# Sustainable Recycling of CuZn40Pb2 Brass for Sanitary Fittings: Process Optimization and Microstructural Assessment

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**Abstract.** This study evaluates the feasibility of producing CuZn40Pb2 brass sanitary fittings with partial recycled materials while ensuring compliance with industrial standards. It compares two casting methods, continuous horizontal and discontinuous vertical, using pure, recycled, and mixed charges. The cast billets were subjected to hot extrusion, forging, and machining. The research investigates how casting method, charge composition, and processing influence microstructure and product quality through chemical analysis, optical microscopy, and radiography. All samples displayed a typical α+β microstructure, with lead mainly situated at grain boundaries. Vertical casting exhibited more heterogeneity, lead segregation, and internal defects. Horizontal casting with proper processing and 25% virgin material produced a uniform structure and mechanical properties comparable to those of fully primary material parts. Lead segregation was under 0.56% in horizontally cast billets, whereas vertically cast billets showed differences up to 3.41%. These results demonstrate that using recycled brass for sanitary fittings is feasible and environmentally friendly, supporting a circular economy in metallurgy.

## 1 Introduction

In Morocco, the market initially relied heavily on imports for sanitary plumbing equipment from Europe, China, and other countries, leading to high consumer costs due to the premium quality of European products that meet international standards. However, low-cost imports often do not comply with quality and regulatory standards, with notable differences in chemical composition, especially in copper and lead content. Some producers reduce copper content from 57% to 54% to cut costs, replacing it with 1 to 3% cheaper lead. These variations may fall outside the compositional limits specified for forging brasses like CW617N, as defined in the EN 12165 standard [1].

However, lead is a toxic heavy metal found in contact alloys in drinking water [2], prompting significant research into lead-free brass alternatives. Studies are exploring lead-free brass alloys and other methods to enhance machinability, since lead plays a crucial role in chip formation and lubrication during the machining of brass alloys [3].

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In Morocco, measures have been taken to improve the national market surveillance system for mental health products, following Law No. 12-06. These efforts aim to protect consumer health, ensure product quality and safety, and promote local manufacturing to support the national economy.

Local industries now produce brass plumbing fixtures that meet international standards. However, their competitiveness still depends on the cost and availability of virgin raw materials such as copper and zinc. To address this issue, manufacturers are increasingly using recycled materials, facing the challenge of optimizing their formulas to include recycled content while ensuring compliance and maintaining the structural integrity associated with virgin materials.

Brass is an alloy mainly composed of about 60% copper and 40% zinc, often including elements like lead, nickel, or tin. Its composition enables various uses such as casting and both hot and cold working [4], making it highly valued in industrial settings for its outstanding technical properties.

Brass alloys are classified as two-phase alloys. Their microstructure comprises two phases: α (lighter) and β′ (darker) [5]. These alloys exhibit good hot workability above 450°C, the temperature at which the β′ phase transforms into β. Due to its low melting point, lead tends to migrate to grain boundaries in the form of globules during cooling after casting [6, 7]. Lead-bearing brass is gaining increasing interest in the scientific community, especially regarding the study of its microstructure characteristics and industrial performance. Several studies have examined the microstructure evolution and defect formation in CuZn40Pb2 alloys [8], as well as lead's role in enhancing machinability during manufacturing processes [9]. Other research has explored the relationship between processing parameters, microstructural evolution, and the mechanical behavior of brass alloys. These studies emphasize how manufacturing conditions such as casting temperature or hot-working processes, can significantly influence the microstructure and the resulting properties of the material [10, 11], and may also contribute to defects or failures in industrial brass components [12]. However, any change in microstructure, alloy composition, or processing parameters can substantially impact not only the mechanical properties but also the thermal and electrical performance of the material [13].

The study explores the feasibility of producing defect-free brass sanitary fittings from recycled materials in Moroccan manufacturing settings. It assesses the effects of different casting processes, metal charge compositions, and the chemical properties of raw materials on the microstructure and metallurgical quality of leaded brass alloys. Three alloy variants are examined: pure materials, a mixture of 75% recycled and 25% pure materials, and entirely recycled materials. This approach aims to clarify how recycled content influences alloy quality and whether it meets industrial and environmental standards. However, the combined effect of recycled charge composition and casting method on the metallurgical quality of CuZn40Pb2 brass under real industrial conditions remains underexplored. While several studies have investigated recycled brass alloys, fewer have evaluated the combined impact of recycled charge composition and casting technique in actual industrial manufacturing environments. Consequently, this research compares horizontal continuous casting and vertical discontinuous casting for producing CuZn40Pb2 sanitary fittings.

# 2 Materials and Methods

## 2.1 Materials and charge composition

The study examines the CuZn40Pb2 leaded brass alloy used in sanitary fittings, focusing on how recycled content affects its metallurgical quality. The recycled material mainly includes industrial brass scrap and mixed brass waste, such as machining chips from production as well as old sanitary brass parts like fittings, gas valves, water meters, and various taps and plumbing components. Virgin materials consist of commercial copper and zinc used in standard industrial practices. It tests three batches: one made from new materials, one from recycled materials, and one with a 75% recycled and 25% new material mix, assessing material quality and compliance with CW617N standards. The mixed charge was tested to determine its ability to compensate for variations associated with recycled materials.

### 2.2 Casting process and billet production

Two methods for industrial casting of billets were used: vertical discontinuous casting and horizontal continuous casting. Vertical casting involves molten metal solidifying in a water-cooled mold under gravity, guiding the solidification process. Conversely, horizontal casting features a continuous flow of alloy through a graphite mold, enabling more uniform cooling and solidification. The melting and casting procedures were performed under industrial conditions, optimizing fluidity while minimizing zinc evaporation and oxidation. The pouring temperature ranged from 1010 °C to 1120 °C. Cooling was managed with a water-cooled mold, with inlet water temperatures of approximately 31–33 °C and outlet temperatures of about 45–48 °C, and flow rates between roughly 23 and 58 L/min. In horizontal continuous casting, the billet extraction speed varied between approximately 41 and 56 mm/min, depending on the charge composition. For clarity, billets produced by horizontal casting were labeled B1, B2, and B5, while those made by vertical casting were labeled B3 and B4, based on the charge type.

### 2.3 Thermomechanical processing

After casting, billets were hot-worked through various stages to produce sanitary fittings. They were preheated and hot-extruded to create precise brass bars, with conditions optimized for uniform deformation and microstructural refinement. The billets were preheated to approximately 690–730 °C before extrusion, with extrusion speeds ranging from about 25.5 to 28.5 mm/s and system pressure around 140–147 $kg/cm^2$, depending on the processing setup. The extruded rods were straightened and hot forged at controlled temperatures to ensure proper material flow without defects. For forging, the bars were preheated to about 680–720 °C (usually around 690 °C) before deformation in a 100-ton automated hot forging press. Finally, finishing operations ensured dimensional accuracy and surface quality.

### 2.4 Characterization techniques

The study used optical emission spectroscopy to analyze the chemical composition and identify elemental distribution and segregation influenced by casting conditions. Additionally, optical microscopy was employed to observe microstructural features such as phase distribution, grain morphology, and lead particle dispersion. Non-destructive testing methods were applied to detect internal defects like cracks and inclusions, aiming to evaluate microstructural integrity and internal quality under real production conditions..

## 3 Results and Discussion

### 3.1 Chemical homogeneity and lead distribution

The statistical analysis of lead content at the center and edge of the billets shows clear differences between the two casting methods. As shown in Table 1, billets produced through horizontal continuous casting display minimal variation in Pb content, with low relative deviation and standard deviation values, indicating good chemical uniformity. In contrast, vertically cast billets exhibit a larger difference between the composition at the center and edges, suggesting more lead segregation during solidification. This behavior results from high thermal gradients and directional solidification in vertical casting. Data indicate that horizontal casting improves lead distribution consistency, reduces internal defects, and supports stable downstream processing with recycled raw materials.

**Table 1.** Statistical variation of Pb content in CuZn40Pb2 billets produced by different casting routes.

| Billet | Casting Process | Pb Center (%) | Pb Edge (%) | Absolute Difference (%) | Relative Difference (%) | Standard Deviation |
|---|---|---|---|---|---|---|
| B2 | Horizontal | 2.460 | 2.450 | 0.010 | 0.41 % | 0.0071 |
| B1 | Horizontal | 2.490 | 2.476 | 0.014 | 0.56 % | 0.0099 |
| B5 | Horizontal | 2.146 | 2.135 | 0.011 | 0.51 % | 0.0078 |
| B3 | Vertical | 2.448 | 2.366 | 0.082 | 3.41 % | 0.0580 |
| B4 | Vertical | 2.268 | 2.194 | 0.074 | 3.32 % | 0.0523 |

The statistical results in Table 1 are based on 13 analyzed points on the billet surface as shown in figure 1.

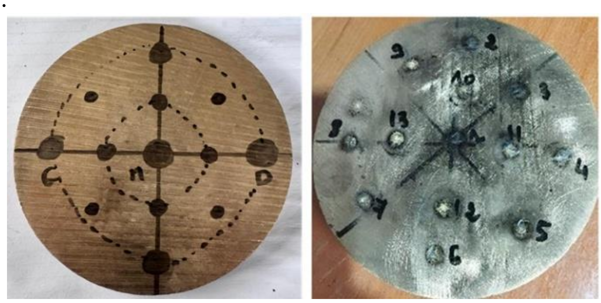

**Fig. 1.** Distribution of the 13 analyzed points on the surface of a leaded brass (CuZn40Pb2) billet

### 3.2 Microstructural integrity after casting and extrusion

Optical microstructural observations (Figures 2 and 3) reveal that all the billets studied exhibit the typical α+β two-phase structure of CuZn40Pb2 brass. However, significant differences depend on the type of casting and the nature of the charge. The billets produced by horizontal continuous casting display a finer and more uniform microstructure, especially for mixed charge (75% recycled and 25% pure) and modified parameters, where the phase distribution is consistent and the lead particles are finely dispersed (similar to those obtained with pure material charge). In contrast, billets cast by vertical discontinuous casting show coarse grains, uneven phase distribution, and local segregation of lead. These microstructural features highlight the influence of solidification conditions on phase morphology and chemical homogeneity.

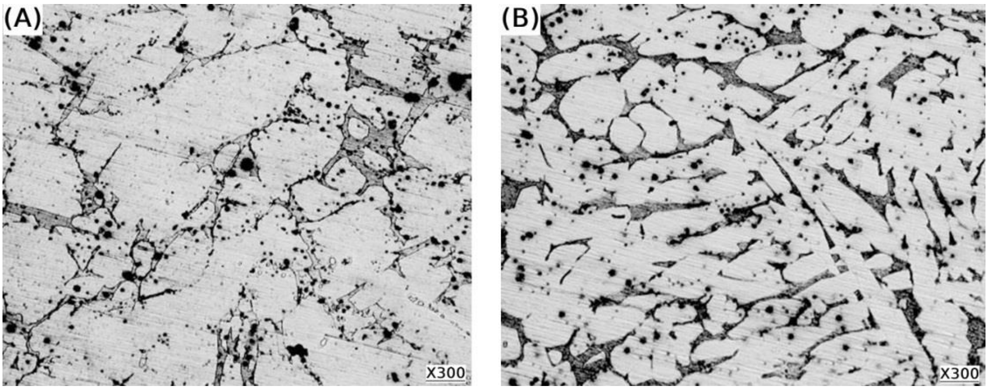


**Fig. 2.** Optical microscopy (OM) microstructures of CuZn40Pb2 billets produced by vertical discontinuous at 300×: (a) B3 (fully recycled charge) and (b) B4 (pure charge), Light regions: α phase; darker regions: β phase. Small dark spots: Pb particles; larger dark spots: defects.

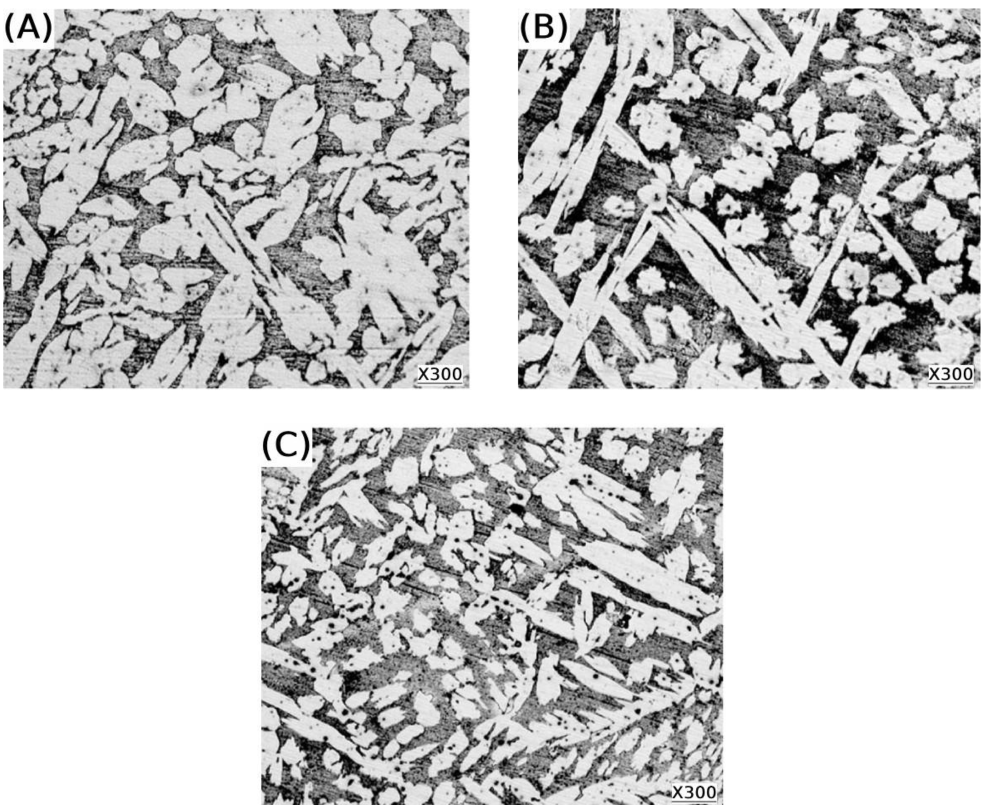


**Fig. 3.** Optical microscopy (OM) microstructures of CuZn40Pb2 billets produced by horizontal continuous casting at 300×: (a) B5 (pure charge), (b) B1 (fully recycled charge), and (c) B2 (mixed charge, 75% recycled + 25% pure). Light regions: α phase; darker regions: β phase. Small dark spots: Pb particles; larger dark spots: defects.

SEM/EDS analyses confirmed phase composition and lead patterns observed in optical microscopy. SEM images show the 100% recycled sample from vertical casting (B3) with elongated grains, segregation, inclusions, and coarse lead at grain boundaries

(Figure 4). The 25% pure material cast horizontally (B2) displays a uniform structure with well-distributed α and β phases, fine grains, and no defects, due to optimized processing (Figure 5). EDS results for the recycled sample show minor differences: the α phase has slightly more copper (62.1 wt%) than the β phase (58.3 wt%), indicating partial diffusion or incomplete transformation. Zinc in the β phase (~40–45 at%) is lower than expected, indicating uneven distribution. Bright lead precipitates are at grain boundaries or within phases. The 25% pure sample shows clearer phase separation: the α phase is enriched with copper (57.9 wt%), while the β phase has less copper (52.4 wt%).

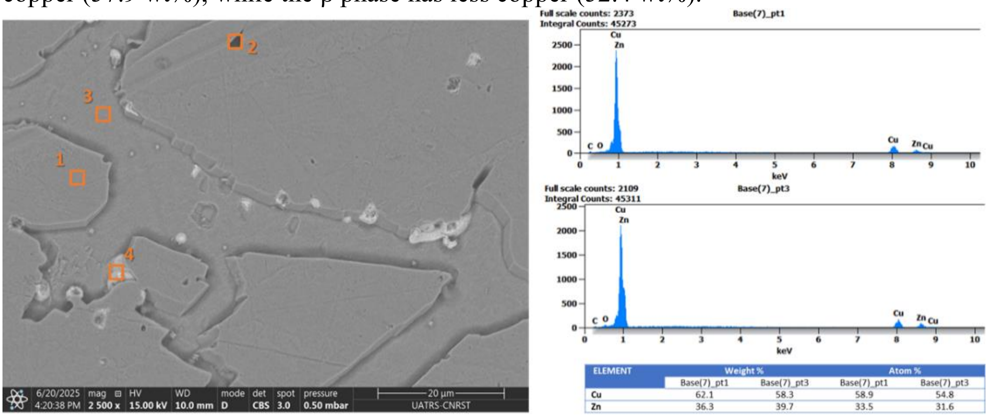


**Fig. 4.** SEM image of a leaded brass alloy sample (B3) accompanied by EDS analysis results for spectra (1 and 3).

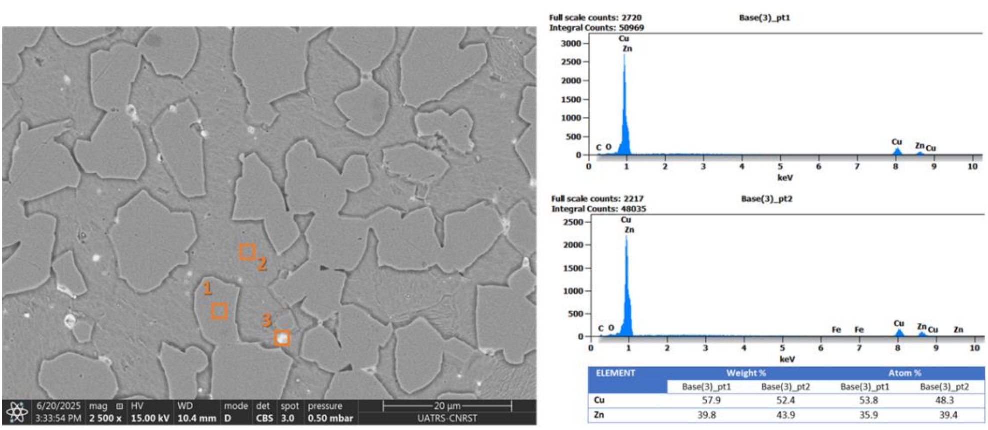


**Fig. 5.** SEM image of a leaded brass alloy sample (B2) accompanied by EDS analysis results for spectra (1 and 2).

### 3.3 Internal quality and non-destructive testing

Radiographic examination of the manufactured fittings confirms the microstructural observations. Parts produced under non-optimized conditions, especially those made from billets cast vertically from 100% recycled feedstock, sometimes display visible surface defects (Fig. 6). Conversely, fittings made from horizontally cast billets under optimized processing conditions, with a mixed charge consisting of 75% recycled materials and 25% virgin materials, show no visible defects. These results demonstrate that good control of the casting process and charge composition enhances internal strength and ensures industry-standard quality for sanitary fittings.

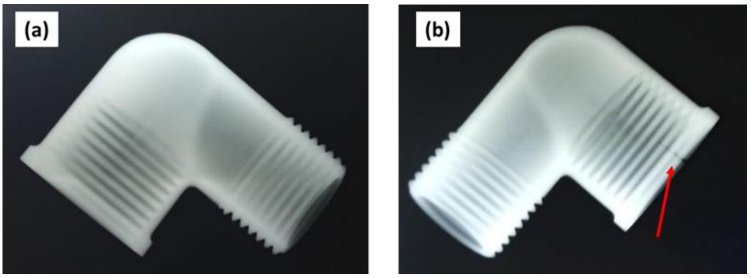


**Fig. 6.** Radiographic inspection of CuZn40Pb2 sanitary fittings: (a) fitting produced under optimized conditions, (b) fitting manufactured under non-optimized conditions, revealing internal defects

## 4 Conclusion

This research shows that high-quality CuZn40Pb2 sanitary fittings can be produced from partially recycled raw materials if the casting process and treatment parameters are properly controlled. Horizontal continuous casting with a mixed feedstock (75% recycled and 25% virgin) and adjustments to the process parameters improve chemical homogeneity, refine the microstructure, and achieve acceptable internal quality (comparable to that obtained with virgin materials) while minimizing defects in the final product. Notably, horizontally cast billets exhibited very low Pb segregation (relative differences about 0.41–0.56%), whereas vertically cast billets showed higher variations, reaching approximately 3.3–3.4%. These findings underscore the technical feasibility and industrial relevance of incorporating recycled brass into the manufacturing of sanitary fittings, offering an economical and sustainable solution aligned with resource efficiency goals, especially within the Moroccan industrial sector.

## References

1. J. Choucri, F. Talhaoui, K. El Ganaoui, et al., Corrosion behavior and susceptibility to stress corrosion cracking of leaded brass alloys in simulated drinking water, Materials 15, 144 (2021). https://doi.org/10.3390/ma15010144
2. P. Jarvis, J. Fawell, Lead in drinking water – An ongoing public health concern?, Curr. Opin. Environ. Sci. Health 20, 100239 (2021). https://doi.org/10.1016/j.coesh.2021.100239
3. J. Johansson, P. Alm, R. M'Saoubi, P. Malmberg, J.-E. Ståhl, V. Bushlya, On the function of lead (Pb) in machining brass alloys, Int. J. Adv. Manuf. Technol. 120, 7263–7275 (2022). https://doi.org/10.1007/s00170-022-09205-0
4. S. Jasper, R. Subash, K. Muthuneelakandan, D. Vijayakumar, S. Jhansi Ida, The Mechanical Properties of Brass Alloys: A Review, Eng. Proc. 93, 11 (2025). https://doi.org/10.3390/engproc2025093011
5. H. Lee, I. Lee, X. Xu, T. Omori, R. Kainuma, Revisiting the phase equilibria in the Cu–Zn binary system, J. Phase Equilibria Diffus. 45, 304–317 (2024). https://doi.org/10.1007/s11669-023-01061-z
6. E. Mohsine, I. Touaiher, H. Oudghiri Hassani, S. Taibi, K. Azzaoui, Microstructural integrity of recycled CuZn40Pb2 brass in defect-free sanitary fittings: A process optimization approach, Moroccan J. Chem. 13, 1808–1824 (2025). https://doi.org/10.48317/IMIST.PRSM/morjchem-v13i4-59972

7. P. Stavroulakis, A. I. Toulfatzis, G. A. Pantazopoulos, A. S. Paipetis, Machinable leaded and eco-friendly brass alloys for high-performance manufacturing processes: A critical review, Metals 12, 246 (2022). https://doi.org/10.3390/met12020246
8. K. J. Al-Fadhalah, M. A. Rafeeq, N. Thomas, Microstructure and texture development in thermomechanically processed leaded brass, *Metals* **11**, 998 (2021). https://doi.org/10.3390/met11070998
9. J. Krawczyk, The role of lead in the machinability of copper alloys, Adv. Mater. Sci. 25, 1–12 (2025). https://doi.org/10.2478/adms-2025-0015
10. H. Y. Atay, G. Uslu, Y. Kahramaz, Ö. Atay, Investigations of microstructure and mechanical properties of brass alloys produced by sand casting at different casting temperatures, IOP Conf. Ser.: Mater. Sci. Eng. 726, 012018 (2020). https://doi.org/10.1088/1757-899X/726/1/012018
11. J. Y. Kim, J. E. Lee, M. S. Kim, Enhancing machinability in free-cutting duplex brass alloys: Isotropic blocky α phase formation via optimized hot extrusion processing, J. Alloys Compd. 1010, 177062 (2024). https://doi.org/10.1016/j.jallcom.2024.177062
12. L. Bertoletti, M. Gelfi, L. Girelli, A. Pola, Failure analysis of a hot stamped CuZn40Pb2 brass hydraulic component, Eng. Fail. Anal. 187, 110617 (2026). https://doi.org/10.1016/j.engfailanal.2026.110617
13. L. Huang, B. Peng, Q. Yue, G. Huang, C. Wang, R. Wang, N. Tian, First-principles study on the electrical and thermal conductivities of Cu–Zn binary alloys, Materials 18, 2310 (2025). https://doi.org/10.3390/ma18102310