

Analysis of Mild Steel Corrosion Rate Based on Variations of Electrodes and Corrosion Media in SMAW Welding

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ABSTRACT

This study aims to determine the effect of electrode variations on mild steel plates using variations in corrosive environments. The method used in this study is experimental. Data collection techniques are carried out by documenting workpieces that have been welded using variations of electrodes dipped in variations of corrosion media for 15 days and observed using a digital microscope with a magnification of 50X. The results of this study show that workpieces that have been welded SMAW using variations of electrodes E6010, E6013, E7018 and using corrosive solutions of seawater and rainwater to be able to see the results of the development of the corrosion rate that occurs in the workpiece, which experiences a slow corrosion rate is found in the E6013 electrode using rainwater due to the strong current in the place when welding gets good results, and it is difficult for the corrosion rate to occur. While the type of E6010 electrode immersed in seawater solution shows a very rapid corrosion rate compared to other electrodes. The initial weight of the workpiece is 215.77 grams, and after 15 days of immersion, the weight of the workpiece decreases to 213.88 grams, resulting in a weight loss of 1.89 grams.

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INTRODUCTION

With the increasing development of technology, many people have created various things, including materials made from metal, and along with the rapid progress of technology, various new methods in metal joining techniques continue to be discovered. One of them uses a process of melting metal with additional or unusual materials, also called the welding process (Susetyo et al., 2021).

Welding is a fabrication method for joining two metal, thermoplastic, or other materials by heating the ends of the two objects until they melt, then cooling them to fuse. Thus, welding can be tailored to the needs of the work to be done (Teknika, 2020).

Each type of welding has different characteristics, starting from the implementation technique, the work process, to the type of welding material used (Sultoni et al., 2020). One example is *MMA* (*Manual Metal Arc*) welding which is also known as *SMAW* (*Shielded Metal Arc Welding*). This is a

type of welding machine that is often used in general. This is due to its light weight and low power consumption. *MIG (Metal Inert Gas) welding* and FCAW welding are the same type of welding and are easy to use (Mulyadi et al., 2022). The significant difference is in the type of welding wire roll. MIG and FCAW electrodes have a roll of welding wire that is elongated and continuous when used. *TIG (Tungsten Inert Gas) welding* is categorized as one of the types of welding that is challenging to learn because it requires the use of both hands in its operation (Qi et al., 2022). One hand is used to hold the welding torch equipped with a tungsten electrode, while the other hand is used to hold the filler material or feed (Jumaidin et al., 2019).

Plasma cutting welding is almost similar to acetylene welding. The difference is that this type of plasma cutting welding does not require a gas cylinder in its operation. It only requires a compressor. Because it requires air thrust to remove the heated metal from the plasma cutting welding torch. *Oxy-acetylene welding*, or often known as acetylene welding or carbide welding, is one of the traditional welding methods (Saputra et al., 2022). The process is carried out by mixing oxygen and acetylene gas, then igniting it using a lighter or match to produce a welding flame. Meanwhile, laser welding is a welding technique that utilizes very high heat energy, where this method is able to produce higher temperatures and better joint quality compared to other conventional welding methods (Haris & Widodo, 2021).

The Shielded Metal Arc Welding (SMAW) welding process, commonly known as electric arc welding, is a method of joining metals by melting the parent metal and electrode (as filler material) using heat (Mahgoub et al., 2019). This heat is generated from the transfer of electrical ions between the cathode and anode, namely between the tip of the electrode and the surface of the plate to be joined, with temperatures that can reach around 4000 to 4500°C. In SMAW welding, there are two types of current sources used, namely direct current (DC) and alternating current (AC) (Nanda, Rohma, Rugshi, 2022).

In general, welding is a method of joining materials through the process of melting the surface of the workpiece to a certain temperature, which is carried out without pressure and sometimes without additional filler materials. However, to obtain optimal joint quality, electrodes are often used as additional filler materials. These electrodes are available in various sizes and types according to the needs of the welding process (Anhar, 2019). The amount of electric current and the diameter of the electrode also greatly affect the quality of the welding results. Therefore, setting these parameters is important in the welding process, often used materials commonly found in everyday life, especially on steel plates that have a low level of hardness. Steel plates with a low level of hardness refer to the type of low carbon steel (Darmo et al., 2021).

This low carbon steel contains limited alloying elements, usually less than 2%. The use of low carbon steel in the metal industry is very broad. Some examples include pipes, bolts, bicycle chains, nails, and various other construction materials in the form of profiles or rods (Haris & Widodo, 2021).

These components generally interact directly with the environment, so they are susceptible to corrosion processes. The speed of corrosion is often influenced by corrosive environmental conditions and the type of electrode used, especially if the electric current used in the welding process is not appropriate (Studi et al., 2022). Corrosion can occur due to contact or interaction of metal with the surrounding environment (Erizal Maulana, 2020).

One of the environmental factors that are corrosive comes from seawater and rainwater. Seawater contains chloride ions which are the main cause of increased corrosion rates, where the higher the concentration of chloride ions, the faster the corrosion process occurs in metal materials (Mulyadi et al., 2022). The content of compounds such as NaCl, KCl, and H₂O in seawater has high electrical conductivity, so it can penetrate metal surfaces and accelerate the corrosion process. Meanwhile, from an environmental perspective, rainwater — especially during acid rain — can have a lower pH value than the normal pH of rainwater (5.6), and can even reach a pH between 2 and 3 (Yaqin et al., 2022). This condition causes rainwater to also have the potential to accelerate the corrosion rate in a relatively short time.

In addition, the duration of time also influences the rate of corrosion that occurs. In the book *Corrosion Engineering Third Edition* by Mars G. Fontana, it is recommended that observations of the corrosion rate be carried out for at least two weeks to one month to obtain more accurate data regarding the speed of the corrosion process (Sugihrahma, 2020).

Changes in corrosion rates can also be caused by problems with the material itself, such as the influence of the welding process on the material which can result in recrystallization and change the strength structure and the resulting engineering structure (Tarigan, 2021). The use of different electrodes will result in differences in the chemical composition of the weld metal and the heat-affected zone (HAZ), which in turn will affect the corrosion rate that occurs. The use of electrodes with chemical characteristics that match the welding process specifications plays an important role in suppressing the potential for corrosion (Zulhafril et al., 2020). By comparing the corrosion rates from the use of different electrodes, the minimum value of the corrosion rate can be found. This can reduce the required maintenance costs.

Plate thickness has a significant influence on the quality of the resulting joint. This is because the heat input received by the plate varies depending on its cross-sectional area. Meanwhile, heat input in the welding process will have an impact on the microstructure formed (Haris & Widodo, 2021). Environmental factors also affect the corrosion rate, where environments with a high pH tend to accelerate the corrosion rate in general. Factors such as air humidity, rainwater, mud, and impact or friction with other objects can cause the protective coating on the metal to peel off, which ultimately accelerates the corrosion process. The taste arises from the oxidation reaction between the metal and oxygen (Disya Haeriyati Ariwiana Putri et al., 2023). Sea water containing salt content and water with added table salt (NaCl) can be factors that accelerate corrosion on metals, including the formation of

rust (A et al., 2021). The formation of rust on metals is caused by direct interaction between the metal surface and water containing acid, causing an oxidation process by air. If water and dirt are left to stick to the steel for a long time, the acid will react with the iron, resulting in the formation of rust (Aldo & Hariyono, 2022).

The use of electrode variations in corrosion research is carried out to determine the effect of differences in chemical composition, electrochemical potential, and characteristics of the welding layer on the corrosion resistance of the material. Each type of electrode has a different alloying element content and metallurgical properties, which can produce different microstructures, hardness levels, and weld joint quality. These variations directly affect the corrosion rate because differences in microstructure can trigger the formation of local galvanic cells, porosity, microcracks, and non-uniformity in the HAZ (Heat Affected Zone) area. In addition, the type of flux and the content of elements such as chromium, nickel, or manganese in the electrode can increase or decrease the material's ability to form a protective passive layer against corrosive environments. Therefore, the use of electrode variations is important to determine the type of electrode that is capable of producing weld joints with the most optimal corrosion resistance according to the material application conditions.

This research was conducted to determine the analysis of the effect of the SMAW (shielded metal arc welding) welding process using various electrodes and corrosive environments on the corrosion rate of low carbon steel using an experimental method by immersing it in seawater and rainwater solutions for 15 days.

METHOD

This study uses an experimental approach as a research method. The experimental approach is a research method used to identify the effect of special treatments on other variables under controllable conditions [13]. Figure 1 shows the material used in this study, namely a square-shaped mild steel plate with a length of 10 cm, a thickness of 0.5 cm, and a width of 0.6 cm. The type of welding used is SMAW welding and the type of electrode used is E6010, E6013, and E7018 using immersion media using sea water and rain water and observations were carried out for 15 days and observations were made using a digital microscope with a magnification of 50X.

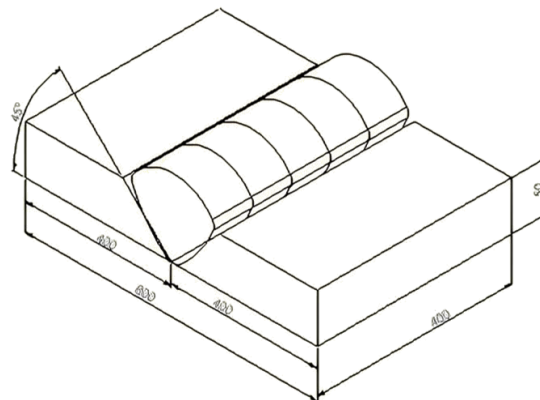


Figure 1. Welding Specimens and Corrosion Test

The data analysis technique was carried out by comparing the results of corrosion testing on each electrode variation based on the corrosion rate values obtained. The test data were then calculated using the standard corrosion rate formula and presented in tabular or graphical form to facilitate analysis. Furthermore, a comparative analysis was carried out on the effect of electrode variations on the corrosion resistance of the material, then linked to the surface condition of the specimen, the structure of the welding results, and the HAZ (Heat Affected Zone) area to obtain research conclusions. The research flowchart in this study is shown in Figure 2.

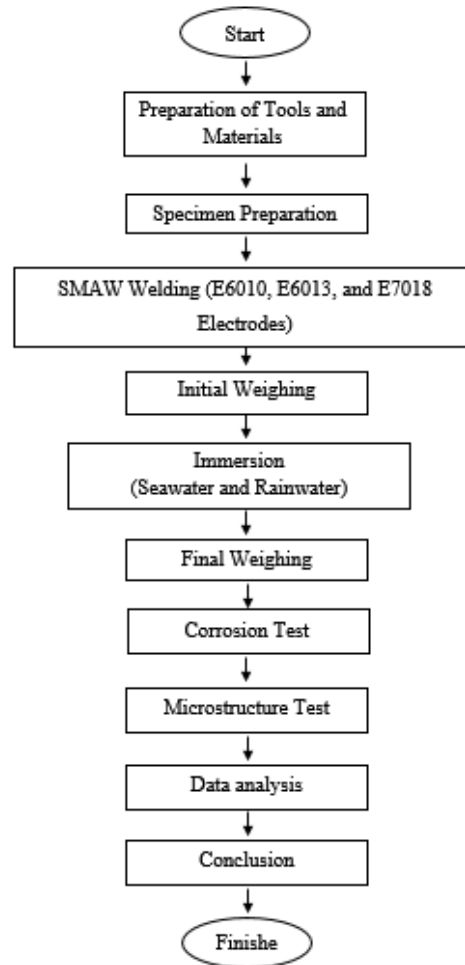


Figure 2. Research Flowchart

RESULTS AND DISCUSSION

Development of Corrosion Rate Variations of E6010 type electrodes using seawater and rainwater

Table 1. Corrosion Rate Variation of E6010 type electrode using seawater and rainwater

Electrode	Corrosion Rate		Percentage of Damage	
	Sea water	Rainwater	Water Sea	WaterRain
E6010	1.89 grams	0.07 grams	0.87%	0.032%

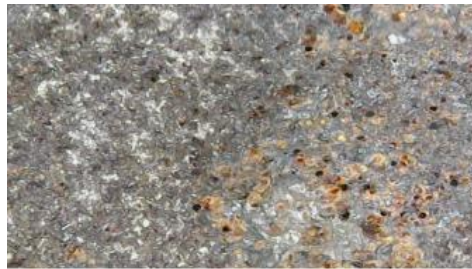


Figure 3. E6010 Seawater Electrode Day 15



Figure 4. E6010 Electrode Rainwater Day 15

Examples of specimens that have undergone a welding process using an E6010 electrode in seawater and rainwater solutions are shown in Figures 3 and 4. The results of the observations indicate a significant difference in the corrosion rate, as demonstrated by measurements of the specimens' weight loss following the test. This is evidenced by the data contained in the available graph. After 15 days of immersion using a seawater solution, a decrease in weight is seen as measured using a digital scale. The initial weight before immersion, after the welding process, was 215.80 grams, and after 15 days of immersion the weight of the specimen decreased to 213.91 grams. By calculating the weight difference using the weight loss formula, it is seen that the weight of the workpiece is reduced by 1.89 grams from the initial weight. The resulting percentage of damage is 0.87%. The available image also indicates that corrosion occurs in weld defects, with the type of crevice corrosion occurring in the gaps in the weld results.

On the 15th day, it was seen that the initial weight of the workpiece using the rainwater solution was 212.88 grams, and on the 15th day the weight of the workpiece decreased to 212.81 grams, resulting in an observed difference. After calculations using the weight loss formula, there was a decrease of 0.07 grams. In addition, by using the percentage of damage formula, a percentage of 0.032% was obtained. In the presented image, it can be seen that corrosion occurs in the *HAZ (Heated Affected Zone)* zone on the workpiece. After observation with a digital microscope with a magnification of 50X, it can be seen that the type of corrosion that occurs is crevice corrosion, which appears in the gaps caused by the corrosion process. Development of Corrosion Rate Variations of E 6013 type electrodes using seawater and rainwater.

Corrosion Rate Development of Variations of E 6013 Type Electrode Using Seawater and Rainwater

Table 2. Corrosion Rate Variation of E 6013 type electrode using seawater and rainwater

Electrode	Corrosion Rate		Percentage of Damage	
	Sea water	Rainwater	Sea water	Rainwater
E6013	0.97 grams	0.03 grams	0.45%	0.014%



Figure 5. E 6013 Seawater Electrode Day 15



Figure 6. Electrode E 6013 Rainwater Day 15

Welding samples were produced using E6013 electrodes; the solutions of seawater and rainwater can be seen in Figures 5 and 6. From the results of the weight loss calculation, it is clear that the corrosion rate experienced a rapid development, as recorded in the available table. On the 15th day with the use of seawater solution, weight loss measurements were carried out using a digital scale. The initial weight before immersion after the welding process was 215.82 grams, and after 15 days of immersion, the sample weight decreased to 214.83 grams. From the calculation using the weight loss formula, there was a difference of 0.99 grams, and the percentage of damage that occurred was 0.45%. Through the image, it is also clear that corrosion occurred at the weld defect, and the type of corrosion formed was crevice corrosion that appeared at the crack resulting from the welding.

On the 15th day, it was seen that the initial weight of the workpiece using rainwater solution was 213.93 grams, and on the 15th day the weight of the workpiece decreased to 213.90 grams. After being calculated using the weight loss formula, there was a difference in reduction of 0.03 grams. In addition, the percentage of defects calculated using the formula was obtained at 0.014%. The workpiece showed corrosion in its HAZ area. After observation with a microscope with 50X digital magnification, the type of corrosion that occurred in the welding results was crevice corrosion. Development of Corrosion Rate Variations of E 7018 type electrodes using seawater and rainwater.

Corrosion Rate Development of Variations of E 7018 Type Electrode Using Seawater and Rainwater

Table 3. Corrosion Rate Variation of E 7018 type electrode using seawater and rainwater

Electrode	Corrosion Rate		Percentage of Damage	
	Sea water	Rainwater	Sea water	Rainwater
E7018	1.08 grams	0.04 grams	0.44%	0.018%



Figure 7. E 7018 Seawater Electrode Day 15



Figure 8. E7018 Rainwater Electrode Day 15

The samples that have undergone welding with an E7018 electrode using seawater and rainwater solutions are shown in Figures 7 and 8. The results of the corrosion rate measurements on these samples indicate that the corrosion rate is very high. This is evidenced by the data in the available graph, where on the 15th day using the seawater solution, a decrease in weight was seen as measured using a digital scale. The initial weight of the specimen before immersion after welding was 216.85 grams, and after 15 days of immersion, the weight of the specimen became 215.77 grams. The difference calculated using the weight loss formula is 1.08 grams from the initial weight of the workpiece, which indicates a decrease. The percentage of damage obtained is 0.49%. The types of corrosion that occurred in the workpiece tested were crevice corrosion and pitting corrosion.

On the 15th day using the rainwater solution, it was seen that the initial weight of the workpiece was 216.90 grams, and after 15 days the specimen weight became 216.86 grams. After calculation using the weight loss formula, a difference of 0.03 grams was obtained, indicating a decrease in weight. The percentage of damage calculated using the percentage formula was 0.018%.

After observation with a digital microscope with a magnification of 50X, the type of corrosion that occurred on the tested workpiece was crevice corrosion, which occurred in the gaps resulting from welding. The overall percentage of corrosion rate on electrode types E6010, E6013 and E7018 using salt water and sea water.

Overall Percentage of Corrosion Rate on Electrode Types E6010, E6013 and E7018 Using Salt Water and Sea Water

Table 4. Overall Percentage of Corrosion Rate on electrode types E6010, E6013 and E7018 using seawater and rainwater

Electrode	Corrosion Rate		Percentage of Damage	
	Sea water	Rainwater	Sea water	Rainwater
E6010	1.89 grams	0.07 grams	0.87%	0.032%
E6013	0.97 grams	0.03 grams	0.45%	0.014%
E7018	1.08 grams	0.04 grams	0.44%	0.018%

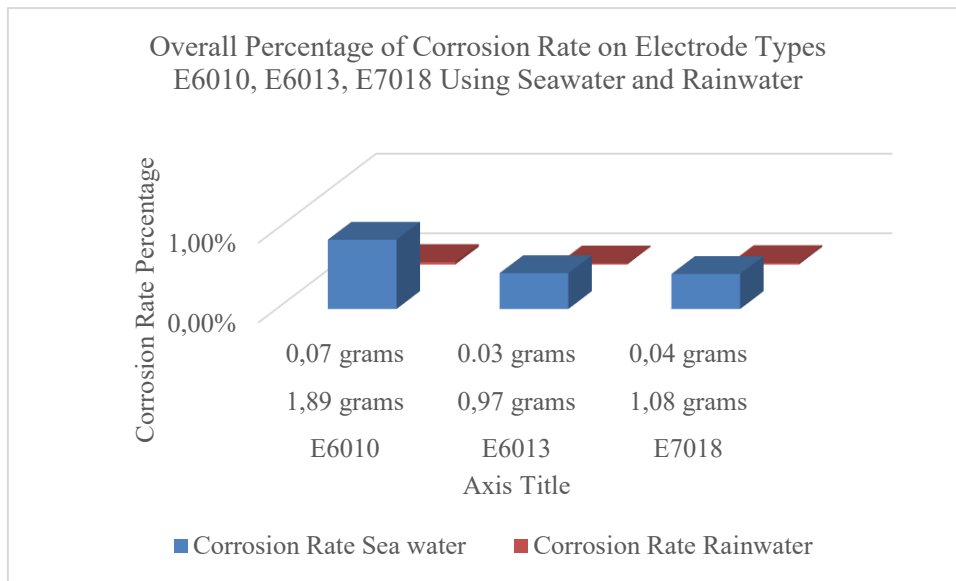


Figure 9. Overall Percentage of Corrosion Rate on electrode types E6010, E6013 and E7018 using seawater and rainwater

Based on Figure 9 and Table 4 presented, it appears that the use of the E6010 electrode results in a significantly higher corrosion rate compared to other electrodes. This electrode is less suitable for welding mild steel plates. This is demonstrated by the larger sparks produced, resulting in faster heat distribution compared to other electrode types. This high heat input also accelerates the corrosion rate of the welded material.

In addition, the results of the study showed that carbon steel immersed in seawater solution experienced a faster corrosion process than that immersed in rainwater. This is due to the chemical elements contained in the solution, where approximately 89% of the composition of seawater consists of chloride salts, while the remaining 11% consists of other elements. The chloride ion content is very influential in damaging the surface of carbon steel, because these ions can stick to the metal surface and inhibit the formation of a protective (passive) layer on the metal surface.

From the presented graphs and tables, researchers can conclude that the use of the E6013 electrode resulted in a slower corrosion rate. This is due to the more even heat input characteristics, thus covering the entire test specimen. Therefore, the E6013 electrode is more suitable for use in welding low-carbon steel. Damage to the weld also affects the rapid corrosion rate, mainly due to flame instability during the welding process.

CONCLUSION

It can be concluded that the corrosion rate is calculated based on the change in the weight of the workpiece. The results showed that the E6010 electrode immersed in seawater solution experienced a significantly higher corrosion rate compared to other electrodes. The initial weight of the workpiece measured was 215.77 grams, and after 15 days of immersion, the weight of the workpiece decreased to 213.88 grams. Therefore, the initial weight of the workpiece decreased by 1.89 grams. The cause was

the use of a welding current of 80 amperes (A), which was not in accordance with the E6010 electrode which should be used with a current between 100 and 120A.

This can be observed with smaller welding spatter and slower electrode melting, the electrode is not completely melted and is unable to cover the entire area to be welded. This results in a rapid increase in corrosion rate and the heat generated spreads more quickly compared to other electrodes. Heat input also plays a role in increasing the rapid corrosion rate. However, when the applied current is stable, good welding results can be achieved, and the corrosion rate will not be too rapid over a 15-day period.

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