Atmospheric Corrosion Assessment of Structural Steel Exposed in The Environment of Palm Oil Processing (PKS) Industry Around Coastal Zone

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Abstract. Corrosion is the main cause of mature failures for infrastructure such as residential, public facilities, and also industries. Regarding of industry which having a rapid growth in the province of Aceh, especially Palm Oil Processing (PKS), the existence must be noticed in line with the environmental impact that caused by operations such as industrial gases which can be polluted the atmosphere. This condition can transform the infrastructure especially steel which is located around PKS becomes more vulnerable to the corrosion attacks. This study aims to investigate the corrosion atmospheric of structural steel in the PKS area and operational impacts for the infrastructure of PKS at PT. Ensem Sawita and PKS PT Anugerah Fajar Rejeki(AFR). Infrastructure corrosion is focused on measuring atmospheric corrosion rate of structural steel surrounding PKS area. Several types of steels will be selected as a specimen. The corrosion rate is calculated with mass-loss method referring to ASTM G50 standard. The location of selected PKS is around ± 5km from the coast. The results are obtained after exposure during 4 months, the corrosion rate that occurs for 5 types of structural steel was in normal level. It is classified in the outstanding level of relative corrosion resistance (<1mpy). So, the usage of 5 types structural steel is relatively safe on palm industries and related areas.

1. Introduction

Aceh is an area which has many Palm Oil Processing (PKS) industries. The industries mostly located in every area of Aceh. In addition, it has positively contributed in terms of local society and labor absorption. PKS industry also has a negative impact namely environmental damage. For instance,
Corrosion atmospheric occurred and led to producing exhaust gases (exhaust fumes) which contributed from the PKS.

Corrosion is the main contributory factor for the early failures on many stuff and infrastructure due to being in a corrosive operating environment [1], [2], [3], [4]. Corrosion can be caused by direct or indirect damage [1], [5]. Direct losses are the amount of costs incurred to replace corrosion-damaged equipment, while indirect losses from corrosion include: stopped of factory operations, reduced production, reduced efficiency, etc.

Research on long-term atmospheric corrosion of mild steel [6], observes the process of long-term atmospheric corrosion after 13 years of use in five regions of Spain with different atmospheric types: rural, urban, industrial, light severe ocean-atmosphere using X-ray diffraction method (XRD) and scanning electron microscope/energy dispersive spectroscopy (SEM/EDS). Research on atmospheric corrosion of carbon steel has also been conducted in Colombia [7], observing this atmospheric corrosion using X-ray diffraction (XRD), SEM and EDS. The purpose of the study was to determine the effect of the amount of chloride ions and SO2 as well as the time of wetness of various atmospheric types in Colombia. The investigation of atmospheric corrosion product also has been conducted by [8] in Banda Aceh, Indonesia and show that corrosion products consist of lepidocrocite and goethite.

If the corrosion occurs due to the active substances that come from the surrounding air, then this corrosion is called atmospheric corrosion. Active substances that can primarily because atmospheric corrosion is pollutants from burning fossil fuels (such as SO2) that are common in urban areas, and many chloride ions contained in the air of marine areas. In rural areas, although pollutant levels are low (or with no count), atmospheric corrosion can be caused by water vapour, oxygen and carbon dioxide [9] produced by industry, for example, PKS industry

In the operation of PKS, one of the activities in environmental management is to measure and to monitor air emissions. The use of boilers with fuel in the form of fibers and palm shells should be in accordance with emission quality standards that issued by the ministry of environment sector. So, it can reduce the impact of atmospheric corrosion in areal of PKS and related areas.

This study aims to investigate the corrosion atmospheric of structural steel in the PKS area and operational impacts for the infrastructure of PKS, i.e. PT. EnsemSawita and PT. AFR.

2. Methodology

2.1. Set Up and Measurement of Atmospheric Corrosion Rate

The research was conducted in two locations, namely PT.EnsemSawita (ES) and PT. Anugerah Fajar Rejeki (AFR), both locations are adjacent to the coastal area of ± 5 km.

The measurement of the atmospheric corrosion rate can be done by two methods, depending on the perspective in determining atmospheric corrosion, whether from the material perspective or from the factors causing it. The first perspective-based test involves the specimen directly, by measuring the mass loss that airborne corrosion can cause in an environment. This method involves the exposure of the sample material in the open air until the sample material is corroded. Samples of this material are usually cut in practical forms called coupons. Over time the specimen will experience depletion due to mass loss. Measurements of mass loss within specified time intervals (per day, week or month, depending on the corrosion rate visually) are performed, and atmospheric corrosion rates at those sites, for tested metals, can be determined and represented in units of penetration per year (eg mils per year or millimetres per year), through the following equation (ASTM G 50) [10]:

\[
\text{Corrosion Rate} = \frac{(K \times W)}{(A \times T \times D)}
\]

where:
\(K\) = constant conversion rate of corrosion rate unit
\(W\) = loss of mass, (grams)
\(A\) = surface area, cm²
T = exposure time, hour
D = density, g / cm$^3$

Figure 1. (a) Research Sites at PKS, (b). PT.EnsemSawita, (c). PT.AFR (source: Google. Maps)

Figure 1 depicts the location of the study. The standard for this method is ASTM G 50 or ISO 8565. This method is called the exposure test. Furthermore, based on the data of the corrosion rate obtained from equation (1), it can be determined the relative corrosion resistance (relative corrosion resistance), with reference to Table 1. for each type of exposed specimen.

| Relative Corrosion resistance | Approximate Metric Equivalent |
|-------------------------------|-----------------------------|
|                               | mpy | mm/year | μm/yr | mm/yr | pm/sec |
| Outstanding                   | < 1  | < 0.02  | < 25  | < 2   | < 1    |
| Excellent                     | 1 - 5 | 0.02 -0.1 | 25 - 100 | 2 - 10 | 1 - 5   |
| Good                          | 5 - 20 | 0.1 - 0.5 | 100 - 500 | 10 - 50 | 5 - 20  |
| Fair                          | 20 - 50 | 0.5 - 1 | 500 - 1000 | 50 - 100 | 20 - 50 |
| Poor                          | 50 - 200 | 42125 | 1000 - 5000 | 150 - 500 | 50 - 200 |
| Unacceptable                  | 200+ | 5+      | 5000+ | 500+  | 200+   |

2.2. Materials and equipment

2.2.1. Material

Test specimens consist of important and often used of steel samples i.e. strip steel, elbow steel, plate steel, cylindrical steel and low carbon steel type SAPH 620 with carbon composition of 0.06-0.15 and 4 mm thickness often used in MCC industry. Each specimen is ± 4 mm plate and consists of 3 (three) pieces for each type of test specimen placed in each test site. The size of the test specimen is based on
ASTM G 50 standard. Table 2 demonstrates the dimension of test specimen while Figure 2 shows the test specimen in the test rack used at the research locations.

Table 2. The dimension of Test Specimen

| No. | Specimens         | Dimensions (mm) | Total |
|-----|-------------------|-----------------|-------|
|     |                   | Length | Width | Thickness | Diameter |
| 1   | strip steel       | 150    | 48    | 4         | 6        |
| 2   | elbow steel       | 150    | 100   | 3         | 6        |
| 3   | cylindrical steel | 150    |       | 22        | 6        |
| 4   | plate steel       | 150    | 100   | 4         | 6        |
| 5   | low carbon steel  | 150    | 100   | 4         | 6        |
|     | Total of Specimens|        |       |           | 30       |

Figure 2. Test specimens in the Test Rack (PT. AFR & PT. ES Locations)

2.2.2. Equipment

The equipment used in the process of this research are: rack placement of test specimens, digital scales with an accuracy of 0.001 grams, cleaning reagents and cleaning equipment specimens such as containers, gloves, brushes, etc. that will be used when the test specimen cleaning schedule and weight loss data from the test specimen.

2.2.3. Research procedure

Research begins with literature studies on atmospheric corrosion, the factors that influence it, the harm, the cause and the method of measurement. Field surveys are then conducted to determine the exact location to test exposure. Determination of the location of this test is also based on the ASTM G 50 standard. Based on data from literature studies and field surveys, problem formulation is made for this study. From a variety of problems set the scope of the problem. Then set the objectives of the study. Based on research objectives formulated hypotheses for research to be executed.

In this study, it uses exposure testing methods with the perspective that atmospheric corrosion rates are determined through the material itself in the form of penetration per year. Exposure testing is considered to be more practical both in terms of implementation and results obtained. The exposure test considers only the mass loss variables, assuming that all atmospheric corrosion factors are represented in the form of mass loss. The measurement of atmospheric corrosively is done through exposure testing based on the ASTM G 50 standard.
3. Results and Discussion

3.1. Corrosion Rate of Strip Steel

The corrosion rate of strip steel in two research sites including PKS of PT EnsemSawita and PKS PT Anugerah Fajar Rezeki can be explained as follows, that is in Figure 3. Corrosion rate on strip steel after exposure for 4 months showed that the highest corrosion rate occurred at the location of Palm Oil Factory PT Anugerah Fajar Rejeki and occurred in the third month of exposure that is 0.62 mpy. While the lowest corrosion rate occurred at the location of PKS EnsemSawita reached 0.14 mpy in the 4th-month exposure. Differences in the rate of corrosion that occurs between the 2 (two) locations of the PKS is more due to the conditions of rainfall, humidity and the direction of the wind. In the location of the PT EnsemSawita, the installation of specimens on the test rack is located east of the factory, while at the location of PT Anugerah Fajar Rezeki, test specimens mounted on the test rack are placed to the west of the factory. This condition causes the difference in corrosion rate on the steel specimen because influenced by the direction of the wind that occurs at the test site.

![Figure 3. The corrosion rate of Strip steel in the research location](image)

Seeing the rate of corrosion is still very slow and is on the permissible threshold in accordance with Table 1. That is still below 3 mpy, the corrosion rate ranges between 0.14-0.62 mpy. So, it can be concluded that the use of strip steel for steel construction both for PKS itself and also for construction of settlement of population still very feasible to be used.

3.2. Corrosion Rate of Elbow Steel

The corrosion rate occurring in elbow steels at 2 (two) research sites in PT Ensem Sawita and PT Anugerah Fajar Rejeki after placement of specimen for 4 months on the test rack in open field in PKS industry environment can be explained as follows. The highest corrosion rate occurred at the location of PKS test of PT Anugerah Fajar Rezeki that is 0.55 mpy and happened in third month of test specimen in exposure in field, whereas lowest corrosion rate happened at the test location of PKS PT Ensem Sawita that corrosion rate only reaches 0.14 mpy in the fourth month on exposure in the field (Figure 4).

The corrosion rate occurring in the two different locations is still below the threshold in accordance with the description in Table 1 above. The average corrosion rate occurring in elbow steel is smaller than the corrosion rate occurring on strip steel. The influence of moisture, temperature and rainfall that occurred causing the fluctuation of corrosion rate happened at two locations. In PT Anugerah Fajar Rejeki, corrosion rate that happened higher caused by rainfall and wind direction happened at that location. This condition is also caused because the location of the exposure is also adjacent to the coast which is still within a radius of ± 5km from the coast.
3.3. Corrosion Rate of Cylindrical Steel

Figure 5 shows the graph of the corrosion rate of cylindrical steel to the research location. After the placement of the specimen for four months at the research site in PT Ensem Sawita and PT Anugerah Fajar Rezeki, the highest corrosion rate data was obtained at the location of PT Anugerah Fajar Rejeki which reached 0.40 mpy and the lowest corrosion rate occurred at location of PT Ensem Sawita which was 0.10 mpy and happened in the fourth month of specimen at exposure at research location.

While in the first month conducted exposure, corrosion rate that occurs is still very low at the location of PT Ensem Sawita that corrosion rate of 0.17 mpy and at the location of PT Anugerah Fajar Rezeki, the corrosion rate of 0.26 mpy. The corrosion rate occurring in the first month is almost equal to the rate of corrosion rate occurring in the fourth month of test specimens in the exposure. The low rate of corrosion rate occurring in the first and fourth months due to climate influence is not too extreme. Humidity, temperature, rainfall and wind direction are more stable than the second and third months of exposure at the research site.

3.4. Corrosion Rate of Plate Steel

Figure 6 shows the graph of the corrosion rate of plate steel in the study. After the placement of the specimen for four months at the research site in PT Ensem Sawita and PT Anugerah Fajar Rezeki, the highest corrosion rate data obtained at the location of PT Anugerah Fajar Rejeki reached 0.51 mpy in the fourth month of the specimen in the field exposure. And its lowest corrosion rate occurred at the location of PT Ensem Sawita is 0.10 mpy which also occurred in the fourth month of the specimen at the exposure
at the research location. The climatic conditions in the fourth month of the test specimen in the field exposure are relatively stable and not extreme.

While in other months of exposure, the corrosion rate that occurs on the steel plate looks stable and still far below the limits of the desired corrosion rate. That is the corrosion rate occurred only ranged from 0.18-0.24mpy for research location in PT Anugerah Fajar Rejeki and 0.16-0.18mpy for research location in PT EnsemSawita. For research location of PT EnsemSawita, corrosion rate which happened in steel plate is lower and stable compared to strip steel, elbow steel and cylindrical steel, while at research location of PT EnsemSawita corrosion rate which happened at steel plate seen higher than that of elbow steels and close to the level of corrosion rate occurring in cylindrical steel. The low corrosion rate occurring in the first and fourth months due to climate influence is not too extreme. Humidity, temperature, rainfall and wind direction are more stable compared to the second and third months of exposure at the study sites.

Figure. 6. The corrosion rate of plate steel in the research location

3.5. Corrosion Rate of Low Carbon Steel

Figure 7 shows the graph of the corrosion rate that occurs in low carbon steel that almost equal to the rate of corrosion which occurs in the steel plate. The highest level of corrosion rate occurring at the research site of PT Anugerah Fajar Rezeki reached 0.34mpy in the fourth month of exposure, while the lowest corrosion rate occurred in the first month of low carbon steel specimen in the exposure of 0.17mpy. While corrosion rate occurred at research location of PT EnsemSawita, the highest value of its corrosion rate reached 0.28mpy i.e. in the fourth month conducted exposure in the location, while the lowest level of corrosion rate occurred in the second month of the specimen in the exposure at the location that reached 0.16mpy.

Figure. 7. The corrosion rate of low carbon steel in the research location
3.6. **Comparison of Corrosion Rate of Structural Steel**

Figure 8 and 9 indicate the degree of difference in corrosion rates occurring of the 5 types of steel used in the atmospheric corrosion testing after the placement of the test specimen at the research location in the PT EnsemSawita and PT AFR for four months. The comparison of corrosion rate can be explained as follows:

3.6.1. **Corrosion Rate Level of Structural Steel in PT EnsemSawita**

Figure 8. The corrosion rate occurring of 5 types of steel exposed for 4 months at the study site indicated that the highest corrosion rate occurred on strip steel reaching 0.31mpy in the first month of exposure. And the level of corrosion rate of strip steel is always higher than other types of structural steel until the third month of research. Entering the fourth month, it shows a lower corrosion rate than the previous months of 0.14. While the lowest rate of corrosion occurred for elbow steel which only reached 0.06mpy in the fourth month conducted exposure at the research location. The average of corrosion rate occurring on the elbow steel for 4 months in exposure is always lower compared to other types of structural steel.

For low carbon steel, its fluctuating corrosion rate is in the first month conducted exposure at the location of the research rate of corrosion rate of 0.18mpy and slightly decreased in the second month of the exposure of 0.16mpy. Entering the retrieval of exposure data at the end of the third month, the rate of corrosion of low carbon steel increased again to 0.21mpy and continued to increase until the end of the third month of exposure of 0.28mpy.

For the five types of structural steel that have been studied for 4 months at the location of PT EnsemSawita, shows the corrosion rate that occurs is in the range between 0.06–0.31mpy. This indicates that the relative corrosion resistance of these steels can be classified in the outstanding category (<1mpy). And the most corrosion-resistant structural steel that found in this research is elbow steel type that exposed at PT EnsemSawita.

3.6.2. **Level of Corrosion of Steel Construction in PKS PT AFR**

Figure 9 shows the corrosion rate occurring for 5 (five) types of construction steel which have been exposed for 4 (four) months in the research location and it shows a similar trend to the location of PT EnsemSawita. The highest rate of corrosion still occurs for strip steel type reaches 0.62mpy in the third month of the specimen in exposure. And the rate of corrosion of strip steel is always higher than other types of structural steels in the first month and the second test specimen is exposed at the research location. In the fourth month, the specimens showed a lower corrosion rate compared to the previous
months of 0.24mpy and also lower than the corrosion rate occurring for the plate steel and low carbon steel.

The lowest level of corrosion rate also occurs for elbow steel type and it's the same as the location of PT EnsemSawita which only reach 0.16mpy in the fourth month done exposure at the research location. However, during the first month until the third month of exposure, the rate of corrosion occurring for the elbow steel is higher than other types of steel and is almost equivalent to the rate of corrosion occurring for the strip steel. While the level of corrosion rate that occurs for plate steel continues to increase starting from 0.18mpy in the first month to 0.51 at the end of the fourth month conducted exposure. For cylindrical steel and low carbon steel, corrosion rate that occurs for 4 (four) months exposure, looks more stable and can be seen in figure 9.

![Corrosion Rate Chart](image)

Figure. 9. The corrosion rate of structural steels at PT. AFR

4. Conclusion
The results showed that the corrosion rate that occurred on the structural steel with 5 types of steels and exposure for 4 months in two research sites were stripped steel 0.14–0.31mpy and 0.24–0.62mpy respectively for the location of PT EnsemSawita and PT AFR. While for elbow steel, corrosion rate ranges 0.06–0.10mpy at PT ES and 0.16–0.56mpy at PT AFR. For cylindrical steel were 0.10–0.21mpy for PT ES and 0.18–0.40mpy for PT AFR. And for plate steel were 0.10–0.18mpy for PT ES and 0.18–0.51mpy for PT AFR and for low carbon steel were 0.16–0.21mpy and 0.17–0.34mpy, respectively for research location at PT EnsemSawita and PT AFR.

After 4 months of exposure, the corrosion rate of 5 types of structural steel is classified into the category of outstanding (<1mpy). So that the use of 5 types of steel is relatively safe within that palm oil processing (PKS) industries and surrounding residential areas.

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