An Analysis on copper corrosion SUS304 corrugated metal gasket electroplating

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Abstract. The objective of this study was to examine the corrosion characteristics on the copper coating on SUS 304 corrugated metal gasket electroplating. The corrosion process on the gasket coating surface generates an oxide coating which affects the gasket quality both in the decorative aspect and the performance of the SUS 304 corrugated metal gaskets. The experiment method was used in this study. The objects involved consisted of five variants of copper coating thickness of 10, 15, 20, 25, and 30 µm. Each variant consisted of three samples. Analysis on the corrosion was done through the experiment and reference review. The findings show that the 10 µm thickness variant has a near perfect or flawless coating result. The oxide coating formed from the corrosion is not significant. On gaskets with 15 and 20 µm coating thickness variants, copper (I) oxide or Cu₂O is formed with a reddish hue characteristic. Meanwhile, on gaskets with 25 and 30 µm coating thickness, two types of oxide coating, namely Cu₂O and CuO are formed with a blackish grey hue. The corrosion level is a result of inadequate electroplating process.

1. Introduction

Gaskets are highly needed for pipe installation to distribute fluid. After the use and production of asbestos are banned, the next challenge is to find the suitable alternative material. One of the developments is the use of the SUS304 material for corrugated metal gaskets which are coated with a softer material, such as copper. This type of gasket has worked well in preventing fluid leakage in various simulations and experiments [1,2]. However, in a certain period, corrosion occurs on the copper coating on the gasket material.

Metal has become a necessity in various industries to produce a product. One of the issues in using metal for the industry is corrosion [3]. Corrosion is defined as the process of material damage caused by reactions toward the environment [4]. It can also be defined as the decrease of metal quality due to electrochemical reactions with the environment [4]. Corrosion process occurs in nearly all types of metal, such as steel, zinc, and copper. The corrosion speed of each metal is different based on the material. This condition causes the material to have an age limit [5].

Electroplating is one of the methods to prevent corrosion in metal. The term refers to a method of coating the surface of a material in an electrolyte solution by charging an electric current through an anode to the work object as the cathode [6]. Not only does it prevent corrosion, but electroplating also has other benefits based on the priority of the coating objectives. Electroplating can be done on a certain metal for a number of reasons, namely improving the hardness of the surface, wear resistance,
fixing the surface, and repairing the wear. The types of metal that can be coated include stainless steel, aluminum, nickel, alloy, etc. [7].

In this study, SUS 304 corrugated metal gaskets are electroplated using pure copper to improve the gasket performance in sustaining leakage. Corrosion on the surface of the copper gaskets impacts on the gasket performance in sustaining leakage. Therefore, this study found the need to conduct an analysis on the corrosion characteristics on the SUS 304 corrugated metal gaskets copper coating in order to examine the weakness during the electroplating process.

2. Method
This study used the experiment method. Research began with substrate preparation which is a process of making the SUS 304 corrugated metal gaskets. This stage consisted of the cutting, machining, and forming process. The cutting and machining were conducted on the SUS 304 plate with a 1.5 mm thickness according to the gasket material dimension. The forming process was done to make the metal gaskets corrugated. The cutting, machining, and forming process was based on a study by Nurhadiyanto et al [2].

The next stage was the gasket electroplating. In this process, the corrugated metal gaskets with SUS304 material was coated with copper through electroplating. The process involved two main stages, namely identifying the parameters, and making the gasket coating thickness variants [2,3]. The first stage identified the gasket weight gain after coating a certain time. Coating was done uniformly by placing copper parallel to the gaskets as the ion movement formed a straight line. The second stage was determining the coating thickness by measuring the weight gain. In this stage, the gasket area had been identified, thus the coating thickness could be calculated. The electroplating used a 4-volt voltage, and a current of 7A.

The last process was analyzing the characteristics of the electroplating coating result visually and comparing the results to prior studies. This last process was the very essence of the research.

3. Result and Discussion
The result of the gasket electroplating process is the weight gain in the gaskets due to the change in the electroplating time and the gasket thickness. Data on table 1 refers to the first stage, illustrating the relation between the weight change and the time unit in this experiment process. The relation between the total gasket weight (y) and the coating time (x) is stated in the following equation (1).

| No | Initial weight (g) | 5' | 10' | 15' | 20' | 25' | 30' | 35' | 40' | 45' | 50' | 55' | 60' |
|----|-------------------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | 37.47             | 38.16 | 38.80 | 39.45 | 40.08 | 40.78 | 41.44 | 42.11 | 42.77 | 43.51 | 44.22 | 44.91 | 45.59 |
| 2  | 37.62             | 38.38 | 38.98 | 39.58 | 40.30 | 40.98 | 41.65 | 42.29 | 42.99 | 43.63 | 44.23 | 44.86 | 45.52 |
| 3  | 37.65             | 38.12 | 38.78 | 39.47 | 40.10 | 40.72 | 41.37 | 41.98 | 42.72 | 43.46 | 44.14 | 44.79 | 45.48 |
| Mean | 37.58          | 38.22 | 38.85 | 39.50 | 40.16 | 40.83 | 41.49 | 42.13 | 42.83 | 43.53 | 44.20 | 44.85 | 45.53 |

In this experiment, three gaskets samples were used. Each of them was coated and weighed every 5 minutes until minute 60. The relation between the weight change and the time unit in this experiment process is presented in a chart, as seen in figure 1.

The figure shows that the one-hour coating process by taking weight measurements every five minutes generates a linear chart. The addition of the copper coating weight on the gasket is directly proportional to the coating time. The relation between the total gasket weight (y) and the coating time (x) is stated in the following equation (1).
Figure 1. Chart of the relation between gasket weight and coating time

\[ y = 0.1329x + 37.527 \]  

This equation can be used to determine the estimated coating time to achieve the desired copper coating thickness in this study.

The result of the second stage electroplating experiment in the form of the copper thickness as a result of electroplating is presented in Table 2. The gasket thickness variants of 10, 15, 20, 25, and 30 \( \mu m \) are essentially the results of the theoretical approach, as in reality, it is difficult to obtain whole numbers in the thickness aspect.

**Table 2. Data on the thickness experiment**

| Coating thickness variation (\( \mu m \)) | Coating period (minute:second) | Sample number | Initial weight (g) | Final weight (g) | Difference (g) | Actual thickness (\( \mu m \)) | Mean (\( \mu m \)) |
|----------------------------------------|--------------------------------|---------------|-------------------|-----------------|----------------|-------------------------------|------------------|
| 10                                     | 5:24                           | 1             | 37.49             | 38.14           | 0.65           | 9.86                          | 10.82            |
|                                        |                                | 2             | 37.32             | 38.07           | 0.75           | 11.38                         |                  |
|                                        |                                | 3             | 37.49             | 38.23           | 0.74           | 11.23                         |                  |
|                                        |                                | 1             | 37.49             | 38.43           | 0.94           | 14.26                         |                  |
| 15                                     | 7:48                           | 2             | 37.33             | 38.35           | 1.02           | 15.47                         | 15.58            |
|                                        |                                | 3             | 37.66             | 38.78           | 1.12           | 16.99                         |                  |
|                                        |                                | 1             | 37.53             | 38.80           | 1.27           | 19.27                         |                  |
| 20                                     | 10:18                          | 2             | 37.53             | 38.80           | 1.27           | 19.27                         | 19.37            |
|                                        |                                | 3             | 37.10             | 38.39           | 1.29           | 19.57                         |                  |
|                                        |                                | 1             | 37.65             | 39.31           | 1.66           | 25.19                         |                  |
| 25                                     | 12:48                          | 2             | 37.54             | 39.21           | 1.67           | 25.34                         | 25.09            |
|                                        |                                | 3             | 37.57             | 39.20           | 1.63           | 24.73                         |                  |
|                                        |                                | 1             | 37.56             | 39.54           | 1.98           | 30.04                         |                  |
| 30                                     | 15:18                          | 2             | 37.61             | 39.49           | 1.88           | 28.53                         | 29.08            |
|                                        |                                | 3             | 37.54             | 39.43           | 1.89           | 28.53                         |                  |

Figure 2 illustrates the condition of gasket surface after electroplating. It can be seen that the color is a shiny orange. Figure 3 contains photographs taken after the objects were stored in a lid container.
Overall, the gaskets experience an oxidation process, although in different stages, as shown by the colors formed depending on the oxide coating as a result of the corrosion process.

Figure 2. The conditions of copper coating after electroplating
Figure 3. Copper surface experiencing the corrosion process after several days
In practice, the electroplating process does not always work perfectly. Defects may occur when the parameters and procedure used in the electroplating process do not meet the requirements. In the electroplating process, defects must be avoided. In addition to reducing the aesthetics of the object, they also lead to the possibility of corrosion. Defects may occur due to several factors, whether prior to or during the electroplating process [8]. Nishi & Doering discover two types of defects in the electroplating with copper, namely pitting or missing metal and abnormal growth. Pitting refers to a defect in which copper as the metal coating fail to fully attach to the surface of the object. Meanwhile, abnormal growth is defined as extra spots or residue caused by conductive particles which accidentally get into the coating and stick to the substrate surface during the electroplating process [9].

The research findings show that corrosion formed is made worse with the defects of pitting and abnormal growth on the outer part of the gaskets (figure 4). The thicker the copper coating, the bigger are the defects. There is no significant change in color indicating the corrosion process on gasket with 10 µm thickness. However, there are changes in hue in other thickness variants. Gaskets with 15 and 20 µm coating thickness show a reddish hue due to the formation of the copper (I) oxide coating or Cu₂O which has a reddish characteristic. Moreover, the corrosion on gaskets with 25 and 30 µm thickness is formed by two types of oxide coating, namely copper (I) oxide and copper (II) oxide or CuO with a blackish grey color. The CuO layer is only formed on the most outer part of the gasket.

The corrosion process on the surface of pure copper is a natural occurrence. Corrosion may happen faster due to inadequate electroplating process. The research finding shows that gasket with 10 µm thickness shows no defect such as abnormal growth or pitting. A good result of electroplating will have a slower oxidation process. In the same relative period, gaskets will show no significant change in color. On the contrary, gaskets with other coating thickness variants of 15, 20, 25, and 30 µm show that the thicker the copper coating on the gaskets surface, the bigger the abnormal growth defects on the outer part of the surface are. The more abnormal growth defects will result in roughness on the coating. As a result, the oxide layer caused by the corrosion process will be formed faster. Such defects may be caused by conductive particles attached on the substrate surface during the electroplating process. In order to reduce these organic or inorganic conductive particles, it is necessary to filter the copper bath solution periodically. Abnormal growth defects that lead to roughness can also be caused by incomplete pre-copper plating or substrate preparation which includes degreasing, pickling, activating, and nickel strike. Due to the basic characteristics of stainless steel that makes it hard to apply electroplating, there needs to be a well-planned substrate preparation. Any flaw in the process will cause the nickel strike basic coating process to be inadequately attached or coated. If this happens up to the copper coating, there will be roughness defects and acceleration of the corrosion process. Therefore, in order to minimize the corrosion process, there needs to be an
optimal thickness and appropriate electroplating process. In order to refine the process, the copper needs to be passivated in order to be resistant against extreme environment conditions.

Defects on the electroplating result will induce the corrosion process. Timar & Eastop explain that corrosion on copper will result in oxide compounds depending on the type of environment. Copper that reacts with oxygen (O₂) will turn into copper (I) oxide or Cu₂O with a reddish hue, and copper (II) oxide or CuO with a black coating. Copper exposed to hydrogen sulfide (H₂S) will form black, nonprotective copper sulfide (CuS), while copper which reacts to CO₂ will form green copper (II) carbonate [Cu₂CO₃.Cu(OH)₂]. Finally, copper exposed to ion Cl will form copper (I) chloride (CuCl). From these types of corrosion, CuCl is found to be the most harmful for the copper structure [8].

The corrosion level in copper is regulated in the ASTM D130 standard [11]. This standard is essentially used to measure the corrosion level on petroleum processed products. Crude petroleum essentially contains sulfur compounds which will remain in the final product in a small amount even after the refining process. Copper sulfide is the compound formed during the corrosion process between copper and sulfur. Sulfur has a highly corrosive quality on copper, especially when the copper is not passivated [12].

4. Conclusion
Corrosion on pure copper is a natural occurrence. This also applies to the copper surface resulted from the electroplating process. The electroplating result of the SUS 304 corrugated metal gaskets with copper material experiences a change in color as the indicator of the corrosion process. The gasket with 10 µm copper coating thickness is found to have a near-perfect coating with a shiny orange hue. In the coating thickness variants of 15 and 20 µm, there seem to be a change toward a reddish hue. The change in color is caused by the forming of copper (I) oxide surface or Cu₂O with the characteristic of a reddish color. Meanwhile, the corrosion on the gaskets with 25 and 30 µm coating thickness is caused by a formation of two types of oxide coating, namely copper (I) oxide and copper (II) oxide or CuO with a blackish grey color. The CuO coating is only formed on the most outer part of the gasket.

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