EFFECT OF PARAMETER CONTROLLED IN TIN COATING ON THE MILD STEEL SUBSTRATE

Mohd Yuhazri, Y.*, Jeefferie, A.R., Haeryip Sihombing, and Siti Rahmah, S.

Material Engineering, Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal,
Melaka, Malaysia*

Abstract:

Corrosion is a one of problem encountered in steel industry and there are much of prevention and solution ideas applied and proposed by researches and engineers in order to avoid this problem from occurring in the future. In this research, the corrosion prevention of the mild steel is through the treatment process by the tin electroplating process. The trial and prepared specimens are addressed to the before and after corroded forms in which the surface testing is carried out through several processes such electroplating, electroplating process with various coating parameters, determination of thickness coating, as well as surface morphology examination. To determine the corrosion rate based on Tafel extrapolation, the observation is by using the scanning electron microscope. The standard measurement for tin electroplating, surface preparation, and corrosion rate is according to the ASTM B545, ASTM B183, and ASTM G102, respectively, whereas the parameters of process are regarding to the current density of coating, times and constant of solution bath. Based on the result, the best parameter finding of current density is at 6 A/dm² and 10 minutes of coating time. This parameter is capable to give a less of corrosion rate in both conditions of coatings, which is scratched coating and unscratched coating. In addition, by the lower of current density promotes the formation of tin whiskers and thin of coating but it gives a less of corrosion rate. The higher of current density promotes formation of cracking and worst of corrosion rate.

Keywords: tin electroplating; mild steel; current density; time; solution bath; corrosion rate.

1. Introduction

Corrosion engineering is the application of science and art to prevent or control corrosion damage economically and safely (Smidt, 1994). This address to corrosion as one of material problems, particularly metals, which capable to extend the life span (Yip, 2006). Corrosion is the destruction or deterioration form of a material due to reaction with its environment (Callister, 2005) and (Henkel & Pense, 2002).

In the world of engineering, corrosion and coating have a correlation. Typically, once of the metals are fabricated and used for any application which by then must be followed by coating method in order to prevent any corrosion or deterioration thus retain the mechanical behavior (Ashiru & Shirokoff, 1996) and (Grainger & Blunt, 1998). This research is to identify which coating conditions on the mild surfaces are suitable against the selected environment as well as corrosion properties, and how the tin-electroplating should be carried out for corrosive prevention in which the thickness of coating is the most influences the corrosion properties. This research will address also the applications of electroplating techniques such as coating by using chromium electroplating (Fontana, 1987).

2. Test Preparation

2.1. *Specimens preparation*

Substrate of mild steel should be by condition without significant pores or defects, such as cracks. The surface should be clean, smooth, as well as burrs and debris free. Therefore, a polished or fine mechanical finish is most suitable. Pre-cleaning involves degreasing by solvent and alkaline electrolytic bath. To avoid unnecessary plating, those areas - which are not requiring the treatment –therefore treated by using of lacquer, tape, or a well-fitting mask. In this research, the prepared specimens are 15 pieces. The testing of all the specimens are conducted at various coating conditions (coating parameters) followed by corrosion testing (Grainger & Blunt, 1998).

2.2. Electroplating process

The optimum results of prevention towards the corrosion behavior obtained by conducting the electroplating process through various coating parameters based on coating thickness results. Here, the parameter observed by using SEM or optical microscope to the current density as well as composition of bath and time (Srinivasan & Dae, 2007).

2.3. Corrosion rate measurement

ASTM G102 is as guidance used to determine the corrosion rate based on the results conversion of electrochemical measurements to rates of uniform corrosion (Hsu, 1978) and (Lim et al., 2007). While the calculation method as for most engineering metals, based on converting corrosion current density values to either mass loss rates or average penetration rates. In this research, to observe and investigate the corrosion problems, extract mechanistic information, and predict long-term corrosion rates from an array of experiments (Lim et al., 2007) are by using Gamry DC Corrosion Techniques Software as the instrument to determine corrosion measurements. Particularly, for corrosion test, all of the coated specimens have to scratch.

2.4. Surface analysis

The analyses to the specimens' surfaces should be done before and after corrosion rate measurement. Then the specimens for each coating parameter would undergo in three conditions, such as uncoated, tin coated on mild steel, and scratch tin coated on mild steel. To observe the microstructure, the test use SEM or optical microscope. These analyses will shows on which specimens are less or worst of corrosion behavior based on the respective coating conditions (Smidt, 1994).

3. Results and Discussion

3.1. Thickness determination

The effect of time to coating process and thickness lead to the higher time applied where the thickness will more become thickens (Bayramoglu et al., 2008). Based on the conducting parameters, 12 A/dm², 9 A/dm², 6 A/dm², 4.5 A/dm² and 3 A/dm², the increasing of current density may also influences the coating thickness, time of deposition rate, and surfaces of coating itself. During the electroplating process, the deposition of tin to the substrate is obviously faster once the higher current density used. By comparing the times, the thickness shows that time also influences the thickness of coating. However, the current density is the most parameters that influence the coating thickness (Lim et al., 2007).

Table 1. 10 minutes coating with variables current density

Parameters (A/dm²)	Reading (µm)
3	5.87
4.5	5.91
6	17.07
9	18.25
12	21.64

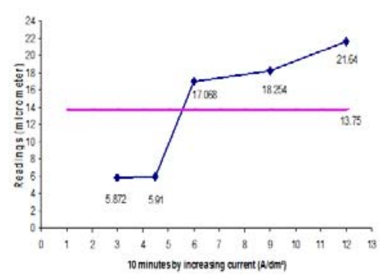

Fig. 1: Graph for variables current density with 10 minutes coating

Table 1 shows the five specimens with variables current density applied by constant concentration of acid formic and 10 minutes of time. As shown in Figure 1, the trend of the increasing of current density is proportion to the thickness of coating itself. The parameters of 3 A/dm² and 4.5 A/dm² stated the near of value for coating thickness. The increasing of thickness from 3 to 4.5 A/dm² is 0.65 percent. After the current density is advanced to 6 A/dm², the value of thickness is vastly higher with thickness 17.068 µm and the percentage value stated about 189 percent increased from thickness with 6 A/dm² applied. According to this trend, by using current density of 6 A/dm², the incremental of thickness is rapidly raising. It is contrast to the increasing of percentage from current density of 6 to 9 A/dm², where the increment is gradually with percentage of 6.95 percent. The parameters of 9 and 12 A/dm² stated 18.254 and 21.64 µm respectively. At this point, the increasing of thickness value by just a little due to the solution almost saturated. Besides, the deposition of tin processes in a slow rate which resulted thin plating on the substrate. The average value of thickness coating is 23.75 µm.

Table 2. 20 minutes coating with variables current density

Parameters (A/dm²)	Reading (µm)
3	6.91
4.5	10.02
6	22.63
9	24.77
12	26.97

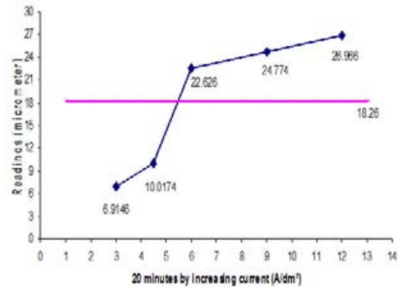

Fig. 2. Graph for variables current density with 20 minutes coating

Table 2 shows the data of thickness with variables current density by 20 minutes of coating times. The trend of thickness so as the increasing of current density and time is resulting the higher value of coating thickness. By comparing the data between the 20 minutes and 10 minutes of coating, it shows that the current density and times is main parameters that influence to the value of coating thickness (Bayramoglu et al., 2008).

Based on the parameter of 3 A/dm², both of times that are used as the test, stated a different reading. It shows that the time factor may influence the value of coating thickness. For 20 minutes, the current density of 3 to 4.5 A/dm² stated the increasing of 55.9 percent for it thickness. While to other value of current density, such as after 4.5 A/dm², the thickness is 6 A/dm² with 125.9 percent of increasing percentage value. In contrast, the increasing of thickness from current density of 6 to 9 A/dm², shows just a little value with 8.8 percent of incremental. By the current density of 9 A/dm² and 12 A/dm², shows the trend of thickness that gradually increases to 9.5 percent of percentage. Figure 2 shows the trend of thickness value so as by increasing the time factor and current density (Jimenez et al., 2008).

Table 3. 30 minutes coating with variables current density

Parameters (A/dm²)	Reading (µm)
3	7.99
4.5	11.39
6	23.69
9	24.77
12	31.81

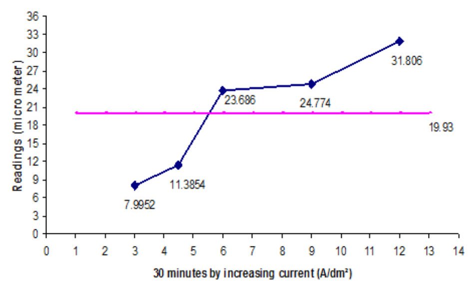

Fig. 3. Graph for variables current density with 30 minutes coating

Table 3 shows that by increasing of the times and current density results the thickness of coating itself. The parameters of current density which is starting from 3 A/dm² to 12 A/dm², shows are the higher values of thickness compared to parameters of current density of both 10 and 20 minutes. As its means, that the data of thickness is meet the theoretical concept whereby the parameters of current density and times may results the thin or thickens of coating itself (Bayramoglu et al., 2008).

The increasing of percentage value for thickness of current density from 3 to 4.5 A/dm² is 42.4 percent. This is similar with both time of 10 and 20 minutes. However, by 30 minutes results a rapidly increment once the current density is increased from 4.5 to 6 A/dm². The percentage of increment is 108 percent. The percentage of incremental of current density from 6 to 9 A/dm² and 9 to 12A/dm² is 4.6 and 28.4 percent respectively. Figure 3 shows the trend of the value coating thickness where the value increased by increasing the current density. Based on the observation during the tin electroplating process, once the electrolyte of acid formic is in saturation, the deposition rate of tin to the substrate also will be slow even though the higher current density applied. Consequently, the electrolyte for each of coated substrate must be changes in order to prevent the errors during conducted the electroplating.

3.2 Corrosion rate analysis

The analysis is carried out against uncoated mild steel, scratched coating and unscratched coating. All of these parts are tested in NaCl as corrosive environment, and then compared against its corrosion rate measurement in order to determine which the best parameters resulted refers to the less corrosion rate.

3.3 Uncoated mild steel

In order to determine the corrosion rate, the uncoated mild steel is exposed to the corrosive environments. The corrosion rate measurement is 1.49 mm/year.

3.4 Unscratched coating

In this section, the specimens were through a coating without subjected to the scratched condition. Based on the observation, the best parameter is at 6 A/cm^2 of current density and 10 minutes of time. According to this parameter, it resulted the best corrosion rate measurement among the others parameters with i_{corr} of 1.13 x 10^{-4}.

3.5 Scratched coating

In this section, the specimens were through a coating subjected to the scratched condition to represent as in real industry, where the coated mild steel exposed to the various conditions such as scratching and cracking. The observation is need to ensure that coating condition is in good treatment, before it is applied in real condition since the metal is easy exposed to the corrosion properties without taking the protection action (Ashiru & Shirokoff, 1996).

Based on the observation and test, for current density of 6 A/cm^2 and 10 minutes, the corrosion current density, i_{corr} is 2.70 x 10^{-4} . For 10 minutes of coating time, the total of anode current for current density of 3, 4.5, 9 and 12 is 1.15 x 10^{-3}, 1.17 x 10^{-3}, 3.28 x 10^{-3} and 4.07 x 10^{3} respectively. For 20 minutes of coating time, total anode current for 3, 4.5, 6, 9 and 12 is 1.74 x 10^{-3}, 1.77 x 10^{-3}, 6.19 x 10^{-4}, 1.48 x 10^{-3} and 4.81 x 10^{-3} respectively. Other than that, for 30 minutes of coating time, the total anode current for 3, 4.5,6, 9 and 12 is 2.59 x 10^{-2}, 1.14 x 10^{-3}, 1.16 x 10^{-3}, 2.82 x 10^{-3} and 1.07 x 10^{-2} respectively.

As a result, the data for current density 12 A/cm^2 almost promotes poor properties in terms of corrosion rate and surface examination. The possible cause for this mechanism is due to the out of range from theoretical value of current density. The increasing of current density also would result the poor uniformity of coating itself. In this regard, the formation of cracking influences the corrosion rate. By referring to the data, all current density of 12 A/cm^2 with all three times period shows a worst corrosion rate.

In terms of good corrosion rate, the lower of current density is almost result the less of corrosion rate. It is due to during carried out the electroplating, the lower current density promotes the good uniformity of coating itself. The good uniformity of coating will produce a good inhibit with corrosion properties (Jimenez et al., 2008). The lower of current density will promotes a slow deposition rate. Refers to this mechanism, the slow rate of deposition will result a good surface and no surface cracking. Despite the lower current density promotes a thin of coating, but at the same time, it becomes a good corrosion property. The less of corrosion rate that stated is current density of 6 A/cm^2 and 10 minutes. The current density of 3 and 4.5 A/cm^2, also stated a less of corrosion rate compared with corrosion rate of higher current density. By comparing the variables of time, the increasing of time also result the poor of corrosion rate. It is due to the bath solution is already saturated with long time of coating. The concentration of ion in solution is no longer concentrate, thus the tin coating will produce with a less of corrosion behavior.

3.6 Analysis of surface coating after corroded

Mostly, all of the specimens that undergo the various parameters are resulted the pitting corrosion. The anodic and cathodic reaction as follows:

$$Sn \rightarrow Sn^{2+} + 2e^- \quad \text{(anodic)} \qquad (1)$$
$$2H_2O + O_2 + 4e^- \rightarrow 4OH^- \quad \text{(cathodic)} \qquad (2)$$

Figure 4 mentioned the pitting corrosion that occurred on the tin surface. The pitting corrosion formed at almost the specimens. Pitting corrosion is form when the surface appears a hole or pit.

3.7 Effect pH value

The best parameter of coating which resulting the less of corrosion rate in NaCl is taken and compared with acidic and alkaline solution. It is to determine the corrosion behavior in different corrosive environments. According to the results obtained from specimens that are exposed to the NaCl, the less corrosion chosen and compared to the other environments, such as alkaline and acidic. In real industry, the specimen would undergo the several of pH value (Jimenez et al., 2008). This section is important to determine the value of corrosion rate. The worst corrosion rate on particular environment towards the materials coated by tin, therefore should be identified in order to promote a better lifetime once it applied on that environment.

The corrosion current density is 18.28 and 1.47 A/cm^2 respectively. For scratched and unscratched coating, the corrosion current density is 118.03 and 94.26 A/cm^2 respectively. By exposing the NaCl environment, the value with less corrosion rate for unscratched is 2.56 x 10^{-2} mm/year. The value for specimen exposed in NaOH is 4.07 x 10^{-2} mm/year whereas 2.61 mm/year for specimen exposed to HCl. It shows that the specimen exposed to the acidic environment results a worst of corrosion rate by 2.61 mm/year. The acidic, basically, is a corrosive environment that promotes corrosion to occur rapidly (Ashiru & Shirokoff, 1996).

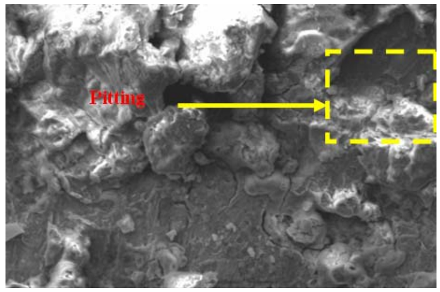

Figure 4. Pitting corrosion on tin surface

The data of corrosion rate for specimen exposed to the NaCl is 6.11 x 10^{-2} mm/year. For NaOH environment, the value is 5.08 x 10^{-1} mm/year while 3.28 mm/year for specimen exposed in HCl environment. Similar with the data of unscratched coating, the specimen that exposed in acidic environment stated a worst value of corrosion rate.

4. Conclusions

This research provides a tin coating on the mild steel substrate with various coating condition by using electroplating method. Also, to investigate the corrosion properties of mild steel with various coating conditions once immersed in various corrosive environments. The best parameter in tin electroplating is determined by conducting in current density of 6 A/cm^2 and 10 minutes of time coating.

During process of the electroplating, it must be controlled by several factors in order to give a good result in term of uniformity of coating (Callister, 2005), (Fontana, 1987), (Henkel & Pense, 2002) and (Yip, 2006). The lower of current density resulted a thin coating and formation of tin whiskers. The moderate of current density promotes the best packages such as uniformity of coating, no formation of tin whiskers, free from surface cracking and promotes a less of corrosion rate. In contrast, in this research also try to apply the current density where the previous researcher not applied. The current density is 12 A/cm^2. As a result, this current density stated a poor result in term of tin surface by shows a cracking and worst of corrosion rate (Srinivasan & Dae, 2007).

Even though it gave thickens of thickness coating, it unable to inhibit the corrosion properties. On the other hand, the scratched and unscratched condition of tin coating will be in a slow rate while applying the current density of 6 A/cm^2 and 10 minutes of time. According to the results, the highest rise percentage of thickness coating is from 4.5 to 6 A/cm^2. This exceeds 100 percent of almost coating times. Regarding this phenomenon, it is possible to apply this parameter in order to get the highest thickness of coating itself.

5. References

[1] Ashiru, O. A., & Shirokoff, J. (1996). Electrodeposition and characterization of Tin-Zinc alloy coatings. Applied Surface Science, pp. 156-169.

[2] Bayramoglu, M., Onat, B., & Geren, N. (2008). Statistical optimization of process parameters to obtain maximum thickness and brightness in chromium plating. Journal of Materials Processing Technology, pp. 277-286.

[3] Callister, W. D. (2005). Fundamentals of material science and engineering. (2nd ed.). New York, USA: Addison-Wesley Publishing Company.

[4] Fontana, M. G. (1987). Corrosion engineering. (3rd ed.). Library of Congress Cataloging in Publication Data, Singapore, pp. 3-4, 244-245, 304-305, 360-369, 445-500.

[5] Grainger, S., & Blunt, J. (1998). Engineering coatings, design and application. (2nd ed.). England: Woodhead, pp. 167-193.

[6] Henkel, D., & Pense, A. W. (2002). Structural and properties of engineering materials. (4th ed.). New York: McGraw-Hill, p. 199.

[7] Hsu, G. F. (1978). Tin/lead plating bath and method. U. S. Patent 4118289.

[8] Jimenez, H., Gil, L., Mariana, H. S., & Cabrera, E. S. P. (2008). Effect of deposition parameters on adhesión, hardness and wear resistance of Sn-Ni electrolyte coatings. Surface and Coatings Technology, pp. 2072-2079.

[9] Lim, C. Y., Lee, F. T., & Lim, Y. Y. (2007). Corrosion investigation of coatings on mild steel substrate exposed to various corrosive environments. Malaysian Journal of Chemistry, 9(1), pp. 40-50.

[10] Smidt, F. A. (1994). ASM handbook volume 5 surface engineering. America: United States, pp. 239-241.

[11] Srinivasan, M., & Dae, K. K. (2007). Influence of alternating, direct and superimposed alternating and direct current on the corrosion of mild steel in marine environments. Science Direct. Desalination (216), pp. 103-115.

[12] Yip, W. C. (2006). Introduction to materials science and engineering. China: CRC Press, pp. 112-113.