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The Effect Analysis of Coating Thickness Variation and Mixture Composition of Magnesium – Flake Glass on Epoxy Coating on Abrasive Resistance, Adhesion Strength, and Prediction of Corrosion Rate of ASTM A36 Steel Plate

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ABSTRACT
Steel cannot be separated from the marine manufacturing industry. It is important to control the corrosion rate of steel used for offshore structures. The coating method can be used in mobilization areas and splash zones that have high corrosion rates due to sustained friction loads in the marine environment. The purpose of this study was to analyze the different in adhesion strength, abrasion resistance, and corrosion rate prediction of ASTM A36 low carbon steel plate with coating thickness variations of 300µm, 500µm, and 700µm and Magnesium Carbonate - Flake Glass mixture variations of 10%, 20%, and 30%. In the pull-off test, the highest value of adhesion strength was obtained from specimen with 300µm coating thickness and 10% Magnesium Carbonate - Flake Glass mixture with a value of 5.67 Mpa. The highest abrasion test value was obtained from specimen with 700µm coating thickness and 30% Magnesium Carbonate - Flake Glass mixture with a value of 0.91 Wear Cyces per Micrometer. Whereas in the three cells electrode test, the highest value was found at specimen with 700µm coating thickness and 30% Magnesium Carbonate - Flake Glass mixture with a value of 0,00010 mmpy.

Keywords: *ASTM A36 Steel Plate, Epoxy Coating, Flake Glass, Magnesium, Adhesion, Abrasion, Corrosion.*

1. INTRODUCTION

Indonesia is an archipelagic country with approximately seventeen thousand islands and has the second longest coastline in the world. Indonesia is also blessed with a sea area that is 70 percent wider than its island territory, as well as one of the countries that is rich in natural resources. Therefore, maritime sector activities and utilization of marine products are the main focus in supporting economic, environmental, socio-cultural, legal, and security aspects. Various maritime technology innovations to support the implementation of a modern maritime industry need to be done for the development of all the needed facilities and infrastructure. The Indonesian government is currently doing a major breakthrough in the field of exploration, exploitation, and sea transportation. The rapid development of the marine industry must also be balanced with high quality facilities and infrastructure so that it can be used for a long period of time. At present, most of the materials used in the maritime industry are steel. This is because steel is able to withstand long-term operational conditions. However, steel can be easily corroded so protection methods are needed to prevent it.

Environmental condition is one of the main causes of natural corrosion, so the maritime industry which operate in the seawater environment is very susceptible to corrosion. Corrosion can be described as a decrease in the quality of metals caused by electrochemical reactions between metals and the surrounding environment [20]. Corrosion can result in material losses due to the decreasing quality of steel so that the steel can be easily damaged [14]. Corrosion is also one of the main causes of failure of a structure, especially in offshore structures. Therefore, the rate of corrosion that occurs in offshore structures that comes in direct contact with the corrosive environment needs to be reduced. Many methods in controlling corrosion include cathodic protection, coating, and the use of chemicals [10].

The most common method used for controlling corrosion is the coating method. Coating itself is a process to coat a substrate which aims to protect the material from corrosion and provide protection to the material [2]. Coatings carried out on shipbuilding, offshore structures, helicopter decks, and barges are not only for protection from corrosion but also have abrasion and adhesion properties [7]. Application of coating material on these components will receive friction due to mobilization, such as when the helicopter landed or when the ship docked, another factor causing friction is the friction of particles such as sand due to waves or tidal waves. The coating material will be rubbed away so that it cannot protect from corrosion, in order to withstand the harsh environment, the coating must have high toughness, shock resistant and adhesion properties [11]. Meanwhile, according to Afandi (2015) [1] the thicker the coating thickness does not guarantee a perfect protection because of the mechanical and physical strength of the coating material.

According to Turel (2011) [19] in his research stated that the addition of magnesium powder has been successfully used as an anti-corrosive pigment in primary coatings containing magnesium on metal substrates and to cathodically protect metals from corrosion. The addition of magnesium to epoxy primary coatings is very beneficial to increase the lifetime of offshore structures that are directly exposed to corrosive environments. In a study conducted by Lu (2010) [17] also stated that metals that have been coated with epoxy coating containing magnesium can cause the rate of corrosion that occurs in the metal to be delayed / low so that the protective effect (barrier effect) really works.

According to Barbhuiya (2017) [9] in his study explaining the presence of glass flakes further enhances the anti-corrosion performance of this layer. The effect of the addition of the glass flake element on material's corrosion rate was also investigated by Banerjee (2014) [8] who explained that the epoxy flake glass system is a chemical cross-linked structure with a much less porosity for dry films. Whereas in the research of Gonzalez-Gusman (2010) [13] explained that the organic layer which contains glass flakes as pigments to improve its protective characteristics and shows that this layer adheres better and shows higher protection characteristic when applied to carbon steel substrates than galvanized steel.

Therefore, in this final project, an experiment is carried out on anti-abrasion testing, adhesion strength and corrosion rate in a variation of the composition of the magnesium-flake glass mixture and thickness of the epoxy coating on ASTM A36 steel plate. The results of this final project are expected to know the optimal Magnesium-flake glass composition and thickness in epoxy coating for abrasion and adhesion protection on ASTM A36 steel plate.

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 magnesium carbonate powder and flake glass which will be applied using the Airless Spray Coating method.

2.2 Material Preparation

In this study the material used was 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. As for the coating material used were the epoxy primer paint with the brand of *Jotun Penguard* Gray and MgCo3-Flake Glass. The following is the naming table of test specimens used in accordance with variations in the addition of MgCo3-Flake Glass levels.

Table 1. Naming of Test Specimens

Content of $MgCO_3$-Flake Glass	10%	20%	30%
Adhesion Test	A1	B1	C1
Abrasive Test	A11	B11	C11
Corrosion Rate Test	A111	A221	A331

2.3 Blasting Process

Before conducting the coating process, the materials were cleaned from dirt and dust that were still attached, because the dust and dirt will affect the adhesion level of the paint with the specimen. Specimen was cleaned using the Dry Abrasive Blasting method. There are several levels of specimen cleanliness, that could be seen in the *Jotun* Technical Data Sheet coating, the recommended level of cleanliness is SA 2½ with ISO 8501-1 standard [15]. In addition, there are levels of dust impurities that were still present on the surface of the material in accordance with the specifications of the paint and regulated to the ISO 8502-1 standard [16].

Figure 1. Cleanliness Level SA 2 ½ [15]

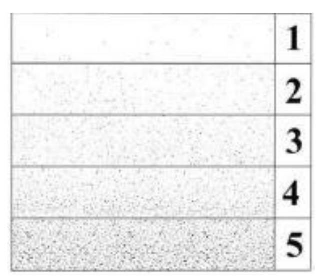

Figure 2. Pollution Level of Dust Surface on Material [16]

2.4 Surface Roughness Measurement

This test was 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 affects the adhesion level of the paint on the test material. This test used a roughness meter and the D4417 standard "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel" [4]. This test was carried out at three points on each specimen and the average value was calculated.

Figure 3. Specimen Surface Roughness Testing Process

2.5 Coating Process

The coating process must follow guidelines contained in the Technical Data Sheet of paint so that the coating process gets maximum results and uses an air spray gun. In this study, epoxy primer paint was mixed with MgCO3-Flake Glass with variations of 10%, 20%, and 30% of the total volume of paint used, which is 200 ml per variation. The epoxy primer paint used was 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 in the ratio of 4: 1 (by volume). The thinner uses *Jotun* thinner product no. 17.

Table 2. Composition of Coating Content

Percentage of $MgCO_3$-Flake Glass	Composition		
	$MgCO_3$ (ml)	Flake Glass (ml)	Cat (ml)
10%	20	20	160
20%	40	40	120
30%	60	60	80

2.6 Measurement of Coating Thickness

In the coating process, there are two kinds of thickness, namely wet 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 by following the drying time specified in the technical data sheet, the desired wet film thickness will be obtained. The instrument used to measure wet film thickness was wet film comb. While the tool used to measure dry film thickness was a thickness gauge coating. In this study, the desired variations of dry film thickness were 300 μm, 500 μm, and 700 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 can be used:

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

Then the calculation results will be obtained with a total volume used of 200 ml.

Table 3. Calculation of Wet Film Thickness

Dry Film Thickness (μm)	Solid Volume (%)	Dry Film Thickness (μm)
300	51±2%	±600
500	51±2%	±1000
700	51±2%	±1400

2.7 Adhesion Testing

Adhesion strength testing was carried out to determine the effect of variations in the addition of MgCO3-Flake Glass and coating thickness on the adhesion of the material. The method used to test the adhesion level of the coating was Pull Off Test with ASTM D4541 standard "Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers" [5]. Each specimen was tested three points to get detailed results, then the three results were averaged. This test was carried out using 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 was 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 composition of MgCO3-Flake Glass and epoxy coating thickness using the Taber Abraser method using the ASTM D4060 standard "Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser" [3]. This test was carried out using a load of 1000 grams, a stone grinding wheel type 120, a lathe with 170 rpm, and an auxiliary arm to clamp the test specimen on a 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 was done as an indicator to determine the influence of the addition of MgCO3-Flake Glass composition and epoxy coating thickness using the three electrode cell method using ASTM G102 standard "Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements" [6]. In this test, NaCl solution with a salinity of 3.5%, which had been generalized by sea water into the real conditions in the field, was used. One specimen was tested in 3 parts and then the averaged value was calculated.

3. RESULT ANALYSIS AND DISCUSSION

3.1 Coating Adhesion Testing

Table 4. Adhesion Test Results

Specimen Name	Content of $MgCO_3$-Flake Glass	Adhesion Value (Mpa)			
		1	2	3	Average
A1	10%	6.02	5.68	5.32	5.67
B1	20%	1.23	1.38	1.42	1.34
C1	30%	0.72	0.53	0.51	0.59
A2	10%	3.93	4.07	3.93	3.98
B2	20%	1.25	1.28	1.31	1.28
C2	30%	0.68	0.4	0.48	0.52

From the table above, the highest adhesion value was obtained by specimen A1 which had 10% mixture of MgCO3-Flake Glass and coating thickness of 300 µm, with a value of 5.67 MPa, while the lowest adhesion value was obtained by specimen C3 which had 30% MgCO3-Flake Glass mixture and coating thickness of 700 µm, with a value of 0.48 Mpa.

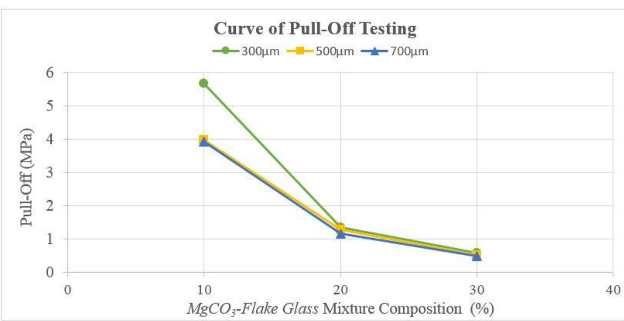

Figure 4. Graph of Adhesion Test Results

Based on the pull off tests results presented on the graph above, it shows that the specimens experienced adhesive failure (bond failure between coating and substrate / steel) and cohesive failure (bonding failure between coating and coating). Cohesive failure occurs because the addition of MgCO3-Flake Glass pigment added to the epoxy prevents the bonding that occurs between the components of the epoxy or commonly called a coating disbondment. This is consistent with previous studies conducted by Olad (2012), [18] who explained that the increasing number of pigments added to organic epoxy can reduce the adhesion properties of the coating.

3.2 Testing of Abrasion Coating Resistance

Table 5. Abrasion Testing Results

Specimen Name	Time Test (s)	Variation	Wear Cyces Per Micro	Average
A11	9	300µm, 10%	0.09	0.18
A12	28	300µm, 10%	0.26	
A13	21	300µm, 10%	0.20	
A21	48	500µm, 10%	0.27	0.32
A22	35	500µm, 10%	0.20	
A23	85	500µm, 10%	0.48	
A31	129	700µm, 10%	0.52	0.57
A32	63	700µm, 10%	0.26	
A33	230	700µm, 10%	0.93	
B11	23	300µm, 20%	0.22	0.23
B12	27	300µm, 20%	0.26	
B13	23	300µm, 20%	0.22	
B21	52	500µm, 20%	0.29	0.42
B22	80	500µm, 20%	0.45	
B23	92	500µm, 20%	0.52	
B31	157	700µm, 20%	0.64	0.75
B32	181	700µm, 20%	0.73	
B33	217	700µm, 20%	0.88	
C11	30	300µm, 30%	0.28	0.34
C12	30	300µm, 30%	0.28	
C13	49	300µm, 30%	0.46	
C21	64	500µm, 30%	0.36	0.51
C22	96	500µm, 30%	0.54	
C23	112	500µm, 30%	0.63	
C31	264	700µm, 30%	1.07	0.91
C32	116	700µm, 30%	0.47	
C33	292	700µm, 30%	1.18	

From Table 5. it can be seen that the highest abrasion resistance value was obtained by specimens that had 30% MgCO3-Flake Glass mixture and coating thickness of 700 µm with a value of 0.91 Wear Cyces Per Micro, while the lowest adhesion value was obtained by specimens that had 10% MgCO3-Flake Glass mixture and coating thickness of 300 µm with a value of 0.18 Wear Cyces Per Micro.

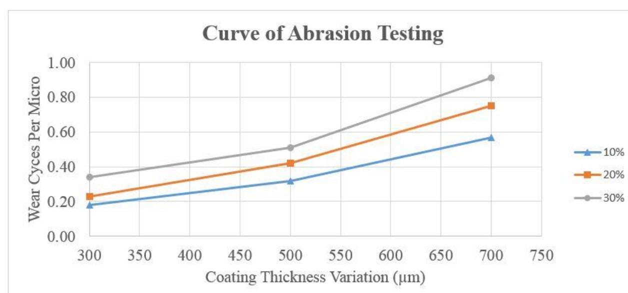

Figure 5. Curve of Abrasion Test Results

From the results of the abrasive test, it was found that the thicker the coating, the greater the abrasive resistance, referring to Figure 6., it can be seen that the best abrasion resistance were obtained on specimens that had a variation of 700 µm coating thickness, this is because with thick coating, the abrasion process will be longer along with the addition of the appropriate $MgCO_3$-Flake Glass pigment filler so that it increases the physical properties of the coating. In a previous experiment conducted by Barbhuiya (2017) [9] stated that the thicker the coating, the greater the bond between molecules. Whereas in this study it was found that for the best composition variation was a 30%

composition which result in 0.91 wear cyces per micrometer, this was due to the increasing mixture of $MgCO_3$-Flake Glass filler compositions, so that the fillers can be distributed more evenly.

3.3 Corrosion Rate Prediction Testing

Table 6. Corrosion Rate Testing Results

Specimen Name	$MgCO_3$-Flake Glass	Potential (V)			Total Potential (V)
		1	2	3	
A111	10	-0.53295	-0.55218	-0.55762	-0.54758
B112	20	-0.50947	-0.52594	-0.53846	-0.52462
C113	30	-0.42321	-0.44678	-0.44217	-0.43739
A221	10	-0.50655	-0.52377	-0.53107	-0.52046
B222	20	-0.40405	-0.47648	-0.48647	-0.45567
C223	30	-0.35463	-0.40024	-0.42951	-0.39479
A331	10	-0.49531	-0.52046	-0.52930	-0.51502
B332	20	-0.35221	-0.42202	-0.43770	-0.40398
C333	30	-0.38830	-0.42387	-0.44955	-0.42057

The table above was obtained from testing using the three-electrode cell method in CS Studio5 software. The electrolyte solution used was NaCl with a salinity of 3.5%. The output of the test according to Table 6., will produce a predicted value of the corrosion rate on each specimen contained in Table 7.

Table 7. Corrosion Rate Value Results

Specimen Name	MgCO3-Flake Glass	Potential (V)			Total Potential (V)
		1	2	3	
A111	10	0.91116	1.66270	1.88470	1.48619
B112	20	0.07905	0.42821	0.22979	0.24568
C113	30	0.00086	0.00185	0.00405	0.00225
A221	10	0.72164	1.02550	1.19460	0.98058
B222	20	0.00940	0.21171	0.13171	0.11761
C223	30	0.00106	0.00499	0.00974	0.00526
A331	10	0.72162	0.76004	1.03490	0.83885
B332	20	0.00013	0.00101	0.00223	0.00112
C333	30	0.00005	0.00007	0.00018	0.00010

From Table 7., specimen C333 with 30% MgCO3-Flake Glass mixture and 700 mm coating thickness had the lowest corrosion rate, with a value of 0,00010 mmpy. Whereas the highest predicted corrosion rate was obtained in specimen A111 which contained 10% MgCO3-Flake Glass and coating thickness of 300 µm, which had a value of 1.48619 mmpy.

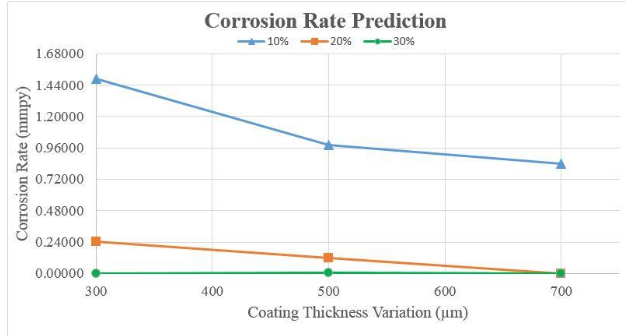

Figure 6. Graph of Corrosion Rate Prediction Test Results

It is shown in the graph above that the addition of coating layer thickness and substrate addition in the form of $MgCO_3$-Flake Glass can affect the corrosion resistance of ASTM A36 steel plate, in this case 3.5% NaCl acts as a substitute for real corrosive solution. The graph above shows that greater $MgCO_3$-Flake Glass mixture combined with thicker coating shows 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 [12].

3.4 Selection of Coating Thickness and Composition of Magnesium – The Right Flake Glass Coating on ASTM A36 Steel

Table 8. Test Criteria for the Exponential Comparison Method

Content of MgCO3-Flake Glass (%)	Coating Thickness (µm)	Cost for the addition of 2 Elements	Average Testing		
			Adhesion (Mpa)	Abrasive (Wear Cyces Per Micro)	Corrosion Rate (mmpy)
10	300	Rp 1800	5.67	10	300
10	500		0.94	10	500
10	700		0.59	10	700
20	300	Rp 3600	3.98	20	300
20	500		1.28	20	500
20	700		0.52	20	700
30	300	Rp 5400	3.92	30	300
30	500		1.17	30	500
30	700		0.48	30	700

After knowing the test criteria, an assessment of each test criterion will be made according to the comparative value of each test criterion. In this case, the largest value is 5 point and the smallest value is 0 point. For the weighting of each coating test has a weight of 3, and while the cost is 2, the weighting value is an assumption according to the author. Henceforth will be calculated assessment of the test criteria.

Table 9. Assessment of Test Criteria for the Exponential Comparison Method

item	Alternative	Criteria				Decision Value
		Adhesion	Abrasive	Corrosion Rate	Element Cost	
1	10%, 300µm	5.00	1.01	0.00034	5.00	151.02
2	10%, 500µm	0.83	1.75	0.00052	5.00	30.92
3	10%, 700µm	0.52	3.14	0.00060	5.00	56.09
4	20%, 300µm	3.50	1.27	0.00206	2.50	51.33
5	20%, 500µm	1.13	2.33	0.00431	2.50	20.39
6	20%, 700µm	0.46	4.13	0.45169	2.50	76.86
7	30%, 300µm	3.45	1.89	0.22507	1.67	50.80
8	30%, 500µm	1.03	2.83	0.09625	1.67	26.62
9	30%, 700µm	0.43	5.00	5.00000	1.67	252.86
weight		3	3	3	2	

After assessing each test parameter using the exponential comparison method, the best results are epoxy coating with a thickness of 700 µm and a mixture of 30% MgCO3-Flake Glass composition, because it has the highest value in both the abrasion resistance test and corrosion rate prediction test, while almost has the lowest value on the adhesion test criteria.

4. CONCLUSIONS

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

1. From the adhesion test using the Pull-off Test method, the greatest adhesion value on specimen A1 with 10% MgCO3-Flake glass composition and coating thickness of 300 µm, with an adhesion value of 5.67 MPa. Whereas the smallest adhesion value was obtained by specimen C3 with 10% MgCO3-Flake glass composition and coating thickness of 700 µm with an adhesion value of 0.48 MPa.
2. From the abrasive resistance testing using the Taber Abraser Test method, the highest abrasion resistance value was found in the variation with 30% MgCO3-Flake Glass mixture with a coating thickness of 700 µm, with a value of 0.91 Wear Cyces Per micrometer. While the smallest abrasion resistance value is obtained by specimens with 10% MgCO3-Flake Glass mixture and coating thickness of 300 µm, with a value of 0.18 Wear Cyces Per micrometer.
3. From the corrosion rate prediction testing using the Three Cell Electrode method, it was found that the lowest corrosion rate prediction value on the C333 specimen with 30% MgCO3-Flake Glass composition variation and coating thickness of 700 µm with predicted corrosion rate of 0,00010 mmpy. While the highest corrosion rate prediction value was obtained in specimen A111 with 10% MgCO3-Flake Glass composition variation with a coating thickness of 300 µm with predicted corrosion rate of 1.48619 mmpy.
4. Based on the results of the calculation of the exponential comparison method, the addition of MgCO3-Flake Glass by 30% and the usage of 700 µm coating thickness on the epoxy coating applied to ASTM A36 Steel obtained a decision value of 252.86 due to the abrasion resistance test criteria and corrosion rate prediction test gets the highest value, but it almost has the lowest value in the adhesion test criteria.

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