International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Fingerprint of Precious Metals Ornaments to Post-Mortem Inventory by Energy Dispersive X-Ray Fluorescence Spectrometry

Maria Cristina Tessari-Zampieri[1], Marycel Elena Barboza Cotrim[2], Marcos Antonio Scapin[3]

[1]Instituto de Pesquisas Energéticas e Nucleares IPEN-CNEN, Av. Prof. Lineu Prestes, 2242, Cidade Universitária, CEP 05508-000, São Paulo – SP - Brasil
Corresponding Author Email: *mczampieri[at]ipen.br*

[2]Instituto de Pesquisas Energéticas e Nucleares IPEN-CNEN, Av. Prof. Lineu Prestes, 2242, Cidade Universitária, CEP 05508-000, São Paulo – SP - Brasil
Email: *mecotrim[at]ipen.br*

[3]Instituto de Pesquisas Energéticas e Nucleares IPEN-CNEN, Av. Prof. Lineu Prestes, 2242, Cidade Universitária, CEP 05508-000, São Paulo – SP – Brasil
Email: *mascapin[at]ipen.br*

Abstract: ***Quantitative analysis of metal alloys in ornaments can reveal relevant aspects about the substrates used in the manufacturing process. Fifty-three female ornaments (chains, rings, and earrings) were identified as jewelry and semi-jewelry using EDRFX. Twenty-three samples were identified and evaluated as jewelry because they had a substrate composed of different concentrations of gold (40-83%) ranging from 10 to 21 carats. This study can be considered the first to use EDRFX to analyze jewelry and semi-jewelry for post-mortem inventory, and substrate composition was decisive for fingerprinting the valuation of each artifact.***

Keywords: jewelry, semi-jewelry, post-mortem inventory, fingerprint

1. Introduction

The post-mortem inventory in succession law is used to make a detailed list of inheritance author (*cujus* or deceased) assets. According to Brazilian Civil Code Law 10406 [1], an inventory person in possession can leave real estate or movable property such as jewelry as an inheritance [31].

Jewelry is an eccentric and expensive piece that can be disputed between heirs as it has economic [2], [3], historical, social, and cultural value [4]. Metal alloys of noble metals such as gold (Au), palladium (Pd), platinum (Pt), silver (Ag), and titanium (Ti) are used in jewelry making [4]. These alloys combine two or more metal characteristics: malleability, toughness, change in concentration, and shade [5]. The alloys are according to evaluated to concentration Au in carats (K), 24 K (100% Au); 22 K (91.6% Au); 18 K (75% Au); 14 K (58.5% Au); 9 K (37.5% Au) [6].

The most common ternary alloys have shades and concentrations [4], [6-8]: Yellow (Au 18 K) composition 75% Au + 16.66% Ag + 8.33% Cu; White (Au 18 K) with 75% Au + 12.50% Ag + 12.50% Pd; Red (Au 14 K) 75% Au + 8.33% Ag + 16.66% Cu; Yellow (Au 14 K) 58.33% Au + 27.78% Ag + 13.89% Cu; Red (Au 14 K) 58.33% + 13.89% Ag + 27.78% Cu; White (Au 14 K) 58.33% Au + 20.80% Ag + 20.80% Cu; Yellow (Au 12 K) 50% Au + 25% Ag + 25% Cu; Red (Au 12 K) 50% Au + 50% Cu; White (Au 12 K) 50% + 25% Ag + 25% Pd. Every piece of jewelry has alloys made from Au (75%) Cu and Ag, available commercially in wide jewelry and semi-jewelry varieties [8]. Semi-jewelry is electroplated [4] depending on its purpose and according to the manufacturer [8]. Semi-jewelry is produced from metal alloys, stainless steel, zamak, brass, and alpaca and coated by deposition or electroplating noble metals Ag and Au [9]. After deposition, there is no visual distinction between semi-jewelry and jewelry.

Jewelry appraisal consists of identifying, classifying, and pricing the piece. The pieces are identified using physical tests such as checking for welds, oxidation, the manufacturer's signature, defects, adornments, plagiarism, and determining mass, size, and density. Chemical tests that damage pieces use royal water and touchstones (basalt or slate) [10]. In addition, the chemical constitution of jewelry-making alloys can contain elements in minor or trace concentrations that can be difficult to detect and dramatically affect economic value. Therefore, thorough analysis for post-mortem inventory is essential, and selecting analytical techniques is very important since analysis must be non-destructive, fast, highly sensitive, and quantitative [11], such as energy dispersive X-ray fluorescence spectrometry (EDXRF).

EDXFR is an instrumental technique with a sufficient spectral resolution to identify and quantify various elements in different matrices [12]-[27]. In addition, analytical methods involving EDXRF do not usually require the sample to be subjected to chemical treatment with concentrated acids, heating, or dilution in organic solvents [17], [20]. It has excellent sensitivity and measurement accuracy in solid samples, making it extremely important for its application in identifying precious metal artifacts and jewelry for post-mortem inventory. Therefore, this work aims to evaluate fingerprint precious metals in jewelry and semi-jewelry for post-mortem inventory by EDXFR.

2. Methodology

Two lot (AM and CR) jewelry artifacts were identified, including rings, earrings (Figure 1), pendants, and neck chains.

Figure 1: Lot AM artifacts considered precious jewels.

The individual artifacts were inserted into the support for analysis with special care (cotton insertion to protect the pieces) (Figure 2).

Figure 2: Sample AM-14 upper face (a) and lower face (b).

Data acquisition was carried out using a Shimadzu Co. Energy Dispersive X-ray Fluorescence Spectrometer (EDXRF-model 720), cooled with liquid N_2 and 1-10 mm collimator, configured with X-ray tube Rh (250W), Si (Li) semiconductor detector, instrumental conditions: voltage 15-50 kV, self-adjusting current of max. 1 mA, air atmosphere. For each sample, 2,048 points were measured at energies ranging from 0.00 to 40.96 keV with a 0.02 keV interval. The exposure time samples in the chamber were 20 s, and the "dead time" detector (DT) was 40%.

The layers' thicknesses are calculated after determining the heaviest elements using software coupled to the EDXRF system.

2.1. Interpreting data

The data are interpreted by identifying the elements using the intensity/count rate (cps μA^{-1}) obtained by the fundamental parameter (FP) algorithm (Eq 1).

$$I_L = I_0 \omega_A g_L \frac{r_{A-1}}{r_A} \frac{d\Omega}{4_\pi} \frac{C_A \, \mu_A (\lambda_{prim}) \cos \sec \varphi}{\mu_M (\lambda_{prim}) \cos \sec \varphi + \mu_M (\lambda_L) \cos \sec \psi} \quad (1)$$

where:

IL - the intensity of element A; I0 - the intensity of the primary beam in dispersive energy λprim; λprim - wavelength the primary X-ray beam; λL - line energy of element A; ωA - fluorescence yield element A; g - value the fraction in line L of the element in its series; rA - ratio absorption edge element A; dΩ/4π - value fluorescent X-ray beam directed at the detector; CA - concentration element A; µA (λprim) - mass absorption coefficient of element A for λprim; µM (λprim) - mass absorption coefficient the matrix for λprim; µM (λL) - mass absorption coefficient the matrix for λL; φ - incidence angle the primary beam; ψ - exit angle the fluorescent beam [28].

The jewelry samples were evaluated by determining the carat (Eq 2).

$$Carat\ (K) = \frac{Au\ (\%)}{\frac{100}{24}} \quad (2)$$

where:

Au (%) - concentration gold in the sample; 24 - 100% concentration Au in the Certified Reference Material [29].

3. Results and Discussion

Each sample has a very heterogeneous composition, as they are made from different alloys. This allowed us to calculate the concentration (%) composition of each piece of gold, whose Cu, Zn, Ni, Au, Ag, and Sn contents are shown in Table 1. We can see the variety in the composition of alloys used in the jewelry evaluated, ranging from high-purity gold alloys (86.8% Au + 2.5% Ag + 9.9% Cu) to copper-rich gold alloys (30.4% Au + 65.5% Cu + 1.9% Zn +2.2% Ni). Cu was identified in all the samples, with concentrations varying from 7.7 to 65.5%, because when it is added to metal alloys, there is a considered increase in various physical-chemical parameters such as mechanical strength, anti-corrosion, malleability, and ductility [10], [30].

The elements spectra are shown in Figure 3 of the samples evaluated as jewelry; Au 18 K, compared to Au 24 K reference standard (CRM).

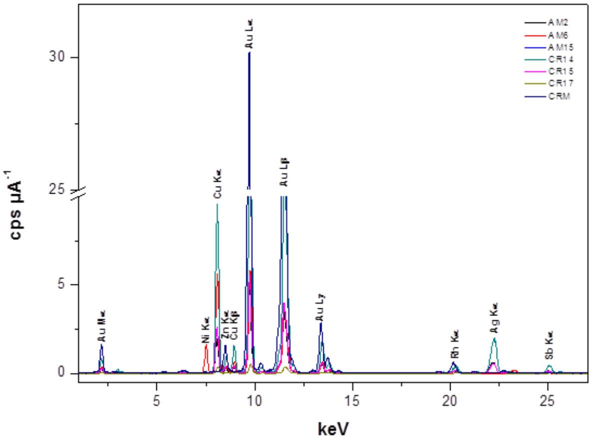

Figure 3: Elements spectra in the samples evaluated in jewelry (18 K).

Twenty-two jewelry compositions were added to the ternary diagram in Figure 4, containing Au 30.4-86.8% and Cu 7.7-65.5% about K.

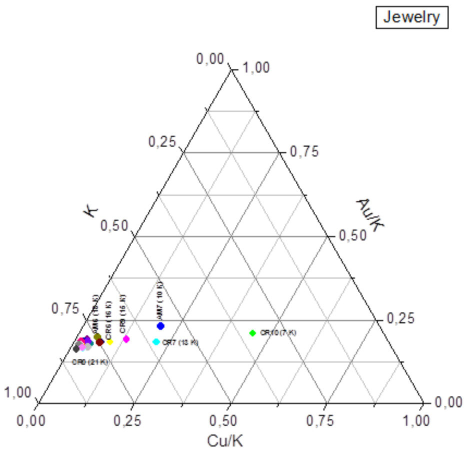

Figure 4: Fingerprint the jewelry about a carat.

The composition of gold alloys indicates low Cu/Au ratios (0.1-2.2), which correspond to malleability and ductility [10], [30]. The ratio Au/K and Cu/K concentrations show the fingerprint of the jewelry about the carat. The higher-carat jewel has a more significant shift to the left in Figure 4. For example, sample CR0 (21 K) is to the left, and CR10 (7 K) is more to the right. Gold fingerprints on jewelry are crucial for post-mortem inventory, criminal forensics, and jewelry theft.

The pieces considered semi-jewelry varied in the substrate used to give. The substrates identified in this work were alpaca alloys (Table 2), stainless steel, brass, and indeterminate (Table 3), and a layer Au used in electrochemical/electroplating processes. The Au electrodeposition layers showed different layer thicknesses, ranging from 0.2 to 966.5 nm, for the substrates evaluated. This variation in Au thickness may be due to wear and tear or the quality of the semi-jewelry.

The alpaca alloy used in producing semi-jewelry is made up of Cu, Zn, and Ni, which has ductility and resistance to oxidation [4], [24]. In this study, a wide range of Cu, Zn, and Ni content was in the samples evaluated (Table 2). The percentages can vary according to the manufacturer, and the most common contents are 65% Cu, 23% Zn, and 12% Ni [4], [24].

The semi-jewelry made with brass substrate had a chemical composition of Cu ranging from 99.0 to 79.2% and Zn from 0.9 to 11.9% (Table 3). Brass is an alloy of Cu and Zn, with up to 36% Zn used in producing semi-jewelry and ornamental objects, among others [4].

Stainless steel is used in semi-jewelry as an alternative substrate for enhancing ornamental pieces with an Au or Cu layer. There was slight variation in Ni and Cr in pieces identified with stainless steel substrate, while Fe varied from 57 to 76%.
In the other pieces, there was variation in element concentration, and we could not precisely identify the alloy substrate, and they were considered indeterminate.

4. Conclusion

This study can be considered the first to use EDRFX to analyze jewelry and semi-jewelry for post-mortem inventory. Quantitative analysis of metal alloys in jewelry and semi-jewelry can reveal exciting aspects of the manufacturing process. Based on practical knowledge, non-destructive methodology and matrices properties with different metal concentrations samples considered jewelry with different carats can be evaluated. As with any quantitative chemical analysis experiment, non-destructive reiteration is of fundamental importance for developing and testing hypotheses and acquiring and collecting knowledge through manipulation matrices. The analyses in this work serve as a reference for confirming, modifying, or suggesting financial hypotheses for post-death inventories.

Author contributions

Conceptualization, M.C.T.-Z. and M.A.S.; methodology, M.A.S.; validation, M.C.T.-Z. and M.A.S.; formal analysis, M.A.S.; investigation, M.A.S. resources, M.C.t.-Z.; data analysis, M.C.T.-Z. and M.A.S.; writing - original draft preparation, M.C.T.-Z. and M.A.S.; writing-review and editing, M.C.T.-Z.; supervision, M.E.B.C.

Conflicts of interest

The authors declare that they are unaware of any financial interests or personal relationships that could influence the work reported in this document.

Acknowledgment

This article is a preliminary contribution to the COPDE/IPEN (CNEN/SP) Inter-Center Project No. 6/2020.

References

[1] Código Civil - Lei 10406/02 | Lei no 10.406. de 10 de janeiro de 2002. Disponível em: https://presrepublica.jusbrasil.com.br/legislacao/91577/codigo-civil-lei-10406-02 Acesso em: 24/03/2023.

[2] Scozzafave. F.Familiares começam batalha pela herança milionária de Maradona-Craque argentino teve um ganho estimado em quase R$ 3 bilhões ao longo da vida. Além de cinco filhos reconhecidos. outros seis tentam paternidade. 27/11/2020. Disponível em: https://esportes.r7.com/futebol/familiares-comecam-batalha-pela-heranca-milionaria-de-maradona-29062022 Acesso em: 24/03/2023.

[3] Bombana. L. Fundos que compram heranças em disputa judicial oferecem retornos de até 20% ao ano. 25/12/2022. Disponível em: https://br.financas.yahoo.com/noticias/fundos-que-compram-heran%C3%A7as-em-184000780.html?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlLmNvbS8&guce_referrer_sig=AQAAAAOPE8Y4ORrc4QmU-Bu6aKfqTpOArYUK8PQ0NuKN16np5XrdrN0dtGZFo5gfucBNbO8WUTQpDbCYlwcJrOs8Vz-ryA1lsPOYZdD_upTUcZdnUgYua6bxwoT-UT3_pUuyxvWUVsQHk7MdAySg4NTAWoB3T2CGYTpBFg5nyuhtPE8F Acesso em: 24/03/2023.

[4] Rick. C.F. Estudo da liga à base de Zn-Al-Cu-Mg aplicada na fabricação de joias folhadas. Dissertação

de mestrado. Pontifícia Universidade Católica do Rio Grande do Sul. 2006.

[5] Salem. C.Joias: Os Segredos da Técnica.São Paulo. Gráfica Newpress. 2000.

[6] Lisboa. A.; Barin. C.S. Eletrodeposição de Ligas Metálicas Nobres para Fabricação de Jóias e Jóias Folheadas.UNOPAR Cient. Exatas Tecnol. Londrina. v. 8. n. 1. p. 27-33. nov. 2009.

[7] Morikawa. M.; Hosoda. N. New composite material of gold alloys for jewelry use. Proceedings of the Fifth International Precious Metals Institute Conference. Held in Providence. Rhode Island. June 2–5. 1981-1982. Pages 185-192. https://doi.org/10.1016/B978-0-08-025392-3.50025-9

[8] Jurado-López A., Castra M.D.L. Rank correlation of laser-induced breakdown spectroscopic data for the identification of alloys used in jewelry manufacture. Spectrochimica Acta Part B 58 (2003) 1291–1299.

[9] Santos, M.S. Bijuterias. São Paulo: CETESB, 2005. 54 p. Disponível em: <http://www.cetesb.sp.gov.br>.

[10] Morioka. R.M.; Silva. R.R. A atividade de penhor e a química. Química Nova na Escola. v. 34. n. 3. p. 11-117. 2012.

[11] Fierascu. R.C.; Fierascu. I.; Ortan.A.; Constantin. F.; Mirea. D.A.; Statescu. M. Complex archaeometallurgical investigation of silver coins from the XVIth-XVIIIth century. Nuclear Instruments and Methods in Physics Research B 401 (2017) 18–24.

[12] Kaniu. M.I.; Angeyo. K.H.; Mwala. A.K.; Mwangi. F.K. Energy dispersive X-ray fluorescence and scattering assessment of soil quality via partial least squares and artificial neural networks analytical modeling approaches. Talanta 98(2012)236–240.

[13] Mijatovis. N.; Vassie. M.; Milicié. L.; Radomirovic. M.; Radojevic. Z. Fired pressed pellet as a sample preparation technique of choice for an energy dispersive X-ray fluorescence analysis of raw clays. Talanta 252 (2023) 123844.

[14] [14] Aslan. F.; Tor. A. Determination and speciation of trace inorganic arsenic species in water samples by using metal organic framework mixed-matrix membrane and EDXRF spectrometry. Chemosphere 307 (2022) 135661

[15] Lener. N.; Sedgi. I.; Chernia. Z.; Zeiri. O. Rapid direct determination of tin in beverages using energy dispersive X-ray fluorescence. Talanta 199 (2019) 662–666.

[16] Gaeta N.C.; Carvalho D.U.O.G.; Alemán M.A.R.; Carvalho. J.S.; Cedraz. P.P.; Ulrich. J.C.; Jovane. L.; Gregory. L.; Scapin. M.A. Quantitative analysis of minor and trace elements in blood serum of dairy cattle (Bos taurus) by WDXRF. Brazilian Journal of Radiation Sciences 10-03B (2022) 01-10.

[17] Caldana. C.R.G.; Hanai-Youshida. V.M.; Paulino. T.H.; Baldo. D.A.; Freitas. N.P.; Aranha. N.; Vila. M.M.D.C.; Balcão. V.M.; Oliveira Junior. J.M. Evaluation of urban tree barks as bioindicators of environmental pollution using the X-ray fluorescence technique. Chemosphere 312 (2023) 137257.

[18] Aidene. S.; Semenov. V.; Kirsanov. Denys; Kirsanov. Dmitry; Panchuk. V. Assessment of the physical properties. and the hydrogen. carbon. and oxygen content in plastics using energy-dispersive X-ray fluorescence spectrometry. Spectrochimica Acta Part B 165 (2020) 105771.

[19] Angeyo H.K.; Gari. S. Direct rapid quality assurance analysis of complex matrix materials: A chemometrics enabled energy dispersive X-ray fluorescence and scattering spectrometry application. Applied Radiation and Isotopes 186 (2022) 110274.

[20] Cornejo-Ponce. L.; Acarapi-Cartes. J; Arenas-Herrera. M. Development an validation of a method for simultaneous arsenic. antimony. selenium and mercury determination in plants by energy dispersive X ray fluorescence spectrometry. Interciencia. 43. 6. 425-433. 2018.

[21] Ferreira. V.J.; Lemos. V.A.; Teixeira. L.S.G. Dynamic reversed-phase liquid-liquid microextraction for the determination of Cd. Cr. Mn. and Ni in vegetable oils by energy dispersive X-ray fluorescence spectrometry. Journal of Food Composition and Analysis 117 (2023) 105098.

[22] Kumar. S.S.; Dhara. S. Energy dispersive X-ray fluorescence determination of uranium in different uranates using Rh Kα scattered peaks for matrix correction. Spectrochimica Acta Part B: Atomic Spectroscopy 193 (2022) 106427.

[23] Okonda J.J., Angyeo H.K., Mangala J.M., Kisia S.M. A nested multivariate chemometrics based calibration strategy for direct trace biometal analysis in soft tissue utilizing Energy Dispersive X-Ray Fluorescence (EDXRF) and scattering spectrometry. Applied Radiation and Isotopes 129 (2017) 49–56.

[24] Silva. N.C. Influência do pH e do tempo de contato na lixiviação dos metais constituintes de brincos. Dissertação de mestrado. Universidade Federal Fluminense Escola de Engenharia Industrial Metalúrgica de Volta Redonda. 2021. Volta Redonda - RJ.

[25] Sorokin I.A., Kolodko D.V. On the possibility of indirect measurement of the thin carbon films thickness using energy-dispersive analysis. Thin Solid Films 737 (2021) 138937.

[26] Shao J., Li Rongwu, Pan Q., Cheng Lin. Determination of low Z elements concentrations in geological samples by energy dispersive X-ray fluorescence with a back propagation neural network. Spectrochimica Acta Part B: Atomic Spectroscopy 196 (2022) 106518.

[27] Sichang, E.K.; Angeyo, H.K.; Dehayem-Kamadjeu, A. Hybridized robust chemometrics approach for direct rapid determination of trace biometals in tissue utilizing energy dispersive X-ray fluorescence and scattering (EDXRFS) spectrometry. Radiation Physics and Chemistry 153 (2018) 198–207.

[28] Scapin, M.A.; Silva, C.P.; Cotrim, M.E.B.; Pires, M.A.F. Application of multivariate calibration for simultaneous determination of major and minor constituents in U3Si2 by WDXRF technique. Radioanal Nucl Chem (2014) 302:1077–1085. DOI 10.1007/s10967-014-3332-6.

[29] Gold Foil 29-79-399-10. Materials Rearch Corporation, Orangebrurg, New York 10962.

[30] Alves. T.S. Determinação de metais pesados em bijuterias comercializadas na região metropolitana do rio de janeiro. Monografia em Química Industrial da Universidade Federal Fluminense. 2016.

[31] TJDFT - Tribunal de Justiça do Distrito Federal e dos Territórios. Corregedoria da justiça do distrito federal e dos territórios. Secretaria Geral da Corregedoria-Secretaria dos Órgãos Auxiliares da Justiça. Manual de procedimentos das contadorias-partidorias. v. 2 – Inventário. 5ª ed. 2012. Disponível em: https://www.tjdft.jus.br/publicacoes/edicoes/manuais/manual-das-contadorias-partidorias/inventario-volume-2 Acesso em: 24/03/2023.

Table 1: Metal concentration in the samples considered jewelry.

Sample	Cu (%)	Zn (%)	Ni (%)	Au (%)	Ag (%)	Sn (%)	Evaluation (K)
AM2	9.8	-	-	75.8	14.4	-	18
AM3	28.1	-	-	71.1	0.3	-	17
AM6	19.1	-	6.2	74.7	-	-	18
AM7	35.7	4.3	1.7	40.9	-	-	10
AM10	11.6	-	16.9	71.5	-	-	17
AM15	11.3	-	-	76.8	11.9	-	18
AM17	16.7	-	-	83.0	-	-	20
CR0	9.9	-	-	86.8	2.5	0.8	21
CR1	17.1	1.6	-	81.4	-	-	20
CR2	9.9	-	-	79.1	8.7	2.3	19
CR3	26.5	2.8	-	70.0	0.5	0.3	17
CR6	33.8	1.4	-	64.8	-	-	16
CR7	46.4	5.2	8.8	39.7	-	-	10
CR8	19.1	5.4	-	67.7	-	7.8	16
CR9	38.4	6.5	-	55.1	-	-	13
CR10	65.5	1.9	2.2	30.4	-	-	7
CR11	20.5	0.5	-	77.5	-	1.6	19
CR12	32.0	3.5	-	61.8	2.7	-	15
CR13	8.2	0.4	-	78.1	13.2	-	19
CR14	13.6	-	-	73.7	12.7	-	18
CR15	15.3	3.5	4.6	76.7	-	-	18
CR16	16.1	0.5	-	83.1	0.3	-	20
CR17	7.7	-	-	75.1	17.3	-	18

- Undetermined.

Table 2: Semi-jewelry with Alpaca substrate.

Sample	Cu (%)	Zn (%)	Ni (%)	Au (%)	Thickness Au (nm)
AM4	76.2	18.7	5.1	24.2	848.8
AM5	76.1	16.6	7.3	13.5	343.4
AM8	71.0	26.4	2.6	10.7	277.9
AM12	65.7	6.4	27.8	27.6	966.5
AM16	80.8	10.6	8.6	12.2	716.6
AM18	60.4	11.7	27.9	5.3	237.1
AM20	74.5	9.8	15.7	9.6	248.8
AM24	83.1	1.2	11.6	4.0	5.9
AM27	57.8	5.3	27.8	8.9	20.2
AM28	58.1	5.4	27.6	8.9	20.4
AM29	43.9	20.3	33.1	2.6	52.0
AM30	51.9	26.0	19.8	2.3	50.7
AM33	89.7	2.2	6.4	1.1	35.8
AM35	86.8	4.0	0.02	9.2	13.5
AM36	89.6	6.0	0.1	4.3	55.2

Table 3: Semi-jewelry with stainless steel, brass, and indeterminate substrates.

Sample	Substrate	Cu (%)	Zn (%)	Ni (%)	Fe (%)	Cr (%)	Mn (%)	Au (%)	Thickness Au (nm) Layer 1	Thickness Cu (nm) Layer 2
AM25	Stainless steel	0.3	-	8.3	73.6	15.6	2.1	-	1.1	11.4
AM26	Stainless steel	0.3	-	8.4	74.5	16.4	-	-	-	1.1
CR5	Stainless steel	14.9	-	4.2	57.3	15.1	-	8.5	1.7	4.5
AM1	Brass	95.1	1.7	-	-	-	-	3.1	17.0	-
AM19	Brass	97.5	1.8	-	-	-	-	0.7	12.3	-
AM21	Brass	99.0	0.9	-	-	-	-	0.1	0.3	-
AM22	Brass	79.2	11.9	5.5	-	-	-	3.3	7.5	*58.8
AM23	Brass	98.1	1.9	-	-	-	-	-	0.2	-
AM9	Indeterminate	52.7	-	45.7	-	-	-	1.6	34.8	-
AM13	Indeterminate	89.2	-	2.6	-	-	-	8.2	20.4	-
AM14	Indeterminate	100	-	-	-	-	-	-	-	-
AM31	Indeterminate	-	-	98.3	0.5	0.1	0.1	-	188.8	-
AM32	Indeterminate	59.7	-	37.3	2.7	-	0.3	**0.1	**83.9	9,435.3
AM37	Indeterminate	0.6	-	-	-	0.01	-	3.8	24.6	-
AM38	Indeterminate	0.8	-	99.1	-	-	-	-	3.4	-

- Undetermined; * Ni (%); **Ag (%).

Author Profile

Maria Cristina Tessari-Zampieri IPEN-CNENVolunteer Researcher (2021) at the Centre for Chemistry and the Environment (CEQMA) X-ray Fluorescence Laboratory (Application of Artificial Intelligence for Elemental Chemical Analysis by X-ray Fluorescence). PhD in Sciences at the Centre for Chemistry and the Environment (CEQMA) Chemical and Isotopic Characterization Laboratory at IPEN-CNEN (2017)-University of São Paulo. Master of Science in Nuclear Technology - Applications, at the Research Reactor Centre (CERPq) IPEN-CNEN (2011)-University of São Paulo. Specialization in Management and Handling in the Agroindustry from the Federal University of Lavras (2009). Bachelor's degree in Computer Engineering from the Virtual University of the State of São Paulo (2022). Bachelor's degree in Environmental Engineering from the Federal University of São Carlos (2017). Graduated in Biological, Exact and Experimental Sciences from the Mackenzie Presbyterian Institute (2007). Currently working as a researcher/collaborator at IPEN-CNEN in the Chemistry and Environment Centre (CEQMA) X-ray Fluorescence Laboratory. She has experience in General Biology/Environmental Engineering/Computer Engineering. Her main areas of expertise are: Nuclear Forensics; Safeguarding; Environmental Metrology; Data Science; Database; EMS; QMS; Environmental Biomonitoring using plants and animals; Chemical and Biological Analyses; 27001 Auditing; among others.