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

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**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.

**Keywords**

Antifouling Paint, Anticorrosion Paint, Biofouling, Weight Loss, Corrosion, Salinity

**Paper History**

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**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>CR</td>
<td>Corrosion rate (mpy)</td>
</tr>
<tr>
<td>W</td>
<td>Weight loss (mg)</td>
</tr>
<tr>
<td>D</td>
<td>Metal density (g/cm²)</td>
</tr>
<tr>
<td>A</td>
<td>Area of sample (cm²)</td>
</tr>
<tr>
<td>T</td>
<td>Time of exposure (hour)</td>
</tr>
</tbody>
</table>

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

Commonly the primary mitigation for the severity of bio fouling 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 bio fouling 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 bio fouling 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 performace on antifouling paints compared to anticorrosion paint and bare metal as referenced materials in Bali Sea and the denticmental 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, 0.11 wt% 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). 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>
<thead>
<tr>
<th>TABLE 1. Antifouling paint composition</th>
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<tbody>
<tr>
<td>Substances</td>
</tr>
<tr>
<td>Cu₂O</td>
</tr>
<tr>
<td>ZnO</td>
</tr>
<tr>
<td>CuPT</td>
</tr>
<tr>
<td>Xylene</td>
</tr>
<tr>
<td>Ethylbenzene</td>
</tr>
<tr>
<td>Colophony</td>
</tr>
<tr>
<td>Rosin</td>
</tr>
<tr>
<td>Hydrocarbons, C9, aromatics, (&lt;0.1% Benzene)</td>
</tr>
<tr>
<td>TiO₂</td>
</tr>
<tr>
<td>Methanol</td>
</tr>
<tr>
<td>Ethanol</td>
</tr>
<tr>
<td>Other substances : Plasticizer, Anti settling agent, Extenders and Anti sagging agents</td>
</tr>
</tbody>
</table>
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 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:

\[ CR = \frac{W \times K}{D \times A \times T} \]

where \( W \) = weight loss in milligrams, \( K \)-factor = a constant (3.45 x 10), \( D \) = metal density in g/cm\(^3\), \( A \) = area of sample in cm\(^2\), \( T \) = 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.

![Figure 3](image1.png)

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

![Figure 4](image2.png)

**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

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

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 $1.80655 \times [\text{Cl}^-]$, 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 decreases 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 μS/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 is 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](image)

<table>
<thead>
<tr>
<th>Depth of the sea (m)</th>
<th>AC paint A</th>
<th>AF paint A</th>
<th>Depth of the sea (m)</th>
<th>AC paint B</th>
<th>AF Paint B</th>
</tr>
</thead>
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<td><img src="image" alt="Image" /></td>
<td>3</td>
<td><img src="image" alt="Image" /></td>
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</tbody>
</table>
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 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 against 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$_2$O 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$_2$O 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$_2$O) 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$_2$O in seawater in following chemical equation:

$$\text{Cu}_2\text{O} (s) + 2\text{H}^+ (\text{aq}) + 4\text{Cl}^- (\text{aq}) \rightarrow 2\text{CuCl}^- (\text{aq}) + \text{H}_2\text{O} (l) \quad (2)$$

The high salinity is induced by the presence of high concentration of chloride ions which increase the dissolution rate of Cu$_2$O [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.

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 siliyl acrylate matrix leaves behind small

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

<table>
<thead>
<tr>
<th>Elements</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>36.36</td>
<td>32.42</td>
</tr>
<tr>
<td>O</td>
<td>16.44</td>
<td>11.90</td>
</tr>
<tr>
<td>Mg</td>
<td>-</td>
<td>1.67</td>
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<tr>
<td>Si</td>
<td>0.73</td>
<td>2.72</td>
</tr>
<tr>
<td>S</td>
<td>1.26</td>
<td>1.10</td>
</tr>
<tr>
<td>Ti</td>
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</tr>
<tr>
<td>Fe</td>
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<td>2.38</td>
</tr>
<tr>
<td>Cu</td>
<td>38.34</td>
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<td>Zn</td>
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<tr>
<td>Ba</td>
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**Table 5. EDAX results of the element composition of AF Paints after exposure**

<table>
<thead>
<tr>
<th>Elements</th>
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<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>39.38</td>
<td>34.55</td>
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<tr>
<td>O</td>
<td>9.21</td>
<td>12.87</td>
</tr>
<tr>
<td>Mg</td>
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<td>-</td>
</tr>
<tr>
<td>Si</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>S</td>
<td>1.26</td>
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<td>Ti</td>
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<tr>
<td>Fe</td>
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<td>-</td>
</tr>
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<td>Cu</td>
<td>27.15</td>
<td>44.24</td>
</tr>
<tr>
<td>Zn</td>
<td>2.46</td>
<td>6.50</td>
</tr>
<tr>
<td>Na</td>
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<td>Al</td>
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<td>Ca</td>
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</tr>
<tr>
<td>Ba</td>
<td>-</td>
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</table>
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]. Indonesien 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 rate of 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]. In addition, 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](image)

<table>
<thead>
<tr>
<th>Depth of seawater (m)</th>
<th>Weight loss (gram)</th>
<th>Corrosion rate (mpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.09</td>
<td>13.03</td>
</tr>
<tr>
<td>1</td>
<td>6.075</td>
<td>13.00</td>
</tr>
<tr>
<td>2</td>
<td>7.07</td>
<td>15.13</td>
</tr>
<tr>
<td>3</td>
<td>6.62</td>
<td>14.17</td>
</tr>
</tbody>
</table>

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

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6. REFERENCES


برای جلوگیری از رشد بیوفیلم رسوبی دریایی از رنگ‌های ضد فولیگ استفاده می‌شود. در اندونزی، این رنگ به طور گسترده‌ای برای حمل و نقل استفاده می‌شود و عموماً از مواد زیست کش پایه مسی استفاده می‌شود. در حقیقت، هیچ مطالعه‌ای جامعی در مورد رنگ ضد رطوبت در اندونزی در مقایسه با سایر کشورهای گرمسیری انجام شده است. در این مطالعه، ارزیابی عملکرد برای رنگ ضد آلودگی در جایی انجام شد که رنگ ضد خوردگی و فولاد پوشیده شده به طور عمده عوامل محلول قرار گرفتند. اندازه‌گیری‌های میزان خوردگی بر روی فولاده و روش کاهش وزن انجام شد. پانل‌ها به مقادیر مختلف دریا تا 3 متر مایل در دشت‌های آب‌دریایی مشکل از دما، pH، شوری، رسانایی و همچنین خصوصیات پوشش اندازه‌گیری شد. نتایج نشان داد که هر دو سطح رنگ ضد خوردگی و نمونه‌های فولادی پوشیده شده از بیوفولیگ، اما رنگ ضد رسوب‌گذاری همچنین در خصوصیات رنگ ضد آلودگی قبل و بعد از قرار گرفتن در مکان‌های مختلف دریا ثابت گردیدند. کاهش ضخامت در بالای رنگ ضد آلودگی ظاهراً عادی است و تحت تأثیر جریان دریا می‌باشد. میزان سرعت خوردگی در فولاد پوشیده در مکان‌های مختلف دریا تقریباً در همه مناطق محلی از دست داده شده است. در این مطالعه، مقایسه عملکرد رنگ در تمام مناطق محیطی لازم است تا در تمام مناطق محلی اندونزی انجام شود.