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The Effect Analysis of Coating Thickness Variation and Mixed Composition of Zinc - Graphite on Epoxy Coating with Steel Plate ASTM A36

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ABSTRACT

Steel has an important role in the world of marine manufacturing industry. Steel for offshore buildings needs to be reviewed in terms of controlling metal corrosion. The coating method can be used in mobilization areas and splash zones of offshore buildings that have high corrosion rates due to sustained friction loads in the marine environment. This study used steel plate ASTM A36, which is a low carbon steel, and analyze its adhesion strength, abrasion resistance, and corrosion rate prediction by varying the coating thickness of 100µm, 200µm, and 300µm, with a mixture of Zinc-Graphite on epoxy coatings of 2%, 6%, and 10 %. In the Pull-Off test the highest value of adhesion strength was obtained at a mixture of 2% and coating thickness of 100µm with a value of 8.73 Mpa. In the highest abrasion test values was obtained with a variation of 10% mixture and coating thickness of 300µm with a value of 0.91 Wear Cyces per Micrometer. Whereas in the three-cell electrode test the highest value was at a 100% mixture variation and coating thickness of 300µm with a value of 0,00010 mmpy..

Keywords: *Epoxy Coating, Graphite, Zinc, Adhesion, Abrasion, Corrosion.*

1. INTRODUCTION

Indonesian territorial waters have the potential to support the nation's economy if developed correctly. The development of the maritime industry in Indonesia continues to bring innovations that support the facilities and infrastructure needed. The current government also conducts massive exploration, exploitation, and marine transportation. To support all of that, facilities and infrastructure must meet high standard so that it has a long operational life. Steel is a very commonly used material in the industrial world. ASTM A36 steel is widely used in the maritime industry due to its easiness to forge, machine, and weld. Although it does have a high level of ductility and toughness, the steel is not free from corrosion. Corrosion on steel materials can lead to a decrease in material quality.

Corrosion is inevitable, it can occur in all materials. One of the factors that affects the rate of corrosion is the environmental conditions, especially in maritime industry. Environmental corrosion with chloride ion levels of more than 3% is highly susceptible to steel materials. Corrosion can decrease in the quality of metals caused by electrochemical reactions between metals and the surrounding environment. Corrosion is a very serious problem, it can become the cause of many offshore structure failures. Some methods of corrosion resistance are cathodic protection, coating, and the use of chemicals.

Coating is a process of applying layer to the surface of a substrate that can be used for decorative purpose, functional aspect, or both. In experiments conducted by Afandi (2015) [6], it is found that thicker coating thickness did not guarantee perfect protection due to the mechanical and physical strength of the coating material. The application of coatings besides protecting against corrosion must also have abrasion and adhesion strength, another factor of particle friction caused by sand due to waves or tidal waves. The coating material will experience friction and become worn out so that it cannot protect against corrosion, in order for the material to survive in the above environment then the coating must have high hardness properties, shock resistant and tough adhesion. The addition of zinc is often used to make the rate of corrosion in substrates slower. The addition of zinc-phosphate with a non-dissolved modification in epoxy can increase the corrosion resistance of up to >11,000 hours to aluminum alloy material [9]. Zinc is non-toxic, environmentally friendly, relatively cheap and has good corrosion resistance [10]. While for abrasive strength the addition of materials is also required, one of them is graphite. Graphite has unique properties with high rigidity but is easily shifted [11]. The addition of graphite to the NiCrBSi coating led to increased abrasive strength. The addition of graphite to Al2O3-13TiO2 lowers the coefficient of friction and abrasive wear rates due to graphite self-lubricating film properties. Rekha M.Y. (2019) [14] and Ge et al. (2020) [15] combined zinc and graphite materials to strengthen abrasive resistance and reduce corrosion rates on substrates, both studies did not experiment on A36 steel materials.

Therefore, this final task research will conduct experiments on anti-abrasion testing, adhesion strength and corrosion rate with various zinc-graphite composition and thickness variation of ASTM A36 steel epoxy coating. The result of this research is to know the optimal composition and thickness of epoxy coating for abrasion, adhesion, and corrosion protection in ASTM A36 steel.

2. RESEARCH METHODOLOGY

2.1 Literature of the Study

This research was carried out based on the literature referring to journals and books from sites that discuss the application of corrosion control with the Coating method using a mixture of Epoxy paint with zinc and graphite that applied using the Airless Spray Coating method.

2.2 Material Preparation

In this study the material used is ASTM A36 steel plate. The dimensions of the specimen used were 120x90x10 mm for adhesion testing, 50x50x10 mm for abrasion testing, and 40x20x10 for corrosion rate testing. The coating material used were the epoxy primer paint with the brand of Jotun Penguard Gray and Zinc-Graphite. The naming scheme of test specimens used in accordance with variations of Zinc-Graphite levels is shown in Table 1.

Table 1. Naming of Test Specimens

Zn-Graphite Content	2%	6%	10%
Adhesion Test	A1	A2	A3
Abrasion Test	A11	A21	A31
Corrosion Test	a11	a21	a31

2.3 Blasting Process

Before conducting the coating process, the material is cleaned from dirt and dust that may affect the level of adhesion of the paint on the test material. Specimen is cleaned using the Dry Abrasive Blasting method. There are several levels of specimen cleanliness, which can be found in Jotun Technical Data Sheet coating, the recommended level of cleanliness is SA 2½ with ISO 8501-1 standard [21]. There are also levels of dust impurities that are still present on the surface of the material in accordance with the specifications of the paint and regulated to the ISO 8502-1 standard [22].

Figure 1. Cleanliness Level SA 2 ½ [20]

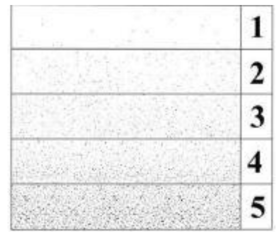

Figure 2. Pollution Level of Dust Surface on Material [21]

2.4 Surface Roughness Measurement

This test is carried out to determine the roughness profile of each specimen that has passed the blasting process. The roughness profile of the material is important because it can affect the level of adhesion of the paint on the test material. This test used a roughness meter and the D4417 "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel" [23]. This test is carried out at three points on each specimen and the average value is calculated.

Figure 3. Specimen Surface Roughness Testing Process

2.5 Coating Process

The coating process must follow the guidelines contained in the Technical Data Sheet of paint so that the coating process gets maximum results by using an air spray gun. In this study, epoxy primer paint was mixed with Zinc-Graphite with variations of 2%, 6%, and 10% of the total paint volume used, that is 100 ml per variation. The epoxy primary paint used is from Jotun Penguard Primary Gray product. This product has 2 components, namely component A as base and B as curing. When mixing the two components, they must refer to the Technical Data Sheet with the ratio of 4: 1 (by volume). The thinner used was Jotun thinner product no. 17.

Table 2. Composition of Coating Content

Zn-Graphite percentage	Composition		
	Zn (ml)	Graphite(ml)	Paint(ml)
2%	1	1	98
6%	3	3	94
10%	5	5	90

2.6 Measurement of Coating Thickness

In the coating process, there are two kinds of coating thickness, namely wet film thickness and dry film thickness. The coating layer that has been applied will shrink according to the Technical Data Sheet of each paint. The shrinking of paint has been listed on the volume of solid paint (Jotun) used, which is 51±2%. So that within the drying time specified in the technical data sheet, the desired wet film thickness can be obtained. The instrument used to measure wet film thickness is wet film comb. While the tool used to measure dry film thickness is a thickness gauge coating. In this study, the desired variation of dry film thickness is 100 µm, 200 µm, and 300 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 used were:

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

The obtained calculation results, with 100 ml of total paint volume, is shown in Table 3.

Table 3. Calculation of Wet Film Thickness

Dry Film Thicknesss (µm)	Volume Solid (%)	Wet Film Thickness (µm)
100	51±2%	±200
200	51±2%	±400
300	51±2%	±600

2.7 Adhesion Testing

Adhesion strength testing is carried out to determine the effect of variations in the addition of Zinc-Graphite and thickness of the coating on its adhesion to the material. The method used to test the adhesion of the coating is Pull Off Test with ASTM D4541 "Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers" [20]. Three points of each specimen was tested to get detailed results, then the three results were averaged. This test used a dolly with a diameter of 20 mm and then placed on the surface of the material with glue for 24 hours. The next step is pulling the dolly with a portable adhesive tester.

2.8 Abrasion Testing

In this study, the Abrasive Test was conducted as an indicator to determine the effect of adding the Zinc-Graphite composition and thickness of the epoxy coating, using the Taber Abraser method with the ASTM D4060 "Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser" [24]. In this test using a load of 1000 grams, a stone grinding wheel type 120, a lathe at 170 RPM, and an auxiliary arm to clamp the test specimen on the lathe with a test interval for 1 minute until the steel substrate is visible.

2.9 Corrosion Rate Prediction Testing

In this research, the prediction of corrosion rate testing is done as an indicator to determine the influence of the addition of Zinc-Graphite composition and thickness of epoxy coating using the three electrode cell method with ASTM G102 "Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements" [25]. In this test the use of NaCl solution with a salinity of 3.5% to represent the real sea water. Each specimen will be tested on 3 different points and then the results value will be averaged.

3. RESULT ANALYSIS AND DISCUSSION

3.1 Coating Adhesion Testing

From Table 4, it can be seen that the highest adhesion value obtained by specimen A1, which has a mixture of Zinc-Graphite of 2% and coating thickness of 100 µm, with a value of 8.73 MPa. While the lowest adhesion value obtained by specimen C3 which has 10% Zinc-Graphite mixture and coating thickness of 300 µm with a value of 3.03 MPa.

Table 4. Adhesion Test Results

Specimen Name	Zn-Graphite Composition	Adhesion Strength (Mpa)			
		1	2	3	Mean
A1	2%	8,57	9,97	7,65	8,73
B1	2%	5,42	5,8	7,83	6,35
C1	2%	5,25	5,37	5,85	5,49
A2	6%	6,77	6,26	6,22	6,42
B2	6%	5,44	4,96	5,16	5,19
C2	6%	3,68	3,72	4,26	3,89
A3	10%	4	3,61	2,6	3,40
B3	10%	3,3	2,53	3,9	3,24
C3	10%	3,9	2,04	3,14	3,03

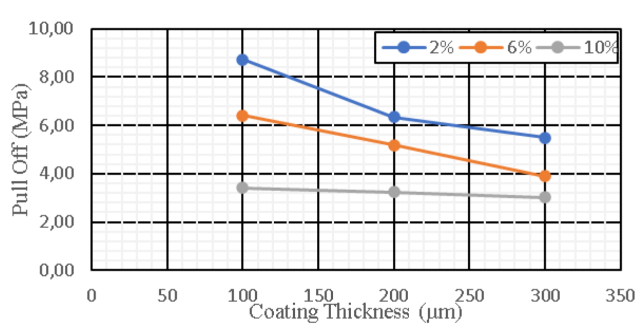

Figure 4. Graph of Adhesion Test Results

Based on the results of pull off tests displayed on the graph above, it shows that adhesive failure (bond failure between coating and substrate / steel) and cohesive failure (bonding failure between coating and coating) occurred in the test specimens. Cohesive failure occured because the addition of Zinc-Graphite pigment added to the epoxy prevented the bonding process between epoxy constituents. This phenomenon is commonly called coating disbondment. This is consistent with previous studies conducted by Olad (2012) [26] who explained that the increasing number of pigment additions to organic epoxy can reduce the adhesion properties of the coating.

3.2 Testing of Abrasion Coating Resistance

From Table 5, it can be seen that the highest abrasion resistance value is obtained by specimens that have 10% Zinc-Graphite mixture and coating thickness of 300 µm with a value of 0.81 Wear Cyces Per Micro, while the lowest adhesion value is obtained by specimens that have 2% Zinc-Graphite mixture and coating thickness of 100 µm with a value of 0.30 Wear Cyces Per Micro.

Table 5. Abrasion Test Results

Specimen Name	Testing time (s)	Variation	Wear Cyces Per Micro	Average
A11	11	100µm, 2%	0,31	0,30
A12	9	100µm, 2%	0,26	
A13	12	100µm, 2%	0,34	
B11	25	200µm, 2%	0,35	0,41
B12	29	200µm, 2%	0,41	
B13	33	200µm, 2%	0,47	
C11	47	300µm, 2%	0,44	0,47
C12	50	300µm, 2%	0,47	
C13	53	300µm, 2%	0,50	
A21	15	100µm, 6%	0,43	0,41
A22	14	100µm, 6%	0,40	
A23	14	100µm, 6%	0,40	
B21	33	200µm, 6%	0,47	0,51
B22	37	200µm, 6%	0,52	
B23	38	200µm, 6%	0,54	
C21	58	300µm, 6%	0,55	0,56
C22	57	300µm, 6%	0,54	
C23	64	300µm, 6%	0,60	
A31	20	100µm, 10%	0.57	0.62
A32	24	100µm, 10%	0.68	
A33	22	100µm, 10%	0.62	
B31	47	200µm, 10%	0.67	0.60
B32	49	200µm, 10%	0.69	
B33	50	200µm, 10%	0.71	
C31	81	300µm, 10%	0.77	0.81
C32	85	300µm, 10%	0.80	
C33	90	300µm, 10%	0.85	

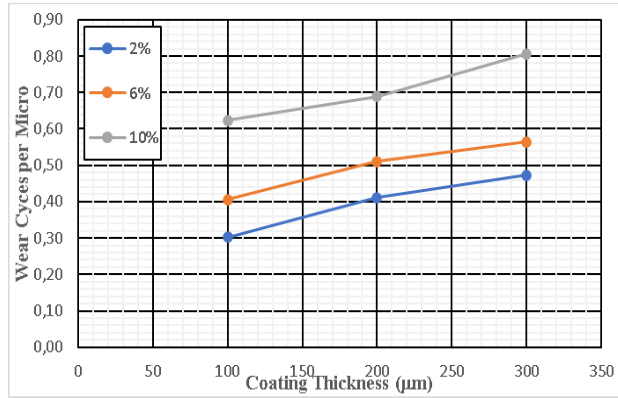

Figure 5. Curve of Abrasion Test Results

From the results of the abrasive test, it was found that the thicker the coating, the greater the abrasive resistance would be. Referring to Figure 5, it can be seen that the best abrasion resistance obtained on specimens that have coating thickness variation of 300 µm. It is due to the thick coating, that the abrasion process will take longer time along with the addition of the appropriate Zinc-Graphite pigment filler, so that it increases the physical properties of the coating. In a previous experiment conducted by Barbhuiya (2017) [28] stated that the thicker the coating, the greater the bond between molecules would be. Whereas in this study it was found that 10% Zinc-Graphite gives the best result with 0.81 wear cyces per micrometer, this was due to more even distribution of the filler composition.

3.3 Corrosion Rate Prediction Testing

From Table 6, c3 specimen with 10% Zinc-Graphite content and 300 mm thickness had the lowest corrosion rate, with a value of 0,00012 mmpy. Whereas the highest predicted corrosion rate was obtained in specimen A1 which contained 2% Zinc-Graphite and coating thickness of 100 µm which had a value of 0.04270 mmpy.

Table 6. Corrosion Rate Value Results

Specimen Name	Zinc-Graphite (%)	Corrosion Rate(mmpy)			Total Corrosion Rate(mmpy)
		1	2	3	
a1	2	0,03351	0,038512	0,04270	0,03824
b1	2	0,00084	0,00076	0,00990	0,00383
c1	2	0,00022	0,00032	0,00065	0,00040
a2	6	0,01403	0,01217	0,01506	0,01375
b2	6	0,00345	0,00179	0,00241	0,00255
c2	6	0,00024	0,00014	0,00019	0,00019
a3	10	0,01340	0,01383	0,01294	0,01339
b3	10	0,00157	0,00197	0,00185	0,00180
c3	10	0,00017	0,00012	0,00024	0,00018

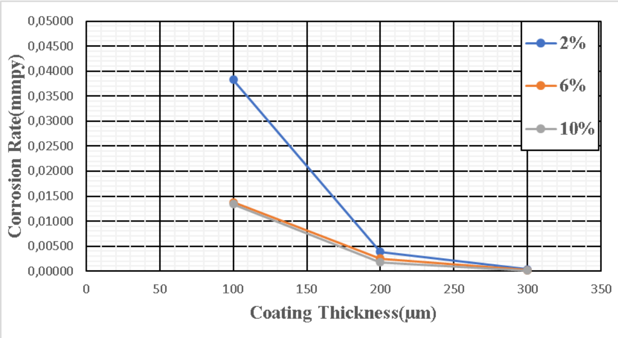

Figure 6. Graph of Corrosion Rate Prediction Test Results

It can be seen in Figure 6, that the increase of coating layer thickness and substrate addition in the form of Zinc-Graphite can affect ASTM A36 steel plate corrosion resistance to the surrounding environment, in this case 3.5% NaCl represent the real conditions as a corroder liquid. The graph above shows that the increase in Zinc-Graphite powder applied and epoxy coating thickness follow a downward trend in predicted corrosion rate. The smaller the value of the corrosion rate of a material, the better the resistance of the material to corrosion [3].

4. CONCLUSIONS

Based on the discussion and results of analysis conducted in the previous chapter on the influence of variations in the composition of Zinc powder with graphite powder and thickness of epoxy coating on ASTM A36 steel, several conclusions were obtained in response to the formulation of problems in this study, which were:

1. From the adhesion test using Pull Off Adhesion Test method, the largest adhesion value can be found in specimen A1 with coating thickness variation of 100 µm and composition of Zn-Graphite 2% with adhesion value of 8.73 MPa. While the smallest adhesion value obtained by specimen C3 with a variation in coating thickness of 300 µm and composition of Zn-Graphite 10% with an adhesion value of 3.03 MPa. It can be concluded that the increase of zinc-graphite pigment and coating thickness can lower the value of its adhesion.
2. From abrasive resistance testing using Taber Abraser Test method, the largest abrasion resistance value obtained at 300 µm coating thickness variation and 10% Zn-Graphite composition with a value of 0.81 Wear Cyces Per Micrometer. While the smallest abrasive resistance value is obtained with a variation in coating thickness of 100 µm and 2% composition of Zn-Graphite with a value of 0.30 Wear Cyces Per Micrometer. Thus, the increase in zinc-graphite pigment and coating thickness can increase the abrasion resistance.
3. From the corrosion rate prediction test using the Three Electrode Cell method assisted by CS Studio 5, the lowest corrosion rate prediction value obtained by 300 µm thickness variation and Zn-Graphite composition of 10% by 0.00018 mmpy. While the highest corrosion rate prediction value is obtained by the variation in thickness of 100 µm and the 2% composition of Zn-Graphite by 0.03824 mmpy. Therefore, the addition of coating thickness and zinc-graphite pigment will result in a very small rate of corrosion compared to that which consist of only one pigment.

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