Recovery of Tin from Sn–Pb Alloy via Hydrometallurgical Leaching and Its Utilization for Synthesis of SnO2

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**Abstract.** The processing of tin ore in Indonesia generally increases the Sn content by 20-30% through extraction and gravity separation, producing a concentrate containing 72-74% Sn suitable for smelting. Smelting at high temperatures yields raw tin, which is subsequently refined by crystallization and electrolytic methods to achieve 99.9% purity. However, these processes generate residues that remain largely unutilized, presenting opportunities for recovery and conversion into valuable products. This study investigates the recovery of tin from Sn-Pb alloy waste using a hydrometallurgical route, with the aim of synthesizing SnO₂ as a value-added material. Leaching experiments were conducted using hydrochloric acid solutions with concentrations ranging from 1 M to 7 M at 50 °C, as well as at 50, 70, and 90 °C with reaction times of 6, 12, and 24 hours. The results revealed that 5 M HCl provided the highest dissolution efficiency of 77.27%. Increasing the acid concentration beyond this level reduced yields due to the formation of a passivation layer and diffusion limitations. The study further showed that elevated temperatures combined with moderate leaching times were most effective for tin dissolution. The obtained leachate was utilized as a precursor for SnO₂ synthesis via oxidation, precipitation with ammonia solution, and calcination. XRD characterization confirmed the formation of a tetragonal rutile SnO₂ phase in all samples. The diffraction peak intensity improved with higher leaching temperatures and longer reaction times, with the best crystallinity observed at 70 °C for 12 hours. These findings highlight the importance of controlling leaching parameters to maximize tin recovery and produce high-quality SnO₂, enabling alloy waste to serve as a secondary source of strategic metals.

**Keyword**: *Extracttion, Hydrothermal, Recovery, Sn-Pb Alloy, Tin Oxide*

# INTRODUCTION

Indonesia is acknowledged as a premier tin producer, holding the second position globally after China, due to its significant tin ore reserves. The International Tin Association (ITA) and the CRU Tin Monitor (2022) report that Indonesia produced approximately 26,500 metric tons of refined tin in 2021, with approximately 94% exported to Asia, America, and Europe. The residual 6% was allocated for domestic consumption. In the same year, Indonesia's tin ore resources were estimated to exceed 900,000 tons, with confirmed reserves around 300,000 tons [1]. The reported domestic value of tin remains relatively low, as almost all of its production is exported globally in either semi-finished or raw form. The Indonesian government has implemented a policy that involves limiting the export of raw tin, with the goals of encouraging downstream processing and enhancing the economic impact of the industry. In Indonesia, the downstream processing level remains significantly low, comprising only 5% of the total tin production, in significant contrast to China, which displays a remarkable 70% of total production [2]. Additionally, the government has mandated that all export tin products contain at least 95% Sn [3]. Consequently, it is required that each processing and refining stage be strictly regulated to hold to specifications and effectively handle byproducts throughout the smelting and refining processes. These materials can be hazardous for the environment and the economy if they are not used properly [4].

Tin ore processing in Indonesia generally enhances the Sn content by 20-30% via extraction and gravity separation, yielding a concentrate with an Sn content of 72–74% appropriate for smelting. Smelting occurs in heated conditions to yield raw tin, which is subsequently refined through crystallization and electrolytic processes to attain a purity level equal to 99.9% Sn [3]. The refined products correspond to the specifications for high-value applications, such as electronics and soldering. Nevertheless, these processes produce significant quantities of waste and by-products. Tin sludge and tailings possess some application in construction materials [5]. In contrast, the Sn-Pb alloy waste has primarily remained unprocessed [6]. The residue from the Sn-Pb alloy exhibits a significant lead concentration, leading to further processing steps. Consequently, these residues develop into waste in landfills. The potential of these residues remains relatively unexplored, offering opportunities for recovery and conversion into valuable materials [7]. One promising approach to recover tin from Sn-Pb alloy is hydrometallurgical leaching, which offers advantages such as selective dissolution, lower energy consumption, and simpler operating conditions compared to pyrometallurgical [8]. Among leaching reagents, hydrochloric acid (HCl) has demonstrated high effectiveness for tin extraction compared to microwave digestion. This is because microwave digestion typically requires the use of large amounts of mixed acid systems, such as HNO3/HF, HClO4/HNO3, HF/HNO3/HCl, HNO3/HCl, and HNO3/H2SO4, which pose greater safety and environmental risks [9,10]. HCl was found to exhibit a superior extraction efficiency than H2SO4 and HNO3, achieving 95.97% dissolution of the metal in solution. The reaction of Sn with HCl forms tin(II) chloride (SnCl2) in solution [11]. The resulting SnCl2-rich leachate has considerable potential for further processing. In particular, SnCl2 can serve as a precursor in the synthesis of tin(IV) oxide (SnO2), an advanced material with diverse technological applications. SnO2 is widely employed in gas sensors, transparent conductive films, lithium-ion batteries, and catalysts. Therefore, transforming tin-containing leachates into SnO2 aligns with the circular economy approach and supports Indonesia’s strategy for sustainable resource utilization [12].

The application of Sn-Pb alloy as a precursor for the formation of SnO2 through leaching and synthesis processes enhances economic value while simultaneously reducing the environmental impact linked to waste produced by tin production [13]. Moreover, such integrated processing supports the goal of increasing Indonesia’s downstream processing capacity and reducing dependency on imported materials for advanced technologies. Unlike most previous studies that separately addressed tin recovery from secondary sources or SnO₂ synthesis from commercial precursors. This research combines both aspects into a single pathway by selectively dissolving Sn-Pb alloy residues and directly converting the resulting solution into functional SnO₂ material. This research involves exploring the recovery of tin from Sn-Pb alloy residues using hydrochloric acid dissolution methods. The research focuses on evaluating the leaching efficiency, identifying optimal process parameters, and characterizing the chemical composition of the leachate. Additionally, this work explores the conversion of the SnCl₂ solution into tin(IV) oxide, examining the crystallographic properties of the synthesized SnO2 powder.

## EXPERIMENTAL

## Materials

The materials used in this study comprised Sn-Pb alloy, hydrochloric acid solution (37%, Smart-Lab), nitric acid solution (65%, EMSURE), ammonia solution (25%, Sigma Aldirch), deionized water, tin(II) chloride dihydrate (SnCl₂·2H₂O, EMSURE), and lead(II) chloride (PbCl₂, SAP Chemical).

## Acid Leaching Process for Tin Recovery

A total of 2 grams of Sn-Pb alloy was dissolved into an HCl solution, ensuring a liquid-to-solid ratio of 0.08 g/mL. The solution was given heating at 90 °C and agitated at a rate of 300 rpm for a duration of 24 hours. After the reaction, the mixture was left to sit at room temperature and then filtered. The solid residue was dried in an oven at 60°C and weighed to determine mass loss. The evaluation of leaching efficiency involved varying the concentration of HCl from 1 M to 7 M, keeping a temperature of 90 °C and a reaction duration of 24 hours. Further experiments were carried out to investigate the influence of temperature utilizing HCl solution under optimal conditions at temperatures of 50 °C, 70 °C, and 90 °C. Leaching was conducted under each temperature condition for durations of 6, 12, and 24 hours to evaluate the impact of time on the extraction of tin.

## Synthesis of SnO2

Before synthesizing SnO₂, an oxidation process was carried out using hydrochloric acid (HCl) and nitric acid (HNO3) as oxidizing agents added to the SnCl₂ filtrate. Specifically, 10 mL of SnCl2 filtrate was mixed with 50 mL of 2 M HCl and 50 mL of 2 M HNO3. The mixture was stirred at room temperature for 30 minutes to obtain a clear and colorless solution. Subsequently, ammonia solution was added dropwise until the pH reached 8.5, resulting in the formation of a dense white suspension. The mixture was stirred for 3 hours. After stirring, the suspension was allowed to settle overnight for complete sedimentation. The precipitate was then separated by filtration and dried in an oven at 60°C for 5 hours. The dried product was calcined at 400°C for 3 hours.

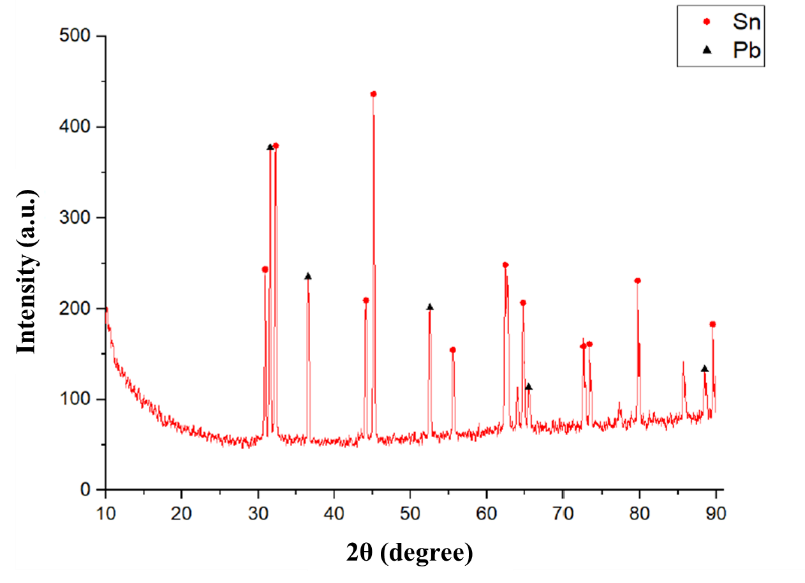
## Characterization

The Crystal phase of the prepared samples was characterized by X-ray diffraction (XRD) PANalytical X’Pert PRO. The XRD analysis was performed using XRD PANalytical under Cu Kα irradiation (λ = 1.5406 Å), with accelerating voltage and current of 40 kV and 40 mA, respectively. The analysis was carried out at a diffraction angle of 2θ of 10 – 100° [14]. The XRF analysis was conducted by PANalytical/ Minipal 4 provided with 9 W X-ray tube Rh (0.1 mA and 20 kV), 5 tube filters, equipped with a high resolution Silicon Drift Detector and a 12-position sample tray with sample spinner [15].

# rESULT AND DISCUSSION

## Characteristic of Sn-Pb Alloy

Sample preparation of the Sn–Pb alloy was conducted by machining the material using a milling machine to produce scrap or turnings suitable for subsequent processing. In this study, the alloy samples were characterized using X-ray diffraction (XRD) to identify the mineral phases present and to determine the crystallinity of the material [16]. The resulting XRD diffractogram of the Sn–Pb alloy is presented at **Figure 1**. The XRD analysis was complemented by X-ray fluorescence (XRF) measurements to obtain a more detailed assessment of the elemental composition. According to the XRF results summarized in **Table 1**, the alloy sample contained two major metallic components: tin (Sn) at 75% and lead (Pb) at 24.3%. The high lead content in the alloy is a primary factor contributing to the material not being further processed, and as such, it is classified as industrial waste. However, given the substantial residual tin content, this study was carried out to explore the potential recovery of tin through hydrometallurgical extraction processes.



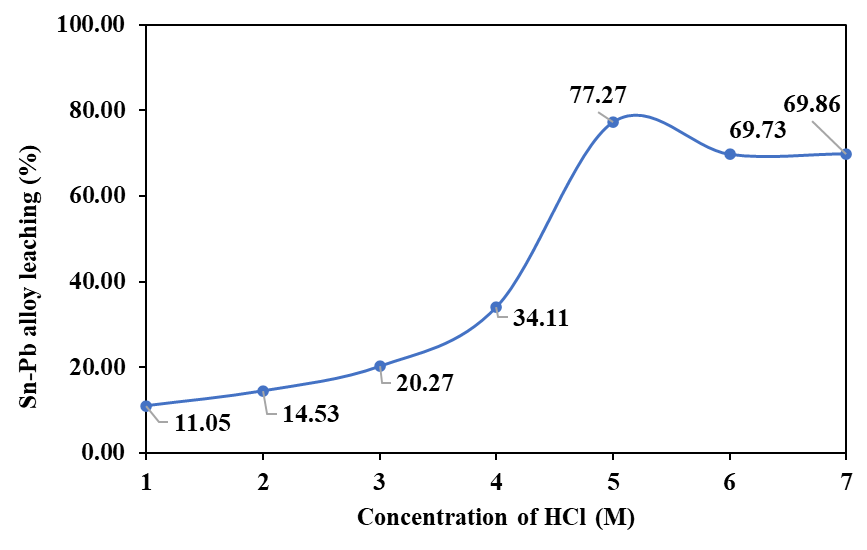
**FIGURE 1**. XRD pattern of Sn-Pb Alloy

**TABLE 1.** Elemental composition of the Sn–Pb alloy sample as determined by X-ray fluorescence (XRF) analysis

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Element | P | Fe | Cu | Zn | Sn | Os | Pb | Th |
| Concentration (%) | 0.2 | 0.17 | 0.26 | 0.006 | 75.00 | 0.05 | 24.30 | 0.06 |

## Effect of Concentration of HCl on Leaching Efficiency

The leaching efficiency of the Sn–Pb alloy was investigated by varying the concentration of hydrochloric acid (HCl) between 1 M and 7 M, while maintaining constant leaching conditions at 90 °C for 24 hours and a stirring speed of 300 rpm. The results, as presented in **Figure 2**, show a clear dependence of leaching yield on acid concentration. At lower HCl concentrations (1–3 M), the leaching percentages were relatively low, ranging from 11.05% to 20.27%. Specifically, the leaching efficiency was only 11.05% at 1 M HCl, which increased modestly to 14.53% at 2 M and further to 20.27% at 3 M. This trend indicates that limited proton availability in dilute acid solutions constrains the dissolution of metallic tin and lead. The low leaching yields at these concentrations are attributed to the lower acid strength, which limits the disruption of the alloy surface and slows down the kinetics of metal dissolution [17]. A notable increase in leaching efficiency was observed when the acid concentration was raised to 4 M, reaching 34.11%.



**FIGURE 2.** The effect of HCl concentration in leaching Sn-Pb alloy

This enhancement suggests that higher chloride ion concentration significantly promotes the formation of soluble tin (II) chloride complexes. Further increasing the acid concentration to 5 M resulted in the maximum leaching efficiency of 77.27%, indicating that this concentration provided optimal conditions for tin dissolution from the alloy matrix. The substantial increase in leaching yield between 4 M and 5 M can be ascribed to the combined effects of increased proton activity, enhanced complexation with chloride ions, and improved mass transfer at the solid–liquid interface [11]. However, when the HCl concentration was further increased beyond 5 M, a decline in leaching efficiency was observed. At 6 M, the yield decreased to 69.73%, and a similar value of 69.86% was obtained at 7 M. This reduction may be due to several factors. First, the formation of passive layers or insoluble chloride salts on the alloy surface can hinder further dissolution [18]. Second, higher acid concentrations can lead to increased solution viscosity, reducing diffusion rates and limiting mass transfer [19]. Finally, excessive proton concentrations may promote competitive side reactions or precipitation phenomena that inhibit effective metal extraction [20].

## Effect of Temperature and Time on Leaching Efficiency

A graph of different temperature

AI-generated content may be incorrect.

**FIGURE 3.** The effect of temperature and time in leaching Sn-Pb alloy

**Figure 3** shows the influence of leaching temperature and reaction time on Sn–Pb alloy dissolution using 5 M HCl. At 24 hours, leaching efficiency was highest at 90 °C (approximately 80%) and decreased progressively to around 28% at 120 °C before rising again to nearly 50% at 150 °C. This trend suggests that prolonged exposure to elevated temperatures can initially promote tin dissolution but may also facilitate the formation of passivation layers or the reprecipitation of reaction products, reducing extraction at intermediate temperatures. For shorter reaction times (6 and 12 hours), increasing the temperature led to a steady improvement in leaching yields. This phenomenon is possible because the reaction took place in an open setting, given the volatility of HCl. At high temperatures, HCl can evaporate rapidly into the atmosphere, and its vapor doesn't interact with the Sn particles, leading to a decrease in Sn solubility. At 6 hours, the yield increased modestly from about 17% at 90 °C to 31% at 150 °C, indicating enhanced reaction kinetics with higher thermal energy. For 12-hour reactions, efficiency rose more significantly, reaching approximately 54% at 150 °C, demonstrating the combined positive effects of time and temperature on dissolution rates. Overall, these findings highlight that the interplay between temperature and leaching duration is critical.

## Synthesis of SnO2

The synthesis of SnO₂ was carried out using the SnCl₂ filtrate precursor obtained from the leaching of Sn–Pb alloy under various temperatures and reaction times, which had been oxidized in a prior step. Concentrated ammonia solution was employed to precipitate Sn4+ ions, resulting in the formation of a solid precipitate. The precipitate consisted of tin(IV) hydroxide, Sn(OH)4. Subsequently, the Sn(OH)₄ was subjected to calcination to convert it into SnO2, thereby enhancing the crystallinity, stability, and crystalline size of the material. The total reaction process from leaching to the synthesis of SnO2 is highlighted in equations 1-5. Leaching of tin (from metallic Sn) in hydrochloric acid.

Sn(s) + 2HCl(aq) → SnCl2(aq) + H2(g)  (1)

Pb(s) + 2HCl(aq) → PbCl2(s) + H2(g)  (2)

Oxidation of Sn2+ to Sn4+ in solution:

SnCl2(aq) + 2HNO3(aq) + 2HCl(aq) → SnCl4(aq) + 2NO2(g) + 2H2O(l) (3)

Precipitation of Sn (IV) using ammonia solution:

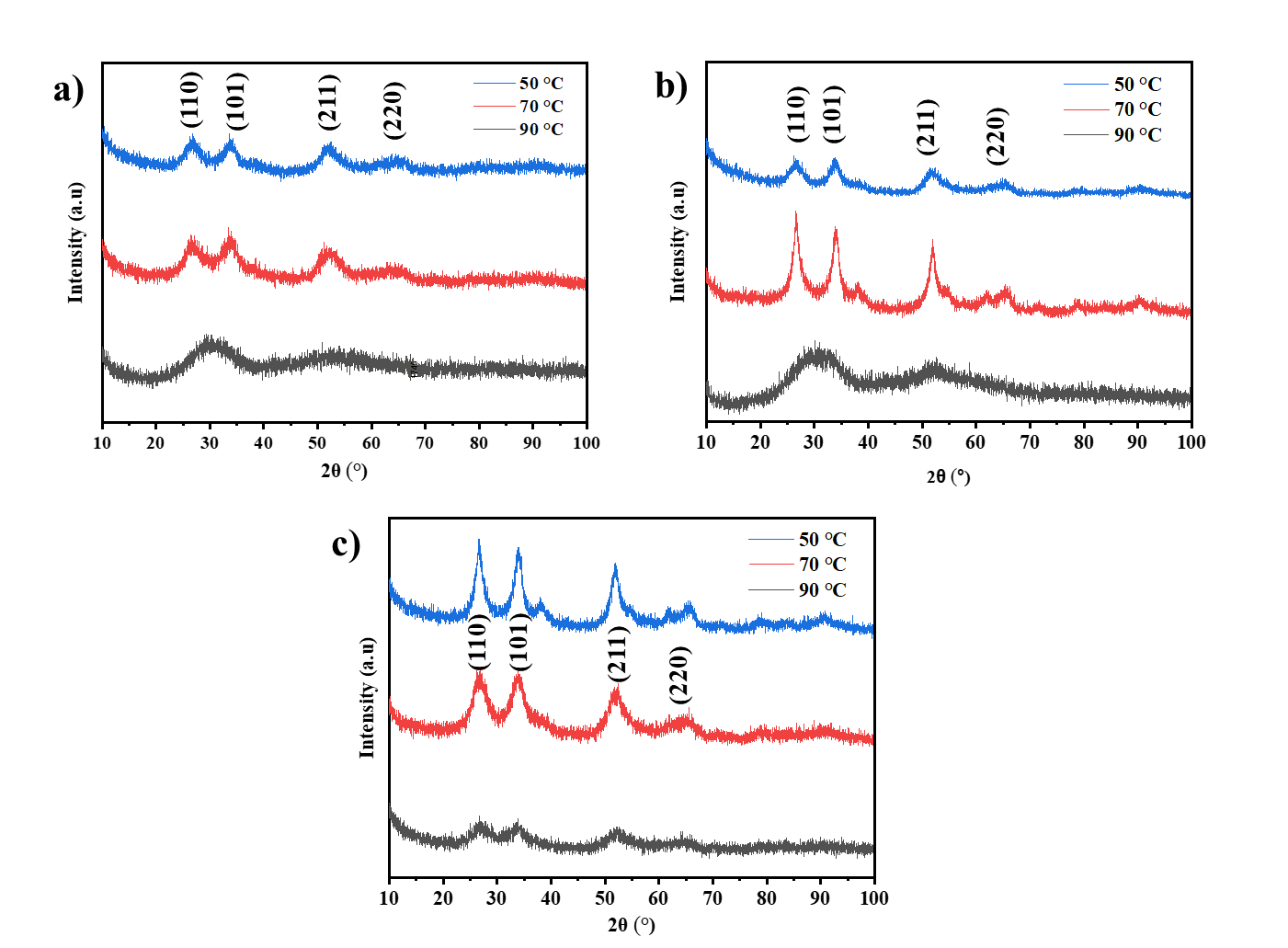
SnCl4(aq) + 4NH4OH(aq) → Sn(OH)4(s) + 4NH4Cl(aq)  (4)

Calcination, heating of tin(IV) hydroxide yields crystalline SnO2:

Sn(OH)4(s) → SnO2(s) + 2H2O(l)  (5)

Thus, the leaching step converts tin into soluble chlorides, which upon oxidation and precipitation yield tin (IV) hydroxide, and subsequent calcination affords crystalline SnO₂.

**Figure 4** presents the X-ray diffraction (XRD) patterns of SnO₂ synthesized from leaching residues obtained under varying leaching temperatures (90 °C, 120 °C, 150 °C) and reaction times (6 h, 12 h, and 24 h). In **Figure 4a** (6-hour leaching), the diffraction profiles display relatively broad and low-intensity peaks, indicating incomplete crystallization of SnO2. The observed gradual increase in peak intensity with higher leaching temperatures suggests that elevated temperatures facilitate more effective dissolution of Sn from the Sn–Pb alloy, thereby yielding a greater amount of Sn precursor available for subsequent precipitation. **Figure 4b** (12-hour leaching) demonstrates clearer and sharper diffraction peaks compared to the shorter leaching duration. The most pronounced intensities are recorded at 150 °C, indicating that combining a longer reaction time with higher temperature enhances both tin extraction and the crystallinity of the final SnO2 product.



**FIGURE 4**. XRD Pattern of SnO2 (a) 6h, (b) 12h, (c) 24h

In contrast, **Figure 4c** (24-hour leaching) shows an interesting trend. At 90 °C, the SnO₂ peaks remain relatively sharp, reflecting efficient leaching over prolonged contact time. However, at 120 °C, the diffraction intensities decrease, possibly due to the formation of passivation layers that inhibit further dissolution of Sn during extended reaction periods. At 150 °C, the intensities increase again, suggesting that higher temperatures can overcome such passivation effects when sufficient thermal energy and agitation are applied. Overall, the diffraction patterns consistently confirm the formation of tetragonal rutile SnO₂ (JCPDS No 41-1445) [21], with characteristic reflections located at 2θ values near 26°, 33°, 38°, 51°, and 54° corresponding to plane (110), (101), (211), and (220), respectively. The variation in peak sharpness and intensity across the conditions highlights the importance of optimizing leaching parameters to improve the crystalline quality of the oxide product. These findings demonstrate that leaching temperature and reaction time play a critical role in determining the availability of soluble tin species and, consequently, the degree of crystallinity of SnO₂ synthesized by subsequent precipitation and calcination. The combination of higher temperatures and moderate leaching durations (12 h) appears most favourable for producing well-defined crystalline SnO₂ under the conditions investigated.

# CONCLUSIONS

This study investigated the recovery of tin from Sn–Pb alloy waste through hydrometallurgical leaching and its subsequent utilization for the synthesis of SnO₂. The leaching experiments demonstrated that hydrochloric acid is an effective solvent, with 5 M HCl providing the highest tin dissolution efficiency of 77.27%. The combination of 70 °C and 12 hours was identified as the most favorable condition to achieve efficient leaching. The recovered leachate was successfully converted into SnO₂ via precipitation and calcination, with XRD confirming the formation of a tetragonal rutile phase across all samples. Improved crystallinity was observed under optimal leaching conditions, indicating that process control during leaching directly affects the structural quality of the final oxide product. These findings not only demonstrate the feasibility of transforming alloy waste into advanced oxide materials but also emphasize the potential of an integrated leaching–synthesis route to reduce reliance on commercial precursors. Overall, the study establishes a sustainable approach to alloy waste management by converting a hazardous residue into a high-value functional material.

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# References

1. Willoughby, J. Indonesian Government to Review Export Licenses. *International Tin Association* 2022.
2. Dahani, W.; Sundari, R.; Somali, S.; Marwanza, I.; Andriyani, A.; Hartanto, D.; Arifin, K.; Ediati, R. Induced Roll Magnetic Separator Applied for High Grade Ilmenite Separation from Mining Tailing. *Sinergi* **2023**, *27*, 271, doi:10.22441/sinergi.2023.2.015.
3. Wulandari, N.; Wismogroho, A.S.; Widayatno, W.B.; Amal, M.I.; Kusuma, D.Y. Optimization Process In The Synthesis of Stannous Chloride (SnCl2 ) by Redox Method In The Context of Downstream Tin Derivative Product. *J. Phys.: Conf. Ser.* **2021**, *1764*, 012034, doi:10.1088/1742-6596/1764/1/012034.
4. Yifu, L.; Bin, Y.; Kuangdi, X. Tin Metallurgy. In *The ECPH Encyclopedia of Mining and Metallurgy*; Xu, K., Ed.; Springer Nature Singapore: Singapore, 2023; pp. 1–4 ISBN 978-981-19074-0-1.
5. Dahan, W.; Hartanto, D.; Ediati, R.; Sundari, R.; Subandrio; Marwanza, I. Data of REEs (Ce, Nd, Th) Analysis from Bangka Tin Tailing Applying Froth Flotation Method Using Sodium Oleate and KClO3. *Data in Brief* **2024**, *57*, 111157, doi:10.1016/j.dib.2024.111157.
6. Liu, W.; Gu, K.; Han, J.; Ou, Z.; Wu, D.; Zhao, D.; Qin, W. Innovative Methodology for Comprehensive Use of Tin Anode Slime: Preparation of CaSnO3. *Minerals Engineering* **2019**, *143*, 105945, doi:10.1016/j.mineng.2019.105945.
7. Liu, B.; Shi, C.; Huang, Y.; Han, G.; Sun, H.; Zhang, L. Intensifying Separation of Pb and Sn from Waste Pb-Sn Alloy by Ultrasound-Assisted Acid Leaching: Selective Dissolution and Sonochemistry Mechanism. *Ultrasonics Sonochemistry* **2024**, *102*, 106758, doi:10.1016/j.ultsonch.2024.106758.
8. Zhu, P.; Tang, J.; Tao, Q.; Wang, Y.; Wang, J.; Li, Z.; Cao, Z.; Qian, G.; Theiss, F.; Frost, R.L. The Kinetics Study of Dissolving SnPb Solder by Hydrometallurgy. *Environmental Engineering Science* **2019**, *36*, 1236–1243, doi:10.1089/ees.2019.0087.
9. Nemati, K.; Abu Bakar, N.K.; Abas, M.R.B.; Sobhanzadeh, E.; Low, K.H. Comparative Study on Open System Digestion and Microwave Assisted Digestion Methods for Metal Determination in Shrimp Sludge Compost. *Journal of Hazardous Materials* **2010**, *182*, 453–459, doi:10.1016/j.jhazmat.2010.06.053.
10. Fosu, A.Y.; Bartier, D.; Diot, F.; Kanari, N. Insight into the Extractive Metallurgy of Tin from Cassiterite. *Materials* **2024**, *17*, 3312, doi:10.3390/ma17133312.
11. Kim, S.; Lee, J.; Yoo, K. Leaching of Tin from Waste Pb-Free Solder in Hydrochloric Acid Solution with Stannic Chloride. *Hydrometallurgy* **2016**, *165*, 143–147, doi:10.1016/j.hydromet.2015.09.018.
12. Ichlas, Z.T.; Rustandi, R.A.; Mubarok, M.Z. Selective Nitric Acid Leaching for Recycling of Lead-Bearing Solder Dross. *Journal of Cleaner Production* **2020**, *264*, 121675, doi:10.1016/j.jclepro.2020.121675.
13. Yao, L.; Liu, T.; Chen, X.; Mahdi, M.; Ni, J. An Integrated Method of Life-Cycle Assessment and System Dynamics for Waste Mobile Phone Management and Recycling in China. *Journal of Cleaner Production* **2018**, *187*, 852–862, doi:10.1016/j.jclepro.2018.03.195.
14. Utomo, W.P.; Farida, N.; Aisyah, B.; Babgei, A.A.; Karimah, N.; Rozafia, A.I.; Susilo, I.; Widjaja, T.; Nur, H.; Sari, R.; et al. Facile Synthesis of Flower-like Bismuth Oxybromide Anchored on ZSM-5 for Enhanced Photocatalytic Dye Degradation. *South African Journal of Chemical Engineering* **2025**, *53*, 386–399, doi:10.1016/j.sajce.2025.05.012.
15. Dahani, W.; Marwanza, I.; Kurniawati, R.; Fadhilah; Kirana, O.S.S.; Farida, N.; Abdullah, M.R.; Rozafia, A.I.; Saputra, N.M.; Ediati, R.; et al. Preparation and Characterization of Bamboo Based Activated Carbon Prepared by Hydrochloric Acid.; Yogyakarta, Indonesia, 2025; p. 020012.
16. Yuhaneka, G.; Rozafia, A.I.; Utomo, W.P.; Iryani, A.; Hartanto, D. Synthesis of Porous G-C₃N₄ and Its Application as Photocatalyst for Methylene Blue Degradation. *Mal. J. Fund. Appl. Sci.* **2022**, *18*, 463–472, doi:10.11113/mjfas.v18n4.2496.
17. Choi, S.; Yoo, K.; Alorro, R.D. Hydrochloric Acid Leaching Behavior of Metals from Non-Magnetic Fraction of Pb Dross. *Geosystem Engineering* **2019**, *22*, 347–354, doi:10.1080/12269328.2019.1681301.
18. Wang, Q.; Zhang, J.; Wu, Y.; Shen, Y.; Liu, Y.; Wu, C.; Su, X. The Microstructure and Electrochemical Performance of the Al-10Si-3.5Fe-xZn-yGa Alloys for Hot-Dip Galvanizing in Low-Chloride Environments. *Materials Chemistry and Physics* **2024**, *319*, 129363, doi:10.1016/j.matchemphys.2024.129363.
19. Lawton, J.S.; Tiano, S.M.; Donnelly, D.J.; Flanagan, S.P.; Arruda, T.M. The Effect of Sulfuric Acid Concentration on the Physical and Electrochemical Properties of Vanadyl Solutions. *Batteries* **2018**, *4*, 40, doi:10.3390/batteries4030040.
20. Xhaferaj, N.; Ferella, F. Extraction and Recovery of Metals from Spent HDS Catalysts: Lab- and Pilot-Scale Results of the Overall Process. *Metals* **2022**, *12*, 2162, doi:10.3390/met12122162.
21. Osuntokun, J.; Onwudiwe, D.C.; Ebenso, E.E. Biosynthesis and Photocatalytic Properties of SnO2 Nanoparticles Prepared Using Aqueous Extract of Cauliflower. *J Clust Sci* **2017**, *28*, 1883–1896, doi:10.1007/s10876-017-1188-y.