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# Characteristics of ASTM A36 steel plate corrosion rate due to bending treatment with angle, corrosion media, and corrosion time variations

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ABSTRACT

Bending can cause stress to the workpiece, where the stress can cause a fine crack in the metal which can lead to corrosion. Corrosion that occurs can result in a decline in the quality of metals, especially in mechanical properties. This study aims to determine the characteristics of the corrosion rate of each bending angle. This study uses low carbon steel with ASTM A36 type plates, this type of steel is often used in ship production. This research is an experimental study using descriptive statistical methods, and 3x3 factorial Anava for testing hypotheses. From this research, the results obtained in the form of corrosion rate values, where the characteristics of the corrosion rate of steel plates with the lowest corrosion resistance are at 60$^o$ bending treatment, seawater media, and 48 hours with a corrosion rate of 2.005 mmpy. Corrosion rate characteristics with the best resistance are in the bending treatment of 120$^o$, PDAM water media, and 24 hour time with a corrosion rate of 0.695 mmpy. Hypothesis test results state that there is a significant effect of variations in bending angle, corrosion media, and corrosion time on the value of the corrosion rate.



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## 1. Introduction

Bending is widely applied to the manufacturing industry, especially in the manufacture of machine bodies, engine covers, brackets, truck bodies, and another. In the process of bending can result in stress on the workpiece, where the stress can result in fine cracking of metals that can trigger corrosion. Corrosion that occurs can result in a decline in metal quality. The decline in quality is certainly something to consider in the bending process, and therefore it is necessary to test the corrosion rate of the bending plate.Quality degradation in question is the decline in mechanical properties of metals.

Decreased mechanical properties caused by corrosion include; decreased steel strength, steel tenacity, and steel toughness. Mechanical properties are very important in the planning of a metal product, especially that the products resulting from bending of the plate (fold) are machined products, which require planning and maintenance, so that the loss of corrosion caused by bending becomes a consideration in plate Works

## 2. Method

This study uses an experimental method with a one shot case study model, where specimens are given certain treatments, then the results are observed. Data analysis techniques used in this study were descriptive statistics and 3x3 factorial anova statistical. Descriptive statistics are used to discuss the characteristics of the corrosion rate, while 3x3 factorial inferential statistics are used to test the research hypothesis.

The material used in this research is ASTM A36 low carbon steel plate with a thickness of 4.8 mm. Before bending, the specimen is cut to size 20 mm x 50 mm by 90 pieces. Specimens with bending treatment amounted to 81, with a bending angle of 60$^o$, 90$^o$ and 120$^o$, so that each bend angle was 27 specimens. The remaining plates are without bending treatment which amounts to 9.

This research focuses on stress corrosion, but in the bending process there are parts of the plate that are affected by stress, and some are not affected by stress. The part that is affected by the stress is the center of the plate with a size of 25 mm x 20 mm, while the part that is not affected by the voltage is the two ends of the plate with a size of 12. 5 x 20 mm, the part has the same dimensions or can be called ½ the part that is affected by the stress.

So that the results of corrosion testing carried out purely by stress corrosion require a plate without bending treatment which is then the weight of ½ plate of the corrosion rate test results are used to reduce the weight of ½ plate by bending treatment. The weight reduction is carried out at the initial weighing, and at the end of the specimen. Weighing the specimens in this study using a digital scale with a precision of 0.001 gr.

The corrosion rate testing standard used in this study is ASTM G31-72 Standard Practice for Laboratory Immersion Corrosion Testing of Metals. Fig. 1 is an illustration of the bending process with the part of the plate being affected and not affected by stress.

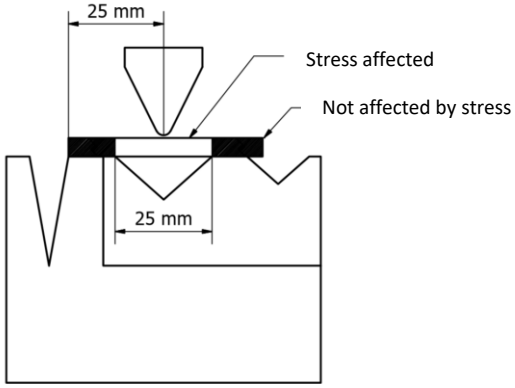


**Fig. 1.** Plate section

Corrosion media used are PDAM Malang City water, Malang City rainwater, and Sendang Biru Regency Malang sea water. Rainwater media, and PDAM water are taken directly with each volume of 19L, specifically for sea water media taken at a distance of about 1 km from the beach so that the sea water used is not contaminated with fresh water. The volume of the corrosion media can be calculated using the formula based on the following ASTM G31-72 standard.

$$\text{Liquid volume} = (\text{Minimum ratio}) \times (\text{Surface area}) \quad (1)$$

Information:
Minimum ratio = 0.20 - 0.40 (ml/mm$^2$)
Surface area = 2 x (p x l + p x t + l x t) (mm$^2$)

Thus the minimum volume of fluid that can be used is

Liquid volume = 0.20 x [2 x (50 x 20 + 50 x 4.8 + 20 x 4.8)
= 0.20 x 2672
= 534 ml

Corrosion rate testing method used is a weight loss method, this method is often used because the equipment used is simple, and the test results are accurate. Corrosion time variations used in this study were 24 hours, 48 hours and 72 hours. Based on ASTM G31-72 the minimum time to check corrosion rate is 48 hours, but because the material used is classified as susceptible to corrosion, the lowest variation used is 24 hours. The formula used to calculate the corrosion rate is as follows.

$$\text{Corrosion rate} = \frac{K \cdot w}{\rho \cdot A \cdot T} \quad (2)$$

Information:
K = Constants in mmpy (8.76 x 10$^4$)
W = Weight loss (mg)
$\rho$ = Density (mg/mm$^3$)
A = Surface area (mm$^2$)
T = Corrosion time (hours)

## 3. Results and Discussion

Corrosion rate testing is carried out for the part that is affected by the stress that is the middle part of the plate with a size of 20 mm x 25 mm x 4.8 mm. The results of this study are the corrosion rate values of each treatment. Treatments with time variations (A), bending angles (B), and corrosion media (C). Table 1 shows the presentation of the data of ASTM A36 steel plate corrosion test results.

**Table 1**. Corrosion rate value (mmpy)

| No | Time | Angle | Corrosion Media | | |
|---|---|---|---|---|---|
| | | | PDAM | Rain water | Sea water |
| | | 60 | 1.444 | 2.406 | 0.962 |
| | 24 | 90 | 1.444 | 2.085 | 0.962 |
| | | 120 | 1.444 | 1.764 | 0.962 |
| | | 60 | 1.444 | 1.604 | 1.845 |
| 1 | 48 | 90 | 1.444 | 1.444 | 1.845 |
| | | 120 | 1.764 | 1.283 | 1.363 |
| | | 60 | 1.39 | 1.497 | 1.978 |
| | 72 | 90 | 1.497 | 1.176 | 1.23 |
| | | 120 | 1.176 | 0.749 | 1.123 |
| | | 60 | 1.123 | 1.764 | 1.283 |
| | 24 | 90 | 0.481 | 0.802 | 1.283 |
| | | 120 | 0.481 | 1.123 | 1.283 |
| | | 60 | 1.764 | 1.283 | 2.326 |
| 2 | 48 | 90 | 1.764 | 1.604 | 1.684 |
| | | 120 | 1.604 | 1.604 | 1.524 |
| | | 60 | 1.176 | 1.925 | 1.764 |
| | 72 | 90 | 1.069 | 1.497 | 1.337 |
| | | 120 | 1.069 | 1.283 | 0.802 |
| | | 60 | 0.802 | 0.481 | 1.283 |
| | 24 | 90 | 0.481 | 0.16 | 0.962 |
| | | 120 | 0.16 | 0.16 | 0.962 |
| | | 60 | 1.123 | 2.567 | 1.845 |
| 3 | 48 | 90 | 0.802 | 1.764 | 1.845 |
| | | 120 | 0.642 | 1.123 | 1.845 |
| | | 60 | 1.497 | 1.283 | 1.551 |
| | 72 | 90 | 0.642 | 1.069 | 1.337 |
| | | 120 | 0.856 | 0.856 | 0.588 |

### 3.1. Characteristics of Corrosion Rate Due to Bending 60º

Stresses that occur due to bending 60º, 90º and 120º are certainly different, this is evidenced by using Autodesk Inventor 2017 software, this simulation is in the form of stress analysis in order to determine the stress distribution caused by the bending process. In this simulation each is given the same load that is 100N on bending 60º, 90º, and 120º.

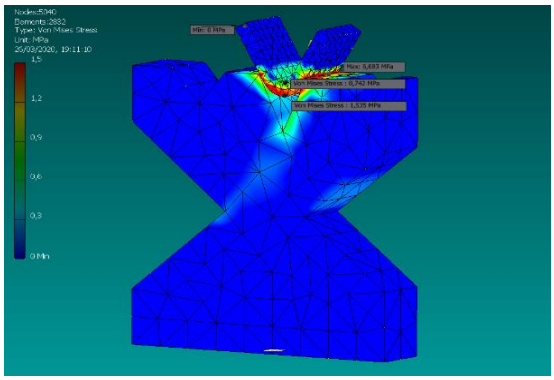

**Fig. 2.** Stress distribution bending 60º

The stress that occurs in bending 60º is the biggest compared to the others. The part that is affected by the maximum stress is red area, and the neutral stress is blue area. The maximum stress that occurs is 6.683 MPa. As a result of this bending treatment the thickness of the plate in the middle is reduced by 0.7 mm.

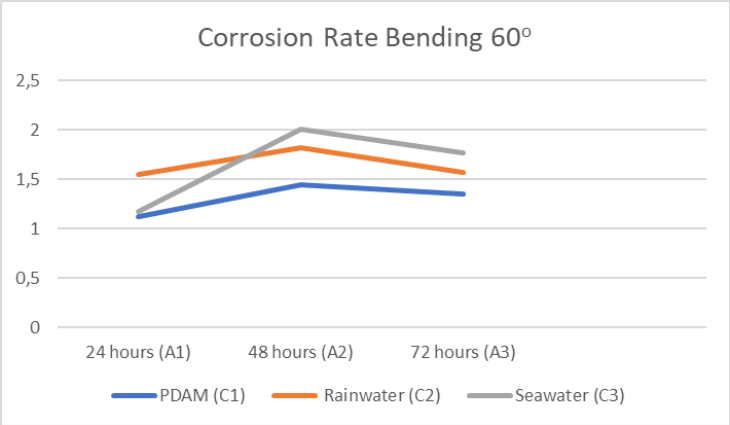


**Fig. 3.** Bending 60º corrosion rate chart

The characteristics of ASTM A36 steel plate corrosion rate due to bending 60º can be seen in the Fig. 3. At 24 hours the rainwater media was the most corrosive, but at 48 hours the sea water media became the most corrosive. The lowest corrosion rate value is at $A_1C_1$ treatment (24 hour time, and PDAM water media), the highest corrosion rate value is at $A_2C_3$ treatment (48 hour time, and seawater media). The quality of the corrosion resistance is classified as poor.

### 3.2. Characteristics of Corrosion Rate Due to Bending 90º

Maximum stress that occurs due to bending 90º is in the middle of the plate with a value of 5.742 MPa, while the part that is not affected by the stress is the blue area. For more details, the stress distribution can be seen in Fig. 4 below.

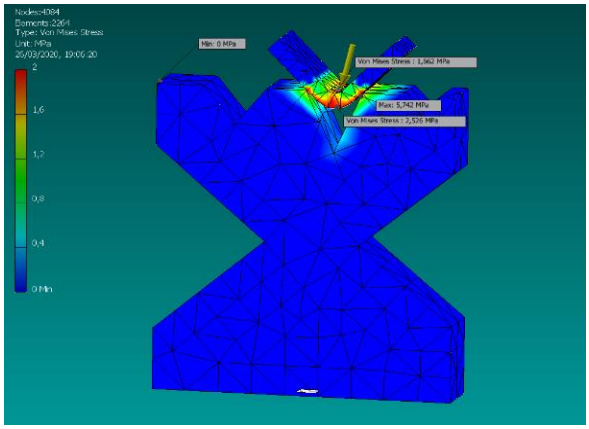

**Fig. 4.** Stress Distribution Bending 90º

As a result of bending 90º plate thickness is reduced by 0.4 mm in the middle. Just like the previous stress analysis simulation using Autodesk Inventor 2017 software, with a load of 100N. The characteristics of ASTM A36 steel plate corrosion rate due to bending 90º lower than with bending 60º that is because the stress that occurs is smaller. The greater the bending angle, the smaller the stress that occurs. The characteristics of the corrosion rate due to bending 90º can be seen in Fig. 5 below.

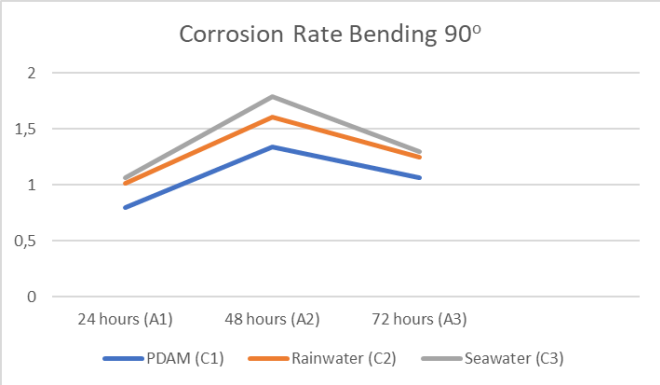


**Fig. 5.** Bending 90º Corrosion Rate Chart

Corrosion rate tends to increase at 48 hours, then decrease at 72 hours. The most corrosive media are sea water with a pH of 7.3, then rainwater with a pH of 6.4, and PDAM water with a pH of 6.2. The highest corrosion rate is in the $A_2C_3$ treatment (48 hours, and seawater media) with poor corrosion resistance. Corrosion rate with the lowest value is at $A_1C_1$ treatment (24 hours, and PDAM water media) with fair corrosion resistance.

### 3.3. Characteristics of Corrosion Rate Due to Bending 120º

The stress that occurs due to bending 120º is the smallest compared to other angular variations. The maximum stress that occurs is in the red area, which is in the middle of the plate with a value of 4.453 MPa. The part that is blue is the part of the plate that is not affected by stress.

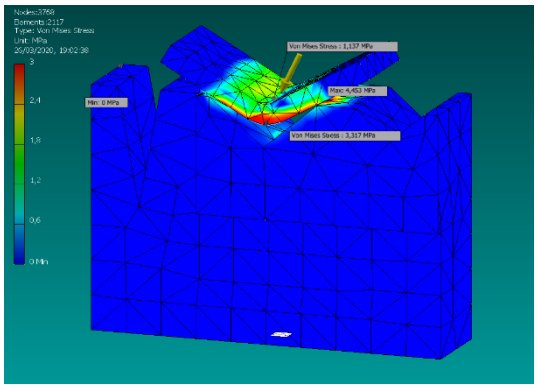

**Fig. 6.** Stress Distribution Bending 120º

In the stress analysis simulation the same as before, namely by using a load of 100N. The bending treatment with an angle of 120º causes the thickness of the center of the plate to be reduced by 0.2 mm, so that the thickness of the plate becomes 4.6 mm.

Corrosion rate characteristic of 120º bending is the best corrosion resistance compared to other angular variations, it is because the stress (corrosion trigger) at 120º bending is relatively low. The greater bending angle that is formed, the smaller the stress that occurs. Here is Fig. 7 on the chart of ASTM A36 steel plate corrosion rate due to bending 120º.

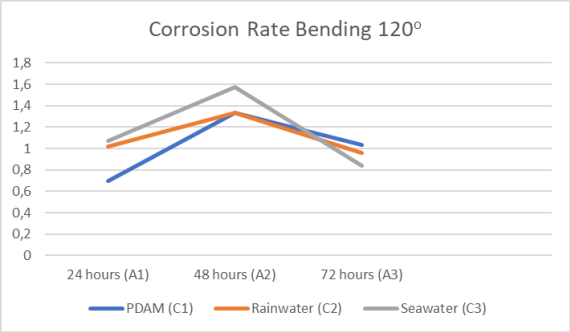


**Fig. 7.** Bending 120º Corrosion Rate Chart

Corrosion rate with the greatest value is in the $A_2C_3$ treatment (48 hours, and seawater media) with poor corrosion resistance. Corrosion rate with the lowest value is at $A_1C_1$ treatment (24 hour time, and PDAM water media) with fair corrosion resistance. Classification of the corrosion rate is based on ASTM G31-72 standard, where if the corrosion rate value of 1-5 mmpy is classified as poor, and 0.5-1 mmpy is classified as fair.

From the whole test it is proven that the bending angle with the best corrosion resistance is 120º, and the bending angle with the worst corrosion resistance is 60º. This is due to the stresses that occur due to bending, the greater the stresses resulting in rapid corrosion rates. The results of hypothesis testing also stated that there was a significant effect of variations in bending angle, corrosion media, and corrosion time on the corrosion rate values.

## 4. Conclusion

The results of ASTM A36 steel plate corrosion rate due to bending with variations in angle, corrosion media, and corrosion time prove that there is an influence of the three variations on the value of corrosion rate. The smaller of bending angle causes the faster corrosion rate, it is because the small bending angle causes a large stress in the bending process.

Sea water corrosion media is the most corrosive, it is due to the large pH of sea water. The pH of sea water is 7.3, while the pH of rainwater is 6.4, and the pH of PDAM water is 6.2. This research proves that the greater the pH value of the corrosion media, the higher the corrosion rate can be.

Corrosion time also affects the corrosion rate value, the corrosion time with the highest corrosion rate value of all tests is 48 hours, and the corrosion time with the lowest corrosion rate value is 24 hours. The results of hypothesis testing also state that there is a significant effect of variations in bending angle, corrosion media, and corrosion time on the corrosion rate values.

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