Study of Atmospheric Corrosion of Structural Steel Surrounding the Palm Oil Industry in The Region of Eastern Coastal and Northern Aceh

Banta Cut [1*], Muhammad Zulfri[1], Syarizal Fonna[2], Syifaul Huzni [2] , Ferry Safriwardy[3], Abdul Rahman[3], Budi Istana[4]

[1]Program Studi Teknik Mesin, Universitas Samudra, Meurandeh - Langsa 24416, Aceh
[2]Program Studi Teknik Mesin dan Industri, Universitas Syiah Kuala, Banda Aceh, 23111, Aceh
[3]Program Studi Teknik Mesin, Universitas Malikussaleh, Lhokseumawe, 24353, Aceh
[4]Program Studi Teknik Mesin, Universitas Muhammadiah Riau, Pekanbaru, 28294, Riau
E-mail: bantacut@unsam.ac.id *

Abstract

Corrosion is the primary cause of premature infrastructure damage, affecting everything from homes and public spaces to industrial facilities, including the rapidly expanding palm oil industry in Aceh, particularly along its eastern and northern coasts. This rapid growth necessitates careful consideration of environmental impacts, including pollution, which can also degrade air quality. Pollutants increase the susceptibility of steel-reinforced structures to atmospheric corrosion. This research, therefore, investigates atmospheric corrosion of structural steel at several palm oil processing plants: PTPN 1 Tanjung Seumantoh in Aceh Tamiang, PT Ensem Sawita and PT Anugerah Fajar Rejeki (AFR) in East Aceh, and PTPN 1 Cot Girek in North Aceh.This study measures the atmospheric corrosion rate of structural steel typically used in industrial and nearby residential settings. Five steel types were tested: strip, angular, cylindrical, commercial plate, and low-carbon steel. Following the American Standard Testing and Material-G50 (ASTM G50), the mass loss method was used to calculate corrosion rates. After six months of exposure, all five steel types exhibited corrosion rates below 0.7 mils per year (mpy). This result showed that the relative corrosion resistance of structural steel is on outstanding category (<1mpy).

Keywords: *Structural Steel, corrosion rate, ASTM G50, palm oil industry, Aceh coastal region*

1. Introduction

Palm oil production is widespread throughout Indonesia, including Aceh, which in 2016 had approximately 1.19 million hectares dedicated to palm plantations [1]. These plantations are owned by state-owned enterprises (PTPN 1), private companies, and local farmers, leading to a proliferation of processing plants in Aceh. While the palm oil industry has positively impacted local communities through job creation and increased local revenue, it has also generated negative environmental consequences, notably pollution. Waste gases (flue gas) emitted from palm oil processing are a specific type of pollution that can contribute to atmospheric corrosion.

Corrosion is a primary cause of premature equipment and infrastructure failure, particularly in corrosive environments [2] [3]. The resulting losses can be both direct and indirect [4][5], direct losses include the costs of replacing corroded equipment, while indirect losses encompass disruptions like plant shutdowns, reduced production, and decreased efficiency.

Research about 'long-term atmospheric corrosion of mild steel'[6], [7], [8], observed a long-term atmospheric corrosion process after 13 years of using in 5 regions of Spain with the different types of atmospheres with rural, urban, industrial light sea of atmosphere and severe sea atmosphere using the X-ray diffraction (XRD) methods and electron microscopic scanning or energy dispersive X-ray spectroscopy (SEM/EDS). Long-term corrosion is generally more severe in industrial and marine environments than in urban or rural settings. In most cases, corrosion rates decrease and stabilize after the initial 4 to 6 years of exposure. Fuente et al. highlighted important differences in rust layer formation: compaction in rural and urban atmospheres, and the formation of less common hematite and ferrihydrite phases in industrial and marine environments. Morphological analysis typically identifies lepidocrocite (appearing as crystal sand or flat flowers), goethite and akaganeite.

The scientific investigation on atmospheric corrosion of carbon steel have conducted in Kolombia [9], the observation of atmospheric corrosion uses the X-ray diffraction (XRD), SEM and EDS methods. The purpose of this study was to determine the effect from the amount of chloride and SO_2 ions and the time of wetness from various types of atmospheres in Colombia.

Corrosion caused by airborne substances is termed atmospheric corrosion. Key contributors include pollutants from fossil fuel combustion, such as SO2, prevalent in urban areas, and chloride ions, common in marine air. While pollutant levels are generally low or negligible in rural areas, atmospheric corrosion can still occur due to the presence of water vapor, oxygen, and carbon dioxide [10], which can also be by products of industrial activities like palm oil processing.

Figure 1. Infrastructure Corrosion on Industry of PTPN 1 Cot Girek (by research).

Figure 1 illustrates the corrosion and rust formation on industrial equipment, leading to material loss. This study experimentally maps atmospheric corrosion of structural steel around palm oil mills along Aceh's east coast and northern region. The objective was to assess the impact of palm oil processing on corrosion in both industrial and residential areas. The research focuses on four locations: the PTPN 1 Tanjung Seumantoh mill, PT Ensem Sawita, PT Anugerah Fajar Rezeki (AFR), and the PTPN 1 Cot Girek mill.

2. Methodology

2.1. Set Up and Measurement of Atmospheric Corrosion Rate

This research was conducted at four locations in eastern coastal and northern Aceh: the PTPN 1 Tanjung Seumantoh palm oil mill in Aceh Tamiang, the PT Ensem Sawita (ES) and PT Anugerah Fajar Rezeki (AFR) mills in East Aceh, and the PTPN 1 Cot Girek mill in North Aceh.

Figure 2. Research Area (4 locations of PT) at eastern coastal and northern Aceh (by googlemaps).

Atmospheric corrosion rates were determined by directly measuring the mass loss of exposed specimens. This involved placing material samples in open air until corrosion occurred. These samples, typically cut into practical shapes called coupons, gradually thinned due to mass loss. Mass loss was measured periodically (daily, weekly, or monthly, depending on the corrosion rate) to determine the atmospheric corrosion rate of the tested steel. This rate is expressed as penetration per year (e.g., mils per year or millimeters per year) using an equation defined by ASTM G50 [11]:

$$Corrosion\ Rate = (K.W)/(A.T.D) \qquad (1)$$

description:
K = conversion unit for the corrosion rate
W = mass losses, (grams)
A = surface area, cm^2
T = exposure time, hour
D = density, g per cm^3

This method, known as the exposure test, adheres to ASTM G50 or ISO 8565 standards. Corrosion rate data obtained from Equation (1) can then be used to determine relative corrosion resistance by referencing Table 1 for each exposed specimen type.

Table 1.
Corrosion resistance level based on corrosion rate.

Relative Corrosion resistance	Approximate Metric Equivalent				
	mpy	mm/year	µm/yr	nm/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 Tools

a. Materials

The test used samples of commonly employed structural steel, including strip steel, steel plate elbows, 4 mm flat plate steel, cylindrical steel, and 4 mm thick low-carbon SAPH 620 steel (with a carbon content of 0.06 to 0.15), typical in the palm oil industry. Testing adhered to the ASTM G50 standard.

Table. 2.
Dimensions of Test Specimens

No.	Test Specimens	Size (mm)			
		L	W	T	D
1	Strip steel	150	48	4	
2	Elbow steel	150	100	3	
3	Cylinder steel	150			22
4	Steel Palte Market	150	100	4	
5	Low Carbon Steel	150	100	4	

Figure 3. Test Specimens on Measurement Tray (location of palm oil industry of PTPN 1 Tanjung Seumantoh)

b. Equipments

This research utilized several tools, including specimen trays, digital scales with 0.001-gram precision, cleaning reagents, and specimen handling equipment such as containers. These tools were used during specimen cleaning and data collection of weight loss.

2.3. Research procedures

The research began with a literature review on atmospheric corrosion, its influencing factors, resulting damage and drawbacks, and measurement methods. A field survey was then conducted to identify suitable exposure test locations, adhering to ASTM G50 standards. Based on the literature and survey data, the research scope was defined, leading to problem identification and the establishment of research objectives. Finally, a hypothesis was formulated to guide the research

This study employed exposure measurements to determine atmospheric corrosion rates as material penetration per year. This direct measurement method is considered practical for both application and result interpretation. By focusing solely on mass loss, the method assumes that all contributing factors to atmospheric corrosion are reflected in the measured weight reduction. Atmospheric corrosivity was evaluated through exposure testing following the ASTM G50 standard.

3. Results and Discussion

3.1 Corrosion Rate of Strip Steel on Research Location

Figure 4 illustrates the correlation of corrosion levels on strip steel across four locations in eastern coastal and northern Aceh. After six months of exposure, the highest corrosion rate for strip steel occurred at the Tanjung Seumantoh palm oil mill, peaking at 0.60 mpy in the third month. A lower peak of 0.11 mpy was observed at the same location in the fourth month. In the other three locations, corrosion rates for strip steel remained relatively stable and similar throughout the data collection period, except for slight increases in the third and fourth months. The highest corrosion rates among these three locations were observed at PT AFR (0.62 mpy) and PT Ensem Sawita (0.56 mpy).

After the research is conducted during 6 (six) months in four research area, it is showed that the fluctuation of corrosion level is widely occured at tboth times and locations of the research, namely the average of corrosion rate level during 4 months after testing the exposure in research zones.

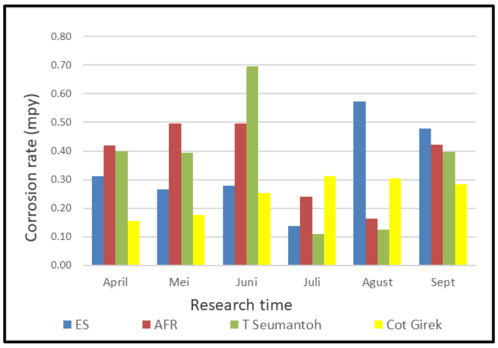

Figure 4. Graph for the relationship between corrosion rate of strips steel with study site

Across nearly all research locations, samples were exposed for six months. As shown in Figure 4, by the sixth month, the corrosion rate of strip steel across all locations stabilized, ranging from 0.28 to 0.50 mpy.

3.2 Corrosion Rate of Plat Elbow Steel on Research Location

Figure 5 illustrates the corrosion rates of elbow steel across the four study areas after a six-month exposure period. The highest corrosion rate (0.55 mpy) was observed at PT Anugerah Fajar Rezeki in the third month. Conversely, the lowest corrosion rate (0.04 mpy) occurred at PTPN 1 Tanjung Seumantoh in the fourth month.

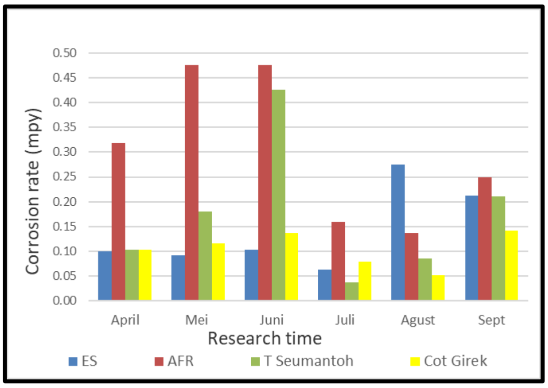

Figure 5. Graph for the correlation of corrosion rate elbow steel on research location

While the highest corrosion rate for elbow steel (0.56 mpy) was observed at the AFR palm oil mill during the third month of exposure, the average corrosion rate for elbow steel was lower than that of strip steel and the other steel types tested. The increased corrosion rates observed in the third month are attributed to the combined effects of humidity, temperature, and rainfall during that period.

3.3 Corrosion Rate of Cylinder Steel on Research Location

Figure 6 presents the corrosion rate correlation for cylindrical steel at the research locations. After six months of exposure, the highest corrosion rates for cylindrical steel, similar to other forms tested, were observed during the third month. This peak is attributed to harsher weather conditions during that month, including increased rainfall and humidity compared to other periods

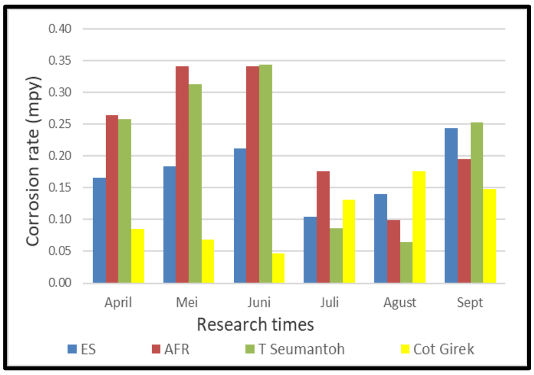

Figure 6. Graph for the correlation of corrosion rate on cylinder steel in the research location

The lowest corrosion rates were observed in the fourth and fifth months of exposure, averaging between 0.08 and 0.18 mpy. While other months also showed higher corrosion levels (peaking in the fourth and fifth months), the rate tended to stabilize across most locations.

3.4 Corrosion Rate of Commercial Plate Steel on Research Location

Figure 7 showed the graph for correlation of corrosion rate on commercial plate steel for each research location.

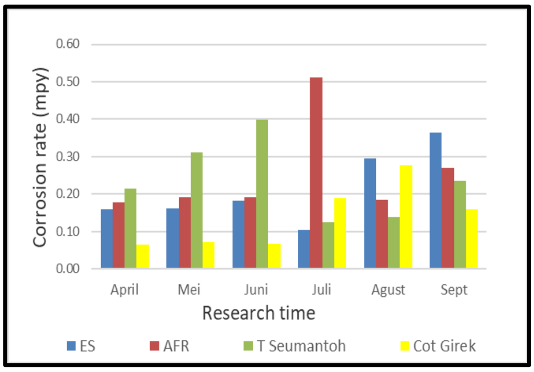

Figure 7. Graph of correlation rate of corrosion rate on commercial plate steel in the research location

After a six-month investigation across four locations, the highest corrosion rates were generally observed in the fourth month of exposure, peaking at 0.51 mpy at PT AFR. The lowest rates occurred in the first month, with a minimum of 0.06 mpy. Corrosion rates in the other locations remained relatively stable. The lower corrosion rates in the first and second months, particularly at PTPN 1 Cot Girek, are attributed to more stable climatic conditions, specifically more consistent humidity and rainfall compared to other months in the same research area.

3.5 Corrosion Rate of Low Carbon Plate Steel on Research Location

Figure 8 described the graph trend for correlation of corrosion rate that occured on low carbon plate steel performed similar profiles with the commercial plate steel.

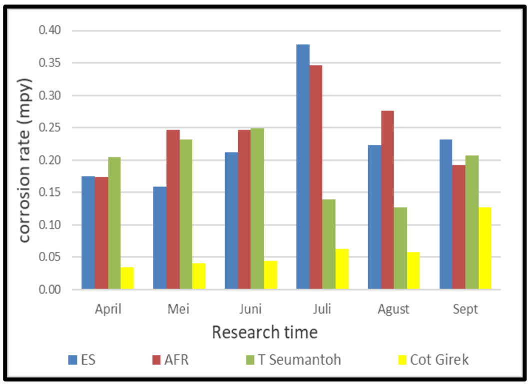

Figure 8. Graph of correlation of corrosion rate on low carbon plate steel in the research location

As shown in Figure 8, the highest corrosion rates were observed in the fourth month of exposure, reaching 0.44 mpy at PT Tanjung Seumantoh and 0.34 mpy at PT AFR. The lowest corrosion level was recorded for low-carbon plate steel at PT Cot Girek, peaking at 0.03 mpy in the first month. Subsequently, at PT Cot Girek, the corrosion rate remained low, measuring 0.04 mpy in the following month and 0.14 mpy in the final (sixth) month of exposure.

3.6 Corrosion Rate of Structural Steel regarding the Type of Metal Steel

The following discussion compares the corrosion rates of the five structural steel types across the four palm oil industry research locations. The corrosion levels observed after the six-month exposure period are as follows:

3.6.1 Level of Corrosion Rate on Structural Metal Steel at PT Tanjung Seumantoh.

Regarding the figure 9 performed that level of corrosion rate which is exposuring on five types of structural metal steel after giving the measurement during 6 (six) months, it performs the highest level of corrosion rate on steel with the strip plate metal and occured at the third month of test specimens and exposured in the research location. In line with the last month after exposuring, metal steel with the strip plate type performed the highest on level of corrosion rate comparing with another type of metal steel.

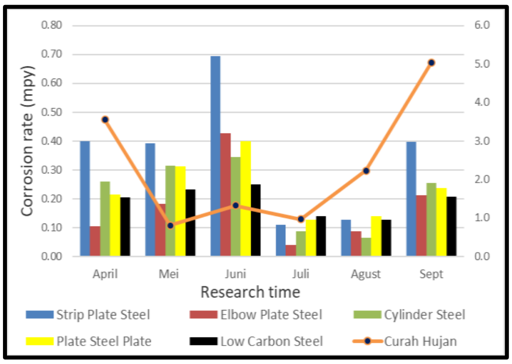

Figure 9. Level of corrosion rate on structural metal steel in PT Seumantoh

Elbow steel exhibited the lowest corrosion rate, reaching 0.03 mpy in the fourth month of exposure at the research sites. As shown in the graphs, elbow steel consistently demonstrated lower corrosion rates compared to the other steel types across all data sampling points.

3.6.2 Level of Corrosion Rate on Structural Metal Steel at PT Ensem Sawita

Figure 10 shows the corrosion rates of the five structural steel types after six months of exposure at the research sites, demonstrating a similar trend to that observed at PT Tanjung Seumantoh. At PT Ensem Sawita, strip steel exhibited the highest corrosion rate (0.58 mpy) in the fifth month, remaining the highest among all steel types at 0.50 mpy. The lowest corrosion rate (0.06 mpy) was recorded for elbow steel in the fourth month. The corrosion rates of the other steel types fell between those of strip steel and elbow steel, consistent with figure 10.

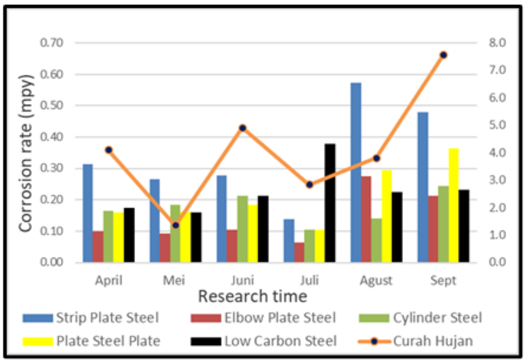

Figure 10. Level of corrosion rate of structural metal steel at PT Ensem Sawita

3.6.3 Level of Corrosion Rate on Structural Metal Steel at PT AFR

As depicted in figure 11, at PT AFR, cylindrical steel experienced the lowest corrosion rate in the fifth month of exposure. Conversely, elbow steel exhibited the lowest corrosion rate in the fourth month, with another low point also observed in the first month of measurement.

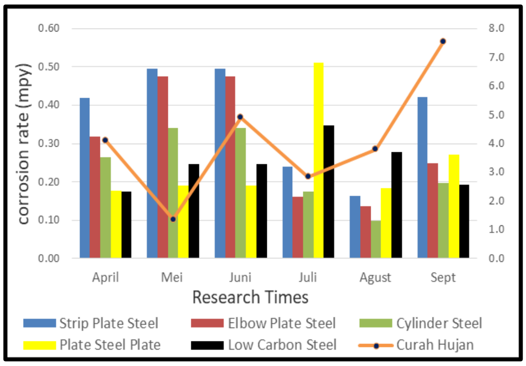

Figure 11. Level of corrosion rate of structural metal steel at PT AFR.

3.6.4 Level of Corrosion Rate on Structural Metal Steel at PTPN 1 Cot Girek

Figure 12 shows that strip steel consistently exhibited the highest corrosion rates across all measurement months. The highest corrosion levels for strip steel were recorded in the fourth (0.32 mpy) and fifth (0.31 mpy) months of exposure. These results for strip steel differ from those observed at the other research locations.

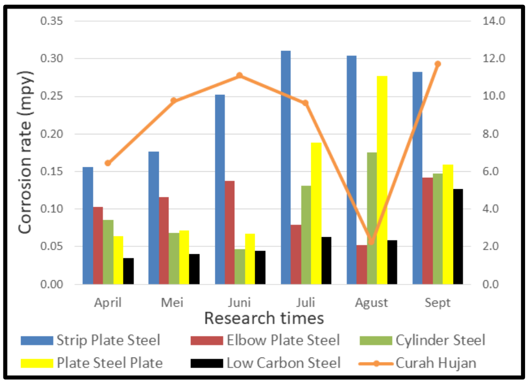

Figure 12. Level of corrosion rate on structural metal steel at PT Cot Girek

Low carbon steel consistently exhibited the lowest corrosion rates, starting at 0.03 mpy in the first month of exposure and remaining the lowest throughout the six-month test period. These rates for low carbon steel ranged from 0.03 to 0.14 mpy. The corrosion rates of the other steel types fell between those of low carbon steel and strip steel.

3.7 Results of Surface Morphology Test on 5 (five) Types of Structural Metal Steel

The following figures present the results of morphology tests conducted on the five structural steel types used as test specimens at the four palm oil industry locations. After six months of exposure, SEM was performed to analyze the surface microstructure of all specimens. Results from two locations, the Cot Girek mill in North Aceh and the Tanjung Seumantoh mill in Aceh Tamiang, are shown. Figure 13 displays corrosion products in the form of lumps on all five steel types after the six-month exposure. This uniform corrosion is caused by electrochemical reactions resulting from atmospheric influences within the palm oil mill environment, with the corrosion products appearing as hollow lumps scattered across the specimen surfaces

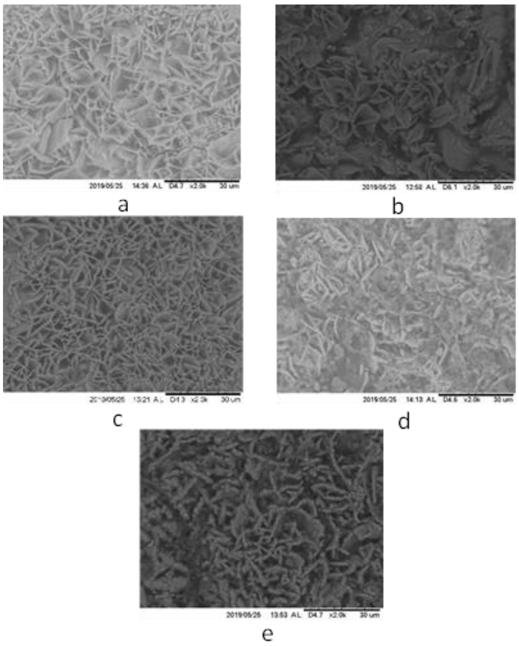

Figure 13. Results of Surface Microstructural Test on five types of Metal Steel using SEM in area of Cot Girek: (a) Strip steel; (b) Elbow steel; (c) Cylinder steel; (d) Plate steel; (e) Low carbon plate steel.

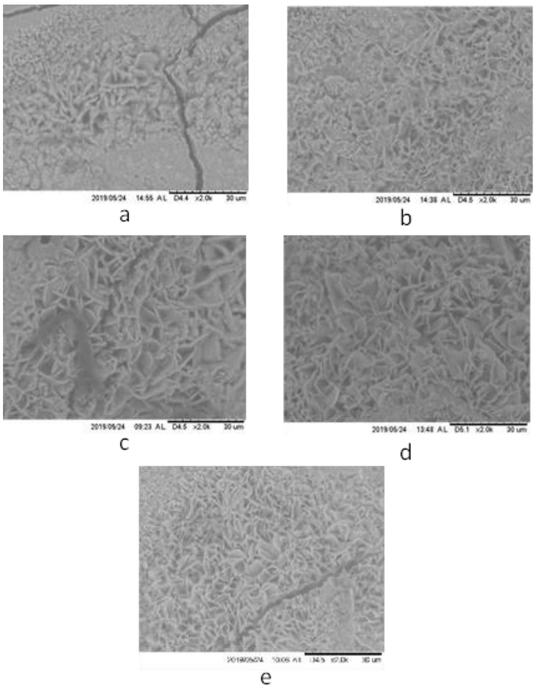

Figure 14. Results of Surface Microstructural Test on five types of Metal Steel using SEM in area of Cot Girek: (a) Strip steel; (b) Elbow steel; (c) Cylinder steel; (d) Plate steel; (e) Low carbon plate steel.

The Tanjung Seumantoh palm oil mill in Aceh Tamiang Regency exhibited similar corrosion patterns to the Cot Girek mill in North Aceh. All five test specimens displayed uniform corrosion, and the resulting corrosion products were similar in appearance. However, the corrosion at Tanjung Seumantoh was more compact and even, unlike the more scattered, lumpy corrosion observed at Cot Girek

4. Conclusion

This study investigated atmospheric corrosion of structural steel in palm oil mill environments over a six-month exposure period. The resulting corrosion rates for the 5 (five) tested steel types are summarized below:

1. Strip steel at the Tanjung Seumantoh industrial site experienced the highest atmospheric corrosion rate, measuring 0.60 mpy in the third month of exposure
2. At the PTPN 1 Cot Girek industrial site, low carbon steel showed the lowest corrosion rate, reaching only 0.03 mpy during the first month of exposure
3. At the Tanjung Seumantoh industrial site, cylindrical steel consistently exhibited the lowest corrosion rates compared to the other steel types throughout the six-month measurement period
4. At the Cot Girek palm oil industry site, strip steel consistently exhibited higher corrosion rates than the other steel types throughout the six-month measurement period.
5. The palm oil mills at PT. AFR and PT. Ensem Sawita, being located closer to the coast, exhibited higher average corrosion rates compared to the other research sites

This study's findings suggest that the structural steel tested maintains excellent corrosion resistance (<1 mpy). Therefore, the use of these five steel types in palm oil industry settings in both eastern coastal and northern Aceh is considered relatively safe.

Daftar Pustaka

1. Huseinhz. Perkebunan Kelapa Sawit di aceh. 2018.
2. Cicek V. Corrosion Engineering. Vol. 9781118720, Corrosion Engineering. 2014. 1–266 p.
3. Lyon S. Overview of corrosion engineering, science and technology. Nucl Corros Sci Eng. 2012;3–30.
4. R. Winston Revie, Uhlig HH. “Corrosion and Corrosion Control”An Introduction to Corrosion Science and Engineering. Vol. 4, Proceedings - Annual Meeting of the Decision Sciences Institute. 1996. 681 p.
5. Pierre R. Roberge. Handbook of Corrosion Engineering [Internet]. Vol. 98, Metal Finishing. 2000. 70 p. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0026057600834455
6. Ridha M, Supardi J, Huzni S, Fonna S. Pemetaan Korosi Atmosferik Logam Struktural di Kawasan Landaan Tsunami Aceh 2004. 2012;(Snttm Xi):16–7.
7. Zulfri M, Ali N, Husaini, Fonna S, Huzni S, Mulyati S, et al. Atmospheric Corrosion Assessment of Structural Steel Exposed in the Environment of Palm Oil Processing (PKS) Industry Around Coastal Zone. IOP Conf Ser Mater Sci Eng. 2019;536(1).
8. de la Fuente D, Alcántara J, Chico B, Díaz I, Jiménez JA, Morcillo M. Characterisation of rust surfaces formed on mild steel exposed to marine atmospheres using XRD and SEM/Micro-Raman techniques. Corros Sci. 2016;110:253–64.
9. Castaño JG, Botero CA, Restrepo AH, Agudelo EA, Correa E, Echeverría F. Atmospheric corrosion of carbon steel in Colombia. Corros Sci [Internet]. 2010;52(1):216–23. Available from: http://dx.doi.org/10.1016/j.corsci.2009.09.006
10. Seuss F, Seuss S, Turhan MC, Fabry B, Virtanen S. Corrosion of Mg alloy AZ91D in the presence of living cells. J Biomed Mater Res - Part B Appl Biomater. 2011;99 B(2):276–81.
11. ASTM International. G50 Standard Practice for Conducting Atmospheric Corrosion Tests on Metals. Astm. 2012;76(Reapproved):1–6.