



## Review

## Techniques for testing and monitoring the cathodic disbondment of organic coatings: An overview of major obstacles and innovations



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## ARTICLE INFO

## Article history:

Received 15 August 2016

Received in revised form

26 November 2016

Accepted 27 November 2016

## Keywords:

Coatings

Cathodic disbondment

Assessment techniques

Monitoring techniques

Electrochemical measurements

Scanning methods

## ABSTRACT

Coatings in conjunction with cathodic protection (CP) have been widely used for protecting buried metallic structures such as steel pipelines against corrosion. A drawback of the combined use of these two techniques is cathodic disbondment of coatings, i.e. the loss of adhesion between a coating and its metal substrate due to the products of cathodic reactions that take place at the coating and metal interface. Disbonded coatings provide easy lateral paths for corrosive species to reach the metal surface while simultaneously shielding cathodic protection currents from reaching the metal substrate. Currently, corrosion under disbonded coatings remains as a major issue affecting the integrity of civil and industrial infrastructures such as buried pipelines; therefore the ability of testing and monitoring coating disbondment is important for ensuring the durability of these infrastructures. This paper provides an overview of major innovative efforts made over the past several decades to overcome technical obstacles in testing and monitoring the cathodic disbondment of coatings. The limitations of various techniques including the standard cathodic disbondment test (CD test), electrochemical impedance spectroscopy (EIS), localized electrochemical spectroscopy (LEIS), scanning Kelvin probe (SKP) and scanning acoustic microscopy (SAM), have been critically reviewed. The recent application of multi-electrode array method has been discussed to illustrate an innovative approach aimed at addressing major difficulties in the in situ measurement and monitoring of cathodic disbondment of coatings.

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## 1. Introduction

Organic coatings protect the underlying metallic substrate against corrosion by acting as a barrier to corrosive species such

as water, ions, and, oxygen. Unfortunately, coatings might contain defects and could degrade or disbond under some complex environmental conditions which results in forming pathways for corrosive species to reach metal substrate. Coating disbondment has been widely reported in the literatures. There are various ways that the coating could disbond from a metal substrate such as, (i) blistering, (ii) anodic undermining, and, (iii) cathodic disbond-

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ment. Coating's blistering is a common form of localized adhesion loss which happens through various mechanisms such as coating's swelling and volume expansion due to water absorption, gas inclusion, electroosmotic, and, osmotic influences [1,2]. Anodic undermining occurs when corrosion reactions beneath an organic coating are the major reason for separation of coating from metal surface [1–4]. Cathodic disbondment is a more important and common form of coating disbondment that occurs frequently on coated metal structures protected by cathodic potential. When the coated metal is exposed to CP potential, the products of CP induced oxygen reduction or hydrogen evolution reactions such as hydroxyl ions, hydrogen gas and short lived superoxide intermediates could form at coating's defect sites. These products are believed to cause cathodic disbondment of coatings either through dissolving metal oxide layer, saponification of polymer coating, or displacing the coating at metal/coating interface [1,5–9].

Cathodic disbondment is one of the most significant failure modes of coatings used for protecting civil and industrial infrastructures such as buried metallic structures [10]; and it can promote general and localized corrosion on metal surface under disbonded coatings due to a phenomenon usually referred to as cathodic shielding [6,11–16]. Cathodic disbondment provides a lateral pathway for the access of corrosive solution to metal surface and at the same time, is considered to limit the access of CP currents to metal surface at the disbonded area. Consequently, corrosion under disbonded coatings represents one of the 'worst case scenario' corrosion problems in various industries such as the pipeline industry.

Practical methods for avoiding corrosion issues related to cathodic disbondment of coatings include (i) to pre-assess the cathodic disbondment resistance of coatings; and (ii) to perform in situ monitoring of the cathodic disbondment of coatings. Pre-assessment of coatings can assist the appropriate selection of coatings, while monitoring can assist the maintenance and CP level control of coated metal structures. Techniques that are able to perform accurate assessment of coating's cathodic disbondment resistance, and to carry out in situ monitoring of cathodic disbondment would be an essential needs. The ability to measure cathodic disbondment is also important for achieving a mechanistic understanding of the phenomenon. The purpose of this paper is to critically review the state of the art methodologies for measuring, testing and monitoring cathodic disbondment of coatings, with particular focus on recent innovations made to overcome major technical barriers for assessing and evaluating the cathodic disbondment.

## 2. Major techniques used for testing and monitoring cathodic disbondment

Traditional methods of evaluating cathodic disbondment of coatings have been based on the excavation and visual inspection of coated metal structures such as buried pipelines. This is a useful, but an expensive and laborious way of inspecting and evaluating coating disbondment. A more effective and common approach to minimizing the excavation costs and structural failure risks is to perform laboratory tests for pre-assessing coating's resistance against cathodic disbondment before being applied on metallic structures.

### 2.1. Standard cathodic disbondment (CD) tests

Currently the most widely used laboratory testing method for pre-assessing coating's ability to resist the cathodic disbondment is standard cathodic disbondment tests (CD tests). These test methods are based on ex situ observation of test samples subjected to the accelerated CD test conditions after a specific time. There are

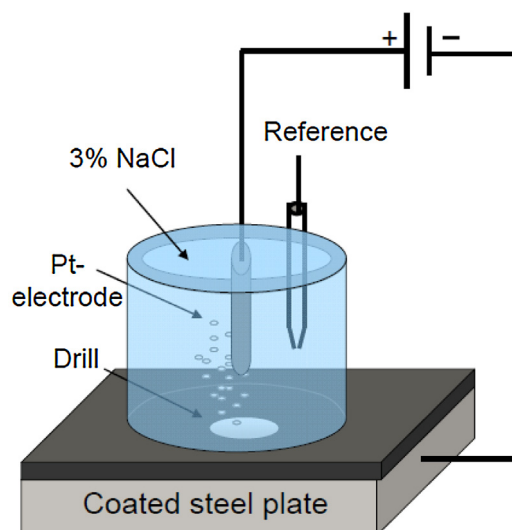


Fig. 1. Schematic of CD test set up [20].

variations of standard CD tests such as those described in AS4352 [17], ASTM G8-96 [18] and ISO15711 [19], however, in general, the test requires a coated sample with an artificial defect exposed to a test solution at a selected temperature under an applied constant current or a constant potential. The schematic of the test set up is shown in Fig. 1. After a certain time of exposure, the sample is removed from the test cell and the radial disbondment of the coating film is estimated by destructively stripping the coating using a knife and visually inspecting the test specimen.

In practice, the CD test is an accelerated test operating at a controlled current or potential significantly higher than those experienced in normal industry practice, therefore, the test results may not be representative of the long term coating performance under normal CP operating conditions [20]. Also it has been reported that many CD tests, especially those performed at elevated temperatures, have resulted in disbonded areas that do not correlate well with those observed in the field [21]. This was explained to be due to differences in chemical reactions occurring under laboratory CD testing conditions and those taking place under field conditions. For instance a well-known oxidant compound, sodium hypochlorite (NaOCl), has been reported to form in the CD tests as result of the mixing of the anodic and cathodic reaction products in aqueous solution of sodium chloride (NaCl) [20,21]. This oxidant is believed to cause the destruction of the metal/coating bonds in laboratory CD tests, although in some CD test standards such as AS4352 and ASTM G95 the anode is separated from the electrolyte using a fritted glass to diminish the possibility of forming the oxidant. However this oxidant would not form under real field conditions [20,21]. It should also be noted that in all CD test standards the disbonded area is evaluated based on physically stripping the disbonded coating using a knife and observing the disbonded area, therefore the test results can be subjective to human error [22]. Another issue with the CD test is that there are inconsistencies and controversies in selecting the test conditions and parameters. Table 1 summarizes various test parameters used in different CD test standards. Holub et al. [20] reported major discrepancies in evaluated disbonded areas arising from the lack of restrictions in the selection of test conditions such as temperature, solution contents, and, test durations. They considered that some unspecified conditions in CD tests, such as coating thickness, electrolyte refreshment, current and chlorate concentration measurement might also be a matter of controversies [20].

Despite the discussed shortcomings of CD tests in assessing the coating cathodic disbondment, the method has been widely

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