Effect of Corrosion on Steel Strength (St. 37)

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ABSTRACT

Rust on steel is often a problem in construction work. Rust occurs when iron oxidizes. The cause is prolonged exposure to water, air, or an acidic environment. Iron will bind oxygen atoms in the air to form iron oxide/rust. Rust continues to increase, accelerating the process of damage to buildings. Rust cannot be avoided, but it can control its rate. St.37 carbon steel is the most widely used material for various types of building construction. Therefore, it is necessary to carry out experimental tests regarding the rate of corrosion and its effect on the strength of steel. In this research, using St.37 steel plates, the corrosion process was carried out by leaving the specimens in an open space, immersing the specimens in sea water, and immersing the specimens in fresh water for 15 days. The aim of this research is to analyze the corrosion rate and its effect on the strength of St.37 carbon steel material. Based on the research results, the average corrosion rate of test plates in open spaces was 0 MPy with an extraordinary resistance category; soaked in sea water 14.76 MPy with good category; and soaked in fresh water 39.37 MPy with the fair category. Meanwhile, based on the tensile test results, the average strength was 560.8 MPa for objects, 510.4 MPa, and 492.8 MPa, respectively. This corrosion rate affects the strength of the steel, the greater the corrosion rate, the tensile strength of the steel plate decreases.

Keywords: steel St.37; corrosion; tensile strength.

INTRODUCTION

Rust is a process of damage to metal materials caused by metal reactions with the surrounding environment (Utomo, 2009). There are two types of corrosion processes, namely chemical and electrochemical processes. Steel that rusts in the open air is an example of chemical process corrosion where corrosion occurs directly and spreads evenly over the entire metal surface, without any electrical current in the metal. Meanwhile, electrochemical corrosion causes the metal surface to form anode and cathode areas so that electrons flow from the anode to the cathode and corrosion occurs. (Natasya et al., 2022).

Types of corrosion based on shape and location include crevice corrosion, pitting corrosion, selective attack corrosion, grain boundary corrosion, erosion corrosion and biological corrosion. Crevice corrosion is local corrosion in areas covered by deposits, often occurring in stainless steel, or aluminum corroded by sea water. Pit corrosion is corrosion in the form of small holes with different diameters and depths and located close together. Selective attack corrosion, usually occurs on mass-produced metals that either have volume defects due to shrinkage or are free of defects that can be attacked by this corrosion. Intergranular corrosion usually occurs in grain boundary areas as a place for the deposition process. Erosive corrosion is the accelerated rate of corrosion caused by very fast relative movement between the corrosive fluid and the metal surface. This happens a lot in piping systems. Biological Corrosion is the result of the activities of living micro or macro organisms either directly or indirectly found in soil, sea water or fresh water, and so on. (Nasution, 2018)

Steel St. 37 is a mild steel, generally described as a low carbon steel that is widely used in making steel bars, bridges, towers, and other construction. This steel is widely used because it is easy to

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weld, does not crack easily, and can be used for welding thin plates and thick plates (Subardi, Djoko Suprijanto, 2009).

One of the weaknesses of steel structures is that they rust easily, this is due to the iron (Fe) atom content in steel. All materials that contain metal, sooner or later will experience corrosion, including steel frame structures. The impact of this corrosion is a decrease in the strength of the steel structure, this is due to the destruction of the carbon content in the steel so that the hardness, tensile strength and compressive strength are also reduced. Apart from that, the function of the structure is not optimal, the building looks unaesthetic/ugly, and maintenance costs are getting higher. For this reason, the rate of corrosion must be prevented or controlled.

Several papers state that in the same time period, the rate of corrosion and structural damage by seawater chloride ions is higher than corrosion in river environments and toilet waste fluids. (Putri & Amalia, 2022).

Based on the various impacts caused by corrosion, especially on steel structures, this experimental research discusses the analysis of the corrosion rate on test plates with various treatments and the influence of corrosion that occurs on test plates on the strength of steel plates. The corrosion process is carried out by immersing the test material in sea water, fresh water, and leaving it without soaking for 15 days. Then calculate the corrosion rate for each test object. The rate of corrosion can be measured using the weight loss method, namely by calculating the weight loss that occurs after a certain amount of immersion time or the difference between the initial weights as in equation [1] below:

$$MPy = 534\frac{W}{DAT} \quad \text{............................ [1]}$$

Information

MPy = miles per year

W = weight lost (mg)

D = density of the corrosion test object (g/cm3)

A = surface area (in2)

T = time (hours)

(Kevin J. Pattireuw, Fentje A. Rauf, 2013)

The relative corrosion resistance of steel is a metal material's resistance to corrosion. There are 6 categories of relative corrosion resistance of a metal. The classification is based on the value of the corrosion rate that occurs. The classification of relative corrosion resistance for steel can be seen in Table 1 below.

Table 1. Relative corrosion resistance of steel

Relative Corrosion Resistance	**Approximate metric eqivalent**		
	MPy	**Mm/year**	***µm/yr***
Outstanding	< 1	<0.02	<25
Excellent	1 – 5	0.02 – 0.1	25 – 100
Good	5 – 20	0.1 – 0.5	100 – 500
Fair	20 – 50	0.5 – 1	500 – 1000
Poor	50 – 200	1 – 5	1000 – 5000
Unacceptable	200+	5+	5000+

Source (Fontana, 1987)

Meanwhile, the effect of corrosion on steel strength is carried out through tensile tests using a UTM (Universal Testing Machine) on each test object with various treatments. From the results of the tensile test, a graph of load vs. length increase at yield and at ultimate is obtained, after which the yield stress, ultimate stress and breaking form of the material are obtained.

RESEARCH METHODS
Materials

The material used for this research was St. Steel plate. 37 2.5 mm thick which is formed to sizes according to ASTM E8 standards for tensile tests. (ASTM E8, 2010). Each treatment consisted of three specimens, namely 3 plates for seawater corrosive media, 3 plates for freshwater corrosive media, and 3 plates for normal conditions (without treatment), for a total of 9 specimens, as shown in Figure 1.

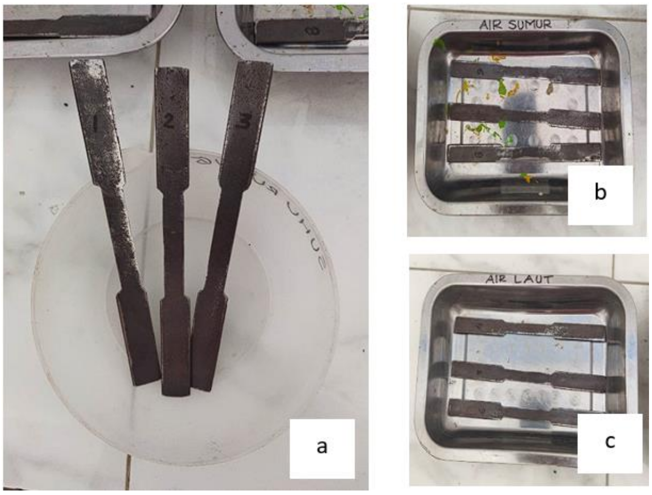

Figure 1. Plate Specimen and Treatment

The tool used for the tensile test is a UTM – TMR 15 T machine equipped with a computer as in Figure 2. Other equipment needed is a caliper for measuring sample dimensions including thickness and sample size in mm, digital scales for calculating sample weight in grams. , a grinding machine for cutting smooth steel plates, and a cup as a container for test samples. The corrosion media used are Lamongan sea water, fresh water and open spaces.

Figure 2. UTM-TMR 15T machine equipped with a computer

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Methods

This experimental research was carried out at the Civil Engineering Laboratory, Faculty of Engineering, Hasyim Asy'ari University Tebuireng Jombang for four months starting from July 2023 to November 2023.

The stages of this research include:

1. Preparation of materials and tools
2. Making test objects
3. Test plate samples were made according to ASTM E8 standards for tensile tests of steel plates. The image of the test object is plotted on a steel plate and cut by machine, then smoothed with sandpaper or a grinder.
4. Each test object is given a number to make it easier to observe, Numbers 1, 2, and 3 for test samples that are left in the open without treatment. Numbers 4, 5, and 6 are for test samples soaked in fresh water. Numbers 7, 8, 9 for test samples soaked in sea water.
5. All test samples were weighed and recorded their weight (Wo) in mg units, then left for 15 days. Taking 15 days as per R. Hartono and D. Subigyar's research regarding the corrosion rate of A36 steel plate soaked in sea water and fresh water for 2 weeks, the results were 0.125 MPy and 0.104 MPy respectively (Hartono & Subigyar, 2020). Apart from that, the highest corrosion rate occurred on the 6th day of immersion, as previous research showed that the highest corrosion rate for mild carbon steel immersed in Gresik seawater, Lamongan seawater and Surabaya seawater was 6 days and after that it decreased (Saputro & Sutjahjo, 2017) .
6. After 15 days of further observation, the test samples were cleaned from attached rust, then the final weight (Wa) was weighed.
7. Calculate the corrosion rate of each sample using the weight loss method.
8. Carrying out a tensile test at the Mechanical Engineering Laboratory, Faculty of Engineering, State University of Malang on August 14 2023.
9. Carry out analysis and discussion
10. Drawing conclusions and suggestions.

For greater clarity, the research stages are as depicted in the research flow diagram in Figure 3.

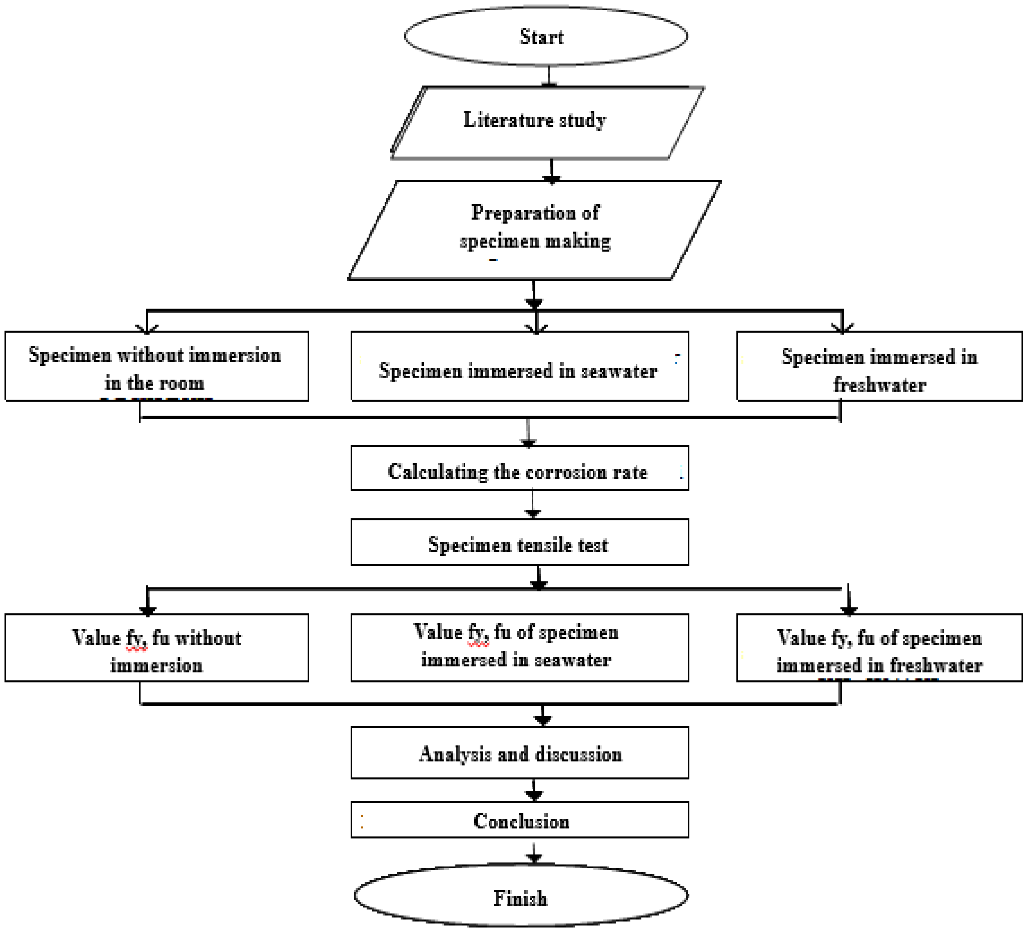

Figure 3. Research Flow Diagram

Data Analysis

The data was analyzed using the weight loss method to calculate the corrosion rate, then the results were compared with the relative corrosion resistance value of the steel for classification (outstanding to unacceptable). To determine the effect of corrosion on the strength of St. 37 was carried out by analyzing the yield stress and ultimate stress of each sample from the material tensile test results.

RESULTS AND DISCUSSION

Corrosion Rate

Figure 4 shows the corrosion that occurred over 15 days. The differences between the three treatments can be seen. For specimens 1, 2, and 3 which were left without soaking, the rust only stuck to the edges of the plate, there were no noticeable changes. For specimens 3, 4, 5 treated with immersion in fresh water, high corrosion was seen with a dark orange color and the water in the cup was dry. This is due to a small leak/water seepage in the cup. Meanwhile, specimens 7, 8, and 9 also experienced corrosion to the point where they were brick red in color and the specimens were still submerged in the cup. Judging from the type of corrosion, this includes uniform corrosion, because it occurs evenly across the surface of the plate with the same composition/intensity, and this corrosion is usually influenced by the atmosphere. (Ginting, 2022).

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Figure 4. Specimens after immersion

Next, the test object is cleaned from attached rust and weighed to determine the weight lost (W). The following are specimen data:

W = Wo – Wa in mg units

A = 12.8 in2

D = 7.85 gr/cm3

T = 360 hours

The results of the corrosion rate calculation are shown in Table 2.

Table 2. Calculation results of corrosion rate for each specimens

Specimens	W (mg)	A (in^2)	MPy	Average MPy
Number 1	0	12,8	0	
Number 2	0	12,8	0	0
Number 3	0	12,8	0	
Number 4	3000	12,8	44,29	
Number 5	3000	12,8	44,29	39,37
Number 6	2000	12,8	29,52	
Number 7	1000	12,8	14,76	
Number 8	1000	12,8	14,76	14,76
Number 9	1000	12,8	14,76	

From the calculation results it is shown that the highest corrosion rate is the specimen soaked in fresh water (specimens number 3, number 4, and number 5) with an average MPy of 39.37, meaning that it has corrosion resistance including the "Fair" category as stated in Table 1. Then followed by specimens soaked in sea water (specimens number 6, number 7, and number 9) with an average MPy of 14.7 including the "Good" category and specimens in open space (specimens number 1, number

2, and number 3) including "outstanding" category. The graph of the relationship between the corrosion rate and the corrosive medium is shown in Figure 5.

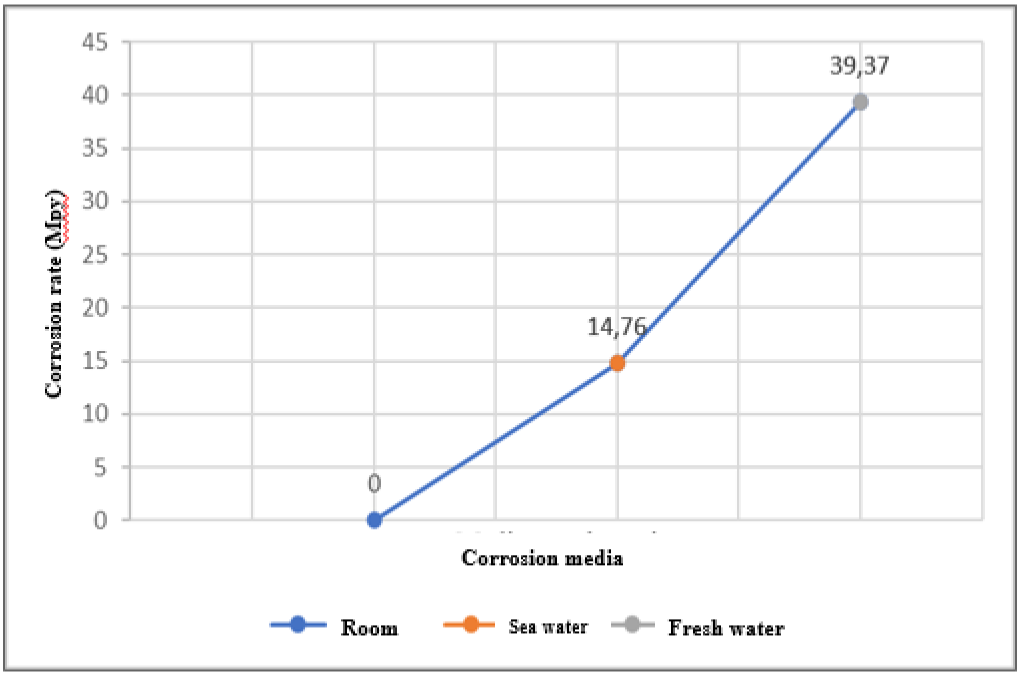

Figure 5. Relationship between corrosion rate and corrosion medium

Based on the graph above, fresh water corroding media has the highest corrosion rate value, namely 30.37 MPy, which is higher than sea water, namely 14.76 MPy. This means that it is different from Hartono & Subigyar's research on medium carbon steel plate A 36 which showed that for 2 weeks the corrosion rate in sea water was 0.125 MPy, higher than 0.104 MPy in fresh water. (Hartono & Subigyar, 2020).

Based on research by H. Irawan, et al, it was found that the corrosion rate of Ss-Aisi 304 steel with pool water for 336 hours (14 days) was 0.018247 mmpy, higher than sea water, namely 0.01746 mmpy but for a soaking time of 504 hours (21 days) the seawater corrosion rate is the highest, namely 0.0356634 mmpy. (Irawan et al., 2023).

Research by Gurum AP, et al shows that in ASTM A36 iron soaked in sea water, the corrosion rate was found to decrease from 72 hours (3 days) to 360 hours (15 days), starting from 6.93 x 10-5 mmpy to 5.42 x 10-5mmpy. (Gurum AP. Ayu SA, Dita Rahmayanti, 2015).

St. Steel Plate Strength 37

Tensile tests were carried out first on specimens without immersion, namely specimens number 1, 2, and 3. The load was applied gradually, starting with zero load and then increasing it little by little until finally the specimen broke. When the load is pulled, the magnitude of the load, increase in length, stress and strain will be recorded by the computer. All data can be displayed in diagram form on the monitor screen which can be formatted according to needs.

Figure 6 is a diagram of load (kgf) vs increase in length (mm) from the tensile test results of specimen number 1. Based on this figure, the yield load is 2071.3 kgf with an increase in length of 3.23 mm. This point is the largest load value that the specimen can withstand without permanent deformation occurring or is the elastic limit of the material where Hooke's Law still applies, so if the load is removed the material will return to its original shape. The area after the elastic limit is the plastic area, where the deformation that occurs is permanent even if the load is removed. Meanwhile, the ultimate load is 2099.2 kgf with a deformation of 5.25 mm.

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Meanwhile, Figure 7 shows the stress (MPa) vs strain (%) diagram of the tensile test results of specimen 1. The relationship between stress and strain is still linear until the yield stress is 677.1 MPa and the strain is 5.38% which is the elastic limit. The slope of the line is the elastic modulus of the material E. However, if the load is increased further, there will be an increase in strain without an increase in stress (plastic area). Then the strain hardening area is an increase in strain with a slight increase in stress. The maximum stress at 686.2 MPa is called the ultimate stress (limit tensile stress). And if the load is increased again, the specimen will break.

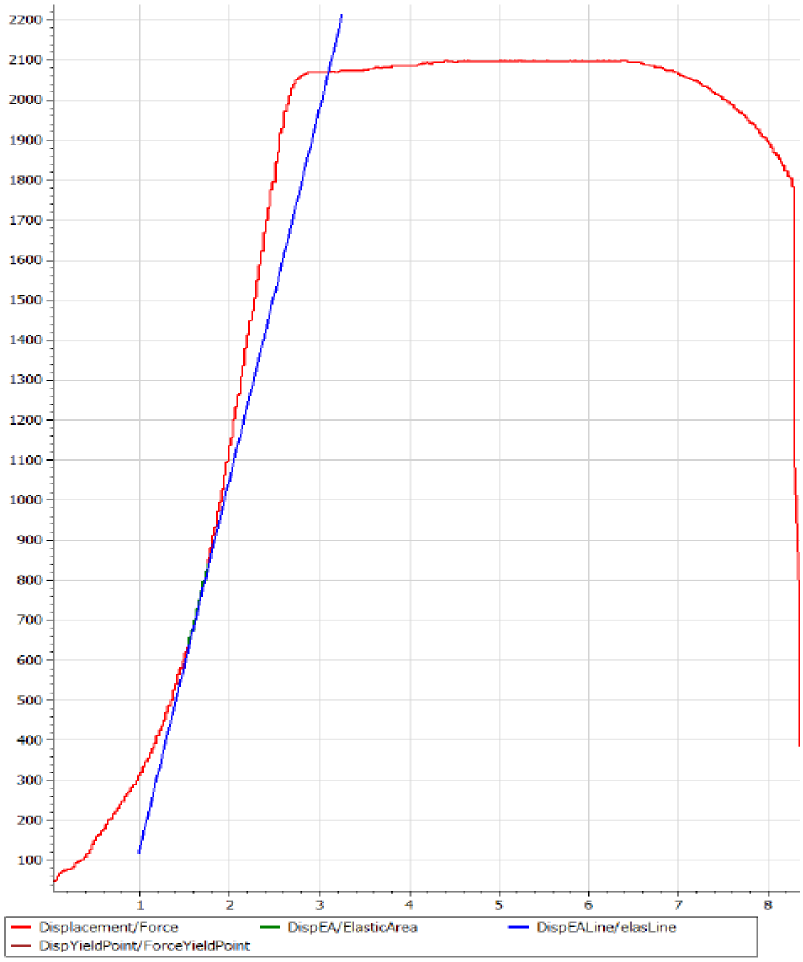

Figure 6. P - Δl diagram of Specimen 1

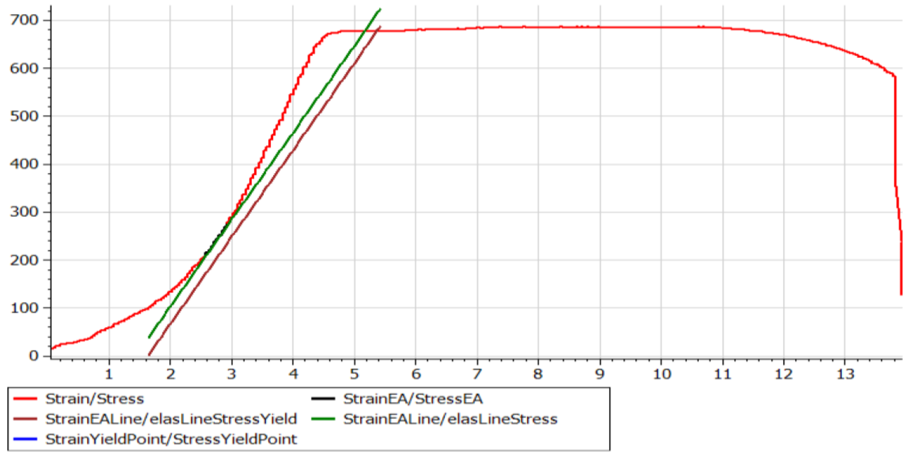

Figure 7. σ - ε diagram for specimen number 1

The tensile test results of the specimens are as presented in Table 3, Table 4, and Table 5.

Table 3. Tensile test results for specimens 1, 2, and 3 (without immersion)

Specimens	σ_{leleh} (MPa)	$\sigma_{ultimat}$ (MPa)	ε_{leleh} (%)	$\varepsilon_{ultimat}$ (%)
No 1	677,1	686,2	5,38	8,74
No 2	479,1	713,3	6,25	20,16
No 3	526,1	741	3,66	19,99
Average	560,8	713,5	5.10	16,30

Table 4. Tensile test results for specimens 4, 5, and 6 (immersion in fresh water)

Specimens	σ_{leleh} (MPa)	$\sigma_{ultimat}$ (MPa)	ε_{leleh} (%)	$\varepsilon_{ultimat}$ (%)
No 4	492,9	704,8	3,7	20,16
No 5	499,4	692,8	3,96	15.25
No 6	486,1	685,3	3,58	18,78
Average	492,8	694,30	3,75	19,47

Table 5. Tensile test results for specimens 7, 8, and 9 (immersion in sea water)

Specimens	σ_{leleh} (MPa)	$\sigma_{ultimat}$ (MPa)	ε_{leleh} (%)	$\varepsilon_{ultimat}$ (%)
No 7	510,4	736,9	2,27	12,97
No 8	504,5	720,4	2,4	10,67
No 9	504,8	717,9	2,46	11,48
Average	521,8	725,1	2,4	11,7

Steel plates left at room temperature are more resistant to rust attacks than plates soaked in fresh water or sea water as shown in Table 6. From the tensile test results it was found that the average yield load of the three specimens was 1715.4 kgf and the average yield stress The average of the three specimens is 560.8 MPa. This value indicates the highest load/stress that the material can withstand without permanent deformation, so if the load/stress is removed the material will return to its original shape. This is the elastic limit where Hooke's law still applies, and this stress value is an important point for designing steel structures using the elastic method. (Matheus Souisa, 2011)

Recapitulation of tensile test results as shown in Table 6 below.

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Table 6. Recapitulation of specimen tensile test results

Specimen treatment	σ_{level} (MPa)	$\sigma_{ultimate}$ (MPa)	ε_{level} (%)	$\varepsilon_{ultimate}$ (%)
left at room temperature	560,8	713,5	5,1	16,3
soaked in sea water (Lamongan)	510,4	725,1	4,0	11,7
soaked in fresh water	492,8	694,3	3,7	19,47

From table 6 it is known that specimens left at room temperature have the highest yield stress with the lowest corrosion rate compared to specimens with immersion treatment which have a high corrosion rate. This shows that the corrosion rate affects the strength of the specimen. As research by Amri Abdullah, et al shows that the rate of corrosion has an impact on reducing the strength of AISI 1065 carbon steel in wire belt ovens, thereby reducing service life. (Amri Abdulah et al., 2019). And the greater the yield stress, the greater the yield strain.

The breaking shape of specimens number 1 to specimen number 9 as in Figure 7 shows that the steel plate is ductile or ductile, that is, when the load reaches its maximum there will be an increase in strain around the area where the cross-sectional area is reduced until finally the material breaks. (Hajar Isworo, S.Pd., 2018)

Figure 8. Shape of Specimens 1 – 9

CONCLUSION

Based on the research results, it can be concluded that the highest corrosion rate is the specimen immersed in fresh water with an MPy value of 39.37 with corrosion resistance in the "fair" category, then the specimen immersed in sea water with an MPy of 14.76 is in the "good" category. . And specimens placed in the open without soaking have the best corrosion resistance in the "outstanding" category. The results of this study are slightly different from previous research in that the corrosion rate in sea water is always higher than fresh water because of the salt content in sea water, but several studies also stated that the corrosion rate in sea water during 15 days of immersion also decreased and vice versa in fresh water. actually higher. In general, the rate of seawater corrosion is maximum in the first week and decreases in the following weeks. This shows that there are many factors that influence the rate of corrosion, for example soaking time, temperature, corrosion media, chemical content, homogeneity and microstructure of the material. Likewise, the greatest influence of corrosion on steel strength is that specimens immersed in fresh water have the lowest yield stress, namely 492.8 MPa, then specimens immersed in sea water have a yield stress of 510.4 MPa, and specimens left in the open have the highest yield stress, namely 560.8 MPa. However, the highest ultimate stress was achieved by specimens soaked in sea water, namely 725.1 MPa, which was greater than specimens left at room temperature without immersion, namely 713.5 MPa. Based on the results of this research, it can also be concluded that materials that have a high corrosion rate have a low yield stress, such as specimens soaked in fresh water, but for the ultimate stress value, a high corrosion rate does not necessarily mean a low ultimate stress. And the highest yield strength is in specimens left at room temperature with the lowest corrosion rate. This yield strength/stress is proportional to the yield strain. The yield strain values, respectively from the lowest, are 3.7% for specimens soaked in fresh water, 4% for specimens soaked in sea water, and 5.1% for specimens left at room temperature. Meanwhile, the ultimate strain values were respectively 19.5% for specimens in fresh water, 11.7% for specimens in seawater, and 16.3% for specimens in room.

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