

The Study of Corrosion Behavior and Hardness of AISI Stainless Steel 304 in Concentration of Chloride Acid Solution and Temperature Variations

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Abstract. This research aims at investigating the corrosion behavior and hardness of AISI Stainless Steel 304 (AISI SS 304) in corrosive hydrochloric acid solution and temperature variation treatment. In this study, the samples of AISI SS 304 are immersed for six (6) days in the corrosive acid solution at the temperature of 30°C and 50°C. The solution used as the corrosive media are HCl, FeCl₃, and NaCl in the concentration of 5%, 10% and 15%. The results show that the higher the concentration of the solution, the higher the corrosion rate of AISI SS 304 will be, and the higher the temperature, the higher corrosion rate will also occur in all corrosion media. The corrosion that occurs in AISI SS 304 is mostly in the form of uniform corrosion and some pitting corrosion, and the value of hardness decreases after corrosion.

1. Introduction

Corrosion is a decrease in the quality of materials caused by the chemical reaction of metals with other elements found in the natural environments [1]. Corrosion can occur in dry and wet environments. The rate of corrosion depends on temperature, reactant concentration, the initial number of particles (mass) of metals, and mechanical factors such as stress [2].

Stainless steels are kind of materials which are widely used in the industrial world because they are easy to obtain and have relatively cheap prices. Based on the crystal structure, stainless steels have five groups, they are austenitic stainless steels, ferritic stainless steels, martensitic stainless steels, duplex stainless steels and depositional hardening stainless steels [3].

Austenitic stainless steels are kind of steels that have good corrosion resistance, formability, weldability and non-ferromagnetic properties. At low temperatures, they are often used for cryogenic applications. Austenitic stainless steels which contain chromium and nickel are given serial numbers 300. Stainless Steel 304 (SS 304) is a type of austenitic stainless steels with good weldability, mechanical strength, and corrosion resistance. Stainless steel 304 can be applied to various industrial and non-industrial fields. The use of SS-304 is for various types of liquids and solids (tanks and containers), mining equipment, chemical, food, and pharmaceutical industries. However, SS 304 can also be corroded in a highly corrosive environment [3-4].

SS 304 can still be attacked by corrosion. Corrosion that can occur is in the form of grain boundary corrosion (intergranular corrosion), hole corrosion (crevice corrosion), pitting corrosion, and stress



corrosion cracking [5]. To find out the superiority of austenitic stainless steel as a construction material, it is necessary to do research on the local corrosion of stainless steel. examined the effect of pH and chloride concentration on corrosion of stainless steel duplex. This test was carried out with the ASTM G-48 standard, which was immersed in two different temperatures 25 ° and 50 ° C for 72 and 144 hours. The steel is immersed with a solution of FeCl, HCl and NaCl. The conclusion is that the greater the temperature and concentration of chloride, the higher the corrosion rate will be [6].

The research was conducted on the hardness and corrosion rate of stainless steel 304 in corrosive media. The corrosive media used are 3.5% of NaCl, sea water, and HCl. In this study, the test sample was immersed in a corrosive medium (3.5% of NaCl, sea water, and HCl solution) for 7 days. Corrosion rate does not significantly affect the level of hardness in the sample. The hardness of the sample decreased by about 0.1 HRB after being immersed in the corrosive media. The sample immersed in 3.5% of NaCl experienced the highest corrosion rate compared to sea water and HCl solution [7].

In this study, corrosion testing is carried out using the weight loss method with the sample of AISI 304 stainless steel (AISI SS 304) which is immersed in HCl, FeCl₃, NaCl solution media for 6 days, with concentrations of 5%, 10% and 15% of the solution in the temperature of 30 ° C and 50 ° C [7-8].

This study aims to study the corrosion behavior and the hardness of SS 304 after the treatments, so the results of this research can be used as one of the considerations to determine the lifetime of AISI stainless steel 304 in an acidic environment which is a highly corrosive environment.

2. Method

The method used in the study was divided into four (4) stages, they were:

1. The preparation of SS 304 Sample which referred to ASTM G48;
 - a) SS 304 samples were cut into size of 25 mm x 25 mm x 3 mm.
 - b) The samples that had been cut were then cleaned and smoothed (their surface) using sandpaper with a roughness of 80, 120, 200, 800 1500 grit.
 - c) The samples were then dipped in acetone and distilled water to clean the impurities attached to the steel and then washed using distilled water.
2. The Preparation of Corrosive Media referred to ASTM G31-72.

The minimum volume of corrosive media is $(0.2-0.4 \text{ ml} / \text{mm}^2) \times (\text{surface area of the sample})$. Corrosive medium is a solution that causes corrosion. In this study, the corrosive media to be used were in the form of solution of HCl, FeCl₃, and NaCl, with concentration of 5%, 10% and 15% at the temperature of 30°C and 50°C.
3. The Immersion process referred to ASTM G31-72
The process of sample immersion referred to the ASTM G31-72 standard which was carried out for 6 days. SS 304 samples were immersed in corrosive HCl, FeCl₃, NaCl in concentrations of 5%, 10% and 15%) for 6 days at 30°C and 50°C.
4. The Calculation of the corrosion rate of the immersion test method.
The corrosion rate measurement used was the weight loss method. The weight loss method is the most widely used method of measuring corrosion rates. The samples were placed in the media and let them be corroded. Afterwards, the corrosion rate was then calculated through the weight loss that occurred in the samples.

3. Results and discussion

3.1. The Corrosion rate of SS 304

Based on the data generated in the test of corrosion rate using the AISI SS 304 weight loss method with the corrosion media of HCL, FeCl₃, and NaCl at temperatures of 30°C and 50°C, that are shown in figures 1, 2 and 3, it can be analyzed that the corrosion rate increases with the increase of the concentration of electrolyte solution and also with the increase of the temperature. The highest corrosion rate was found in the solution of FeCl₃ in the concentration of 15% with the temperature of 50 °C (shown in figure 2). its corrosion rate is 77.3 mm / y.

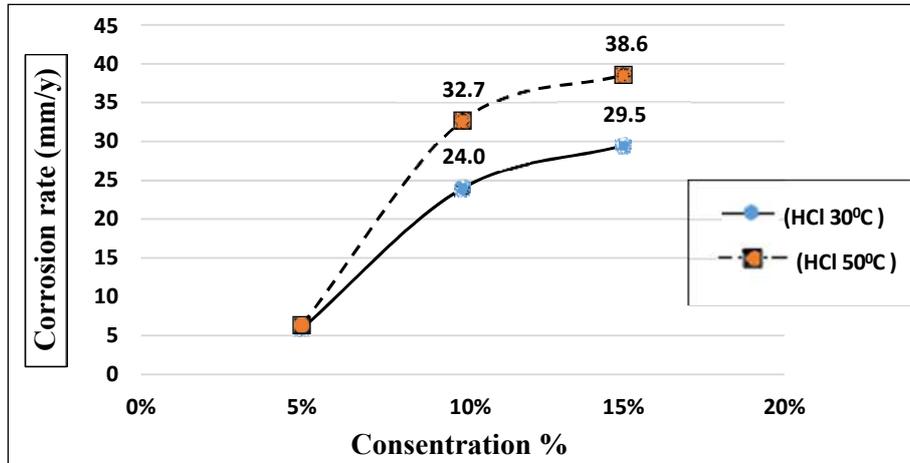


Figure 1. SS 304 corrosion rate on HCL corrosion medium and temperature of 30 ° C and 50 ° C

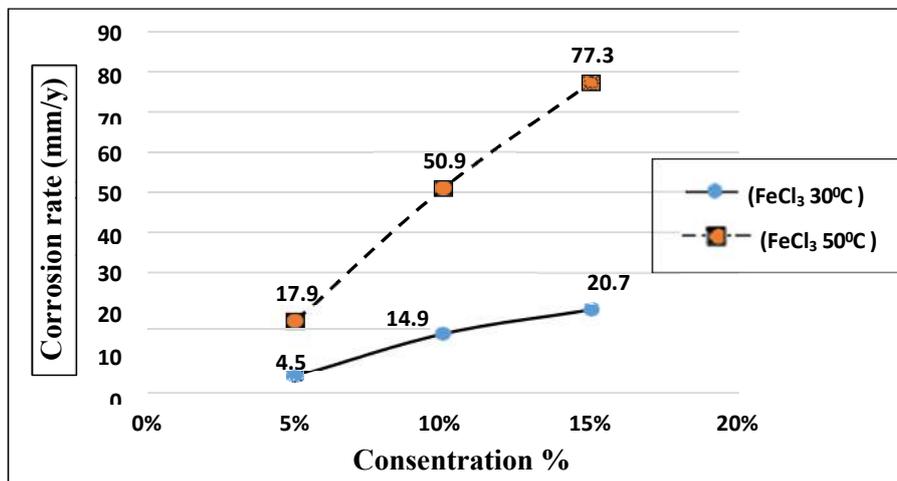


Figure 2. SS 304 corrosion rate on FeCL₃ corrosion medium and temperature of 30 ° C and 50 ° C

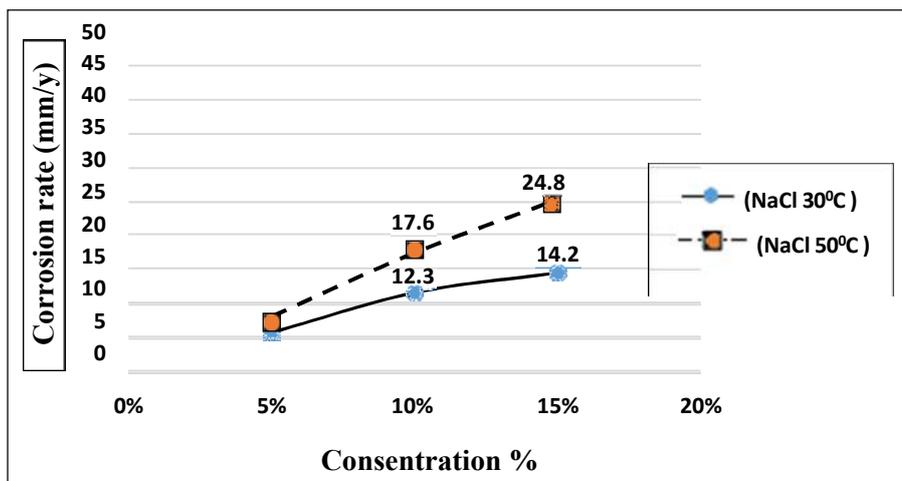


Figure 3. SS 304 corrosion rate on NaCl corrosion medium at temperature of 30 ° C and 50 ° C

The corrosion rate of AISI SS 304 with HCl medium is shown in figure 1. The figure shows that the corrosion rate of SS 304 increases with increase of HCl concentration, this is because if the

concentration of reagents is added or enlarged, the reaction rate is faster. The greater the concentration of substances, the more substances are dissolved in the solvent, so that collisions between the particles become more and more.

While the corrosion rate of AISI SS 304 with FeCl_3 medium is shown in figure 2. The figure 2 shows that the corrosion rate of AISI SS 304 increases very high in line with the increase of FeCl_3 concentration. The highest corrosion rate is in the concentration of 15% of the solution at the temperature of 50 °C, that is 77.3 mm / y. With the same concentration at 30 °C, the resulting corrosion rate is 20.7 mm / y.

Figure 3 shows the corrosion rate of AISI SS 304 with NaCl media. From figure 3, it is known that there is very little corrosion that occurs on AISI SS 304 at the concentration of 5% and 10%, which is only 6.8 mm / y. The figure shows that AISI SS 304 begins to corrode in the concentration of 15% of the solution, with a value of 24.8 mm / y. This shows that AISI 304 stainless steel has fairly good resistance to NaCl corrosion media. Besides NaCl is also a salt, in chemistry; salt is an ionic compound consisting of positive ions (cations) and negative ions (anions), thus forming neutral compounds (uncharged). NaCl also has a pH of 7, one of the factors that influence corrosion is pH. For $\text{pH} \leq 7$ is acidic and corrosive, while for $\text{pH} \geq 7$ is alkaline is also corrosive. But for iron, the corrosion rate is low at a pH between 7 and 13. The corrosion rate will increase at $\text{pH} \leq 7$ and at $\text{pH} \geq 13$.

3.2. SS 304 Surface Hardness after Corrosion

Figure 4 shows the graph of AISI SS 304 hardness in HCl medium. As seen in the Figure below, the greater the value of the concentration of corrosive medium, the smaller the value of its hardness. Based on the data shown by the graph, when the HCl concentration is 5% at the temperature of 30 °C, the corrosion rate is 0.233 mm / y with a hardness value of 95.6 HRB, when the HCl concentration is 10% with the corrosion rate of 2,786 mm / y, the hardness value of AISI SS 304 decreases to 97 HRB, and when the concentration is 15% with the corrosion rate of 9,836 mm / y, the hardness value decreases again to 94 HRB.

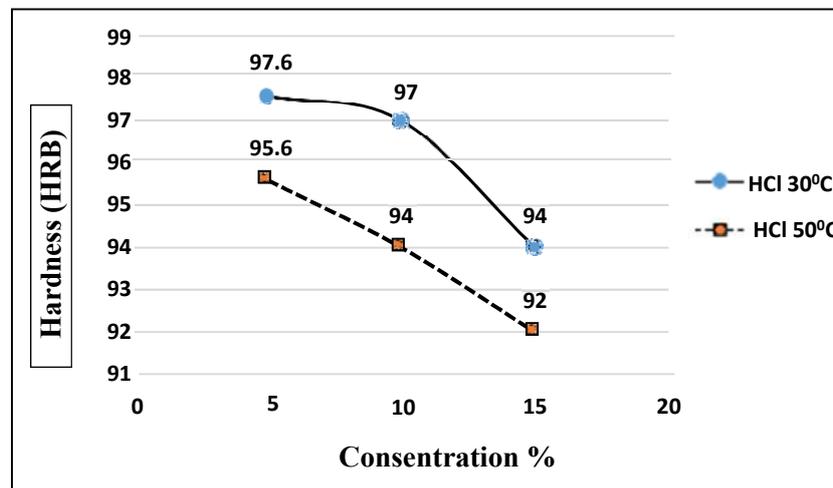


Figure 4. Surface hardness value of SS 304 steel after experiencing corrosion on immersion of HCl medium

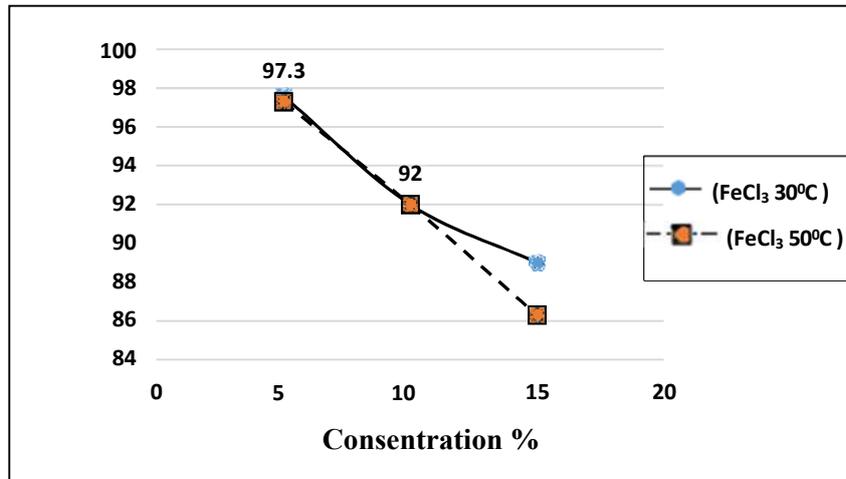


Figure 5. Surface hardness value of SS 304 steel after experiencing corrosion in the immersion of FeCl₃ medium

All figures show that the greater the corrosion rate of AISI SS 304, The smaller the hardness value will be. The decrease in the value of hardness also occurs in the samples that have been immersed with corrosion media FeCl₃ and NaCl, as shown in Figure 5 and Figure 6, the decrease occurs on the value of hardness of AISI SS 304 due to the increase of concentration of the corrosion media. For example, in the FeCl₃ corrosion media with a temperature of 30 °C, the hardness value has dropped from 97.6 HRB to 92 HRB, and 89 HRB. This also happens at the temperature of 50 °C.

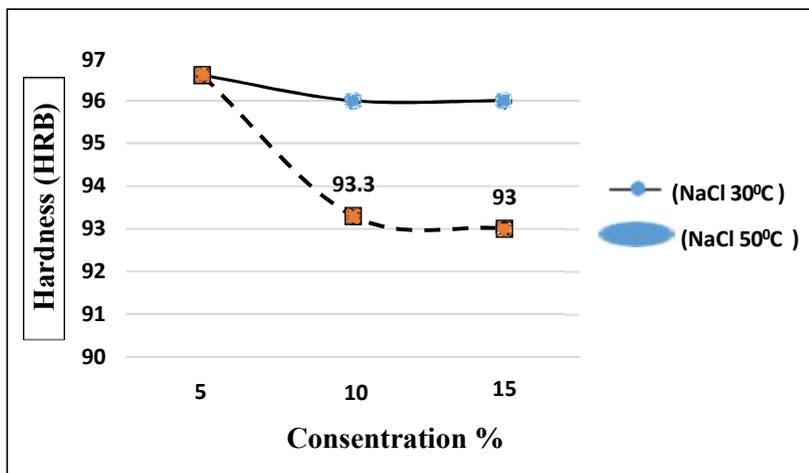


Figure 6. Surface hardness value of AISI SS 304 after experiencing corrosion in the immersion of NaCl medium

3.3. Microstructure Observation

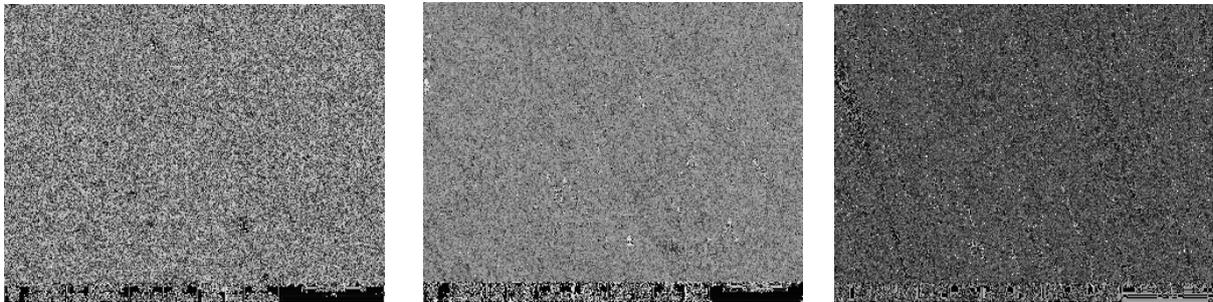


Figure 7. Observation Result of SEM Surface Morphology of AISI SS 304 in HCl Media at Temperature 50 °C with Magnification of 1000x (a) Concentration of 5% (b) Concentration of 10% (c) Concentration of 15%

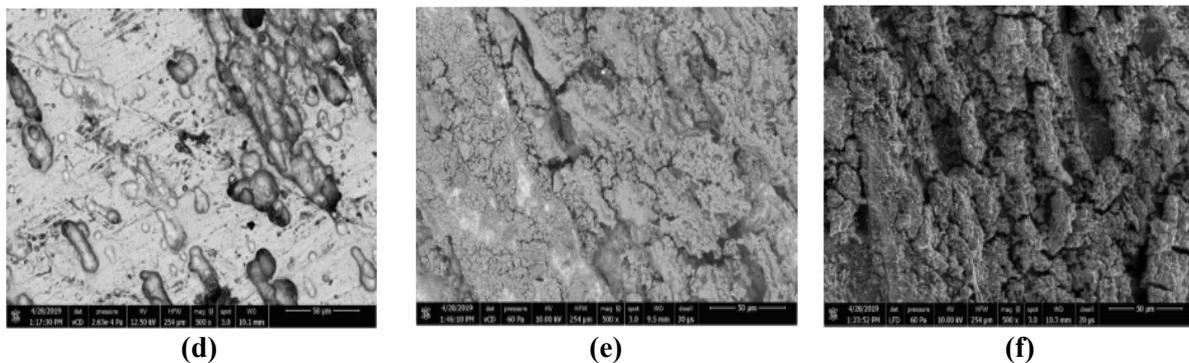


Figure 8. Observation Result of SEM Surface Morphology of AISI SS 304 in FeCl Media at Temperature 50 °C With Magnification of 1000x (d) Concentration of 5% (e) Concentration of 10%. (f) Konsentrasi 15%

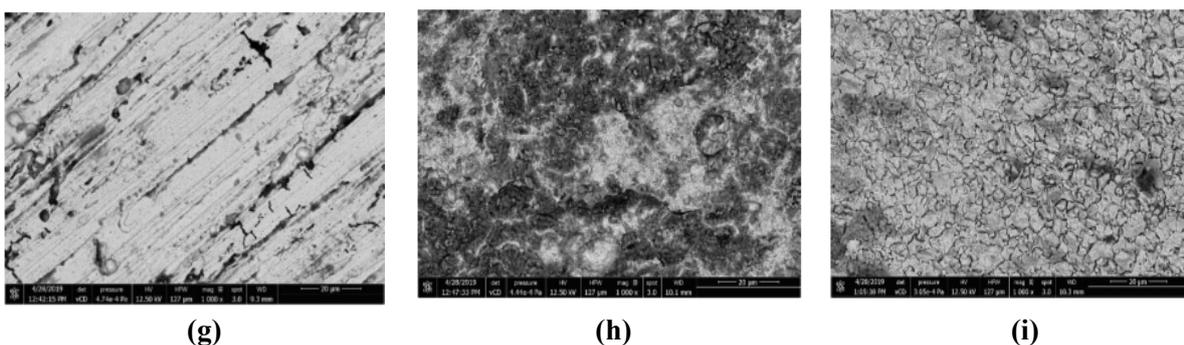


Figure 9. Observation Result of SEM Surface Morphology of AISI SS 304 in NaCl Media at Temperature 50 °C With Magnification of 1000x (g) Concentration of 5% (h) Concentration of 10%(i) Concentration of 15%

To analyze the appearance of corrosion morphology formed on AISI SS 304, a macro-visual test has been performed using a stereo microscope with a magnification of 1000 times. This test is carried out to investigate the differences occur on the surface shapes which are corroded due to the influence of acid media as electrolyte solutions. This macro-visual test has been carried out on the samples that had been immersed in HCl, FeCl, NaCl media at concentration of 5%. 10%, and 15% at temperatures of 30 °C and 50 °C.

Figure 7 shows the morphology of AISI SS 304 in the HCl medium. SS 304 surface is highly corroded and the pattern of corrosion that occurs is a kind of uniform corrosion although there is a small portion of the surface where pitting corrosion occurs. For SS 304 surfaces with FeCl₃ solution corrosion medium as shown by Figure 8, corrosion is very high and SS 304 surfaces have very large damage on all surfaces, corrosion that occurs with HCl is uniform corrosion and pitting corrosion on a small surface. As for SS 304 which has been immersed in NaCl corrosion solution that occurs is not too large but it also is equally damaged on its surface. The absence of morphological changes in this samples is in accordance with the results obtained, as explained in Figure 9, NaCl is a salt, in chemistry salt is an ionic compound consisting of positive ions (cations) and negative ions (anions), thus forming neutral compounds (uncharged) so that the reaction occurs between oxidation in the samples is very low.

The figures above show that the corrosion that occurs in AISI SS 304 is generally uniform corrosion or even corrosion because this corrosion occurs evenly on the surface, causing a reduction in the dimensions of the metal. Usually, this corrosion occurs on homogeneous steel and metal plates. Uniform corrosion in stainless steel occurs when the passive layer is damaged completely or on a large part of the surface. Anode and cathode reactions occur on the same surface when there is a constant change in location. In the environments with constant temperature and chemical composition, uniform corrosion occurs at a constant rate. In addition to the uniform corrosion shown by the figures above, there are also black holes which indicate that the surface of the samples is a kind of pitting corrosion.

4. Conclusions

Based on the result analysis, it can be concluded that:

1. The higher the concentration of the electrolyte solution, the higher the corrosion rate of AISI SS 304 will be, and the higher the temperature, the higher corrosion rate of AISI SS 304 will also occur in all corrosion media.
2. AISI SS 304 has very good corrosion resistance to NaCl media. But on HCl media, FeCl₃, the corrosion resistance is included in the Unacceptable category. The highest corrosion rate occurs in FeCl₃ medium with a concentration of 15% at a temperature of 50 °C, which is 77.287 mm / y.
3. The corrosion rate of AISI SS 304 steel in all corrosion media increases with the increase of the concentration and the temperature. On HCl, FeCl₃, NaCl media, the form of corrosion that occurs is evenly distributed corrosion (uniform corrosion), and there is also a kind of pitting corrosion like what have occurred on FeCl₃ medium.
4. The hardness value of AISI SS 304 decreases with the increase of the concentration and the temperature of the electrolyte solution, this is because the surface of Stainless Steel 304 has been corroded thereby reducing its hardness.

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