

# Study on the Potential Use of Plastics from Electronic Waste to Produce Construction Materials with Enhanced Performance Characteristics

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This study explores the recycling of end-of-life mobile phone components, specifically printed circuit boards (PCBs) and housing plastics, for construction applications. Tin was extracted from PCBs using a hydrometallurgical method in hydrochloric acid solution. The optimal conditions were identified as a Hydrochloric acid (HCl) concentration of 2 mol/L, a temperature of 75 °C, a solid-to-liquid ratio of 1:10, and a stirring rate of 300 rpm for 6 h. Vibrational activation significantly enhanced the cementation process efficiency, reducing its duration by 70 % and increasing the deposition rate by more than threefold, with the most effective vibration frequencies at 25 and 50 Hz. Recycled housing plastic was tested as a partially acceptable aggregate replacement (5–20 wt% %) in concrete. Compressive strength decreased by 3.12–25.00 % compared to the control; however, even at the 20 wt % level, the resulting concrete met the M200 strength grade, confirming the material's potential for structural use.

## Introduction

The rapidly increasing volume of electronic waste (e-waste) poses a significant environmental threat across the globe. E-waste consists of a wide range of hazardous and valuable components, including metals, cathode ray tubes, liquid crystal displays, printed circuit boards (PCBs), cables, metal-plastic composites, and various plastics. Most users are unaware of the potential negative impact of the rapidly growing use of computers, monitors, the scale of the problem, and the dangers to the environment and health (Needhidasan et al., 2014). According to Vishnu et al. (2024), one of the most effective approaches to e-waste management involves extracting useful products that retain material value. The potential of e-waste recycling as a profitable business opportunity has also been widely recognised (Sharma et al., 2023).

The growing market for microelectronics, smartphones, and other devices continuously increases the global demand for metals such as copper, tin, lead, zinc, iron, aluminium, gold, silver, platinum, and rare earth elements, along with polymers. E-waste materials, after mechanical processing, typically consist of 38.1 % ferrous metals, 16.5 % non-ferrous metals, 26.5 % plastics, and 18.9 % other materials (Isildar et al., 2018). Given the current rate of resource consumption, the reserves of primary mineral ores may become depleted in the foreseeable future. Recycling of e-waste offers a viable path to conserving natural resources while significantly reducing the carbon footprint (Moyen and Archodoulaki, 2023).

Plastics contained in e-waste are also receiving increasing attention, particularly in terms of their reuse and impact on environmental health (Butturi et al., 2020). As a result, the efficient collection and processing of e-waste is gaining relevance, especially in regions facing rising volumes of discarded electronics. In Kazakhstan, the national e-waste monitoring system projected an increase in annual e-waste generation from 136,100 t in

2019 to 432,000 t by 2050. Strategic policies targeting waste reduction and low-carbon development aim to halve the volume of unmanaged e-waste by 2050. Previously, the authors Kulenova et al. (2024) have already considered some options for the disposal of plastic waste generated during the dismantling of worn-out fragments of computer equipment and household electronic devices. This study focuses on the extraction of tin, which is primarily used in soldering applications on PCBs, from outdated mobile phones and smartphones. It also investigates the potential reuse of housing plastics through the fabrication of construction-grade concrete materials.

## Materials and methods

The experimental work focused on printed circuit boards (PCBs) from obsolete mobile phones and smartphones manufactured in 2010–2011. The experimental workflow is illustrated in Figure 1. The average elemental composition of the shredded PCBs is presented in Table 1.

*Table 1: Average metal content in the PCB mixture (wt %)*

Sn	Pb	Zn	Cu	Fe	Ag	Al	Ni
2.13	0.68	0.73	28.60	3.56	0.15	1.40	1.92

The printed circuit boards (PCBs) used in this study originated from obsolete mobile phones and smartphones manufactured in 2010–2011. Prior to processing, the boards were mechanically shredded into particles with a maximum size of 5 mm. In industrial-scale recycling, precise classification of PCBs by brand, model, or production year is generally impractical. A representative mixed batch of various PCB types was selected to simulate real processing conditions.

Quantitative determination of valuable metals, including tin, copper, nickel, lead, and others, was conducted in raw PCB samples, leachates, and solid residues. Analysis was performed using an ICP-MS 7500cx spectrometer (Agilent Technologies, USA) with inductively coupled plasma, providing high sensitivity and multi-element detection capabilities.

Acid leaching experiments were carried out in sealed, heat-resistant chemical reactors. Hydrochloric acid with a concentration of 2 mol/L was used as the leaching agent. The process conditions were systematically varied within the following parameters: temperature in the range of 25 °C to 85 °C, a solid-to-liquid ratio of 1:10, and a constant stirring speed of 300 rpm. The leaching duration was fixed at 5 h. After processing, the resulting pulp was separated by vacuum filtration. The filtrate (productive solution) was collected for metal analysis, while the solid residue (cake) was washed with deionised water, oven-dried, weighed, and further analysed for residual metal content. The research program included experiments performed in triplicate.

To recover tin from the productive solution, a cementation method was employed using aluminium plates (30 × 10 × 1.5 mm) as the reactive surface. Experiments were conducted under both static and vibrationally assisted conditions. The cementation was performed at room temperature and atmospheric pressure for 5 h. To assess the impact of mechanical activation, vibrational mixing was applied at frequencies of 10, 25, and 50 Hz. Liquid samples were extracted periodically—every 30 min during the first hour and then hourly—to monitor the deposition rate of tin.

The vibrational intensification system consisted of two opposing perforated discs, each featuring 22 cylindrical holes with a diameter of 6 mm. These discs performed reciprocating motions with an amplitude of 4 mm and adjustable frequency. The disc diameter was 80 mm, and the internal diameter of the reactor vessel was 163 mm. A motor with a power rating of 0.18 kW provided the mechanical drive. The reactor vessel was sealed with a rubber lid to minimise solution loss and allow the passage of shaft rods connected to the oscillating discs. Vibrational mixing is recognised as an effective approach to enhance mass transfer in multiphase and heterogeneous systems. In the described configuration, the reciprocating motion of perforated discs generated directed fluid jets, promoting turbulent flow. The geometry of the perforations played a crucial role in controlling jet intensity. Specifically, tapered holes were found to accelerate fluid velocity, increasing shear forces and enhancing the efficiency of tin cementation by facilitating better contact between the metal ions and the aluminium surface.

Cement, coarse aggregate (crushed stone), fine aggregate (sand), crushed plastic (5–20 % of the fine aggregate mass), water, and plasticizer were used to prepare experimental concrete samples. The resulting concrete samples (cubes with a 15 cm edge size) were kept in special chambers for 28 days. After that, the samples were tested for compressive strength using a PGM-100MG 4 hydraulic press in accordance with EN 12930–3:2009. Testing hardened concrete – Part 3: Making and curing specimens for strength tests. The experimental scheme is shown in Figure 1.

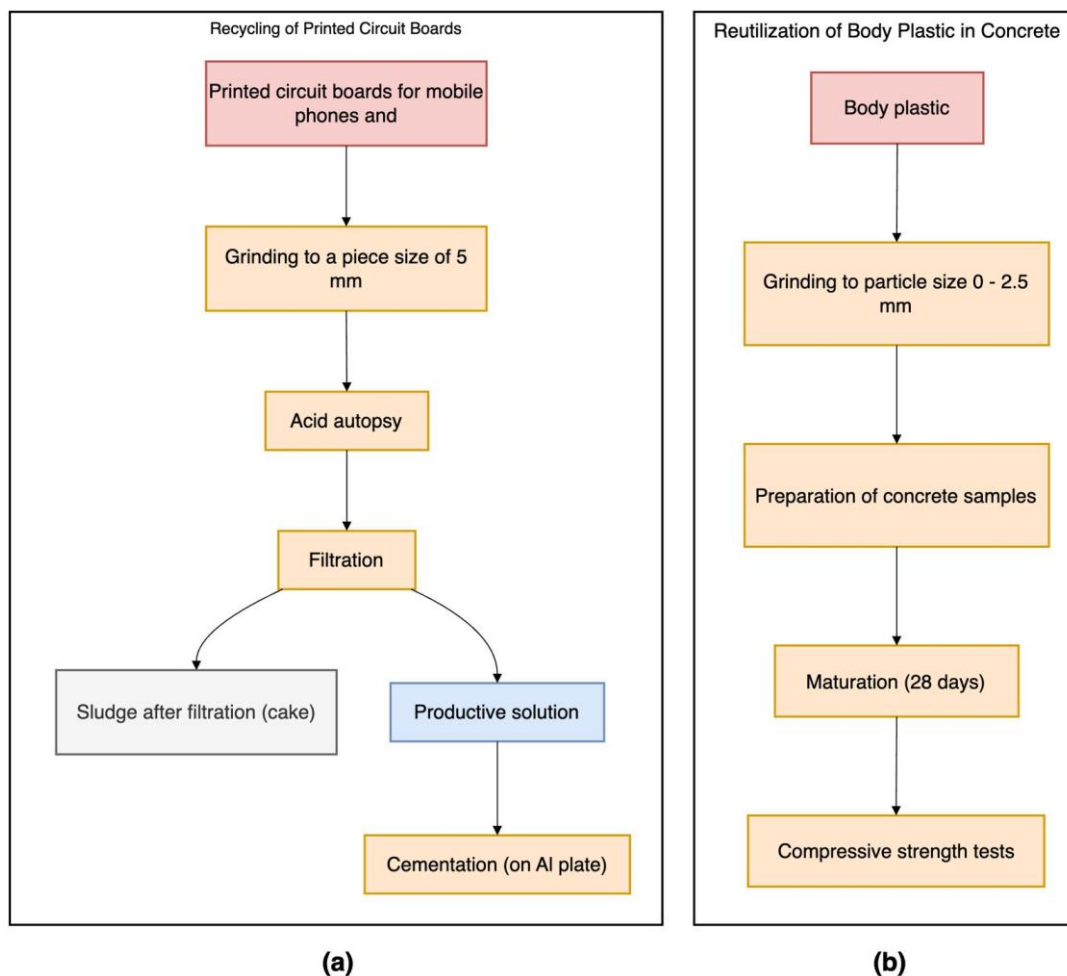


Figure 1: Schematic of the experiments: a – processing of PCBs for tin recovery; b – processing of housing plastic for experimental concrete samples

### 3. Results and discussion

#### 3.1 The process of opening crushed boards with a solution of hydrochloric acid

Figure 2 shows the experimental data on tin leaching into the productive solution as a function of temperature and leaching duration using hydrochloric acid as the leaching agent. The results clearly show that temperature has a significant effect on the efficiency of the leaching process. When the temperature was increased from 25 °C to 85 °C, the amount of tin transferred into the solution increased by approximately 32 %. This increase in extraction yield can be explained by the improvement of the reaction kinetics and the increase in the solubility of metal ions at higher temperatures. Although a general trend towards an increase in tin recovery into the productive solution with increasing temperature was noted, a comparative analysis showed that the difference in the efficiency of tin recovery into the productive solution between 75 °C and 85 °C was relatively small - less than 2 %. This indicates that 75 °C may represent a more favourable operating point from an energy saving perspective. It was also noted that most of the tin dissolution occurred during the first 120 min of the process, especially at elevated temperatures. This suggests that the reaction rate is greatest early in the leaching process, after which the system approaches equilibrium. These results indicate that extending the leaching time beyond a certain point results in reduced efficiency, especially at high temperatures. Therefore, optimizing both temperature and time is important to maximize recovery while maintaining process efficiency and minimizing energy consumption.

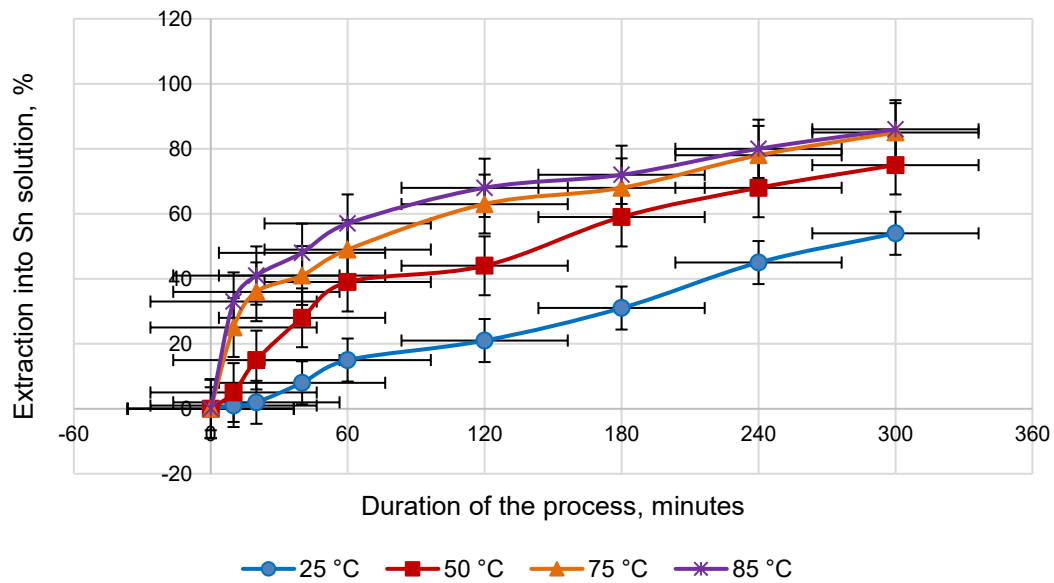


Figure 2: Tin extraction from shredded mobile phone PCBs as a function of temperature and time

Further analysis of the extraction kinetics depending on the temperature (Figure 2) showed that with an increase in the process temperature from 25 °C to 85 °C and a stirring duration of 10 min, the degree of tin extraction into the productive solution increases by 32 %. The positive effect of elevated temperatures becomes especially noticeable at the early stage of the leaching process. The research program included experiments with 3-fold replication. Standard deviation limits (min-max) at 25 °C 0.04 ÷ 0.19; at 50 °C 0.03 ÷ 0.20; at 75 °C 0.06 ÷ 0.14; at 85 °C 0.07 ÷ 0.21.

### 3.2 The process of tin precipitation from the productive solution

Tin precipitation from the productive solution was studied using cementation on aluminum plates with and without vibrational stirring. Figure 3 and Table 2 show the time dependence of tin precipitation at different vibration frequencies (10, 25, and 50 Hz) compared to a static state. Under conditions without stirring, 5 h were required for the complete precipitation of tin. In contrast, vibrational stirring significantly accelerated the process. At all vibration frequencies studied, a tin extraction rate of over 90 % was achieved in 90 min. Almost complete precipitation of tin was achieved in 120 min.

Table 2: Degree of tin precipitation from the productive solution depending on the duration of the process (wt%)

0	Duration of the process, min									
	30	60	90	120	150	180	210	240	270	300
Without intensification										
0	15	25	40	47	60	75	80	90	95	99
Intensification, 10 Hz										
0	60	80	93	98	-	-	-	-	-	-
Intensification, 25 Hz										
0	75	91	97	100	-	-	-	-	-	-
Intensification, 50 Hz										
0	77	92	98	100	-	-	-	-	-	-

Destructive testing is a mandatory procedure in constructing concrete structures to evaluate mechanical performance. The standard method involves applying compressive force using a hydraulic press. In this study, experimental concrete mixtures were prepared with varying proportions of recycled housing plastic, ranging from 5 wt % to 20 wt % relative to the fine aggregate (sand) mass, as illustrated in Figure 4.

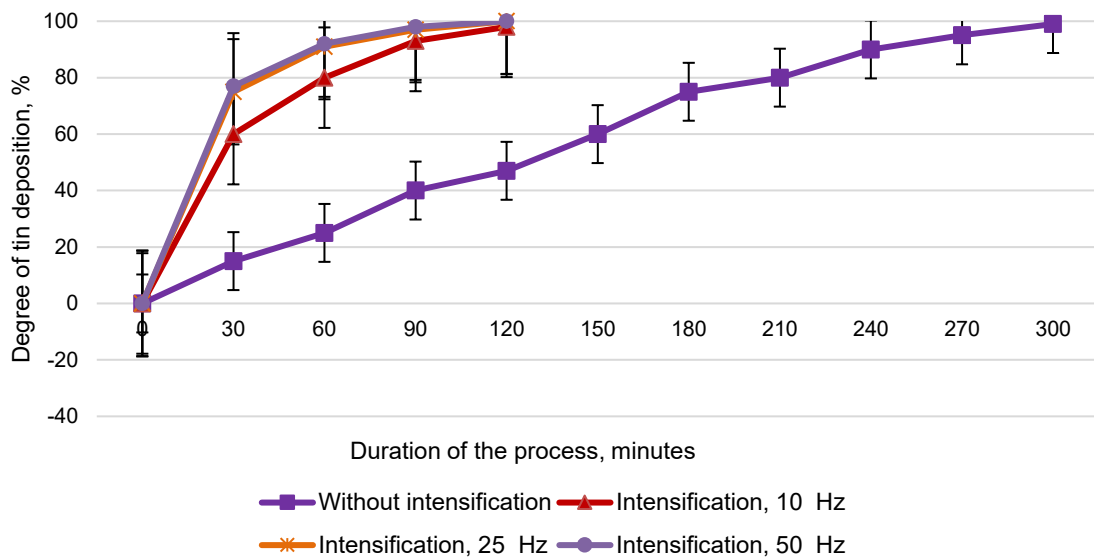


Figure 3: Tin precipitation from the productive solution as a function of cementation time under different vibration frequencies

### 3.3. Research on the use of hull plastic as an additive to concrete

Following the experimental design (Figure 1), experimental concrete mixtures were prepared with different contents of crushed hull plastics material, from 5 to 20 wt % of the mass of fine aggregate (sand). Destructive testing is mandatory in constructing concrete structures to evaluate mechanical performance. The standard method involves applying compressive force using a hydraulic press. Cubic specimens (150 mm edge length) were subjected to compressive strength tests. The results illustrating the effect of plastic content on compressive strength are shown in Figures 4 and 5. The initial compressive strength of the reference concrete was 32 MPa. With increasing plastic content in the mix, a gradual reduction in strength was observed. For the sample containing 5 wt % plastic (relative to sand), the strength decreased slightly to 31 MPa. In contrast, the specimen with 20 wt % plastic exhibited a strength of 24 MPa. Overall, the compressive strength was reduced by 3.12 % to 25.00 % compared to the control, depending on the amount of plastic added (ranging from 5 % to 20 % of sand mass).

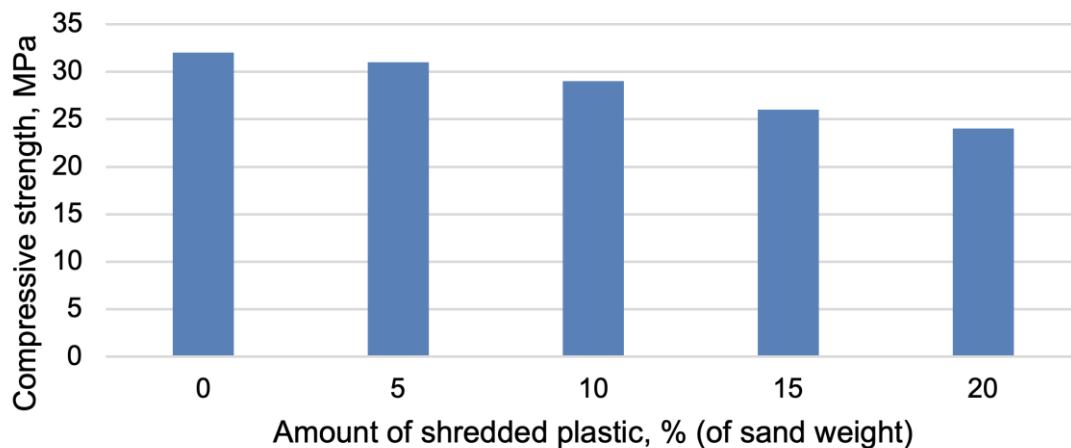


Figure 4: Influence of plastic content in the concrete mix on compressive strength

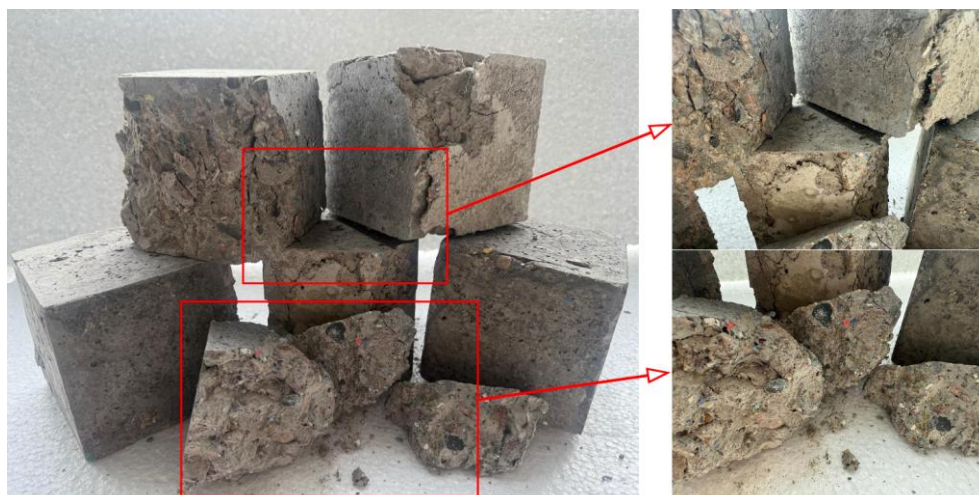


Figure 5: Concrete samples with different amounts of housing plastic added

#### 4. Conclusions

This research addressed recycling obsolete mobile phone and smartphone components, specifically printed circuit boards and housing plastics. Tin was extracted from PCBs using hydrometallurgical techniques. The optimal parameters for leaching tin into hydrochloric acid solution were established: HCl concentration of 2 mol/L, temperature of 75 °C, solid-to-liquid ratio of 1:10, and stirring speed of 300 rpm over 6 h. From the analysis of kinetic data, it follows that the positive effect of elevated temperatures becomes especially noticeable at the early stage of the leaching process. For example, with a stirring duration of 10 min and an increase in the process temperature from 25 °C to 85 °C, tin extraction into the productive solution increases by 32 %.

The application of vibrational activation during tin cementation significantly enhanced process performance, increasing recovery efficiency by more than threefold. The most effective stirring frequencies were 25 Hz and 50 Hz. Under these conditions, the duration of the cementation process was reduced by 70 %.

The experiments confirmed the feasibility of incorporating plastic waste into concrete mixtures. Although compressive strength was reduced by 3.12 % to 25.00 % depending on the plastic dosage, even at the highest level of 20 wt % (relative to sand mass), the resulting concrete achieved the M200 strength class. This demonstrates the potential of using recycled plastic as a partial sand replacement in sustainable construction materials. Complete tin deposition was achieved in 90 min at 25 and 50 Hz and in 120 min at 10 Hz. This corresponds to a reduction in processing time from 300 to 90 min.

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