Abstract. Corrosion is one of the degradation materials in Industrial problem. One of the processing to choose material is to determine how to have resistance to all the environment. This research is carried out to determine characterize the effect of various temperatures (150, 200, 250°C) and time (4, 6 and 8 hours) of exposure of Low Carbon Steel in corrosion rate and mechanical properties by using Mass Balance method and Potassium Chromate vapor as medium corrosion. The results have shown that the increasing temperature ids increasing corrosion rate which is the maximum value is $5.1215 \times 10^{-4}$ miles/years. The difference in corrosion rate increasing by 6.3% based on increasing temperature. The microstructure has shown is intergranular corrosion mode.

Keywords: Low Carbon Steel, Potassium Chromate, Corrosion rate.
2. Method and Materials

Carbon steel is an alloy between iron (Fe) with carbon content between 0.10% - 0.14% C. Based on the amount of carbon content, carbon steel can be clarified into three types. The material used was Carbon Steel S45C.

2.1 Strain Gauge

A strain gauge is a metal or semiconductor element whose resistance changes when under pressure [2]. A strain gauge consists of three core parts, namely: wire, base, and adhesive. Because all materials are resistant to deformation, several forces must be applied to cause a deformation, and resistance can be related to the force applied.

The number of strain gauges applied at high temperatures using platinum metal groups has been developed. Platinum, a metallic metal used in strain gauge has a composition in percent by weight: platinum (8.5 - 9.5), tungsten (Pt - (8.5 - 9.5) W), platinum-8 nickel-2 tungsten (Pt-8Ni-2W), platinum-8 nickel-2 chromium (Pt-8Ni-2Cr), and palladium-13 chromium (Pd-13Cr). Strain gauges containing non-precious metals are copper-nickel (Cu-Ni), nickel-chrome (Ni-Cr), and iron-chrome (FeCr-Al) [3].

Corrosion is metal degradation or damage caused by a redox reaction between a metal and the surrounding environment that produces unnecessary materials. In everyday language, corrosion is called rusting. The most common example of corrosion is iron rusting [14]. In the event of corrosion, the metal undergoes oxidation, while oxygen (air) has a reduction. Metal rust is generally in the form of oxide or carbonate. The chemical formula for iron rust is Fe₂O₃.nH₂O, a red-brown solid.

The average static corrosion rate at high temperatures is indicated by the change in mass per unit area expressed in Equation 2.1 [4].

\[
\Delta m = \frac{(W_\text{F} - W_\text{O})}{A}
\]  

where:
\( \Delta m \): changing of mass divided by exposed area \( \text{[g/m}^2\text{]} \)

\( W_\text{F} \): oxides mass \( \text{[g]} \)

\( W_\text{O} \): Before oxides mass \( \text{[g]} \)

\( A \): exposed cross section area \( \text{[m}^2\text{]} \)

When the relationship curve is made between changes in the mass of the broad unity with the oxidation time, for materials that have corrosion resistance at high temperatures, because the surface has a strong and stable protective layer, usually the curve is parabolic, the standard parabolic equation can be stated in Equation 2.2.

\[
\Delta m = k \sqrt{t}
\]  

where:
\( k \): reaction rate constant \( \text{[g/m}^2\sqrt{\text{time}}\text{]} \)

\( t \): oxidation time \( \text{[s]} \)
\[ \Delta m = \left( kpt \right)^{1/2}. \]

where \( \Delta m \): changing mass divided by exposed area \[ \text{g/m}^2 \]

\( k \): parabolic constant \[ \text{g/m}^2 \text{s}^{-1} \]

\( t \): oxidizing time \[ \text{h} \]

The test materials used:

- Fig 2: Potassium Chromate
- Fig. 3: S45C Spec
- Fig. 4: Demineral Water
- Fig. 5: Demineral \( \text{K}_2\text{CrO}_4 \) (K2CrO4)
- Fig. 6: Corrosion Mass Test Equipment

3. Results and Discussions

Retrieval of test data is carried out to determine the change in output voltage (Vout) on a digital multimeter due to chemical reactions between the element Fe with the element K\(_2\)CrO\(_4\). The data is obtained by recording a multimeter and digital multimeter display for 1 minute per hour during the test time conditions (4, 6, 8 hours). To obtain accurate data, 12 data are taken in 1 minute, meaning that data is taken every 5 seconds in 1 minute.

Chemical reaction that occurs in this study is:

\[ \text{K}_2\text{CrO}_4 + 3\text{O}_2 + 2\text{Fe} = \text{CrO}_2 + 2\text{K}_2\text{O} + 2\text{Fe}(\text{O})_3. \]

On the results of the study in Table 4.1, Table 4.2, and in Table 4.3, the results obtained in that table can be found the mass change in units of grams. By way of converting the output voltage (Vout) becomes mass in units of grams. In the example the calculation is given in the Appendix.
The following table is the calculation results overall for S 45 C steels in Figure 4.34 and Table 4.35:

### Table 1. Mass Calculation Results in S 45 C Steel With Temperature 150°C, 200°C, 250°C With 8 Hours Test Time

| No. | Test (Hour) | Temperature | m (gram) | ∆m (gram) | M (gram) | ∆m (gram) | M (gram) | ∆m (gram) |
|-----|-------------|-------------|----------|-----------|----------|-----------|----------|-----------|
| 1   | 0           | 150°C       | 0.009560348 | 0         | 0.009615656 | 0         | 0.009631576 | 0         |
| 2   | 1           | 150°C       | 0.009536839 | 0.000023509 | 0.009711973 | 0.000096317 | 0.009687713 | 0.000056137 |
| 3   | 2           | 150°C       | 0.009583973 | 0.000047314 | 0.009752677 | 0.000040704 | 0.009736354 | 0.000048641 |
| 4   | 3           | 150°C       | 0.009615656 | 0.000040773 | 0.009785486 | 0.000041604 | 0.009835117 | 0.000049631 |
| 5   | 4           | 150°C       | 0.009720086 | 0.000104430 | 0.009818518 | 0.000033032 | 0.009895290 | 0.000067649 |
| 6   | 5           | 150°C       | 0.009793723 | 0.000050051 | 0.009902079 | 0.000041957 | 0.009935117 | 0.000051348 |
| 7   | 6           | 150°C       | 0.009826811 | 0.000033088 | 0.009952903 | 0.000050824 | 0.010004251 | 0.000051348 |
| 8   | 7           | 150°C       | 0.009760859 | 0.000040773 | 0.009860122 | 0.000041604 | 0.009885254 | 0.000050137 |
| 9   | 8           | 150°C       | 0.009876862 | 0.000050051 | 0.010012860 | 0.000059957 | 0.010047447 | 0.000043196 |

### Table 2. Results of Calculation of Average Corrosion Rate Per Year Against Temperature On Testing For 4 Hours

| No. | Temperature (°C) | m (gram) | ∆m (gram) | Corr.Rate (mm/hour) | Corr.Rate (mils/year) |
|-----|------------------|----------|-----------|---------------------|-----------------------|
| 1   | 150°C            | 0.009603380 | 0.000041387 | 0.0008427446 | 4.5872 x 10^{-6} |
| 2   | 200°C            | 0.009736862 | 0.000040572 | 0.0008261573 | 4.4969 x 10^{-6} |
| 3   | 250°C            | 0.009787772 | 0.000045903 | 0.0009347019 | 5.0877 x 10^{-6} |

### Table 3. Results of Calculation of Average Corrosion Rate Per Year Against Temperature On Testing For 6 Hours

| No. | Temperature (°C) | m (gram) | ∆m (gram) | Corr.Rate (mm/hour) | Corr.Rate (mils/year) |
|-----|------------------|----------|-----------|---------------------|-----------------------|
| 1   | 150°C            | 0.009653069 | 0.000040082 | 0.0008161674 | 4.4425 x 10^{-6} |
| 2   | 200°C            | 0.009778073 | 0.000040917 | 0.0008261573 | 4.5351 x 10^{-6} |
| 3   | 250°C            | 0.009787772 | 0.000045903 | 0.0009347019 | 5.0877 x 10^{-6} |
Table 4. Results of Calculation of Average Corrosion Rate Per Year Against Temperature in Testing for 8 Hours

| No. | Temperature (°C) | m (gram) | ∆m (gram) | Corr. Rate (mm/hour) | Corr. Rate (mils/year) |
|-----|------------------|----------|-----------|----------------------|------------------------|
| 1   | 0                | 0        | 0         | 0                    | 0                      |
| 2   | 150              | 0.000040412 | 0.000040412 | 0.0008228911 | 4.4791 x 10^{-6} |
| 3   | 200              | 0.000044134 | 0.000044134 | 0.000896804  | 4.8917 x 10^{-6} |
| 4   | 250              | 0.000046208 | 0.000046208 | 0.000940124  | 5.1215 x 10^{-6} |

Results of Discussion and Analysis of Observation of Macro Structure and Microstructure. From the observation of microstructure testing with temperatures of 150°C, 200°C, 250°C for 4 hours, 6 hours, 8 hours, seen in the macrostructure there are green spots caused by the evaporation of potassium chromate solution. In the microstructure testing, it is clear that the structures that look ferrite and pearlite. The test results confirm that after Nital etching and 500 times magnification, each it is seen in the example Figure 4.44.

Figure 4.44: The sample it had been in 500 x magnification

Vickers hardness test results on S 45 C steel obtained using the Micro Hardness Test Instrument. In this hardness test, the hardness value of specimen 0 to specimen 9 is obtained, the value of hardness does not increase constantly because homogenization has not been done.
No. Specimen | D1 (µm) | D2 (µm) | HV
--- | --- | --- | ---
S0 | 58.44 | 58.44 | 271.5
S1 | 59.63 | 59.63 | 260.8
S2 | 57.50 | 61.19 | 263.6
S3 | 59.88 | 59.88 | 258.6
S4 | 62.13 | 61.38 | 243.2
S5 | 57.56 | 66.31 | 241.7
S6 | 60.56 | 60.56 | 252.8
S7 | 50.06 | 50.19 | 369.0
S8 | 59.88 | 64.19 | 241.2
S9 | 63.06 | 60.44 | 243.2

4. Conclusion

The highest corrosion rate is found in the specimen tested at temperature 250°C, because the higher the test temperature, the greater the mass change that occurs.

Potassium chromate solution is alkaline which means it is also corrosive.

The results of the calculation of the corrosion rate on the S 45 C steel for 4 hours with the temperature of 150°C is 4.5872 x 10^-6 mils/year, at a temperature of 200°C with a corrosion rate of 4.4969 x 10^-6 mils/year, and at a temperature of 250°C with a corrosion rate of 4.5119 x 10^-6 mils/year.

The results of the calculation of the corrosion rate on the S 45 C steel for 6 hours with the temperature of 150°C is 4.4425 x 10^-6 mils/year, at a temperature of 200°C with a corrosion rate of 4.5351 x 10^-6 mils/year, and at a temperature of 250°C with a corrosion rate of 5.0877 x 10^-6 mils/year.

The results of the calculation of the corrosion rate on the S 45 C steel for 8 hours with a temperature of 150°C is 4.4791 x 10^-6 mils/year, at a temperature of 200°C with a corrosion rate of 4.8917 x 10^-6 mils/year, and at a temperature of 250°C with a corrosion rate of 5.1215 x 10^-6 mils/year.

Percentage change in corrosion rate by using a solution of potassium chromate of 6.3%.

References

[1] Wilson, E. J. (1976). Transducer and Turbine Applications of Strain Gages. Colorado: Society for Experimental Stress Analysis.

[2] Bentley, J. P. (2005). Principles of Measurement Systems Fourth Edition. Malaysia: Prentice Hall.

[3] Jinxing Guo, L. T. (1997). Platinum Alloy Strain Gauge Materials Noble Metals. Platinum Metals Rev., 24-32.

[4] Fontana, Mars. G., Corrosion Engineering, 3rd Edition. Houston: McGraw-Hill, 1986. U. A. Bakshi, A. a. (2008). Electronic Measurements & Instrumentation. India: Technical Publication Pune.

[5] U. A. Bakshi, A. a. (2008). Electronic Measurements & Instrumentation. India: Technical Publication Pune.

[6] O. A. Omotosho, dkk. 2014. Investigating Potassium Chromate and Aniline Effect on Concrete Steel Rebar Degradation in Saline and Sulphate Media.