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ANALYSIS OF THE EFFECT OF THE SECOND THICKNESS LAYER OR INTERMEDIATE LAYER ON THE THREE-LAYER SYSTEM ON ADHESION STRENGTH ON CARBON STEEL SURFACE

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ABSTRACT

Generally, the marine & offshore industry uses a wide range of coatings, both liquid and thermal, which aim to protect or inhibit the rate of corrosion of materials in the surrounding environment. Referring to the Norsok M-501 standard, there is a Coating System Data Sheet (CSDS) that provides an overview of the coating system according to the surrounding environment. In CSDS 1B, a three-layer system is employed, consisting of a zinc-rich epoxy primary layer, an epoxy intermediate layer, and a UV-resistant top layer. The specification provides the thickness of each coating layer from the first layer to the top layer. However, during the fabrication process, there are some challenges that occur with the second layer, which is epoxy. Sometimes, during the application of the second layer, the thickness of this layer is less than or more than the specified thickness. This study aims to determine the effect of the thickness of the second layer (intermediate layer), namely epoxy, on the adhesion of the three-layer system. This research will be carried out through experimental testing with variations in the thickness of the second layer (intermediate coat) of 50, 100, 150, 200, and 250 microns. The adhesion test for the second layer will use the X-Cut Tape Test and Pull-Off Test methods. The results of the adhesion strength test show that the thickness of the second layer affects the adhesion value of the coating system itself; The thicker the intermediate layer, the worse the adhesion strength, or there is a decrease in adhesion strength. This is supported by the test results on panel 1 with a second layer thickness of 50 microns, which obtained an average tensile test result of 18.37 MPa, and on panel 5 with a second layer thickness of 250 microns, which obtained an average tensile test result of 14.19 MPa.

Keywords: Coating, intermediate layer, pull-off test, three-layer system, x-cut tape test

Introduction

In the marine and offshore industries, steel is a major material widely used for structural construction because it has high strength and abundant availability. However, steel is particularly susceptible to corrosion due to exposure to the aggressive marine environment. Corrosion is one of the main causes of structural damage, increased maintenance costs, and disruption to safety and operational continuity. Therefore, mitigation efforts through surface coating systems have become a key strategy that continues to be developed to protect metal structures, particularly in marine installations [1]. As the need for reliable maritime infrastructure increases, both globally and nationally, industry attention is now focused on the effectiveness of corrosion protection systems that are able to adapt to extreme conditions. Oil and gas exploration and production in the deep sea, as well as the development of ports and marine facilities in tropical regions such as Indonesia, make the study of coating systems increasingly relevant. In the national context, this urgency is reinforced by the increasing economic value of Indonesia's marine and fisheries sectors, which directly require durable structures and minimal maintenance [2].

Various international standards, such as NORSOK M-501, have recommended specific coating systems, one of which is the CSDS 1B system, which consists of three layers of protection. However, there is still a gap in understanding the actual performance of these coating systems, especially regarding the thickness of each layer, the order of application, and their adaptability to tropical environmental conditions that have high humidity and significant chloride levels. Previous studies have examined the effectiveness of coating with zinc-rich epoxy bases, pure epoxy, and UV-resistant top coatings, but the results still show inconsistencies, especially in terms of thickness optimization and the influence of environmental conditions on corrosion resistance [3, 4].

In addition, most of the previous studies were conducted in temperate or polar environments, so their relevance to Indonesia's tropical climatic conditions has not been thoroughly verified. The lack of comprehensive studies linking technical data in the field to the effectiveness of coating systems recommended by international standards suggests that evaluation of CSDS 1B systems in local contexts is still urgently needed. Taking into account the differences in environmental characteristics, it is important to know the extent to which existing coating systems can guarantee optimal protection of steel structures [5, 6].

Based on this background, this study aims to evaluate and analyze the performance of the CSDS 1B coating system on steel structures in tropical marine environmental conditions. This research will focus on the thickness of the coating, the order of its application, and its effectiveness in preventing corrosion according to the conditions found in Indonesia's maritime area. The results of this study are expected to contribute to the development of a more contextually appropriate and effective corrosion protection system.

Methodology

a. Flow Chart

This study aims to investigate the adhesion strength of coatings on carbon steel surfaces with varying intermediate paint thicknesses. The methodology is systematically illustrated in a flowchart (Figure 1) and starts with basic steps before moving through the preparation, testing, and analysis phases.

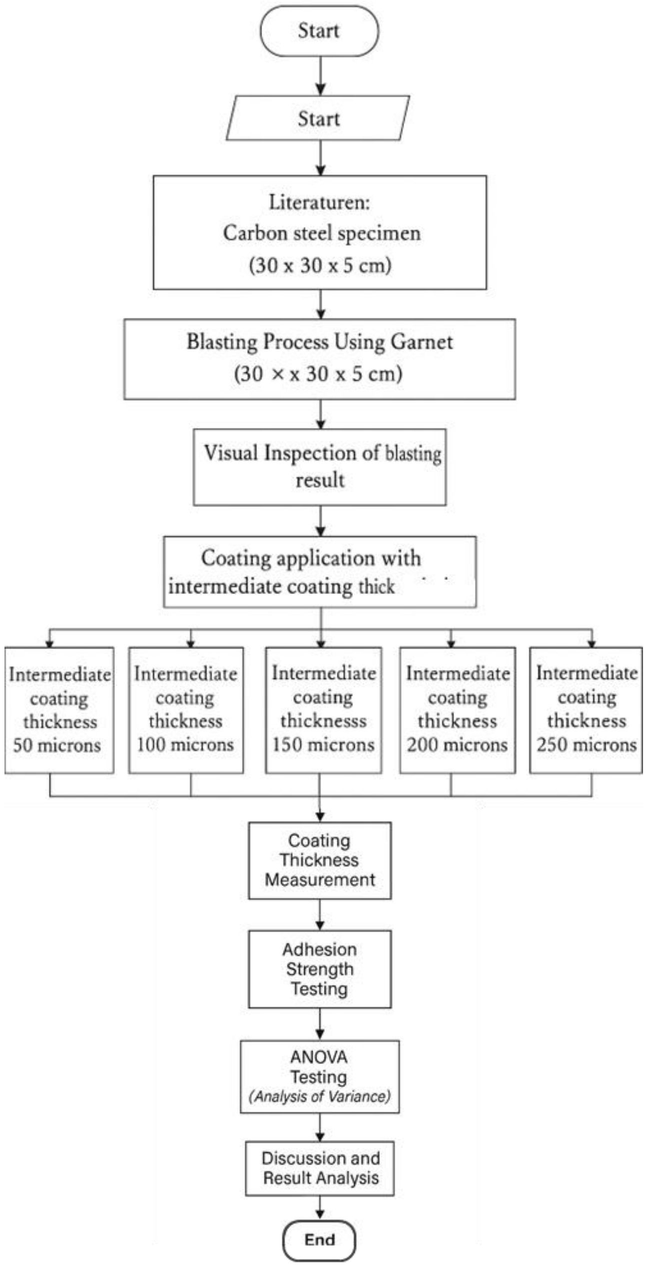

Figure 1. Flowchart

This process begins with a literature study to understand the theoretical background and previous research relevant to surface preparation and coating adhesion [7, 8]. This is followed by the preparation of test specimens, especially carbon steel samples with dimensions of 30 x 30 x 5 cm. Furthermore, the blasting process is carried out using garnet abrasive materials to clean and prepare the surface of the specimen [9, 10]. Visual inspection is carried out to ensure that the blasting results meet the required hygiene and texture standards. If the results are not satisfactory, the process is repeated.

After passing the visual inspection, the surface roughness test is carried out to measure the roughness of the blasted surface. Once the desired surface profile is confirmed, the coating application is applied with varying medium paint thicknesses—specifically 50, 100, 150, and 200 microns. These variations are essential for analyzing the impact of thickness on adhesion strength [2-31].

After coating, the thickness of the paint is measured. If the measured thickness does not match the intended specifications, a repair process is carried out to correct the variation. Once the thickness is verified, the sample undergoes adhesion strength testing [10, 11, 15, 24].

Furthermore, the results of the adhesion test were analyzed using ANOVA (Analysis of Variance) to determine the statistical significance of thickness variation on adhesion performance. Finally, this study ends with a discussion and analysis of the results, summarizing the findings and their implications. After coating, the thickness of the paint is measured. If the measured thickness does not match the intended specifications, a repair process is carried out to correct the variation. After the thickness is verified, the sample undergoes adhesion strength testing.

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b. Test Materials and Equipment

1) Test materials
   - Sister Baja Carbon ASTM A36
   - Garnet-type abrasive material
   - Three-layer coating system (Hempel): Avantguard 750 (primary), Mastic 45881 (intermediate layer), and HS55610 (topcoat)

2) Test equipment
   - Dry abrasive blasting machine
   - Surface roughness gauge (ASTM D4417)
   - Sling hygrometer and steel surface thermometer
   - Paint mixing machine
   - Pistol semprot (spray gun)
   - Wet (WFT) and dry (DFT) thickness gauges
   - Pull-Off and tape test equipment (X-Cut, ASTM D3359).

c. Research Procedure

1) Specimen preparation (cleaning and blasting).

The surface of the ASTM A36 carbon steel specimen is cleaned by abrasive blasting using garnet material to achieve a cleanliness level of SA21/2 (ISO:8501-1) or SP 10 (SSPC-SP) [3].

The blasted surface is visually inspected and compared to the SSPC-VIS 1 standard to ensure compliance. Surface roughness is measured using a roughness gauge according to the ASTM D4417 standard. Measurements were made at 15 points per specimen, and the average value was calculated [4].

2) Application of coatings of varying thicknesses.

Paint is applied to the specimen using a spray gun. To test the effect of layer thickness, five variations were created, with the second (intermediate) layers measuring 50, 100, 150, 200, and 250 microns. Paint is prepared by adding a thinner and mixing it with a paint mixer. This mixture is then poured into a spray gun. During application, each specimen is placed in place of the panel, and the paint is sprayed onto the surface from a distance of about 30 cm.

3) WFT (Wet Film Thickness) measurement.
   - WFT is measured immediately after coating application, when the paint is still wet, following the ASTM D4414 standard [5].
   - These measurements determine the thickness of the wet paint on the specimen.
   - A wet film comb is used for this measurement.

4) Dry Film Thickness Measurement (DFT)

DFT is measured after the paint has completely dried, using the ASTM D4138 standard. A layer thickness gauge is used for this measurement. Measurements were taken on 5 different areas of each specimen, with 3 measurements in each area. The average dry film thickness was then calculated for each specimen [6].

5) Adhesion strength testing (X-Cut Tape Test and Pull-Off Test).

X-Cut Tape tests are performed to evaluate the adhesion strength of paint coatings at different thicknesses. Testing follows the ASTM D3359 standard, with a minimum acceptable rating of 4A. Required tools include cutters, rulers, and transparent adhesive tape. A clean, smooth surface is selected for testing to ensure accurate results. First, two intersecting pieces (~40 mm long) are made at an angle of 30°–45° through the layer to the substrate. Depth is verified by checking the visibility of the substrate under light. If the cut is insufficient, a new X-cut is made in a different area—deepening the initial cut is avoided, as it can distort the results. Next, a strip of 75 mm adhesive tape is applied over the X-cut, pressed firmly to remove air bubbles, and rubbed until it sticks uniformly. Within 90 ±30 seconds, the tape quickly detaches at a 180° angle. The test area is then inspected for layer detachment and assessed in accordance with ASTM D3359. This method ensures reliable adhesion assessment for quality control in coating applications [10, 24, 25].

d. Research Work

1) Specimen preparation

To experiment, a small sample of steel, referred to as a specimen, is required. The specimens used were 300 × 300 × 5 mm in size, with a total of 5 specimens prepared to match the variations tested for adhesion strength using the tensile test and X-Cut Tape Test.

2) Blasting process

The blasting process uses garnet abrasive material. The desired cleanliness level of blasting is SA 21/2 (ISO 8501-1). According to the project specifications, the minimum required cleanliness level is SA 21/2 [26]. Visual Inspection of Blasting Results

3) Visual inspection of blasting results

Visual inspection of the blasted material is carried out to determine whether the surface preparation meets the required cleanliness level of Sa 21/2 (ISO 8501-1). This standard, also known as Near White Blast Cleaning, specifies that the surface, when viewed without magnification, must be free of oil, grease, rust, paint, and other visible foreign objects, with only a slight trace of staining. The visual inspection process involves comparing the blasted material directly with the ISO 8501-1 standard.

4) Surface roughness test

After visual inspection, surface roughness measurements are then carried out, which aim to determine the level of roughness of the material after undergoing the blasting process. According to the recommended surface roughness specification, it is 50 – 85 microns [4]. See Table 1.

Table 1. Surface roughness measurement results

Example	Surface Roughness
Panel 1	80 microns
Panel 2	72 microns
Panel 3	71 microns
Panel 4	78 microns
Panel 5	83 microns

5) Ambient temperature measurement

Before the painting activity, it is necessary to measure the ambient temperature conditions. This measurement is carried out using a sling hygrometer to measure wet and dry temperatures, and an elcometer to determine the dew point and relative humidity. Before taking measurements, the axis of the sash hygrometer should be moistened with water to measure the wet temperature of the environment. The sling hygrometer is then rotated for several minutes until consistent readings are obtained (3 times) for parameters such as wet temperature, dry temperature, dew point, relative humidity, and surface temperature. The following are the results of ambient temperature measurements. Table 2 for temperature results.

Table 2. Environmental temperature measurement

Example	Surface Roughness
Dry temperature	28 °C
Wet temperature	25 °C
Relative humidity	79%
Surface temperature	31.3 °C

6) Coating applications/painting process

The coating is applied in three layers: primer, intermediate layer, and top layer. In this study, the thickness of the intermediate layer varied (50, 100, 150, 200, and 250 microns) to assess its effect on adhesion [2, 3, 5, 7, 10, 13, 23, 28, 31]. The time between applications of each layer follows the product's technical data sheet to ensure proper preservation. The adhesion strength was then tested using a standard X-cut tape test to compare results across various thicknesses [10, 24, 25].

- First layer/primary layer

The first coat is applied using Hempadur Avantguard 750 paint with a recommended dry film thickness (DFT) range of 75-120 microns. For optimal results, the coating is sprayed onto the surface using the professional spray application method.

- Second coat/intermediate coat

The second coat uses Hempadur Mastic 45881 paint, applied in five different thickness variations: 50, 100, 150, 200, and 250 microns. To ensure proper application, the wet film thickness (WFT) of each test panel is carefully measured and adjusted to match the target dry film thickness for a given sample [5, 7, 13, 23, 28, 31].

- Third coat/topcoat

The final top coat uses Hempathane HS55610 paint, applied at a standard dry film (DFT) thickness of 75 microns. This yellow finish layer (RAL code 1004) serves as a protective outer layer and meets the project's defined color requirements.

Table 3. Wet film thickness

Dry Coat	Film Thickness (µm)	Solid Volume (%)	Wet Film Thickness (µm)
Hempadur Avantguard 750	75 – 120	65	115 – 185
Damar wangi hempadur 45881	50 100 150 200 250	80	63 125 188 250 313
Hempathane HS55610	40 - 75	67	60 – 112

WFT (Wet Film Thickness) Measurement During the painting process, workers measure the thickness of wet paint using a notch gauge following the ASTM D4414 standard. This measurement helps determine the thickness of the coating while it is still wet, as wet and dry thickness differ due to the solid content of the paint (as specified in the product technical data sheet) [5]. See Table 3 for results.

Result and Discussion

a. DFT (Dry Film Thickness) Measurement

DFT (Dry Film Thickness) measurement is performed to determine the thickness of the paint when dry. DFT measurements are taken on each layer before applying the next layer to verify that it meets the specifications. The following describes the DFT measurements for each layer application.

The DFT measurements in the table above show a difference of 50 microns between each panel. This is supported by the interpretation of the dry film thickness measurement graph in Figure 2. The DFT measurement results for the first layer/primary layer are in the range of a single point of about 88 microns. Furthermore, the DFT measurements for the intermediate layer show a trend of 50-micron difference between each panel, corresponding to the variation of the second layer/intermediate layer. DFT measurements for the top layer follow the same trend as the second layer. Therefore, the results of this DFT measurement have met the objectives of this study. See Table 4-6.

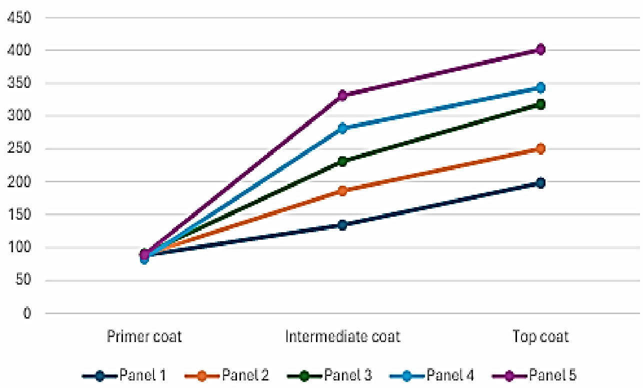


Figure 2. DFT measurement

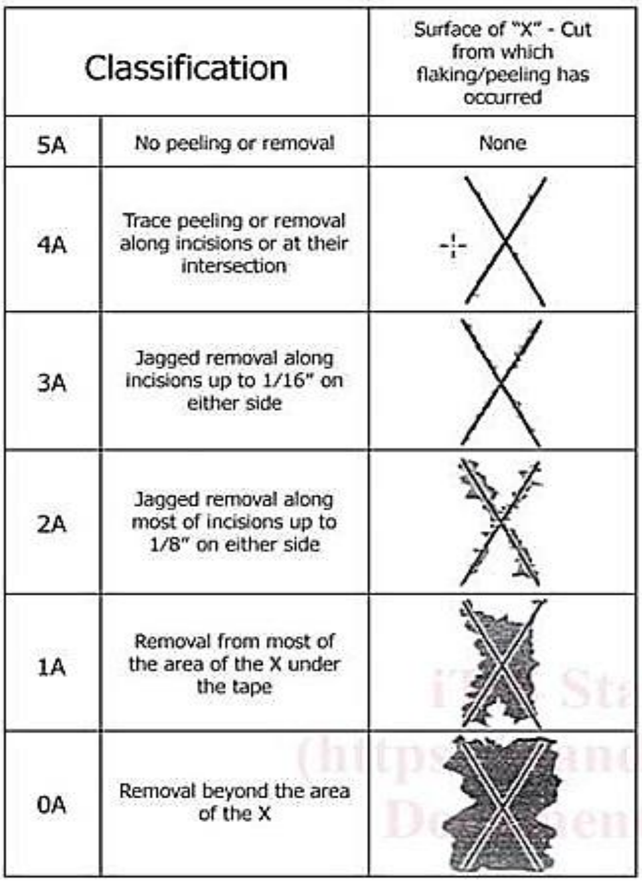
1) Adhesion test

This test (Figure 4) is carried out to determine the adhesion between the paint and the material, and also between the paint layers. This test is a destructive test, which means destructive. Referring to the ABC Project Specification document, it has been mentioned that if the test is damaged, it will take at least 14 days after the painting is completed. This test was carried out using 2 (two) methods, namely the X-Cut Tape Test and Pull-Off Test [10, 24, 25].

2) X-Cut tape test

The X-Cut Tape Test (Figure 5) is performed in accordance with ASTM D3359 – Test Method A, which evaluates the adhesion of the coating by making an X-shaped cut through a film and applying adhesive tape over the incision to assess the number of layers removed. This test uses a classification scale ranging from 5A (no removal) to 0A (removal greater than 65%). In this study, all five panels or specimens tested achieved a 5A classification, which showed excellent adhesion performance [10, 24, 25].

This result means that there is no peeling, peeling, or peeling of the coating after the tape is removed, indicating that the coating is firmly bonded to the substrate. Achieving a rating of 5A in all samples shows not only the effectiveness of the surface preparation and application process, but also the quality and compatibility of the coating system used. This provides confidence in the durability and integrity of the coating under normal service conditions. Figure 3. X-Cut Tape Test Classification.



Classification		Surface of "X" - Cut from which flaking/peeling has occurred
5A	No peeling or removal	None
4A	Trace peeling or removal along incisions or at their intersection	
3A	Jagged removal along incisions up to 1/16" on either side	
2A	Jagged removal along most of incisions up to 1/8" on either side	
1A	Removal from most of the area of the X under the tape	
0A	Removal beyond the area of the X	

Figure 3. X-Cut tape test classification

3) Tensile test

This test refers to the ASTM D4541 standard "Coating Tensile Strength Using a Portable Adhesion Tester". The following are the results of the tensile test. Based on the pull-off test, each panel is tested with three dolls, and the results are averaged. The highest adhesion strength was observed in Panel 1 with an intermediate layer thickness of 50 microns, reaching 22.82 MPa in Dolly 3 [2, 3, 7, 10, 15, 23, 28, 31]. In contrast, the lowest adhesion strength was recorded on Panel 5 with a thickness of 250 microns, indicating a value of 10.9 MPa on Dolly 3 [2, 3, 7, 10, 15, 23, 28, 31]. See Table 7.

From Figures 6 and 7, trends were observed that showed that the thickness of the paint affects the adhesion results, where thicker paints tended to result in lower adhesion values [2, 3, 7, 10, 15, 23, 28, 31]. This is supported by Panel 5, which has a paint thickness of 250 microns and shows lower adhesion than the others. However, when referring to the standard or project specification documents used in Project ABC, the minimum adhesion value is 5 MPa, which means that overall, the result still meets the required criteria.

Figure 4. Pull-off adhesion test process

Figure 5. X-Cut Tape Test Process

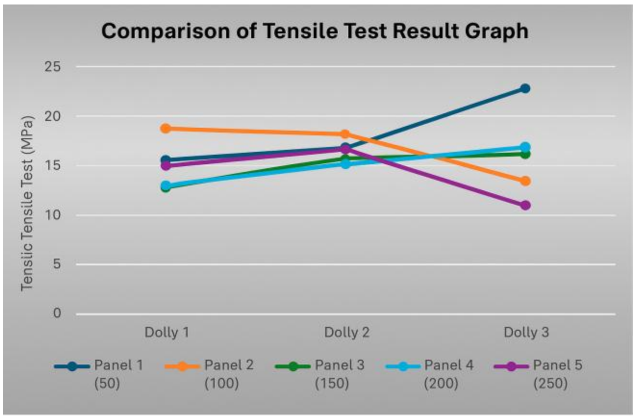


Figure 6. Tensile test results comparison chart

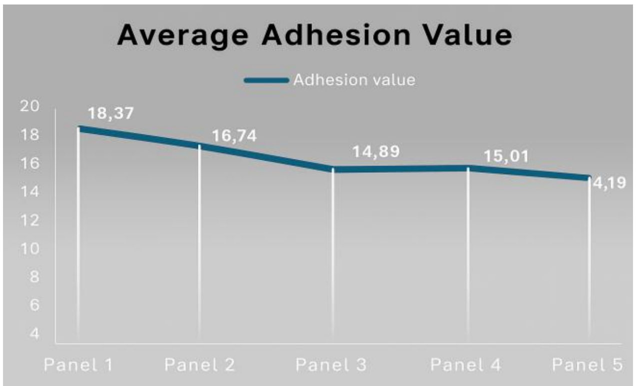


Figure 7. Average adhesion value graph

b. ANOVA (Variance Analysis) Testing

1) Assumption test

Table 4. Measuring the thickness of the dry film of the first coat/primer coat

Panel	First-layer DFT measurement (µm)					Average DFT (µm)
	1	2	3	4	5	
Panel 1	76	94	104	88	76	88
Panel 2	106	80	96	84	80	89
Panel 3	86	94	100	88	80	90
Panel 4	78	82	90	80	84	83
Panel 5	90	96	100	86	84	89

Table 5. Measuring the thickness of the dry film of the second layer/intermediate layer

Panel	First-layer DFT measurement (µm)					Average DFT (µm)
	1	2	3	4	5	
Panel 1	136	134	128	133	132	134
Panel 2	188	184	186	196	178	186
Panel 3	226	236	230	234	230	231
Panel 4	280	276	278	288	284	281
Panel 5	336	328	334	326	330	331

Table 6. Measuring the thickness of the dry film of the third layer/top layer

Panel	First-layer DFT measurement (µm)					Average DFT (µm)
	1	2	3	4	5	
Panel 1	184	228	216	170	192	198
Panel 2	222	230	234	286	280	250
Panel 3	328	342	306	316	300	318
Panel 4	330	326	368	340	350	343
Panel 5	416	388	418	374	408	401

Table 7. Measuring the thickness of the dry film of the first coat/primer coat

Panel	Variations in Intermediate Paint Thickness	Adhesion Value (MPa)			Average Adhesion (MPa)
		1	2	3	
Panel 1	50	15.53	16.78	22.82	18.37
Panel 2	100	18.72	18.15	13.36	16.74
Panel 3	150	12.73	15.77	16319	14.89
Panel 4	200	12.97	15.20	16.88	15.01
Panel 5	250	15.04	16.65	10.9	14.19

Table 8. Normality Test Results

Normality Test						
	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statics	Df	Itself.	Statistics	Df	Itself.
Variations in Intermediate Paint Thickness	.153	15	.200*	.902	15	.103
Adhesion Value (MPa)	.159	15	.200*	.955	15	.598

- Normality test

Based on the Shapiro-Wilk test Table 2, it can be seen that the normality test for the above data shows that the created data follows the normal distribution. This can be seen from the value of Asym sig (2 Tailed) 0.200 > 0.05, so it can be concluded that the data used in this study is distributed normally (Table 8).

- Homogenites

Based on the results of the homogeneity analysis (Table 3), it can be seen that the Sig. The value based on the mean is 0.424 > 0.05, so it can be concluded that the data is homogeneous.

- Independent Sample T-Test

Based on the results of the analysis, the significance value (Sig.) was found to be 0.594, which is greater than 0.05. Therefore, the decision is to fail to reject H0. It can be concluded that there is no significant difference in adhesion values between panels with different intermediate layer thicknesses. See Table 10.

2) ANOVA test

Analysis of Variance (ANOVA) is a statistical method used to test research hypotheses by comparing the averages of several groups to determine if there are statistically significant differences between them. This method is especially useful when dealing with more than two groups or treatment conditions [8]. The core result of the ANOVA test is the F-statistic, which represents the ratio of variance between group averages to in-group variances [8]. See Table 11. Once the F-statistic is calculated, it is compared to the critical (F-critical) value, which is determined based on the degree of significance chosen (usually 0.05) and the degrees of freedom. If the F-statistic exceeds the critical F-value, this suggests that the observed differences among the group averages are unlikely to have occurred by chance.

In such cases, the null hypothesis (H0), which states that there is no significant difference between the groups, is rejected in favor of an alternative hypothesis (H1). This suggests that at least one group of averages differs significantly from the others, providing meaningful insights into the effects of the independent variables being studied [8]. The Shapiro-Wilk test is used to assess the normality of data distribution. As presented in Table 9, the results show that the dataset follows a normal distribution, supported by an asymptotic significance value (2 tails) of 0.200, which exceeds the threshold of 0.05. This confirms that the data meet the assumption of normality, validating the use of parametric statistical methods for further

Table 9. Homogeneity Test Results

Tes Homogenitas Varians					
		Statics Levene	df1	DF2	Itself.
Adhesion Value (MPa)	Based on Average	1.063	4	10	.424
	By Median	.154	4	10	.957
	Based on Median and with Adjusted df	.154	4	7.252	.955
	Based on Trimmed Average	.935	4	10	.482

Table 10. Independent Sample Test Results

Independent Sample Test										
	Levene Test for Equivalence of Variance	t-test for Facility Equity								
		F	Itself .	t	Df	Sig. (2 Oaks)	Average Difference	Std. Error Difference	95% Confidence Interval of Difference	
									Lower	Above
Adhesion Value (MPa)	The same variance is assumed	.488	.523	.579	4	.594	1.63333	2.82043	6.19743	9.46410
	Equal variance is not assumed			.579	3.721	.596	1.63333	2.82043	6.43429	9.70096

analysis [8]. The homogeneity of the variance was evaluated to ensure consistency across the trial group. The analysis, summarized in Table 10, reveals a significance value (based on average) of 0.424, well above the benchmark of 0.05.

These findings confirm that the data were homogeneously distributed, reinforcing the reliability of subsequent comparative tests. Independent hypothesis tests were conducted to examine whether the thickness of the second coat of paint significantly affects the surface adhesion strength of carbon steel. The results (Table 11) yield a significance value of 0.417, which is greater than the critical alpha level (0.05). As a result, we failed to reject the null (H_0) hypothesis, which suggests that there was no statistically significant effect of paint thickness on adhesion strength detected under the tested conditions [8].

3) Comparison with Previous Research

This study aims to evaluate the adhesive strength by varying the thickness of the second/middle layer in a three-layer system [2, 3, 5, 7, 10, 13, 23, 28, 31]. A previous study titled "Analysis of the Effect of Thickness Variation and Coating Type on Corrosion Rate and SS400 Steel Plate Adhesion Test" performed an adhesion test using a single layer of Hempadur Mastic 45881 epoxy layer with thickness variations of 75, 125, and 250 microns, resulting in the following results [29]. See Table 12. Based on data from Table 8 obtained through adhesion testing using the Pull-Off Test method, the best results for epoxy coatings of varying thickness were achieved at 250 µm, with an adhesion strength of 18.78 MPa [29].

Another study examined the effects of different abrasives—aluminum oxide, steel sand, and volcanic sand—on the adhesive strength and corrosion resistance of epoxy and zinc-rich paints in seawater environments. The results showed that steel sand provided the best performance among the abrasives tested. In addition, zinc-rich paints exhibit superior adhesive properties compared to epoxy paints. In terms of corrosion resistance, surfaces coated with zinc-rich paints also show a much lower degree of corrosion than those treated with epoxy paints. These findings suggest that steel grit abrasives combined with zinc-rich paints offer optimal durability for marine applications [10].

In a separate study, the researchers examined the effects of different layer thicknesses and compositions of magnesium carbonate powder in epoxy coating mixtures on adhesion strength, metallographic characteristics, and corrosion rate prediction for ASTM A36 steel. These findings concluded that the highest tensile adhesion strength was achieved with a 10% magnesium carbonate composition at a layer thickness of 100 microns, resulting in a value of 11.95 MPa [29]. In a separate study, the researchers examined the effects of different layer thicknesses and compositions of magnesium carbonate powder in epoxy coating mixtures on adhesion strength, metallographic characteristics, and corrosion rate prediction for ASTM A36 steel. These findings concluded that the highest tensile adhesion strength was achieved with a 10% magnesium carbonate composition at a layer thickness of 100 microns, resulting in a value of 11.95 MPa [29].

Table 11. ANOVA Test Results

ANOVA					
Adhesion Value (MPa)	Number of Squares	Df	Square Average	F	Itself.
Antar Group	34.556	4	8.639	1.078	.417
In a Group	80.151	10	8.015		
Entire	114.708	14			

Table 12. Results of Previous Research: Tensile Tests

Panel	Thickness variations	Average Adhesion (MPa)
Panel 1	75	10.34
Panel 2	125	15.34
Panel 3	250	18.78

On the contrary, when compared to the results of current research, the trend is the opposite. Here, the highest thickness variation of 250 µm showed the lowest average adhesion strength of 14.19 MPa, while the best adhesion results were found at 50 µm thickness, with an average strength of 18.37 MPa [2, 3, 7, 10, 15, 23, 28, 31].

However, it is important to note that previous studies tested thickness variations using single-layer (single-layer) epoxy systems, while current studies applied thickness variations in three-layer systems [2, 3, 7, 10, 15, 23, 28, 31].

Conclusion

Based on the results of the analysis on the effect of the variation in the thickness of the second layer (intermediate layer) in the three-layer coating system on the adhesion strength of the carbon steel surface, it can be concluded that the thickness of the intermediate layer significantly affects the adhesion performance of the coating system. Tests using the X-Cut Tape Test and Pull-Off Test methods showed that specimens with an intermediate layer thickness of 250 microns (Panel 5) produced the lowest adhesion strength value compared to other specimens with a lower thickness. These findings indicate that an increase in the thickness of the intermediate layer tends to decrease the adhesion strength of the coating.

As a follow-up to this study, it is recommended to conduct a test of the corrosion rate to evaluate the effectiveness of the coating in the long term. In addition, the research can also be expanded by testing the permeability of the coating to identify potential coating failures due to the penetration of moisture or other corrosive compounds.

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