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Experimental Investigation of the Corrosion Rate of Factory Original Motorcycle Exhausts in NaCl Solution and Natural Seawater

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Abstract-- *Corrosion is a significant factor that decreases the performance and service life of motorcycle components, especially exhaust pipes that are directly exposed to the environment. This study aims to analyze and compare the corrosion rate of factory-made motorcycle exhausts when exposed to two corrosive media: a 3.5 wt% sodium chloride (NaCl) solution and natural seawater. An immersion test was conducted under laboratory conditions for seven days (168 h) using eight AISI 1010 coupons (2 × 2 cm). Four specimens were immersed in seawater, and four in 3.5 % NaCl. After pickling, each coupon was weighed, immersed, cleaned, and re-weighed. Mass loss was converted to a corrosion rate using the gravimetric method and expressed in millimeters per year (mm· year¹). The average corrosion rate in seawater was 4,121.9 mm/year, whereas in 3.5% NaCl it was 71.7 mm/year. The significantly higher rate in seawater is attributed to additional ions, such as magnesium, calcium, and sulfate, that accelerate electrochemical reactions. These findings underscore the importance of adequate surface protection for exhaust pipes, particularly for motorcycles operating in coastal or high-humidity environments, and serve as a basis for developing corrosion-resistant materials or coatings for automotive components.*

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1. INTRODUCTION

Southeast Asia boasts the highest per capita motorcycle ownership rate in the world [1]. In Indonesia, motorcycles are more than just a practical mode of transport—they are a key part of daily life, offering freedom and convenience, especially in busy urban and semi-urban areas. Indonesia broke the sales record of 6,333,310 motorcycles in 2024, indicating that demand for two-wheeled vehicles is expected to continue rising in the future [2]. With a total population of 270.2 million in 2020, approximately 62% of the population in Indonesia resides in coastal areas, meaning about 167.5 million Indonesians live along the coast [3].

However, those living in these areas face a growing issue: the increasing risk of deterioration affecting their motorcycles, particularly metal components such as exhaust systems. The combination of salty sea air and high humidity creates an ideal environment for this process to occur at an accelerated rate. It is a slow yet continuous deterioration of metal materials due to their interaction with the surrounding environment, especially when exposed to corrosive liquids. In coastal areas, chloride ions (Cl^-) in seawater exacerbate the deterioration of metal surfaces, leading to the damage of components, such as those used in motorcycles. In simple terms, metals lose electrons (oxidation) when they react with oxygen and moisture, forming rust, or iron oxide, on the metal surface. High humidity, salt spray, and temperature fluctuations significantly increase the deterioration rate in marine environments. Recent studies have shown that thin electrolyte layers on metal surfaces influence these rates in coastal areas, helping to form microgalvanic cells and accelerate the process.

Furthermore, the type of metal and its microstructure play a crucial role in how well it resists damage. Carbon steels, commonly used in motorcycle components, typically provide limited resistance in harsh environments unless they are properly coated or treated [7]. Liu et al. (2024) observed that steel exposed to a coastal environment in China for one year showed significant damage, mainly due to high salinity and fluctuating humidity [8]. Similarly, Pusparizkita et al. (2023) found that low-carbon steel immersed in artificial seawater showed a significant degradation rate after just 14 days, with products forming on the surface, such as hematite, lepidocrocite, and magnetite [9]. Further research has shown that higher salinity and hydrogen sulfide (H_2S) from decaying algae accelerate the formation of products that cause material thickness loss of nearly 1 mm per year [10]. A review of marine atmospheric deterioration highlighted how compounds like akaganeite contribute to the formation of weak layers that affect the deterioration rate over time [11]. Additionally, research from Colombia showed how factors such as time of wetness (TOW), SO_2 concentrations, and nearby industrial activities can significantly influence steel degradation rates [12]. These findings underscore the need for protective coatings, such as epoxy or ceramic, on motorcycle components, particularly exhaust systems and steel frames, that operate in harsh environments.

AISI 1010, a low-carbon steel, is commonly used in motorcycle parts due to its good formability and affordability. However, this material is particularly susceptible to degradation in harsh coastal environments. Research by Alharbi et al. (2024) revealed that the degradation rate of AISI 1010 is influenced by its microstructure, with finer-grained structures offering better resistance due to enhanced charge transfer [13]. Razak and Ng (2024) discovered that MIG welding techniques can help reduce degradation in 3.5% NaCl environments [14]. Additionally, Kubisztal et al. (2023) investigated the behavior of AISI 1010 in sulfolane solvents and found that higher temperatures accelerate degradation, although product layers may provide some protection [15]. Moreira et al. (2023) found that organic inhibitors such as imidazole and benzimidazole can significantly reduce the degradation rates of AISI 1010, highlighting the effectiveness of chemical protection techniques [16]. Furthermore, Pusparizkita et al. (2023) observed that hematite and magnetite formed on AISI 1010 when immersed in artificial seawater, resulting in considerable degradation rates under humid tropical conditions [17]. These studies reinforce the understanding that despite the advantages of AISI 1010 in terms of cost and manufacturability, this material requires additional protective measures to remain effective in aggressive environments [18].

The objective of this study is to examine how different immersion media influence the degradation rate of AISI 1010 steel, specifically from standard motorcycle exhaust pipes, with a focus on comparing natural seawater to a 3.5% NaCl solution. Additionally, the study aims to explore how ions in seawater, such as Mg^{2+}, Ca^{2+}, and SO_4^{2-}, impact electrochemical reactions on metal surfaces. Furthermore, we will examine how degradation rates evolve, primarily since the products in seawater often do not provide sufficient protection. Our research will also investigate the variation in degradation rates and the likelihood of localized damage (pitting) in samples immersed in seawater, as opposed to those in a saline solution, which tends to cause more uniform damage behavior. The results of this study aim to provide valuable insights into protecting the metal components of motorcycles, especially those that operate in the harsh conditions found in coastal environments.

.2. METHODOLOGY

This study used an experimental method to measure and compare the corrosion rates of AISI 1010 low-carbon steel, sourced from factory-original motorcycle exhaust pipes, when exposed to two corrosive environments: natural seawater and a 3.5% sodium chloride (NaCl) solution. The details of the experimental procedure are shown in Figure 1.

Initially, exhaust pipe specimens were cut into uniform dimensions of 2×2 cm using a metal saw. The surface of each sample was then prepared by sanding with 400–1000 grit sandpaper, followed by a 10-minute pickling process using 0.495 M hydrochloric acid (HCl) to remove any protective coating residues and oxides. After pickling, the samples were rinsed, dried with tissue, and weighed using an analytical balance to determine the initial mass (W_1).

The prepared samples were then divided into two groups. Samples 1–4 were immersed in natural seawater, while samples 5–8 were immersed in a 3.5% NaCl solution. Each sample was submerged for varying durations: 24, 48, 96, and 192 hours, all at room temperature. After the immersion period, all specimens were cleaned to remove corrosion products, dried, and weighed again to determine the final mass (W_2).

This study began with cutting samples from the motorcycle exhaust pipe into 2 × 2 cm pieces. The surface of the samples was then prepared by sanding with grit 400 to 1000 sandpaper, followed by a pickling process using hydrochloric acid (HCl) solution to remove any protective layers and oxides. After that, the samples were weighed using an analytical balance to obtain the initial weight. The next step was immersing the samples in media (such as seawater or 3.5% NaCl solution) for 168 hours at room temperature. After immersion, the samples were cleaned with distilled water and dried with tissue. The samples were then weighed again to obtain the final weight. The mass loss was calculated by subtracting the initial weight from the final weight. Using the appropriate formula (based on ASTM G31-21), the corrosion rate was calculated, and the results were analyzed. These calculations were then compared for the two immersion media used, natural seawater and 3.5% NaCl solution, to analyze the impact of each medium on the corrosion rate of AISI 1010 steel used in motorcycle exhaust components.

2.1 Research Material

The material used in this study was an original, factory-made motorcycle exhaust pipe, identified as low-carbon steel type AISI 1010. Samples were manually cut using a hacksaw to obtain surface dimensions of 2 × 2 cm, resulting in a total surface area of 8 cm² (accounting for both prominent faces). The selection of this material and dimension was based on the ease of replication and its realistic representation of automotive components exposed to the external environment. This cutting method is commonly applied in recent corrosion studies on automotive parts .

2.2 Sample Preparation

Before immersion, all sample surfaces were ground using sequential silicon carbide sandpapers (grit 400 to 1000) to remove the factory-applied protective oxide layer and to level the surface. Next, a pickling process was conducted using a HCl solution at a concentration of 0.495 mol/L, prepared by diluting 32% pure HCl with distilled water—the pickling process aimed to remove any remaining dirt or microcontaminants from the metal surface. The samples were immersed in the HCl solution for 10 minutes. After pickling, samples were rinsed and dried with lint-free tissue, then immediately weighed using an analytical balance to record the initial weight.

2.3 Immersion and Time Variation

A total of 8 samples were divided into two immersion media groups:

- Samples 1–4: Immersed in natural seawater
- Samples 5–8: Immersed in 3.5% NaCl solution

Each sample was immersed at room temperature (~27 °C) with the following immersion time variations:

- 24 hours
- 48 hours
- 96 hours
- 192 hours

Samples were individually immersed in 500 mL of solution to prevent interactions between samples. Immersion was carried out in a suspended position (hanging) to ensure that all surfaces were uniformly exposed and did not come into contact with the bottom of the container. This procedure was adapted from the design of the immersion corrosion test.

2.4 Post-Immersion Process and Weighing

After the predetermined immersion times were reached, the samples were removed from the media, rinsed with distilled water to remove residual corrosive media, and then dried. No further pickling was performed; samples were directly weighed to determine the final mass. This approach was taken to ensure that the weight loss accurately represented corrosion-related degradation only. The difference between initial and final weights was recorded as mass loss due to corrosion.

2.5 Corrosion Rate Calculation

The corrosion rate was calculated using the gravimetric method based on ASTM G31-21 standard (ASTM International, 2021), using the following formula:

$$\text{Corrosion Rate (mm/year)} = \frac{8.76 \times 10^4 \times \Delta W}{\rho \times A \times t} \quad (1)$$

Where:

- **ΔW**: Mass loss (mg)
- **ρ**: Density of AISI 1010 steel = 7.87 g/cm³
- **A**: Sample surface area (cm²) = 8 cm²
- **t**: Immersion time (hours)
- **8.76×10^4**: Conversion constant to obtain units in mm/year

After the calculation, descriptive statistical analysis was performed, including the mean and standard deviation for each immersion medium.

3. RESULT AND DISCUSSION

3.1 Average Corrosion Rate

The corrosion rate of AISI 1010 steel immersed in two different media—natural seawater and 3.5% NaCl solution—was calculated using the gravimetric method. The results revealed a substantial difference between the two media.

Table 1. Corrosion Rate Analysis Results

No.	***Sampel***	***Medium***	***Initial Weight (g)***	***Final Weight (g)***	***ΔW (g)***	***Time (Hours)***	***Surface Area (cm^2)***	***Corrosion Rate (mm/year)***	***ΔW (mg)***
1	S1	Sea Water	4.3129	4.3116	0.0013	24	4	150.7306	1.3
2	S2	Sea Water	3.899	3.7824	0.1166	48	4	6759.689	116.6
3	S3	Sea Water	3.7852	3.6043	0.1809	96	4	5243.687	180.9
4	S4	Sea Water	3.9022	3.6032	0.299	192	4	4333.505	299
5	S5	NaCl 3.5%	3.9465	3.9461	0.0004	24	4	46.3787	0.4
6	S6	NaCl 3.5%	4.3169	4.3147	0.0022	48	4	127.5413	2.2
7	S7	NaCl 3.5%	3.6659	3.6637	0.0022	96	4	63.7706	2.2
8	S8	NaCl 3.5%	3.3512	3.3478	0.0034	192	4	49.2773	3.4

Seawater produced an average corrosion rate of 4121.90 mm/year with a standard deviation of 2830.27 mm/year. The 3.5% NaCl solution produced an average corrosion rate of 71.74 mm/year with a standard deviation of 37.97 mm/year.

This difference indicates that seawater causes corrosion nearly 57 times faster than the NaCl solution. This is due to the presence of additional ions in seawater, such as magnesium, calcium, and sulfate, which accelerate electrochemical reactions on the metal surface.

3.1.1 Bar Chart of Average Corrosion Rate by Medium.

To illustrate the significant difference in corrosion rates between the two media, a bar chart is provided below, comparing the average corrosion rates observed in seawater and the 3.5% NaCl solution.

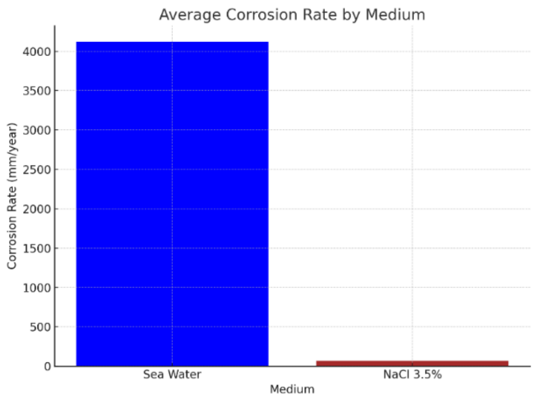

Figure 1. Bar Chart of Average Corrosion Rate by Medium

This chart presents a comparison of the average degradation rates between samples immersed in natural seawater and a 3.5% NaCl solution. The analysis reveals that seawater results in a degradation rate of 4,121.90 mm/year, significantly higher than the 71.74 mm/year recorded for 3.5% NaCl. This difference highlights that seawater, as a natural medium, contains additional ions such as Mg^{2+}, Ca^{2+}, and SO_4^{2-}, which accelerate electrochemical reactions and intensify the deterioration process compared to pure NaCl solution. These average values align with prior theories and literature, which indicate that marine environments are highly aggressive to carbon steel.

3.1.2 Corrosion Rate Trend Chart Over Immersion Time

To further analyze how the corrosion rate evolves over time, the following trend chart illustrates the changes in corrosion rates for both seawater and 3.5% NaCl solution over varying immersion periods.

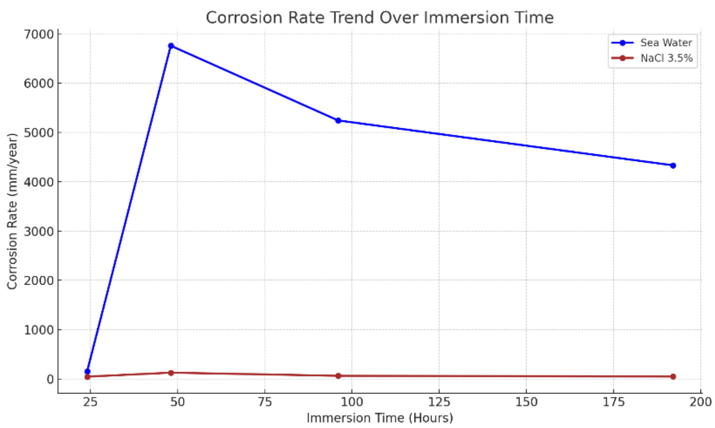

Figure 2. Corrosion Rate Trend Chart Over Immersion Time

This chart illustrates how the corrosion rate changes over immersion durations of 24, 48, 96, and 192 hours in both media. In seawater, the corrosion rate remains consistently high throughout the period with no significant reduction. This suggests that the corrosion products formed on the steel surface fail to create a stable protective layer, allowing corrosion to continue aggressively. In contrast, the trend in 3.5% NaCl is relatively more stable, with a tendency to decrease over time. This may be due to the formation of temporary passive layers such as **$Fe(OH)_2$** or **Fe_3O_4**, which slow down the metal degradation process. This pattern supports literature findings that artificial media, such as NaCl, exhibit more controlled corrosion behaviour compared to natural environments (Alharbi et al., 2024).

3.1.3 Boxplot of Corrosion Rate Distribution by Medium

To further explore the variability in corrosion rates across different samples, the following boxplot illustrates the distribution of corrosion rates for both seawater and 3.5% NaCl solution

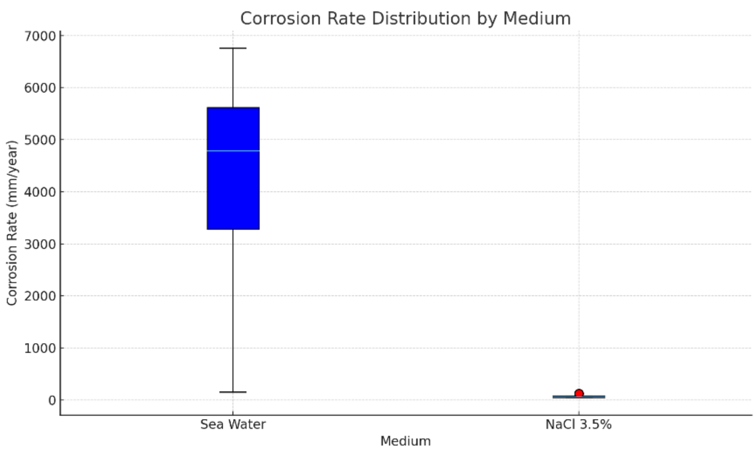

Figure 3. Boxplot of Corrosion Rate Distribution by Medium

This boxplot reveals the variability (dispersion) of corrosion rate values for each medium. Samples immersed in seawater exhibit a wide spread of values (high variance), indicating uneven corrosion among the specimens. This can be attributed to differences in microstructure, surface irregularities, or the presence of localized corrosion (pitting). In contrast, the boxplot for 3.5% NaCl shows a narrower distribution, reflecting more consistent corrosion processes across samples. These findings highlight that the natural variability of seawater introduces greater uncertainty in corrosion behavior, posing challenges for material protection in marine environments (Mahado et al., 2024).

3.2 Time Trend and Surface Pattern

Although both media contain chloride ions, the more complex ionic composition in seawater enables more aggressive localized corrosion (such as pitting) compared to the uniform corrosion observed in NaCl solution. The high deviation values also suggest irregularities due to surface heterogeneity or initial microstructural defects.

The duration of immersion (24–192 hours) affected the corrosion rate. Over time, the mass loss rate increased, although passive film formation may have contributed to a deceleration of the corrosion process at later stages (Alharbi et al., 2024).

3.3 Implications

These findings highlight the importance of corrosion protection for metal components, especially motorcycle exhaust systems operating in coastal regions. Without additional protection such as epoxy coatings or sacrificial anodes, AISI 1010 steel is prone to rapid degradation in marine environments.

4. CONCLUSION

This study demonstrates that the immersion medium significantly affects the degradation rate of AISI 1010 steel, particularly in factory-standard motorcycle exhaust pipes. The results show that natural seawater, with its complex ionic composition—including Mg^{2+}, Ca^{2+}, and SO_4^{2-}—accelerates electrochemical reactions much more aggressively than a 3.5% NaCl solution, with seawater producing an average degradation rate of 4121.90 mm/year compared to only 71.74 mm/year in the NaCl solution. Over time, particularly in seawater, the degradation rate increased, suggesting that the products formed on the metal surface failed to provide an effective protective barrier against further damage. The variation and dispersion in degradation rates among the seawater samples indicated a tendency for localized damage, such as pitting, while samples in the NaCl solution exhibited more uniform behavior. These findings align with previous literature, reinforcing the importance of applying protective measures to motorcycle components, especially those operating in coastal environments. This study serves as a foundation for future research focused on material selection and protection strategies for automotive components exposed to marine conditions.

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