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Analysis The Effect Of Different Surface Preparation Methods On Corrosion Resistance Of Astm-A36 Steel

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ABSTRACT
In the industrial world, to extend the service life of materials, protection methods are carried out to slow down the material's corrosion rate. The protection method that is often used is the coating method. The coating method is a protection method by coating the substrate material using a coating material to prevent contact between the substrate material and the environment. In this research, the substrate material used is ASTM A36 steel and the coating material used is Surface Tolerant Epoxy paint. The independent variable used in this study lies in the surface preparation method which consists of solvent cleaning, hand tool cleaning, power tool cleaning, power tool to bare metal cleaning, and abrasive blast cleaning. Different preparation methods result in different roughness and cleanliness of the surface. This can affect changes in the mechanical properties of the coating material, such as corrosion resistance and adhesion strength. Based on the corrosion resistance test, it is found that the abrasive blast cleaning and power tool to bare metal cleaning methods produce the highest corrosion resistance properties because both have a rating number of 8 in the salt spray test results. Based on the adhesion strength test, it is found that the abrasive blast cleaning method also produces the highest adhesion strength. This conclusion refers to the results of the tape x-cut test where the sample produces a rating number 5A where the sample does not experience peeling after testing. In addition, the abrasive blast cleaning method produced the highest adhesion strength in the pull-off test, which was 7.16 Mpa. Thus, the abrasive blast cleaning method is the most effective surface preparation method for ASTM A36 steel before being coated with the coating material. In addition, it can also be concluded that the higher the surface roughness of the sample, the better the corrosion resistance and adhesion strength.

***Keywords**: Adhesion; Corrosion; Steel ASTM A36; Surface Preparation; Surface Tolerant Epoxy.*

INTRODUCTION

Steel is a material that is often chosen for various sectors, such as automotive, construction, oil and gas, electronics, heavy equipment, transportation, defense equipment, telecommunications, etc [1]. It fulfills the needs of all construction processes and is often called the mother of Industry, which means the mother of all industries.

Based on data obtained from World Steels, world steel demand is expected to continue to increase in 2022 by 0.4%, or reaching 1,840.2 million tons, and in 2023 by 2.2%, or reaching 1,881.4 million tons [2]. This is certainly good news for Indonesia, which has iron ore reserves of 1.7% of total world reserves and iron ore production of 0.2% of total world production [3]. Based on data obtained from the Ministry of Industry, it is said that Indonesia's iron and steel trade balance experienced benefits with an increase in exports from 2020 to 2021 of 51.8% [4]. Therefore, if Indonesia, which is rich in iron ore, is supported by mastery of advanced steel technology, it will certainly help this country become a developed country [5].

In its application, steel materials have great potential to interact with the natural atmosphere [6]. This is what makes steel susceptible to corrosion. Corrosion is considered detrimental because parts affected by corrosion will experience decomposition, resulting in a decrease in the quality of the steel and also making the steel prone to failure [7]. Corrosion is something that cannot be avoided but can be managed and controlled. By treating and controlling corrosion, the service life of steel materials will be longer, losses due to failure can be minimized, and worker safety will be maintained [8].

Hence, to reduce the possibility of corrosion, steel materials need to be given a coating treatment [9]. Coating treatment is a method of coating the surface of a material using corrosion-resistant material so that the possibility of a reaction between the material and the environment can be minimized [10]. One of the most frequently used coating methods is the organic coating method. Organic coatings are considered to have effective coating results in inhibiting corrosion, tend to be easy to apply, and also provide added value in the form of aesthetic value [11]. However, it should be noted that the quality of the coating produced is not only determined based on the type of coating material used. There are other factors, such as environmental conditions around the steel, surface preparation that has been carried out, accuracy of the operator in coating, etc. Among these factors, surface preparation is the factor that has the most significant impact on the quality of the resulting layer. Sample preparation is often the main cause of coating failure. Some failures often occur, such as the presence of bubbles that are still trapped between the surface of the substrate and the coating layer, low adhesion to the layer so that it is easily degraded, shrinkage, blistering phenomena, etc. These things can occur due to weak adhesion properties between the substrate surface and the layer so that the layer cannot adhere optimally [12]. The non-adhesion of the layer was caused by the sample preparation treatment that had been carried out which was deemed inappropriate [13]. The sample preparation carried out did not comply with the Steel Surface Painting Council (SSPC) standards [14]. Starting from the surface cleaning method, and mechanical treatments, surface roughness is not done properly so the resulting adhesion strength is not optimal.

Therefore, in this research, various experiments were carried out in carrying out coating methods with surface-tolerant epoxy paint on the surface of ASTM A36 steel substrates. This research uses a variety of surface preparations, including solvent cleaning, hand tool cleaning, power tool cleaning, abrasive blast cleaning, and power tool to bare metal cleaning. This report will also discuss the testing methods used and their objectives. The expected result of this research is to find out the effect of the surface preparation used on corrosion resistance and the adhesion strength between the substrate material and the layer that protects the surface.

MATERIALS AND METHODS

Surface Preparation

The sample material used in this research is ASTM A36 steel, with dimensions of 70 x 150 x 3 mm, and is at rust grade B. In this research, the samples were divided into 5 groups based on the type of sample preparation (solvent cleaning, hand tool cleaning, power tool cleaning, abrasive blast cleaning, power tool to bare metal cleaning). Then, the five groups were divided into four groups based on the type of test characterization (electron impedance spectroscopy, salt spray test, tape test x-cut, pull-off test). That way at least 20 samples are needed.

Surface Roughness

The method used for this research is a surface profile depth micrometer because it is considered to have the most accurate results and is easy to apply. The surface roughness testing method using ASTM D4417 aims to measure the depth of the sample surface profile. Measurements were carried out using an Elcometer 224 Digital Surface Profile. Before using this measuring instrument, it needs to be calibrated first on a flat surface.

Preparation of Organic Coating Materials

In this research, the type of paint used is surface-tolerant epoxy paint. In its application, this type of paint is intended for components that cannot be regularly maintained, such as painting ships, infrastructure, storage tanks, the oil and gas industry, and other industries. Before application, the paint needs to be prepared first by referring to the guidelines in the technical data sheet for the related paint type to obtain appropriate results. Preparation is carried out by paying attention to the mixing ratio of each paint component. The paint component consists of part A as base paint and part B as curing agent. The mixing ratio for this type of surface-tolerant epoxy paint is 5.67:1. Apart from these two components, a solvent agent in the form of thinner is also added, amounting to 10% of the total components. The thinner solution is used to break down the viscosity of the paint and also make the application process easier. Then these three components are mixed using a paint mixer.

Organic Coating Application Process

Visual inspection is carried out by comparing the prepared samples with existing visual standards. This aims to ensure that the cleanliness level of the sample meets standards before finally being coated with organic coating material. Apart from preparing the coating material and

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sample, what is no less important to pay attention to is the environmental conditions of the painting area. The things to pay attention to when checking the environmental conditions around the sample (environment test), include: steel temperature, wet temperature, dry temperature, dew point (DP), and relative humidity (RH). When the sample has met the desired level of surface cleanliness and the sample environment has also met the provisions of the environment test. Then the sample is ready to be applied with organic coating material. The application method used is the rolling method using a roller as the application tool.

Layer Thickness

The measurement process is carried out twice, namely when the paint is still wet (wet film thickness) and when the paint is dry (dry film thickness). When the paint is still wet, the layer thickness test is carried out using an Elcometer 112 wet film thickness. When the solvent contained in the paint has evaporated and the paint is in a dry condition, the layer thickness test is carried out again using the PosiTector 6000 Coating Thickness Gauge. Measurements were carried out at 5 different points on the sample and at each point 3 measurements were taken. Then, calculate the average of the 3 values from each point and calculate the combined average of the 5 points to get the overall dry film thickness (DFT) value.

Characterization of Coating Corrosion Resistance Test and Coating Adhesion Strength Test

The tests used to test the corrosion resistance of the organic coating layer are EIS and salt spray test [15]. The solution used to test the corrosion resistance of the organic coating layer is NaCl 3.5% for the EIS and NaCl 5% for the salt spray test, refers to ASTM G106-89 and ASTM B117 which are the standards for EIS and salt spray test [16].

The tests used to test the adhesion strength of the organic coating layer are tape test x-cut and pull-off test. The tape test x-cut is a test characterization method that aims to determine the adhesion strength of the organic coating to the ASTM A36 steel substrate. The characterization method is carried out based on the ASTM D3359 standard. The pull-off test is a test method that aims to determine the adhesion strength of the organic coating to the ASTM A2238 steel substrate. It refers to the ASTM D4541 standard.

RESULTS AND DISCUSSION

Steel Surface Roughness

The results of the surface roughness test are shown in Table 1.

Table 1. Sample Roughness Value After Surface Preparation.

Sample	Surface Preparation	Surface Roughness	Average
SC1	Solvent Cleaning	51.70	69.03
SC2		87.80	
SC3		75.00	
SC4		52.67	
SC5		78.00	
HTC1	Hand Tool Cleaning	10.90	14.72
HTC2		9.10	
HTC3		14.50	
HTC4		19.00	
HTC5		20.10	
PTC1	Power Tool Cleaning	27.30	19.68
PTC2		20.50	
PTC3		14.30	
PTC4		18.30	
PTC5		18.00	
PTBMC1	Power Tool to Bare Metal Cleaning	119.00	80.28
PTBMC2		79.90	
PTBMC3		90.10	
PTBMC4		57.90	
PTBMC5		54.50	
ABC1	Abrasive Blast Cleaning	153.10	122.95
ABC2		98.67	

Sample	Surface Preparation	Surface Roughness	Average
ABC3		100.91	
ABC4		94.91	
ABC5		167.18	

Wet Film Thickness

Referring to the technical data sheet for surface tolerant epoxy paint, the desired DFT in this research is 200 µm. If this number is converted in (1), then the value of the wet film thickness (WFT) is obtained.

$$Wet\ Film\ Thickness = \frac{Dry\ Film\ Thickness}{\%\ Volume\ Solid} \quad (1)$$

Based on the technical data sheet, the solid volume of surface tolerant epoxy paint is 82 ± 3%. If the DFT used is 200 µm. So, the WFT obtained is 243.90 µm.

Dry Film Thickness

When the applied paint has dried and cured on the substrate surface completely. DFT measurements were carried out. The results of measuring the DFT are shown in Table 2.

Table 2. DFT Results.

Sample	Sample Measurement					DFT Sample	Average DFT	Purpose
	A	B	C	D	E			
SC1	218.00	292.67	269.33	223.67	220.33	244.80		EIS
SC2	215.00	230.00	189.00			211.33		Pull Off
SC3	204.00	334.00	412.00	180.00	166.00	259.20	226.71	Tape X-Cut
SC4	182.39	197.56	208.96	194.52	180.97	192.88		Back Up
SC5	189.33	240.00	225.33	214.00	258.00	225.33		Salt Spray
HTC1	252.67	243.33	197.33	230.67	264.00	237.60		EIS
HTC2	186.55	208.00	190.87	170.43	182.81	187.73		Back Up
HTC3	192.00	192.00	220.00			201.33	216.93	Pull Off
HTC4	240.00	194.00	308.00	136.00	268.00	229.20		Tape X-Cut
HTC5	208.00	232.67	246.00	231.33	226.00	228.80		Salt Spray
PTC1	200.00	200.00	240.00			213.33		Pull Off
PTC2	174.67	190.93	185.26	203.56	192.28	189.34		Tape X-Cut
PTC3	241.33	256.00	268.00	147.33	270.00	236.53	206.64	Salt Spray
PTC4	185.33	190.67	231.33	154.67	173.33	187.07		EIS
PTC5	223.87	201.86	188.41	202.49	217.92	206.91		Back Up
PTBMC1	249.33	242.67	326.00	307.33	287.33	282.53		EIS
PTBMC2	192.18	201.64	184.42	170.33	180.71	185.86		Tape X-Cut
PTBMC3	214.32	183.28	190.22	200.56	202.20	198.12	234.35	Back Up
PTBMC4	258.00	202.00	284.00			248.00		Pull Off
PTBMC5	248.67	216.00	248.00	313.33	260.33	257.27		Salt Spray
ABC1	223.33	213.33	218.67	212.00	171.33	207.73		Salt Spray
ABC2	252.00	153.33	244.67	185.33	182.00	203.47		EIS
ABC3	230.00	204.00	238.00			224.00	208.57	Pull Off
ABC4	241.45	224.26	194.81	197.21	226.30	216.81		Back Up
ABC5	205.67	192.35	183.77	189.52	182.94	190.85		Tape X-Cut

Salt Spray Test

The surface of the sample that has been coated with coating material is scratched using a cutter to form an X pattern with a scratch width of ± 0.5 mm. The average result is compared from the initial scratch width to obtain the value of the change in scratch width. The scratch width change values are grouped based on the ASTM D1654 standard which is presented in Table 3 which is a reference for determining the rating number for each sample

.

Table 3. Scratch Widening Reference (Astm D1654)

Representative Mean Creepage from Scribe		
Milimeters	Inches (Approximate)	Rating Number
Zero	0	10
Over 0 to 0.5	0 to 1/64	9
Over 0.5 to 1.0	1/64 to 1/32	8
Over 1.0 to 2.0	1/32 to 1/16	7
Over 2.0 to 3.0	1/16 to 1/8	6
Over 3.0 to 5.0	1/8 to 3/16	5
Over 5.0 to 7.0	3/16 to 1/4	4

Representative Mean Creepage from Scribe		
Milimeters	Inches (Approximate)	Rating Number
Over 7.0 to 10.0	1/4 to 3/8	3
Over 10.0 to 13.0	3/8 to 1/2	2
Over 13.0 to 16.0	1/2 to 5/8	1
Over 16.0 to more	5/8 to more	0

The data regarding the value of changes in scratch width which have been grouped based on rating number has been summarized in Table 4.

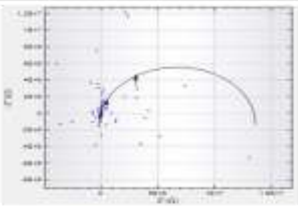
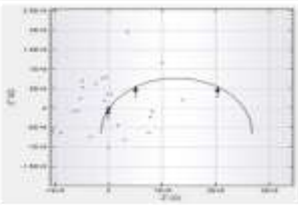
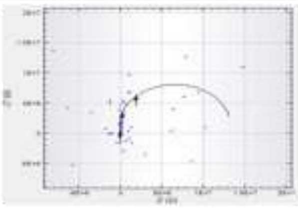
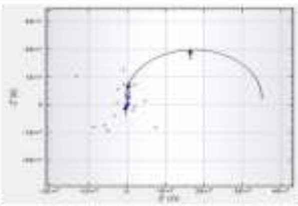
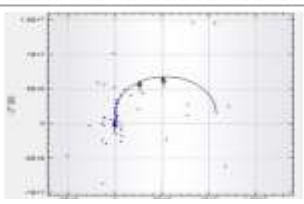
Table 4. Salt Spray Test Results.

	SC	HTC	PTC	PTBMC	ABC
N1	1.80	1.19	2.53	1.22	2.04
N2	1.65	1.89	1.83	1.50	0.58
N3	2.18	1.92	1.82	1.91	1.07
N4	1.25	1.57	1.30	1.23	1.58
Average	1.72	1.64	1.87	1.47	1.32
Difference	1.22	1.14	1.37	0.97	0.82
Rating Number	7	7	7	8	8

EIS Test

This test uses a tool in the form of a flat cell which acts as a medium for electrochemical cells to enable measurements of electrochemical impedance in various electrochemical systems. In Table 5, it can be seen that the Nyquist plot from each sample forms a scatter plot.

Table 5. Eis Results.

Sample	Nyquist Plot	Chi-Square
SC2		92.446
HTC1		91.772
PTC1		93.884
PTBMC4		42.404
ABC3		90.678

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The threshold value of chi-squared is: (1) if the value of $\chi2 < 10\text{-}6$ indicates that the fitting results are very suitable, (2) if the value of 10-5 <$\chi2$ < 10-6 is quite reasonable, (3) if the value of 10-4 < $\chi2$ < 10-5 then it is included in the acceptance threshold, and (4) if the value of $\chi2$ > 10-4 then it is a bad value and cannot be used as data interpretation. Based on this, it can be seen that none of the chi-squared values for each sample meets the threshold. In this way, we can be sure that there are errors occurring in the resulting data, so that the resulting data can be said to be invalid and unusable. Usually the scatter plot formed on a Nyquist graph is caused by non-uniformity of the coating layer, such as: uneven coating layer thickness, defects in the substrate, or impurities still attached to the substrate surface. The non-uniformity of the layer can cause variations in the impedance response at different measurement points, resulting in a scatter plot being formed on the Nyquist graph.

Tape X-Cut Test

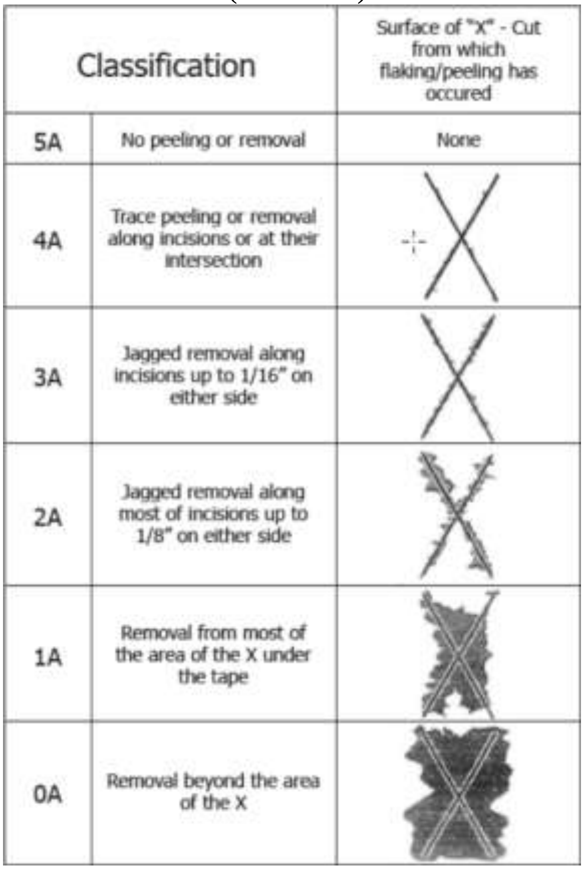
The tape x-cut test results can be seen in Table 6 with various surface preparation methods.

Table 6. Tape X-Cut Test Results.

Sample	Tape X-Cut	Adhesion Strength
SC2		3A
HTC1		4A
PTC1		5A
PTBMC4		5A
ABC3		5A

The results of the inspection were compared with the illustrative images and the Rating Number description in Table 7 from ASTM D3359.

Table 7. Astm D3359 (Method A) X-Cut Procedure.



Classification		Surface of "X" - Cut from which flaking/peeling has occured
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	

To strengthen the conclusion regarding the most effective surface preparation method in producing a layer with the highest adhesion strength, a quantitative strength analysis using the pull-off testing method is needed to provide precise adhesion strength values.

Pull Off Test

Table 8 contains the results of pull-off tests on samples with various surface preparations. Visual failures that occur on the surface of the coated substrate are shown in Table 9 which are then classified based on the type of failure. The type of failure that occurs on the coated substrate surface when the dolly is pulled can be a benchmark for determining the adhesion of the organic layer to the substrate surface. In this research, the only types of failure that occurred were adhesion and cohesion failure. Adhesion failure is a failure condition where the coating layer is completely peeled off from the substrate surface during testing, this indicates that the adhesion between the organic layer and the substrate surface is very weak. Meanwhile, the type of cohesion failure is a failure condition where peeling occurs only between layers without peeling until it reaches the surface of the substrate. This indicates that the organic layer tends to have strong adhesion where the peeling that occurs only reaches between the layers.

Table 8. Pull-Off Test Results.

Sample	Adhesion Strength (Mpa)	Average Adhesion Strength (Mpa)
SC2	4.30	4.65
	4.34	
	5.32	
HTC1	4.71	5.07
	5.23	
	5.27	
PTC1	6.34	6.06
	5.75	
	6.10	

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Jurnal Rekayasa Material, Manufaktur dan Energi

Sample	Adhesion Strength (Mpa)	Average Adhesion Strength (Mpa)
PTBMC4	6.80 5.96 7.59	6.78
ABC3	5.44 8.10 7.93	7.16

Table 9. Visual Results of Failure.

Sample	Visual Failure	Failure
SC2		70% Adhesion Failure 30% Cohesive Failure
HTC1		60% Adhesion Failure 40% Cohesive Failure
PTC1		50% Adhesion Failure 50% Cohesive Failure
PTBMC4		10% Adhesion Failure 90% Cohesive Failure
ABC3		0% Adhesion Failure 100% Cohesive Failure

When the applied coating material cures, a mechanical interlocking bond occurs between the layer and the substrate surface. Based on these results, it can be concluded that roughness is proven to be able to influence the adhesion strength value of the organic layer. It can be seen that the ratio between surface roughness and adhesion strength is directly proportional, where the higher the level of roughness, the higher the adhesion strength produced. The rougher the surface, the more area there is for the coating material to penetrate the gap.

There is an anomaly where the sample using the solvent cleaning method does not form a linear graph which is in accordance with the previous explanation. This discrepancy occurs because the surface preparation method using solvent cleaning on samples only removes oil, grease, and dirt. This method is considered ineffective in removing rust attached to the substrate surface. As a result, the roughness value is the roughness of the rust that is still attached to the substrate surface, not the roughness of the substrate surface itself. Therefore, why samples with solvent cleaning have the lowest adhesion strength value even though they have the third highest roughness value is because the coating material only penetrates the rust part, the penetration does not reach the gaps on the substrate surface. That way, the mechanical interlocking bond that is formed is not optimal.

CONCLUSION

Based on surface roughness testing referring to ASTM D4417, the abrasive blast cleaning method is the method that produces the highest surface roughness with a roughness value of 122.95 µm, followed by the power tool to bare metal cleaning, solvent cleaning, power tool cleaning and hand tool cleaning methods with a roughness value of 80 28 ; 69.03 ; 19.68 ; and 14.72 µm. To analyze the corrosion resistance of the coating layer in protecting ASTM A36 steel substrates from corrosive environments, 2 testing methods were used, namely the salt spray method and electrochemical impedance spectroscopy (EIS). In the salt spray test, the results showed that the abrasive blast cleaning method and power tool to bare metal cleaning were the surface preparation methods with the highest level of effectiveness in preventing corrosion with changes in the width of the scratches formed by 0.82 and 0.97 µm. Both are included in rating number 8. Meanwhile, in the EIS test, a randomly arranged pattern (scatter plot) was produced. This has an impact on the resulting chi-square value which is also high. The chi-square value is large, indicating that the discrepancy between the experimental data and the predicted data from the equivalent circuit model is also large, so it can be ascertained that the possibility of errors occurring in the resulting data is very large. The conclusion obtained after carrying out the adhesion strength test using the x-cut and pull-off tape method is that the abrasive blast cleaning surface preparation method produces the highest adhesion value between the surface of the steel substrate and the coating layer. This refers to the x-cut tape test results which show a rating number of 5A where there is no peeling of the coating layer at all. On the other hand, the average adhesion strength value obtained through pull-off testing for samples treated with abrasive blast cleaning has a value of 7.16 MPa. This value is also the highest average adhesion strength value compared to other samples. Based on the conclusions, there are several suggestions that can be considered for similar research; apply a surface preparation method with a high level of surface roughness and cleanliness, so that impurities that are still attached do not affect the test results or characterization. Use the airless spray method so that the surface tolerant epoxy paint applied has the same wet film thickness. Ensure that the test environment conditions are stable and controlled. Especially for factors that can affect the accuracy of EIS measurements, such as: non-uniformity of the coating and the persistence of impurities on the substrate surface.

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