



Mix Sustentável



Sustainable Alloys in Contemporary Jewelry: a study on copper-silver compositions

Ligas Sustentáveis na Joalheria Contemporânea: um estudo sobre a composição nas ligas de prata-cobre

Aleaciones Sostenibles en la Joyería Contemporânea: un estudio sobre la composición en las aleaciones de plata-cobre

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Resumo: A integração de metais reciclados na produção de joias apresenta tanto desafios técnicos quanto ambientais. Nesse sentido, são necessárias diferentes abordagens para seleção e processamento de materiais em prol da sustentabilidade na joalheria contemporânea. Desta maneira, o presente estudo examina ligas de prata-cobre formuladas com cobre recuperado de resíduos eletrônicos, com objetivo de avaliar se ajustes no teor de cobre na liga Ag-Cu podem fornecer resultados tecnicamente consistentes e esteticamente aceitáveis, ao mesmo tempo em que reduzem a dependência de nova extração. O estudo seguiu duas etapas complementares: pesquisa bibliográfica para consolidar os fundamentos teóricos e experimentação em laboratório para testar seis ligas diferentes. As amostras foram analisadas durante os processos de fundição e laminação, e suas qualidades estéticas foram avaliadas por meio de lixamento e polimento. O comportamento mecânico foi examinado através de ensaios de dureza Vickers. A análise revelou que ligas Ag850, com 85% de prata contendo 15% de cobre reciclado, mantêm níveis satisfatórios de resistência, maleabilidade e qualidade visual. Apresentam diferenças mínimas em relação às ligas convencionais, preservando características essenciais para o uso na joalheria. Esses resultados sugerem que estratégias de uso eficiente de recursos podem ampliar as práticas sustentáveis no setor joalheiro, reduzindo custos ambientais associados à extração mineral.

Palavras-chave: Liga de Prata e Cobre; Propriedades Mecânicas; Propriedades Estéticas; Metais; Joalheria.

Abstract: The integration of recycled metals into jewelry production presents both technical and environmental challenges. So on, sustainability in contemporary jewelry requires new approaches to material selection and processing. This study examines silver-copper alloys formulated with copper recovered from discarded electronics. The aim was to assess whether adjustments in copper content could provide technically consistent and aesthetically acceptable results while reducing dependence on newly mined silver. The investigation followed two complementary stages: literature research to consolidate theoretical foundations and laboratory experimentation to test six different alloys. Samples were analyzed during casting and rolling, and their aesthetic qualities were assessed through sanding and polishing. Mechanical behavior was further evaluated using Vickers hardness tests. The analysis revealed that alloys with 85% silver (Ag850) containing 15% recycled copper maintain satisfactory levels of strength, malleability, and visual quality. It has minimal differences compared to conventional alloys, preserving essential characteristics for jewelry use. These results suggest that

permite o compartilhamento do trabalho com reconhecimento da autoria e publicação inicial nesta revista.

Contribuição dos autores segundo a Taxonomia CRediT

JTP: investigation, validation, visualization, writing - original draft FLP: formal analysis, data curation, writing - review MKC: project administration, methodology, resources, writing - review, and supervision

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Nothing to declare.

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resource-efficient strategies can expand sustainable practices in the jewelry sector, lowering environmental costs linked to mineral extraction.

Keywords: Silver-Copper Alloys; Mechanical Properties; Aesthetic Properties; Metals; Jewelry.

Resumen: La integración de metales reciclados en la producción de joyería presenta tanto desafíos técnicos como ambientales. En este sentido, se requieren distintos enfoques para la selección y el procesamiento de materiales en favor de la sostenibilidad en la joyería contemporánea. De este modo, el presente estudio examina aleaciones de plata-cobre formuladas con cobre recuperado de residuos electrónicos, con el objetivo de evaluar si los ajustes en el contenido de cobre en la aleación Ag-Cu podrían proporcionar resultados técnicamente consistentes y estéticamente aceptables, al mismo tiempo que reducen la dependencia de la plata extraída de nuevas minas. El estudio se desarrolló en dos etapas complementarias: una revisión bibliográfica para consolidar los fundamentos teóricos y una experimentación en laboratorio para ensayar seis aleaciones diferentes. Las muestras fueron analizadas durante los procesos de fundición y laminación, y sus cualidades estéticas se evaluaron mediante esmerilado y pulido. El comportamiento mecánico se examinó a través de ensayos de dureza Vickers. El análisis reveló que las aleaciones Ag850, con 85% de plata y 15% de cobre reciclado, mantienen niveles satisfactorios de resistencia, maleabilidad y calidad visual. Presentan diferencias mínimas con respecto a las aleaciones convencionales, preservando características esenciales para su aplicación en joyería. Estos resultados sugieren que estrategias de aprovechamiento eficiente de los recursos pueden ampliar las prácticas sostenibles en el sector joyero, reduciendo los costos ambientales asociados a la extracción minera.

Palabras clave: Aleación de Plata y Cobre; Propiedades Mecánicas; Propiedades Estéticas; Metales; Joyería.

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1 INTRODUCTION

During the 1960s, the first ecological concepts emerged to support what we now call sustainability or “sustainable development” (Walker, 2006). The latter term was popularized in the 1980s through the Brundtland Report. Written by Gro Harlem Brundtland, former prime minister of Norway, the report was published in 1987. It informed discussions on sustainable development during the Earth Summit, or Rio-92, the United Nations Conference on Environment and Development (Botelho, 2012).

Over the last 35 years, the urgency of implementing sustainable practices across productive sectors has grown. Kazazian (2005) and Peltier e Saporta (2009) argue that material life cycles and sustainability are interrelated. According to the authors, environmental, material and relational impacts are defined from extraction through creative processes to end-of-life or renewal cycles, such as incineration or recycling. Jewelry and sustainability research follows this path, seeking new uses for materials otherwise discarded and pointing to innovations and alternatives for reduction or transformation.

In jewelry, it is possible to say that “traditional pieces” contribute to sustainability because these pieces are passed down through generations or remodeled into new forms and meanings. These practices extend life cycles, offering longevity, permanence, and a reduced demand for natural resources. Traditional processes are also artisanal. Production occurs at a slower pace than industrial manufacturing, thus proving more sustainable (Spinassé; Cateb, 2022; Walker, 2006). Moreover, the materials employed in jewelry design may align with sustainable practices, especially regarding the extraction of precious metals such as gold, silver, and platinum (Spinassé; Cateb, 2022).

Precious metals in jewelry require alloying with other elements to achieve hardness, malleability, or ductility (Kliauga; Ferrante, 2009). For example, in the 13th century, King Afonso II of Portugal established legal standards for silver purity, known as “sterling silver.” Today, Ag925 and Ag950 alloys still hold this designation (Santos, 2019). Different uses demand different alloys. Another example, pins and brooches require harder alloys due to wear, while filigree work demands softer alloys (Santos, 2019).

The annual use of silver in jewelry alone reached 6,000 tons in 2024, representing 17% of the total consumption (Statista, 2025). To explore the feasibility of unusual alloys with higher copper content, given copper’s lower cost, this study tested variations in Ag-Cu gradations. Alongside pure silver as a control, five alloys were created: Ag950, Ag850, Ag750, Ag650, and Ag550. Copper came from recycled electronic waste. Each alloy underwent casting, rolling, sanding, and polishing, with comparative evaluations of copper’s impact on production, aesthetics, and Vickers hardness. Although copper is typically added in small amounts in jewelry, any reduction in silver is significant given its high cost. This justifies exploring less conventional alloys.

2 SUSTAINABILITY CONCEPTS AND THEIR ROLE IN THE JEWELRY FIELD

For Boff (2017), sustainability serves as a concept used in many contexts to add value to processes. He traces “prehistoric” ideas of sustainability to forestry, later highlighting the 1972 Stockholm Conference as the moment when “sustainable development” entered history. Salcedo (2014) views sustainability as a set of measures to ensure industry functionality, given resource scarcity and concerns about social justice. Berlim (2020) defines sustainability as a philosophy and not a commodity, an idea also echoed by Walker (2006). To enhance sustainability in companies and industries a mix of effective practices is required side by side to consumer awareness (Wobeto; Neira, 2019).

Walker (2006) stresses that sustainability should integrate cultural and human dimensions. It is not a “cure for all environmental and social issues” but a crucial element for human survival. It demands paradigm shifts in production and capital structures inherited since the 18th century. At that time, resources were seen as infinite. From the mid-19th century onward, efforts emerged toward ecologically responsible industry (Wobeto; Neira, 2019). Skoda (2012) argues that design can draw attention to issues of production and consumption, projecting new environmental horizons beneficial to individuals and society.

Such principles were anticipated by Papanek’s *Design for the Real World* (1971), which stressed the designer’s role in product development. Walker (2006) also cites Schumacher and Fuller, who linked environmental and social reforms to design responsibilities. The 3Rs—reduce, reuse, recycle—summarize practical strategies. Elkington (1998) conceptualized sustainability as the “triple bottom line”: economically viable, socially just, and environmentally sound, ensuring future generations’ survival.

Consumer awareness drives attention to product origins and environmental consequences (Berlim, 2020). Buyers of sustainable goods often feel they play a role in conservation (Wobeto; Neira, 2019). For some, sustainable products also signal prestige within social circles (Griskevicius; Tybur; Van den Bergh, 2010). Others view their choices as signs of environmental superiority (Turunen; Cervellon; Carey, 2020).

In Rio-92, Agenda 21 expanded sustainable development planning into new spheres, local and globally, including socioeconomic aspects (Pereira; Silva; Carbonari, 2012). In Brazil, local actions prioritized education, health, income programs, and natural resource conservation (Pereira; Silva; Carbonari, 2012). These actions point out to a pathway well known in the jewelry field: 3Rs principles, like the 3Rs, as metal melting and reuse are infinite, we’re reducing extraction when creating new pieces with reusing "old" metal.

Hawkes (2001) proposed culture as a fourth dimension of sustainability. This dimension was only looked in to more carefully in the beginning of 2000’s. Boff (2017) stresses that culture counters economic focus on profit, encompassing intrinsic aspects of human life, such as art, creativity, and faith. Preserving local material culture through natural resources connects with contemporary jewelry by combining innovation with cultural value (Cidade; Perini; Palombini, 2022).

In jewelry, sustainability often means reusing discarded materials or employing unusual ones, fostering “alternative jewelry” (Barbosa; Kattel; Razza, 2021; Cidade; Perini; Palombini, 2022). Lower-cost metals, long undervalued compared to gold, now gain relevance (Cintra; Cidade, 2020). Status linked to jewelry

merges with material and symbolic values, communicated through recycling and reuse, essential to circular economy practices (Turunen; Cervellon; Carey, 2020).

For silver, material value comes from physical-chemical qualities: brightness, malleability, strength, and conductivity (Edensor; Sobell, 2021). Yet meaning also arises from shape, symmetry, curves, or color (Alexander, 2008). Historically, silver symbolized refinement and industrial progress, gifted to elites (Glanville, 2006). Pure silver, or Ag1000, is mined mainly as a by-product of lead extraction (Santos, 2019). In 2004, 72% of commercial silver came from mining, primarily in Mexico, Peru, and Australia, with 28% from reserves and recycling (Kliauga; Ferrante, 2009). By 2024, Mexico, China, and Peru led global production (Statista, 2024). Brazil, lacking large reserves, sources silver mostly through recycling, as a by-product of gold refining (Souza *et al.*, 2013). Industrial recycling is increasing, reaching 7% in 2022 (The Silver Institute, 2024). One method involves extracting silver from radiographic films (Duarte, 2016).

Copper, by contrast, links to femininity, vitality, and life processes (Falchetti, 2021). Designated as Cu in the periodic table, its name derives from the Latin cuprum (Rodrigues; Silva; Guerra, 2012). Copper possesses several important characteristics that make it widely used in electrical wiring, due to its excellent electrical conductivity and resistance to corrosion (Silva, 2010). In jewelry, in turn, it plays a crucial role as a component of metal alloys. According to Kliauga e Ferrante (2009), in 2005, copper was mined in countries such as Chile, the United States, Canada, Zambia, Mauritania, and Poland. According to more recent data from the Statista (2024), Chile remains the country with the largest copper reserves. It is also the largest producer of the ore, followed by Peru and the Democratic Republic of Congo. In Brazil, copper is extracted and exported as ore, because the country lacks self-sufficient refining capacity (Kliauga; Ferrante, 2009). Given the recent demand for the material – driven largely by vehicle electrification and the high consumption of the metal for these motors – an important source of copper comes from the recycling of electronic waste (Cândido; Kindlein Júnior; Palombini, 2015; Oliveira *et al.*, 2024).

Noble metals such as gold (Au), silver (Ag), and platinum (Pt) are widely used in jewelry and decorative objects (Spinassé; Cateb, 2022). Silver, among the first metals manipulated, was symbolized by the moon in alchemy and designated as argentum in Latin (Souza *et al.*, 2013). Classified as a noble metal, it resists oxidation, conducts electricity and heat, and offers ductility (Etris, 2004; Santos, 2019). In pure form, however, noble metals are soft and require alloying (Spinassé; Cateb, 2022). In other words, noble metals need to be unified with two or more metallic elements to improve their properties. In this way, copper plays a central role in Ag-Cu and Au-Cu alloys. Desired properties in the jewelry field include ductility, resistance, plasticity, and shine (Pessin *et al.*, 2015). Silver alloyed with copper becomes harder, cheaper, and has a lower melting point (Santos, 2019). However, excess copper in Ag-Cu alloys changes silver's white brilliance to yellow or red, signaling low market value and the perception of a "cheap piece".

To produce artifacts, the alloy known as "sterling silver" (or Silver 925) is commonly used. It is composed of 92.5% Ag and 7.5% Cu. Other frequently used alloys include coin silver (Silver 900), formed by 90% Ag and 10% Cu; and the eutectic or brazing alloy (Silver 719) with 71.9% Ag and 28.1% Cu (Costa, 2001). For jewelry production in the Brazilian market, the preference is for Sterling Silver 925 and Silver 950 alloys. The latter contains only 5% copper in the alloy and is commonly handled in the jewelry trade. Furthermore, in

Brazil, the use of silver and other metals in jewelry is regulated by the NBR ISO 9202 standard. This standard establishes minimum fineness thresholds of 800, 925, 958, 990, and 999. Values below these are not permitted.

3 NEW USES OF METALS IN JEWELRY

The value of gold is not explained solely by its physical properties like beauty, luster, malleability, resistance to corrosion, and natural rarity. It's also explained by a social history of power and scarcity, whether artificially constructed or not (Schoenberger, 2011). The price fluctuations observed in 2025, driven by geopolitical conflicts, make this relationship particularly evident (Race, 2025). Furthermore, the environmental impact and the “hidden costs” of gold (Human Rights Watch, 2018) have led jewelers and designers to seek alternatives that are both environmentally and economically sustainable in the production of their pieces. As a result, the use of silver in jewelry has grown considerably over the years (Mordor Intelligence, 2025), given its excellent qualities, as noted in Section 2. Beyond silver, in innovative and creative ways, jewelry designers have also turned to other metals such as bronze, iron, copper, aluminum, and titanium, some of which are employed in oxidized form or even with patina.

One notable example is the work of Philippe Guilhem. A designer and gemologist from a family of jewelers, Guilhem has gained recognition for over two decades for his use of an uncommon metal in fine jewelry (White Magazine, 2020). Responsible for the Mashandy collection, he creates most of his pieces in bronze (Figure 1). The jeweler incorporates the natural patina that develops on bronze over time as a deliberate aesthetic feature in his work.

Figure 1 – Mashandy Collection bronze rings.



Source: Perez (2023).

Another example is the French brand Studio C, founded by jewelry designer Charlotte Romer. At Studio C, jewelry is crafted exclusively in aluminum as the primary metal (Studio C, 2023). The objective is to produce lightweight pieces with bold forms, manufactured in small series (Figure 2).

Figure 2 – Bracelet in aluminum, rutilated quartz, and tourmalines.



Source: Second Petale (2025).

Other designers have also adopted oxidized metals and patina as central features in their work (Figure 3). In Figure 3 A, one observes a pair of earrings in sterling silver (950) and oxidized copper, created by researcher Giovanna de Oliveira. Portuguese jeweler Vera Pinto designed the ring in Figure 3 B, employing oxidized silver to generate textured surfaces. Finally, Hungarian designer Nóra Tengely makes use of patina on copper to impart new colors to the metal (Figure 3 C).

Figure 3 – Oxidized and patinated jewelry: (A) Earrings in oxidized copper; (B) Textures II ring in oxidized silver; (C) Earrings from the Strong collection in patinated copper



Source: (A) de Oliveira *et al.* (2024), (B) Galeria Alice Floriano (2016); (C) Pistachios Gallery (2021).

These examples highlight the directions taken by contemporary jewelry and the fertile ground for exploring new possibilities in metals and alloys, opening pathways beyond what is conventionally considered traditional. Such innovations not only expand the aesthetic and technical repertoire of the field but also reflect broader cultural and environmental shifts that increasingly demand sustainable and experimental approaches.

4 HANDS ON: PREPARING AG-CU ALLOYS

To understand usability and apply other notions of value associated with silver alloyed with copper, different gradations beyond the traditional alloy were tested. This approach made it possible to observe both aesthetic and mechanical impacts resulting from the variation in copper content. As noted earlier, the Ag-

Cu alloy has been used in many artifacts throughout human history (Costa, 2001). It is therefore essential to examine differences and impacts derived from alloy gradation.

According to Kliauga e Ferrante (2009), color variation occurs as more copper is added. Alloys with 7.5% or less copper remain white. Those with 20–30% copper take on a yellowish tone, while alloys with up to 50% copper appear reddish. For this study, five different proportions were selected, in addition to pure silver as a reference, according to what is set out in Table 1. Each alloy was subjected to mechanical rolling and malleability tests, as well as evaluations of brightness and color.

Table 1 – Percentage Gradation in Ag-Cu Alloys.

Alloy	Ag (%)	Cu (%)	Ag/Cu Ratio	Final weight after casting (g)
Ag1000	100	0	0	2.0
Ag950	95	5	19.00	2.1
Ag850	85	15	5.60	2.2
Ag750	75	25	3.00	2.7
Ag650	65	35	1.85	3.0
Ag550	55	45	1.20	3.7

Source: Authors (2025).

Each alloy was prepared using 2 grams of pure silver (Ag1000) as the base. Proportions of silver and copper were calculated to determine the amount of copper required for each alloy. These values correspond to the fourth column in Table 01. For example, in the Ag950 alloy, 95% silver is divided by 5% copper, yielding a ratio of 19. The silver mass, 2 g, is divided by 19, resulting in 0.105 g of copper to be added to form the alloy. The final column in Table 1 presents the approximate final weight of each sample after casting.

Using a precision balance, the metals were portioned into containers according to each alloy and melted individually, starting with Ag1000 and proceeding gradually to Ag550. This sequence was followed to avoid copper contamination, since Ag1000 contains no copper. After melting silver and copper in the crucible, the molten metal was poured into a wire-shaped mold. Each ingot was then placed in a 15% sulfuric acid solution for three minutes to purify the bonded metals. It was subsequently neutralized in a sodium bicarbonate solution. The ingots were then rinsed in running water, dried, and weighed (Figure 4).

Figure 4 – Ag-Cu ingots after casting.



Source: Authors (2025).

Next, each ingot was passed through different grooves of an electric rolling mill, in wire format, until reaching a uniform appearance and a width of 2.8 mm (Figure 5). The metal was then rolled into sheets until reaching an approximate thickness of 1 mm.

Figure 5 – Ingots transformed into wire after passing through the electric rolling mill.



Source: Authors (2025).

After the rolling process, each sheet was divided into three parts. One was left unaltered, another was only sanded, and the last was sanded and polished. The goal was to analyze differences in color and aesthetics. Sanding was performed with sandpapers of 400, 800, and 1200 grit. Polishing was carried out with abrasive pastes. The sanding process is shown in Figure 6).

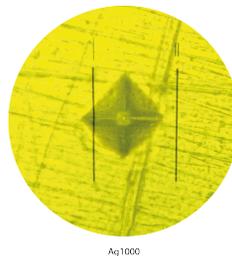
Figure 6 – Sanding sample with sandpaper.



Source: Authors (2025).

To assess hardness, a Vickers hardness test was conducted using the HMV – Micro Hardness Tester (Shimadzu). Each sheet was subjected to ten indentations, with a load of 2.942 Newtons applied for 15 seconds, producing an indentation on the material (Figure 7). The number of indentations per sample was chosen to ensure greater reliability of results.

Figure 7 – Indentation obtained in the Ag1000 sample by the punch.

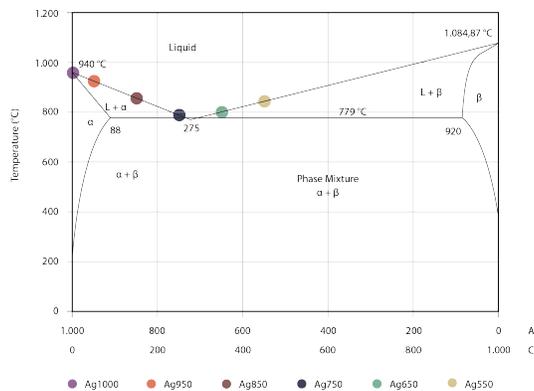


Source: Authors (2025).

5 RESULTS AND DISCUSSION

From the casting stage onward, changes were observed in the behavior of the alloys compared to the standard composition. When compared with Ag950, the most used alloy, Ag850 and Ag750 showed greater resistance to melting. They required more time to achieve a homogeneous mixture. Alloys Ag650 and Ag550, although slower to reach the melting point, homogenized rapidly once molten. Ag1000 presented the greatest difficulty in melting, despite not requiring homogenization. These observations align with the phase diagram presented by Kliauga e Ferrante (2009), shown in Figure 08. The diagram illustrates how different copper concentrations in the Ag-Cu alloy alter the melting point (the beginning of the “Liquid” phase).

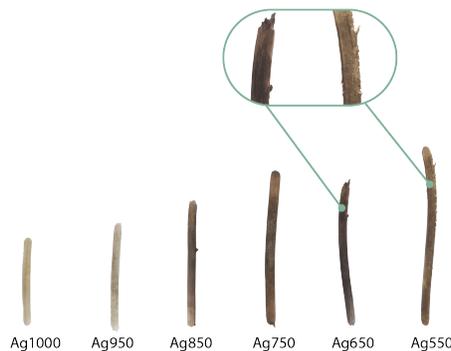
Figure 8 – Ag-Cu phase diagram.



Source: Adapted from Kliauga and Ferrante (2009).

During the rolling process, because the equipment was electric, no clear changes in resistance to deformation were observed. However, a notable distinction among alloys was heat generation. The higher the copper content (closer to Ag550) the more the samples heated during rolling, especially Ag650 and Ag550. Another observation in these alloys was the formation of cracks and a rougher surface texture (Figure 9 and details).

Figure 9 – Rolled sheets and details.



Source: Authors (2025).

Regarding brightness, after sanding and polishing each sheet, aesthetic changes became visible with the addition of copper (Figure 10). Ag1000, Ag950, and Ag850 still exhibited the white brilliance characteristic of silver jewelry. From Ag750 onward, a yellow-reddish brilliance appeared, becoming more intense with each gradation.

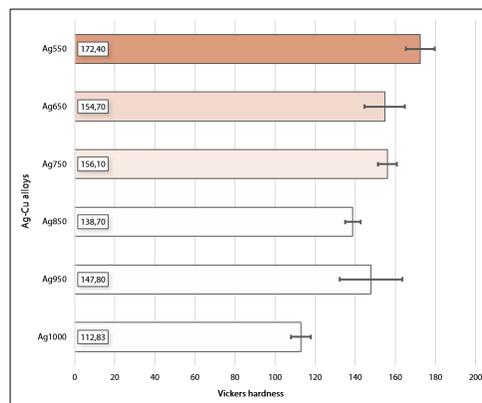
Figure 10 – Sanded and polished sheets.



Source: Authors (2025).

Figure 11 presents the results of the Vickers hardness test for all alloys, including mean values and standard deviations. In this test, the larger the indentation left by the indenter, the softer the material and the lower the hardness value. Pure silver (Ag1000) obtained the lowest hardness. Hardness gradually increased with higher copper content in Ag-Cu alloys, consistent with findings in the literature (Kliauga; Ferrante, 2009).

Figure 11 – Results of Vickers hardness tests, showing mean values and standard deviations for each Ag-Cu alloy.



Source: Authors (2025).

A particular case was observed in Ag950, which showed higher hardness than Ag850, despite containing less copper. This occurred due to a specific Ag-Cu ratio in which dispersed copper precipitates (phase) increased hardness when rolled without subsequent heat treatments (Kliauga; Ferrante, 2009). This also explains the larger standard deviation in Ag950, since localized measurements may have struck copper precipitates unevenly.

Regarding to the main mechanical properties –elastic modulus and yield strength – both directly related to hardness, the addition of copper in Ag950 increases strength and durability. This justifies its widespread use in jewelry. Nevertheless, the results indicate that higher concentrations of recycled copper can be used in Ag850 without compromising final quality, whether aesthetic (brightness and color) or mechanical (hardness and strength). For Ag750, however, the alloy shows a slightly reddish tone and greater mechanical resistance compared to Ag850, making manipulation more difficult in processes such as ring shank fabrication.

6 CONCLUSIONS

This study aimed to examine the potential use of different alloys in jewelry, linking them to sustainability concepts through the combination of silver and greater amounts of recycled copper. Although the percentage of copper added remains relatively small, given the high cost of silver, any reduction in its use can generate significant impact.

The experiment with different Ag-Cu gradations sought to evaluate the aesthetic and mechanical feasibility of these compositions, incorporating more copper from electronic waste – a material that is cheaper and more accessible than silver. During testing, changes were observed in color, which became reddish, as well as in thermal conductivity, weight, and sheet resistance depending on copper content. The results indicate that alloys with recycled copper up to Ag850 can be used without compromising aesthetic attributes (brightness and color) or mechanical properties (hardness and strength). This contributes to a reduction in the amount of silver required.

Overall, the search for alternatives that enable recycling and reuse of metals, thereby reducing the environmental impact of mineral extraction, points to new aesthetics. Such aesthetics encourage the creative use of nontraditional alloys, while preserving visual similarities to conventional Ag-Cu alloys. Future research should analyze both the aesthetic and mechanical properties of jewelry produced with these alloys, with emphasis on their usability in daily wear.

REFERENCES

- Alexander, J. C. Iconic consciousness: the material feeling of meaning. **Environment and Planning D: Society and Space**, v. 26, n. 5, p. 782–794, 2008.
- Barbosa, A. B. A.; Kattel, C. do C. L.-B. E.; Razza, B. M. Joalheria em pautas sociais: as joias como potencialização para sustentabilidade e empoderamento feminino. In: **Anais do II Simpósio Internacional de Ourivesaria, Joalheria e Design**. [S.l.]: Editora Blucher, 2021. p. 104–115.
- Berlim, L. **Moda e sustentabilidade: uma reflexão necessária**. Barueri: Editora Estação das Letras e Cores, 2020.
- Boff, L. **Sustentabilidade: o que é - o que não é**. Petrópolis: Editora Vozes Limitada, 2017.
- Botelho, C. R. O. M. **Preservação ambiental, um discurso de todos da Eco 92 à Rio+20**. Brasília: Câmara dos Deputados, 2012.
- Cidade, M. K.; Perini, J. T.; Palombini, F. L. Bionics for inspiration: A new look at brazilian natural materials for application in sustainable jewelry. In: Palombini, F. L.; Muthu, S. S. (Ed.). **Bionics and Sustainable Design**. Singapore: Springer Singapore, 2022. p. 195–223.
- Cintra, L. S. K.; Cidade, M. K. Reutilização e reciclagem: desenvolvimento de joia com componentes oriundos de resíduos eletroeletrônicos. **MIX Sustentável**, v. 6, n. 3, p. 27–36, 2020.
- Costa, V. The deterioration of silver alloys and some aspects of their conservation. **Studies in Conservation**, v. 46, n. 2, p. 18–34, 2001.
- Cândido, L. H. A.; Kindlein Júnior, W.; Palombini, F. Indicators for the feasibility of weee processing plants in brazil: a relationship between virgin mineral copper ore and the recycling of consumer electronic products. **Design e Tecnologia**, v. 5, n. 09, p. 59, 2015.
- Duarte, J. J. P. Práticas sustentáveis nas produções do polo joalheiro do pará. In: **Anais do 12º Congresso Brasileiro de Pesquisa e Desenvolvimento em Design**. São Paulo: Blucher, 2016. p. 1720–1731.
- Edensor, T.; Sobell, B. Keeping the family silver: The changing meanings and uses of manchester’s civic plate. **Journal of Material Culture**, v. 26, n. 3, p. 280–297, 2021.
- Elkington, J. **Cannibals with Forks: The Triple Bottom Line of 21st Century Business**. Gabriola Island: New Society Publishers, 1998.
- Etris, S. F. Silver and silver alloys. In: **Kirk-Othmer Encyclopedia of Chemical Technology**. 5. ed. Nova Jersey: John Wiley & Sons, 2004. v. 22, p. 636–667.
- Falchetti, A. M. El poder simbólico del cobre en la metalurgia de la américa antigua: metáfora de la vida humana. In: Parodi, L. V.; Pérez, R. L. (Ed.). **Los metales en nuestra historia**. 1. ed. Lima: Academia Colombiana de Historia, 2021. p. 359–399.
- Glanville, P. **Silver in England**. Londres: Routledge, 2006.
- Griskevicius, V.; Tybur, J. M.; Van den Bergh, B. Going green to be seen: status, reputation, and conspicuous conservation. **Journal of Personality and Social Psychology**, v. 98, n. 3, p. 392–404, 2010.

Hawkes, J. **The Fourth Pillar of Sustainability: Culture's essential role in public planning**. Melbourne: Common Ground Publishing, 2001.

Human Rights Watch. **The Hidden Cost of Jewelry: Human Rights in Supply Chains and the Responsibility of Jewelry Companies**. Nova York, 2018. Acesso em: 29 abr. 2025. Disponível em: <https://www.hrw.org/sites/default/files/report_pdf/jewellery0218_web_0.pdf>.

Kazazian, T. **Haverá a idade das coisas leves: design e desenvolvimento sustentável**. São Paulo: Editora Senac São Paulo, 2005.

Kliauga, A. M.; Ferrante, M. **Metalurgia básica para ourives e designers: do metal à joia**. São Paulo: Editora Blucher, 2009.

Mordor Intelligence. **Silver Market Size & Share Analysis - Growth Trends and Forecast (2025 - 2030)**. 2025. Acesso em: 27 set. 2025. Disponível em: <<https://www.mordorintelligence.com/industry-reports/silver-market>>.

Oliveira, G. R. de *et al.* Utilization of accessible 3d technologies for the study of bionics in jewelry design. In: Arruda, A. J. V. D.; Palombini, F. L. (Ed.). **Biology, Biomimetics and Natural Design**. Suíça: Springer Cham, 2024. p. 13–29.

Peltier, F.; Saporta, H. **Design sustentável: caminhos virtuosos**. 1. ed. São Paulo: Senac, 2009.

Pereira, A. C.; Silva, G. Z. da; Carbonari, M. E. E. **Sustentabilidade, responsabilidade social e meio ambiente**. Brasil: Editora Saraiva, 2012.

Pessin, L. *et al.* Análise de corrosão de ligas de prata para uso em joalheria. **Blucher Physics Proceedings**, v. 2, n. 1, p. 45–48, 2015.

Race, M. **A escalada de tensão que faz valor do metal bater recorde**. Rio de Janeiro: [s.n.], 2025. Acesso em: 28 set. 2025. Disponível em: <<https://www.bbc.com/portuguese/articles/czrn0nzlpxeo>>.

Rodrigues, M. A.; Silva, P. P.; Guerra, W. Cobre. **Química Nova na Escola**, v. 34, n. 3, p. 161–132, 2012.

Salcedo, E. **Moda ética para um futuro sustentável**. São Paulo: Editora Gustavo Gili, 2014.

Santos, R. **Jóias: fundamentos, processos e técnicas**. São Paulo: Editora Senac São Paulo, 2019.

Schoenberger, E. Why is gold valuable? nature, social power and the value of things. **Cultural Geographies**, v. 18, n. 1, p. 3–24, 2011.

Silva, S. de A. **Uso de buscas de documentos de patentes na área de processamento mineral: um estudo de caso direcionado para a construção de panoramas tecnológicos sobre processos de produção de cobre**. 2010. Dissertação (Mestrado) — Instituto Nacional da Propriedade Industrial, Rio de Janeiro, 2010.

Skoda, S. M. de O. G. **Evolução da arte da joalheria e a tendência da joia contemporânea brasileira**. 2012. Dissertação (Mestrado) — Universidade de São Paulo, São Paulo, 2012.

Souza, G. D. de *et al.* Prata: Breve histórico, propriedades e aplicações. **Educacion Quimica**, v. 24, n. 1, p. 14–16, 2013.

Spinassé, M. A.; Cateb, M. Anatomy of jewelry: metallic components. **DATJournal**, v. 7, n. 3, p. 309–336, 2022.

Statista. **Leading silver producing countries worldwide in 2022**. 2024. Acesso em: 6 dez. 2024. Disponível em: <<https://www.statista.com/statistics/253339/leading-silver-producing-countries/>>.

Statista. **Demand for silver worldwide in 2024, by end use**. 2025. Acesso em: 6 dez. 2024. Disponível em: <<https://www.statista.com/statistics/253345/global-silver-demand-by-purpose/>>.

Studio C. **The Studio**. 2023. Acesso em: 29 set. 2025. Disponível em: <<https://studioc-paris.com/en/the-studio>>.

The Silver Institute. **Silver Supply & Demand**. 2024. Acesso em: 6 dez. 2024. Disponível em: <<https://www.silverinstitute.org/silver-supply-demand/>>.

Turunen, L. L. M.; Cervellon, M. C.; Carey, L. D. Selling second-hand luxury: Empowerment and enactment of social roles. **Journal of Business Research**, v. 116, p. 474–481, 2020.

Walker, S. **Sustainable by Design: Explorations in Theory and Practice**. Londres: Earthscan, 2006.

White Magazine. **Philippe Guilhem: Joaillier-Créateur & Sculpteur**. 2020. Acesso em: 28 set. 2025. Disponível em: <<https://guilhem-joaillier.com/assets/uploads/white-magazine-winter-2020-1.pdf>>.

Wobeto, D.; Neira, D. S. M. Sustentável, ética e consciente - que moda é essa. In: Seabra, L. (Ed.). **Processos contemporâneos: da ideia à aplicação**. Goiânia: Gráfica UFG, 2019. p. 1–322.