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Analysis of the Effect of Nano-Alumina Addition on Epoxy Coating on Abrasive Resistance, Adhesion Strength, and Corrosion Rate of ASTM A36 Steel Plate

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ABSTRACT

The maritime industry is one of the natural resources management industries that uses steel as its fundamental component. Much research and development have been conducted to increase the quality and life span of the steel used. ASTM A36 low-carbon steel is one of the steel variants commonly used on offshore structures because of its advantages. This research was conducted to achieve the additional effect of nano-alumina of 0%, 1,5% and 3% in the epoxy coating on adhesive strength, abrasive resistance and corrosion rate prediction. At pull-off testing, the highest adhesion strength was obtained at a mixed variation of 0% with a value of 7,7022 MPa. At the abrasion resistance test, the highest abrasion resistance was obtained at a mixed variation of 3% with a value of 16.7 grams. The lowest value of the corrosion rate prediction test was obtained on the mixed variation of 1.5% with a value of 0.005410622 mph.

Keywords: *Maritime industry, ASTM A36, Coating, Epoxy, Nano-alumina, Adhesion, Abrasion, Corrosion*

1. INTRODUCTION

Steel is the main building block material used in the maritime industry, including oil and gas. The widespread use of steel is because steel has advantages in strength, hardness, and ductility. Steel has a main component, iron, a basic element, along with several other elements, such as carbon—the carbon content in steel ranges from 0.2% to 2.1%. Based on the carbon content, steel is divided into three levels: low-carbon, medium-carbon, and high-carbon. The higher the carbon content in the steel, the harder the steel will be, but the steel will be more brittle and decrease the ductility [1].

Steel is a type of metal that is susceptible to corrosion. Corrosion is a process of material damage caused by a material reaction with its environment [2]. Corrosion cannot be prevented, but the corrosion rate can be slowed down. The corrosion rate can be slowed using cathodic protection, inhibitors, or surface coating [3].

Coating application is commonly used for steel protection with a large surface area in direct contact with a corrosive environment. Coating is the coating of a surface using paint, which mainly separates the object's surface and the environment. Epoxy-type paint is widely used as a coating because epoxy has high strength and modulus of elasticity, can stick firmly, and has good chemical stability. However, epoxy paint has several shortcomings, such as brittleness and sensitivity to fine cracks, which can affect its physical shape and reduce its toughness so that it can affect the coating's performance in protecting steel.

Several types of nano and micro-sized particles have been studied and tested to increase the quality of coatings, such as SiO2, TiO2, ZnO, Al2O3, and Fe2O3 [4]. This is because these small particles have hard properties and can enter the cavity of the paint, thus making the coating have novel properties that can increase the quality of the coating [5]. However, these particles are non-organic material in the coating, so their addition can result in a decrease in the mechanical properties of the coating, which will affect the bonds between the particles so that they can reduce the adhesion value of the paint [6]. In an experiment conducted by Chen Li et al. [6], the addition of nano-alumina to an epoxy coating applied to carbon steel reduces the adhesion strength but, at the same time, increases the wear resistance of the coating. Experiments conducted by Wang et al. [7] by adding nano-alumina to the polymer coating applied to low-carbon steel were shown to be able to increase the abrasive resistance of the coating. In another experiment, it was found that adding nano-alumina to the epoxy coating increased wear resistance compared with no additives, with the best results at an addition of 0.25 wt% [8].

In another experiment, the application of an epoxy coating to low carbon steel AISI 1020 with the addition of about 26 vol% alumina microparticles in the epoxy coating can increase wear resistance and corrosion resistance due to the

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presence of alumina microparticles, which improve the physical properties of the epoxy paint [9]. Experiments conducted by Mohsen et al. [10] by adding several types of micro and nanoparticles to the hot dip zinc coating found that adding alumina nanoparticles can improve corrosion resistance compared to no additives. This research will be conducted on the effect of the nano-alumina composition on the epoxy paint, which will be applied to ASTM A36 low-carbon steel, to analyze the tested specimens' adhesion strength, abrasion resistance and corrosion rate.

2. RESEARCH METHODOLOGY

2.1 Literature Study

Studies and literature collection were conducted regarding adding nano-alumina to coatings, especially epoxy, as a reference, a source of theory, and material for consideration in the research.

2.2 Preparation of Tools and Materials

The material used in this experiment is ASTM A36 steel plate size 50x50x10mm for abrasion testing, 120x60x10mm for adhesion testing, and 40x20x10mm for corrosion rate testing. The paint used was the JOTUN Penguard Primer-Gray epoxy paint and nano-alumina with an average particle size of 208.7 nm. The test specimens are named according to the nano-alumina grade as follows:

Table 1. Naming of specimens

Addition of Nano Alumina	0%	1.50%	3%
Adhesion Test	Ad0	Ad1	Ad3
Abrasion Test	Ab0	Ab1	Ab3
Corrosion Rate Test	Lk0	Lk1	Lk3

2.3 Blasting Process

Before the coating process, the material's surface is first cleaned of dirt through the dry abrasive blasting process. In addition to cleaning the surface, the dry abrasive blasting process also aims to provide a profile with a certain roughness on the surface of the object so that the paint can adhere to the surface of the material perfectly. The blasting process in this experiment uses an abrasive material in the form of steel grit G16 with a compressor pressure of 7 bar. The cleanliness level of the blasted surface refers to the ISO 8501-1 [16] Sa 2.5 standard.

Figure 1. Cleanliness level Sa 2.5

2.4 Roughness Measurement

After the inspection and the material's surface has met the level of cleanliness of Sa 2.5, the next step is to measure the roughness value. Roughness measurements were carried out according to ASTM D4417 standard [17]. The roughness value is obtained using a roughness meter, where the roughness test will be carried out by measuring three different points on the surface of the material to get the average value of the surface roughness of the material.

2.5 Coating Process

After the surface preparation and inspection have passed, the coating process will be carried out. The method of applying coatings in this study is air spray painting. In the paint products used in this study, the ratio of the base component to the curing agent is 4 1 by volume. Epoxy paint is given a mixture of nano-alumina with variations of 0%, 1.5% and 3% of the total paint volume with the following ratio:

Table 2. Coating composition

Presentation of Nano-Alumina	Composition	
	Nano-alumina (ml)	Paint (ml)
0%	0	100
1.50%	1.5	98.5
3%	3	97

2.6 Coating Thickness Measurement

Measuring wet film thickness is the process of measuring the thickness of the paint immediately after it is applied to the surface of an object, which aims to estimate the thickness of the paint after experiencing the drying process. WFT measurement uses a wet film comb according to ASTM D4414 standard [18]. After the coating layer is declared to have dried completely (cured for service) as stated on the TDS, which is 7 days at 23 C, the next step is to measure the dry film thickness using a coating thickness gauge. Measurements were made according to the ASTM B499 standard [19].

Measurements are made by measuring three points on the material's surface to get the material's average dry film thickness.

2.7 Adhesion Strength Testing

The adhesion strength test was carried out under the ASTM D4541 standard. The test was carried out using a portable adhesive tester. This tool works by attaching the dolly using epoxy Araldite type adhesive at three different points on the material; then, the dolly is allowed to dry at room temperature for 24 hours. After making sure it dries, the remaining glue around the dolly is removed first using the crop, then removing the dolly from the material's surface using a portable adhesive tester.

2.8 Abrasion Resistance Testing

The abrasion resistance test is carried out to determine the resistance of the coating layer to damage due to abrasion. The tests were conducted according to the ASTM D4060 standard [20]. The calculation method used is weight loss, which is achieved by observing changes in the weight of the specimen before and after testing. The grinding wheel used in the test measures 120 grit, with an engine speed of 170 rpm. The specimen was subjected to a load of 1000 g, and the abrasion test was carried out for 4 seconds.

2.9 Corrosion Rate Prediction Test

Corrosion rate testing was carried out using the three-electrode cell method, which refers to the ASTM G102 standard. The test uses a potentiostat as a current source connected to the CS Studio 5 software as a response receiver to the current flowing in the specimen. The solution used as a corrosive medium was NaCl, with a concentration of 3.5%.

3. RESULT ANALYSIS AND DISCUSSION

3.1 Adhesion Test Results

Table 3. Adhesion test results

Specimen Code	Nano-alumina (%)	Adhesion (%)			Cohesion (%)			Glue Failure (%)			Average Total
		1	2	3	1	2	3	1	2	3	
Ad0a	0	0	0	0	25	7	0	75	93	100	7.7
Ad0b	0	0	0	0	9	70	93	91	30	7	
Ad0c	0	0	0	0	85	96	91	15	4	9	
Ad1a	1.5	0	0	0	6	3	2	94	97	98	7.35
Ad1b	1.5	0	0	0	94	70	90	6	30	10	
Ad1c	1.5	0	0	0	89	100	99	11	0	1	
Ad3a	3	0	0	0	3	8	0	100	97	92	5.38
Ad3b	3	0	0	0	5	6	5	95	94	95	
Ad3c	3	0	0	0							

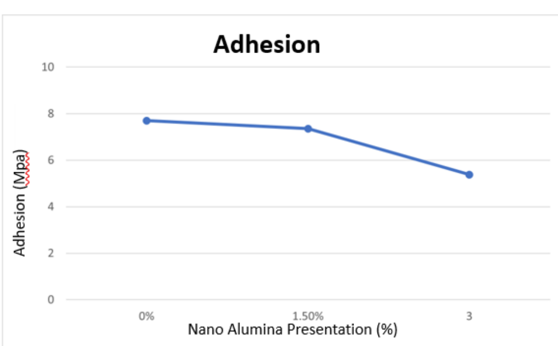

Figure 2. Graph of adhesion test results

From the graph and table of the results of the pull-off test above, it can be concluded that quantitatively, there is no adhesive failure (failure of the bond between the paint and the steel surface). However, the failure is in the form of cohesive and glue failures. This indicates good mechanical interlocking between the paint and the steel surface due to a good surface preparation process, which is under the standards. In terms of quality, the adhesion value of the coating decreases with the addition of the nano-alumina composition because the presence of additional pigments in the coating can cause pigment coagulation, thus reducing the adhesion value [21]. This is also consistent with research conducted by Hesselbach et al. [22], who stated that more pigment added to the coating can reduce the adhesion value.

3.2 Abrasion Resistance Test Results

Table 4. Abrasion resistance test results

Specimen Code	Testing Time (s)	Starting Weight (mg)	Final Weight (mg)	Weight Loss / L (mg)	Average Total (mg)
Ad0a	4	203010	202940	70	63.3
Ad0b	4	194680	194610	70	
Ad0c	4	172880	172830	50	
Ad1a	4	196250	196220	30	30
Ad1b	4	193810	193780	30	
Ad1c	4	210520	210490	30	
Ad3a	4	199590	199570	20	16.7
Ad3b	4	182020	182010	10	
Ad3c	4	201360	201340	20	

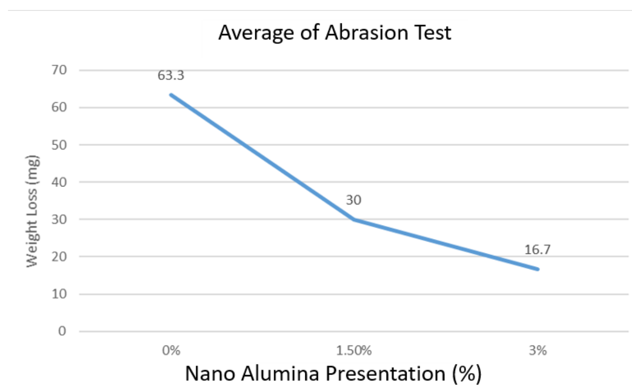

Figure 3. Graph of abrasion resistance test results

From the graph and table of the abrasion test results above, it can be concluded that the more nano-alumina levels are added to the coating, the weight loss is decreased gradually, which indicates that the abrasion resistance of the coating will be better. Stated that adding a nano-alumina composition increased the abrasion resistance of the coating. Another experiment conducted by Yousri et al. (2017) also concluded that adding nano-alumina to an epoxy coating increases wear resistance compared to no additives, with the best results at an addition of 0.25 wt%. In another study, adding alumina nanoparticles increased the abrasion resistance of coatings compared to no additives [23]. Research conducted by Kurahatti et al. (2014) [24] also concluded that adding nano-alumina increases the abrasion resistance of the coating compared to no additives due to the addition of hard ceramic particles. Similar results were obtained by research conducted by Ai et al. (2015) [25], which stated that the addition of nano-alumina particles could reduce the wear rate of the epoxy coating by 5 times with an additional 3% due to the high hardness of the nano-alumina particles.

3.3 Corrosion Rate Prediction Test Results

From the table and graph below, it can be concluded that the nano-alumina content affects the corrosion rate of the material. Adding nano-alumina as much as 1.5% can reduce the value of the corrosion rate compared to without additives. However, the effectiveness was reduced with the addition of nano-alumina content by 3%.

Table 5. Corrosion rate prediction test results

Specimen Code	Rate of Nano Alumina (%)	Potential (V)	Corrosion Rate (mmpy)	Average Total (mg)
Ad0a	0	-0.38969	0.00049	0.0139
Ad0b	0	-0.3734	0.00981	
Ad0c	0	-0.50693	0.01439	
Ad1a	1.5	-0.40182	0.0017	0.00541
Ad1b	1.5	-0.37586	0.00011	
Ad1c	1.5	-0.2707	0.00002	
Ad3a	3	-0.38557	0.0153	0.00694
Ad3b	3	-0.33654	0.00515	
Ad3c	3	-0.31667	0.00037	

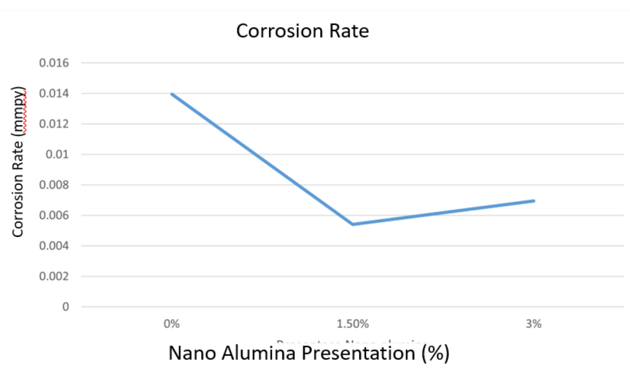

Figure 4. Graph of corrosion rate prediction test results

This is under the research conducted by Chen et al. [26], who stated that adding nano-alumina content to the coating can increase the material's corrosion resistance compared to without additives. Other studies have also concluded that adding nano-alumina can reduce the corrosion rate because the addition of small nano-alumina forms a protective layer that enters the gaps of the coating, thereby inhibiting corrosion [27]. Experiments conducted by Mohsen et al. (2016) also concluded that adding alumina nanoparticles can improve corrosion resistance compared to no additives. However, too many nanoparticles will cause agglomeration so that the nanoparticles do not disperse well on the surface and eventually form active site formations, which can reduce the corrosion resistance of the coating layer [28].

4. CONCLUSIONS

Based on the analysis and discussion carried out in the previous chapter regarding the effect of variations in the composition of nano-alumina on the epoxy coating applied to the ASTM A36 steel plate, a conclusion is obtained that answers the problem formulation in this study. Some of these conclusions include:

1. From the adhesion test carried out using the pull-off method, the highest average adhesion value of the specimen with a variation of nano-alumina content is 0%, with a value of 7,7022 MPa. Meanwhile, the smallest average adhesion value was obtained in specimens with a variation of nano-alumina content of 3% with a value of 5,381 MPa, so it can be concluded that the more the addition of nano-alumina to the epoxy coating can reduce the adhesion value of the coating.
2. From the abrasive resistance test carried out using the abrasion Taber, the largest average abrasive resistance value was found in the specimen with a variation of nano-alumina content of 3% with a weight loss value of 16.7 grams. As for the average value of the smallest abrasive resistance obtained in specimens with variations in nano-alumina levels as much as 0% with a weight loss value of 63.3 grams, it can be concluded that the more addition of nano-alumina to the epoxy coating can increase the abrasive resistance of the coating.
3. From the predictive test of the corrosion rate carried out using the Three Electrode Cell method integrated with CS Studio 5 software, the average value of the lowest corrosion rate prediction in the specimen with a variation of nano-alumina content was 1.5% with a value of 0.005410622 mph. At the same time, the highest average predictive value of corrosion rate was obtained in specimens with a variation of nano-alumina content as much as 0% with a value of 0.013950662 empty, so it can be concluded that adding nano-alumina content to the epoxy coating can reduce the corrosion rate compared to without additives.

REFERENCES

1. Brady, G. S., Clauser, H. R. & Vaccari, J. A., (2002). "Materials Handbook", edisi 15. McGraw-Hill Education.
2. Gapsari, F., 2017. "Pengantar Korosi", edisi 1. Universitas Brawijaya Press.
3. Sidiq, M. F., (2013). "Analisa Korosi dan Pengendaliannya". Jurnal Foundry, Vol. 3: 25–30.
4. Golru, S. S., Attar, M. M. & Ramezanzadeh, B., 2014. "Studying the Influence of nano-Al2O3 Particles on the Corrosion Performance and Hydrolytic Degradation Resistance of an Epoxy/Polyamide Coating on AA-1050". Progress in Organic Coatings, Vol.77: 1391-1399.
5. Zhang, X., Wang, F. & Du, Y., (2007). "Effect of Nano-sized Titanium Powder Addition on Corrosion Performance of Epoxy Coating". Surface & Coatings Technology, Vol. 201: pp. 7241–7245.
6. Li, C., Fenglei, C., Zhi, L. & Ying, X., 2016. "Study of Nano-alumina Impact on the Performance of a CaCO3-Epoxy Composite Coating". Nanomaterials and Nanotechnology, Vol. 8: 1-7.
7. Y, Wang; S, Lim; L, Luo J.; H & Xu Z. 2006. "Tribological and Corrosion Behaviors of Al2O3/Polymer Nanocomposite Coatings". Wear, Vol. 260: 976-983.
8. Yousri, O. M., Hazem, A. M. & Bassioni, G. (2018). "Effect of Al2O3 Nanoparticles on Mechanical and Physical Properties of Epoxy Composite". Arabian Journal for Science and Engineering, Vol. 43: 1511-1517
9. Oliveira, J. D., Rocha, R. C. & Galdino, A. G. d. S., 2019. "Effect of Al2O3 Particles on the Adhesion, Wear, and Corrosion Performance of Epoxy Coatings for Protection of Umbilical Cables Accessories for Subsea Oil and Gas Production Systems". Journal of Materials Research and Technology, Vol. 8: 1729-1736.
10. Mohsen, M., Ali, H. & Mardali, Y., 2016. "Effect of Nano-Oxide Addition on Corrosion Performance of Hot Dip Zinc Coating". Protection of Metals and Physical Chemistry of Surface, Vol. 52: 100-103.
11. Steiner, R., (1983). "ASM Handbook Volume 1: Properties and Selection: Irons, Steels, and High-Performance Alloys". ASM International.
12. ASTM A36/A36M. 2012. "Standard Specification for Carbon Structural Steel". ASTM International.
13. Zhai, L. L., Ling, G. P. & Wang, Y. W., 2007. "Effect of nano-Al2O3 on Adhesion Strength of Epoxy Adhesive and Steel". International Journal of Adhesion & Adhesives, Vol. 28: 23-28.
14. ASTM D4541. (2001). "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers". Annual Book of ASTM Standards.
15. ASTM G102, (1994). "Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements". Washington: ASTM Publishing.
16. ISO 8501. 2011. "Corrosion Protection of Steel Structures by Painting". International Organization for Standardization.
17. ASTM D4417. (2011). "Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel"—Annual Book of ASTM Standards.
18. ASTM D4414. (1996). "Standard Practice for Measurement of Wet Film Thickness by Notch Gages". Annual Book of ASTM Standards.
19. ASTM B499. (2014). "Standard Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals". Annual Book of ASTM Standards.
20. ASTM D4060-02, (2010). "Standard Test Method for Abrasion Resistance of Organic Coating by the Taber Abraser". Washington: ASTM Publishing.
21. *Mirabedini, S. M., Mohseni, M., PazokiFard, S. & Esfandeh, M., 2007. "Effect of TiO2 on the Mechanical and Adhesion Properties of RTV Silicone Elastomer Coatings". Colloids and Surfaces, Vol. 317: 80-86.*
22. Hesselbach, J; Böttcher, A; Kampen, I; Garnweitner, G; Schilde, C & Kwade, A. 2018. "Process and Formulation Strategies to Improve Adhesion of Nanoparticle Coating on Stainless Steel". *MDPI Materials*. Vol. 8: 1-11
23. Raghavendra, C. R., Basavarajappa, S. & Solagad, I., 2018. "Study on Influence of Surface Roughness of Ni-Al2O3 Nanocomposite Coating and Evaluation of Wear Characteristics". India, IOP Publishing.
24. Kurahatti, R. V; Surendranathan, A. O; Kumar, A. V. R.; Auradi, V; Wadageri, C. S & Kori, S. A. "Mechanical and Tribological Behaviour of Epoxy Reinforced with Nano Al2O3 Particles". Applied Mechanics and Materials, Vol. 592–594: 1320–1324.
25. Ai, A. N., Hussein, S. I., Jawad, M. K. & Al-Ajaj, I. A., (2015). "Effect of Al2O3 and SiO2 Nanopartical on Wear, Hardness and Impact Behavior of Epoxy Composites". Chemistry and Materials Research, Vol. 7: pp. 34–39.
26. Chen, Y., Hao, Y., Huang, W., Ji, Y., Yang, W., Yin, X., Liu, Y. & Ling, X., 2017. "Corrosion Behavior of Ni-P-Nano-Al2O3 Composite Coating in the Presence of Anionic and Cationic Surfactants". Surface & Coatings Technology, Vol. 310: 122-128.
27. Feng, Q., Li, T., Teng, H., Zhang, X., Zhang, Y., Liu, C. & Jin, J., (2008). "Investigation on the Corrosion and Oxidation Resistance of Ni–Al2O3 Nano-composite Coatings Prepared by Sediment Co-deposition". *Surface & Coatings Technology*, Vol. 202: pp. 4137–4144.
28. Abdeen, D. H; El, H. M.; Muammer, K.; Atieh M. A. 2019. "A Review on the Corrosion Behaviour of Nanocoatings on Metallic Substrates". MDPI Materials, Vol. 12: 1-42.