

Corrosion Resistance of FBE internal Coating Pipe in High Temperature and High CO₂-H₂S-Cl⁻ Environment

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ABSTRACT

Fusion Bonded Epoxy (FBE) internal coating pipe is a kind of internal coating technology for piping and pipeline, which has a good corrosion resistance, and had become one of the important measures of corrosion control for pipes in oil & gas fields. A high temperature resistant FBE with primer internal coating system of pipe was chosen as the experimental object, and conducted long period (30 days) immersion tests and electrochemical impedance spectroscopy (EIS) tests of the FBE coatings under

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various temperatures with high content of $\text{CO}_2\text{-H}_2\text{S-Cl}^-$, combined morphology observation & adhesion performance test to study the corrosion resistance and corrosion mechanism of the FBE with primer internal coating system under various high temperatures. The results showed that no visible corrosion damage was found on FBE coating surface at high temperature with high content of $\text{CO}_2\text{-H}_2\text{S-Cl}^-$ condition. However, there had been obvious local damages such as small cracks and holes on the coating surface by microscopic morphology analysis at high temperature condition. The corrosion damage of the FBE with primer internal coating system is the most severe at 150°C , and H_2S corrosion occurred on the substrate; EIS test results showed that the coating resistance R_{coating} and the interface transfer resistance R_{ct} were significantly reduced with the increase of temperature, and the corrosion process was accelerated. At 150°C service condition, the coating resistance and interface transfer resistance R_{coating} decreased the most. Correspondingly, the coating pull-off adhesion (10.19MPa) at 150°C decreased by approximately 53% compared with the original coating system (21.75MPa), which showed a large decrease.

Key words: Fusion bonded epoxy (FBE); Internal coating pipe; Pull-off adhesion; Electrochemical impedance spectroscopy

INTRODUCTION

In 1950s, as an important measure to improve the corrosion resistance of base metal, internal coating pipes was first applied to sour crude oil and natural gas pipelines^[1]. Among the coating systems, FBE coating has good impact resistance, bending resistance, high bonding strength, good resistance for acid, alkali, salt, oil and water fluid. The coating can reduce the internal surface roughness friction resistance of piping & pipeline to reduce project investment.

FBE internal coated piping/pipeline has been successfully applied in downhole pipes, oil/gas/water multiphase flow flowlines and trunklines, oil/gas pipelines, water transfer pipelines, water injection pipelines and process piping system^[2-8]. At present, relevant standard systems have been formulated, such as SY/T 0442-2018 "Technical Standard for Fusion Bonded Epoxy Powder Internal Coating for Carbon Steel Pipeline", Saudi Aramco standard 09-SAMSS-091-2018 "Qualification Requirements for Shop-applied Internal FBE Coatings" and SHELL standard DEP 31.40.30.39-GEN-2017 "Fusion Bonded Epoxy Powder Internal Coating for Water Injection Pipeline", etc.^[9-11].

The temperature is one of the key parameters affecting FBE coating performance. With the deepening of oil and gas exploitation, the fluid medium temperature is rising, and the operating temperature of flowlines in some oilfields can be up to 110°C . For the traditional FBE coating system of oil and gas pipelines, normally the glass transition temperature (T_g) is less than 110°C , and the maximum operating temperature should be controlled 95°C and below. When the operating temperature is higher than T_g , the penetration rate of oxygen, CO_3^{2-} , HCO_3^- , and S^{2-} into the interior of coating system will increase significantly, and accelerating the failure of the coating system^[12,13]. In order to improve the service temperature and coating system performance of FBE internal coating, manufacturers have gradually developed high-temperature FBE coating with higher application temperature range, such as SCOTCHKOTE 6258/6258 XLG coating by 3M, NAP-GARD 7-2555 coating by Axalta, PFG80308 coating by Valspar, etc.. The maximum service temperature of these new high temperature resistant FBE coating is from 120°C to 160°C based on the coating product data sheet supplied by coating manufacturers.

Chloride ion is another key parameter affecting the FBE coating application. In the long-term service process, on the one hand, chloride ion penetrates into the coating and can cause base metal corrosion; on the other hand, high chloride ion content will increase the solution osmotic pressure, when the solution osmotic pressure is higher than the minimum critical bubbling osmotic pressure at the tiny defects inside the coating, bubbling may occur at the defects of the coating, thus accelerating the coating failure^[7,14].

Therefore, a typical Middle East oil field with high temperature (110°C) and high Cl^- (170,150 mg/L) and containing $\text{H}_2\text{S}/\text{CO}_2$ is taken as the target service condition. The internal coating pipe with coating system consists of a primer (phenolic resin) and high temperature resistant FBE is selected as the experimental object.

By high temperature and high pressure corrosion simulation experiments, combined with microscopic morphology / component characterization, electrochemical impedance spectroscopy test and coating adhesion performance test, the corrosion damage behavior of FBE with primer internal coating pipes was studied and analyzed at high temperature and high content of $\text{CO}_2\text{-H}_2\text{S-Cl}^-$ condition of oil fields. The influence of various temperatures on the corrosion resistance of FBE internal coating under ultra-high Cl^- content was obtained, and the corrosion mechanism was preliminarily discussed, which provided theoretical basis and data support for the application of this kind of temperature resistant FBE internal coating.

EXPERIMENTAL PROCEDURE

Experimental Materials

The experimental object is the high temperature resistant FBE with primer internal coated pipe produced by a Chinese Manufacturer. The base material is API 5L-PSL2 X60 pipeline. The coating system consist of phenolic resin primer and fusion epoxy powder with a high temperature performance, the primer thickness shall be 15~25 μm , total thickness of coating system shall be 375~625 μm , and the measured thickness of the coating system is about 400 μm at laboratory. The sand blasting requirement of the base metal material surface is Sa 3.0.

Corrosion Simulation Experiment

The samples for high temperature and high pressure corrosion simulation test were cut from FBE internal coated pipe by wire cutting. The surrounding and outer surface of the samples was sealed by epoxy resin. The sample size is 80mm long $\times$ 60mm wide, and the wall thickness of samples is consistent with the original pipeline, the coating color is dark green. According to NACE TM0169-2021/ASTM G31-21^[15], the corrosion simulation test of FBE internal coated samples under simulated service conditions was carried out by using high temperature and high pressure $\text{H}_2\text{S}/\text{CO}_2$ Hastelloy C autoclave (as shown in Figure 1) combined with booster pump and high precision dissolved oxygen control device. The test conditions are shown in the Table 1. All tests were carried out under dynamic conditions, and the simulated rotation rate is 3m/s.

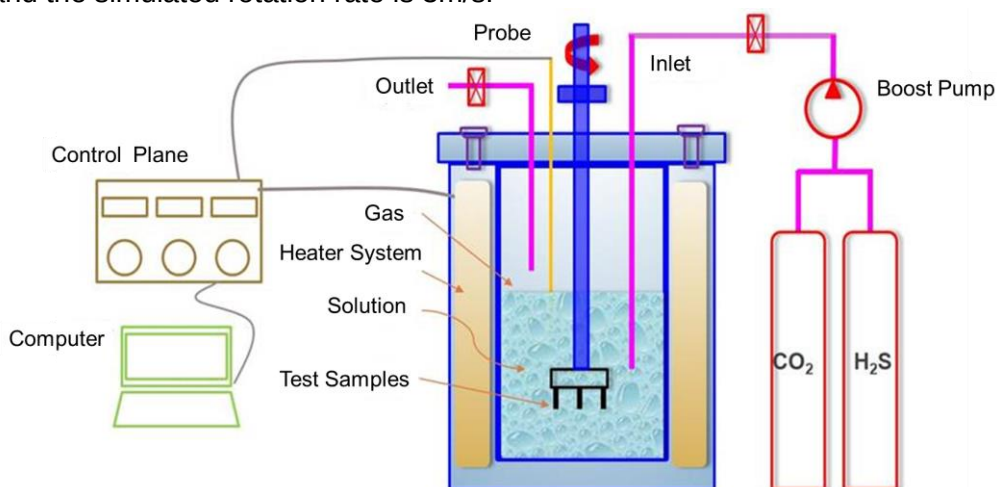


Figure 1: Scheme of $\text{H}_2\text{S}/\text{CO}_2$ Corrosion Simulation Test Device at High Temperature and High Pressure Environment.

Table1: High Temperature and High Pressure Corrosion Simulation Experimental Parameters

No.	Temperature/°C	Pressure/MPa	CO ₂ Content/%mol	H ₂ S Content/%mol	Cl ⁻ /mg/L
1	110	4	10	1.5	170 150
2	130	4	10	1.5	170 150
3	150	4	10	1.5	170 150

Microscopic Morphology, Component Analysis and Coating Adhesion Test

After the corrosion simulation test, the samples were washed with deionized water, dehydrated with acetone and dried by cold air. SEM and EDS were used to analyze the corrosion microscopic morphology and composition. The adhesion properties of coating samples were tested according to ISO 4624-2016^[16].

High Temperature and High Pressure Electrochemical Testing

The traditional three-electrode system was used for electrochemical test. The auxiliary electrode was platinum electrode, reference electrode was high temperature and high pressure Ag/AgCl reference electrode manufactured by CORR Company, and the working electrode was FBE coated sample. Test parameters of electrochemical test are shown in Table 1. All tests were completed in a high-temperature and high-voltage chemical reaction autoclave, and relevant equipment information is referred to reference [17]. The test content includes open circuit potential and AC impedance test. Open circuit potential test stability time at least 1h, AC impedance measurement frequency range of 100 kHz to low frequency 10 mHz, and the amplitude is ± 10 mV.

RESULTS AND DISCUSSION

Analysis of Macro / Micro Corrosion Morphology and Corrosion Products

After immersion for 30 days under high temperature and high content of CO₂-H₂S-Cl⁻ oil field simulation conditions, the macroscopic morphology is shown in Figure 2. Under various temperatures conditions, the surface of FBE internal coating sample is relatively integrated, without blistering, cracking, peeling or other type's damage. The coating color is slightly lighter and showing grayish green. The microscopic morphology is shown in Figure 3. With the increase of temperature, micro cracks, holes and other damages appear on the sample surface, especially at 150°C. As shown in Figure 3-d), there are more damaged areas on the coating samples surface, and the damaged area size is larger than the surface sample at 130°C. Figure 4-a) shows the local enlarged morphology of the typical damaged area (marked in Figure 3-c)) on the sample surface at 150°C. It can be observed that the damaged area is radial cracking and presents a certain trend of peeling, which is unfavorable to the performance of the coating. When the radial cracking and damage gradually expand and connect, it is very likely to induce a large area of peeling and damage and lead to the coating failure. It can be observed from the energy spectrum test results (Figure 4-b)) that there are more Fe and S elements in the damaged area, which indicates that H₂S as a small molecular form may penetrate into the coating and metal substrate interface through the cracking of the coating, resulting in the corrosion of the metal substrate and the formation of FeS_{1-x} and other corrosion products distributed on the surface of the sample.