



A Preliminary Field Study of Antifouling Paint Performance After Short Exposure in Mandara Bali, Indonesia

G. Priyotomo^{*a}, L. Nuraini^a, H. Gunawan^b, J. Triwardono^a, S. Sundjono^a, S. Prifiharni^a

^a Research Center for Metallurgy and Material, Indonesian Institute of Sciences, Banten, Indonesia

^b Research Center and Development of Roads and Bridge, Indonesia's Ministry of Public Works and Housing, Bandung, Indonesia

PAPER INFO

Paper history:

Received 09 June 2020

Received in revised form 13 November 2020

Accepted 08 December 2020

Keywords:

Antifouling Paint

Anticorrosion Paint

Biofouling

Weight Loss

Corrosion

Salinity

ABSTRACT

Antifouling paints are applied to prevent the growth of marine biofouling. In Indonesia, that paint is widely used for ship which commonly used copper-based biocide. In fact, there is no or little comprehensive studies on antifouling paint in Indonesia compared to other tropical countries. In this study, the evaluation of the performance for antifouling paint was carried out where anticorrosion paint and bare steel were also studied as references. The measurement of corrosion rate on steel was conducted by weight loss method. The panels containing specimens were exposure up to 1-month for immersion in different depth of sea up to 3 meters. Seawater parameters consisting of temperature, pH, salinity, conductivity and dissolved oxygen were measured as well as coating properties. The results showed both surfaces of anticorrosion paint and steel specimens covered by biofouling, but not on antifouling paint. There also is not much different in antifouling paint properties before and after exposure in various depth of sea. The reduction of thickness for antifouling paint is apparently predominant to be affected by sea current. The magnitude of corrosion rate on bare steel is almost the same in different depth of sea which took place due to the effect of dissolved oxygen and biofouling. In the future, the comparison of the paints performance all local regions is necessary to be conducted in all local regions of the Indonesia.

doi: 10.5829/ije.2021.34.04a.24

NOMENCLATURE

CR Corrosion rate (mpy)	Corrosion rate, Mils per year (mpy)	A	area of sample (cm ²)
W	Weight loss (mg)	T	Time of exposure (hour)
D	metal density (g/cm ³)		

1. INTRODUCTION

Biofouling is the term to define undesired plants and animals which attach and grow on submerged artificial static or mobile in seawater. The attachment and colonization of life organisms has a deleterious impact on most offshore submerged structures [1-3]. Moreover, the biological process due to biofouling metabolism could yield detrimental effects on ships such as decreasing the time frequency of dry-docking operation, increasing the frictional resistance, and losing of corrosion resistance [4-7]. The reduction of corrosion resistance could decrease mechanical strength and life time of structure particularly in marine environment [8, 9]. The safety

problem is also considered when the decrease of structure stability and concealment structural defects takes place due to the aggressiveness of biofouling growth [9, 10]. Mostly surface temperature, water flow and salinity are predominantly to take the essential part of an activity of biofouling [11] where the other parameters are also considered such as pH and oxygen concentration to stimulate the growth of biofouling in marine water [12]. In tropical region, the rapid growth of marine biofouling occurs mostly due to high seawater temperature and high salinity [13, 14] compared in subtropical region. The growth of attached marine biofouling tends to increase rapidly in low ocean current rates and vice versa [12]. Indonesia has tropical climates, where the seasonal

*Corresponding Author Email: gadangp@gmail.com (G. Priyotomo)

change is relative stable annually for surface temperature and high salinity in marine environment. Therefore, the growth of tropical marine biofouling continues without disruption in this country.

Commonly the primary mitigation for the severity of biofouling is to utilize antifouling (AF) paint on marine structure application. The mechanism of biocide compound such copper (Cu) releasing from AF paint could minimize the attachment of biofouling on the structure [2]. In addition, the toxic function of copper compound as main additive of AF paint is to prevent the growth of certain biofoulings such as molluscs, algae, bacteria and so on [15]. Generally the utilization of AF paint is the most economical and proven manner in most marine structures until present [16]. Besides both hard and ablative antifouling paints, self-polishing copolymer antifouling (SPC-AF) paint is used for the most widely used AF paint due to the consideration of the cost-benefit analysis, and the optimized control of the leaching process for copper compound or cuprous oxide (Cu₂O) as main biocide additives [9]. In addition, due to harmful effects of tributyltin (TBT) as biocides [12], nowadays, tin-free self polishing copolymers (tin-free SPC) antifouling paint utilized as commercial environmentally friendly AF paint, containing copper compounds. Most a generic formulation of that paint consists of resin, pigment, solvent, primary biocide, co-biocide, organic or organo-metallic booster biocides, plasticizer, extender and so on which are constructed as AF paint system.

Furthermore, in last two decades, researchers had investigated extensively the performance of AF paint which related to paint formulations, mechanisms of biofouling inhibition, and the effect of surrounded environment [9, 10, 12], but no or less comprehensive investigation in Indonesia as a representative of tropical country in south east asia region. In addition, the Indonesian researcher has reported the performance of commercial AF paints that exposed in Madura strait, East Java Province [8]. Therefore, the objective of this work is to elucidate the efficacy of performance on antifouling paints compared to anticorrosion paint and bare metal as referenced materials in Bali Sea and the dentrimetal effect of corrosion attack on bare metal without protection of AF paint during field exposure in different depth of the sea.

2. MATERIALS AND METHODS

2.1. The Preparation of Specimens The chemical composition of bare mild steel was 99.0 wt.% Fe, 0.29 wt.% Si, 0.20 wt.% Cr, 0.13 wt.% C, 0.11wt% Si, 0.02 wt% P, 0.01 wt% Ni, 0.01 wt% Cu and 0.01 wt.% Ti that used in this work. The measurement of its composition utilized ARL 3460 optical emission spectrometers (OES). The plates of mild steel were made (length: 250 mm,

width: 200 mm and thickness: 3 mm) for coating substrate. All steel plates were sanded by sandblasting machine according to ISO 8501-1 Sa 2.5. In addition, that standard specifies that stains, shadows and streaks have to be restricted to 5% of the clean surface steel area in which it applied commonly for off-shore structure, vessel and others. Both commercial AF paints were multilayer coating system which comprises epoxy primer base coat, epoxy intermediate base coat and top coat (SPC-AF Paint). In particular, intermediate coat of Paint A system consist of glass flake as additive, but not Paint B.

Both anticorrosion (AC) paints also were prepared which consist of primer and intermediate coats without addition AF paint. In addition, all anticorrosion paints is a type of epoxy-based paint without addition main biocides. AC paint and bare mild steel were as referenced materials. The bare metal steels were cut into specimens (150 mm x 75 mm x 3 mm) in which were used to measure their corrosion rates through weight loss method. Furthermore, both commercial AF paints were received from two different companies in Indonesia which is based in tin-free self-polishing copolymers (SPC). The formulation process of AF paints was carried out in those companies with following the approximate chemical composition of paints is shown in Table 1.

Each batch of panels consist of AF paint, AC paint and bare metal plates was attached and placed on submerged piles of Mandara Bali Highway during tropical wet season in early September, at depth of 0 to 3

TABLE 1. Antifouling paint composition

Substances	Approx. w/w% antifouling paint A	Approx. w/w% antifouling paint B
Cu ₂ O	40 - 50	≥25 - ≤50
ZnO	1 - 5	≤5
CuPT	1 - 5	≤5
Xylene	17	≥10 - ≤25
Ethylbenzene	11	<10
Colophony	-	≤5
Rosin	5 - 10	-
Hydrocarbons, C9, aromatics, (<0.1% Benzene)	-	≤5
TiO ₂	0.1 - 1	-
Methanol	0.1 - 1	-
Ethanol	0.1 - 1	-
Other substances : Plasticizer, Anti settling agent, Extenders and Anti sagging agents	Remains	Remains

meters in Benoa Bay (8°45'56.9"S 115°11'48.6"E) are shown in Figure 1. After 30 days of exposure, a batch of panels was retrieved from the sea and dry-stored until further characterization and analysis processes. In Figure 2, the test racks which consist of AF paint, AC paint and bare metal plates were embedded on piles of Mandara Bali Highway, Bali Province.

In previous work, the seawater parameters which comprise dissolved oxygen (DO), temperature, pH, salinity and conductivity can affect the corrosion resistance of material [17] and the growth and the settlement of marine biofouling on offshore structure [7]. Therefore, these factors could be considered to be conducted in this recent work. In measuring them, the apparatus in utilized was HACH HQ40d Advanced Portable meter with field probe type.

2. 2. Evaluation of Painting Properties The evaluations of painting properties were carried out before and after field exposure. The measurement of the painting hardness utilized pencil hardness tester Elcometer 501 in which refer to American Standard Testing and Material (ASTM) D-3363. The adhesion strength of coating was conducted by using automatic adhesion tester Elcometer 510 (ASTM D-4541). The gloss property of coating was also done in specified



Figure 1. Location for placing the specimens in Bali Bay, Indonesia



Figure 2. The test rack of specimens for submerged piles of Mandara Bali highway

measurement angle of 60° using Horiba Gloss Checker IG-331 (ASTM D-523). In our work, in order to make ensure the validity of data, we carried out all measurement of test samples of coating (paint) at least 5 times. In addition, after retrieving paint specimens from the sea, the visual investigation is necessary to observe the appearance and distribution of attached biofouling. The observation of the cross-sectional morphology and elements in both AF paint A and AF paint B was carried out by using Energy Dispersive X-Ray Spectroscopy (EDAX) and JEOL JSM-6390 series Scanning Electron Microscope (SEM).

2. 3. Weight Loss Analysis of Bare Metals After retrieving from the sea, the attached fouling was scraped off from surface of bare mild steel. The corrosion product which was located underneath fouling had been removed by chemical cleaning method according to ASTM G-1. After that, the specimens were rinsed with distilled water, dried with blower, and then weighed to calculate their mass losses. The tests were repeated in twice to make ensure the reliability of the results, the corresponding corrosion rates (CR) were calculated, assuming uniform corrosion over the entire surface of the specimens. The corrosion rate in mils per year (mpy) was calculated from the weight loss using the following formula:

$$CR = \frac{W \times K}{D \times A \times T} \quad (1)$$

where W = weight loss in milligrams, K-factor = a constant (3.45 x 10), D = metal density in g/cm³, A = area of sample in cm², T = time of exposure of the metal sample in hours.

3.RESULTS AND DISCUSSION

3. 1. The Evaluation of Paint Properties and Seawater Parameters after Exposure Figure 3 shows gloss properties of AF paints after exposure in various depth of seawater. The value of AF Paint A and B gloss are 7.0 and 3.0 before exposure, respectively. The magnitude of gloss AF Paint A was higher than that of AF Paint B due to lower solid content of paint A compared to that of paint B [18]. The result of both AF paints was less than 10 Gross Units (GU) in which is categorized as low gloss paint. On the basis of the results obtained, there is no different magnitude of gloss paint in various depth of the sea within a month of exposure. In addition, there is also less difference for the gloss property of both AF paints before or after exposure.

Jaic and Palija [19] had reported that the decrease of the surface roughness of paint could increase gloss level of paint. It implies that there is no alteration of surface roughness for both AF paint A and B during one month after exposure. Moreover, both AF paints are classified

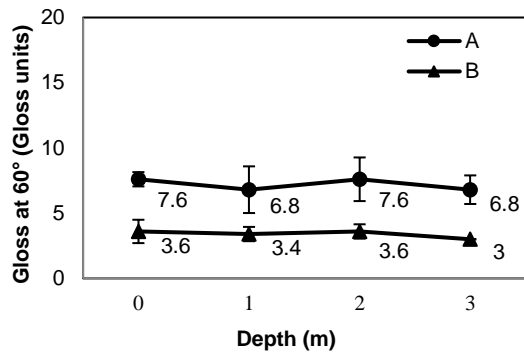
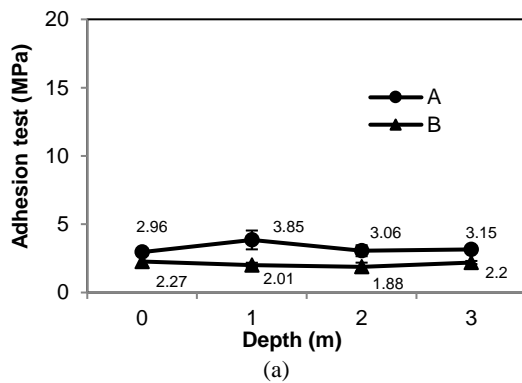


Figure 3. Gloss level of AF Paints as function of depth of the sea

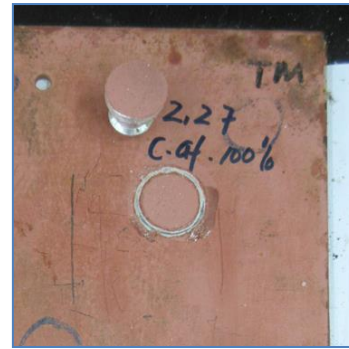
as tin-free self-polishing copolymers (tin-free SPC) in which have self-polishing mechanism for minimizing the level of surface roughness [12]. On the basis of results, the hardness of both AF paint A and Paint B were classified in B before and after exposure in the seawater which are classified as soft coating. There are no difference of pencil hardness in both AF Paint A and B during exposure

Figure 4a shows adhesion strength of AF Paint A and AF Paint B after exposure in the sea. The adhesion strengths of the paints were almost the same magnitude in different depth level of the sea. The type of failure indicates that the systems of coating tend to 100% cohesion pattern, where the both coating of A and B took place failure inside antifouling coating layer as shown in Figure 4b. In addition, cohesive failure is commonly in the coating itself such as abrasion, cracking due to aging, abrasion, dissolving in solvent and so on.

The habitation of marine fouling organisms is affected by parameters such as salinity, pH, temperature, the intensity of solar radiation and so on [20]. In particular seawater temperature approximately more than 20°C and pH around 8 are proper for the growth and settlement of marine biofouling [21]. In this work the pH and water temperature tends to become the suitable growth for fouling organisms as shown in Table 2.



(a)



(b)

Figure 4. (a) Adhesion strength for AF paints as function of depth levels of the sea after exposure ; (b) A representative figure of adhesion failure for a specimen of AF paint after pull off test

TABLE 2. Parameter of seawater after 1 month of exposure in Mandara, Bali Bay

Depth (meters)	Temperature (°C)	pH	Salinity (ppt)	Conductivity (µs/m)	Dissolve Oxygen (mg/L)
0	28.1	8.3	28.9	47.5	5.08
1	28.0	8.3	28.8	47.2	5.19
2	27.9	8.4	28.7	47.1	5.10
3	27.9	8.4	28.6	47.0	5.05

However, there is no significant shift for pH and seawater temperature in various depth of sea level. Furthermore, salinity is defined as the dissolved salt content of water where generally average seawater salinity is 35 ppt [22]. In theory the salinity is assessed by determination of chloride [Cl⁻] ion concentrations in the body of water, where empirical dependence, which defines that parameter equals $1.80655 \times [Cl^-]$, is employed. Table 2 shows the magnitude of seawater salinity was less than 35 ppt. Benoa Bay is categorized as a semi-enclosed estuary which has several big river estuaries in Bali Island [23]. It implies that the level of salinity in Benoa Bay is lower than that in ocean outside of coastal area.

In ocean the solubility of dissolved oxygen (DO) decreases as water temperature increases and vice versa where the lower DO concentrations near the equator increase the salinity compared to subtropical area [24]. Commonly oxygen level decrease with increasing depth in the ocean. However, in Table 2, the magnitude of DO of the sea is almost homogenous distributed in different depth. The highest DO concentration took place at the surface layer of the water due to the penetration of intense sunlight and the photosynthesis process in supplying oxygen in the body of water [25]. In this work, the panels only were embedded on piles in shallow depth of the sea

up to 3 meters which is in euphotic zone. In that zone the sunlight could penetrate intensively into the body of ocean [26].

Water conductivity is shifted into salinity by using empirical relationship [17] which is dependent on the concentration of conductive ions present containing the dissolved salt content in the water. According to the results, water conductivity is almost the same magnitude in different depth of the sea as shown in Table 2. The lower water conductivity is indicated to take place due the existence of estuaries near test panels. As reference, generally sea water has a conductivity of about 55 $\mu\text{S}/\text{m}$ at temperature of 25°C [27] but not in the present work.

3. 2. The Visual Observation of Paint Specimens after Exposure

The visual observation of AC and AF paints was carried out by using digital Canon macro photograph. Figure 5 shows photographs of anticorrosion and antifouling paints A and B before exposure in Benoa Bali Bay. For comparison after field exposure, Table 3 shows the visual observation of all various paints A and B. On the basis of overall visual observation, the utilization of AF paint definitely is paints in different depth of the sea. It implies that seawater quality parameters is almost the same due to the euphotic zone [26]. In addition, after 1 month of exposure, there were some fouling organisms such as slime, brown



Figure 5. Photograph of (a) AC and AF paints A and (b) AC and AF paints B before exposure

TABLE 3. The visual observation of specimen after 1 month of exposure

Depth of the sea (m)	AC paint A	AF paint A	Depth of the sea (m)	AC paint B	AF Paint B
0			0		
1			1		
2			2		
3			3		

weed and barnacles on AC paint panels. Barnacles and brown weed are categorized as hard shelled macrofouling and plant macrofouling, respectively [28]. The initial stage of marine fouling growth is commonly found various type bacterial colonies on AF paint which those colonies is as nutrition sources for the growth of invertebrates and microalgae in several days of exposure [29-31]. It is presumed that initial stage was took place in present work. It will be predicted that the growth of biofouling continues to the mature condition over one month of exposure due to suitable environment of seawater.

3. 3. Proposed Mechanism of Antifouling Paint against Marine Biofouling

The representative cross section images of both AF paints are shown in Figures 6 and 7. In previous description, both AF paints have three layers coating which consist of primer coating (first layer), intermediate coating (second layer) and top coating (AF paint). The average thickness of both AF paint A and B are 176 μm and 114 μm before exposure, respectively. The reduction of layer thickness in both paints took place after 1 month of field exposure. Furthermore, the AF paint thickness reduction in paint A is lower than that in paint B after exposure as shown in

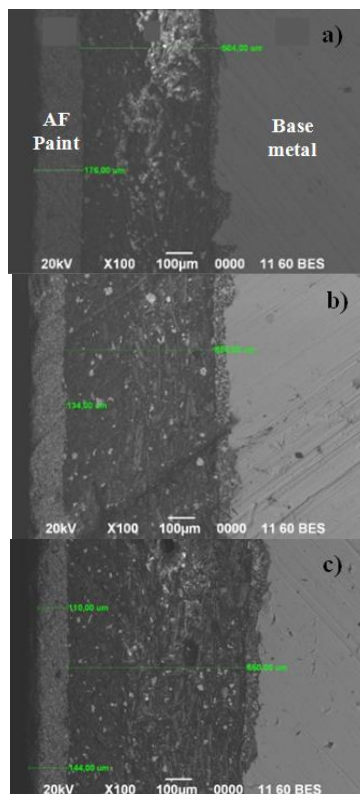


Figure 6. Representative cross-section images of Paint A (a) before exposure and after exposure in seawater at depth of (b) 0 m and (c) 1 m

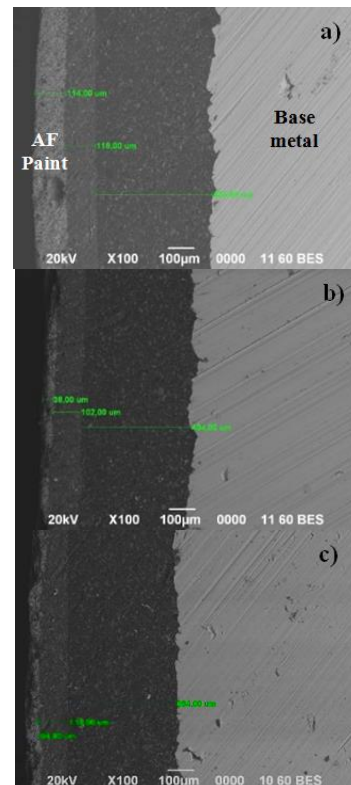


Figure 7. Representative cross-section images of Paint B (a) before exposure and after exposure in seawater at depth of (b) 0 m and (c) 1 m

Figures 6 and 7. The difference of loss thickness of both AF paints is probable due to the difference of their initial thickness. Some papers reported that the service life of AF paint is estimated by the magnitude of initial thickness for coating before exposure [32-34] as well as present study. It implies that the predictive service life of AF Paint A tends to be much longer than that of AF Paint B beyond 1 month of exposure.

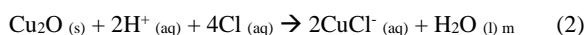
In this work, the type of both as-received AF paints is categorized as tin-free-polishing copolymer (tin-free SPC) in which is based on silyl acrylate (SA) polymers as paint binder according to technical data sheet (TDS) of both paints. Tin-free SPC AF paint commonly had been intensively reported [12, 35-37]. The service life of tin-free SPC AF paint commonly is corresponded to the performance of its paint which inhibits the attachment of marine fouling with slow release of binder matrix [12], thus controlling the reduction rate of thickness of the paint.

Furthermore, in the protective mechanism of SPC-AF paint againts the attachment of biofouling, sea water enters into the paint matrix, dissolve such biocides, co-biocides and other additives and diffuse out into the bulk paint again in slow reaction [12]. The thin leached layer of AF paint consist of depleted main biocide and co-

biocide particles such Cu_2O and ZnO [12]. In addition, in self-polishing copolymer (SPC) AF paint, the leaching release of paint commonly consist of into initial leaching and steady-state leaching releases [12, 38, 39]. In initial stage, leaching rate starts at once when fresh surface of paint is immersed in seawater and biocide particles begin to dissolve at the interface between the paint layer and water [38, 39]. The absence of soluble pigment biocide will leave behind pores in the matrix paint which is defined as leached layer as show in Figure 8.

AF Paints were formulated by incorporation of binder, solvent, biocide, co-biocide, booster biocide, extender, pigment and other substances as shown in Table 1. In both AF paint A and B, the additive of Cu_2O is as primary biocide in AF paint, where booster biocides such CuPT is used to increase the efficacy of the paint. Co-biocide compound such ZnO is added to improve the performance of the paint by providing enhanced activity against macroalgae fouling and/or algae and bacterial biofilms.

Table 4 shows element composition of AF paint A and AF Paint B before exposure. On the basis of the results, the high concentration of Cu has indication the presence of primary biocides (Cu_2O) and booster biocides (CuPT) in both the AF paints. The element of Zn was also found in both the paints in which refers to the presence of ZnO as co-biocide compound. On the other side, Table 5 also shows element composition of AF paint A and AF Paint B before after exposure. After 1-month exposure, the presence of copper as an essential element of main biocide is still inhibit the settlement of biofouling on the both AF paints. Furthermore, the mechanism of dissolution primary biocide of Cu_2O in seawater in following chemical equation:



The high salinity is induced by the presence of high concentration of chloride ions which increase the dissolution rate of Cu_2O [2]. When cuprous oxide comes into contact with sea water, it generates soluble hydrated Cu(I) chloride complexes which are then rapidly oxidized to Cu^{2+} as the main biocidal species.

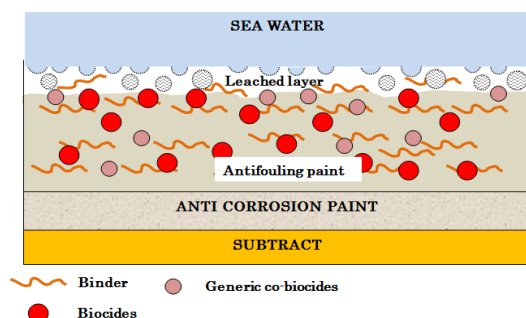


Figure 8. Proposed illustration of nature on antifouling paint system exposed to seawater

TABLE 4. EDAX results of the element composition of AF Paints before exposure

Elements	A	B
	Mass %	
C	36.36	32.42
O	16.44	11.90
Mg	-	1.67
Si	0.73	2.72
S	1.26	1.10
Ti	-	0.81
Fe	-	2.38
Cu	38.34	42.75
Zn	6.23	4.25
Na	-	-
Al	0.62	-
Cl	-	-
Ca	-	-
Ba	-	-

TABLE 5. EDAX results of the element composition of AF Paints after exposure

Elements	A	B
	Mass %	
C	39.38	34.55
O	9.21	12.87
Mg	-	-
Si	-	0.85
S	1.26	0.99
Ti	0.64	0.81
Fe	-	-
Cu	27.15	44.24
Zn	2.46	6.50
Na	-	-
Al	-	-
Cl	-	-
Ca	-	-
Ba	-	-

The mechanisms of controlling the release rate of biocides and co-biocides consist of chemical reactions and diffusion where sea water soluble pigment dissolution, binder reaction and paint polishing process occur simultaneously [2]. That mechanism could affect the consistency for thin thickness of leached layer SPC-paint [12, 40]. It implies that the absence of biocides and co-biocides in silyl acrylate matrix leaves behind small

pores in that matrix and increases the total wetted area on the paint. The hydrolysis reaction occur throughout the leached layer where there is the shift of wettability of binder from hydrophobic to hydrophilic [12]. Partially reacted binder prone to be eroded by the moving seawater and exposed at a less reacted paint surface (self-polishing effect). The less reacted paint surface consists of biocide and co-biocides enriched matrix which protects further the attachment of biofouling. The condition of steady-state leaching release take places where ion diffusion from seawater through the leached layer is equal to the erosion rate of the paint binder [12].

Furthermore, the release rate of biocide from the paint bulk is induced by current of seawater [41], where leached layer can be easy to polish or erode gradually. Kojima and co-workers [38] reported that the SPC AF paint thickness could be reduced significantly in increasing flow rate of seawater. The slow ocean current occurs in 0.55 m/s which are categorized as ocean drift [42]. Indonesian researchers reported that the range of ocean current around 0.88 m/s to 1.71 m/s where type of that current is affected predominantly by tidal current in Benoa bay [43]. It implies that the ocean current of Bali bay is not slow. The existence of tidal current is able to erode a leached layer of AF paint in which create fresh surface of biocide enriched layer. The fresh layer surface containing biocides is renewed continuously and degradation in paint thickness takes place [44]. The protection of attached biofouling keeps going continuously until there is no AF paint layer on the substrate of steel. The role of pH, salinity and water temperature apparently are not predominant to induce the mechanism of biocide and co-biocide release out from both AF paint matrix due to the same magnitude of the seawater parameters in various depth of the sea. In addition, the geographic location of also lead the different release rate of them in freshwater compared to marine water due to salinity difference [45, 46].

3. 4. Corrosion Behavior of Bare Steel without Coating after Exposure

Figure 9 shows the visual observation of bare mild steels before and after field exposure. For quantification of corrosion behavior, Table 6 shows the weight loss and corrosion rate of the bare mild steel after exposure. The weight loss of specimens took place due to the synergism between oxygen reduction in the electrochemical process [17] and the metabolism activity of attached biofouling [4, 8]. The electrochemical reaction is related to the synergic activity between anodic and cathodic area [46-48]. In addition, from the laboratory simulation, the average corrosion rate of steel was 4.1 mpy in seawater which was taken in Mandara Bali without the appearance of fouling on metal substrate [17]. By comparing the present field results, it implies that the loss weight of bare steel apparently increase due to the presence of marine biofouling.

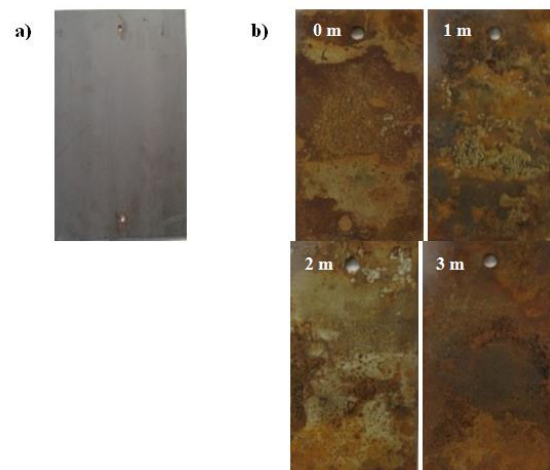


Figure 9. Visual observation of bare mild steel specimens a) before and b) after exposure in different depth of the sea

TABLE 6. The weight loss of specimen in various depth of seawater

Depth of seawater (m)	Weight loss (gram)	Corrosion rate (mpy)
0	6.09	13.03
1	6.075	13.00
2	7.07	15.13
3	6.62	14.17

The magnitude of weight loss of metal is corresponded to corrosion rate as shown in equation 1. On the basis of result, there is no significant difference for the corrosion rate of bare steel at the various depth of seawater. Lutviasari et al. [8] also reported that there is less difference for the magnitude of corrosion rate on bare steel in the seawater depth of 1, 2 and 3 meters in Madura strait, Indonesia as well as the present study. In the case of submerged structures in sea water, the magnitude of corrosion rate is related to the complexity of combination of temperature, salinity, pH, and dissolved oxygen (DO) [47]. In addition, the corrosion rate of bare mild steels took place predominantly due to the effect of DO and biofouling as well as the weight loss of them. Therefore, the presence of antifouling paint with multilayer system decreases the susceptibility of corrosion due to the resistance of corrosion ability in primer coating [48, 49].

4. CONCLUSIONS

The performance of antifouling paint within 1 month of field exposure showed essential results compared to anticorrosion paint and bare mild steel in Bali Sea against the growth of biofouling. AF paint has remarkable

efficacy to protect attached marine fouling organisms, but not AC paint and bare mild steel. The role of various depth of the sea up to 3 meters has no essential effect on the properties of the paints. The presence of copper as a primary biocide could inhibit the growth and habitation of biofouling in both the AF paints. The reduction of thickness for AF paints are predominant to be affected by sea current compared to the parameter of pH, salinity and temperature in different depth of the sea. The magnitude of corrosion rate for bare mild steel is almost same in various depth of the sea where the role of dissolve oxygen and marine bio fouling organisms increase the severity of corrosion during service.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the Research Center for Metallurgy and Material – LIPI and Ministry of Research, Technology and Higher Education– Republic of Indonesia for financial support in this research under LIPI Priority and Advanced Research Projects. The authors also thankful to the very helpful support from Research Center and Development of Roads and Bridge, Indonesia's Ministry of Public Works and Housing conducting present research.

6. REFERENCES

- Peres, R.S., Armelin, E., Moreno-Martínez, J.A., Alemán, C. and Ferreira, C.A., "Transport and antifouling properties of papain-based antifouling coatings", *Applied Surface Science*, Vol. 341, (2015), 75-85. DOI:10.1016/j.apsusc.2015.03.004
- Ytreberg, E., Bighiu, M.A., Lundgren, L. and Eklund, B., "Xrf measurements of tin, copper and zinc in antifouling paints coated on leisure boats", *Environmental Pollution*, Vol. 213, (2016), 594-599. DOI: 10.1016/j.envpol.2016.03.029
- Hakim, M., Nugroho, B., Nurrohman, M., Suastika, I. and Utama, I., "Investigation of fuel consumption on an operating ship due to biofouling growth and quality of anti-fouling coating", in IOP Conference Series: Earth and Environmental Science, IOP Publishing, Vol. 339, No. 1, (2019), 012037. DOI: 10.1088/1755-1315/339/1/012037
- Priyotomo, G., "A short review of antifouling paint performance in tropical seawater of Indonesia", *Research & Development in Material Science*, Vol. 8, No. 4, (2018). DOI: 10.31031/rdms.2018.08.000695
- Schwindt, E., Gappa, J.L., Raffo, M.P., Tatián, M., Bortolus, A., Orensanz, J.M., Alonso, G., Diez, M.E., Doti, B. and Genzano, G., "Marine fouling invasions in ports of patagonia (argentina) with implications for legislation and monitoring programs", *Marine Environmental Research*, Vol. 99, (2014), 60-68. DOI: 10.1016/j.marenvres.2014.06.006
- Lord, J.P., Calini, J.M. and Whitlatch, R.B., "Influence of seawater temperature and shipping on the spread and establishment of marine fouling species", *Marine Biology*, Vol. 162, No. 12, (2015), 2481-2492. DOI:10.1007/s00227-015-2737-2
- Ferry, M., Wan Nik, W. and Mohd Noor, C.W., "The influence of seawater velocity to the corrosion rate and paint degradation at mild steel plate immersed in sea water", in Applied Mechanics and Materials, Trans Tech Publ. Vol. 554, (2014), 218-221. DOI: 10.4028/www.scientific.net/AMM.554.218
- Nuraini, L., Prifiharni, S., Priyotomo, G., Sundjono and Gunawan, H., "Evaluation of anticorrosion and antifouling paint performance after exposure under seawater surabaya–madura (suramadu) bridge", in AIP Conference Proceedings, AIP Publishing LLC. Vol. 1823, No. 1, (2017), 020101. DOI: 10.1063/1.4978174
- Turner, A., "Marine pollution from antifouling paint particles", *Marine Pollution Bulletin*, Vol. 60, No. 2, (2010), 159-171. DOI: 10.1016/j.marpolbul.2009.12.004
- Almeida, E., Diamantino, T.C. and de Sousa, O., "Marine paints: The particular case of antifouling paints", *Progress in Organic Coatings*, Vol. 59, No. 1, (2007), 2-20. DOI: 10.1016/j.porgcoat.2007.01.017
- Azemar, F., Faÿ, F., Réhel, K. and Linossier, I., "Development of hybrid antifouling paints", *Progress in Organic Coatings*, Vol. 87, (2015), 10-19. DOI: 10.1016/j.porgcoat.2015.04.007
- Yebra, D.M., Kiil, S. and Dam-Johansen, K., "Antifouling technology—past, present and future steps towards efficient and environmentally friendly antifouling coatings", *Progress in Organic Coatings*, Vol. 50, No. 2, (2004), 75-104. DOI: 10.1016/j.porgcoat.2003.06.001
- Farhat, N., Vrouwenvelder, J.S., Van Loosdrecht, M.C., Bucs, S.S. and Staal, M., "Effect of water temperature on biofouling development in reverse osmosis membrane systems", *Water Research*, Vol. 50, (2016), 149-159. DOI: 10.1016/j.watres.2016.07.015
- Hermansyah, H., Atmadipoera, A.S., Prartono, T., Jaya, I. and Syamsudin, F., "Stratification and stability of seawater mass in sulawesi sea", *International Journal of Sciences: Basic and Applied Research*, Vol. 36, No. 8, (2017), 36-44.
- Carteau, D., Vallée-Réhel, K., Linossier, I., Quiniou, F., Davy, R., Compère, C., Delbury, M. and Faÿ, F., "Development of environmentally friendly antifouling paints using biodegradable polymer and lower toxic substances", *Progress in Organic Coatings*, Vol. 77, No. 2, (2014), 485-493. DOI: 10.1016/j.porgcoat.2013.11.012
- Liu, C., "Development of anti-fouling coating using in marine environment", *International Journal of Environmental Monitoring and Analysis*, Vol. 3, No. 5, (2015), 373. DOI: 10.11648/j.ijema.20150305.30
- Sundjono, S., Priyotomo, G., Nuraini, L. and Prifiharni, S., "Corrosion behavior of mild steel in seawater from northern coast of java and southern coast of bali, indonesia, Bandung Institute of Technology, (2017). DOI: 10.5614/j.eng.technol.sci.2017.49.6.5
- Tiarks, F., Frechen, T., Kirsch, S., Leuninger, J., Melan, M., Pfau, A., Richter, F., Schuler, B. and Zhao, C.-L., "Formulation effects on the distribution of pigment particles in paints", *Progress in Organic Coatings*, Vol. 48, No. 2-4, (2003), 140-152. DOI: 10.1016/S0300-9440(03)00095-X
- Jaić, M. and Palija, T., "High gloss finish: The impact of surface roughness on gloss", *Zaštita Materijala*, Vol. 56, No. 4, (2015), 457-462. DOI: 10.5937/zasmat1504457j
- Bressy, C. and Lejars, M., "Marine fouling: An overview", *The Journal of Ocean Technology*, Vol. 9, No. 4, (2014), 19-28.
- Rodriguez, S.G.S., Sithole, N., Dhakal, N., Olive, M., Schippers, J.C. and Kennedy, M.D., "Monitoring particulate fouling of north sea water with sdi and new astm mfi0. 45 test", *Desalination*, Vol. 454, (2019), 10-19. DOI: 10.1016/j.desal.2018.12.006
- Suriani, M., Ramlan, S. and Nik, W.W., "Antifouling properties of zinc nitrate in seawater", *International Journal of Chemical Engineering and Applications*, Vol. 7, No. 5, (2016), 314. DOI: 10.18178/ijcea.2016.7.5.596

23. Rachman, H.A., Hendrawan, I.G. and Putra, I.D.N.N., "Studi transpor sedimen di teluk benoa menggunakan pemodelan numerik", *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology*, Vol. 9, No. 2, (2016), 144-154. DOI: 10.21107/jk.v9i2.1617
24. Breitburg, D., Levin, L.A., Oschlies, A., Grégoire, M., Chavez, F.P., Conley, D.J., Garçon, V., Gilbert, D., Gutiérrez, D. and Isensee, K., "Declining oxygen in the global ocean and coastal waters", *Science*, Vol. 359, No. 6371, (2018). DOI : 10.1126/science.aam7240
25. Leidonald, R., Muhtadi, A., Lesmana, I., Harahap, Z. and Rahmadya, A., "Profiles of temperature, salinity, dissolved oxygen, and ph in tidal lakes", in IOP Conference Series: Earth and Environmental Science, IOP Publishing. Vol. 260, No. 1, (2019), 012075. DOI: 10.1088/1755-1315/260/1/012075
26. Jaud, T., Dragon, A.-C., Garcia, J.V. and Guinet, C., "Relationship between chlorophyll a concentration, light attenuation and diving depth of the southern elephant seal *mirounga leonina*", *PLoS one*, Vol. 7, No. 10, (2012), e47444. DOI: 10.1371/journal.pone.0047444
27. Sauerheber, R. and Heinz, B., "Temperature effects on conductivity of seawater and physiologic saline, mechanism and significance", *Chemical Sciences Journal*, Vol. 6, No. 4, (2016), 1-5. DOI: 10.4172/2150-3494.1000109
28. Doble, M., "Polymers in a marine environment, Smithers Rapra, (2014).
29. Lanneluc, I., Langumier, M., Sabot, R., Jeannin, M., Refait, P. and Sablé, S., "On the bacterial communities associated with the corrosion product layer during the early stages of marine corrosion of carbon steel", *International Biodeterioration & Biodegradation*, Vol. 99, (2015), 55-65. DOI: 10.1016/j.ibiod.2015.01.003
30. Chen, C.-L., Maki, J.S., Rittschof, D. and Teo, S.L.-M., "Early marine bacterial biofilm on a copper-based antifouling paint", *International Biodeterioration & Biodegradation*, Vol. 83, (2013), 71-76.
31. Mieszkin, S., Callow, M.E. and Callow, J.A., "Interactions between microbial biofilms and marine fouling algae: A mini review", *Biofouling*, Vol. 29, No. 9, (2013), 1097-1113. DOI: 10.1080/08927014.2013.828712
32. Swain, G.W., Kovach, B., Touzot, A., Casse, F. and Kavanagh, C.J., "Measuring the performance of today's antifouling coatings", *Journal of Ship Production*, Vol. 23, No. 3, (2007), 164.
33. Atlar, M. and Callow, M., "The development of foul-release coatings for seagoing vessels", *Journal of Marine Design and Operations*, No. 4, (2003), 11-23.
34. Takahashi, K., Release rate of biocides from antifouling paints, in Ecotoxicology of antifouling biocides. 2009, Springer.3-22. DOI: 10.1007/978-4-431-85709-9_1
35. Lagerström, M., Lindgren, J.F., Holmqvist, A., Dahlström, M. and Ytreberg, E., "In situ release rates of cu and zn from commercial antifouling paints at different salinities", *Marine Pollution Bulletin*, Vol. 127, No., (2018), 289-296. DOI: 10.1016/j.marpolbul.2017.12.027
36. Amara, I., Miled, W., Slama, R.B. and Ladhari, N., "Antifouling processes and toxicity effects of antifouling paints on marine environment. A review", *Environmental Toxicology and Pharmacology*, Vol. 57, (2018), 115-130. DOI: 10.1016/j.etap.2017.12.001
37. Chambers, L.D., Stokes, K.R., Walsh, F.C. and Wood, R.J., "Modern approaches to marine antifouling coatings", *Surface and Coatings Technology*, Vol. 201, No. 6, (2006), 3642-3652. DOI: 10.1016/j.surfcoat.2006.08.129
38. Kojima, R., Shibata, T. and Ueda, K., "Leaching phenomena of antifouling agents from ships' hull paints", *Journal of Shipping and Ocean Engineering*, Vol. 6, No. 5, (2016).DOI: 10.17265/2159-5879/2016.05.002
39. Laidlaw, F.B., "The history of the prevention of fouling", *Marine Fouling and Its Prevention*, No. 580, (1952), 211-22.
40. Ytreberg, E., Karlsson, J. and Eklund, B., "Comparison of toxicity and release rates of cu and zn from anti-fouling paints leached in natural and artificial brackish seawater", *Science of the Total Environment*, Vol. 408, No. 12, (2010), 2459-2466. DOI: 10.1016/j.scitotenv.2010.02.036
41. Al Tanto, T., Wisna, U.J., Kusumah, G., Pranowo, W.S., Husrin, S., Ilham, I. and Putra, A., "Karakteristik arus laut perairan teluk benoa-bali", *Geomatika*, Vol. 23, No. 1, (2017), 37-48. DOI: 10.24895/jig.2017.23-1.631
42. Fay, F., Linossier, I., Peron, J.J., Langlois, V. and Vallee-Rehel, K., "Antifouling activity of marine paints: Study of erosion", *Progress in Organic Coatings*, Vol. 60, No. 3, (2007), 194-206. DOI: 10.1016/j.porgcoat.2007.07.027
43. Rachmat, B. and Ilahude, D., "Estimation of sea current energy potential by using calculation models of horizontal axis current turbine in toyapakeh strait, nusa penida, bali", *Bulletin of the Marine Geology*, Vol. 32, No. 2, (2018). DOI: 10.32693/bomg.32.2.2017.352
44. Khavasfar, A., Moayed, M.H. and Jafari, A.H., "An investigation on the performance of an imidazoline based commercial corrosion inhibitor on CO₂ corrosion of mild steel", *International Journal of Engineering, Transactions A: Basics*, Vol. 20, No. 1, (2007), 35-44.
45. Lagerström, M., Ytreberg, E., Wiklund, A.-K.E. and Granhag, L., "Antifouling paints leach copper in excess—study of metal release rates and efficacy along a salinity gradient", *Water Research*, Vol. 186, (2020), 116383. DOI: 10.1016/j.watres.2020.116383
46. Wrange, A.-L., Barboza, F.R., Ferreira, J., Eriksson-Wiklund, A.-K., Ytreberg, E., Jonsson, P.R., Watermann, B. and Dahlström, M., "Monitoring biofouling as a management tool for reducing toxic antifouling practices in the baltic sea", *Journal of Environmental Management*, Vol. 264, (2020), 110447. DOI: 10.1016/j.jenvman.2020.110447
47. Shahrabi, T., Hosseini, M., Ghorbani, M. and Arshadi, M., "Synergistic influence of benzoate ions on inhibition of corrosion of mild steel in 0.5 m sulfuric acid by benzotriazole", *International Journal of Engineering*, Vol. 16, No. 3, (2003), 255-264.
48. Gu, Y., Yu, L., Mou, J., Wu, D., Xu, M., Zhou, P. and Ren, Y., "Research strategies to develop environmentally friendly marine antifouling coatings", *Marine Drugs*, Vol. 18, No. 7, (2020), 371. DOI: 10.3390/MD18070371
49. Mahmood, M., Suryanto, S., Al Hazza, M. and Haidera, F., "Developing of corrosion resistance nano copper oxide coating on copper using anodization in oxalate solution", *International Journal of Engineering, C: Aspects*, Vol. 31, No. 3, (2018), 450-455. DOI: 10.5829/ije.2018.31.03c.07

Persian Abstract

چکیده

برای جلوگیری از رشد بیوفیلم رسوبی دریایی از رنگ های ضد فولیگ استفاده می شود. در اندونزی، این رنگ به طور گسترده ای برای حمل و نقل استفاده می شود که معمولاً از مواد زیست کش پایه مسی استفاده می شود. در حقیقت، هیچ مطالعه جامعی در مورد رنگ ضد رطوبت در اندونزی در مقایسه با سایر کشورهای گرمسیری انجام نشده است. در این مطالعه، ارزیابی عملکرد برای رنگ ضد آلودگی در جایی انجام شد که رنگ ضد خوردگی و فولاد برهنه نیز به عنوان منابع مورد مطالعه قرار گرفتند. اندازه گیری میزان خوردگی بر روی فولاد به روش کاهش وزن انجام شد. پانل های حاوی نمونه ها 1 ماه برای غوطه وری در عمق های مختلف دریا تا 3 متر قرار داشتند. پارامترهای آب دریا متشکل از دما، pH، شوری، رسانایی و اکسیژن محلول و همچنین خصوصیات پوشش اندازه گیری شد. نتایج نشان داد که هر دو سطح رنگ ضد خوردگی و نمونه های فولادی پوشیده شده از بیوفولیگ، اما نه روی رنگ ضد رسوب گذاری. همچنین در خصوصیات رنگ ضد آلودگی قبل و بعد از قرار گرفتن در عمق های مختلف دریا تفاوت چندانی ندارد. کاهش ضخامت برای رنگ ضد آلودگی ظاهراً غالب است که تحت تأثیر جریان دریا باشد. میزان سرعت خوردگی در فولاد برهنه در عمق مختلف دریا تقریباً یکسان است که به دلیل اثر اکسیژن محلول و سوخت زیستی رخ داده است. در آینده، مقایسه عملکرد رنگ در تمام مناطق محلی لازم است تا در تمام مناطق محلی اندونزی انجام شود.
