

Modified Cathodic Disbondment Test Methods for Comparing the Performance of HPPC and FBE Coatings

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ABSTRACT

Modified CD test methods, based on NACE TM0115-2015, were developed to evaluate the performance of pipeline coatings in specific field conditions, such as those that exist in the Rockies in British Columbia, Canada, where pipelines will encounter rough terrain with potentially corrosive and abrasive rocks. One modified CD test uses an overhead agitator to suspend acid generating pyrite particles in the electrolyte to introduce both abrasion and acidification effects. It was found that increasing the mixing rate causes a decrease in coating impedance for fusion bonded epoxy (FBE) coatings. High performance powder coating (HPPC) have about 60% less disbondment compared with FBE, especially in acidic solutions at room temperature. A pH-controlled CD test was also developed to evaluate HPPC and FBE coating performance in electrolytes with pH ranging from 0 to 12. As revealed by scanning electron microscopy and dry film thickness studies, HPPC slows the migration of water and ionic species through the coating, contributing to less disbondment than FBE over the entire pH range. Both coating systems exhibit the poorest resistance to CD at near neutral pH conditions. Different CD mechanisms were proposed and discussed in terms of the solution pH.

Key words: cathodic disbondment tests, pipeline coatings, scanning electron microscopy, Energy-dispersive X-ray spectroscopy.

INTRODUCTION

Protective coatings in combination with cathodic protection (CP) are always used in the field for corrosion protection of oil/gas pipelines. The coatings act as a physical barrier to the corrosive soil environment. Once a defect is formed in the coating during pipeline installation and operations, CP will apply a negative potential to the exposed metal substrate, protecting it from corrosion. However, cathodic disbondment (CD), i.e., the failure of adhesion at the coating/substrate interface due to the application of CP [1,2] is one of the most significant degradation mechanisms for pipeline coatings. A reliable evaluation of the CD resistance of pipeline coatings is critical for selecting a suitable coating system in the field. CD test

standards are therefore generated to provide such guidance in assessing coating quality. There are many test parameters that need to be considered in CD testing, which include applied potential, electrolyte type and concentration, oxygen concentration, temperature, artificial defect/holiday size etc. Representative studies discussing the effect of different test parameters on disbondment can be found in [1,3-6]. Various standards specify different combinations of test parameters and procedures. After investigation of 8 international test methods and standards, NACE TM0115 [7] was developed in 2015 to serve as a universal CD test method. Compared with two other common test methods, ASTM G8 [8] and ASTM G95 [9], that are most widely adopted in CD tests, NACE TM0115-2015 has special enhancements including a regular check of the accuracy of the Ag/AgCl reference electrode used; the description of the test temperature measurement procedure; and the development of an inexpensive anode isolation method to eliminate the hypochlorite formation that may attack the coating [10]. All these standard CD tests were designed to evaluate the coating performance in simulated environments. Nevertheless, the complicated field condition that pipelines are exposed to cannot be fully reflected in such standards. For example, none of these standards considers the mechanical abrasion that will be commonly introduced by soil movement, and which may contribute to CD. Furthermore, in some areas such as in the Rocky Mountains in British Columbia, pipelines are sited near acid generating rocks (e.g. pyrite or other sulfides), that can affect the coating disbondment behavior. Using a standard CD test method may not be sufficient in evaluating pipeline coatings in such an environment and will not be reliable in guiding coating selection. In these cases, modifying one or more parameters from the standard tests, and or implementing specific procedures to simulate the field condition, will provide an alternative to better predict and assess coating performance.

In this study, in order to evaluate and compare the performance of fusion bonded epoxy (FBE) and high performance powder coating (HPPC, consisting of a FBE primer, a polyolefin adhesive layer and a tough powder based polyethylene top coat) in rocky and acid generating areas, two modified CD test methods based on NACE TM0115-2015 were developed. One is referred to as the overhead stirring CD test, in which, suspension of fine pyrite particles is included into the test setup so as to introduce both mechanical abrasion and acidification effects. A further pH-controlled CD test is then developed to elucidate the effect of solution pH on the disbondment behavior of these two coating systems. In terms of practical applications, the results obtained from these modified CD tests can support decision-making on coating selection for these particular service condition. In terms of fundamental understanding, a comprehensive study of the effect of solution pH on CD resistance provides insights into the CD mechanism, especially the role of cathodic reaction products, i.e., hydroxyl ions and hydrogen.

EXPERIMENTAL PROCEDURE

TM0115-2015 NACE International Standard Test Method [7] is used as a reference for creating the modified CD test methods. The attached cell configuration was used, i.e., an acrylic tube was glued to the pretreated coating surface. This tube was then filled with the test electrolyte or slurry. All coating samples were provided by Shawcor Ltd.

Overhead stirring CD test

A schematic drawing of the test setup is shown in Figure 1. An impeller with four 45° pitched blades (overhead agitator) was introduced to suspend the pyrite (from the El Potosí mine, Mexico) into the 3 wt% sodium chloride (NaCl) electrolyte and above the coating surface. These particles impacted the coated surface during testing and resulted in a slight abrasive effect. Furthermore, the reaction of the pyrite with water and oxygen (from ambient air) resulted in acid generation from the minerals [11]. The electrolyte pH was measured periodically during the CD tests. An OAKTON pH 110 meter was used in these tests. Before each measurement, the pH meter was calibrated using three buffer standards: pH = 4, 7 and 10. Between each calibration and test, the probe was rinsed with DI water.

This new protocol aims at improving the latest test method for CD by combining it with quantitative measurements of resistance to abrasion and aggressive chemistry. Coating performance was evaluated at both room and elevated temperatures for a testing period of 4 weeks. Coatings with a holiday of 3 mm were prepared to test the disbondment resistance. This is half of the holiday size recommended by TM0115-2015 NACE standard and was studied to highlight the influence of abrasion and acidification effect that will be discussed in the next section. FBE coatings without a holiday were also used, primarily for studying the influence of mechanical abrasion.

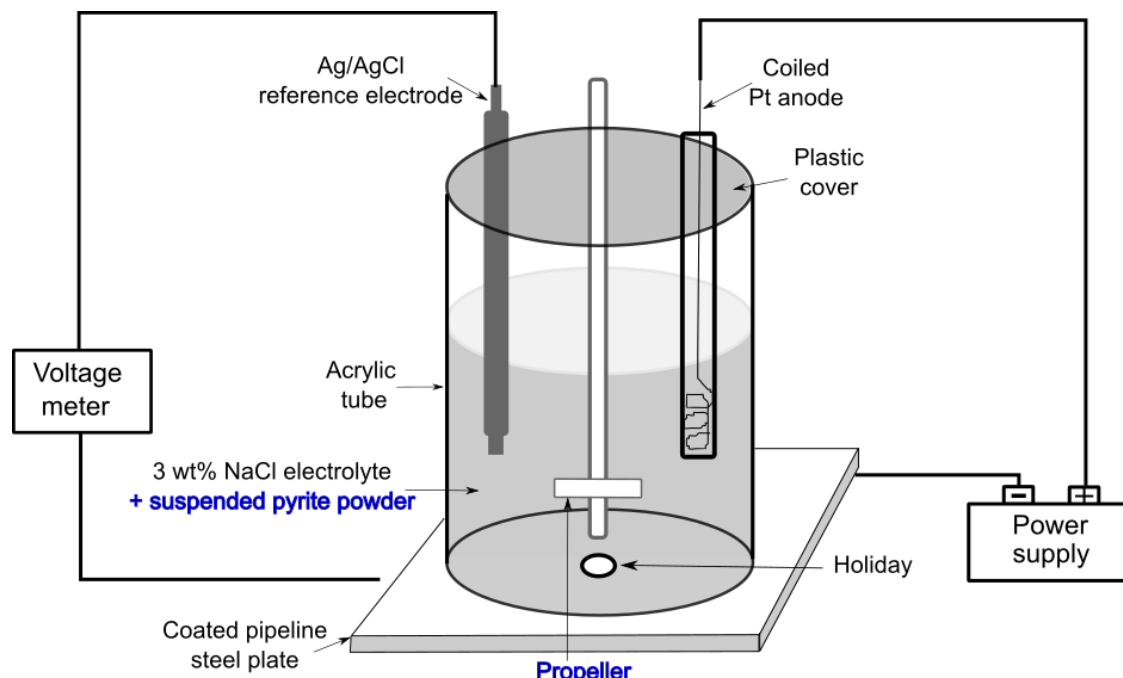


Figure 1: Overhead stirring CD test setup

pH-controlled CD test

For the pH controlled tests, the pH of the 3 wt% NaCl electrolyte was initially adjusted to specific values in the range of 0 to 12 by using either sulfuric acid (0.05 M to 7 M H_2SO_4) or sodium hydroxide (1 M NaOH). During the CD tests, protons are consumed through hydrogen evolution in acidic electrolytes while hydroxyl ions are continually produced through water electrolysis in neutral and alkaline electrolytes due to the application of a cathodic potential on samples with a holiday (6 mm). Both reactions lead to an increase of pH. In order to maintain the initial pH, a pH controlled system was used (Figure 2). A pH probe, connected with a SC200 controller (Hach), was put into the cell to monitor the electrolyte pH. When the solution pH exceeded a programmed value, the controller activated a pump to titrate sulfuric acid into the electrolyte. In this way, the electrolyte pH was always maintained around its initial value, with a variation of ± 0.1 . Coatings were tested at room temperature for one week.

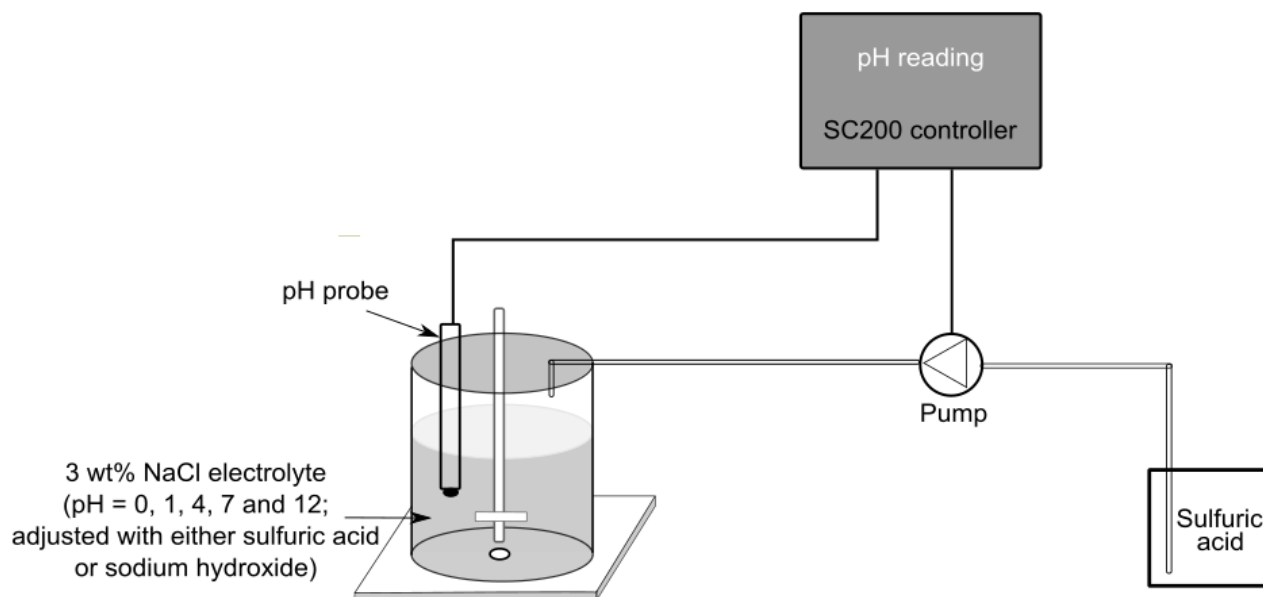


Figure 2. pH-controlled CD test setup

Particle size analysis

The particle size of pyrite powder was analyzed using a Malvern Mastersizer 2000 laser diffraction particle size analyzer. A suspension of 5 % solids in distilled water was prepared for particle size analysis. The suspension was mixed for five minutes before an aliquot was drawn for size analysis. Ultrasonic treatment was applied to disperse any aggregate in the sample. The D10, D50 and D90 values are 3.5 μm , 11.2 μm and 48.8 μm , respectively.

Scanning electron microscopy and energy dispersive X-Ray spectroscopy (EDX)

For samples that underwent pH controlled tests, the morphology and chemical composition of the disbonded area was examined by scanning electron microscope (SEM) (Hitachi S3000N) with the energy dispersive X-Ray spectroscopy (EDX) operated at 15 kV accelerating voltage.

Dry film thickness (DFT) test

A Phase-II PTG-3750 coating thickness gauge was used to measure the DFT of coating samples before and after the CD test. A minimum of nine DFT measurements over the coating surface were conducted and the average DFT was recorded. The DFT of FBE and HPPC coating is around 1100 μm and 450 μm , respectively.

Disbondment determination and measurement

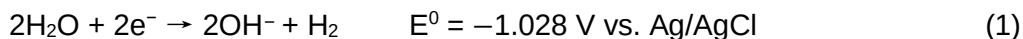
After the completion of the CD test, the holiday samples were rinsed with water and dried with paper towels. Four radial direction cuts were made through the drilled holiday using a motorized blade. All cuts were extended to the edge of the immersed area and 100% through the coating to the steel substrate. A rigid pointed knife was then used to lift the coating at the drilled holiday until no more disbondment could be detected. All the disbondment evaluation was done within two hours of the test completion. The cathodic disbondment was calculated using the equation: Cathodic disbondment = (average disbondment diameter – drilled holiday diameter)/2. For each condition, at least 3 samples were tested. All these procedures are consistent with NACE standard TM0115-2015 [7].

RESULTS

The cathodic disbondment behavior of FBE and HPPC coatings were evaluated and compared by using both NACE TM0115-2015 standard tests and modified CD test methods developed in this study. The influence of mechanical abrasion and acidification on disbondment are discussed.

NACE TM0115-2015 standard tests

By applying a cathodic potential of -1.38 V vs. Ag/AgCl, the dominant cathodic reaction occurring at the holiday area is water reduction:



The continuous generation of hydroxyl ions increases the solution pH shortly after the start of test. The electrolyte pH increases from around 5 to above 11 after one day of testing (Figure 3). The average disbondment radius for FBE and HPPC was 5.7 mm and 2.8 mm, respectively (Figure 4, holiday diameter is 6 mm). That is, HPPC had about 50% less disbondment than FBE.

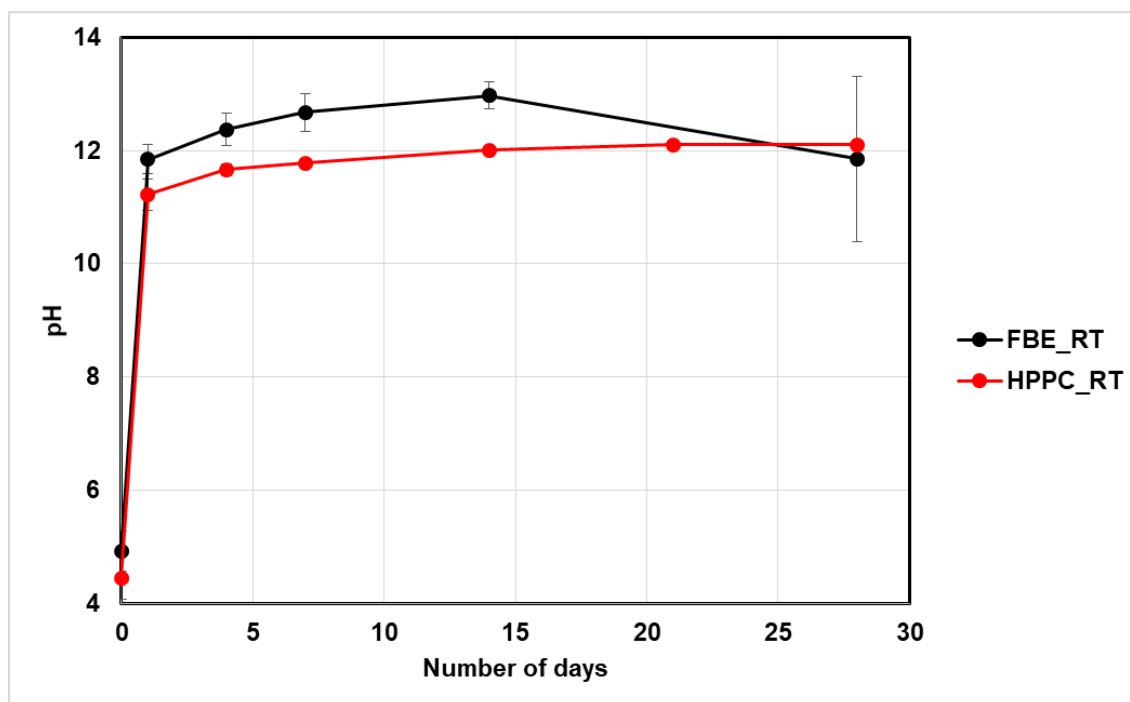


Figure 3: pH variation of the electrolyte (initially 3 wt% sodium chloride) during CD tests at RT

Overhead stirring CD tests

The base solution of 3 wt% NaCl solution was modified by suspending 1 wt% pyrite powder (mass of pyrite divided by mass of slurry) into the solution, the pH of the electrolyte was modified through the following reaction of pyrite with oxygen and water:

