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Comparison of Corrosion Rate on Mild Steel Welded Joints using Acid and Alkaline Solutions

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Abstract. Corrosion is a problem that must be handled in a construction plan. One way to overcome this is by predicting the corrosion rate of material under certain conditions. This study aims to determine the corrosion rate of mild steel welded joints using acid and alkaline solution media. The specimens are made from ST37 mild steel which is welded together. The specimens were divided into two, namely specimens that were not subjected to post-weld heat treatment (PWHT) and specimens subjected to post-weld heat treatment (PWHT). The specimens were immersed in an acid solution, namely 3% KCl and an alkaline solution, namely 10% NaOH for 100 hours, 200 hours, 300 hours, and 400 hours. The 3% KCl solution's corrosion rate had an upward trend, starting from 0.092 mmpy at 100 hours of immersion time to 0.16 mmpy at 400 hours of immersion time. The corrosion rate of 3% KCl is in a good category. In alkaline solutions, the corrosion rate trends to be constant, which is in the range of 0.01 mmpy to 0.024 mmpy. The corrosion rate at 10% NaOH is included in the excellent category. Specimens with a post-weld heat treatment (PWHT) process have a lower corrosion rate than those without a post-weld heat treatment (PWHT) process. A 3% KCl acid solution's corrosion rate was higher than the corrosion rate of 10% NaOH alkaline solution.

Keywords: corrosion rate, mild steel, PWHT, 3% KCl, 10% NaOH, immersion time

INTRODUCTION

Corrosion is an issue that can never be discussed in the world of construction. Corrosion is influenced by various causes, external environmental factors such as air, water, and soil [1] [2]. Corrosion results in construction failure in one unit of time. This construction failure resulted in losses to the company if it was not predicted. As an example, in Fig. 1, we can see a corroded pipe due to external environmental factors, namely soil and air [1]. If it is not predicted, it is impossible to know how long the remaining life of the corroded pipe will be. So, it is crucial in construction planning to estimate the age of the material by knowing the corrosion rate.

One way to predict the age of construction is to calculate its corrosion rate. The corrosion rate can be detected in several ways, namely using a caterpillar wave [3], by electrochemical analysis [4], and with a decrease in weight and size [5]. Apart from external environmental factors, the corrosion rate is also influenced by internal factors, namely the type of material used.

The material that is often studied for its corrosion rate is carbon steel [6]. In addition to carbon steel, some study the corrosion rate of copper to be precise copper and nickel alloys [7]. In construction, it cannot be separated from the material connection process. One of the most commonly used metal joint processes is welding. Knowing the corrosion rate of materials undergoing the welding process is a stimulating discussion. Research on welding results on carbon steel is often done to determine its mechanical and physical properties [8]. Besides, research on welding that is most often carried out is using different types of materials [9]. There is also welding research using simulation software to determine the spread of heat during the welding process [10]. Furthermore, there are many more material tests related to welding and corrosion testing, but it is rare to research corrosion tests on welded materials.

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FIGURE 1. Corroded pipe due to accumulated soil and outside air

In corrosion testing, another thing that is no less important is corrosion media to calculate the corrosion rate. If the construction is used for rigs in the offshore oil and gas industry, then the most suitable corrosion test medium is seawater [7]. However, the seawater concentration in each area was not the same, so several media were investigated using chemical solutions with specific concentrations. One of the media used for the corrosion test is KCl and NH4Cl, which are acidic like seawater [5], and some are using NaCl solution [11]. In this study, besides using an acidic solution such as KCl, it was added by testing using an alkaline solution, namely NaOH. This is to complement several existing studies, namely by examining the corrosion rate of alkaline solutions.

RESEARCH METHOD

Material Used

In this study, the material used as the research object was mild steel plate ST37 with a thickness of 1.3 mm, because when welding it is sticky. Mild steel ST37 was chosen because it is often used in construction design work. Mild steel ST37 is then cut to a length of 30 mm and a width of 15 mm.

Mild steel ST37 is joined by electric welding. The size and geometry of the material to be a specimen are as shown in Figure.2. Where the type of welding used is manual metal arc welding (MMA) or often called shielded metal arc welding (SMAW).

The type of weld joint is a groove with a slope, as shown in Figure. 2.

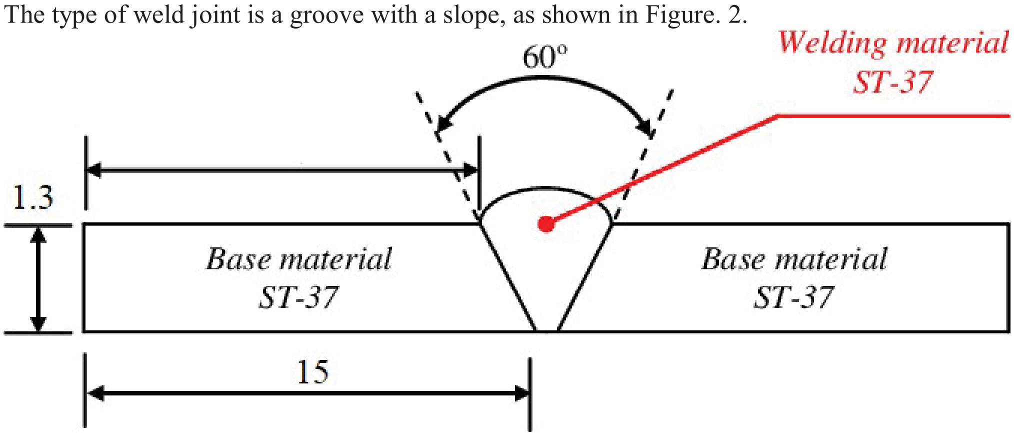

FIGURE 2. Geometry and dimensions of mild steel specimens

In addition to specimen raw materials, other materials prepared are media or solutions used to determine the specimen's corrosion rate. In this study, the solutions used were strong acids and strong alkaline. The acid solution chosen was potassium chloride 3% solution (3% KCl), while for the alkaline solution, 10% sodium hydroxide (10% NaOH) was chosen.[8] [12] [13].

Research Methods

After the mild steel ST37 is welded into a specimen as shown in Fig. 3, the next step in the specimen preparation process is that some of the material is reheated, or often referred to as post-weld heat treatment (PWHT). The PWHT process is usually carried out on low carbon steels that have just undergone a welding process. The PWHT function is to reduce the residual stress [7] [14]. The residual stress is a latent hazard that is not visible at first, but if there is a lightersuch as pressure or a long time, the strength of the material will drop, because the heat treatment is suddenly high in a location. PWHT is reheating carbon steel, a welding processat temperatures of 300 ^{o}C to 700 ^{o}C. The purpose of this process is to reduce the residual stress that occurs due to the welding process. As for this study, the temperature chosen was 300^{o}C.

FIGURE 3. Welded mild steel specimen

When the specimen and solution media are ready, then thenext step is to prepare a measuring instrument that will be used to collect data on the corrosion process that occurs. In this study, the corrosion rate calculation is based on the calculation of the reduction in specimen weight and surface area in a unitof time. Therefore, the tools used to collect specimen weightdata were digital scales with an accuracy of 0.001 grams. Thetools used to retrieve dimensional data were using calipers with an accuracy of 0.02 mm.

The testing process is carried out with a period of every 100 hours. Not exactly 100 hours, but approximately every 100 hours, the specimen is cleaned of corrosion, then weighedand measured in dimensions. The weighing process anddimensional measurements are carried out five times, namelywhen the specimen has not been dissolved. After the dissolving process is 100 hours, 200 hours, 300 hours, and 400 hours. Based on these data, it is expected that the corrosion rate can be calculated every 100 hours of the immersion process in acidic or alkaline solutions.

Corrosion Rate Calculation

If the data related to the specimen's weight and the surfacearea of the specimen immersed in the solution is known, thenthe speed or rate of corrosion of the specimen can be calculated. In calculating the corrosion rate use (1). Equation(1), the constant used to calculate the corrosion rate in mmpyunits is 8.76 x 10^4. Simultaneously, the specimen density is the mild steel ST37 density, namely 7.86 g/cm^3.

$$CR\ (mmpy) = \frac{\Delta W.K}{\rho.A.T}$$

Where:

CR : Corrosion Rate (mmpy)
ΔW : Weight Loss (gram)
K : Factor Constants (8.76 x 10^4)
ρ : Specimens Density (g/cm^3)
A : Surface Area (cm^2)
T : Immersion Time (hour)

Besides, to find out whether the corrosion rate value is good or not good, the corrosion rate data can be used in unitsof mpy (meters per year) and mmpy (millimeters per year) asshown in Table 1. [1]. In this study, the unit used in the calculation is mmpy.

TABLE 1. Corrosion Resistance Standards Based on Corrosion Rate Values

Relative Corrosion Resistance	**Approx. Metric Equivalent**	
	mpy	***mmpy***
Outstanding	<1	<0.02
Excellent	1 to 5	0.02 to 0.1
Good	5 to 20	0.1 to 0.5
Fair	20 to 50	0.5 to 1
Poor	50 to 200	1 to 5
Unacceptable	> 200	> 5

RESULT AND DISCUSSION

Data Results

Based on the test results on specimens that have been put in acidic or alkaline solutions, data on specimen weight and specimen size, including length, width, and thickness of the specimen were obtained. Data were collected by repetition three times for each variable. There are four variables in this research, namely specimens without post-weld heat treatment (PWHT) immersed in 3% KCl solution written with "3% KCl", specimens with post-weld heat treatment (PWHT) processes immersed in 3% KCl solution written as "3% KCl+", specimens without post-weld heat treatment process immersed in 10% NaOH solution are written as "10% NaOH", and specimens with post-weld heat treatment (PWHT) processes immersed in 10% NaOH solution are abbreviated as "10% NaOH +".

The specimen weight data for each variable were processed so that the average weight loss of the specimen for each variable was obtained. The calculation results of specimen weight loss are then made an average so that the data is obtained as in Table 2.

TABLE 2. The Average of Specimens Weight Loss

Immersion Time	**Average ΔW Acid Solution (gr)**		**Average ΔW Alkaline Solution (gr)**	
	3% KCl	3% KCl +	10% NaOH	10% NaOH+
100 hours	0.019	0.016	0.004	0.003
200 hours	0.025	0.026	0.002	0.000
300 Hours	0.022	0.024	0.004	0.006
400 Hours	0.046	0.047	0.000	0.001

Meanwhile, the specimen size is calculated to obtain the submerged surface area. Data in the form of length, width, and thickness of the specimen is calculated every 100 hours so thatthe data on the surface area of the submerged specimen is obtained, in this case, 100% of the surface of the specimen isimmersed. After obtaining the immersed specimen's surface area, then the average of each variable is made so that the datais obtained, as shown in Table 3.

Corrosion Rate Analysis

After obtaining the average weight loss of the specimen and the immersed specimen's average surface area, the next step is to calculate the corrosion rate using (1). The results ofcalculating the corrosion rate for each variable can be seen inTable 3.

TABLE 3. Corrosion Rate Calculation Results

Immersing Time	Corrosion Rate in Acid Solution (mmpy)		Corrosion Rate in Alkaline Solution (mmpy)	
	3% KCl	3% KCl +	10% NaOH	10% NaOH +
100 hours	0.108	0.092	0.024	0.019
200 hours	0.125	0.120	0.017	0.010
300 Hours	0.125	0.125	0.019	0.018
400 Hours	0.158	0.160	0.015	0.014

Based on Table 3, the corrosion rate with an acid solutionor 3% KCl in specimens without PWHT and PWHT can be described in graphical form, as shown in Fig. 4. In Fig. 4, it can be seen that the trend of the corrosion rate from the immersion time of 100 hours to 400 hours trends rose both inspecimens without the PWHT process or with the PWHT process. Despite the upward trend, all corrosion rates are in the range of 0.1 mmpy to 0.5 mmpy, which means it is categorized as good corrosion recession, except for specimens with the PWHT process immersing time of 100 hours below 0.1 mmpy which means it is in the excellent category. Based on this data, the average corrosion rate of mild steel ST37 weld joints in a 3% KCI acid solution is good, so it is still safe to use.

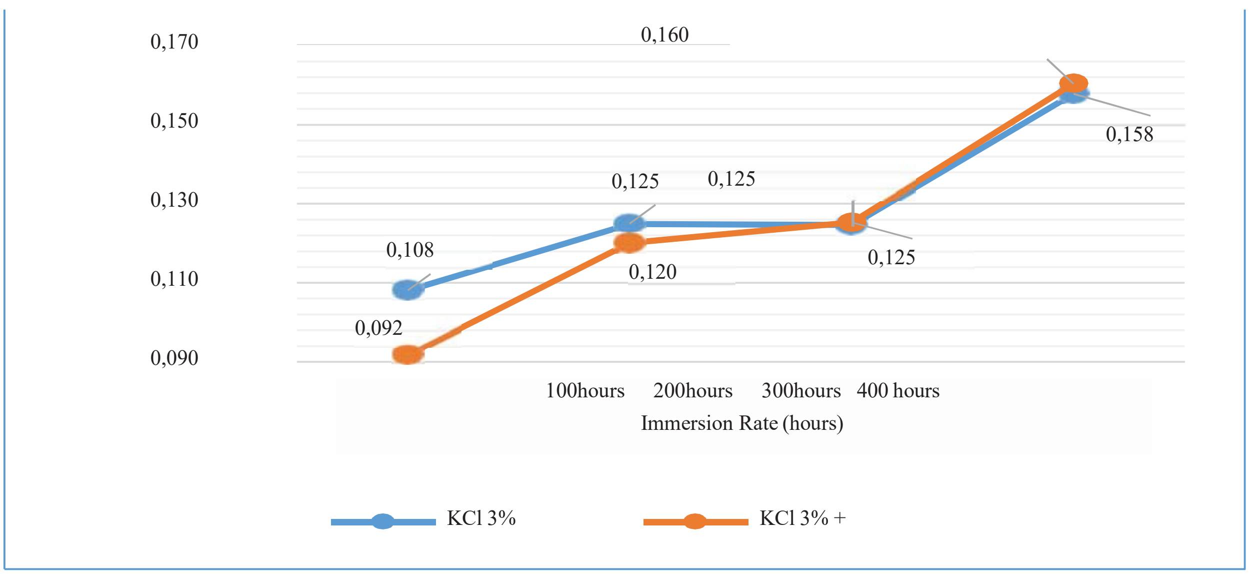

FIGURE 4. Graph of the relationship between the corrosion rate and the immersion time in the acid solution

Based on Fig. 5, which shows the trend of the corrosion rate in alkaline solution media, it can be seen that the graph shows a zigzag pattern. This zigzag pattern does not form a downward or upward trend, and this means that the corrosion rate in the specimen without the PWHT process and the PWHT process in a 10% NaOH solution has a range between 0.010 mmpy to 0.024 mmpy. The corrosion rate between 0.02 mmpy to 0.1 mmpy is an excellent category. Because of that, the average corrosion rate o specimens without PWHT and PWHT in 10% NaOH alkaline solution is at an excellent level, so it is very safe to use.

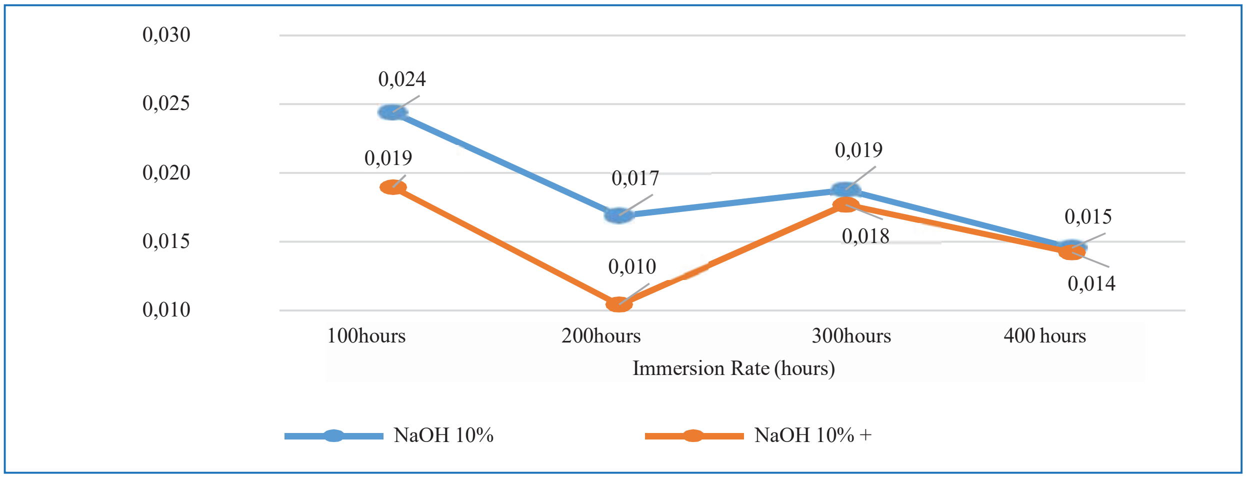

FIGURE 5. Graph of the relationship between the corrosion rate and the immersion time in the acid solution

Based on Figure. 4 and Figure. 5, it can be seen that the corrosionrate of the specimens with the PWHT process is lower than the specimens without the PWHT process. Therefore, it is recommended for ST37 carbon steel welding results to be carried out by the PWHT process to have lower corrosion resistance. In this case, it can be said that specimens with thePWHT process are safer to use than specimens without PWHT.

The comparison of the effects of acidic and alkaline solutions on specimens without the PWHT process can be seen in figure.6. It can be seen that the 3% KCI acid solution has a higher corrosion rate than the 10% NaOH alkaline solution. In alkaline solutions, the corrosion rate trends to be constant, while in acid solutions, the corrosion rate is getting bigger and bigger.

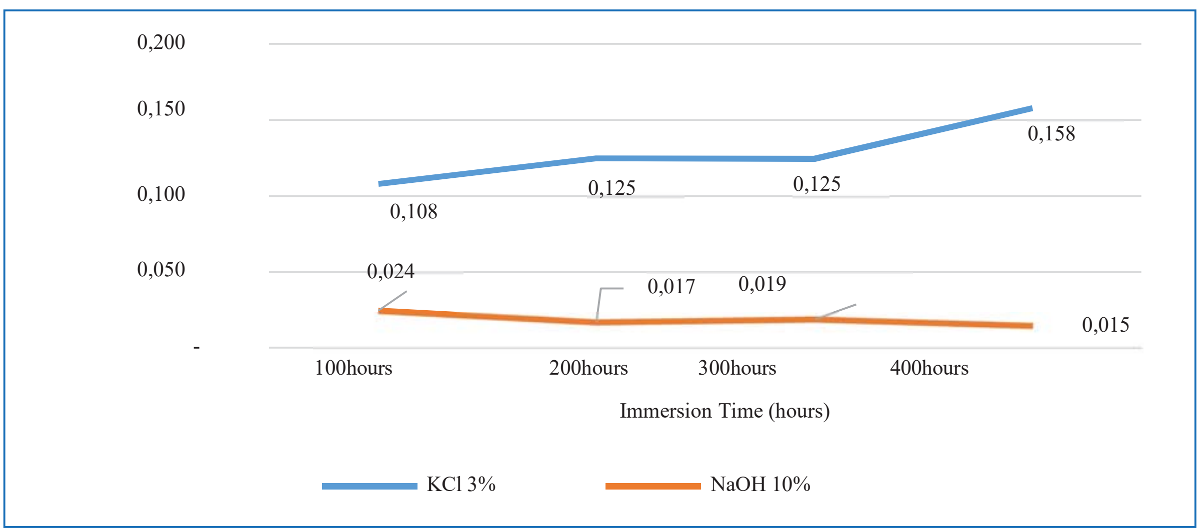

FIGURE 6. Graph of the relationship between the corrosion rate in the specimen without PWHT in acidic and alkaline solutions

The comparison of the corrosion rate in the specimen withthe PWHT process in acidic and alkaline solutions can be seen in Fig. 7. The graph trend is the same as Fig. 6; in alkaline solutions, the corrosion rate trends to be constant, while in acidic solutions, the longer the corrosion rate is greater. Basedon Fig. 6 and Fig. 7, acidic solutions' corrosion rate is higherthan in alkaline solutions. It can also be interpreted that mildsteel welded joints without the PWHT process or the PWHT process are safer in an alkaline environment than in an acidic environment.

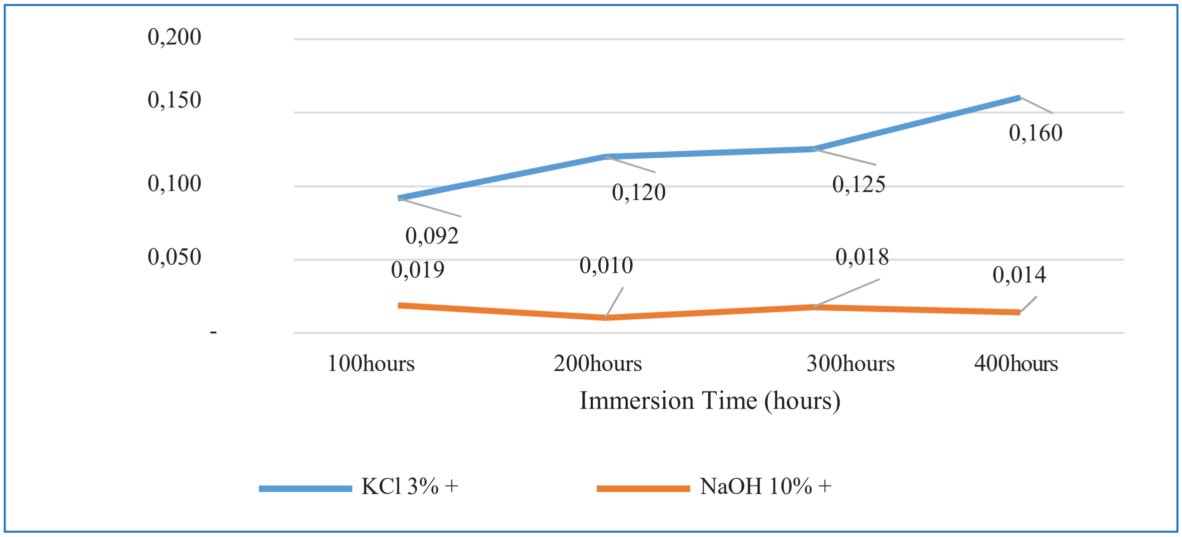

FIGURE 7. Graph of the relationship between the corrosion rate in the specimen without PWHT in acidic and alkaline solutions

CONCLUSION

Based on the research and discussion results, in research on the corrosion rate of specimens without the PWHT process and with the PWHT process in acid and alkaline solutions, conclusions can be drawn, such as:

- In the 3% KCl acid solution, the corrosion rate was obtained between 0.092 mmpy to 0.160 mmpy with a tendency that the longer the immersion time, the higher the corrosion rate. However, the average corrosion rate is in a good category, so it is safe to use.
- In the 10% NaOH alkaline solution, the corrosion rate values were obtained between 0.010 mmpy to 0.024 mmpy. The average rate of corrosion is in the excellent category, so it is very safe to use.
- The PWHT process specimens have a lower corrosion rate than the specimens without the PWHT process in either a 3% KCl acid solution or a 10% NaOH alkaline solution. So it can be suggested to carry out the PWHT process on the welding results on carbon steel to increase corrosion resistance.
- The corrosion rate of the 3% KCl acid solution was higher than that of the 10% NaOH alkaline solution in both the specimens without the PWHT process or the PWHT process.

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