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ADHESIVE COATING VALUE BASED ON THE MAIN INGREDIENT OF SHIP PAINT

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Professional paper

Summary

Coatings are important instruments in inhibiting the corrosion rate. Field facts in various Indonesian shipping industries show that the choice of organic materials as coating for ship paint uses epoxy, vinyl and polyurethane. Therefore an experimental study is needed on the adhesion ability of paint as a coating for ship armor with these three types of organic materials. The preparation of steel specimens with type ASTM A36 is carried out by blasting, visual inspection standard ISO 8501-1, and roughness test standard ISO 8503-4. Painting of specimens by measuring the thickness of the paint in the wet conditions ASTM D4414 standard and ASTM D4138 standard dry conditions. Treatment of specimens in two conditions, are: tropical weather condition and salt spray condition. Observation of specimens by scanning electron microscope and adhesion test standard ASTM D4541-02. The final result shows that the best adhesion ability of the main paint coating in tropical weather conditions was a polyurethane coating with no blister characteristics, but there are fractures on the surface of the material. While the main material for the best coating in salt spray conditions was epoxy coating with characteristics that are resistant to blisters and blends with the surface of the material.

Key words: epoxy; vinyl; polyurethane; adhesive

1. Introduction

Coating on steel ship buildings is an important thing to do in an effort to inhibit the rate of corrosion. Corrosion on ships can cause safety, technical and economic problems. According to Roberge [1], the importance of studying corrosion is to save costs and minimize losses due to material reduction. Direct losses on costs incurred for overlaying corroded parts, replacing corroded parts, and workers' wages. Indirect losses include discontinuation of operations, products that are affected by corroded components, loss of efficiency, product contamination, over-design due to the addition of corroded components. S.B. Lyon et al. [2], paint coatings are generally regarded as functioning by providing a barrier between the substrate and the environment, ideally providing a high resistance to ionic movement.

According to the Mayne [3], the movement of ions in organic coatings is slow and rate limiting. The charge may be carried by cations or anions (or both) depending upon the nature of the polymer. Consider a clean, rust-free steel sheet coated with 25 μm of clear lacquer such as plasticized polystyrene (Figure 1a). After a few weeks of exposure to the environment, a red-brown deposit is observed on the surface of the lacquer, and blisters containing a clear liquid may be observed underneath the lacquer (Figure 1b). Charge transfer must have taken place in order for electrochemical reactions to proceed. Charge transfer is ionic in the electrolyte and electronic in the substrate, so how is the charge carried in the polymer (Figure 1c). The appearance of the red-brown deposit on the surface suggests Fe^{2+} ions must migrate from the substrate into the polymer (Figure 1d). The growth of the under-film blister suggests oxygen and water must migrate from the electrolyte into the polymer (Figure 1). Of course, where anodes and cathodes exist together within a single interfacial defect, ionic transport through the coating thickness would no longer control the under film corrosion process in the manner shown here.

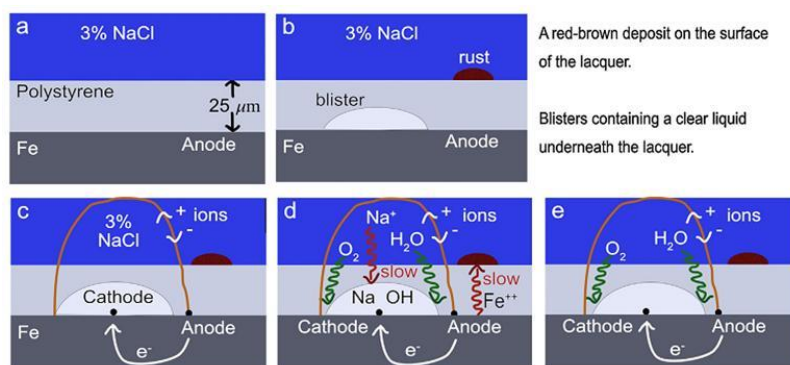


Fig. 1 Experimental observation of under-film corrosion: (a) coating applied on clean substrate, (b) after a few weeks exposure to electrolyte, (c) charge transfer between electrolyte and substrate, (d) ions migrate from substrate, (e) oxygen and water migrate

Therefore the type of coating that is commonly used is a type of liquid coating (resin) which includes epoxy, vinyl, and polyurethane. The epoxy resin has characteristics of resistance to chemical reactions and impact, low shrinkage value, and good adhesive properties to various materials (Claver) [4]. The vinyl resin has the characteristics of resistance to liquid solvents and various solvents others (Zaske & Goodman) [5]. The polyurethane resin has characteristics of resistance to weather, solvents, and mechanical damage (Dodiouk & Goodman) [6].

On the other hand, research by Yong Li et al. [7] on epoxy composites with zinc rich primer and silver epoxy enamel sprayed on Q235 steel, where this type of steel is commonly used for bridges, vehicles, containers and ships. Samples were exposed to an atmospheric environment for 18 months and immersed in 5% NaCl solution for 250 days. The final results show that the resistance of painting is better in an atmospheric environment, where the atmospheric resistance coefficient is higher than the resistance coefficient in the 5% NaCl solution immersion. Meanwhile, research by R. Vera et al. [8] on painting with a polyurethane coating that is sprayed on A36 steel which is commonly used for industrial structures in marine environments. Samples were exposed to an atmospheric environment at five different locations for 24 months and a salt spray test with a maximum exposure of 3,000 hours. The final results show that after 2 years of exposure or after 3,000 hours in the salt spray chamber, both paints still show evenly protective properties.

Based on the above conditions, the researchers carried out experimental activities to explore and compare the value of the adhesiveness of paint as a coating for ship steel with three types of organic materials including: epoxy, vinyl, and polyurethane.

2. Experimental

2.1. The test specimen

The test specimen was cut from a steel plate that conforms to ASTM A36 standards with a specimen size of 100 x 50 x 10 mm. The blasting process uses the dry abrasive cleaning method, Steel Grit 15 type of abrasive material, and according to ASTM D4417 standards as shown in Figures 2 and 3.

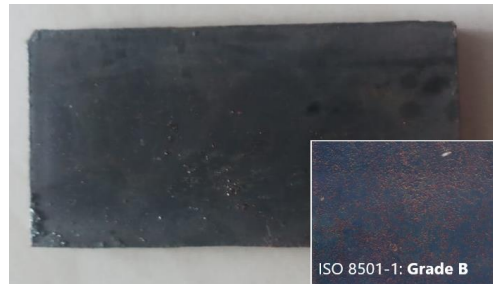


Fig. 2 Steel plate specimen: 100 x 50 x 10 mm

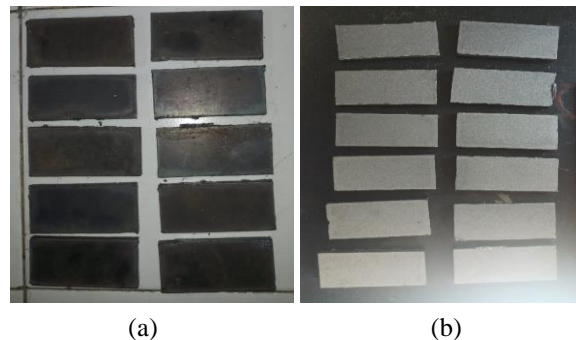


Fig. 3 Specimen condition: (a) Before blasting and (b) After blasting

2.2. Visual inspection of blasted samples

Visual inspection of blasted surface was carried out to see the results of the blasting process on the specimen by comparing the cleanliness level of the specimen with the image contained in the ISO 8501-1 standard, it was Sa 2 ½ as shown in Figure 4.

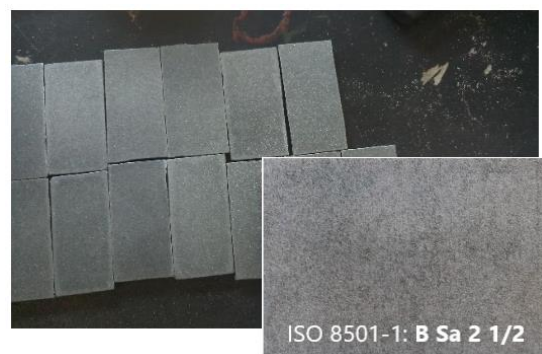


Fig. 4 Visual inspection of blasted surface; grade Sa 2 ½ according to ISO 8501-1

2.3. Roughness test

A roughness test was carried out to ensure that the surface roughness of the specimen was in accordance with ISO 8503-4 and NORSOK M-CR-501 standards. In this study using Testex Replica Tape and Elcometer facilities with roughness values at the Sa-3 cleanliness level reaching 50 µm - 75 µm (A. M. Berendsen) [9] as shown in Figure 5.



Fig. 5 Roughness measurement with Elcometer Testex Replica and Elcometer 124

The Elcometer 122 Testex Replica Tape was a very simple technique to measure a surface profile. The foam side of the Testex Tape was used to mould the peak-to-valley profile of the surface and then the measurement was taken by the Elcometer 124, a mechanical Surface Profile and Thickness Gauge.

2.4. Coating

The comparison between main paint ingredients (part A) and hardener (part B) following the rules of paint product in general and the specimen coating using one layer. The comparison for epoxy paint 2 : 1, for vinyl paint, and for polyurethane paint 4:1. The coating process in this specimen was done horizontally.

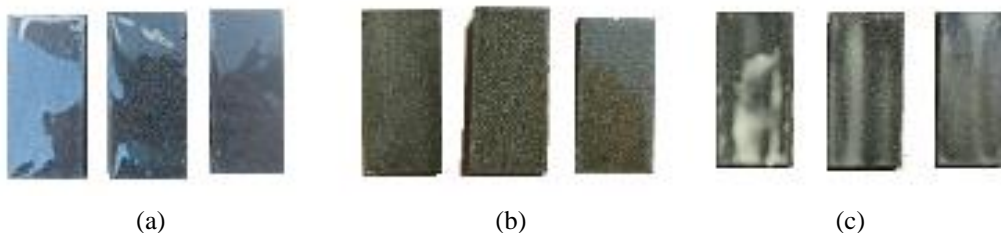


Fig. 6 Specimens coating with resin (a) Epoxy, (b) Vinyl, and (c) Polyurethane

Measurement of paint thickness in wet conditions using the wet film thickness (WFT) comb and the implementation method according to ASTM D4414 standard with a wet thickness between 200-300 μm as shown in Figure 7 (a).



Fig. 7 Measurement of paint thickness

Dry film thickness (DFT) comb and the implementation method according to the ASTM D4138 standard with a wet thickness between 150-200 μm as shown in Figure 7 (b). Meanwhile, the determination of solid by volume in experiment refers to paint products that use the same base material.

2.5. Tropical weather test

A tropical weather test was carried out to analyse the resistance of materials and coatings in open spaces (sunlight, humidity, and temperature). The specimens were placed on a support with a angle of 90 ° and exposed to the weather for 576 hours, where every 192 hours a check was made for changes in the coating material as shown in Figure 8.



Fig. 8 Tropical weather test

Testing with atmosphere exposure was carried out at the laboratory of chemical and material from Indonesian Navy.

2.6. Salt spray test

The salt spray test chamber was a test chamber that assesses the ability of material and its protective layer to withstand salt spray corrosion. Salt spray chambers meet international standards, such as ASTM B 117. The composition of the mixture includes: 100 liters of water [H₂O], 50 grams of salt [NaCl], 350 grams of ammonium sulphate [(NH₄)₂SO₄], and 25 millilitres acetic acid glacial [HC₂H₃O₂]. Specimens were placed in a salt spray chamber with a 90° angle position and a dew rate of 1.0 to 2.0 l/h, with variations in exposure time for 196 hours, 382 hours, and 575 hours as shown in Figure 9.

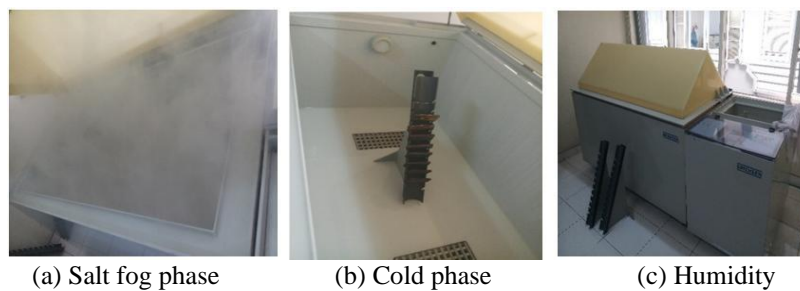


Fig. 9 Salt spray test chamber

The operational standard of the ERICHSEN 608 engine - Corrosion Test Apparatus (P-VW 1210 test) has a 4 hour cycle of salt fog phase, 4 hours of cold phase 18 to 28° Celsius with a humidity of 40 to 60%, and 16 hours of hot phase 40 ± 3° Celsius with 100% humidity.

2.7. Scanning Electron Microscope

Scanning Electron Microscope (SEM) was performed to obtain visual information on specimens from topographic surfaces (K. Akhtar et al.) [10] on coating damage and ASTM A36 material as shown in Figure 10.



Fig. 10 Scanning Electron Microscope

SEM from the Hitachi Table Top Electron Microscope TM-3000 has 3D image capabilities and magnification of x15 to x30,000.

2.8. Adhesive test

After weather and salt spray treatment the specimens were subjected to adhesion measurement using a Pull-Off Test. The adhesion test was conducted to measure the adhesive strength of a paint layer to the substrate.

The adhesion test was done by attaching 2 dolly pins using epoxy glue for 24 hours before testing. This is done so that the dolly pin can adhere perfectly to the specimen, then the dolly pin is pulled using a dolly cutter to test the adhesive strength of the coating. In the test using Dolly Pull-Off, it can be seen the characteristics of the coating based on the adhesive, cohesive, and tensile strength. The adhesive and cohesiveness values were compared with the ASTM D4541-02 and NORSOK M-CR-501 standards. According to the NORSOK M-CR-501 standard for material preparation and painting in shipbuilding the minimum requirement for the adhesive strength of a layer is 5MPa.

2.9. Scatter plot and trendlines

Scatter plots use points that represent values for two different numerical variables and were used to observe relationships between variables. The position of each point on the horizontal and vertical axis shows values for individual data points (Mike Yi) [11], (M. Friendly and D. Denis) [12], (D.A. Keim et al.) [13]. Meanwhile, trend lines were created by connecting between peaks or valleys along the trend. There were three types of trend lines: internal, external, and curved. Reliable trend lines through time, points on trend lines, and slope angles of 24 degrees to 30 degrees (W. Selzer) [14], (M. David) [15].

For scatter plot and trend line analysis in this study using Ms. Excel Software to produce 5 (five) types of functions (linear, exponential, logarithmic, polynomial, and power). The value of R-square was getting closer to the value of 1, then the regression model can be approved (J.W. Gooch) [16].

3. Results and Discussion

3.1. Specimen

3.1.1. Roughness level

The specimen roughness has a minimum roughness value of 70 μm and a maximum of 95 μm as shown in Table 1.

Table 1 Roughness test results

Material Coating	Material Abrasive	Surface roughness value (μm)							Average
		1	2	3	4	5	6	7	
Epoxy	Steel Grit	70	77	82	74	90	88	87	81.14
Vinyl	Steel Grit	88	92	71	74	73	84	81	80.43
Polyurethane	Steel Grit	95	89	72	75	85	83	76	82.14

Table 1 showed that the average roughness value of coating materials for epoxy was 81.14 μm , vinyl 80.43 μm , and polyurethane was 82.14 μm . The three coating materials were included in the medium category in the ISO 8503-1 standard. According to Trijatmiko et al [17] showed that roughness average rating the surface of material was blasted using abrasive material from steel grit type reached of 84.71 μm .

3.1.2. Paint thickness level

The wet film thickness has a minimum value of 217 μm and a maximum of 283 μm as shown in Table 2.

Table 2 Wet film thickness testing results

Material coating	Specimen	Wet film thickness test value (μm)					
		Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
<i>Epoxy</i>	1	228	222	225	230	227	226.40
	2	220	222	217	220	219	219.60
	3	217	225	219	224	218	220.60
	4	222	217	220	219	217	219.00*
	5	228	225	226	225	226	226.00
	6	217	221	220	223	222	220.60
	7	219	223	223	224	224	222.60
<i>Vinyl</i>	1	250	247	244	246	244	246.20
	2	237	244	245	239	240	241.00*
	3	244	243	244	245	240	243.20
	4	236	239	235	235	234	235.80
	5	246	245	244	249	247	246.20
	6	239	244	244	242	240	241.80
	7	239	245	245	240	241	242.00
<i>Polyurethane</i>	1	279	280	276	274	274	276.60
	2	282	278	276	283	283	280.40
	3	272	278	275	275	277	275.40*
	4	277	280	275	276	277	277.00
	5	278	277	274	279	281	277.80
	6	273	279	275	275	276	275.60
	7	277	281	278	275	279	278.00

Table 2 showed that the average thickness value of paint in wet conditions for epoxy 222.114 μm , vinyl is 242.314 μm , and polyurethane 277.257 μm . The three coating materials were included in the ASTM D4414 standard.

The dry film thickness has a minimum value of 170 μm and a maximum of 198 μm as shown in Table 3.

Table 3 showed that the average thickness value of paint in dry conditions for epoxy was 181.857 μm , vinyl 184.029 μm , and polyurethane 181.40 μm . The three coating materials were included in the ASTM D4138 standard.

Based on Table 2, Table 3, and the average from three specimens coating (epoxy, vinyl, and polyurethane), so the calculation DFT / WFT ratio difference regarding solids volume was related to uneven spray paint over a nozzle as shown in Table 4, 5, and 6.

Table 3 Dry film thickness testing results

Material coating	Specimen	Dry film thickness test value (μm)					
		Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
<i>Epoxy</i>	1	181	177	192	188	176	182.80
	2	179	176	188	190	170	180.60
	3	182	179	190	185	177	182.60
	4	177	178	191	186	175	181.40
	5	177	176	187	187	174	180.20
	6	182	175	190	188	176	182.20
	7	181	180	190	190	175	183.20
<i>Vinyl</i>	1	197	198	190	192	195	194.40
	2	187	183	181	185	188	184.80
	3	177	184	181	179	184	181.00
	4	185	190	191	187	188	188.20
	5	184	185	184	186	183	184.40
	6	180	179	181	178	179	179.40
	7	177	174	176	176	177	176.00
<i>Polyurethane</i>	1	176	176	179	178	177	177.20
	2	180	184	183	181	182	182.00
	3	177	180	176	175	175	176.60
	4	185	180	183	183	185	183.20
	5	187	188	187	190	186	187.60
	6	175	177	177	179	176	176.80
	7	188	184	185	187	188	186.40

Table 4 Solid by volume for epoxy

Spot		Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
DFT	Epoxy specimen	179.857	177.286	189.714	187.714	174.714	181.857
WFT	Epoxy specimen	221.571	222.143	221.429	223.571	221.857	222.114
Solid by volume		0.81173	0.79807	0.85677	0.83962	0.78751	0.81875*

Table 5 Solid volume percentage for vinyl

Spot		Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
DFT	Vinyl specimen	183.857	184.714	183.429	183.286	184.857	184.029
WFT	Vinyl specimen	241.571	243.857	243	242.286	240.857	242.314
Solid by volume		0.76109	0.75747	0.75485	0.75649	0.7675	0.75946*

Table 6 Solid by volume for polyurethane

Spot		Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Average
DFT	Polyurethane specimen	181.143	181.286	181.429	181.857	181.286	181.40
WFT	Polyurethane specimen	276.857	279	275.571	276.714	278.143	277.257
Solid by volume		0.65428	0.64977	0.65837	0.6572	0.65177	0.65427*

The predicted dry film thickness (DFT) can be calculated from the wet film thickness (WFT) using the following formula (B. Goldie) [18]:

$$DFT = WFT \times \text{Solid by Volume} \quad (1)$$

- * Epoxy coating a solid by volume of 0.819 and a wet film thickness measured at 219.0 μm , prediction of $DFT = 219.0 \times 0.819 = 179.361 \mu\text{m}$ (7.174 mils).
- * Vinyl coating a solid by volume of 0.759 and a wet film thickness measured at 241.0 μm , prediction of $DFT = 241.0 \times 0.759 = 182.919 \mu\text{m}$ (7.317 mils).
- * Polyurethane coating a solid by volume of 0.654 and a wet film thickness measured at 275.40 μm , prediction of $DFT = 275.40 \times 0.654 = 180.112 \mu\text{m}$ (7.204 mils).

3.1.3. Visualisation of tropical weather test

The test is carried out using a drying rack that conforms to the ASTM standard of G 50 - 10. This drying rack positions of the specimen at an angle of 90°. The position of the 90° angle specimen aims to mimic the original position of the steel plate on the hull. The direction of the specimens is facing to East and West to follow the position of the sun exposure. Changes in the direction of drying the specimens are carried out manually every 12.00 WIB.

3.1.4. Visualisation of salt spray test

Salt spray tests were carried out in a salt spray fog chamber following ASTM B 117 standard. The first phase was carried out for 192 hours, then the second phase for 384 hours, and the third phase for 576 hours, so that the total time needed reached 24 days. The final results of the specimens on the salt spray condition performed visually as shown in Figures 11, 12, 13 and 14.



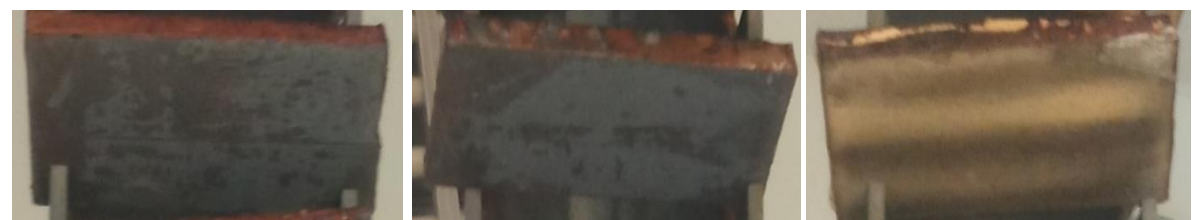
(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours

Fig. 11 Visualisation of No Coating Specimens



(a) Epoxy (b) Vinyl (c) Polyurethane

Fig. 12 Visualisation of Coating Specimens to First Phase: 192 hours



(a) Epoxy (b) Vinyl (c) Polyurethane

Fig. 13 Visualisation of Coating Specimens to Second Phase: 384 hours

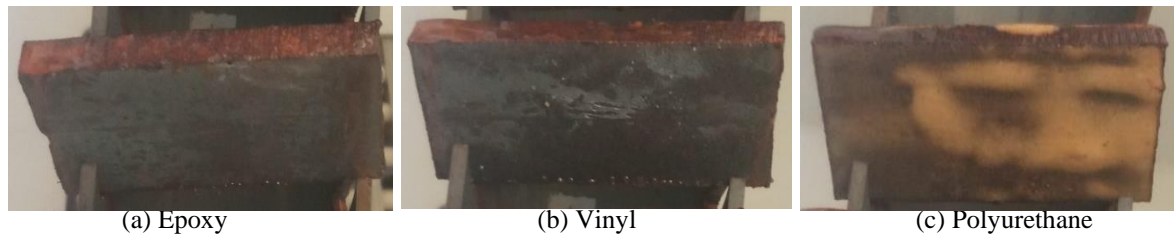


Fig. 14 Visualisation of Coating Specimens to Third Phase: 576 hours

3.2. Scanning Electron Microscope

3.2.1. SEM: tropical weather test

SEM study on specimens without coating in tropical weather test performed to obtain the visual information about material corrosion as shown in Figure 15.

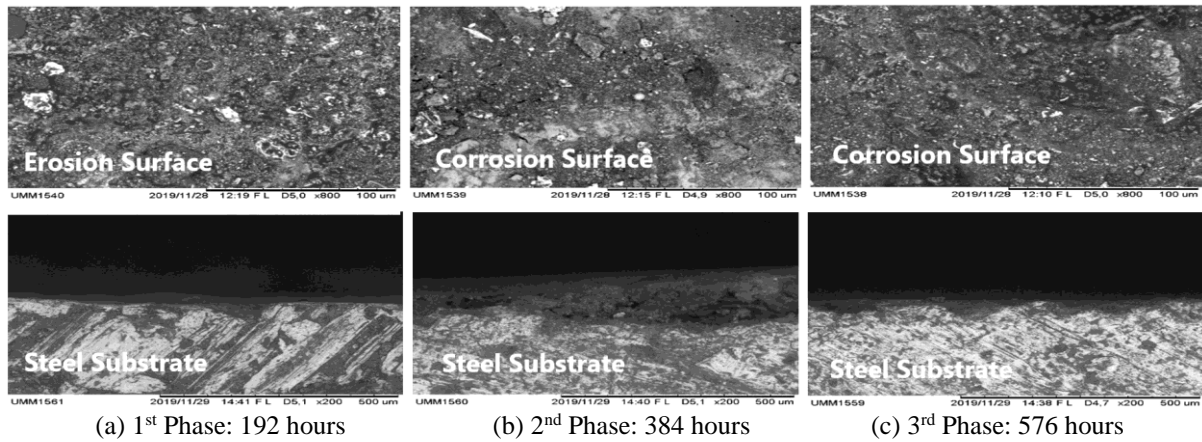


Fig. 15 SEM:TWT – No coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 15, it showed that the first phase at 192 hours corrosion occurs but has not covered the entire surface of the material so that erosion does not occur significantly. Second phase at 384 hours, corrosion has eroded the surface and changed the surface structure so that the material deformation on the surface part occurs significantly. Third phase at 576 hours, corrosion was increasingly significant and the surface that has been deformed has been separated from the material.

SEM activities on epoxy coating specimens in tropical weather test performed to obtain visual information about coating and material damage as shown in Figure 16.

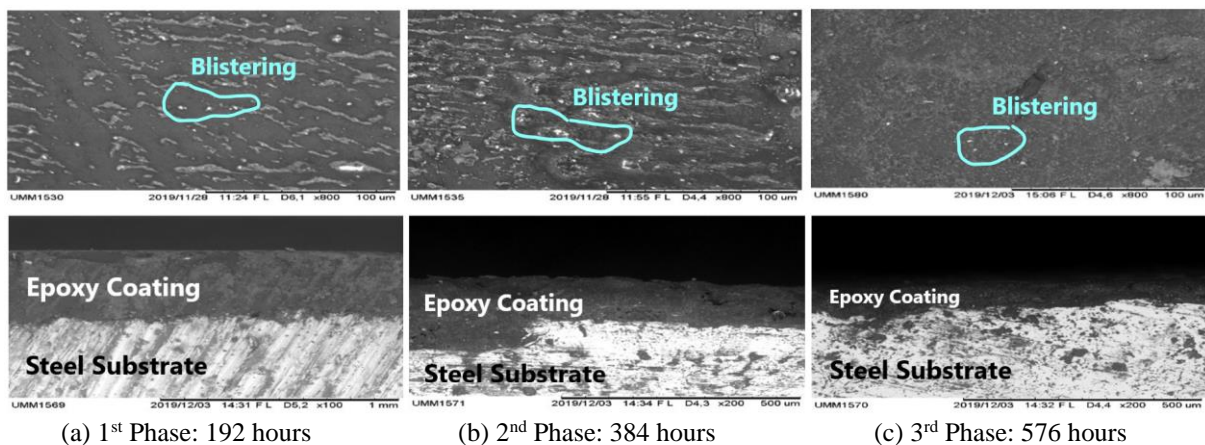
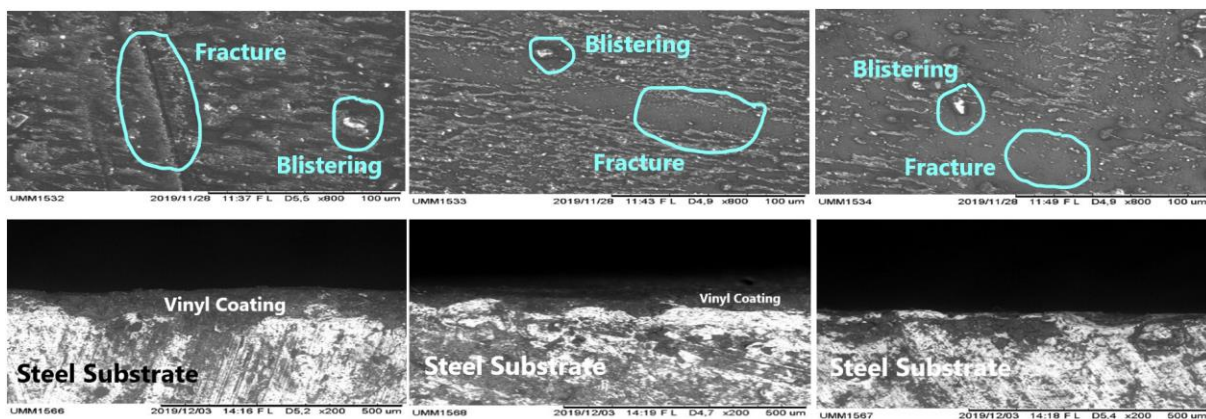


Fig. 16 SEM:TWT – Epoxy coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 16, it shows that the first phase at 192 hours occurs evenly erosion and fractures on the coating surface. The blister is relatively small when compared to the area of

the coating in the field of observation. Second phase at 384 hours, the coating was experienced significant erosion and fracture on the surface and coating. Meanwhile, at the base, the coating was still attached to the surface of the material so that the fracture that occurs does not affect the ability of the coating to protect the material from corrosion. Third phase at 576 hours, the epoxy coating remains and covers the surface of the material. This shows that the epoxy coating has a fairly good resistance even after experiencing abrasion and blister potential. The abrasive conditions occur as a result of corrosive environments and sun exposure. According to Da Silva et al. [19] and Linmin Wu et al. [20] showed that the abrasive resistant coatings may be the only feasible option to protect the product surfaces. In situations where, operating temperatures were extremely high, long operating time, and environments not suitable for surface wear.

SEM study on vinyl coating specimens in tropical weather test performed to obtain visual information about coating and material damage as shown in Figure 17.



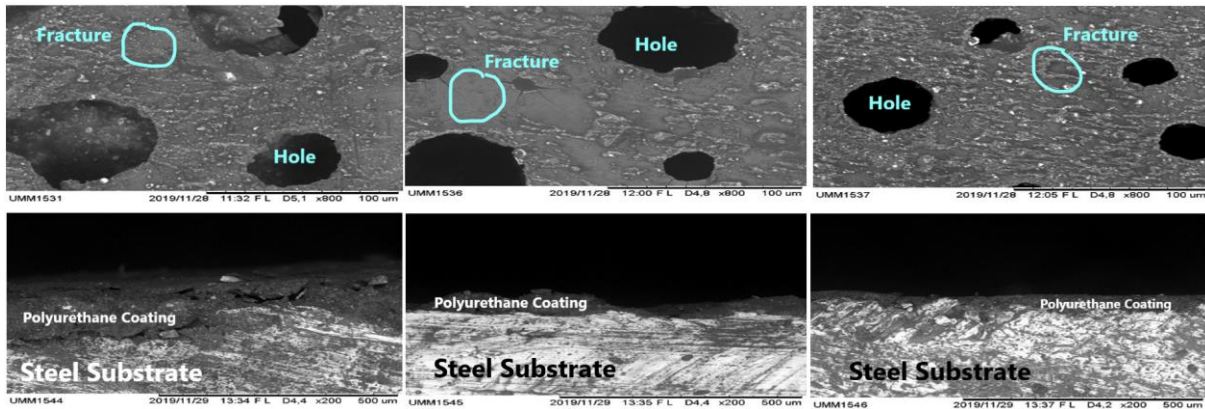
(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours

Fig. 17 SEM:TWT – Vinyl coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 17, it shows that the first phase at 192 hours shown that there was evenly erosion and fracture on the coating surface. The area of the blister was relatively small when compared to the area of the coating in the field of observation. Blisters also occur in coatings that were adjacent to the material but do not interact with the surface of the material. In the second phase at 384 hours, there was uneven erosion, where there was a coating with a thickness higher than other areas. Third phase at 576 hours, there was erosion and the appearance of the material surface. This flatness causes the coating to remain even though it was very thin when compared to the area of the field of observation.

SEM study on polyurethane coating specimens in tropical weather test performed to obtain visual information about coating and material damage as shown in Figure 18.

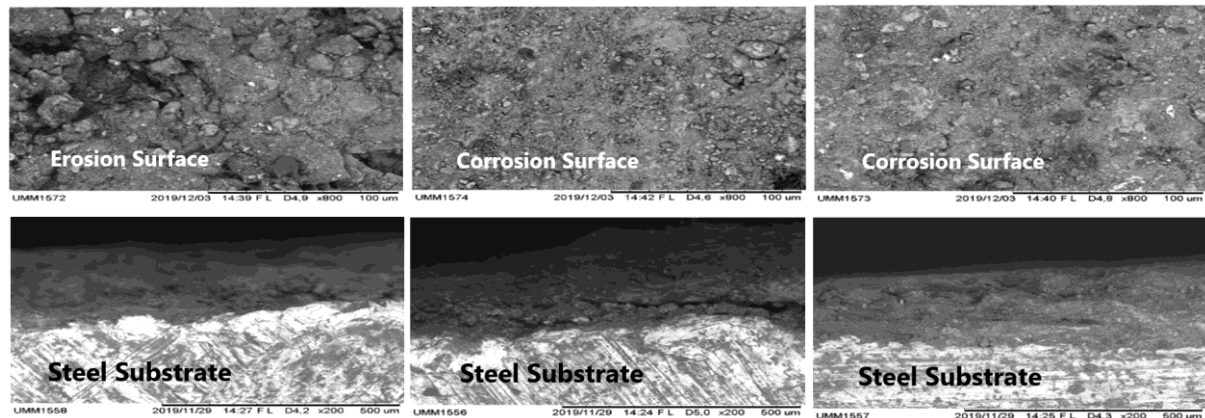
Based on Figure 18, it shows that the first phase at 192 hours show that there was no blister, but there were fractures on the surface, inside, and the base of the coating, as well as some parts of the coating that do not stick to the surface of the material. In the cross-section, a relatively large, round cavity was formed from air trapped during the curing process. Second phase at 384 hours, there were uneven erosion. There was a coating with a thickness higher than other areas. In thicker coatings there are fractures that interact with the surface of the material. Meanwhile, cross-sectional observations show that there were deeper holes and non-uniformity in the coating thickness. Third phase at 576 hours, it appears that the basic part of the coating was attached to the surface of the material, but there were fractures throughout the coating. On cross-sectional observation, the holes in the coating became smaller and the area around the holes was covered by a coating with a finer texture like sand.



(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours
Fig. 18 SEM:TWT – Polyurethane coating (magnification visual of longitudinal x800 and transverse x200)

3.2.2. SEM: salt spray test

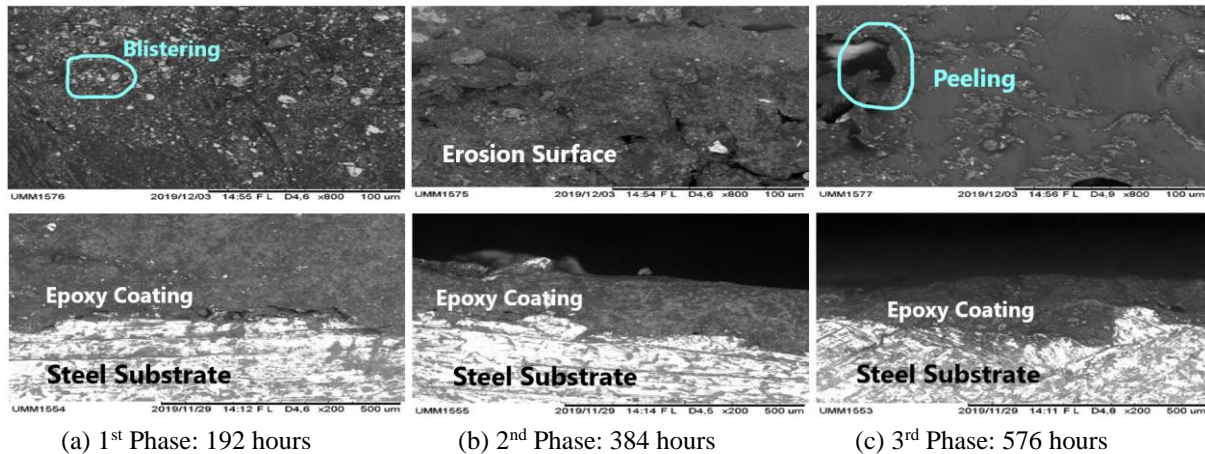
SEM study on specimens without coating in salt spray test performed to obtain visual information about bare material resistance as shown in Figure 19.



(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours
Fig. 19 SEM:SST – No coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 19, it shows that the first phase at 192 hours begins to occur at a minimum, but it has not been significantly proven that there were still intact blasting particles. Second phase at 384 hours, there has been erosion of the surface and changes in the structure of the hollow steel surface. Scraping occurs at the edge of the specimen and was uneven. Third phase at 576 hours, there was a significant change in the surface structure, where the specimen was evenly eroded and there was no residual blasting.

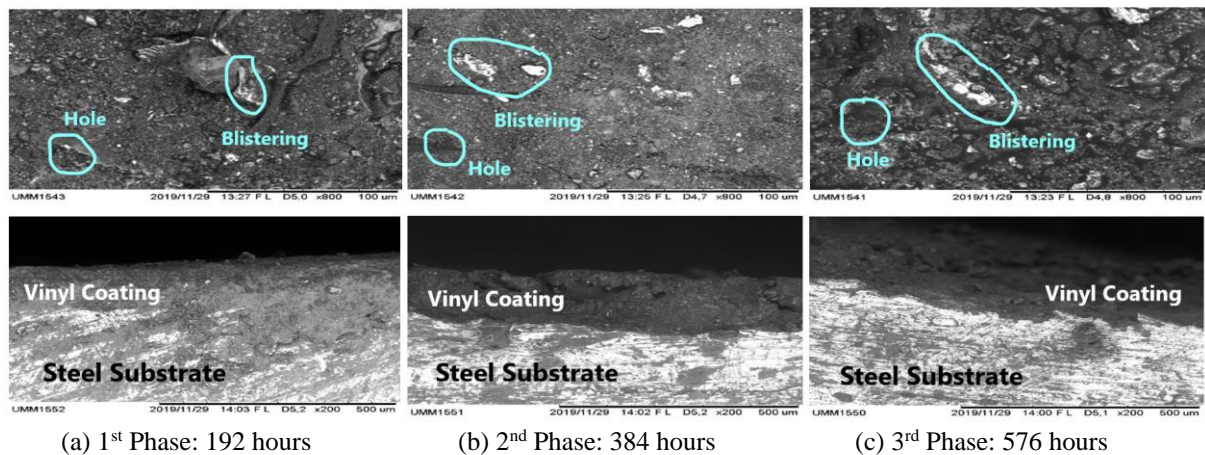
SEM study on epoxy coating specimens in salt spray test performed to obtain visual information about coating and material damage as shown in Figure 20.



(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours
Fig. 20 SEM:SST – Epoxy coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 20, it shows that the first phase at 192 hours begins to appear blisters occur in epoxy coatings, where blisters mainly occur in coatings that interact with the material. On the other hand, epoxy has fairly good adhesive properties and was shown by bonding the epoxy layer to the steel surface. Second phase at 384 hours, there was erosion on the surface of the layer, where the blister was found to be more spread out in the interacting part but still close to the steel surface. Third phase at 576 hours, significant erosion occurred. There were some areas where peeling has occurred and the coating structure becomes hollow, but there were some parts that were still protected by the epoxy layer.

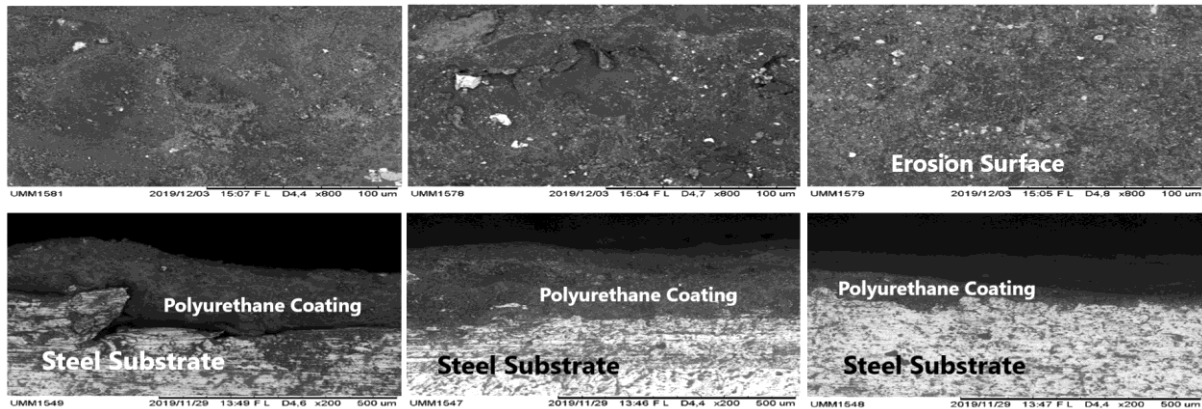
SEM study on vinyl coating specimens in salt spray test performed to obtain visual information about coating and material damage as show in Figure 21.



(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours
Fig. 21 SEM:SST – Vinyl coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 21, it shows that the first phase at 192 hours shown that the specimens with vinyl resin coating experienced blisters in the layers adjacent to the material, but did not interact with the surface of the material. Meanwhile, vinyl coatings have good adhesive properties. Vinyl coating can get into the crevices of the material surface. Second phase at 384 hours, the blister changes the structure of the coating. In the coating there were fractures caused by small holes on the surface of the coating. These small holes cause salt water to enter and erode the inside of the layer. Third phase at 576 hours, the appearance of the material surface in several areas were cause in a very significant change in the coating structure. There were several coatings that get into the crevices of the surface of the material that have not been eroded and protect the surface of the material.

SEM study on polyurethane coating specimens in salt spray test performed to obtain visual information about coating and material damage as shown in Figure 22.



(a) 1st Phase: 192 hours (b) 2nd Phase: 384 hours (c) 3rd Phase: 576 hours
Fig. 22 SEM:SST – Polyurethane coating (magnification visual of longitudinal x800 and transverse x200)

Based on Figure 22, it shows that the first phase at 192 hours show that the polyurethane coating does not appear to blend with the surface of the material but there was no blister. Second phase at 384 hours, no blister and polyurethane coating can blend with the surface of the material. Third phase at 576 hours, the polyurethane coating remains resistant to blisters and can blend with the surface of the material, but on the other hand there was significant erosion of the coating surface.

3.3. Adhesive Test

3.3.1. AT: tropical weather condition

Specimens in tropical weather test for 576 hours show that the adhesion value 0% of constant, cohesion 30 to 80%, glue 20 to 70%, and adhesive 3.95 to 11.87 MPa as shown in Table 7.

Table 7 Adhesive test: tropical weather condition

Time (hours)	Point	Adhesion (%)			Cohesion (%)			Glue (%)			Adhesive (MPa)		
		E	V	P	E	V	P	E	V	P	E	V	P
0	P-1	0	10	15	0	25	25	100	65	60	17.18	15.65	15.65
	P-2	10	0	0	0	0	0	90	100	100	21.78	20.66	20.66
192	P-1	0	0	0	30	80	0	70	20	100	15.27	4.79	9.59
	P-2	0	0	0	50	25	20	50	75	80	14.58	3.8	8.77
384	P-1	0	0	0	30	40	90	70	60	10	9.66	9.65	9.38
	P-2	0	0	0	40	30	40	60	70	60	14.91	8.74	12.32
576	P-1	0	0	0	35	30	75	65	70	25	5.1	5.71	11.87
	P-2	0	0	0	45	45	80	55	55	20	5.75	3.95	9.25

Note: E = epoxy; V = vinyl; P = polyurethane

Trend lines of polynomial function on the adhesion that occurs in epoxy, vinyl, and polyurethane coatings in tropical weather conditions as shown in Figure 23.

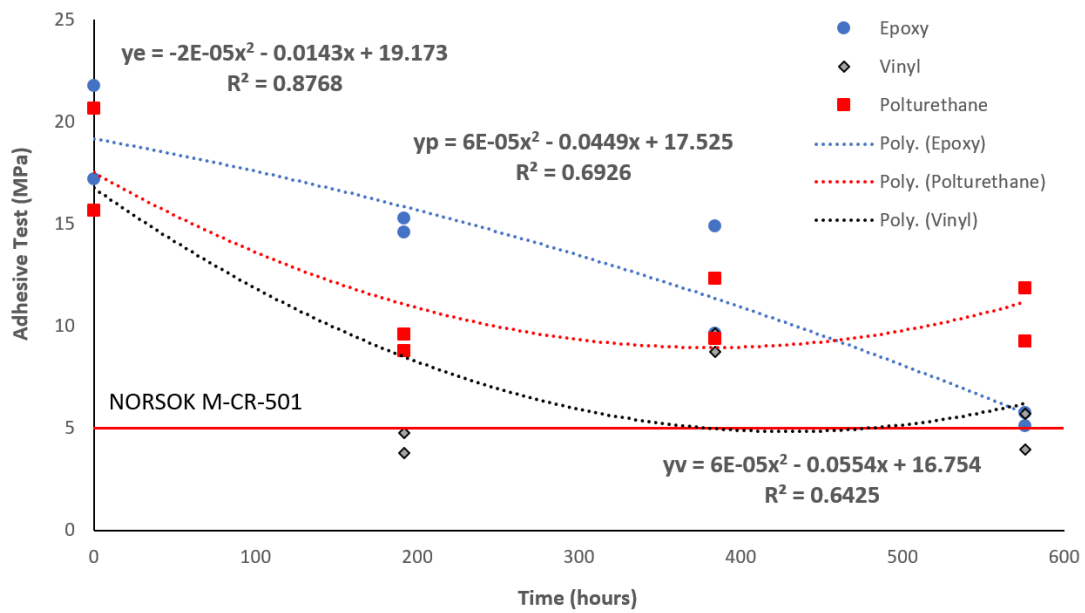


Fig. 23 Trend lines of Adhesive Test: TWC – Epoxy/Vinyl/Polyurethane Coating

Figure 23 showed that the trendlines of epoxy, vinyl, and polyurethane coating have a second polynomial order. Meanwhile, the horizontal line of NOROSOK M-CR-501 was the limit of adhesion that was allowed at least 5 MPa. Taking into account the three polynomial trendlines and horizontal lines of NOROSOK M-CR-501 shows that polyurethane coating in tropical weather conditions has the best adhesion power than epoxy and vinyl coating.

3.3.2. AT: salt spray condition

Specimens in salt spray test for 576 hours show that adhesion value 0 to 40%, cohesion 0 to 45%, glue 60 to 95%, and adhesive 2.64 to 4.31 MPa as shown in Table 8.

Table 8 Adhesive test: salt spray test

Time (hours)	Point	Adhesion (%)			Cohesion (%)			Glue (%)			Adhesive (MPa)		
		E	V	P	E	V	P	E	V	P	E	V	P
0	P-1	0	25	15	0	25	25	100	65	60	17.18	15.65	15.65
	P-2	10	0	0	0	0	0	90	100	100	21.78	20.66	20.66
192	P-1	0	25	25	75	80	20	25	75	55	3.91	3.61	8.77
	P-2	0	40	5	65	25	5	35	60	90	3.12	3.00	9.51
384	P-1	0	45	10	0	40	0	100	55	90	4.10	3.00	5.71
	P-2	0	65	10	0	30	10	100	35	80	2.64	4.95	9.20
576	P-1	0	20	15	25	30	0	75	80	85	4.10	3.51	3.51
	P-2	0	40	5	35	45	0	65	60	95	4.31	2.64	2.64

Note: E = epoxy; V = vinyl; P = polyurethane

Trend lines of polynomial function on the adhesion that occurs in epoxy, vinyl, polyurethane coatings in salt spray condition as shown in Figure 24.

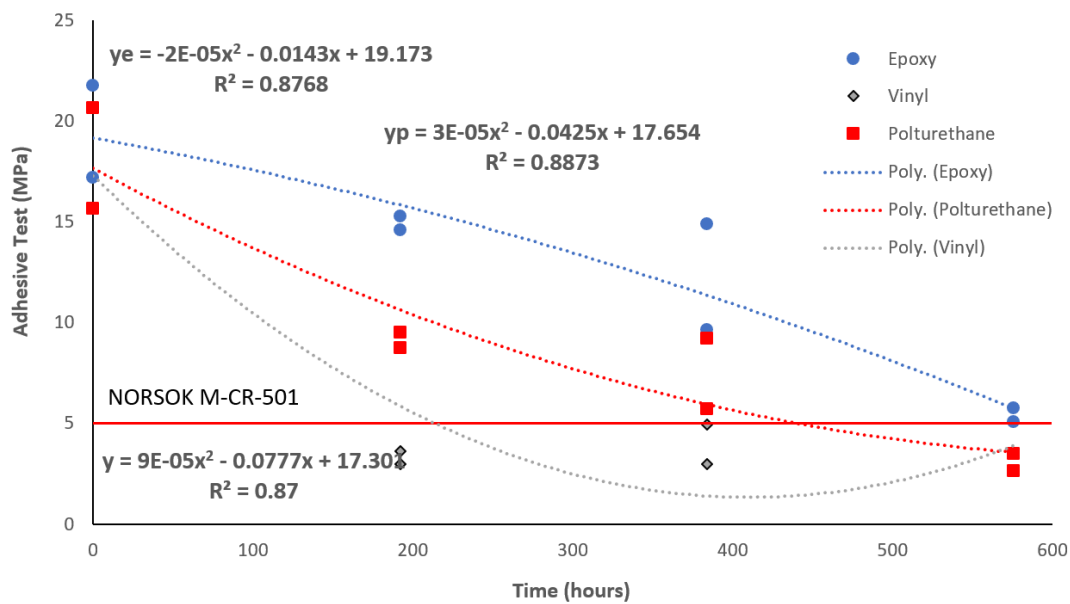


Fig. 24 Trend lines of Adhesive Test: SSC – Epoxy/Vinyl/Polyurethane Coating

Figure 24 showed that the trendlines of epoxy, vinyl, and polyurethane coating have a second polynomial order. Meanwhile, the horizontal line of NORSOK M-CR-501 was the limit of the permissible adhesive power of at least 5 MPa. Taking into account the three polynomial trendlines and horizontal lines of NORSOK M-CR-501 shows that the epoxy coating on salt spray has the best adhesion power than vinyl and polyurethane coatings.

4. Conclusions

Tropical weather conditions as the result of SEM show that the polyurethane coating has the best coating compared to epoxy and vinyl layers. After the 576 hour phase, there was no indication of loss occurring uniformly in the observation area.

Salt spray conditions from SEM show that epoxy coatings have the best coating than polyurethane and vinyl coatings. After the 576 hours phase show that an indication of a denser coating structure and less blistering in the observed area.

Tropical weather conditions show that the three trend lines of epoxy, vinyl, and polyurethane coating have a second order polynomial form and polyurethane coatings have the best adhesion power than epoxy and vinyl coatings. The average adhesion ability of the polyurethane coating at 576 hours was 10.56 MPa.

The salt spray condition shows that the three trend lines of epoxy, vinyl, and polyurethane coating have a second order polynomial form and the epoxy coating has the best adhesion than vinyl and polyurethane coatings. The average adhesive power of the epoxy coating in 576 hours was 4,205 MPa.

The protection implication of ship steel uses an organic coating: Epoxy, Vinyl, and Polyurethane as Anti-Corrosive (AC) were divided into three main groups: Oxidizing (conventional AC coatings), One-component (physically dry), and Two-components (chemically dry).

Oxidizing. Representatives: oil coatings, alkyd coatings, urethane oils, epoxy esters, phenolic coatings. Applications: decks, superstructures, engine rooms, belt line.

One-component. Vinyl to applications: decks. Vinyl-tar (a combination of conventional and complex coatings) to applications: boot topping, wetted area primer, ballast and cargo tanks.

Two-components. Polyurethane coating to application: superstructure. Epoxy coating to applications: hull plating, tanks. Tar-epoxy coatings to applications: boot topping, wetted area, ballast and cargo tanks.

The epoxy coating was customarily applied as a shop primer (using one layer) which functions as temporary protection before the ship construction process at the fabrication to assembly stage. If the epoxy or polyurethane coating was applied as anti-corrosive (after assembly stage) should using two layers.

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