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Fabrication and Characterisation of Eutectic Cast Alloy from Aluminium and Copper Wastes

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Abstract

This project investigates the fabrication and characterisation of aluminium-copper (Al–Cu) eutectic cast alloys using recycled metal waste materials. The primary aim was to explore the viability of repurposing scrap aluminium and copper into hypoeutectic (15% Cu), eutectic (33% Cu), and hypereutectic (40% Cu) alloy compositions. The methodology involved material collection, alloy preparation, casting, and mechanical and microstructural characterisation using hardness testing, impact resistance, optical microscopy, SEM, and EDX. Despite following precise fabrication processes, results showed that the intended compositions were not fully achieved due to copper impurity, equipment limitations, and inadequate homogenisation during melting. All specimens exhibited similar aluminium-rich microstructures and low mechanical performance, with hardness values averaging around 75–95 HV and minimal presence of the θ-phase. The lack of distinction in mechanical and structural characteristics among the samples indicates a significant deviation from the target eutectic and hypereutectic structures. This highlights the importance of material purity and process control when using waste materials for advanced alloy development. Nonetheless, the study demonstrates a foundational approach to sustainable alloy production through metal recycling, with recommendations for future improvements.

1. Introduction

Aluminium and copper are among the most widely used non-ferrous metals in engineering applications due to their excellent mechanical, thermal, and electrical properties. Aluminium is lightweight and corrosion-resistant, while copper offers high electrical conductivity and toughness (Fan et al., 2023; Zhou et al., 2023). The combination of these elements in aluminium–copper (Al–Cu) alloys results in improved strength, castability, and wear resistance, making them suitable for components in the aerospace, automotive, and electronics industries (Lin et al., 2023).

Eutectic Al–Cu alloys, particularly those with approximately 33 wt% Cu, solidify at a constant temperature and form a fine α + θ ($CuAl_2$) lamellar microstructure, which contributes to superior mechanical performance and uniform solidification behaviour (Chen et al., 2024). Figure 1 shows the aluminium–copper binary phase diagram, highlighting the eutectic point and the transitions between hypoeutectic and hypereutectic compositions. In this work, three alloy compositions were selected: 15 wt% Cu (hypoeutectic), 33 wt% Cu (eutectic), and 40 wt% Cu (hypereutectic), to investigate how copper content influences the mechanical properties and microstructure of cast Al–Cu alloys.

Recycling aluminium and copper waste into new alloy compositions offers an environmentally sustainable approach to material development. However, using recycled metals presents challenges such as impurities, inhomogeneous mixing, and difficulty in controlling composition accuracy. These issues can significantly affect the resulting microstructure and properties of the final alloy.

This study focuses on the fabrication of Al–Cu alloys from recycled scrap, characterisation of their mechanical performance through hardness and impact testing, and evaluation of microstructural features via optical and electron microscopy techniques.

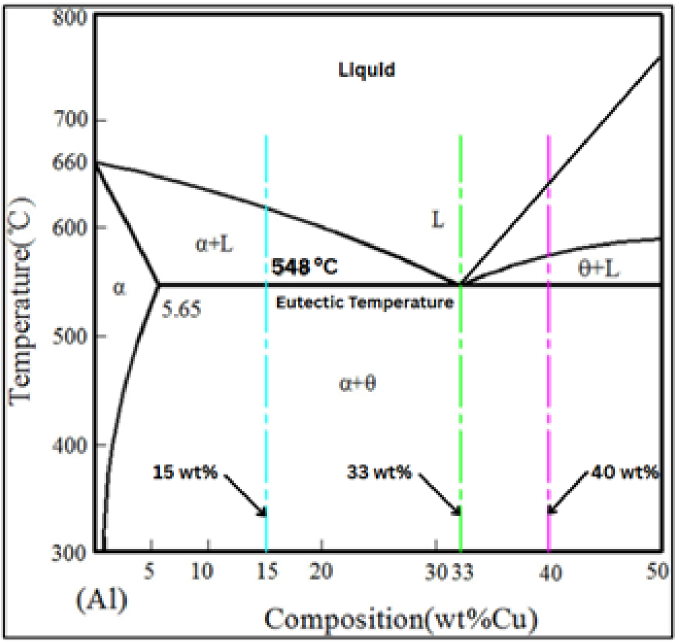


Fig. 1 *Aluminium–copper binary phase diagram indicating eutectic composition at approximately 33 wt% Cu (Liu et al., 2020)*

2. Methodology

This study involves the fabrication and characterisation of aluminium-copper (Al–Cu) alloys from recycled waste materials. The methodology covers material preparation, alloy casting, specimen machining, mechanical testing, and microstructural characterisation.

2.1 Raw Materials and Composition Design

Scrap aluminium was sourced from used beverage cans, while copper was collected from discarded electrical wiring. The scraps were manually cleaned to remove grease, plastic, and other contaminants, then air-dried. Composition calculations were performed to obtain 250 g batches for each alloy type, hypoeutectic (15% Cu), eutectic (33% Cu), and hypereutectic (40% Cu)

(a) **(b)**

Fig. 2 *Weighed scrap materials for Al–Cu alloy fabrication: (a) Aluminium; (b) Copper*

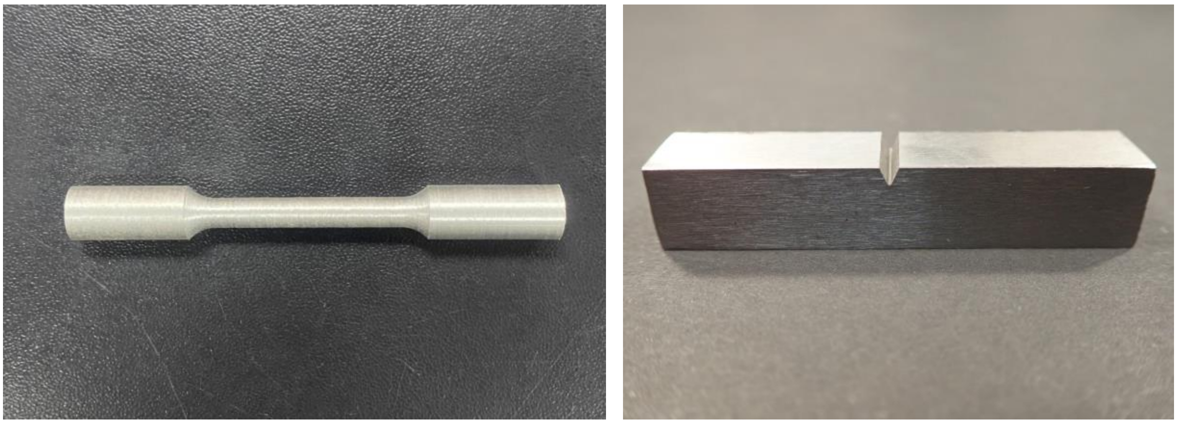
2.2 Melting and Casting Process

The aluminium and copper scraps were melted using a similar furnace occupied by Ayasamy & Badarulzaman (2025). Aluminium was melted first due to its lower melting point, followed by the addition of copper into the molten aluminium. The mixture was stirred to improve homogeneity before casting. Once the temperature reached 1000 °C, the molten alloy was poured into cylindrical steel moulds with a diameter of 20 mm and a length of 125 mm. Casting was performed under ambient condition, without external cooling or pressure, and the moulds were left to cool naturally to room temperature.

Fig. 3 *Pouring molten Al–Cu alloy into cylindrical steel mould.*

2.3 Specimen Machining and Preparation

After solidification, the cast ingots were machined into standardised test specimens using CNC milling and lathe turning, followed by manual grinding to achieve the required dimensions and surface finish. Each alloy composition was processed into three types of specimens. For hardness testing, samples were prepared with flat, polished surfaces to ensure accurate indentation results. Impact testing specimens were machined into V-notched shapes following the ASTM E23 standard, suitable for Charpy impact analysis. Additionally, dog-bone-shaped specimens were also prepared following ASTM E8 specifications for tensile testing. However, tensile tests results were not presented and reported in this publication.



(a) **(b)**

Fig.4 *(a) Dog-bone Specimen (b) Charpy V-notch Specimen*

2.4 Mechanical Testing

Mechanical characterization was conducted to evaluate the performance of the Al–Cu alloys. Hardness testing was performed using a Buehler Vickers microhardness tester, with a 10 kg load applied for 15 seconds on polished surfaces. Impact resistance was assessed using the Charpy impact test following ASTM E23.

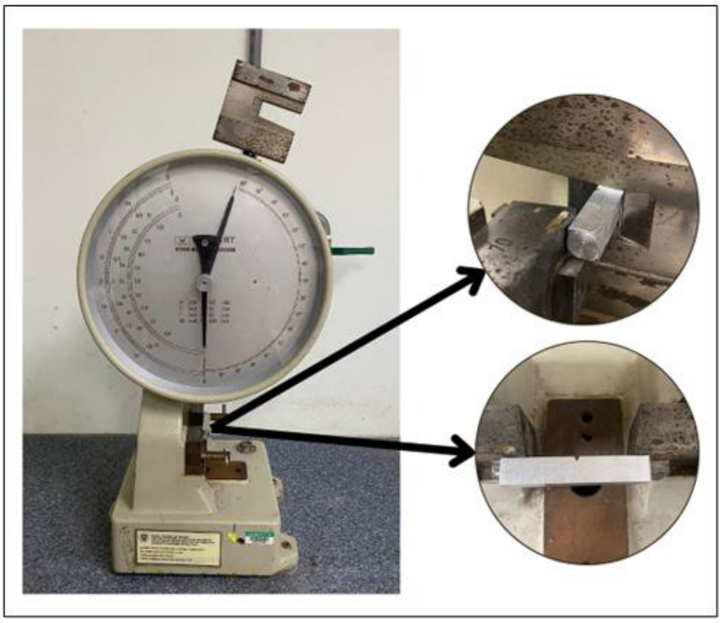


Fig. 5 *WOLPERT Charpy Impact Testing Machine used to evaluate the impact resistance of Al-Cu alloy specimens in accordance with ASTM E23.*

Although specimens were prepared for tensile testing based on the ASTM E8 standard, the test was not conducted due to limitations in available equipment and scheduling constraints. The focus of this study was therefore placed on hardness and impact properties.

2.5 Microstructural and Spectroscopy Analysis

Microstructural and spectroscopic analyses were conducted to examine the internal structure and elemental composition of the fabricated Al–Cu alloys. The specimens were sectioned using a Metacut 302 precision cutting machine, then mounted to facilitate further surface preparation. Mounted samples were ground using silicon carbide (SiC) abrasive papers of increasing grit sizes to remove surface irregularities.

This was followed by polishing with alumina slurry to produce a smooth, reflective surface suitable for microscopic observation.

Optical Microscopy (OM) was used to observe the grain structure and phase distribution of the alloys at magnifications of 200× and 1000×. After OM analysis, the same specimens were examined using Scanning Electron Microscopy (SEM) for more detailed imaging of the surface morphology. Energy Dispersive X-ray Spectroscopy (EDX) was also performed during SEM analysis to determine the elemental composition of selected regions within the sample. These techniques were used to identify features such as copper-rich phases and evaluate the uniformity of the alloy structure.

3. Results and Discussions

Al–Cu alloys with copper concentrations of 15 wt% (hypoeutectic), 33 wt% (eutectic), and 40 wt% (hypereutectic) were fabricated and analysed to investigate the influence of copper content on hardness, impact resistance, and microstructural development. Mechanical and microstructural results were compared to evaluate whether the intended phase transformations and properties were achieved across the three compositions.

3.1 Mechanical Properties

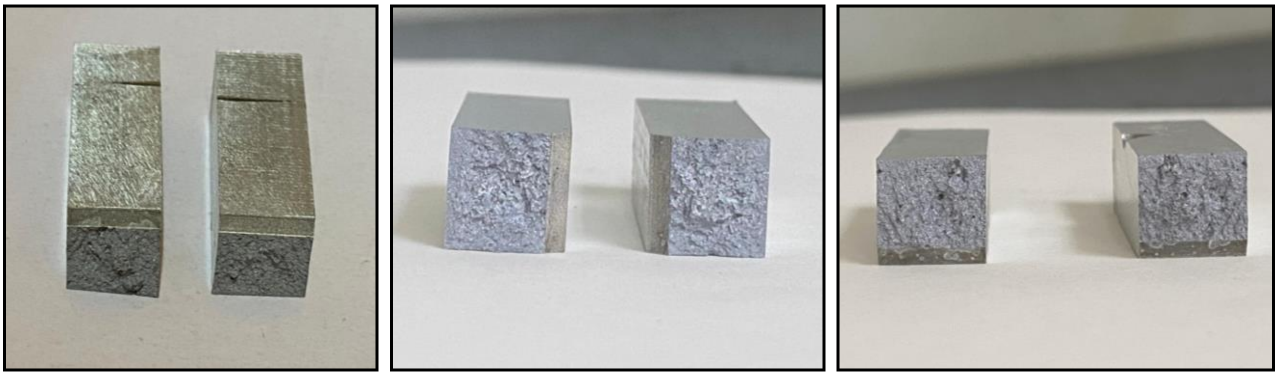
3.1.1 Impact Resistance

The Charpy impact test was conducted on V-notched specimens using a WOLPERT pendulum-type impact tester with a maximum capacity of 4 J. The hypoeutectic sample recorded the highest energy absorption at 2.0 J, followed by the eutectic sample at 1.8 J and the hypereutectic sample at 1.6 J. The results indicate a decreasing trend in impact resistance with increasing copper content.

The slightly higher toughness observed in the hypoeutectic sample can be attributed to the dominance of the ductile α-Al matrix, which becomes less prominent at higher copper levels. The low energy absorption across all samples suggests the absence of significant θ-phase intermetallic formation, resulting in limited improvement in toughness. Fracture surfaces of the tested specimens are shown in Figure 4, confirming brittle failure with minimal plastic deformation.

Table 1 *Charpy impact energy absorbed by Al–Cu alloy compositions with varying copper content.*

Composition	Cu Content (wt%)	Impact Energy (J)
Hypoeutectic	15	2.0
Eutectic	33	1.8
Hypereutectic	40	1.6



(a) (b) (c)

Fig. 6 *Fractured Charpy specimens of Al–Cu alloys: (a) Hypoeutectic (15% Cu), (b) Eutectic (33% Cu), (c) Hypereutectic (40% Cu).*

3.1.2 Hardness

Vickers hardness testing was conducted on all specimens using a 10 kgf load with a dwell time of 10 seconds. Three indentations were made on each sample to obtain average values. The results showed that all three compositions produced similar hardness values, ranging from approximately 75 to 95 HV. These values were lower than expected for Al–Cu eutectic alloys, which typically range from 100 to 130 HV when θ-phase ($CuAl_2$) is present.

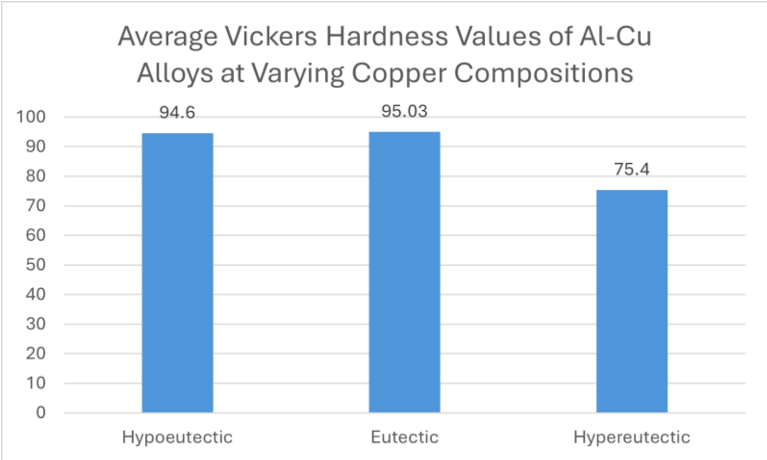


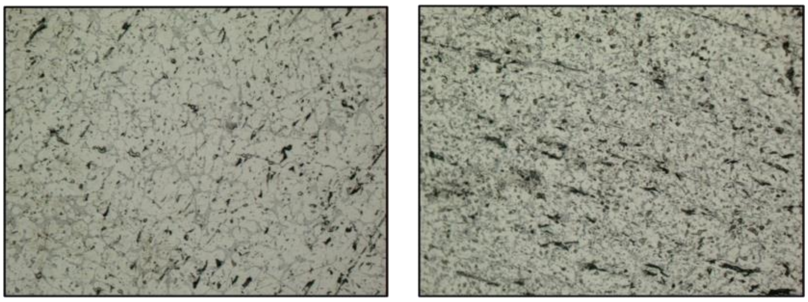
Fig. 7 *Bar chart comparing the average Vickers hardness values for hypoeutectic, eutectic, and hypereutectic Al-Cu alloys.*

The low hardness values are attributed to insufficient copper content caused by impurities in the recycled copper and poor homogenisation during melting. As a result, the desired eutectic and θ-phase structures did not form, leading to aluminium-rich microstructures across all compositions.

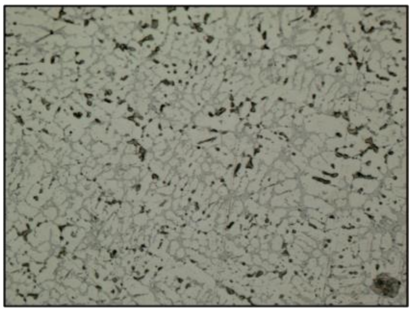
3.2 Microstructural Observations

3.2.1 Optical Microscopy (OM)

OM analysis was performed at 200× and 1000× magnifications. The micrographs revealed that all samples shared a similar morphology, dominated by large α-Al grains with minimal second-phase formation. The hypoeutectic sample showed a uniform α-Al matrix, while the eutectic and hypereutectic samples lacked the fine lamellar eutectic structure expected near 33 wt% Cu.

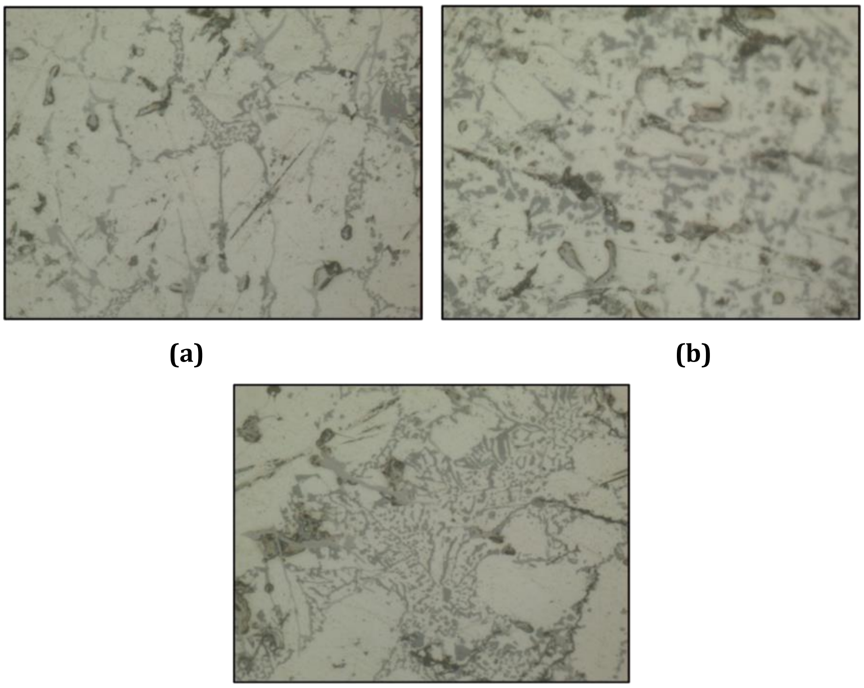


(a) **(b)**



(c)

Fig. 8 *Optical micrographs of Al–Cu alloy samples at 200× magnification (a) Hypoeutectic (15% Cu), (b) Eutectic (33% Cu), (c) Hypereutectic (40% Cu).*



(a) (b) (c)

Fig. 9 *Optical micrographs of Al–Cu alloy samples at 1000× magnification (a) Hypoeutectic (15% Cu), (b) Eutectic (33% Cu), (c) Hypereutectic (40% Cu).*

3.2.2 Energy Dispersive X-Ray (EDX)

While OM analysis revealed that all three Al–Cu alloy compositions lacked clear eutectic α + θ lamellar structures. The surfaces primarily displayed an aluminium-rich morphology with minimal intermetallic phase formation. This visual observation was consistent across hypoeutectic, eutectic, and hypereutectic samples.

EDX analysis provided further insight into elemental distribution. The copper content detected in all samples was significantly lower than their target compositions. In the hypoeutectic alloy (15% Cu target), Cu was found to range from 0.26 to 1.05 wt%. For the eutectic alloy (33% Cu target), Cu ranged from 0.47 wt% to 1.64 wt%. The hypereutectic sample (40% Cu target) recorded values between 0.47 wt% and 1.42 wt%.

These results indicate a substantial deviation from the designed compositions, confirming that the copper from recycled sources was either impure, poorly bonded, or unevenly distributed during melting. The low Cu content explains the absence of θ-phase and the similar microstructure and mechanical behaviour across all three alloy types.

Table 2 *EDX elemental composition (wt%) for alloys at 20 µm and 50 µm scanning areas*

Composition	Cu (wt%) Range	Al (wt%)	Other Elements
Hypoeutectic (15%)	0.26 – 1.05	98.29 – 98.82	Si, Fe, Mn (<1%)
Eutectic (33%)	0.47 – 1.64	97.76 – 98.77	Si, Fe, Zn (<1%)
Hypereutectic (40%)	0.47 – 1.42	98.15 – 98.86	Si, Zn, Fe (<1%)

3.3 Discussion

Mechanical and microstructural results indicate that the target compositions were not achieved. The presence of impurities in the recycled copper, along with poor melting homogenisation and temperature control, contributed to the low copper content in the final castings. As a result, all samples exhibited similar properties, dominated by an aluminium-rich matrix. No clear correlation was observed between increasing copper content and improvements in hardness or toughness. The use of recycled materials in alloy casting requires strict control over raw material quality and melting parameters to ensure consistent alloy behaviour.

4. Conclusion

Aluminium-copper alloys were successfully casted from recycled scrap materials to obtain hypoeutectic (15% Cu), eutectic (33% Cu), and hypereutectic (40% Cu) compositions. Mechanical testing revealed low hardness values (75–95 HV) and low impact resistance (below 2 J) across all samples, with little variation between compositions. Optical microscopy observations confirmed the absence of distinct eutectic or intermetallic structures, and EDX analysis showed copper content was significantly lower than the intended design, ranging from 0.26 wt% to 1.05 wt% in hypoeutectic samples. The deviation from target compositions was attributed to poor copper purity, melting inconsistencies, and insufficient homogenisation during the fabrication process. As a result, all samples behaved as low-copper aluminium alloys, with similar aluminium-rich microstructures. These findings highlight the importance of material purity, precise alloying, and consistent process control in recycled alloy production. Future work should focus on improving raw material selection, refining melting procedures, and expanding the scope of mechanical testing, such as including tensile strength evaluation, to provide a more comprehensive understanding of the performance of recycled Al–Cu alloys.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, analysis and interpretation of results, and draft manuscript preparation.*** *All authors reviewed the results and approved the final version of the manuscript.*

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