TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

Homepage journal: http://jurnal.untirta.ac.id/index.php/ju-tek/

Original research article

Effect of current, time, concentration of tin (II) chloride, and temperature on making tin powder using the electrodeposition

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ARTICLE INFO

Article history
Submitted 6 May 2025
Received in revised form 21 May 2025
Accepted 2 June 2025
Available online 6 June 2025

Keywords
Tin
Electrodeposition
Particle size
Current efficiency
SEM-EDS

Editor:
Indah Uswatun Hasanah

Publisher's note:
The publisher remains neutral regarding jurisdictional claims in published maps and institutional affiliations, while the author(s) bear sole responsibility for the accuracy of content and any legal implications.

ABSTRACT

The process of assembling electronic components into electronic equipment requires tin solder material. Tin solder in the form of paste is used to provide good contact between electronic components and PCB (Printed Circuit Board). To make tin solder paste, tin powder with a size of 15 to 50 microns is required. The development of efficient technology to produce tin powder with controlled characteristics from tin bar raw material is an important challenge to increase the added value of this commodity. This study was conducted to make tin metal powder from tin metal bars by electrodeposition using a chloride electrolyte solution containing tin ions. The experimental variables observed were the current density of the electrodeposition process (0,5-1,1 A/m²), the concentration of tin in the electrolyte solution (5-30g/l), and the temperature of the electrodeposition process (30-60°C). The experimental variables were observed for their effect on the size of the tin powder particles formed and the current efficiency of the tin powder formation process on the cathode surface. The results showed the highest current efficiency (75%) at a current of 0,5 A/m², a time of 15 minutes, and a temperature of 30°C. The tin powder had an irregular morphology, with a more uniform particle size at higher currents. SEM-EDS analysis showed a complex morphology with increasing temperature and deposition time. This process produced tin powder with a purity of up to 99%, the highest (99,4%) at a temperature of 50°C.

1. Introduction

Indonesia is the third largest tin producing country in the world in 2019, which is 76.400 tons. Meanwhile, PT Timah Tbk, an Indonesian state-owned tin mining company, recorded tin ore production of 20.079 tons at the end

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DOI: http://dx.doi.org/10.62870/tjst.v21i1.32459

of 2022 and 14.855 tons at the end of 2023 [1]. Tin is a potential commodity to be developed considering that down streaming in Indonesia has not developed optimally. Based on survey data, almost 50% of the world's tin production is applied in the form of solder wire, especially for the production of electronic goods [2]. In Indonesia, tin companies such as PT Timah Tbk. only produces tin plate and Pb-Sn solder wire [3].

The development of the electronics industry has resulted in an increasing need for tin, which has an impact on the increasing demand for tin derivative products. The first derivative of the solder industry is in the form of tin anode and tin shot which are basic materials in the electroplating process of Printed Circuit Boards (PCBs). Printed Circuit Board (PCB) is one of the main components in the electronics industry which uses a soldering process with a lead (Pb) composition of 37% and tin (Sn) of 63% [4]. Lead (Pb) and tin (Sn) are combined to form a material with a low melting point that makes the process easier and has good conductivity. However, Pb has a negative impact on health and the environment [5]. Although the traditional Pb-Sn solder alloy provides good conductivity and a low melting point, the toxic effects of Pb—including environmental pollution and health hazards such as neurological disorders and reproductive toxicity—have led to increasing regulatory and industrial pressure to develop lead-free alternatives. Tin (Sn), which is non-toxic and exhibits excellent soldering characteristics, has therefore become the primary candidate for replacing Pb in electronic solder applications. While Sn has a good microstructure, mechanical structure, and manufacturing capabilities, a high melting point of 232^{o}C, high corrosion resistance and has a high tensile strength of 25 Mpa [6]. Based on research by Mulyani, et al, Sn powder (white tin) with a purity of up to 99% was obtained which can be applied as a raw material for solder paste [7]. Tin powder can also be used as a Cu-Sn powder alloy [8] and a Sn-Sb -Cu powder alloy for bearings [9].

This situation underscores a significant research gap: the lack of systematic investigation and optimization of local production technologies, specifically electrodeposition, to produce tin powder from Indonesian tin resources that meets the stringent requirements (particle size, morphology, purity) of the electronics industry while ensuring process efficiency. Although electrodeposition is a known method for powder synthesis, detailed understanding of how varying process parameters—current, time, electrolyte concentration, and temperature—affect the final tin powder characteristics from local tin feedstock remains limited.

Therefore, the primary objective of this research is to investigate the effect of key electrodeposition parameters—current density, time, concentration of tin (II) chloride, and temperature—on the characteristics (particle size, morphology, purity) and current efficiency of tin powder produced from tin metal bars. The study aims to identify optimal conditions for synthesizing tin powder suitable for solder paste applications. To achieve these objectives, the electrodeposition method was systematically employed, utilizing a chloride electrolyte solution containing tin (II) ions, with tin bars serving as the anode and SS 316 plates as the cathode. The influence of the aforementioned process variables on the resulting tin powder and process efficiency was thoroughly analyzed.

The findings of this research are expected to contribute significantly by providing a deeper understanding of the electrodeposition process for tin powder synthesis. Specifically, this study will offer valuable data on how to control particle size, morphology, and purity by manipulating process parameters. This work aims to lay a scientific foundation for the development of a domestic tin powder production process, potentially reducing import dependency, enhancing the value chain of Indonesia's tin resources, and supporting the growth of the national electronics manufacturing sector.

2. Literature review

Tin powder is tin metal that has been ground into small particles using an electrodeposition process. Tin powder refers to metallic tin formed as small particles through the electrodeposition process, where metal ions in solution are reduced and deposited onto a cathode surface as fine particulate matter. This method does not involve mechanical grinding and can be performed at relatively low temperatures using affordable laboratory equipment and materials electrodeposition is a method that uses electric current to deposit metal on the surface of the electrode [7].

The components in the electrodeposition process are electrodes (anode and cathode) and electrolyte solutions. The electrodes used in the electrodeposition process are the anode at the positive pole in the form of a tin plate and the cathode at the negative pole in the form of SS 316, a type of stainless steel that has a composition of 0.042% C; 1.19% Mn; 0.034% P; 0.006% S; 0.049% Si; 18.24% Cr; 8.15% Ni; and the rest Fe. SS 316 is good to use because it has high stability so that it does not release unwanted ions during the process [10]. The electrolyte solution used is $SnCl_2$ synthesis.

According to Kakesi, the process of extracting tin from waste by electrorefining in HCl-$SnCl_2$ solution is considered a flexible and efficient method to obtain pure tin [11]. The process of making electrolyte solutions containing tin ions is carried out by dissolving $SnCl_2$ in HCl. In HCl solution, tin ions form complex chloro compounds with chloride ions so that tin ions will be more stable in solution and encourage the electrodeposition process of tin metal on the cathode surface. When the $SnCl_2$ electrolyte solution is heated, the $SnCl_2$ molecules gain sufficient heat energy to increase their kinetic energy. With higher kinetic energy, the $SnCl_2$ molecules can overcome the attractive forces between molecules [12].

The electrodeposition process can produce powder sizes ranging from 20-45 μm which are used for solder powder and a larger powder size of 50 μm can be developed for raw materials for Cu-Sn alloys (bronze) as applications for making bullets. Tin solder that does not contain lead is considered safer than solder that contains lead because it does not cause environmental pollution due to the lead element in the solder [13]. Tin solder in the form of a metal alloy produces a solder bar. There are two types of solder bars, namely those containing lead (Sn/Pb) and those free from lead (lead free). As with solder bars, there are two types of solder wire, namely solid wire and coreflux wire. The next derivative product is solder powder. Solder powder produces solder paste when combined with liquid flux, solid flux and flux paste Solder paste is generally used to clean the solder tip and as a coating material on the metal surface to be soldered so that the solder product does not break and the tin sticks perfectly [3].

Sopiah has analyzed the factors that affect the electrodeposition process using $CuSO_4$ solution [14]. In this research, Sopiah concluded that the efficiency of the electrodeposition process is influenced by current, time, temperature and electrolyte concentration, namely the greater the current, time, temperature and electrolyte concentration, the greater the electrodeposition results will be [14]. Based on previous research by Mulyani et al, the effect of time and current is directly proportional to the mass of tin powder [7]. The greater the current given, the greater the energy supply given to reduce the anode so that the speed of grain growth on the cathode will be greater.

This research makes tin powder using H_2SO_4 and $SnSO_4$ electrolytes with a concentration of 0.1 M with variations in current (5 A, 6 A, and 7 A), and process time (20 minutes, 25 minutes and 30 minutes). The best results in previous research produced tin powder with a purity of 99% at a current strength of 7 A for 1 hour. Temperature can affect the thickness of the deposit on the cathode.

According to research by Asroni et al, the higher or lower the electrolyte temperature will affect the thickness value, the higher the temperature, the thicker the layer. An increase in temperature also causes an increase in the conductivity and diffusivity of the electrolyte solution, which means that the electrolyte resistance decreases so that the potential required to reduce ions to metal decreases [15]. Changes in ion concentration in the electrolyte can affect the conductivity properties of the solution, which results in changes in properties and affects the quality of the tin powder produced. Muhammad stated that the higher the concentration value, the more ions there will be in the solution. The large number of ions will also increase the ionized atoms so that the mass attached to the cathode also increases during the electrodeposition process [1]. Based on these studies, further research was carried out on the effect of current density variables, time, temperature, and SnCl2 concentration through the electrodeposition process on the percentage of current efficiency and the morphology of the resulting powder to produce tin powder with a purity of 99%.

3. Material and method

In this research, electrode plates in the form of tin plates and SS 316 plates were prepared by cutting them with a cutting machine to dimensions of 4 × 4.7 × 1.7 cm for the tin plates and 4 × 4.5 × 0.2 cm for the SS 316 plates. The plates were then sanded, and holes were drilled to attach wires, which were coated with epoxy resin.

To prepare the $SnCl_2$ solution, 37% HCl was added to a 1000 mL beaker containing distilled water, followed by the gradual addition of $SnCl_2{\cdot}H_2O$ (5, 10, 20, or 30 g/L). The solution was stirred, transferred to a 1000 mL volumetric flask, and tightly sealed. The $SnCl_2$ solution was titrated iodometrically using a KIO_3 standard solution until it turned golden yellow.

The electrodeposition process involved a tin plate (anode), an SS 316 plate (cathode), an $SnCl_2$ electrolyte solution, and a DC power supply. The electrode plates were immersed in the $SnCl_2$ electrolyte solution with variations in current density (0.5, 0.7, 0.9, and 1.1 A/m²), time (15, 30, 45, and 60 minutes), electrolyte concentration (5, 10, 20, and 30 g/L), and temperature (30, 40, 50, and 60 °C). The electrodeposition product was washed with distilled water, filtered using filter paper, and the mass of the resulting Sn powder was measured. The Sn powder was dried at 100 °C for 2 hours. Sieve analysis was performed on particle size fractions (+18#, -18+20#, -20+25#, -25+40#, -40+45#, -45+50#, -50+100#, -100+200#, -200+270#, and -270+325#), followed by SEM-EDS characterization.

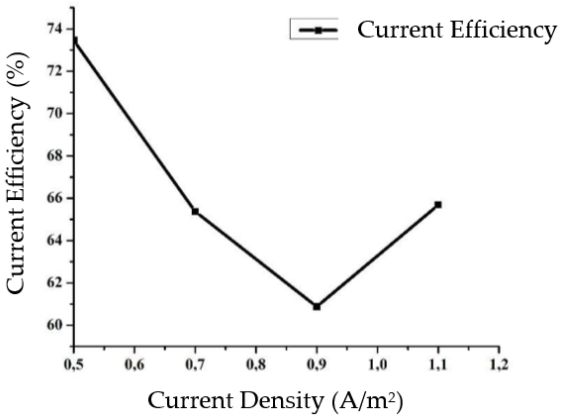


Fig. 1. Effect of current density variation on percentage current efficiency with time of 60 minutes, $SnCl_2$ concentration of 5 g/l, and temperature of 60°C.

4. Results and discussion

This research discusses the electrodeposition process to obtain tin powder using an $SnCl_2$ electrolyte with variations in current density (0.5, 0.7, 0.9, and 1.1 A/m²), process time (15, 30, 45, and 60 minutes), $SnCl_2$ concentration (5, 10, 20, and 30 g/L), and temperature (30, 40, 50, and 60°C). After the electrodeposition process, the sample was dried at 100°C for 2 hours. Subsequently, sieve analysis was conducted with size variations including: +18#, -18+20#, -20+25#, -25+40#, -40+45#, -45+50#, -50+100#, -100+200#, -200+270#, and -270+325#. The sieve analysis was performed to determine the powder quality, particle fineness, and size distribution of the tin powder obtained. The sieved samples were then analyzed using SEM-EDS to examine the morphological structure of the samples. Additionally, EDS was used to identify the compounds and elements present in the samples, thereby assessing the purity of the tin powder obtained from the electrodeposition process.

4.1. Effect of current density on electrodeposition result

Fig. 1 shows the effect of variations in current density on the percentage of current efficiency during the electrodeposition process with a duration of 60 minutes, an $SnCl_2$ concentration of 5 g/L, and a temperature of 60°C. Based on **Fig. 1**, it is evident that the efficiency of tin electrodeposition changes significantly with varying current density. At a current density of 0.5 A/m², the efficiency reaches approximately 75%, the highest value observed. When the current density increases to 0.7 A/m², the efficiency decreases sharply to about 65%. This decline continues until a current density of 0.9 A/m², where the efficiency reaches its lowest value of approximately 60%. Interestingly, at 1.1 A/m², the current efficiency increases again after the initial decline. This may be attributed to improved ion transport dynamics and localized enhancement in Sn^{2+} ion availability near the cathode due to higher field strength. Such non-linear behavior has been reported in prior studies [16], indicating that under certain electrochemical conditions, higher current density may partially offset efficiency losses by accelerating ion migration and modifying surface kinetics. However, the text appears to repeat the statement about efficiency increasing at 1.1 A/m², which seems redundant. Additionally, higher current density can accelerate the evolution of hydrogen gas (H_2) at the cathode, where hydrogen ions (H^+) in the electrolyte solution are reduced to H_2 gas.

The hydrogen reduction reaction has a standard reduction potential of 0 volts, which is more positive than the reduction of Sn^{2+} ions to Sn (with a standard reduction potential of -0.14 volts). Hydrogen reaction at the cathode and tin reaction at the cathode are shown in Eq. (1) and Eq. (2). In this case, hydrogen is more easily reduced at the cathode than tin under certain conditions, particularly at high current densities. Consequently, increasing the current density tends to promote faster hydrogen evolution, which consumes some of the current intended for tin deposition. Additionally, increasing the current density causes an increase in voltage (V), according to Ohm's law (V = IR). This voltage increase is also influenced by other variables, such as temperature, Sn^{2+} ion concentration, and electrodeposition process duration.

$$2H^+ + 2e \rightarrow H_2 \; E^0 = 0 \text{ Volt} \quad (1)$$

$$Sn_2^+ + 2e \rightarrow Sn \; E^0 = -0.14 \text{ Volt} \quad (2)$$

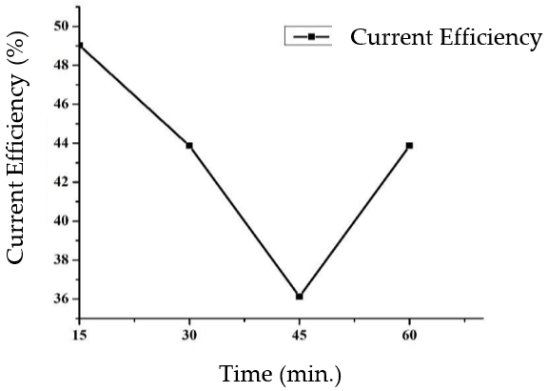


Fig. 2. Effect of time variation on percentage current efficiency with current density of 0,7 A/m2, $SnCl_2$ concentration of 5 g/l, and temperature of 60°C.

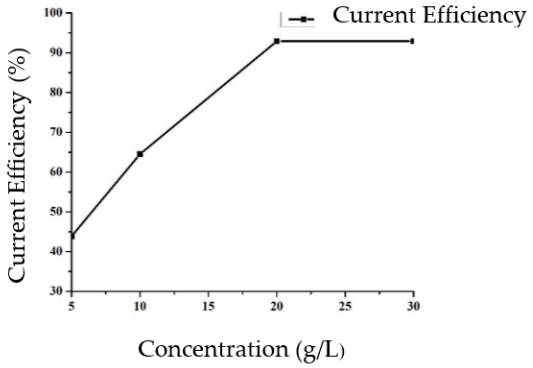


Fig. 3. Effect of $SnCl_2$ concentration variation on current efficiency percentage with current density of 0,7 A/m^2, time of 15 Minutes, and temperature of 60°C.

Under these conditions, optimization is required to minimize hydrogen evolution and maximize tin deposition to achieve higher efficiency [16]. As a result, current efficiency decreases because not all of the current is utilized for tin layer formation. Conversely, at lower current densities, the deposition rate is slower, allowing sufficient time to achieve higher efficiency [17].

4.2. Effect of current density on electrodeposition result

Fig. 2 illustrates the effect of time on the percentage of current efficiency during the electrodeposition process with a current density of 0.7 A/m², a $SnCl_2$ concentration of 5 g/L, and a temperature of 60°C. In the electrodeposition process, duration significantly influences the dynamics of reactions at the cathode and anode. Extending the electrodeposition time tends to reduce hydrogen gas (H_2) evolution, which typically occurs in the early stages of the process. This reduction is due to the prolonged stabilization of ions near the electrode surface, allowing more focused metal layer growth and minimizing hydrogen gas formation. Consequently, longer electrodeposition times can increase current efficiency, as more current is utilized for tin deposition rather than hydrogen gas production. At the start of the process, tin ions in the electrolyte solution readily reach the electrode surface, forming a tin layer with high efficiency [18]. Fig. 2 shows that electrodeposition efficiency varies with time. Initially, the efficiency is approximately 50% at 15 minutes, then decreases to a low of about 38% at 45 minutes, before rising again to nearly 45% at 60 minutes. The observed drop in current efficiency at 45 minutes may be attributed to temporary passivation or surface blockage effects, such as gas bubble accumulation or irregular deposit growth, which reduce the effective cathode area. By 60 minutes, efficiency increases again, likely due to stabilized electrolyte composition and improved surface conditions, enabling more efficient electron transfer and ion reduction.

4.3. Effect of concentration on electrodeposition results

Fig. 3 shows the effect of variations in $SnCl_2$ concentration on the percentage of current efficiency during the electrodeposition process, conducted at a current density of 0.7 A/m², for 15 minutes, and at a temperature of 60°C.

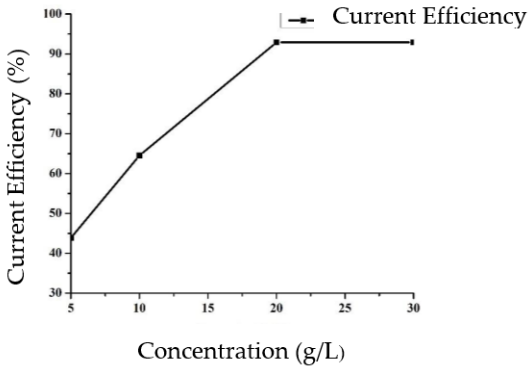


Fig. 4. Effect of temperature variation on percentage current efficiency with current density of 0,7 A/m2, time of 15 minutes, and $SnCl_2$ concentration of 5 g/l.

Based on Fig. 3, increasing the concentration of tin ions in the electrolyte solution leads to a higher percentage of current efficiency. This is because a higher concentration of tin ions increases their availability at the cathode surface, allowing more of them to undergo reduction to form metallic tin. As a result, more tin is deposited on the cathode, thereby improving current efficiency. Additionally, higher tin ion concentrations reduce the formation of hydrogen gas (H_2) on the cathode. By increasing the concentration of metal ions such as Sn^{2+}, the competition for electrons between Sn^{2+} and H^+ at the cathode surface shifts in favor of tin deposition, reducing hydrogen evolution [19]. Consequently, the current is utilized more effectively for forming a tin layer rather than generating hydrogen gas, leading to increased current efficiency.

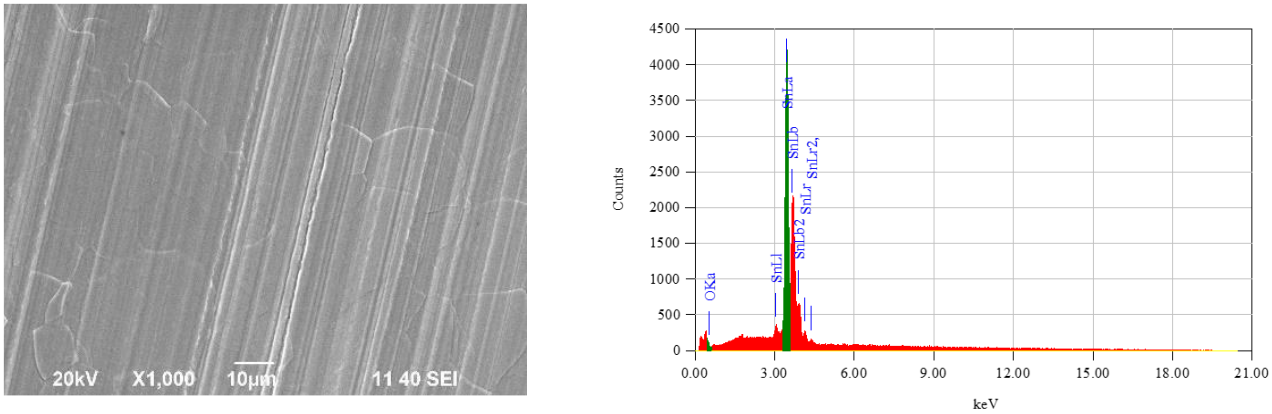
4.4. Effect of temperature on electrodeposition results

The solution temperature has a significant impact on the conductivity and viscosity of the solution. As the temperature increases, the conductivity of the solution tends to increase because the kinetic energy of the ions in the solution also increases. This allows the ions to move faster and more freely, allowing the solution to conduct electric current more efficiently. This increase in conductivity is beneficial in the electrodeposition process because more metal ions, such as Sn^{2+}, are available to be reduced to tin metal (Sn) at the cathode. As the temperature increases, the viscosity of the solution usually decreases. Lower viscosity allows the solution to flow more easily, which accelerates ion diffusion and speeds up the deposition process [20]. It also reduces the energy required to move the solution, thereby increasing the overall efficiency of the electrodeposition process. With a low viscosity, the electric current can be more effectively used for tin deposition, rather than for unwanted side reactions. Figure 4 shows the effect of temperature variation on the percentage of current efficiency during the electrodeposition process with a current density of 0.7 A/m^2, a time of 15 minutes, and a $SnCl_2$ concentration of 5 g/l.

In Fig. 4, the maximum current efficiency is obtained at a temperature of 30°C (49%) and decreases slowly to the lowest point of 50°C reaching (36%) and then increases again at 60°C (44%). The decrease in current efficiency at 50°C can be caused by the increase in hydrogen gas (H_2), resulting in more current wasted to produce gas than for tin (Sn) deposition. In addition, at higher temperatures, the oxidation reaction may also be more active, which can reduce the amount of Sn^{2+} ions reduced at the cathode. However, when the temperature increases to 60°C, the current efficiency increases again. This can happen because at this temperature, the viscosity of the solution becomes lower [21], thus increasing the diffusion of Sn^{2+} ions to the cathode surface. In addition, the higher kinetic energy at 60°C allows the tin deposition reaction to run more efficiently and quickly, reducing the influence of side reactions. In other words, at this temperature, although hydrogen gas evolution may still occur, the increased tin deposition rate is able to offset the current expenditure for side reactions, so that the current efficiency increases again.

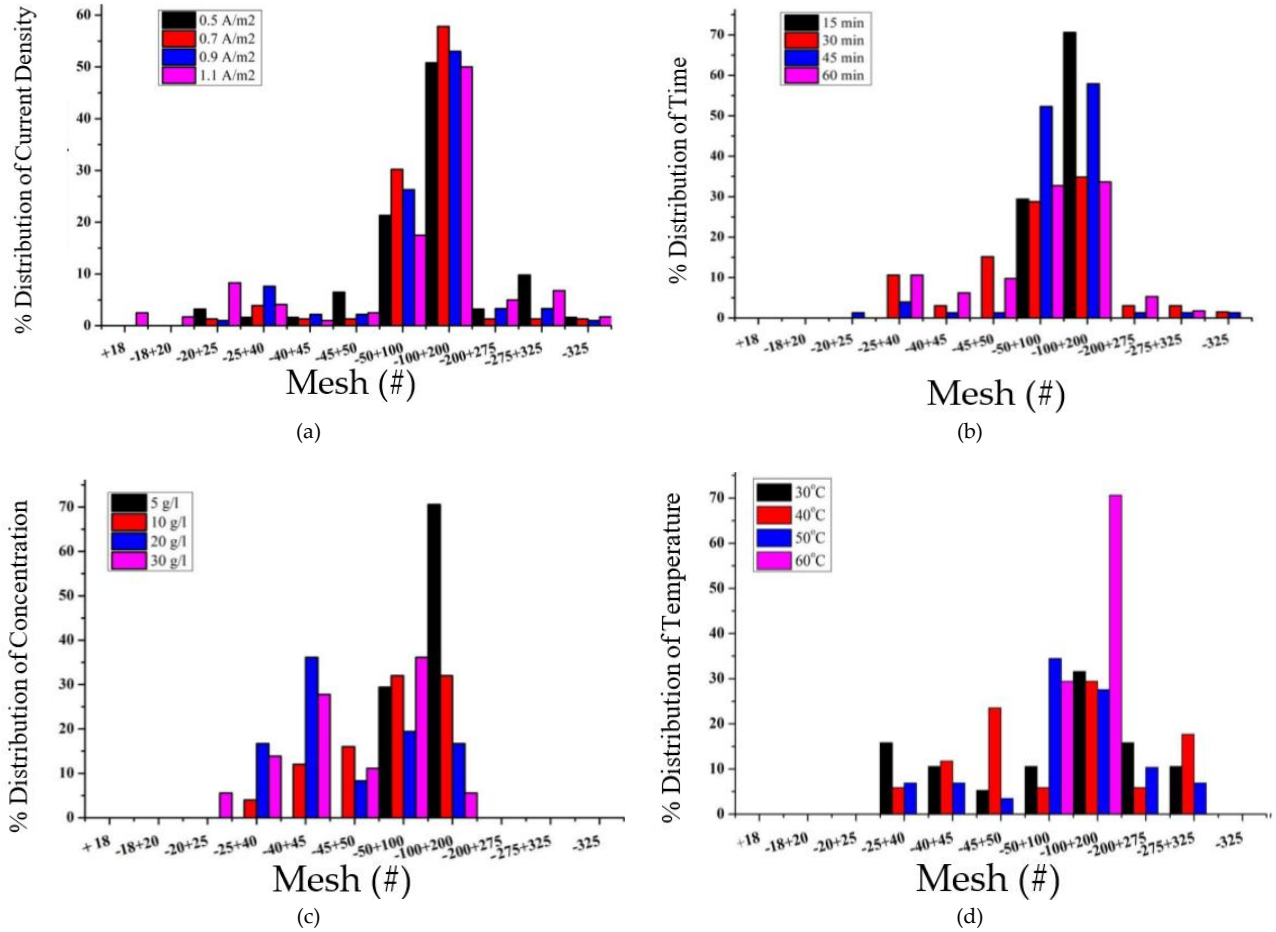
4.5. Initial characterization of SEM-EDS tin plate

Initial characterization of the tin plate was carried out to determine the percentage content and morphology of the tin plate using Energy Dispersive X-ray Spectroscopy (EDS) in collaboration with SEM to provide qualitative and semi-quantitative results. Both techniques, together, have the potential to introduce fundamental information about the composition of the launched product. The main components of SEM testing consist of an electron source, a column where light travels with an electromagnetic lens, an electron detector and a sample chamber. Fig. 5 shows the results of the characterization of the tin plate using SEM-EDS.



(a) (b)

Fig. 5. Characterization results: (a) SEM and (b) EDS tin plate with 1000x magnification.



(a) (b) (c) (d)

Fig. 6. Distribution of grain size on variables: (a) current density, (b) time, (c) concentration, and (d) temperature.

Fig. 5 shows the results of SEM-EDS characterization of tin plates with a magnification of 1000x. The SEM image of the tin plate at a magnification of 1000x shows a smooth surface structure with long lines. These lines are patterns or grooves formed on the surface during the manufacturing process (cutting). Patterns like this are commonly found on the surface of metal materials that have undergone machining (cutting) or grinding. Metal surfaces tend to show parallel linear scratches or textures. This is in accordance with the literature stating that metals often leave long grooves or scratches on the surface of the material [22].

From the results of the EDS analysis of the tin plate, the tin (Sn) content detected was 99% Sn. The presence of oxygen can be detected by EDS due to surface contamination on the plate, causing a thin oxide layer to form naturally on the tin surface. In addition, the EDS technique itself has limitations in quantitative accuracy, especially in detecting light elements and in situations where there are elements with overlapping X-ray energies. As a result, the detected lead levels are often lower than 100%, reflecting the complexity of the real material and the analytical techniques used [23].

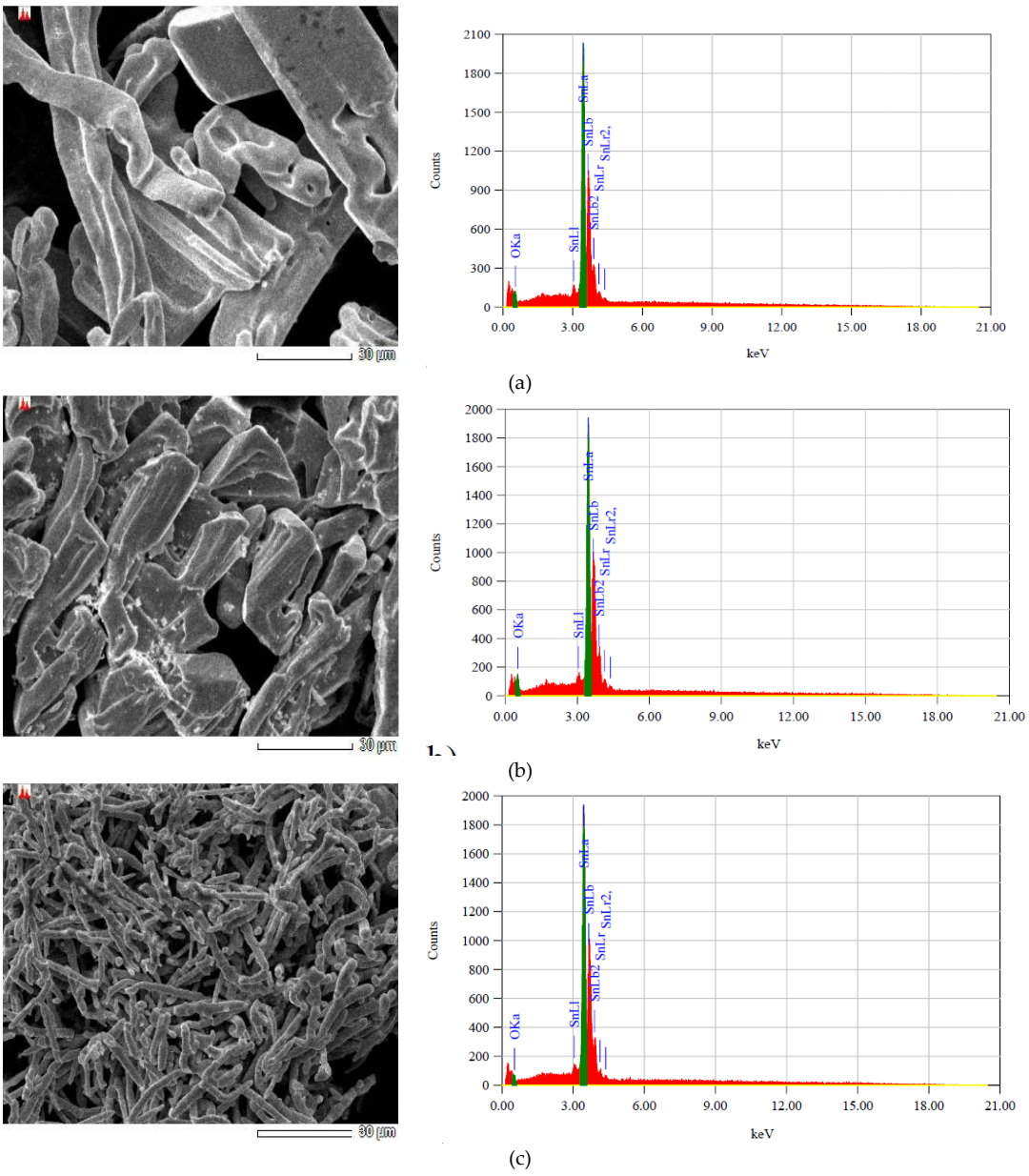


Fig. 7. SEM-EDS characterization results with 1000x magnification: (a) sample of the best current density variation 0,7 A/m^2, (b) sample variation of best holding time 60 minutes, and (c) sample best temperature variation 50^{o}C.

4.6. Characterization of sieve analysis

Sieve analysis was conducted to determine the grain size and size distribution of the electrodeposited tin powder. The sieving series ranged from +18# to +325#, arranged from the coarsest to the finest mesh size. The tin powder was poured onto the top sieve, and through mechanical shaking, the particles were separated according to their size. The resulting size distribution provides important insight into the quality and characteristics of the powder for potential applications.

The size and distribution of tin powder particles in electrodeposition are not influenced by mechanical processes but are instead governed by electrochemical parameters such as current density, ion concentration, deposition time, and temperature. These variables directly affect the kinetics of nucleation and crystal growth on the cathode surface. For example, higher current densities increase the nucleation rate, producing finer and more uniform particles, while lower currents allow more time for crystal growth, resulting in coarser and irregular morphologies. Similarly, elevated temperatures can enhance ion mobility and deposition kinetics, further influencing the resulting grain structure.

As shown in Fig. 6, the most dominant particle size for all variables was around +200#, indicating relatively fine powder formation under the tested conditions. Among the four variables observed, current density of 0.7 A/m^2 produced the highest mass of tin powder in this particle size range (1.48 grams). Likewise, at 15 minutes of deposition time, 5 g/L concentration, and 60°C temperature, the powder mass remained most concentrated in the

+200# fraction (0.17 grams). This trend supports the understanding that optimized electrochemical conditions promote uniform nucleation, leading to a higher fraction of particles within the desired size range.

4.7. Characterization of SEM-EDS

Fig. 7 shows the results of the characterization of tin powder using SEM-EDS. The morphology of the formed tin powder is greatly influenced by the parameters of the electrodeposition process, such as current density, holding time, and temperature. Each variation produces a different powder structure, ranging from more regular particles to irregular shapes. These shapes have an average particle size of 20 microns [7]. The observed powder morphology, such as the large and irregular grains at 0.7 A/m² current density, aligns with theoretical predictions where moderate current densities favor crystal growth over nucleation. In contrast, finer structures at higher temperatures correspond to increased ion mobility and deposition rate, leading to smaller, more dispersed particles. These findings are consistent with prior studies by Sharma et al. and Mallik et al., which describe similar morphological transitions in metal electrodeposition systems. In Fig. 7(a). The powder structure shows a relatively large width and irregular shape. This morphology is usually formed due to low or moderate current density, which allows controlled crystal growth. Fig. 7(b) shows a more structured and segmented powder morphology with a clearer crystal shape. This indicates that the optimal holding time during electrodeposition allows for more regular and dense crystal growth. This denser shape tends to have good electrical conductivity and higher mechanical stability. Fig. 7(c) shows a powder with a smaller and irregular particle shape. This structure indicates a more porous and less regular morphology. $SnCl_2$ in the tin electrodeposition solution can have a significant impact on the nucleation behavior and growth of tin deposits [7]. Meanwhile, the results of the EDS test showed that the purity of the tin powder from electrodeposition had a high purity of up to 90%. The highest tin content was produced at a temperature variation of 50°C, producing a tin content of 99.4%. While the variation of the holding time of 60 minutes produced a tin content of 96.7% and the variation of the current density produced a tin content of 97.8% at a current density of 0,7 A/m².

Temperature can increase the electrochemical reaction, thereby accelerating the rate of tin ion deposition on the cathode. If the temperature is higher, the conductivity of the solution will increase, thereby accelerating the electrodeposition process, this is evidenced by [24] at a temperature of 85°C producing a thicker Sn layer compared to a temperature of 155°C. In addition, at higher temperatures, the mobility of ions in the solution increases, which contributes to the deposition efficiency and purity of the final product [25]. Increasing the temperature can accelerate the electrodeposition reaction and minimize the formation of unwanted by-products. This is indicated by the very high tin content (99.4%) obtained at 50°C. Therefore, temperature not only plays a role in accelerating the reaction but also in increasing the purity of the electrodeposition results, making it the most effective and critical variable in this process

5. Conclusions

Variations in current, time, temperature, and $SnCl_2$ concentration showed that the highest current efficiency was achieved at a current density of 0.5 A/m², with an efficiency of around 75%. In the time variation, the highest efficiency was obtained at 15 minutes, with an efficiency value of approximately 50%. For the temperature variation, the highest current efficiency was achieved at 30°C, reaching 49%. In terms of morphology, the resulting tin powder exhibited various shapes and structures. The powder produced at the optimal current density of 0.7 A/m² had a large and irregular morphology. The powder produced at the optimal deposition time of 15 minutes showed a more structured morphology with distinct crystals, indicating denser and more orderly growth. Meanwhile, the powder obtained at the best temperature of 50°C consisted of smaller and irregular particles. The electrodeposition process was also successful in producing high-purity tin powder, with purity reaching up to 99%. The highest purity was obtained at a temperature of 50°C, with tin content reaching 99.4%. A time variation of 60 minutes and a current density of 0.7 A/m² also produced high-purity tin powder, with purities of 96.7% and 97.8%, respectively. These results indicate that proper control of process variables, especially temperature, plays a significant role in improving the quality and purity of the resulting tin powder.

For future research, further investigation is recommended to optimize other process parameters such as electrolyte pH, agitation speed, and the use of additives to enhance powder morphology and deposition efficiency. Additionally, studying the scalability of the electrodeposition process and the performance of the produced tin powder in specific applications, such as battery electrodes or solder materials, could provide valuable insights for industrial implementation.

Declaration statement

Risa Oktanova: Conceptualization, Methodology, Writing-Original Draft. **Soesaptri Oediyani**: Collecting data. **Anistasia Milandia, Rudi Subagja**: Writing-Review & Editing.

Acknowledgement

The authors thank the anonymous referees for their constructive feedback.

Disclosure statement

This manuscript is free from conflict of interest and has been processed in accordance with applicable journal provisions and ethical publication standards.

Funding statement

The authors received no funding for this research.

Data availability statement

All data generated or analyzed during this study are included in this published article and its supplementary materials.

AI Usage Statement

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