Investigation of corrosion products formed on the surface of carbon steel exposed in Banda Aceh’s atmosphere

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ABSTRACT

This research aims to study the corrosion rate and characteristics of corrosion products of carbon steel due to exposure in the environment of Banda Aceh, Indonesia. The ASTM G50 was used as the basis for the specifications of the specimens for corrosion rate calculation. The corrosion rate was calculated based on ASTM G1. The features of corrosion products studied are morphological features, types, and chemical compounds of the rust. These characteristics were identified using scanning electron microscopy (SEM) and x-ray diffractometer (XRD). The corrosion rate of carbon steel was obtained using the weight-loss method. The study was conducted for twelve months, i.e. January to December of 2018. After one year of exposure, it was found that the highest corrosion rate occurred in the March–April period which was 0.024 mpy and falls into outstanding category of relative corrosion resistance. Various morphological features of corrosion products found during the period of exposure, including worm nest, bird’s nest, globular, cotton ball, laminar, lath, bar, needle-shaped, and whisker structures. These structures were lepidocrocite (γ-FeOOH) and goethite (α-FeOOH). During twelve months of exposure, corrosion products formed were dominantly lepidocrocite and goethite. It was found that the lepidocrocite might transform into goethite through prolonged exposure time.

1. Introduction

Atmospheric corrosion can be defined as the corrosion or the degradation of metals due to interaction with the surrounding pollutants in the atmosphere [1]. Carbon steel is a metallic material widely used in engineering. Corrosion or rust formed on the surface of carbon steel was composed by various oxides such as oxyhydroxides, hydrated oxides, miscellaneous crystalline, and other elements resulting from the reaction of iron (Fe) with its surroundings such as the atmosphere [2]. Many researchers have studied the corrosion products of atmospheric corrosion using X-ray diffraction (XRD) and Raman spectroscopy. Lepidocrocite (γ-FeOOH), goethite (α-FeOOH), and magnetite (Fe3O4) are found as the main morphology of corrosion products [2, 3, 4, 5, 6, 7]. Corrosion products formed on early period of exposure is usually lepidocrocite, and later transformed into goethite [4]. In general, almost all iron oxide, hydroxides, and oxide hydroxides look like crystals [8]. The environmental condition is a parameter that affects the structure and size of the crystals. Table 1 summarized the features of some atmospheric corrosion products such as chemical compounds, crystal structure, and morphology.

The atmospheric corrosion is driven by many environmental factors and the surface conditions of the metal itself [9]. The complex interplay between temperature, RH and Chloride deposition has been demonstrated to be an important factor in carbon steel in several countries [10, 11]. In addition, a model by Cai et al. demonstrated that one environmental factor (RH) could dominate while the others are secondary in atmospheric corrosion [10]. Cai et al. also suggests that Time of Wetness (TOW) can be replaced by temperature and humidity variables. However, another study shows specifically that TOW and accumulation of unwashed pollutants [12]. In low-precipitation environment and non-rainfall period, it is reported that RH plays a more significant role [13]. Furthermore, the type of atmosphere (rural vs coastal) drives the kinetics of corrosion and consequently the corrosion products and resulting metal surface (pits) [14]. The significance of environmental variables to corrosion products is also reported in another study [15]. In the same study, it is also shown the complex relationship between the environmental variables, corrosion products developed, and the
persistence of corrosion. In some cases, the corrosion products help reduce corrosion persistence by sealing the pores on the surface of metal. In conclusion, the intertwined relationship between various environmental variables and corrosion products is a complex and convoluted one. Even standardized guidance and index may fail to capture local atmospheric corrosion condition [11, 16]. To unravel this complex interplay between environmental variables and corrosion products, one must begin with compiling and documenting local corrosion products as a result of the local atmospheric conditions.

Previous research on atmospheric corrosion has been conducted in Banda Aceh, Indonesia. Corrosion rate measurement was performed on the structural steel, and the influence of the distance of the exposure to the coastline to atmospheric corrosion rate in the region of Banda Aceh has been investigated [17, 18]. However, the scope of these previous research is only limited to atmospheric corrosion rates. The corrosion products of carbon steel have not been investigated yet, especially for Banda Aceh, Indonesia. Therefore, this study aims to measure the atmospheric corrosion rate and identify the corrosion products of carbon steel that exposed in Banda Aceh's atmosphere. The properties of corrosion products play a role in determining the kinetics of the corrosion reaction [9]. Hence, it is imperative to identify and compile corrosion products data of local atmospheric corrosion in order to further examining the interplay between corrosion products, environmental factors and corrosion kinetics in local area.

2. Experimental procedure

2.1. Location and time

The research was conducted in the open areas in the Faculty of Engineering, University of Syiah Kuala, Banda Aceh, Indonesia. The location is shown in Figure 1. The location was chosen by considering the safety of on-going experiment and distance to the SEM and X-RD equipment. The exposure period started from January 2018 and ended in December 2018.

2.2. Specimen

The specimen dimensions for the exposure test are given in Figure 2. The thickness of the specimens is 3 mm. Eight specimens were subjected to exposure. Three specimens were used for weight loss measurement, three for SEM test and the final two for XRD. The specimens were mounted on a rack with general dimensions of 126 cm of length, 70 cm of width and 120 cm of height. The mounting inclination on the rack is 66.8°. The rack is shown in Figure 2. Plastic supports were installed on the rack to prevent direct connection of specimens to the rack that may lead to galvanic corrosion. Further details of specifications for specimens can be found in ASTM G50.

The weight loss specimens were measured for a period of two months, while the SEM and XRD test were carried out every month and six months, respectively. The weight loss specimens were cleaned up of dust by brushing and rubbing acetone on the surface of the specimens. The cleaned specimens were then weighed using digital scale with 0.001 g precision. Further details of preparation, cleaning and evaluating corrosion rate can be found in ASTM G1.

2.3. Corrosion rate calculation

The corrosion rate calculation, based on ASTM G1, is carried out according to:

\[
\text{Corrosion Rate} = \frac{3.45 \times 10^6 \times W}{A \times T \times D}
\]

where:

- Conversion factor, 3.45
- Weight loss, gram
- Surface area, cm²
- Exposure time, hours
- Mass density, g/cm³

2.4. Corrosion products morphology and composition measurement

The morphology of corrosion products was analyzed using Hitachi TM3000 scanning electron microscopy (SEM). The SEM specimens were 30 mm by 30 mm. The corrosion products were also identified using Shimadzu XRD-7000 X-Ray Diffractometer. The specimen used in this research was carbon steel with the composition shown in Table 2.

The SEM and XRD tests were carried out on selected spots on the specimen's surface. The specimens were not cleaned for these tests. The spots were picked randomly, and a spot was kept throughout the whole
period of exposure to consistently observe the evolution of corrosion product morphology.

3. Results

3.1. Corrosion rate

The atmospheric corrosion rate was calculated over twelve months of the year 2018 using Eq. (1). Figure 3 shows the corrosion rate of carbon steel for the whole period of exposure. As seen in the figure, the highest corrosion rate occurs in the period of March to April i.e. 0.024 mpy. Table 3 shows the corrosion resistance of carbon steel can be grouped into several categories based on the corrosion rate value. By using this table, the corrosion resistance of carbon steel in the environment in Faculty of Engineering, University of Syiah Kuala, Banda Aceh, Aceh province, Indonesia, is in the category of outstanding. This category is consistent with the previous study by Ridha et al. [18], which also conducted atmospheric corrosion rate measurement for carbon steel in Banda Aceh. The corrosion rate is also comparable to previous study in the same location [17]. However, atmospheric corrosion rate could be as high as 20 mpy in other coastal area (Iran) [11]. Comparison of the corrosion rate pattern to the rainfall data of Banda Aceh in [21] shows that the higher corrosion rate in the period of January–April and October onward are consistent with the wet season periods in Banda Aceh. The link between rainfall and high corrosion rate is also demonstrated in

Figure 2. (a) Specimen for weight-loss measurement; (b) Specimen for corrosion products observation; (c) Exposure rack.

Figure 3. The corrosion rate of carbon steel in Banda Aceh's environment during the year 2018.
another study [13, 22]. All three metals tested in [22] (including steel) experienced higher corrosion rate during rainy season.

3.2. The observation of corrosion products using SEM

A variety of shapes and sizes obtained from the identification using the scanning electron microscope (SEM) after a month of exposure (January) can be seen in Figure 4. The morphologies of corrosion products were analyzed according to characteristics provided in Table 1. The corrosion products formed after a month of exposure (January) were dominantly lepidocrocite (\(\gamma\)-FeOOH) with different shapes and sizes [9].

The goethite (\(\alpha\)-FeOOH) were also observed in Figure 4. It was found that laminar, globular, and sandy lepidocrocite emerged in the first month of exposure. The laminar (bird’s nest) lepidocrocite \([8, 20]\) is indicated by label A in Figure 4(a). The globular, sandy, and laminar (plates) lepidocrocite \([8, 20]\) are indicated by label B, C, and D, respectively. The size of globular lepidocrocite is around 10–30 \(\mu\)m. The size of sandy lepidocrocite is around 1–5 \(\mu\)m. A notable observation is given by flowery plate lepidocrocite that contains smaller spherical goethites that are 1–5 \(\mu\)m in size (Figure 4, label D). This feature may indicate growing goethites that were replacing lepidocrocite. The cotton ball goethite is shown in Figure 4(b) indicated by label E. The size of these goethites is around

Figure 4. The morphology of corrosion product after one-month exposure (January): (a) bird’s nest (A), globular (B), and sandy (C) lepidocrocite; (b) laminar (plates) lepidocrocite (D) and cotton ball type of goethite (E).

Figure 5. The morphology of corrosion product after two months exposure (January to February): (a) worm nest (A) and bird’s nest (B) lepidocrocite, and cotton ball (C) goethite; (b) sandy (D) and bird’s nest (B) lepidocrocite, needle-shaped (C) goethite; (c) the formation of cloud-like goethite (right) among lepidocrocite structure.
This finding agrees with Antunes et al. [3] who concluded that the corrosion products found after the first month of exposure were mainly lepidocrocite and goethite.

The observation of corrosion product using SEM after two months of exposure are shown in Figure 5. The corrosion products formed were still dominantly lepidocrocite with a small amount of goethite. Figure 5(a) shows worm nest (A) and bird's nest (B) lepidocrocite, and cotton ball (C) goethite. It is speculated that the plates of bird's nest grew thicker as exposure continued, and the shape turned into a worm nest type. The previous researcher [20] also indicated that worm nest and bird's nest types of lepidocrocite could be found close to each other as is the case in Figure 5. The sandy (D) lepidocrocite can be found in Figure 5(b), as well as bird's nest type. The cotton ball goethite (with needle-like features on the surface) was also found adjacent to bird's nest lepidocrocite. One notable finding is that the cloud-like goethite was observed among the plates of lepidocrocite [5, 19] as indicated in Figure 5(c).

Figure 6 shows the morphology of corrosion products after three months of exposure (January–March). The corrosion products comprised mainly of lepidocrocite. The globular and flowery (plates) lepidocrocite were shown in Figures 6(a) and 6(b), as indicated with labels A and B.

Figure 7. The morphology of corrosion product after four months exposure (January to April): (a) bird's nest and globular types of lepidocrocite; (b) bird's nest and sandy lepidocrocite; (c) plates of bird's nest (A) lepidocrocite and cotton ball goethite (B).
respectively. It was found that the whisker goethite [20] emerged on the surface of globular lepidocrocite [20] as shown in Figure 6(b). Some features, such as worm nest and bird’s nest lepidocrocite, were not found on the surface of the specimens. Heavy rain during wet-season (October–April) might have cleaned the corrosion products and was responsible for the loss of these features [21].

The corrosion products for January–April period of exposure are shown in Figure 7. It shows a typical bird’s nest and globular lepidocrocite (Figure 7(a)). The image in Figure 7(a) was obtained from a different spot than that in Figure 7(b). The bird’s nest and sandy lepidocrocite were found on another spot of observation as indicated in Figure 7(b). Figure 7(c) shows magnification of bird’s nest lepidocrocite labeled as A in Figure 7(a). Cotton ball goethite, 5–25 μm in size, can be observed emerging from bird’s nest lepidocrocite.

After five months of exposure, various forms of corrosion products can be found as shown in Figure 8. The observation spot in Figure 8(a) is the same as in Figure 7(a) to ensure consistent observation of the morphological evolution of the corrosion products. In this period, the

| Iron oxide | Chemical | Crystal structure | Morphology | Reference |
|------------|----------|-------------------|------------|-----------|
| Goethite   | α-FeOOH  | Orthorhombic      | Acicular   | [8]       |
|            |          |                   | Star (twin), hexagons, bipyramids, cubes, thin rods |          |
|            |          |                   | Cloud-like, thin and flat sheet, cotton balls, tiny rods, nest-like honeycomb | [5, 19] |
|            |          |                   | Needle-shaped, filiform, whiskers, star-like, prismatic | [20]     |
| Akageneite | β-FeOOH  | Monoclinic        | Somatoids, Rods |          |
|            |          |                   | Stairs, crosses (twin), hexagons, prisms |          |
| Lepidocrocite | γ-FeOOH | Orthorhombic | Laths |          |
|            |          |                   | Tablets, plates, diamonds, cubes |          |
|            |          |                   | Thick plates, sandy, thick sheet | [5, 19] |
|            |          |                   | Laminar, globular, sandy grain, worm nest, bird’s nest, feather or broken glass | [20]     |
| Feroxyhyte | δ-FeOOH  | Hexagonal         | Plates    |          |
|            |          |                   | Needles   |          |
|            |          |                   | Flowery, bent plates |          |
| Magnetite  | Fe₃O₄    | Cubic             | Octahedra |          |
|            |          |                   | Intergrown octahedral (twins), rhombo dodecahedra, cubes, spheres, bullets |          |
|            |          |                   | Flat and dark layer, circular grain, donuts |          |
|            |          |                   | Blackish circular rings |          |
| Hematite   | α-Fe₂O₃  | Hexagonal plates  | Spindles, rods, ellipsoid, cubes, discs, spheres, double ellipsoids, stars, bipyramids, peanut |          |
|            |          |                   | -         |          |
|            |          |                   | -         |          |
| Maghemite  | γ-Fe₂O₃  | Cubic             | Laths or cubes |          |
|            |          |                   | Plates, spindles |          |
|            |          |                   | -         |          |
worm nest lepidocrocite features (B) had emerged next to the bird’s nest type (A). The size of the globular lepidocrocite had grown after five months of exposure (as compared to previous months as shown in Figure 7). Figure 8(b) shows the corrosion products on another spot on the specimen. The worm nest (B), globular (C) and plates (D) types of lepidocrocite, and whiskers (E) type of goethite were observed. In Figure 8(c), another form of corrosion product was also observed, i.e., whiskers goethite (F) on the surface of globular lepidocrocite. An unknown bar shape (G) also appeared which may have been bacteria or microbes [20].

Figure 9 shows the morphology of corrosion products after six months of exposure (January to June). The bird’s nest (A) and worm nest (B) lepidocrocite were observed as in previous months. However, the size of these features seemed smaller. It is possible that these features were swept away by the rains since Banda Aceh experiences rainfall all year round with varied degree, even during the dry season (May–September) [21].

The cotton ball goethite (C) was also found on the specimen. Figure 9(b) clearly shows bird’s nest lepidocrocite feature. The worm nest and bird’s nest lepidocrocite as well as unknown star-like shape (Figure 9(c)) were also observed on the specimen. The unknown star-like phase could be bacteria or microbe [20].

The morphology of corrosion products after seven months of exposure is given in Figure 10. The bird’s nest (A) and worm nest (B) lepidocrocite were shown in Figure 10(a). The size of the phases had grown slightly bigger from the previous month. Other morphologies were also observed on the specimen, as seen in Figure 10(b). The thick plates (the beginning of toroidal formations) (C) and globular (D) lepidocrocite were found on the specimen. Another bird’s nest (A) lepidocrocite was also found on another spot of the specimen (Figure 10(c)).

The morphologies of corrosion products after eight months of exposure were still mainly lepidocrocite and small amounts of goethite (Figure 11). The size of the laths of the bird’s nest (A) and worm nest (B) lepidocrocite had grown further compared to the previous month, as seen in Figure 11(a). Figure 11(a) also indicates whisker goethite on the surface of globular lepidocrocite. The plates (flower-like) (C) and bird’s nest (A) lepidocrocite were also found on another spot, as shown in Figure 11(b). The cotton ball goethite and globular lepidocrocite were also observed as seen in the figure. Figure 11(c) shows the bird’s nest (A) lepidocrocite and cotton ball (D) type of goethite on another spot of the specimen.

Figure 12 shows the corrosion products after nine months of exposure. The phases found were the same as in the previous month which are the bird’s nest (A) and worm nest (B) lepidocrocite (Figure 12(a)). However, it seems that the cotton ball type of goethite can be located on the laths of lepidocrocite. The worm nest (B) and bird’s nest (A) lepidocrocite can also be found on another spot of the specimen as seen in Figure 12(b). The needle-shaped goethite (C) was also found in the same spot. In addition, the unknown grass-like feature (D) was found as seen in Figure 12(b).

| Elements | C   | Si   | Mn   | P    | S    | Ni   | Cr   | Mo   | Co   | Al   |
|----------|-----|------|------|------|------|------|------|------|------|------|
| Composition | 0.310 | 0.062 | 0.729 | 0.002 | 0.010 | 0.049 | 0.051 | 0.029 | 0.019 | 0.014 |

Figure 9. The morphology of corrosion product after six months exposure (January to June): (a) bird’s nest (A) and worm nest (B) lepidocrocite, and cotton ball (C) goethite; (b) laminar (bird’s nest type) lepidocrocite; (c) worm nest and bird’s nest types of lepidocrocite, and unknown star-like shape.
The corrosion products after 10 months of exposure are shown in Figure 13. The small amount of bird’s nest lepidocrocite (A), bar (B) and plates (C) lepidocrocite were shown in Figure 13(a). The laths of lepidocrocite had grown thicker and transformed into the bar or plates type. The complete toroidal formation (D) of lepidocrocite was found in another location on the specimen, as seen in Figure 13(b). The globular lepidocrocite (E) and whiskers goethite (F) were found inside the toroidal formation. Figure 13(c) shows the bar lepidocrocite with needle-shaped goethite on its surface, while Figure 13(d) shows the globular lepidocrocite with needle-shaped goethite on the surface.

The morphology of corrosion products after 11 months of exposure can be seen in Figure 14. The bar lepidocrocite was dominantly found as seen in Figure 14(a). A considerable amount of corrosion products might have been swept away by heavy rain during this period (November), leaving only bar lepidocrocite the only remaining feature. Magnification on the bar lepidocrocite shows that the needle-shaped goethite already emerged on the surface of lepidocrocite as shown in Figure 14(b). Furthermore, the worm nest, small amount of bird’s nest and plates (toroidal formations) lepidocrocite were obtained on another location of the specimen (Figure 14(c)). Moreover, the cotton ball goethite features can be observed to have grown on the lath of lepidocrocite as seen in Figure 14(d).

Figure 15 shows the morphology of corrosion products after a year of exposure (January to December). Again, the corrosion products might have been swept away by heavy rain like the previous month. However, the figure shows worm nest and bar lepidocrocite as in the previous month. The needle-shaped goethite can be observed on the surface of bar lepidocrocite as shown in Figure 15(b). Moreover, it was found that the initiation of toroidal formations also occurred on the surface of specimen (Figure 15(c)). The globular lepidocrocite and needle-shaped goethite on

Table 3. The relative corrosion resistance category of carbon steel [23].

| Relative corrosion resistance | Approximate metric equivalent |
|------------------------------|-------------------------------|
|                              | mpy                           | mm/yr |
| Outstanding                  | <1                            | <0,02 |
| Excellent                    | 1-5                           | 0,02-0,1 |
| Good                         | 5-20                          | 0,1-0,5 |
| Fair                         | 20-50                         | 0,5-1 |
| Poor                         | 50-200                        | 1-5 |
| Unacceptable                 | 200+                          | 5+ |
Figure 11. The morphology of corrosion product after eight months exposure (January to August): (a) worm nest (B) and bird's nest (A) lepidocrocite; (b) plates (C) and bird's nest (A) lepidocrocite; (c) bird's nest (A) lepidocrocite, and cotton ball (D) goethite.

Figure 12. The morphology of corrosion product after nine months exposure (January to September): (a) bird's nest (A) and worm nest (B) lepidocrocite; (b) bird's nest (A) lepidocrocite, worm nest (B) lepidocrocite, needle-shaped (C) goethite, and unknown grass-like feature (D).
the surface of globular lepidocrocite were also found in the figure. Magnification on the lepidocrocite's surface confirms the formation of the whiskers or needle-shaped type of goethite.

3.3. The observation of corrosion products using XRD

Corrosion product on the surface of carbon steel consists of various oxides as a result of the reaction between iron (Fe) and its surrounding. XRD and Raman spectroscopy are well-known methods to study corrosion products [2, 3, 5, 6, 7, 20]. In this study, the XRD technique was used to further characterize the corrosion products.

Figure 16 shows the XRD pattern corresponding to the corrosion products on the surface of the specimen. The pattern for the six-months period and 12-months period of exposure were labeled as A and B, respectively. For label A, the first highest peak occurred at the angle 2θ of 14.33°, and it corresponded to the corrosion product of lepidocrocite. The second highest peak occurred at the angle 2θ of 26.97°, and the corrosion product was also lepidocrocite. The third highest peak corresponded to goethite phase that occurred at angle 2θ of 36.33°. Hence, the corrosion products after six months exposure were mainly lepidocrocite and goethite. This result confirmed the morphology of corrosion products shown in Figure 9.

The XRD pattern with label B indicates that the lepidocrocite was formed corresponding to the first highest peak at angle 2θ of 14.05°. The lepidocrocite and goethite are indicated by the second highest peak at the angle of 2θ of 27.01° and the third highest peak at the angle of 2θ of 36.31°, respectively. This result confirmed that the dominant corrosion products for carbon steel exposed in Banda Aceh's atmosphere were lepidocrocite and goethite as shown in Figure 15.

4. Discussion

The corrosion products produced during the atmospheric corrosion in this study were lepidocrocite and goethite. The most common morphologies are bird's nest, worm nest and globular lepidocrocite, as well as cotton ball goethite. The earliest morphology to appear and stayed persistently during the whole exposure period were bird's nest and globular lepidocrocite, and cotton ball goethite. This is consistent with a report by Yamashita et al. [28] and Antunes et al. [3] that lepidocrocite and goethite dominates early period of atmospheric corrosion.
The corrosion products then diversified after longer exposure time. Flowery and bar lepidocrocite, cloud, needle, and whiskers goethite appeared as exposure went on. Bar lepidocrocite and unknown features such as spiky, star shapes in Figure 9(c) and Figure 12(b) appeared near the end of exposure period, while needle goethite appeared more often during the end of exposure period.

Arrangements of corrosion products also confirm previous finding, such as worm nest and bird’s nest lepidocrocite found next to each other [20]. New arrangement was also found in this study: cloud-like goethite was observed among the plates of lepidocrocite (Figure 5(c)).

As mentioned, corrosion products properties may determine corrosion rate [9]. It is possible that the morphology of the corrosion products alters the surface of the material (specimen), and ultimately influences other factors such as Time of Wetness as well as corrosion kinetics. However, rigorously validated atmospheric dataset (such as rainfall, humidity) are needed to test this hypothesis and to find correlation between ambient conditions, morphological evolution of the corrosion products, and corrosion rate.

4.1. Limitation

The SEM images were obtained from random spots on the surface of the specimens. Three samples were taken for each period. Due to the changing nature of the surface, some morphologies and features may have been overlooked. However, the sampling yielded consistent observation of features.

5. Conclusions

The corrosion rate and characteristics of corrosion products of carbon steel due to exposure in the environment of Banda Aceh, Indonesia has been studied. The corrosion rate calculation was performed based on the weight-loss method. The observation of corrosion products was accomplished using SEM and XRD. The results show that the highest corrosion rate was 0.024 mpy and occurred during the period of March–April. Based on the corrosion rate, the relative corrosion resistance of carbon steel in Banda Aceh's environment falls into the outstanding category.
The corrosion products observed were mainly lepidocrocite and goethite. It was found that lepidocrocite formed in the early period and later transformed into goethite. The most common forms of morphology found was bird’s nest and worm nest lepidocrocite. Needle-shaped goethite was found during early period of exposure and became more common at the later stage. However, further study needs to confirm this finding since high precipitation might have influenced the corrosion product persistence and transformation.

Declarations

Author contribution statement

S. Fonna: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Israr Bin M. Ibrahim: Analyzed and interpreted the data; Wrote the paper.

Gunawarman: Analyzed and interpreted the data.

S. Huzni: Conceived and designed the experiments; Analyzed and interpreted the data.

M. Ikhsan: Performed the experiments.

S. Thalib: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article-supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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