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Analysis of Abrasive Materials dan Air Pressure Variations for Thermal Spray Aluminum Coating on Adhesion Strength and Corrosion Resistance in Seawater Environment

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ABSTRACT
Marine structures must withstand the marine environment for a certain design life. However, corrosion causes a decrease in structural integrity before reaching the design life. Thermal spray aluminum coating becomes a protection method because of its resistance to corrosion in the long term. This study analyzed the effect of variations in abrasive materials and air pressure on thermal spray aluminum coating on ASTM A36 steel. The steel material will be blasted with two types of abrasive materials, namely garnet and aluminum oxide, then coated using the electric arc wire spray method at pressures of 2.5 bar, 3.5 bar, and 4.5 bar. Testing was carried out using the pull-off adhesion test and the three-electrode cell method. The results showed that the highest adhesion strength of 12.2 MPa occurred at 4.5 bar aluminum oxide, while the lowest was 6.3 MPa at 2.5 bar garnet. The lowest corrosion rate of 0.001 mm/year was obtained at 4.5 bar garnet, and the highest was 0.101 mm/year at 2.5 bar aluminum oxide. Based on the results of the corrosion rate test, it can be concluded that the increase in pressure is directly proportional to the increase in coating performance in resisting corrosion. Conversely, the increase in surface roughness is inversely proportional to the coating performance in resisting corrosion.

Keywords: *Abrasive Material, Adhesion, Air Pressure, Corrosion, Thermal Spray Aluminum Coating*

1. INTRODUCTION
Fossil energy is still one of the largest energy sources and a commodity that is a global need. Over time, oil and gas exploration and exploitation technology is overgrowing to meet the ever-increasing energy needs. Most of the exploration and exploitation activities are carried out offshore (sea) equipped with supporting facilities and infrastructure such as offshore structures and underwater pipelines.

One of the most frequently used materials in ship structures and offshore structures is steel, especially steel with low carbon content. This is due to the characteristics of low carbon steels, such as good machinability and weldability. This makes low-carbon steels easily machine-formed and easier to join by welding. In addition, this type of steel also has a relatively low price and is easy to obtain. Besides all the advantages of using steel, there are also disadvantages, one of which is corrosion [11].

The primary opponent of steel is corrosion. Corrosion is the destruction or damage (degradation) of materials due to reactions involving reduction and oxidation (redox) between metals and substances in the surrounding environment. This corrosion can decrease the steel quality, resulting in the steel becoming weak and damaged quickly [1].

The corrosion process results are in the form of various products such as metal oxides, damage to metal surface morphology, degradation of mechanical properties, and changes in chemical properties [19]. With a basic knowledge of electrochemical corrosion processes that can explain the mechanism of corrosion, efforts can be made to prevent the formation of corrosion [15]. One of them is to provide a coating on the surface of the material that is prone to corrosion.

Offshore structures, such as jackets, usually have a working life of between 20 and 30 years. Therefore a coating is needed to protect the structure during its operational life. Thermal spray aluminum (TSA) is well known for its advantages, such as its corrosion resistance, no maintenance required, and its ability to protect for a long time so that it can prevent corrosion in the marine environment even beyond the working life of the protected structure [16]. Thermal spray aluminum is often used in offshore building structures because it is suitable for use in areas submerged in water, atmospheric air, or in the splash zone.

The quality and durability of TSA itself are highly dependent on the stage of surface preparation and application [7]. The surface preparation stage is one of the crucial factors in the early stages of coating, which will affect the adhesion strength of the coating [17]. Blasting is the most frequently used method in the maritime industry; the choice of abrasive material used in this process is an essential factor determining the resulting adhesion strength.

It is not uncommon for the coating application process to be carried out outside the room in the maritime industry, which is affected by wind gusts. In the application process carried out outdoors, the air pressure setting provided must be regulated so that the application results can be maximized even though it is exposed to wind gusts.

Therefore, in this final project, we will discuss the effect of variations in abrasive materials and the regulation of air pressure on the nozzle in the application process of TSA on adhesion resistance and corrosion resistance in the marine environment.

2. RESEARCH METHODOLOGY

2.1 Specimen Preparation

This study used ASTM A36 steel plate specimens. The total specimens used were 36 specimens, with 18 specimens measuring 10 cm x 5 cm x 1 cm for adhesion testing and 18 specimens measuring 4 cm x 2 cm x 1 cm for corrosion rate testing.

2.2 Surface Preparation (Blasting)

Surface preparation has the function of cleaning the surface from dust, corrosion, oil, and other impurities. This stage also makes the surface of the material rougher to provide better adhesion strength between the surface of the material and the coating paint. Surface preparation is carried out using the dry abrasive blast cleaning method by spraying the abrasive material until it strikes the material's surface to be coated. In this final project, two types of abrasive materials are used in the sandblasting process, namely aluminum oxide and garnet. The sandblasting process is carried out until it reaches a level of cleanliness in accordance with the desired standard in this study, namely Sa 3 according to ISO 8501 [10].

2.3 Visual Inspection of Blasting Results

At this visual inspection stage, the results of the sandblasting process are visually inspected to ensure that surface of the material after blasting follows the desired standard according to the cleanliness level in ISO 8501-01. This inspection process is carried out by comparing the blasted surface with the level of cleanliness Sa 3 at ISO 8501-01 [10].

Figure 1. Cleanliness Level Sa 3 [10]

2.4 Surface Roughness Testing

The surface of a material must have a specific roughness so the applied coating paint can adhere and have a good level of adhesion. The roughness test in this study used a roughness meter to measure the roughness value on the surface of the test material. The procedure for testing surface roughness in this study refers to the ASTM D4417 [3] standard as a reference.

Figure 2. Surface Roughness Testing Process

2.5 Coating Process

The coating process uses the electric arc wire spray coating method [12] with the coating material in the form of 1.6 mm aluminum wire with a voltage setting of 28 V, a current of 150-250 A, and a temperature of 660ºC. In this study, air pressure variation is 2.5 bar, 3.5 bar, and 4.5 bar.

Figure 3. Coating Layer On Top of Specimen After The Coating Process

2.6 Dry Film Thickness Testing

This measurement aims to determine the thickness of the aluminum layer on ASTM A36 steel when the coating material has dried. The thickness of the layer must be ensured evenly and does not differ much from one point to another. This test refers to the ASTM D4138 standard – Standard Method of Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means [6]. This measurement is carried out using a coating thickness gauge.

In the case of thermal spray aluminum, it is slightly different from liquid coatings in general. In TSA coating, metal material sprayed on the surface of the specimen will dry immediately without requiring drying time (curing time)

So that the results from TSA do not have a wet film thickness (WFT) number. Dry film thickness testing on the TSA coating can be carried out as soon as the coating material attached to the specimen returns to normal temperature or room temperature. Measurement of dry film thickness was carried out using a coating thickness gauge with measurements in 3 areas of each specimen and three measurement points in each area so that for each specimen, nine thickness values were obtained, which were averaged to obtain the dry film thickness (DFT) [6].

Figure 4. Dry Film Thickness Testing Process

2.7 Adhesion Testing

Adhesion testing aims to determine the effect of the choice of abrasive material during the blasting process and air pressure during the application of TSA coating on the adhesion between the paint layer and the substrate material. The method used in this study is a pull-off test that complies with the ASTM D4541-2 standard "Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers." [4]

Figure 5. Pull Off Adhesion Testing Processsa

In this test, each specimen is tested at 3 points which are then averaged to obtain an accurate adhesion value [4]. This test is carried out by attaching the dolly to each test point using a special adhesive glue. Then wait for the glue to dry for 24 hours. After drying, the dolly will be pulled using a portable adhesive tester to get the value of the coating's adhesion to the material.

2.8 Corrosion Rate Testing

The corrosion rate test in this study uses the three-electrode cell method with the help of the CorrTest potentiostat tool and CS Studio 5 software. This corrosion rate test refers to the ASTM G102 - Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements [5]. Corrosion rate testing using ASTM A36 steel samples with dimensions of 40 mm x 20 mm x 10 mm, which has been coated with a layer of aluminum. The electrolyte solution used in this test is a 3.5% NaCl solution. In testing the corrosion rate with the three-electrode cell method, three types of electrodes are used, including:

• The working electrode tested is ASTM A36 steel.
• The reference electrode used is Calomel.
• The auxiliary electrode used is Graphite.

The potentiostat used controls the potential difference between the reference electrode and the working electrode and measures the current flow between the working electrode and the auxiliary electrode. CS Studio 5 software function calculates the corrosion rate, potential, current density and forms a tafel graph. The Tafel diagram consists of the x-axis, which shows the potential, and the y-axis, which shows the current density. During the test, the potential values and current density measured on the specimen are formed into points which will later form a tafel graph [18].

Table 1. Classification of relative corrosion resistance [8]

Relative Corrosion Resistance	Approximate Metric Equivalent				
	mpy	mm/yr	µm/year	nm/yr	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 - 100	20 - 50
Poor	50 - 200	1 - 5	1000 - 5000	150 - 500	50 - 200
Unacceptable	>200	>5	>5000	>500	>200

3. RESULT ANALYSIS AND DISCUSSION

Guidelines for table and figure format and arrangement are described in the following sub-sections.

3.1 Adhesion Test Results

The adhesion test was carried out using the pull-off adhesion test method, which complies with the ASTM D4541 standard. In this adhesion test, each specimen is tested at 3 points [4] which are then averaged so that the following results are obtained :

Table 2. Adhesion Test Results

Abrasive Material	Air Pressure (bar)	Pull-Off Test Results (MPa)
Garnet	2,5	6,3
	3,5	7,6
	4,5	7,1
Aluminium Oxide	2,5	9,3
	3,5	9,5
	4,5	12,2

From the results of the adhesion test above, it can be seen that the value of the greatest adhesion strength is found in the variation of the aluminum oxide abrasive material with a pressure of 4.5 bar at 12.2 MPa and the lowest adhesion value in the variation of the garnet abrasive material with a pressure of 2.5 bar at 6, 3 MPa. It can be seen that the tendency of the adhesion strength of specimens blasted with aluminum oxide abrasive material, which has a higher surface roughness value, can provide better adhesion strength than garnet so that the choice of abrasive material is a very influential factor in the results of the adhesion strength of the TSA coating [2].

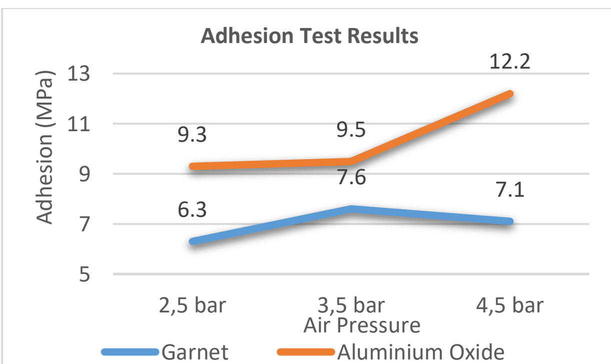

Figure 6. Graphic of Adhesion Test Results

In addition, the aluminum oxide abrasive material shows that the higher the applied pressure, the better the adhesion strength and the higher the value. This pattern is also seen in the garnet abrasive material, where at a pressure of 2.5 bar and 4.5 bar, it shows an increase in the value of adhesion, except at a pressure variation of 3.5 bar, it has a higher value than a pressure of 4.5 bar. This aberration can occur due to the uneven thickness of the aluminum layer during the coating application process. In this study, the desired thickness ranged from 500-700 µm, while the specimen with garnet abrasive material and a pressure of 3.5 bar had a thickness of only 445.48 µm. This makes the specimen has a better adhesion value because of its thinner coating layer [9].

3.2 Corrosion Rate Test Results

Corrosion rate testing in this study used the three-electrode cell method with the help of the CorrTest potentiostat tool and CS Studio 5 software. This corrosion rate test refers to the ASTM G102 standard [5], with the following results:

Table 3. Corrosion Rate Test Results

Material Abrasif	Air Pressure (bar)	Corrosion Rate (mm/yr)
Garnet	2,5	0,034
	3,5	0,007
	4,5	0,001
Aluminium Oxide	2,5	0,101
	3,5	0,065
	4,5	0,013

The table above shows that the lowest corrosion rate was found in specimens with a variation of garnet abrasive material and a pressure of 4.5 bar with an average corrosion rate of 0.001 mm/yr. In contrast, the highest corrosion rate is found in specimens with a variety of aluminum oxide abrasive material with a pressure of 2.5 bar with a corrosion rate of 0.101 mm/yr. The corrosion rate produced by specimens with variations of garnet abrasive material has a lower tendency of corrosion rate when compared to aluminum oxide abrasive material. In addition, if we look at the two variations of abrasive material, the increase in air pressure makes the corrosion rate lower, which means that higher air pressure has a better performance compared to the lower one.

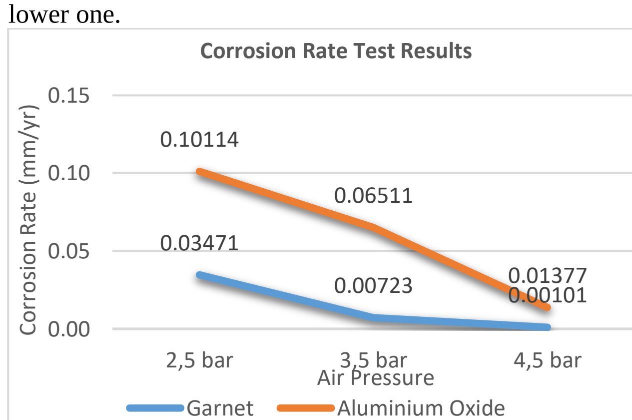

Figure 7. Graphic of Corrosion Rate Test Results

4. CONCLUSIONS

Based on this research and experiment, several conclusions were obtained as follows :

a. From the test results, it was found a trend where specimens blasted with aluminum oxide abrasive material had better adhesion than specimens blasted with garnet abrasive material because aluminum oxide abrasive material provided a rougher surface roughness profile with an average of 104,67 µm compared to garnet abrasive material which has an average roughness of 64.33 µm. This rougher surface profile will help the aluminum material sprayed on the substrate to produce better mechanical interlocking [13].
b. In air pressure variations, there is also a tendency to increase the applied air pressure, accompanied by

increased adhesion strength. The increase in adhesion can happen because the aluminum particle impact speed will increase when the air pressure is higher. The greater the air pressure, plastic deformation will occur between the coating particle and the substrate surface (specimen), so the resulting porosity will be smaller. The sprayed aluminum particles will be smoother and more evenly distributed, which increases the adhesion and cohesion of the coating [14].

c. Based on the corrosion rate test using the three-electrode cell method, the lowest corrosion rate results were found in specimens with variations of garnet abrasive material with a pressure of 4.5 bar at 0.001 mm/yr. In contrast, the highest corrosion rate results were found in specimens with variations of aluminum oxide abrasive material with a pressure of 2.5 bar at 0.101 mm/yr. This result can happen because the surface roughness value of the specimen using the garnet abrasive material is lower than the surface roughness value of the specimen using the aluminum oxide abrasive material. It can be concluded that the higher the surface roughness value of the specimen, the greater the porosity produced; therefore, the growth of the passive layer will be disrupted so that the resulting corrosion rate will be even greater. Likewise, on a smoother surface, the porosity will be smaller, and the formation of a passive layer on the material will be easier so that the resulting corrosion rate will be smaller.

d. Air pressure variations in the corrosion rate test result in a tendency that increasing the applied air pressure causes the resulting corrosion rate to be slower. Both variations of abrasive material show that the lowest corrosion rate results at a pressure of 4.5 bar, which then increases at a pressure of 3.5 bar and 2.5 bar. The stronger the impact produced by the increase in pressure, the porosity of the coating will be smaller, and the material (substrate) can be well insulated. With high air pressure, the atomization speed of aluminum will be better so that the particle size of aluminum becomes smaller/smooth and melts more evenly than at lower pressures because the cavity formed between particles (porosity) can be minimized.

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