted in [35] that the disbonding of coatings from surfaces occurs at defects under the influence of cathodic protection. The disbondment resistance testing is carried out in accordance with current standards for 24 hours or 28 days at 23 and 65 °C. Different researchers use different test duration and evaluation criteria: as a rule, the diameter of an artificial defect is 5 mm for a 24-hour test and 10 mm for a 28-day test [35]. According to DSTU 4219 [22], the diameter of an artificial defect is 6 mm, and the test duration is 30 days at room temperature or at the maximum operating temperature of the coating. Approaches to the choice of testing duration and deviations from the evaluation criteria are within 50 % and therefore remain not entirely clear, so the test results are checked by mathematical methods [35].

In [36], it is shown by mathematical modeling that the current density J_p is concentrated along the perimeter of the damage area (Fig. 8). If this area is large, then J_p is relatively small inside it and increases sharply when approaching the edges (Fig. 8 b). The potential U_p on the damage surface along its perimeter is close to zero and increases in absolute value with approaching the damage center. On a small area, damage J_p changes relatively smoothly.

In [37], an example of numerical simulation for the analysis of the integrity of the pipeline is presented, in which, there is performed a nonlinear stress analysis using the finite element method taking into account the corrosion state of the pipe and the distribution of potentials in the aquatic environment under the disbonded coating of the pipeline. According to the simulation results, the test temperature of 25 °C and 50 °C does not greatly affect the geometry of corrosion defects formed within 3 years. Conversely, the level of cathodic polarization and the change in pH (6.7–8.5) contribute to a significant change in the profiles of corrosion pits, reaching 3 mm. A shift in the cathode potential by 0.25 V, combined with an increase in the disbonding radius by 0.5 mm, reduces the depth of corrosion defects by almost 30 %. The results of determining the geometry of corrosion defects are used to check the stress and evaluate the burst pressure. In addition, non-linear elastoplastic stress analysis is performed using shell elements to predict the burst pressure of corroded pipes. The presence of corrosion
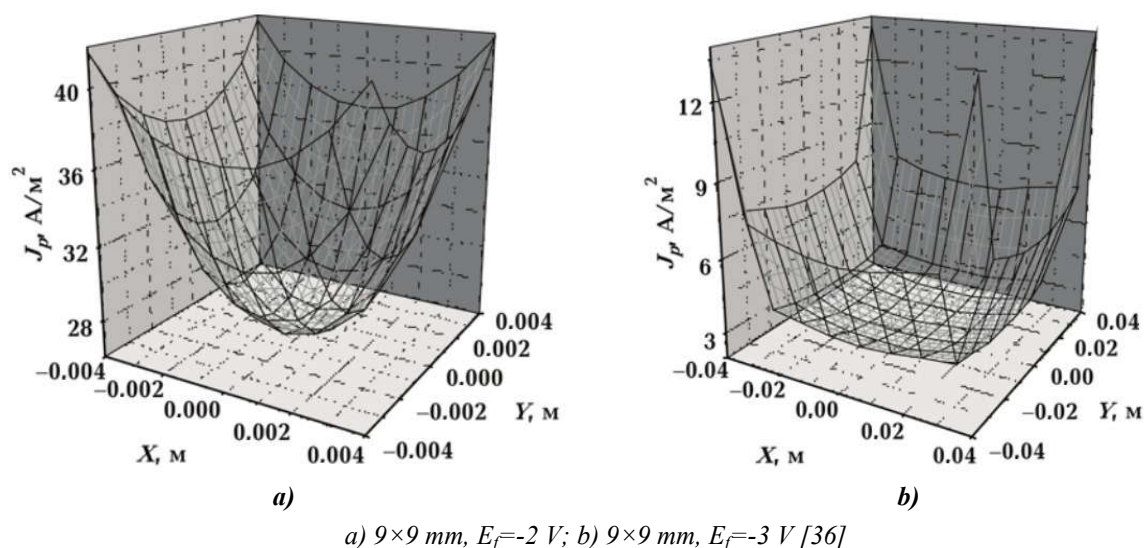
a) 9×9 mm, E_f=-2 V; b) 9×9 mm, E_f=-3 V [36]

Figure 8 – Change in current density on the damage surface with an area

damage is modeled by a decrease in the rigidity of the damaged element, which has the size of the defect. The predicted burst pressure is in good agreement with the pressure obtained from the experimental formula.

In [38], there was studied the effect of an alternating stray current on the efficiency of epoxy coating disbonding by impedance spectroscopy at elevated temperatures. If the disbondment reaches a critical size, the metal surface will corrode. Disbonding mainly occurs due to cathodic hydrogen evolution and crevice corrosion. Since the induction of a stray alternating current accelerates the anodic reaction, the contribution of the anodic reaction to disbonding may increase. Thus, the disbonding rate increases and the degree of cathodic degradation of the epoxy coating also grows with increasing current.

Conclusions

The ability to resist degradation is the main operational property of coatings that affects the external corrosion of main pipelines, including stress corrosion cracking. Important characteristics of coatings are resistance to cathodic disbonding and maintaining a constant resistance over time.

For comparative testing of coatings by cathodic disbonding, there are applied standard test conditions. Test conditions according to standards of different countries differ both in potential values (from -1.5 to -3.5 V), and in the composition of solutions and exposure time (from 28 to 90 days or depending on the conditions of use). This affects the assessment of disbonding: the discrepancy between the results is within 20 % or more.

To study the mechanism of coatings disbonding in real conditions, there have been developed installations, the study of which takes into account the influence of media, the content of oxygen and carbon gas, the level of cathodic polarization, the geometry and size of an artificial defect, etc. The tests simulating the conditions of thin-film corrosion under a disbonded coating, which is typical for underground pipelines with integrated anti-

corrosion protection, are of practical value. To control changes in the properties of coatings, the following methods are used: control of cathodic disbonding, electrochemical impedance spectroscopy, local electrochemical impedance spectroscopy, scanning Kelvin probe, scanning acoustic microscopy.

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Моделювання катодного відшарування захисних покривів. Огляд

С. О. Осадчук, Л. І. Ниркова

Інститут елекозварювання ім. Е. О. Патона НАН України;
вул. Казимира Малевича, 11, Київ-150, 03150, Україна

Проведено огляд літератури щодо моделювання катодного відшарування захисних покривів, яке є важливою характеристикою покривів, а також методів його дослідження. Для вивчення механізму відшарування покривів в реальних умовах розроблені моделі установок з урахуванням впливу різних чинників в об'ємі електроліту: середовищ (з різним рН, що містять кисень, вуглекислий газ), рівня катодної поляризації, форми та розміру штучного дефекту тощо. Перспективним є моделювання умов тонкоплівкової корозії під відшарованим покривом, що характерне для підземних трубопроводів з комплексним захистом.

Ключові слова: *деградація покриву, захисний потенціал, катодна поляризація, моделювання катодного відшарування.*