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# Effect Analysis on Coating Methods and Corrosive Media Variations toward Adhesion Strength, Corrosion Rate, and Metallography of ASTM A36 Steel with Polyurethane Coating

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## ABSTRACT

*Corrosion can cause material damage due to the material's reaction with the environment. Corrosion will affect materials on construction, including metal material, thereby reducing the strength and the construction life, especially in a corrosive environment. The most effective and economical corrosion control is coating. The right coating application method will result in good bonding of the paint with the material, so that the corrosion protection will be better. This research used the ASTM A36 carbon steel material and polyurethane coatings. The purpose of this study is to determine the adhesion strength and corrosion rate by varying the application methods, namely brush, roll, and spray. In the pull-off test, the highest value of adhesion strength was obtained in the spray coating method with an average value of 20,82 MPa. Whereas in the three-electrode cell testing, the lowest corrosion rate using NaCl corrosive media was found in the spray coating method with a value of 0.000025402 mmpy and the lowest corrosion rate using $FeCl_3$ corrosive media was found in the spray coating method with a value of 0.00182 mmpy.*

***Keywords:*** *Coating, Polyurethane, Spray, Roll, Brush, Adhesion, Corrosion.*

## 1. INTRODUCTION

In oil and gas production activities, offshore platforms and subsea pipelines are built to assist exploration and exploitation process. Steel material is a necessity in the construction of these offshore facilities. Steel is a mixture of iron and other additional materials, including carbon. The higher level of carbon addition will increase the hardness of the material, but it will also be brittle and difficult to shape.

Offshore structure is operating in the corrosive environment, which can cause the structure to be easily corroded. Corrosion is defined as a decrease in the quality of metals due to the electrochemical reaction with their environment [1]. Corrosion can make the metal structures thinner, perforated, and eventually cause cracks which then cause sudden structural failure [2]. From economic perspective, corrosion is one of the main problems in the oil and gas industry because it cost a lot of money to deal with [3]. Therefore, the rate of corrosion in oil production facilities can be prevented by several means such as cathodic protection, coating, and the use of chemicals [4]. Coating is often used because it is relatively cheap and easy to apply. There are several coating materials that are often used, such as polyurethane coating. Polyurethane used as a protective coating due to its adhesion power, flexibility, and easy application to low-carbon steel material [5] .

Polyurethane or often called polycarbanate is a linear polymer that has (-NHCO2) bond on its molecular bonds [5]. This polymer is formed from a chemical reaction between isocyanate and a high degree alcohol or commonly called polyol. Isocyanate is a molecule that contains a radical isocyanate group (NCO). The preparation of polyurethane consists of 2 stages, namely pre-polymerization and emulsion phase [6]. The addition of nano silica in a polyurethane mixture is known to improve the adhesion between the polyurethane and the base material [7]. To increase coating's resistance against corrosion, polyurethanes can be added with some other elements, such as silver [8], nanozinc / nanoclay [9], phosphate [10], and graphene [11]. However, this research has not been tested with a mixture of the elements mentioned previously.

According to Widhawardana [12], polyurethane 1 has adhesion strength that meets top coat standards, able to withstand heat, and can withstand corrosion rates of 24.36% in NaCl solutions and 45.66% in $FeCl_3$ solutions. The use of polyurethane as a protective material by Sholeh and Rohani [13] concluded that polyurethane has abrasion resistant, high flexibility, and resistance to wear properties. Research by Nasoetion [2] concluded that the use of polyurethane was not strong enough to handle bending loads but was good enough in blistering, cracking, and rusting testing. Other research conducted by Samimi [3] concluded that polyurethane material has high adhesion strength, suitable flexibility, good chemical and high temperature resistance, and good friction resistance for pipelines. Based on these studies, polyurethane is considered a good quality material if used for coatings. However, further research will be carried out to complete the data.

Application of coatings can be done in various ways, including by using the spray, brush and roll method [14]. These methods have their advantages and disadvantages. The spray method has the advantages of evenly distributed thickness and short processing time, but the spray method has the disadvantage of being difficult to reach narrow areas or edges. Whereas the brush method has advantages that are economical and can reach difficult areas, but the disadvantages of this method are the long workmanship and uneven thickness of the paint. The last method, namely the painting method using a roller has the advantage of painting faster than the brush method, but the disadvantage is that the thickness of the paint is difficult to control.

Previous research has been conducted on the effect of variations in the method of painting by Debrita [14]. However, the use of paint material used for coating is epoxy coating. Therefore, in this study polyurethane coating material will be used because it has some advantages over epoxy, such as scratch resistance, high temperature resistance, and better moisture handling.

Further research will be conducted on how the effect of variations in coating methods on ASTM A36 steel commonly used for pipelines using *polyurethane* coating materials. Each steel specimen will be given a coating as protection by three different methods, namely brush, roll, and spray. Research carried out by testing the coating resistance to the adhesion strength and the rate of corrosion in different corrosive media.

## 2. BASIC THEORY

### 2.1. Steel

Steel is an alloy metal with iron as the basic element and carbon as the main alloying element. Carbon content in steel ranges from 0.2% to 2.1%. The carbon mixture in iron functions as a hardening element. The mixture of carbon content in steel can change the nature of the steel, such as increased hardness value and tensile strength of the steel, but its ductility will decrease and become more brittle. There are many elements that can be combined, such as Manganese (Mn), Chrome (Cr), Vanadium (Vn), and Nickel (Ni). By varying the carbon content and other elements, various types of steel quality can be obtained. According to ASM [15] carbon steel can be divided based on the amount of elemental carbon content in the steel metal, such as:

1. Low Carbon Steel
   Low carbon steel is a type of carbon steel that has carbon content between 0.025% - 0.3%. So, a ton of low carbon steel contains 10-30 kg of carbon. Low carbon steels are tough and ductile, making it easy to shape and apply to the vehicle industry and building structures. In addition, low-carbon steel also has good weldability.
2. Medium Carbon Steel
   Medium carbon steel is a type of carbon steel containing carbon between 0.25% - 0.55% C. So, a ton of carbon steel contains carbon between 30-60 kg. Medium carbon steel has higher strength than low carbon steel and has a high heat treatment quality, is not easily formed by machines, is more difficult to do for welding, and can be hardened (diquenching) properly. Carbon steel is being widely used for shafts, railroads, gears, springs, bolts, and engine components that require high strength.
3. High Carbon Steel
   High carbon steel contains carbon content between 0.56% - 1.7% C. So every one ton of high carbon steel contains carbon between 70-130 kg. This steel has the highest strength and is widely used for material tools. One application of this steel is in the manufacture of steel wires and steel cables.

ASTM A36 steel material used in this study belongs to the category of low carbon steel because it has a carbon composition of less than 0.3%.

### 2.2. Coating

Coating is a method of applying layer to the surface of an object. The purpose of coating is for decorative, functional, or both. Coating is also one of the most common corrosion control methods used in offshore buildings due to its effective and economical way of working. The work method of the coating system is to prevent the environment from interacting with the protected material, by creating a protective layer (barrier). Coating consists of two types, namely liquid coating and concrete coating. Liquid coating is usually in the form of painting, whereas concrete coating is a coating using concrete casting. Application of coatings with painting generally has three layers of protection. The first layer which is directly attached to the material is called the primary layer, the next layer is the intermediate layer, and the outer layer of the coating is in direct contact with the environment, called the top layer. The method for applying the coating can be done with three methods, namely spray, brush and roll methods. These three methods have their advantages and disadvantages.

There are four basic components in liquid coatings, which were:

1. Pigment
   Pigments are usually found in a coat of primary coat that serves as a barrier to corrosion attacks on metals which works passively. Pigments that do not react with the environment will form a complex compound with metal oxides that act as a passive layer and will inhibit the rate of corrosion.
2. Binder
   Binder is a polymer compound that is very important to determine the character of the paint layer because of its function as a binder between the components of paint. Therefore, binders are an important ingredient in paint

mixture formulations.

3. Solvent
   Solvents function to dissolve the binder and also to change the thickness or viscosity of a solution to facilitate the application of coatings. The solvent also controls paint drying, adhesion, and age of the paint. If unsuitable solvents are mixed, several effects will arise, including coatings that cannot form smooth and continuous coatings, coatings that experience rapid hardness, and cannot be blend between the material and the paint.
4. Additive
   The function of the additive is to improve the properties of the paint. Additives are chemical compounds that are usually added in small amounts, but greatly affect the properties of the coating. The usage of additives does not exceed 1 or 2%, and the total rate of all additives in the formulation does not exceed 5% of the total product. Materials including additives are surfactants, anti-settling agents, coalescing agents, anti-skinning agents, catalysts, defoamers, ultraviolet light absorbers, tools dispersions, preservatives, driers and plasticizers.
5. Extender
   Its function is the same as additive, which improves the properties of paint. This extender is a solid material that usually used to help the workings of pigments, for example barite, talc, $CaCO_3$ compounds, and others.

### 2.3. Polyurethane

Polyurethane or often called polycarbanate is a linear polymer that has (-NHCO2) on the molecular bond. This polymer is formed from a chemical reaction between isocyanate and high degree alcohol or commonly called polyol. Isocyanate is a molecule that contains a radical isocyanate group (NCO). The preparation of polyurethane consists of 2 stages, namely pre-polymerization and emulsion phase.

Polyurethane has versatile benefits. Typically, polyurethane is used as a building material insulation, surface coating (coating), elastomer, foam, and adhesive. Its use in the oil and gas industry has also been tested and is being developed for mass use. One of which is for underwater pipelines (pipelines) and for offshore platform foot coating.

### 2.4. Adhesion

Adhesion or adhesion strength is attractive forces between the molecules of different types. This attraction causes one substance to stick to another because the molecules attract to each other. The adhesion force will cause the two substances to stick together when mixed.

Adhesion strength testing can be done using *the pull-off test* refers to ASTM D4541- 0 2 standard [16]. The tool used for adhesion testing is called a *pull off adhesion tester*. This adhesion strength test is done by attaching a dolly with a diameter of 20 mm on the surface of the coating layer using epoxy glue. The dolly is held by a compressor connected to a hydraulic pump. The results of the stickiness test will be displayed on the pressure gauge screen.

### 2.5. Corrosion

Corrosion is failure or degradation of metals or non-metals due to redox reactions with various substances in the environment that produce undesirable compounds. Corrosion is an event of damage or deterioration in the quality of a metal due to electrochemical reactions with its environment [1]. Environmental conditions that often cause corrosion of metals are air and water [17].
Corrosion can occur if there are four elements below:

- Anode
  An oxidation reaction occurs, then the corrosion will occur.
  $$M \rightarrow M^+ + e$$
- Cathode
  A reduction reaction occurs, the region consumes electrons.
- Metallic Pathaway
  Where current flows from the cathode to the anode.
- Electrolyte solution
  Corrosive solutions that can conduct electric current, contain ions.

The slow speed of corrosion of a material is influenced by several general conditions, such as the mixed elements in the metal / material and the construction arrangement of the material. The factors that can affect the rate of corrosion are:

a. Metallurgical factors
   Metallurgical factors are factors related to the composition and construction of the used material. It includes what materials and alloys were used to make the construction and the design of the installed construction.
b. External factors (surrounding environment)
   1. Environmental acidity (pH)
      In acidic conditions or low acidity environment, the corrosion rate will become higher. This is because most of the oxide layer will dissolve easily in the acidic environment.
   2. Electrolyte
      Electrolytes (acids or salts) are good media for charge transfer. This makes it easier for electrons to be bound by oxygen in the air. Rainwater contains a lot of acid, while sea water contains a lot of salt. Therefore, rainwater and sea water are the main causes of corrosion.
   3. Water and air humidity
      Based on the redox reaction of the corrosion process, water has an important role to trigger it. Humid environment that contains a lot of water vapor will accelerate the corrosion process.
   4. Temperature
      Corrosion will occur more frequently at high temperatures than at low temperatures. This is caused by the speed of particles which also increases so that it can triggers more chemical reactions.

### 2.6. Corrosion Rate

Corrosion rate is the propagation speed or speed of decline in material quality with time. Calculation of corrosion rate values in practice is very necessary in determining the economic value and physical resistance of a material. To find the value of the corrosion rate there are several methods, such as weight loss and electrolysis The principle of the weight loss method is to measure the weight loss of the material after a corrosion event or after the corrosion results (rust) have been removed. As for the electrolysis method, it is a method of measuring the rate of corrosion by measuring the difference in object potential until a corrosion rate is obtained. This method does not require a long time to be able to determine the process of corrosion. Corrosion rate values in the electrolysis method can be simultaneously found using software that is integrated with a computer. Corrosion rate testing using the electrolysis method can be calculated using a formula based on Faraday's Law as shown below:

$$CPR = K\,\frac{a.i}{n.D}\;mmpy$$

With,
K = Constant (0.129 for mpy; 0.00327 for mmpy)
a = Corroded metal atomic weight (grams)
i = Current density ($\mu A$ / $cm^2$)
n = Valence electrons of the corroded metal
D = Corroded metal density (gram / $cm^3$)

The smaller the corrosion rate of a material, the more difficult it is to corrode. According to Fontana [17], material corrosion resistance can be classified based on its corrosion rate values as follows:

Table 1. Material resistance criteria differ in corrosion rates.

| *Relative Corrosion Resistance* | *Approximate Metric Equivalent* | | | | |
|---|---|---|---|---|---|
| | *mpy* | *mm/year* | *µm/year* | *nm/year* | *pm/sec* |
| *Outstanding* | <1 | <0,02 | <25 | <2 | <1 |
| *Excellent* | 1-5 | 0,02-0,1 | 25-100 | 2-10 | 1-5 |
| *Good* | 5-20 | 0,1-0,5 | 100-500 | 10-50 | 5-20 |
| *Fair* | 20-50 | 0,5-1 | 500-1000 | 50-1000 | 20-50 |
| *Poor* | 50-200 | 1-5 | 1000-5000 | 150-500 | 50-200 |
| *Unacceptable* | >200 | >5 | >5000 | >500 | >200 |

## 2. RESEARCH METHODS

### 3.1 Literature Study

To conduct this research, the author must first gather and study the literature that supports this research. The literature includes journals, books, and online sites that have coating and polyurethane topics.

### 3.2 Material Preparation

The material used in this research is ASTM A36 carbon steel. The dimensions of specimen used were 100mm x 50mm x 10mm for adhesion testing and 40mm x 20mm x 10mm for the corrosion rate testing. The material coatings used were polyurethane coating types of JOTUN Futura Classic. The following is the naming table of test specimens used according to variations in the coating application method.

Table 2. Naming Scheme of The Specimens

| Coating Method | Testing | Specimen Name |
|---|---|---|
| Brush | Adhesion | KA |
| | Corrosion | KK |
| Roll | Adhesion | RA |
| | Corrosion | RK |
| Spray | Adhesion | SA |
| | Corrosion | SK |

### 3.3 Environmental Test

Before coating application is carried out, the environmental conditions of the material must be tested. The function of this environmental test is to prevent the generation of moisture in the test material so that the test material undergoes corrosion before the coating process is carried out. Environmental tests include dry temperature, wet temperature, surface temperature of the material, relative humidity, and dew point.

### 3.4 Blasting Process

After environmental testing, the material is first cleaned of dirt and dust that is still attached before the coating process. The blasting process is carried out to clean the dust and dirt, because it will affect the viscosity of the paint with the test material. Specimen cleaning (blasting) was done using the dry abrasive blasting method. In the cleaning process there are some levels of specimen cleanliness. The level information is provided in the Jotun Technical Data Sheet coating, the recommended level of cleanliness is SA 2.5 referring to ISO 8501-1 standard [18].

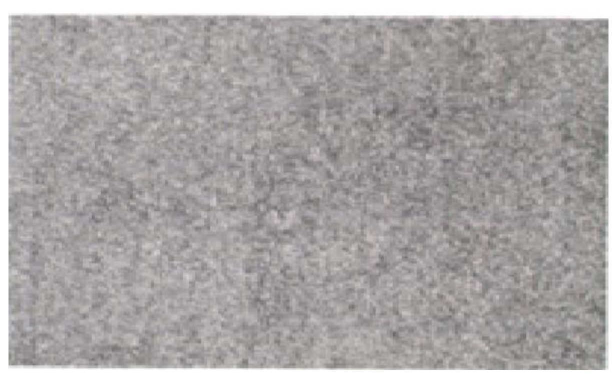

Figure 1. Cleanliness level SA 2,5 [18]

### 3.5 Surface Roughness Measurement

Roughness test is carried out to determine the hardness profile of each specimen that has gone through a blasting process. This test is considered important because it will affect the adhesion properties of the coating to the specimen surface. The standard used in this test is ASTM D4417 - Standard Test Methods for Field Measurement of Blast Cleaned Steel [19]. The hardness testing method is to place the roughness meter on the test specimen, then the roughness value will be known. This test was carried out at three points on each specimen and then the average roughness value of each specimen is calculated.

Figure 2. Surface Roughness Testing Process Specimens

### 3.6 Coating Process

Coating must consider the mixture contained in the Product Data Sheet of paint to allow the coating to get maximum results. The polyurethane paint used was the Jotun Futura Classic product. This product has 2 components, namely component A as base and B as curing. Comparison of component A and B is 4: 1 (by volume). The thinner used was Jotun thinner product no. 10. The coating process was carried out with three different application methods which were the brush, roller, and spray methods.

### 3.7 Measurement of Coating Thickness

After the coating application process is carried out, then the wetness of the paint is calculated to be used as a reference for the dry thickness. Wet thickness is calculated using the formula (1). Depreciation of coating thickness has been listed by the manufacturer on the product data sheet of the paint. The shrinkage of the paint is called solid volume. The volume of solid paint used in this study was 61 ± 2%.

The instrument used to measure wet film thickness is wet film comb. While the tool used to measure dry film thickness is a dry thickness gauge. In this study, the desired film thickness is 60 µm. To get the desired dry film thickness value, you must calculate the wet film thickness value that is applied to the coating process. To determine the wet film thickness the formula [15] can be used:

$$WFT = \frac{Dry\ Film\ Thickness(100+persentase\ thinner)}{\%\ Volume\ Solid} \quad (1)$$

Table 3. Wet Film Thickness Result

| Paint Name | Dry Film Thickness (µm) | Solid Volume | Wet Film Thickness (µm) |
|---|---|---|---|
| JOTUN Futura Classic | 60 | 61±2 | 120 |

### 3.8 Adhesion Testing

Adhesion test is carried out to determine the strength of the coating adhesiveness to the material. The method used to test the adherence of the coating is *pull off test* with ASTM D4541 standard "Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers" [16]. Each specimen was tested at two points to get detailed results and then the average value was calculated. In this test used a tool called a dolly with a diameter of 20 mm and then placed on the surface of the material with epoxy glue for 24 hours. After the glue is dried, then remove the dolly with a *portable adhesive tester*.

### 3.9 Corrosion Rate Testing

Corrosion rate prediction testing in this study used the three electrode cell electrolysis method. This test aims to find out which coating application method is the best to slow down the corrosion rate. The standard used in testing this corrosion rate is ASTM G102 “Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurement” [20]. The equipment used in this test is a three-cell electrode connected to the Autolab PGSTAT128N potentiostat, so that the current generated at any given voltage can be recorded by a computer that has NOVA software in it. This research used NaCl as corrosion media with salinity of 3,5 % and $FeCl_3$ with a salinity of 5% that could represent the sea water as the real corrosion media in the field.

### 3.10 Metallographic Testing

The last test conducted in this study was a metallographic test of materials that had been tested for corrosion before. This test is carried out to determine the type of corrosion that occurs after corrosion testing. Metallographic testing is done by macro and micro photographs. Macro photos are carried out with the help of an ordinary camera without magnification, while micro photographs are carried out with the help of a tool that is usually called a stereo microscope with magnification of 100 µm.

## 3. RESULTS AND DISCUSSION

### 4.1. Roughness Measurement

Table 4. Roughness Measurement Result

| Coating Method | Specimen Name | Surface Roughness | | | Average |
|---|---|---|---|---|---|
| Brush | K1 | 48 | 60 | 50 | 52,7 |
| | K2 | 80 | 82 | 60 | 74,0 |
| | K3 | 60 | 56 | 60 | 58,7 |
| | K4 | 70 | 74 | 69 | 71,0 |
| | K5 | 54 | 50 | 60 | 54,7 |
| | K6 | 56 | 66 | 57 | 59,7 |
| | K7 | 62 | 60 | 62 | 61,3 |
| | K8 | 66 | 72 | 73 | 70,3 |
| | K9 | 68 | 66 | 60 | 64,7 |
| Roll | R1 | 68 | 44 | 50 | 54,0 |
| | R2 | 82 | 70 | 78 | 76,7 |
| | R3 | 54 | 70 | 57 | 60,3 |
| | R4 | 62 | 80 | 76 | 72,7 |
| | R5 | 72 | 58 | 66 | 65,3 |
| | R6 | 60 | 68 | 62 | 63,3 |
| | R7 | 80 | 76 | 60 | 72,0 |
| | R8 | 60 | 72 | 64 | 65,3 |
| | R9 | 68 | 60 | 58 | 62,0 |
| Spray | S1 | 62 | 58 | 64 | 61,3 |
| | S2 | 60 | 66 | 68 | 64,7 |
| | S3 | 70 | 90 | 86 | 82,0 |
| | S4 | 70 | 76 | 78 | 74,7 |
| | S5 | 60 | 62 | 58 | 60,0 |
| | S6 | 70 | 60 | 66 | 65,3 |
| | S7 | 52 | 50 | 58 | 53,3 |
| | S8 | 80 | 62 | 77 | 73,0 |
| | S9 | 72 | 68 | 74 | 71,3 |

### 4.2. *Coating* Thickness Measurement

Table 5. C*oating* Thickness Measurement Result

| Specimen Name | Wet Film Thickness | Dry Film Thickness | | | Average |
|---|---|---|---|---|---|
| K1 | 120µm | 63,5 | 60,4 | 69,9 | 64,6 |
| K2 | 120µm | 54 | 48,5 | 75,6 | 59,4 |
| K3 | 120µm | 73,1 | 74,2 | 77,5 | 74,9 |
| K4 | 120µm | 69,3 | 77,5 | 75 | 73,9 |
| K5 | 120µm | 71,4 | 78,7 | 72,1 | 74,1 |
| K6 | 120µm | 68,3 | 78 | 82 | 76,1 |
| K7 | 120µm | 71,1 | 67,1 | 49,8 | 62,7 |
| K8 | 120µm | 73,5 | 70,7 | 70,9 | 71,7 |
| K9 | 120µm | 78,4 | 75 | 69,6 | 74,3 |
| R1 | 120µm | 74,8 | 60,2 | 52,9 | 62,6 |
| R2 | 120µm | 70,9 | 78,7 | 71,9 | 73,8 |
| R3 | 120µm | 79,5 | 78,5 | 65 | 74,3 |
| R4 | 120µm | 75,5 | 72,4 | 75,1 | 74,3 |
| R5 | 120µm | 73,4 | 71,8 | 67,5 | 70,9 |
| R6 | 120µm | 72,2 | 74,1 | 69,1 | 71,8 |
| R7 | 120µm | 69,8 | 72,1 | 73,8 | 71,9 |
| R8 | 120µm | 78,6 | 69,1 | 70 | 72,6 |
| R9 | 120µm | 68 | 77,3 | 70,4 | 71,9 |
| S1 | 120µm | 69,2 | 75,3 | 71,1 | 71,9 |
| S2 | 120µm | 73,4 | 77,3 | 66,4 | 72,4 |
| S3 | 120µm | 50,2 | 80,1 | 77,3 | 69,2 |
| S4 | 120µm | 78,1 | 67,3 | 70,8 | 72,1 |
| S5 | 120µm | 64,9 | 63,2 | 58,1 | 62,1 |
| S6 | 120µm | 55,6 | 73,2 | 68,9 | 65,9 |
| S7 | 120µm | 69,4 | 64,3 | 75,8 | 69,8 |
| S8 | 120µm | 75,1 | 78,1 | 73 | 75,4 |
| S9 | 120µm | 75 | 73,1 | 67,5 | 71,9 |

From measuring the thickness of the paint in dry conditions, the paint can do the desired tests because it is still within the allowed range based on the desired thickness.

### 4.3. Adhesion Test

Tabel 6. Adhesion Testing Results

| Specimen Name | Adhesion Testing | | Average Adhesion per Specimen (MPa) | Average Adhesion per Method (MPa) |
|---|---|---|---|---|
| | Point 1 | Point 2 | | |
| K1 | 19,22 | 18,85 | 19,04 | 20,40 |
| K2 | 22,04 | 22,02 | 22,03 | |
| K3 | 20,75 | 19,49 | 20,12 | |
| R1 | 22,18 | 18,4 | 20,29 | 20,61 |
| R2 | 22,24 | 18,03 | 20,14 | |
| R3 | 20,71 | 22,07 | 21,39 | |
| S1 | 22,38 | 22,06 | 22,22 | 20,82 |
| S2 | 21,47 | 22,05 | 21,76 | |
| S3 | 19,99 | 16,99 | 18,49 | |

From the table above it can be seen that the highest adhesion value was obtained by S1 specimens with the spray coating application method with an adhesion strength value of 22.38 MPa. The greatest average adhesion strength was also obtained from specimens with the spray coating application method with an averaged adhesion strength value of 20,82 MPa. Whereas the lowest adhesion value was obtained by the specimen S3 with the method of spray coating applications with a value of adhesion strength of 16.99 MPa . The lowest adhesion strength of the specimen obtained by the method of brush coating application with the averaged adhesion strength value of 20.40 MPa.

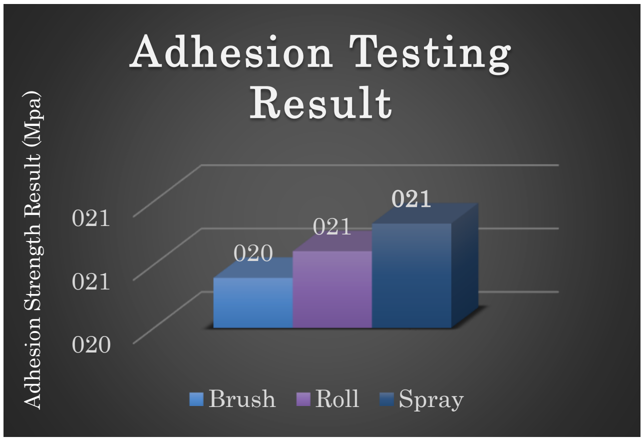


Figure 5. Graphic Adhesion Testing

Based on the results of the conducted pull-off tests, almost all test specimens show that there was a glue failure (bond failure between the glue and the coating) and cohesive failure (a bond failure between the coating and coating). Glue failure occurs because the bond between the coating and the substrate is high with the value of the adhesion strength exceeds the specifications (above 5 MPa). While cohesive failure occurs because the results that have dried paint bubbles appear on the surface due to the uneven coating process using a roller.

### 4.4. Corrosion Rate Prediction Testing

Table 7. Corrosion Rate Testing Result

| Coating Method | Corrosive Media | Specimen Name | Potential (V) | Total Potential (V) |
|---|---|---|---|---|
| Brush | FeCL3 | K4 | - 0,440009 | -0,41529 |
| | | K5 | -0,40747 | |
| | | K6 | -0,39832 | |
| | NaCl | K7 | -0,34153 | -0,35080 |
| | | K8 | -0,34108 | |
| | | K9 | -0,36979 | |
| Roll | FeCl3 | R4 | -0,43261 | -0,44975 |
| | | R5 | -0,42758 | |
| | | R6 | -0,48907 | |
| | NaCl | R7 | -0,45898 | -0,44633 |
| | | R8 | -0,43103 | |
| | | R9 | -0,44899 | |
| Spray | FeCL3 | S4 | -0,36287 | -0,38422 |
| | | S5 | -0,35482 | |
| | | S6 | -0,43496 | |
| | NaCl | S7 | -0,34403 | -0,30410 |
| | | S8 | -0,27667 | |
| | | S9 | -0,29160 | |

Table 7. is obtained from corrosion rate testing using the three electrode cell method with the help of CS Studio5 software. Corrosive media used in this test are NaCl with salinity of 3.5% and FeCl3 with salinity of 5%. Based on the output in Table 7., the predicted values of the corrosion rate on each test material are shown in Table 8.

Table 8. Result of Predicted Corrosion Rate

| Coating Method | Corrosive Media | Specimen Name | Corrosion Rate (mmpy) | Total Corrosion Rate (mmpy) |
|---|---|---|---|---|
| Brush | FeCl3 | K4 | 0,0029401 | 0,0035826 |
| | | K5 | 0,0045436 | |
| | | K6 | 0,0032641 | |
| | NaCl | K7 | 0,000040554 | 0,000043932 |
| | | K8 | 0,000045436 | |
| | | K9 | 0,000045807 | |
| Roll | FeCl3 | R4 | 0,00235 | 0,007273833 |
| | | R5 | 0,0095749 | |
| | | R6 | 0,00990 | |
| | NaCl | R7 | 0,000052981 | 0,00005144 |
| | | R8 | 0,000032647 | |
| | | R9 | 0,000068692 | |
| Spray | FeCl3 | S4 | 0,0017887 | 0,001821507 |
| | | S5 | 0,0033514 | |
| | | S6 | 0,00032 | |
| | NaCl | S7 | 0,000033586 | 0,000025402 |
| | | S8 | 0,000018212 | |
| | | S9 | 0,000024408 | |

From Table 8. the results obtained show that the specimens with spray coating method have the lowest predicted corrosion rate on the corrosive media of NaCl and FeCl3, with the value of 0.000025402 mmpy and 0.00182 mmpy, respectively. While the prediction value of the highest corrosion rate obtained in the coating roll method on the NaCl and FeCl3 corrosive media, with the value of 0.00005144 mmpy and 0.00727 mmpy, respectively.

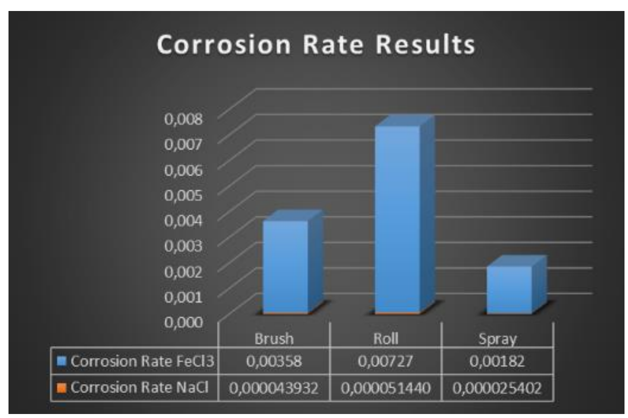


Figure 6. Corrosion Rate Results

Figure 6. shows that the specimen tested using $FeCl_3$ solution has higher corrosion rate than NaCl corrosive media. This is because NaCl is a neutral salt while $FeCl_3$ is an acid salt. Materials with a metal base can corrode quickly to corrosive media containing acids. In addition, specimens

with the spray coating method have the lowest corrosion rate values. This is because the spray coating method produces a flat and smooth surface. While the specimen with coating roll method contains bubbles in its surface. When the paint is dried, the bubbles then make the surface filled with hole and make it easier for corrosive media to contact steel specimens.

### 4.5. Metallographic Testing

This test is carried out to find out what type of corrosion has occurred in the specimens that have been tested to predict the corrosion rate.

Figure 7. Macro Photo Results of $FeCl_3$

Figure 7. shows the results of macro photographs from corrosion rate testing on $FeCl_3$ solution. In the picture, the results show that corrosion has occurred on some surfaces of the test material. Based on direct observation, the type of corrosion that occurs in the image above is the type of pitting and uniform corrosion. Based on ASTM G48, steel materials that work on $FeCl_3$ solution generally experience the phenomenon of pitting and crevice corrosion type.

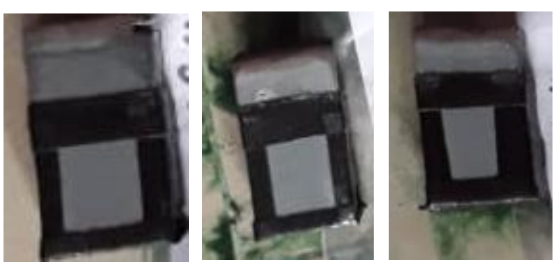

Figure 8. Macro Photo Results of NaCl

Figure 8. shows the results of macro photographs from testing the corrosion rate of NaCl solution. In the picture there is no corrosion occurs on the surface of the test material when seen with the naked eye. However, based on the testing, the corrosion is still occurring albeit the corrosion rate is very small. According Widawardhana (2017), the type of corrosion that occurs in materials that work in the NaCl environment is a type of uniform corrosion.

## 5. CONCLUSION

Based on the research that has been done, the following conclusions are obtained:

1) In adhesion testing the results show that the specimens using spray coating application method have the best adhesive strength values with an average value of 20.77 MPa, while the specimens with brush and roll coating applications each have an average adhesion strength of 20.40 MPa and 20.61 MPa.
2) In testing the corrosion rate prediction using the three electrode cell method with FeCl3 corrosive media, the lowest value was obtained in the spray coating application method with a predicted corrosion rate of 0.00182 mmpy. Whereas the highest corrosion rate prediction on the roll coating application method with the predicted corrosion rate of 0.00727 mmpy.
3) In testing the corrosion rate prediction using the three electrode cell method with NaCl corrosive media, the lowest value was obtained in the method of spray coating application with a predicted corrosion rate of 0.000025402 mmpy. Whereas the highest corrosion rate prediction on the roll coating application method with the predicted corrosion rate of 0.000051440 mmpy.
4) In metallographic testing, the results showed that the corrosion that occurred in the test specimen material with FeCl3 corrosive media experienced a type of pitting corrosion. Whereas the NaCl corrosive media experiences a uniform type of corrosion.

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