

# Effect of Different Surface Preparation Method on Corrosion Resistance and Adhesion Strength of ASTM A36 Steel Substrate with Surface Tolerant Epoxy Paint as Coating Material

I W Santoso<sup>1,\*</sup>, D Aqila<sup>1</sup>, R Riastuti<sup>1</sup>, and R T Ramadhani<sup>1</sup>

<sup>1</sup>Department of Metallurgical and Materials Engineering, Universitas Indonesia, Depok, 16424, Indonesia

\*Email: irwan.wijaya@ui.ac.id

## Article Information:

Received:

13 November 2023

Received in revised form:

2 June 2024

Accepted:

24 June 2024

Volume 6, Issue 1, June 2024

pp. 52 – 58

<http://dx.doi.org/10.23960/jesr.v6i1.152>

## Abstract

*In the industrial world, protection method is used to slow down the corrosion rate and to extend the service life of material. Among the various protection method, one of the most widely used is coating, in which the substrate material is protected using a coating material to prevent contact with the environment. In this study, the substrate material used was ASTM A36 steel, and the coating material was Surface Tolerant Epoxy paint. The independent variable was the surface preparation method, which consisted of solvent, hand tool, power tool, power tool to bare metal, and abrasive blast cleaning. The results showed that each preparation method produced different surface roughness and cleanliness. 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, the abrasive blast and power tool to bare metal cleaning method produced the highest corrosion resistance properties because both had a rating number of 8 in the salt spray test results. The adhesion strength test showed that the abrasive blast cleaning method also produced the highest adhesion strength. According to the tape x-cut test, this method achieved a rating number of 5A, showing that the sample did not experience peeling after testing. The abrasive blast cleaning method produced the highest adhesion strength in the pull-off test, which was 7.16 MPa. Therefore, abrasive blast cleaning was considered to be the most effective surface preparation method for ASTM A36 steel before coating. 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

## I. INTRODUCTION

Steel is a material that is often chosen for various sectors, such as the automotive, construction, oil and gas, electronics, heavy equipment, transportation, defense equipment, and telecommunications. It fulfills the needs for all construction processes and is often referred to as the mother of all industries.

Based on data from Worldsteel, world steel demand increased in 2022 by 0.4% to 1,840.2 million tons and in 2023 by 2.2%, reaching 1,881.4 million tons [1]. This is certainly good news for Indonesia, which has iron ore accounting for 1.7% and 0.2% of total world reserves and production, respectively [2]. According to data from the Ministry of Industry, Indonesia iron and steel

trade balance experienced benefits with an increase in exports from 2020 to 2021 estimated at 51.8% [3]. Therefore, providing support in the form of advanced steel technology will provide a significant benefit.

In the application, steel material has great potential to interact with the natural atmosphere, making steel susceptible to corrosion. Parts affected by corrosion will experience decomposition, resulting in a decrease in the quality of the steel [4]. Corrosion is inevitable, but but can be managed and controlled. By treating and controlling corrosion, the service life of steel material will be longer, losses due to failure are minimized, and worker safety will be maintained.

To reduce the possibility of corrosion, steel material needs to be given a coating treatment. This is a method

of coating the surface of a material using corrosion-resistant material, thereby reducing the possibility of a reaction between the material and the environment. One of the most frequently used coating method is the organic. This method produces effective coating results in inhibiting corrosion, is easy to apply, and also provides added value in the form of aesthetics. However, the quality of the coating produced is not only determined by the material used. There are other factors, such as environmental conditions around the steel, surface preparation, and the accuracy of the operator in coating. Among these factors, surface preparation has the most significant impact on the quality of the resulting layer. Sample preparation is often the main reason for coating failure, causing the presence of bubbles trapped between the surface of the substrate and the coating layer, low adhesion to the layer, leading to easy degradation, shrinkage, and blistering phenomena. These failures occur due to weak adhesion properties between the substrate surface and the layer, limiting optimal adhesion [5]. The non-adhesion of the layer may be caused by the sample preparation treatment that had been carried out without compliance with the Steel Surface Painting Council (SSPC) standards. Improper surface cleaning method, mechanical treatments, and surface roughness can lead to suboptimal adhesion strength [6].

This study carried out coating with surface-tolerant epoxy paint on the surface of ASTM A36 steel substrate. Several varieties of surface preparation method were used, including solvent, hand tool, power tool, abrasive blast, and power tool to bare metal cleaning. The testing method used and the objectives were also discussed. The results will offer insights into the effect of surface preparation method on corrosion resistance and the adhesion strength between the substrate material and the surface protection layer.

## II. MATERIAL AND METHOD

### A. Surface Preparation

The sample material used in this study was ASTM A36 steel, with dimensions of 70 x 150 x 3 mm and rust grade B. More importantly, the sample preparation method were divided into solvent, hand tool, power tool, abrasive blast, and power tool to bare metal cleaning. 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), totaling 20 samples.

### B. Surface Roughness

The method used for this study is a surface profile depth micrometer, 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 the instrument, it was calibrated first on a flat surface.

### C. Preparation of Organic Coating Material

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

### D. Organic Coating Application Process

Visual inspection was 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 sample, the environmental conditions of the painting area were also considered. The conditions observed include steel temperature, wet temperature, dry temperature, dew point (DP), and relative humidity (RH). After meeting the desired level of surface cleanliness and the provisions of the environment test, the sample was coated with organic coating material using the rolling method.

### E. Layer Thickness

The measurement process was carried out twice, namely when the paint was still wet (wet film thickness) and after drying (dry film thickness). During the wet phase, the layer thickness test was carried out using an Elcometer 112 wet film thickness (WFT). When the solvent has evaporated and the paint was in a dry condition, the layer thickness was measured using the PosiTector 6000 Coating Thickness Gauge. Measurements were carried out at 5 different points on the sample, with 3 replicates. Subsequently, the average of the 3 values from each point was calculated as well as the combined average of the 5 points to get the overall dry film thickness (DFT) value.

**F. Characterization of Coating Corrosion Resistance Test and Coating Adhesion Strength Test**

The corrosion resistance of the organic coating layer was assessed using EIS and salt spray test. The solution used to test the corrosion resistance of the organic coating layer was NaCl 3.5% for the EIS and NaCl 5% for the salt spray test, following ASTM G106-89 and ASTM B117, which are the standards, respectively.

The adhesion strength of the organic coating layer was measured using the tape test, x-cut, and pull-off test. The tape test x-cut is a characterization method that aims to determine the adhesion strength of the organic coating to the ASTM A36 steel substrate. The characterization method was carried out based on the ASTM D3359 standard. Pull-off test is a method that aims to determine the adhesion strength of the organic coating to the ASTM A38 steel substrate. It also referred to ASTM D4541 standard.

**III. RESULTS AND DISCUSSIONS**

**A. Steel Surface Roughness**

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

**Table 1.** Sample roughness of the samples that were subjected to various steel cleaning method 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	
ABC3		100.91	
ABC4		94.91	
ABC5		167.18	

**B. WFT**

Referring to the technical data sheet for surface-tolerant epoxy paint, the desired DFT was 200 µm. By converting the number following equation (1), the value of the WFT can be obtained.

$$Wet\ Film\ Thickness = \frac{Dry\ Film\ Thickness}{\% Volume\ Solid} \tag{1}$$

Based on the technical data sheet, the solid volume of surface-tolerant epoxy paint was 82 ± 3%. Using DFT of 200 µm, the WFT obtained would be 243.90 µm.

**C. Dry Film Thickness**

When the applied paint had dried on the substrate surface completely, DFT measurements were carried out. The results of DFT measurements are shown in Table 2.

**Table 2.** The DFT of the samples that were subjected to various steel cleaning method

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	226.71	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		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	216.93	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		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	206.64	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		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	234.35	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		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	208.57	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		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

**D. Salt Spray Test**

The surface of the sample coated with coating material was scratched using a cutter to form an X pattern with a scratch width of ± 0.5 mm. The average result was compared with the initial scratch width to obtain the value of the change in 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.

The data showing changes in scratch width, which have been grouped based on rating number, are summarized in Table 4.

**Table 3.** Scratch Widening Reference (ASTM D1654)

Representative Mean Creepage From Scribe		
Milimetres	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
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	½ to 5/8	1
Over 16,0 to more	5/8 to more	0

**Table 4.** Salt Spray Test of the samples that were subjected to various steel cleaning method

	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

**E. EIS Test**

This test used 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 systems [7]. Table 5 shows that the Nyquist plot from each sample forms a scatter plot.

The threshold value of chi-squared is explained as follows; (1) the value of  $\chi^2 < 10^{-6}$  shows the fitting results are very suitable, (2)  $10^{-5} < \chi^2 < 10^{-6}$  represents quite reasonable, (3)  $10^{-4} < \chi^2 < 10^{-5}$  is included in the acceptance threshold, and (4)  $\chi^2 > 10^{-4}$  represents a bad value which cannot be used as data interpretation [8]. Based on the results, none of the chi-squared values for each sample meets the threshold, showing the presence of errors in the resulting data. Therefore, the data can be considered invalid and unusable. The scatter plot formed on a Nyquist graph is usually caused by non-uniformity of the coating layer, uneven coating layer thickness, defects in the substrate, or impurities still attached to the substrate surface [9]. The non-uniformity of the layer potentially causes variations in the impedance response at different measurement points, resulting in a scatter plot being formed on the Nyquist graph.

**Table 5.** The EIS of the samples that were subjected to various steel cleaning method






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

**F. Tape X-Cut Test**






The tape x-cut test results are shown in Table 6 with various surface preparation method.

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

**Table 6.** Tape X-Cut Test Results

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

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

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	

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 was conducted to provide precise adhesion strength values.

**G. Pull-Off Test**

Table 8 shows the results of pull-off tests on samples with various surface preparation. Visual failures on the surface of the coated substrate are shown in Table 9, which are then classified based on the type. Specifically, 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. In this study, the only types of failure that occurred were adhesion and cohesion. Adhesion failure is a condition where the coating layer is completely peeled off from the substrate surface during testing. This shows that the adhesion between the organic layer and the substrate surface is very weak. Meanwhile, cohesion failure is a condition where peeling occurs only between layers without peeling until it reaches the surface of the substrate. This shows that the organic layer tends to have strong adhesion where the peeling only reaches between the layers.

**Table 8.** Pull-Off Test Results

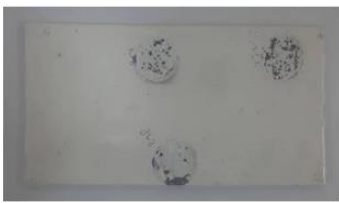




Sample	Adhesion Strength (Mpa)	Average Adhesion Strength (Mpa)
SC2	4.30	4.65
	4.34	
	5.32	
HTC1	4.71	5.07
	5.23	
	5.27	
PTC1	6.34	6.06
	5.75	
	6.10	
PTBMC4	6.80	6.78
	5.96	
	7.59	
ABC3	5.44	7.16
	8.10	
	7.93	

When the applied coating material dries, a mechanical interlocking bond occurs between the layer and the substrate surface. These results show that roughness influences the adhesion strength value of the organic layer. The ratio between surface roughness and adhesion strength is directly proportional, where the higher the level of roughness, the greater the adhesion strength produced. The rougher the surface, the more area there is for the coating material to penetrate the gap [10].

An anomaly occurs when the sample using the

solvent cleaning method does not form a linear graph in accordance with the previous explanation. This anomaly occurs because the surface preparation method using solvent cleaning on samples only removes oil, grease, and dirt [11]. The method is considered ineffective in removing rust attached to the substrate surface. Therefore, the roughness value represents the rust still attached to the substrate surface. Samples with solvent cleaning had the lowest adhesion strength value but had the third highest roughness value. This is because the coating material only penetrates the rust part, and the penetration does not reach the gaps on the substrate surface. Consequently, the mechanical interlocking bond formed is not optimal.

**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

#### IV. CONCLUSIONS

In conclusion, based on surface roughness testing referring to ASTM D4417, the abrasive blast cleaning method produced the highest surface roughness with a value of 122.95  $\mu\text{m}$ , followed by the power tool to bare

metal cleaning, solvent cleaning, power tool cleaning, and hand tool cleaning method with values of 80.28, 69.03, 19.68, and 14.72  $\mu\text{m}$ , respectively.

To analyze the corrosion resistance of the coating layer in protecting ASTM A36 steel substrate from corrosive environments, 2 testing method were used, namely the salt spray and EIS. In the salt spray test, the results showed that the abrasive blast cleaning method and power tool to bare metal cleaning had the highest level of effectiveness in preventing corrosion, with changes in the width values of 0.82 and 0.97  $\mu\text{m}$ , respectively, both included in rating number 8. Meanwhile, in the EIS test, a randomly arranged pattern (scatter plot) was produced, affecting the chi-square value, which was also high. This showed that the discrepancy between the experimental and the predicted data from the equivalent circuit model was also large, suggesting the possibility of errors occurring in the resulting data is very large.

The adhesion strength test was conducted using the x-cut and pull-off tape method. The results showed that the abrasive blast cleaning surface preparation method produced the highest adhesion value between the surface of the steel substrate and the coating layer. The x-cut tape test results 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, several suggestions can be considered. Future studies should apply a surface preparation method with a high level of surface roughness and cleanliness, to ensure impurities that are still attached do not affect the test results or characterization. The airless spray method can also be used to ensure that the surface-tolerant epoxy paint applied has the same WFT. The test environment conditions should also be stable and controlled. Factors that affect the accuracy of EIS measurements, such as non-uniformity of the coating and the persistence of impurities on the substrate surface, should also be considered.

#### V. ACKNOWLEDGMENT

The authors are grateful to the Department of Metallurgical and Material Engineering, Faculty of Engineering, Universitas Indonesia, for the support.

## VI. REFERENCES

- [1] World Steel Association, “Worldsteel Short Range Outlook April 2022,” 2022. [Online]. Available: <https://worldsteel.org/media-centre/press-releases/2022/worldsteel-short-rangeoutlook-april-2022/>.
- [2] Kementerian ESDM RI, “Peluang Investasi Besi Indonesia,” 2021. [Online]. Available: <https://www.esdm.go.id/assets/media/content/content-peluang-investasi-besiindonesia.pdf>.
- [3] KEMENPERIN RI, “Investasikan Rp1 Triliun, Industri Baja Dongkrak Kapasitas Produksi 500 Ribu Ton,” 2022. [Online]. Available: <https://kemenperin.go.id/artikel/23354/Investasikan-Rp1-Triliun,-Industri-Baja-Dongkrak-Kapasitas-Produksi-500-Ribu-Ton>.
- [4] U. Anthony, M. Ikenna, O. B. Ufuma, D. T. Ezemuo, “Corrosion Rates and its Impact on Mild Steel in Some Selected Environments,” 2016. [Online]. Available: <http://jsaer.com/download/vol-3-iss-1-2016/JSAER2016-03-01-34-43.pdf>.
- [5] C. K. Schoff, “Surface defects: Diagnosis and cure,” *J. Coatings Technol.*, vol. 71, no. 888, pp. 56–73, 1999, doi: 10.1007/bf02697888.
- [6] D. G. Weldon, “Failure Analysis of Paints and Coatings: Revised Edition,” *Fail. Anal. Paint. Coatings Revis. Ed.*, pp. 1–362, 2009, doi: 10.1002/9780470744673.
- [7] J. J. Santana, J. E. González, J. Morales, S. González, dan R. M. Souto, “Evaluation of ecological organic paint coatings via electrochemical impedance spectroscopy,” *Int. J. Electrochem. Sci.*, vol. 7, no. 7, pp. 6489–6500, 2012.
- [8] A. C. Lazanas dan M. I. Prodromidis, “Electrochemical Impedance Spectroscopy—A Tutorial,” *ACS Meas. Sci. Au*, 2022, doi: 10.1021/acsmesuresciau.2c00070.
- [9] The Society for Protective Coatings, “Joint Surface Preparation Standard: Hand Tool Cleaning,” *SSPC-SP NO.2*, 2000.
- [10] D. J. Varacalle, D. P. Guillen, D. M. Deason, W. Rhodaberger, dan E. Sampson, “Effect of grit-blasting on substrate roughness and coating adhesion,” *J. Therm. Spray Technol.*, vol. 15, no. 3, pp. 348–355, 2006, doi: 10.1361/105996306X124347.
- [11] The Society for Protective Coatings, “Joint Surface Preparation Standard: Solvent Cleaning,” *SSPC-SP NO.1*, 2000.