COMPARISON OF CREVICE CORROSION OF COPPER AT ROOM TEMPERATURE WITH HIGH TEMPERATURE

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ABSTRACT

Corrosion means combining with oxygen and water vapor. Because of its special electron arrangement, copper metal is more noble gas than other metals and its surface is oxidized very slowly in moist air. Thus, copper metal gets corroded too, but with a much lower rate. The purpose of this study is to compare crevice corrosion of copper at room temperature with high temperature. In this study, laboratory methods for corrosion study were divided into two categories: electrochemical analysis and surface analysis. These two methods were used to test the nature of the phenomenon of reverse crevice corrosion in copper. There are different methods for electrochemical measurements that measure different aspects of the corrosion behavior. For example, measuring the corrosion potential can be used for description of general tendency for corrosion in a long time period. The aim of studying area was atomic force microscopy and Raman spectroscopy to determine the surface morphology and chemical composition of corrosion products in the track and outstanding levels of copper coupons. The results of this study show that AFM is a good objective indication of corroded copper coupons’ surface morphology. It was observed that reverse crevice corrosion does not occur at high temperatures and this hypothesis was reinforced by the AFM images since morphology of total surface of tracked copper coupons were identical at high temperatures. The photo taken from coupons in deoxygenized environment showed that when there is no oxygen in electrolytic, corrosion does not happen, which is consistent with the results of the open circuit potential measurements. Overall, the findings of research suggest that the rate of corrosion at high temperatures is more than in room temperature.

KEY WORDS: Copper corrosion, High temperature, Room temperature, Electrochemical measurements

INTRODUCTION

Corrosion is a spontaneous process, that is, in thermodynamics, it developed in the direction to reach steady state. Of course, metal can rarely be found in the elemental and metal for in environment and it is often found as a combination in minerals and chlorides and sulfide, etc., and we retrieve them. The M+n states can take many different forms of metal components. In other words, using different methods, metals are removed from those compounds. For example, for recovery of copper from its compounds, metal is extracted from its compounds as copper sulfate. Or the aluminum in nature is turned into aluminum oxide by chemical methods and then it can be restored by electrolysis methods. For all these methods, energy consumption is needed that is a non-spontaneous method and process and such a process requires special cost and material. On the other hand, any non-spontaneous process seeks to return to its initial state because returning to initial state is a spontaneous direction, so the extracted metals tend to return to their original essence.

The sources of metals are limited in society, so return direction is such that cannot restore them back again. When a metal is dissolved in acid or windows and doors are corroded, are not retrievable. Corrosion is a picky phenomenon and harmful to the economy. Changes created in materials as a result of surface electrochemical or chemical reactions with its surroundings and cause its gradual destruction is called corrosion. But commonly, corrosion means combining with oxygen and water vapor. Because of its special electron arrangement, copper metal is more noble gas than other metals and its surface is oxidized very slowly in moist air. Thus, copper metal is corroded too, but with a much lower rate. Sometimes when copper metal is exposed to open air, it takes the green cover of hydroxide carbonate (from CO2 from the air) and hydroxyl sulfate (from SO2 in the air) on itself. But one of corrosion types is electrochemical corrosion. Water that contains dissolved salts, such as rain water or sea water, is electrolyte liquid which may result in the highest electrochemical corrosion reactions. But one of corrosion and electrochemical corrosion. Water that contains dissolved salts, such as rain water or sea water, a liquid electrolyte, which may result in electrochemical corrosion reactions are most common. If copper metal is placed prone, it may be corroded by...
performing the following reaction. The purpose of this study is to compare Crevice corrosion of copper at room temperature with high temperature.

**Literature review**

In 1922, McKay was the first scholar who described that the corrosion Crevice corrosion is a serious warning. In later years, a growing number of researchers studied Crevice corrosion mechanism due to its potential serious impact on the lives of people. When sever Crevice corrosion occurs, tracks get anode, while cathodic reactions occur on outer surfaces of the track. Mackay (1925) in an article has defined cell electrolyte concentrations, where the potential difference of the cell has been created due to the two presence of two identical electrodes in two different electrolytes. According to the research by Vichy et al (1959), Crevice corrosion, because of formation of difference in oxygen concentration and the galvanic effects, remains between active and passive metal tracks. Schaeffer and Foster (1959) again proved that all Crevice corrosions are due to the difference in oxygen concentration cells and their only difference is between track geometry and composition of the solution. In addition, they reported that formation of a cell of blow difference is initial stage of the track and continue of the corrosion process due to the acidification of track is because of hydrolysis of metal ions. According to the works by Schaeffer and Foster (1959), Fontana and Greene (1967) have defined a unique Crevice corrosion mechanism. The overall reaction, inside and outside the track, which includes dissolution of the metal and oxygen reduction is shown in Equation 1.

\[ \text{M} \leftrightarrow \text{M}^{n+} + n e^- \]

Then, because of the restrictions on the flow, track gets empty from oxygen. Oxygen reduction in the track can not continue due to oxidation of the metal in the track. Negative ions such as chloride penetrate into the track, so that solution load within the track remains neutral. Hydrolysis of metal ions, as shown in equation (3) leads to a decrease in pH because hydroxide ion is produced in the track.

\[ \text{M} (\text{OH})_n + n\text{H}^+ + \frac{1}{2} \text{O}_2 \rightarrow (3) \text{Mn} + n\text{H}_2\text{O} \]

Due to the combinative effect of low pH and chloride ion, the passive film on the surface of the track is broken and lost. In the middle times, oxygen reduction reaction occurs on the outside of the track, that protects the appropriate surfaces as cathode.

Many numerical models have been developed by researchers to simulate Crevice corrosion process. These models describe electrochemical and chemical nature of Crevice corrosion to various levels. Oldfield and Sutton (1978) have predicted incubation period of track in stainless steel. In this model, it is assumed that there is no concentration gradient in the track, and mass transfer exists just between the volume of solution and the track. Numerical prediction was verified by experimental data. In the study by Brnhardson et al (1983), electrochemical and chemical reactions were summarized by taking into account the effect of cation production, chemical reaction, electromigration, penetration and electric charge neutrality. The period of initial formation of tracks in aluminum was simulated by Lkyr and Sitar (1982), where Single bud hydrolysis of Cations was considered as mechanism of chemical reaction. Then, Hibbert and Alkyr (1983) improved this model and more consistency between simulation and experimental data was obtained. Fu and Chan (1984) developed a mass transfer model for localized corrosion. Many factors, including differences in the electrostatic potential, potential influence, and the chemical potential gradient was included in this model. This model was validated by experimental results obtained from artificial crevice cell. Effects of high temperature was considered in the model of Sharlandz (1988) for stainless steel. Comparison between experimental data and the model showed acceptable consistency. Then, Oiits et al (1993 and 1995), Oiits and Postltvayt (2000) and Postltvayt et al (1994), simulated early stage of Crevice corrosion of metals zincoid such as stainless steel, nickel and titanium numerically in the first phase at high temperatures. All their models were based on diluted solution and to some extent considering temperature effects on transport properties, chemical equilibrium and the Zincoid process. Oiits et al (1996) developed an algorithm for studying the effect of outstanding units on Crevice corrosion process. Apart from other models, this work combined a one-dimensional model with a two-dimensional model and used a mixed potential theory for simulation.

Aldefield et al (1996) developed a model that drew kinetic diagrams for corrosion at every time step. A numerical model for Crevice corrosion for relatively concentrated solution was created by Walton et al (1996) in which ions...
tran simulation of Crevice corrosion have been conducted by Heppner et al (2002, b2002, 2004 and 2005), and Heppner and Oiits (2004) in which a hybrid model for the Crevice corrosion is created. This model can be used for more options and more disabled metals and its applicability on 304 stainless steel has been studied by experimental data which is obtained by the work of others.

There are special mechanisms that have been used for Crevice corrosion of copper. Vichy et al (1959) found that two types of Crevice corrosion of copper alloys can be described by different types of cell density. When a concentration cell of oxygen be present in the track, attack in track occurs as what happens in other alloys. However, when the metal ions accumulate enough in the track, the track geometric constraints, a cell is formed between metal concentrations. In this cell, the concentration of metal ions in the high track, while in the outstanding level is low. This hypothesis has not been proven. Schaeffer and Foster (1959) also doubted that this hypothesis is correct for reverse Crevice corrosion mechanism.

Anodic behavior of copper

Unlike a Ruen metal, copper can create a resistant layer, but the corrosion products formed on copper and its alloys somewhat protects it from corrosion. In most cases, the protective oxide film on copper is single capacity copper oxide in aqueous solutions at room temperature. This film is Viscous and relatively impervious and acts as a penetration barrier, but is easily affected by changing the intensity of stirring the solution. In addition, alkaline copper salts may do some degree of protection (ASM International, 2001). To find the key factors affecting the copper, many researchers have studied the effect of pH, flow rate, temperature, presence of chloride ions, and crystallography on the corrosion rate of copper in a variety of environments. These factors are given in more detail in the next section.

The Effect of Ph

Depending on the pH, copper anodic polarization may occur in the anodic dissolution or film formation. Typically, tendency to form films increases with increasing acidity at low temperatures, in acidic aqueous solution, such as HCl and H2SO4, complexes Cu(1) are formed by connecting with Cl- or SO42-. These porous corrosion products do not prevent further corrosion. Instead, a Cu2O film with more protective feature has been formed in solution of Concentrated sulfuric acid 10M. Film formation phenomena are observed in alkaline solutions too (Leckie, 1970). Leckie (1970), supposed various corrosion products of copper in alkaline solution that are shown in equations 2-1 to 2-7. True corrosion products depend on the flow applied in galvanic measurements which are used in the study.

(1) \[ 2Cu + 2OH^– \rightarrow Cu_2O + H_2O + 2e^– \quad \Delta G = -52.342 \text{ kJ/mol} \]
(2) \[ Cu_2O + 2OH^– + H_2O \rightarrow Cu(OH)_2 + 2e^– \quad \Delta G = 645.628 \text{ kJ/mol} \]
(3) \[ Cu(OH)_2 + OH^– \rightarrow HCUO_2 + H_2O \quad \Delta G = -301.177 \text{ kJ/mol} \]
(4) \[ HCUO_2 + OH^– \rightarrow CuO_{2^–} + H_2O \quad \Delta G = -4.905 \text{ kJ/mol} \]
(5) \[ Cu + 5OH^– \rightarrow HCUO_2 + H_2O + 2e^– \quad \Delta G = -22.379 \text{ kJ/mol} \]

Previous research done on the mechanism of corrosion and corrosion products of copper was limited to alkaline or acidic environments, but recently Feng et al (1997) studied copper corrosion systematically in distilled water simulated in wide range of pH.

The effect of fluid velocity

Fluid velocity is one of the key factors that affect the corrosion rate of copper. According to the findings of Brown and Knob (1973), that have used a rotating disc electrode in acid chloride, the upper limit (where the flow is constant and does not increase with increasing potential) is always proportional to the square root of the rotation speed which directly affect the formation or dissolution of a multiple film CuCl. Turner and Brooke (1973) found that Densities of flow increase by increasing the flow rate of the solution, as potential and corrosion current increase before reaching the stream. In addition, the solution flow rate affects narrowing of critical thickness of CuCl film (minimum thickness to form a stable film). Golpaygani et al (1971) found that the sensitivity of the Cu-Ni alloy corrosion rates ofCu-Ni alloy to solution flow rate in the soluble Cl was relatively low.
The Effect of Temperature

When we get to the effect of temperature on the corrosion rate of copper, little literature is unclear. Melchers (2001) tries the information available understand the relationship between corrosion rate and temperature for 90:10 Cu-Ni alloys that are immersed in sea water. It was found that there is no significant difference between corrosion rate in short-term exposure tests at 10, 20 and oC30. However, it was observed that the rate of corrosion at temperatures of 40 and oC50 oC30 temperature was lower than temperature 30. In Long-term exposure tests, higher corrosion rate in the temperature range oC28 - 18 was observed.

Forms of corrosion found in copper and its alloys
Copper and its alloys are prone environment for almost all types of corrosion-. The following section summarizes the relevant information about the types of corrosion of copper and its alloys is the reference ASM (ASM International, 2001). Uniform corrosion: uniform corrosion is known with corrosion attack that occur gradually over the entire surface. Because it is relatively easy to measure and predict the uniform corrosion, it rarely causes serious problems.

In environments such as salt water or pure water, acidic or alkaline soil and salt solutions, uniform thinning rate is very low. However, the rate of copper corrosion in oxidizing acids, sulfur-containing compounds, NH3, and cyanide is slightly higher (ASM International, 2001).

Pitting : Pitting of copper and its alloys always happens at low fluid flow rates. Long term exposure tests have shown that there is a specific limit for deep holes, and no increase in the depth of the cavity has been observed (ASM International, 2001).

To prevent pitting of porous copper alloy, selecting right copper alloy for the desired environment is important. For example, aluminum brass is the best choice to deal with a pitting, while alloys with high copper while sometimes are pitted (ASM International, 2001). Corrosion wear: copper alloys when exposed to water flow rate and high speed are relatively sensitive to wear corrosion, especially when dealing with turbulent flows.

Because high water flow rate can eliminate any protective layer, copper corrosion rate will be high. When the growth rate of film gets equal to speed of protective layer film due to high rate corrosion, stable state is established. Sometimes, horseshoe-shaped holes are formed, this type of attack is known by wide gaps are known to be free from wear corrosion products and have shears in direction of flow. Selective Corrosion: separation on brass is selective dissolution of zinc on from alloy brass that leaves a porous mass of copper with low strength. brass can be Dezincification by contact with water and being exposed to the external atmosphere. This corrosion is accelerated by the presence of chloride and high temperature. Aluminum bronze with over 8% of Aluminum has good strength and corrosion resistance property, but highly sensitive to selective corrosion of copper, that is dealiminization.

stress corrosion cracking: stress corrosion cracking in copper material occurs because of stress tension stresses that usually occurs as the residual stresses due to using cold knife, combined with a corrosive environment containing ammonia, moisture and mercury. Typically, brass rich in zinc are susceptible to stress corrosion cracking. However, under certain circumstances, other materials containing copper, even pure copper, can be destroyed by this type of corrosion.

Galvanic corrosion: galvanic corrosion is referred to corrosion damage resulting from Contact between two heterogeneous materials in a corrosive electrolyte. According Galvanic series, when the two material are coupled together, Galvanic element is corroded (anode) while the electrolyzed material is protected (cathode). Copper and its alloys almost always behave as cathode due to their position in the galvanic series. Galvanic corrosion intensity depends primarily on two factors: galvanic potential difference between the two components and their relative area. The more the galvanic potential difference between two components, the greater the severity of corrosion. In addition, a situation in which the cathode area is high compared to the anode surface, is not desirable.

Crevice corrosion: Crevice corrosion is a localized form of corrosion that usually occurs in the solution resides in a very small scale environments. Such small inert environments tend to be formed in tracks (environments that are under coverage of something) like the ones are formed under gaskets, washers, insulation materials, fittings, sediment, isolated spots, bolts, fittings together and clamps. Classical Crevice corrosion result from oxygen depletion and attack.
into the tracks. For copper and its alloys, the opposite happens; corrosion attack happens on the outer surfaces of the track, while inside of the track remains relatively non-corrosive and intact.

**Particular cases of copper corrosion**

Although copper is a relatively noble metal, sometimes it is under corrosive attack, particularly localized corrosion. Many studies on copper anode behavior under specific conditions that have been created in the laboratory, but the circumstances are different in many practical situations. Many studies have been conducted on copper anode behavior under specific conditions that have been created in the laboratory, but the circumstances are different in many practical situations. Below are two examples that show the importance of the factors involved in copper corrosion and common corrosion problems. (Royuela, et al., 1993).

**Theoretical foundations**

There are several possible approaches for crevice corrosion of copper. A multi-track structure previously used for crevice corrosion of stainless steels and nickel alloys, was used for the study of copper in this study. Four methods were used for electrochemical measurements: measurements of Corrosion potential, Potentiodynamic measurement, potentiostatic measurement, and electrochemical impedance spectroscopy (EIS). Corrosion potential was measured by measuring the open circuit potential to see whether or not it is changed during the process. Potentiodynamic measurement and potentiostatic measurements were used to determine the behavior of film formation. EIS was used to obtain detailed information on the development of film and testing stages of determining speed in reverse Crevice corrosion of copper. For the analysis of surface, atomic force microscopy with nanometer resolution was used to obtain images of the surface and a physical image of surface morphology of corroded surface is obtained. Raman spectroscopy was used to determine the composition of the corrosion products.

**RESULTS AND DISCUSSION**

**A) Tests at room temperature.**

**Crevice corrosion phenomena of different types**

A piece of stainless steel and copper piece that formed a fabricated track with a washer, were immersed in the solution of NaCl5 / 0 at room temperature, the solution was for a month in the atmosphere. It was observed that for stainless steel corrosion occurred during track wall, that is shown in Figure 1.

![Figure 1. Image of Crevice corrosion in sample of 304L stainless steel after a month of being in M NaCl5 / 0 at room temperature.](image)

In Figure 2, the results related to immersion of copper coupons are shown. On Raised surface, accumulation of a red-brown product on and the inside of it was covered by green corrosion products. Also, black areas between the walls of the track was observed. In the track, the track walls can be recognized from its flower-like shape with a bright metallic color similar to that of pure copper. In addition, red/orange color existed that were observed in the opening tracks.

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How Corrosion Occurs

According to the phenomena observed in these two materials, a comparison corrosion of properties of these two material was performed. In the case of stainless steel, the way Crevice corrosion occurred was classic, with respect to the corroded track and track surfaces’ remaining relatively safe. But in the case of copper, the raised area had been absolutely attacked and tracks remained relatively safe. This phenomenon was also observed by Vichy et al (1959). Specifically, in inverse Crevice corrosion, different colors indicate different corrosion products, such as copper oxide, which were created at different places in raised areas. It was found that if the screw sampler pack is closed more, soluble is not able to penetrate into the track, and so corrosion would not have occurred. In addition, uniform corrosion on raised surfaces of metal were observed that are shown in Figure 3.

Processes involved in reverse Crevice corrosion

1. Change of Open circuit flow potential during process of reverse Crevice corrosion

A coercive copper coupon was dipped in solution of M NaCl5 / 0 at room temperature and corrosion potential was measured for 40 days. For comparison, copper coupon corrosion potential that does not have track was measured for 40 days. Two repetitive measurements were performed, but reverse crevice corrosion phenomenon occurred only in the first trial. The reason of weak replicability can be lack of ability for making repeatable geometry of the track. It is very difficult to make two tracks with one advanced method with exactly identical dimensions. In these experiments, a wrench that had micro torque was used for tightening the screws, so that dimensions of each experiment remain constant. However, this action was not performed for PTFE washers because of the softness of PTFE material.

For experiment in which RCC happened, changes of corrosion potential for reverse Crevice corrosion can be seen in Figure 4. In this figure, the corrosion potential of copper coupons remained constant about VSCE2 / 0- during the first five days. On the sixth day, corrosion potential increased to about VSCE05 / 0. High Potential of VSCE2 / 0- remained up to 20 days from the start of the experiment. Then, potential decreased to about VSCE3 / 0- , and remained constant until the end of the experiment. As seen in Figure 4, the corrosion potential of copper coupons...
remained constant at approximately VSCE2 / 0-, which indicates the presence of uniform corrosion. Based on three separate changes in potential, three-phases come to mind in corrosion phenomenon.

**Figure 4.** The classification of the different stages of reverse Crevice corrosion of copper I: latency (uniform corrosion); II: film formation; III: reverse Crevice corrosion

2. The combined analysis of the corrosion products in reverse Crevice corrosion

The samples used in the corrosion tests were examined by Raman spectroscopy. A typical example is shown in Figure 5. position I refers to the track surface and position II and III refer to the outer raised surface.

**Figure 5-** Image of a sample analyzed by Raman spectroscopy

To identify corrosion elements and products, some reference spectra of corrosion products were collected from papers. This reference spectra were obtained by determining pressed powder samples of appropriate combinations. excitation wavelength was Nm488.

3. Morphology of surface in reverse Crevice corrosion

Several micrographs were obtained by AFM that shows the surface properties of copper coupons after immersion for 40 days in a solution of M NaCl5 / 0 that has way into in the atmosphere at room temperature. A polished copper coupons that were not used first was Imaging was done by AFM. Vertical features in the image are due to the polishing process and has been shown Figure 6.

A coercive copper coupon was imaged in two area, walls of track and raised surface. Figure 7 shows the morphology of the wall of the track that has a Granular structure randomly distributed. Due to accumulation of
corrosion products, for AFM probe tip is hard to go deeper areas of sample. Thus, in the dark areas in the sample can not be imaged by AFM. Figure 8 shows a scan of the surface outside the track. Compared to Figure 7, it is observed that the corrosion products on the surface of the track are more randomly distributed.

**Figure 6.** AFM image of unused copper coupon with (a) 30μm × 30μm in growth page and deep of 450 nm and (b) 10μm × 30μm in growth page and depth of 700 nm.

**Figure 7.** AFM image of the track surface after the copper coupon was placed in a solution of M NaCl5 / 0 for 21 days at room temperature with (a) 30μm × 30μm in growth page and depth nm1000 and (b) 10μm × 10μm in growth page and depth nm700.

**Figure 8.** AFM image of the outside surface of the track after the copper coupon was placed for 21 days at room temperature in a solution of M NaCl5 / 0 with (a) 30μm × 30μm in the growth page and depth nm900 and (b) 10μm × 10μm in growth page and depth nm500.
Assumptions about the Crevice corrosion and proof for proving it

There are three different types of corrosion potential during measurements of reverse crevice corrosion that shows different phases of the process in Crevice corrosion. It is assumed that during the first stage of reverse crevice corrosion all surface of sample is corroded evenly and red Cu(I) is produced.

To sum up, during the third stage, the following reactions may occur in track cathodic reaction gets dominant:

1. \( \text{Cu}^+ + e^- \rightarrow \text{Cu} \) anodic reaction

2. \( \text{Cu}^+ + e^- \rightarrow \text{Cu} \) cathode reaction

3. \( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \) anodic reaction

4. \( \text{Cu}^+ + e^- \rightarrow \text{Cu} \)

5. \( 4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4e^- \) cathodic reaction

To sum up, there are three stages in the process of Crevice corrosion of copper, corresponding to three potential change. These three steps include uniform corrosion; that in this stage potential of corrosion is fixed as VSCE2 / 0, film formation that increased in beginning of the part that potential increased to VSCE05 / 0, and the final stage, beginning of reverse Crevice corrosion that in constant corrosion potential was observed less than the first phase.

4. Crevice corrosion of copper under deoxygenized atmosphere

4.1 Changes in the open circuit potential

Figure 9. Shows Changes in open circuit potential for copper coupons that was immersed in M NaCl5 / 0 deoxygenation the solution of for 31 days. During the first week, corrosion potential was in the range of 2 / 0 to VSCE3 / 0. Then, potential got fixed as about VSCE4 / 0; that is potential tends to be constant after fall and rise during the first two days. Fluctuations are caused by oxygen in the track since working electrode is made in air. A better method for making tracks is proposed in the recommendations of this thesis.

![Figure 9](image)

Figure 9. The open circuit potential for trackd copper coupons placed in a solution of M NaCl5 / 0 at room temperature for 31 days

4.2 AFM results for deoxygenized copper coupons

Effect of oxygen on Crevice corrosion resistance was investigated by AFM. Copper coupon was dipped in a deoxygenized solution by M NaCl5 / 0 for 30 days. It was found that the raised surface was corroded as preferred and size of their corrosion products were different from those whose solutions were exposed to air. It can be said that very little corrosion has occurred on the surface. That can be said, very little corrosion on the surface occurred.

B) High temperature tests
1. Change of open circuit potential for Crevice corrosion of copper

Open circuit potential measurements for temperature oC50 was repeated two times. However, the results shown are similar. In addition, comparison of these with experimental results obtained for room temperature do not show signs for reverse Crevice corrosion.

2. High-temperature corrosion tests

Crevice corrosion at 50 oC in reverse corrosion potential measurements was not observed. A study was done in this regard, so that some samples were put in solution M NaCl5 / 0 o that had way into atmosphere at C50 temperature for a month. It was observed that the corrosion occurred in all parts of the surface of each sample and no reverse Crevice corrosion was observed. Real appearance of samples after one month being suspended are shown in Figure 10.

Figure 10. Picture of sheet coupon of copper after being put in the solution M NaCl5 / 0 at oC50. The solution was exposed to the atmosphere.

Compared to the room temperature testing, reverse Crevice corrosion was not observed at high temperatures, this conclusion was shown by AFM experiments and results. But copper coupons at oC50 got severe corrosion since corrosion rate was higher than room temperature, because the kinetic parameters obtained from the scan. However, an exception was found for the coupon that was dipped for 40 days. Although the mechanism of corrosion has been found in high-temperatures, some facts should be considered. First, fabricated tracks were made at room temperature and then the temperature was increased up to oC50. This method may affect the expansion of the shaper the track and the track width. Track width is very important in Crevice corrosion occurrence because Crevice corrosion occur under conditions of track with special width and reverse Crevice corrosion often follows the same rule. In addition, concentration of saturated dissolved oxygen in oC50 is mg / L576 / 5, while at room temperature it is mg / L32 / 8's (General Chemistry Online, 2005). Dissolved oxygen is the key for oxygen reduction and its next impacts on anodic and cathodic reactions. Suppose the effect of dissolved oxygen concentration on the electrochemical reactions and compare with results obtained from experiments at high temperature, so the presence of reverse Crevice corrosion at high temperatures is questionable.

Figure 11. image of AFM from the outside surface of track after copper coupon being dissolved in oC50 M NaCl5 / 0 for 30 days with (a) 30μm × 30μm in growth range and depth nm500, and (b) 10μm × 10μm growth range and depth nm200
Experimental results are presented and discussed. Based on the potential measurements, it was assumed that reverse Crevice corrosion has three stages: uniform corrosion, reduction of corrosion rate, and reverse Crevice corrosion. This assumption was partially studied by Raman spectroscopy. The relationship between this hypothesis and its prove can be described with figure 12. In this figure, each circle refers to an intermediate phase of two circles is transient process. AFM results are good objective sign showing the surface morphology of corroded copper coupons. It was observed that reverse Crevice corrosion does not occur at high temperature and this hypothesis was reinforced by the AFM images since morphology of all surface of tracked copper coupons were similar at high temperatures. Photo taken from coupons in the deoxygenized environment showed that when there is no oxygen in electrolytic, corrosion will not happen, which is consistent with the results of the open circuit potential measurements.

**Figure 12.** Diagram of the relationship between reverse Crevice corrosion phases and Raman spectroscopy results

Several other electrochemical techniques were used to study the kinetic behavior of the reverse Crevice corrosion. Potentiodynamic Curves describe polarization performance of Crevice corrosion, corrosion rate can be measured in this way. It was found that the rate of corrosion at high temperatures is higher than room temperature although there was an exception. EIS specified controlling stages that occur during different phases of reverse Crevice corrosion. According to the EIS results, speed controller stages of reverse Crevice corrosion, respectively were penetration processes from solution to copper surface control of migration of oxygen to track and recovery of Cu(I) to Cu.

**REFERENCES**


