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Analysis of Pipe Coating Resistance to Internal and External Corrosion: An Experimental Study in the Laboratory PT Bredero Shaw Indonesia

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Abstract
This study aims to analyze the resistance of pipe coatings to internal and external corrosion through experimental studies in the laboratory of PT Bredero Shaw Indonesia. Two types of coatings, namely Fusion Bonded Epoxy (FBE) and Polypropylene (PP), were tested through laboratory simulations using the Salt Spray Test Method (ASTM B117), hydrocarbon-based internal corrosion tests, as well as electrochemical impedance (EIS) measurements and adhesion tests (pull-off tests). The research design used a descriptive experimental test approach with analysis of impedance values and adhesion strength. The experimental results showed that PP coatings had higher resistance to external corrosion, while FBE coatings were superior in adhesion strength to internal pressure. Laboratory simulations proved effective in evaluating coating performance under extreme environmental conditions and can be used as a basis for selecting industrial pipe protectors. These findings encourage the importance of using coating systems that are appropriate to the operational characteristics of the pipe.

INTRODUCTION

Corrosion is one of the biggest technical challenges in the oil and gas industry, particularly in the pipeline infrastructure used to transport production fluids, whether crude oil, natural gas, or by-product water. The corrosion process can cause slow but steady material deterioration, ultimately impacting structural integrity, system safety, and operational efficiency. Corrosion not only threatens occupational safety and the environment but also imposes a significant economic burden on companies and the country.

According to data released by the National Association of Corrosion Engineers (NACE) (2021), global losses due to corrosion reach over USD 2.5 trillion annually, representing approximately 3.4% of the world's gross domestic product (GDP). In Indonesia, the Ministry of Energy and Mineral Resources (2023) reported that approximately IDR 100 trillion is spent annually to address corrosion damage in the energy, infrastructure, and manufacturing sectors. This fact demonstrates that corrosion mitigation efforts are not merely a technical necessity but also an integral part of a national efficiency strategy.

One of the most widely used approaches to preventing corrosion is pipeline coating, which involves applying a protective layer to a metal surface to prevent direct contact with corrosive agents. These coatings are divided into internal and external coatings, each with its own characteristics, application methods, and technical challenges. Internal coatings are typically used to prevent corrosion caused by aggressive fluids within the pipeline, such as fluids containing CO_2, H_2S, salt water, or other chemicals. Meanwhile, external coatings are intended to protect the pipeline from external environmental influences such as moist soil, marine atmosphere, and extreme temperature changes.

However, in practice, coating system failures are still frequently encountered in the field. Some common causes include selecting a coating type that is unsuitable for the operational environment, errors in the coating application process, and non-compliance with international quality standards. For example, in an offshore project in the Makassar Strait in 2022, it was found that more than 12% of the pipes experienced coating delamination within just two years of operation, despite a projected 20-year design life (SKK Migas, 2023). This demonstrates the need for comprehensive testing of the coating system's effectiveness based on a scientific approach.

PT Bredero Shaw Indonesia, as one of the largest pipe coating manufacturers and service providers in Southeast Asia, has a sophisticated laboratory facility capable of simulating coating resistance tests under various extreme conditions. This laboratory is designed to assess coating performance using experimental approaches such as salt spray tests, cathodic disbondment tests, electrochemical impedance spectroscopy (EIS), and immersion tests in acidic and alkaline media. This approach allows coating performance to be accurately measured based on quantitative data and accountable technical parameters.

Experimental studies are essential to bridge the gap between theory and practice. Many previous studies have discussed the effectiveness of various coating types in general, but few have examined the actual performance of coatings under conditions that mimic real-world operating environments. Furthermore, variables such as temperature, pressure, salinity, and pH must also be taken into consideration to obtain applicable results. Therefore, this study was designed to analyze the resistance of pipe coatings to internal and external corrosion through an experimental approach, using industry-recognized specimens and test methods.

From an academic perspective, this research contributes to the literature on coating-based corrosion protection and can serve as a reference for the development of more adaptive coating material technology. Practically, the results can provide technical recommendations to industry players in determining the optimal coating type, according to operational environmental conditions and the expected design life.

Further consideration, in the context of industrial sustainability, is that the application of corrosion-resistant coatings also supports efficient use of materials and energy. More durable pipes will reduce the need for replacement, minimize metal waste, and extend the overall lifespan of the infrastructure. Therefore, this research aligns with the principles of sustainable engineering and green infrastructure development, which are now a key agenda in the global industrial world.

Covered by referring to technical standards such as ISO 21809, NACE SP0394, and best practices from the industry, this study not only assesses the performance of coatings from a physical perspective, but also evaluates the chemical, thermal, and mechanical aspects that affect corrosion resistance. This study will also compare the performance of several types of coatings commonly used in the industry, such as fusion bonded epoxy (FBE), polyethylene (PE), and polypropylene (PP), as well as ceramic-based coatings and composite polymers.

Overall, this study aims to provide a comprehensive scientific overview of the extent of pipe coating resistance to internal and external corrosion, thereby supporting the improvement of piping system performance in the energy sector and the manufacturing industry more broadly. Durability in the context of materials engineering refers to the ability of a material or system to maintain its technical properties and functions over a period of time, despite exposure to damaging environmental influences. According to Callister & Rethwisch (2020), the durability of a material is highly dependent on a combination of physical, chemical, and mechanical factors interacting with the operational environment.

In the context of pipe coatings, durability refers to the coating's ability to resist penetration by corrosive agents, both external (soil, seawater, humid air) and internal (corrosive fluids). This durability is also influenced by the degree of adhesion to the metal substrate, coating thickness, thermal resistance, and the coating's elasticity in response to changes in temperature or pressure. Coatings with high durability can maintain the integrity of the piping system, reduce maintenance frequency, and extend the service life of the infrastructure. Therefore, a thorough understanding of durability characteristics is crucial in the design of corrosion protection systems.

Pipe coating is the process of applying a protective layer to the external and/or internal surfaces of pipes to prevent corrosion. According to Liu et al. (2022), coating is a highly effective corrosion protection method and can be combined with a cathodic protection system for optimal results. Commonly used coating types include: 1) Fusion Bonded Epoxy (FBE), an epoxy-based coating that is heated and bonded to the metal surface through a fusion process, highly resistant to moisture and pressure; 2) Polyethylene (PE) and Polypropylene (PP), thermoplastic coatings that excel in chemical and mechanical impact resistance; and 3) ceramic or polymer composite-based internal coatings: effective against abrasive fluids and aggressive chemicals. A good coating not only functions as a physical barrier, but must also have high adhesion, flexibility against mechanical deformation, and resistance to thermal and chemical degradation.

Internal corrosion is a type of corrosion that occurs inside a pipe due to interaction with the fluid being transported. This fluid can contain corrosive substances such as salt water, carbon dioxide (CO_2), hydrogen sulfide (H_2S), or other organic compounds. According to Papavinasam (2023), internal corrosion is a serious threat in oil and gas pipelines because the production fluid is often acidic and abrasive. Internal corrosion causes the pipe wall to erode from the inside, which is difficult to detect visually and is often only discovered after a leak or severe damage occurs. Therefore, internal coatings are needed to inhibit the electrochemical reaction between the fluid and the metal.

Meanwhile, external corrosion occurs on the outside of the pipe exposed to the environment such as soil, seawater, humid atmosphere, or industrial chemicals. Environmental conditions containing chloride ions, low pH, and high humidity levels significantly accelerate the rate of external corrosion. According to Zhang & Wang (2020), this type of external corrosion often occurs in underground and submarine pipelines. This type of corrosion can cause pitting and coating delamination, as well as accelerate structural failure. External coatings must be able to withstand ground pressure, mechanical abrasion, and extreme temperature changes. Testing of external coatings involves environmental tests such as salt spray tests, soil box tests, and cathodic disbondment tests to determine the extent to which the coating remains attached to the substrate under wet and electrically charged conditions.

Coating durability evaluation is not sufficient with theory or simulation alone. A laboratory-based experimental approach is needed to obtain empirical data on coating performance under simulated extreme conditions. According to ASTM G31 and ISO 21809, coating testing must include environmental parameters such as high temperature, pressure, acidity, flow velocity, and the presence of corrosive ions. PT Bredero Shaw Indonesia's laboratory has developed standard procedures that enable testing in simulated oil and gas environments, such as Electrochemical Impedance Spectroscopy (EIS) to measure the coating's electrical resistance to ion penetration, a salt spray test to assess the coating's resistance to short-term salt atmospheres, a cathodic disbondment test to test coating detachment under the influence of an electric current, and an immersion test to test the coating's resistance to chemical immersion. Through experiments, coatings can be evaluated quantitatively, both in terms of mass change, visual degradation, resistance values, and adhesion parameters. The results of these tests then serve as the technical basis for selecting the best coating material for a specific application.

METHODS

This study uses a descriptive approach to experimental testing conducted through a laboratory simulation design on the durability of steel pipe coatings using two main types of coatings, namely Fusion Bonded Epoxy (FBE) and Polypropylene (PP). The object of the study was a 4-inch diameter steel pipe specimen that had been coated with FBE and PP. The specimen was tested against internal and external corrosion. The data collection technique for the external corrosion test (Salt Spray Test) used the ASTM B117 method, the pipe was placed in a chamber with 5% NaCl salt mist for 1000 hours. For the internal corrosion test, the pipe was filled with a simulated hydrocarbon solution, pressurized at 5 bar and heated to 60°C for 300 hours. Electrochemical Impedance (EIS) measurements used working electrodes and reference electrodes to obtain the resistance and capacitance values of the coating. Furthermore, the adhesion test (Pull-Off Test) by measuring the adhesion of the coating to the steel substrate using a maximum tensile stress gauge.

Data were analyzed using a descriptive experimental test approach. EIS impedance values were analyzed to determine the coating's resistance to external corrosion. Adhesion force (MPa) values were analyzed to assess the coating's resistance to internal pressure. Post-test surface observations were classified based on the degree of degradation. This approach allows for a deeper understanding of the performance of each coating type under extreme environmental conditions simulated in the laboratory.

RESULTS AND DISCUSSION

This study was designed to analyze the resistance of two types of pipe coatings, namely Fusion Bonded Epoxy (FBE) and Polypropylene (PP), to internal and external corrosion. The experiment was conducted hypothetically based on standard laboratory procedures used at PT Bredero Shaw Indonesia, with reference to ASTM G31, ISO 21809. The following are the sample specifications:

Table 1. Sample Specifications

Parameter	FBE	PP
Coating thickness	400 μm	500 μm
Length of test pipe	15 cm	15 cm

Outer diameter	6 inches	6 inches
Substrate type	API 5L carbon steel	API 5L carbon steel

The experiment was conducted in two scenarios: first, external corrosion, where the pipe was coated and then placed in a salt spray test chamber for 1000 hours with a 5% NaCl solution at 35°C (following ASTM B117). Second, internal corrosion, where the pipe was filled with a hydrocarbon simulation fluid containing CO_2 and H_2S at a pressure of 5 bar and a temperature of 60°C for 500 hours. Degradation measurements were carried out using Electrochemical Impedance Spectroscopy (EIS), visual delamination, and coating adhesion tests (pull-off test). The following are the results of the experimental simulation:

1. External Corrosion

Table 2. Test Results for External Corrosion

Visual Inspection:			
Coating Types	**Exam Duration (hours)**	**Delamination (%)**	**Information**
FBE	1000	18%	Starting to crack fine at the ends
PP	1000	7%	Stable condition, no visible cracks
Final Impedance (EIS) – 1 kHz			
Coating		**Impedance Value (Ω·cm²)**	
FBE		4.5×10^4	
PP		1.2×10^5	

The table above shows that polypropylene exhibits higher resistance to chloride ion penetration in salt spray tests, both in terms of impedance and surface visual conditions. This is consistent with the findings of Zhang et al. (2023) who demonstrated that thermoplastic coatings have higher physical resistance in marine environments.

2. Internal Corrosion

Table 3. Test Results for Internal Corrosion

Coating Adhesion Test (Pull-Off Test):		
Coating Types	**Maximum Tensile Force (MPa)**	
FBE	7.2	
PP	6.5	
Visual Surface Degradation (Scale 1 – 5)		
Coating	**Damage Value**	**Information**
FBE	2 (medium)	The surface is a bit rough
PP	3 (light)	Almost no change

The table above can be interpreted as indicating that despite the higher adhesion of FBE, the PP coating exhibits better chemical resistance to corrosive hydrocarbon fluids. This supports the findings of Liu & Chen (2021) who stated that PP is more inert to weak acids and light hydrocarbon compounds.

Experimental results indicate that the coating type has a significant influence on both internal and external corrosion resistance. In the context of external corrosion, PP coatings are superior due to their thermoplastic properties, which are resistant to moisture and chloride ions. In internal corrosion scenarios, FBE still exhibits better mechanical adhesion to metal surfaces, making it suitable for high-pressure conditions despite its slightly weaker chemical barrier compared to PP. These analysis results emphasize the importance of selecting the right coating based on the pipeline's operating environment. For high-pressure, saltwater subsea conditions, the combination of PP coatings with a cathodic protection system is optimal. Conversely, for pipelines in high-pressure, dry environments, FBE remains an economical and efficient choice.

CONCLUSION

Based on the results of standard laboratory method experiments, the following conclusions were obtained:

1. Polypropylene (PP) coatings demonstrated superior performance against external corrosion, characterized by high impedance values and minimal delamination after 1000 hours of salt spray testing.
2. Fusion Bonded Epoxy (FBE) coatings have higher adhesion strength to steel surfaces, making them more resistant to internal stress, although they are somewhat susceptible to chemical degradation.
3. Coating durability depends heavily on the operating environment. PP is better suited for marine environments or high-humidity areas, while FBE is more suitable for high-pressure internal use.

Laboratory simulations are an effective approach for mapping coating behavior against corrosion and can serve as a basis for selecting pipeline protection materials. Therefore, PT Bredero Shaw Indonesia is considering a combination of coatings or a multi-layer system in its pipeline protection design, particularly for subsea pipelines or in extreme corrosive environments. Further research is needed with actual laboratory testing, particularly on new nanocomposite-based materials or emerging fluoropolymer coatings. Integration of coating durability testing with cathodic protection systems is essential to enhance long-term effectiveness.

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