The potential of reprocessing Au and by-products from a tailing dam in the iron quadrangle – The case of the Cuiaba Dam, Sabará, Minas Gerais

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Abstract

As historical mine wastes have accumulated in storage facilities, the interest in studying the reuse of gold (Au) mining tailings has increased, yielding environmental and economic benefits. In the present study, a detailed evaluation of the Cuiaba tailing dam in Sabará, Minas Gerais (Brazil) was performed, answering a new legal framework and agreeing with a circular economy philosophy. The mineralogical analyses revealed that most associations include silicate minerals. In accordance, the Au recovery results reached values below 50%. Because of this, other potential reuse experiments, in addition to Au reprocessing, were conducted. The first product was produced from a particle size partition above 20 µm. Due to the silica concentration, this product became a fine aggregate for the construction sector. Another alternative is generating a pozzolanic product obtained by calcination, which has an application in the cement industry.

Keywords: Circular economy, mining tailings, Au recovery, by-products, construction materials

Introduction

Environmental aspects and the potential for recovering mining waste are among the most relevant and current research topics, especially in sustainable mining and the circular economy. The metallic minerals sector, mainly the one dedicated to the exploitation of noble metals such as Au, is characterized by the production of large quantities of waste with very different properties depending on the nature of the deposits, the beneficiation/metallurgical treatment processes, and the accumulation structures of this waste (Lemos et al. 2023). Brazil is a mining country with a strong tradition in gold mining, which is why this study focuses on this area, specifically the state of Minas Gerais.

The study area is in the Iron Quadrangle (QF – fig. 1), a metallogenetic province that hosts large deposits of Au and iron (Fe), as well as gems and industrial minerals (Porto 2008). The QF represents one of the most important geotectonic units with rocks and geological evolution of the Archean and Proterozoic ages (Almeida 1967). Three main tectonostratigraphic domains make up the QF province: granite-gneiss terrains, a greenschist belt sequence (Rio das Velhas Supergroup – SGRV), and a supra crustal sequence of chemical and clastic sedimentary rocks (Minas Supergroup) (fig. 1).

The solid tailings under study (Cuiaba tailing storage facility – TSF) are in the city of Sabará (fig. 1), resulting from the processing of refractory ore (Au contained mainly in pyrite) with 92% recovery of Au. Ore from underground mines is subjected to split stages of milling, concentration by gravimetry, and

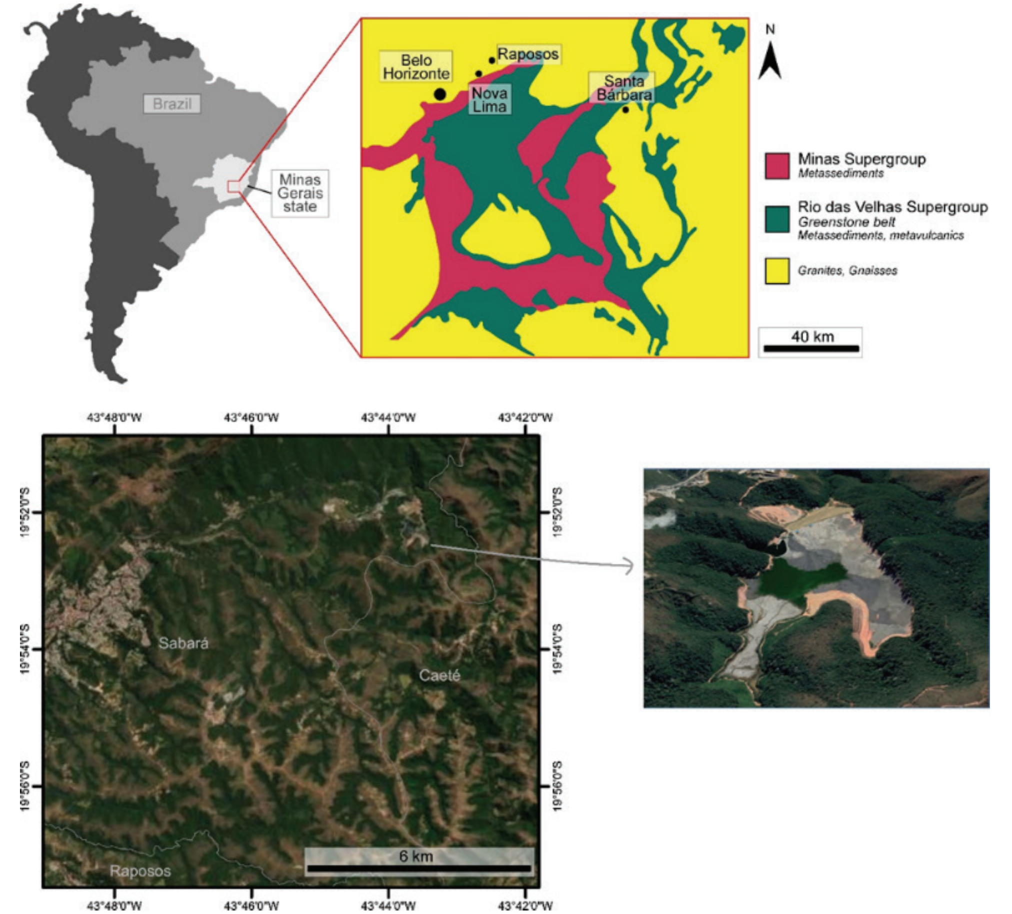

Figure 1 *Location of the Cuiaba tailings dam in Sabará city, Minas Gerais (Brazil), and geological map of the Iron Quadrangle*

sulfide flotation (Moura 2005). The waste from this flotation stage used to be deposited in TSF. However, after the Mariana and Brumadinho tragedies (Lemos et al. 2021), it is filtered and piled up to form heaps that continue to affect the production of various business units due to the high costs of the new deposition method. In addition, the social and environmental impacts continue to be strongly present in this region. In this context, the present work focuses on characterizing these Au mining tailings, including the solid waste from the Cuiaba storage facility. The main goal is to evaluate the potential for reusing these wastes, recovering the Au, and producing fine aggregate for application in the construction industry.

Methods

The sampling occurred during late winter and early spring (late August 2022). A total of 35 samples were collected with an auger, drilling up to two meters for chemical analysis in depth. The distance between samples varied from 15 to 20 m depending on the sampling area. All samples were immediately sealed and refrigerated until analysis. Additional material was transferred to polypropylene bags and frozen until analysis. Refrigerated and frozen samples were packed and sent to the laboratory.

In the laboratory, chemical analysis was performed by atomic absorption spectroscopy (AAS using AAS280 FS Varian) to determine Au, Cu, C, As, Sb, S, Fe, and Si. The fire assay was the procedure used to obtain analytical data of Au from the tailings. The particle size analysis was obtained via laser (CILAS). In addition to the geochemical data, samples were submitted to X-ray diffraction analysis (XRD), and polished sections were prepared. The mineralogical study was done through optical and scanning electron microscopy at UFMG, Belo Horizonte. The samples were analyzed using a FEI electron microscope, Quanta 600 FEG, high vacuum mode, coupled to the automated analyzer software (MLA-GXMAP and SPL-DZ mode) and the EDS Esprit Bruker microanalysis system (20 Kve).

Based on the geochemical and mineralogical characterization, the Au extraction potential for the samples was analyzed. Therefore, it was proposed to grind to a particle size of 74 µm, with 80% of the particles within this range, following a size release analysis for sulfides and Au particles. The milled samples directly subjected to bottle leaching were carried out using a leaching solution containing 2000 mg/kg of cyanide (NaCN) and 4000 mg/kg of lime (CaO), with a solid/liquid ratio of 50%. This step was conducted in triplicate. The samples from this stage were subjected to two tests to generate ground aggregates. The first was the separation of fractions above 20 µm and the partial replacement of sand in the generation of grout in the proportions 25%, 50%, 75%, and 100% within 28 days of the curing period. The second test involved no particle size separation. The total sample was submitted to a flash kiln at temperatures that varied every 200 °C until 1000 °C. The obtained product was then tested as agglomerate in substitution of cement in proportions of 25% and 50%, 28 days of curing period. The products from both experiments were subjected to tests according to Brazilian norms, which were adapted from ISO, such as ABNT NBR 1004, ABNT NBR 7211, ABNT NBR 6118, NBR ABNT NM28, 9774/87, ABNT NBR 5752:2012, englobing corrosivity, reactivity and toxicity. In addition, resistance tests, the pozzolanic activity index (PAI), and its final evaluation in grout for civil construction (ABNT NBR 618 e ABNT NBR 618) were obtained It should be noted that Brazilian standards are adapted from ISO (International Organization for Standardization) standards. The Brazilian standards are very similar to the international standards, but with some variations to consider peculiarities such as the exposure of the material to a hotter and more humid climate.

Results and discussion

General properties of the tailings

Table 1 presents the surveyed database averages, with the chemical results from Sabara´s tailings. The chemical analysis generally indicated a higher Si concentration (22.1%). The tailings are enriched in Fe > Ca > S > Mg > Na > Ti > As.

Regarding the particle size distribution, tailings are Fine Coarse Aggregates with a Fineness Modulus of 0.02 in a Lower Usable zone (NBR 7211: ABNT, 2004). They also meet the parameters for carbonaceous materials, clay clods, and apparent specific mass. Due to the high grain size selectivity, the tailings are Classified Fine Aggregates, which gives them higher market value and applicability.

Table 2 shows the mineralogical composition of the samples. The wastes are richer in quartz, confirming the results obtained for chemical analysis. On the other hand, albite and chlorite are less frequent.

The presence of sulfide minerals can be highlighted, with emphasis on pyrrhotite. Oxides and other silicates are rare and less than 0.1%. Au grains were identified as Au native or electrum and are associated with silicates, mainly quartz, and sulfides, such as pyrite (fig. 2).

The XRD results show 3% of the constituents in amorphous (reactive) phases, with a relevant presence of siliceous compounds. This characteristic may indicate a potential for increasing the resistance of materials it adds to, such as replacing cement

Table 1 *Chemical summary from Sabará's tailings*

Si	Fe	Ca	Al	C	S	Mg	K	Mn	Na	Ti	As	Au
						%						mg/kg
22.1	12.3	5.21	3.49	3.43	2.49	2.02	0.750	0.570	0.460	0.320	0.150	0.200

***Table 2** Mineralogical summary from Sabará's tailings. *Grain number*

Minerals	Chemical Formula	Wt %
Quartz	SiO_2	37.98
Albite	$NaAlSi_3O_8$	4.43
Muscovite Group	$KAl_3Si_3O_{10}(OH)_{1.9}F_{0.1}$	8.92
Chlorite	$(Mg, Fe)_3(Si, Al)_4O_{10}(OH)_2(Mg, Fe)_3(OH)_6$	15.8
Ankerite	$Ca(Fe, Mg, Mn)(CO_3)O_2$	6.95
(Pyrite	$Fe^{2+}S_2$	0.71
Pyrrhotite)	$Fe^{2+0.95}S$	
Au phases*	Au native and electrum	252*

and sand in concrete. Reactivity tests to understand the potential for acid generation showed a low potential. This should be due to compensation associated with the carbonates and cement in the concrete mix.

Au recovery

The leaching tests with material below 74 µm showed recoveries between 38 and 40%, probably due to cyanide's low release and demanding access to these associations since the tests were carried out with the exact dosage of reagents and granulometry. New tests should be carried out soon to optimize this recovery.

Generation of products for the civil construction sector

This potential use was evaluated in an in natura stage for particle sizes above 20 µm. Then, considering the mineralogical study, the sample was calcined to evaluate the pozzolanic potential of this material. The results are summarized below.

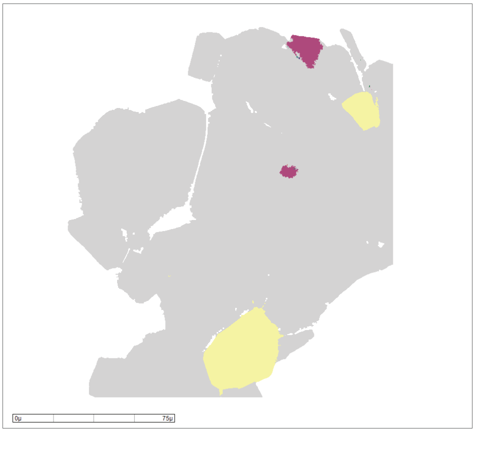

***Figure 2** False electronic image of Au (yellow) enclosed in quartz (gray); purple refers to ankerite*

(i) In natura tailings

Toxicity and reactivity tests were carried out before the strength tests and dosages for addition to mortars as aggregates or binders, according to Brazilian standards ABNT NBR 1004:2004 and NBR 7211:2005. These standards classify wastes according to their risk to humans and the environment so that they can be properly managed. Table 3 shows the results obtained.

According to the standards, the tailings are classified as Class IIA (non-hazardous and non-inert). Non-inert wastes can have properties such as biodegradability, combustibility, or solubility in water. Therefore, the classification obtained is not an obstacle to its use as a raw material for civil construction. Based on these results, the cyclone tailings (above 20 µm) were added to the mortar, replacing sand in the proportions of 25%, 50%, 75%, and 100%.

Fig. 3 indicates good results regarding mortar strength, with optimum points at 50% and 75%. The material was also tested on construction sites close to the location of TSF, and promising results were obtained. The pillar concrete in Fig. 4 was made with this material.

(ii) Calcined tailings

Samples of the total tailings (without any fractionation by particle size) were subjected to calcination to check the potential for generating a pozzolanic material. Fig. 5 confirms that the obtained product showed PAI for tailings proportions between 25 and 50%, which characterizes a material with the desired pozzolanic properties.

Table 3 Leaching results and maximum allowed values (VMP) from Brazilian standards

Element	Leaching Extract Results (mg/L)	VMP (mg/L)
Mn	0.12-0.14	–
SO_4^{2-}	634.4-1236	≈5000

Conclusions

The valorization of gold ore flotation tailings with the recovery of gold from the leaching stage and the study of total reuse for application in civil construction were analyzed in this work. Even with low recoveries of the Au element, alternative and optimization routes can be better evaluated in conjunction with the total reuse stages. In this context, products such as fine aggregates and binders were successfully generated and opened avenues for recovery and use in regional infrastructure works. This type of approach demonstrates that mining activity and society can live in balance.

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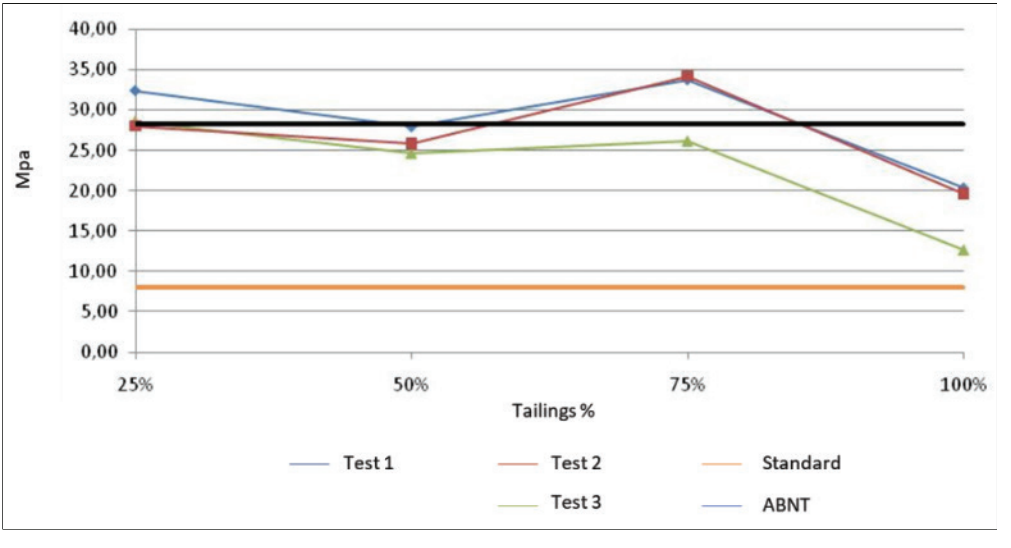

Figure 3 Graph showing the strength of mortar in natura tailings and its relationship with dosages

Figure 4 Images of applying the materials obtained from the tailings: a) in natura and b) calcined

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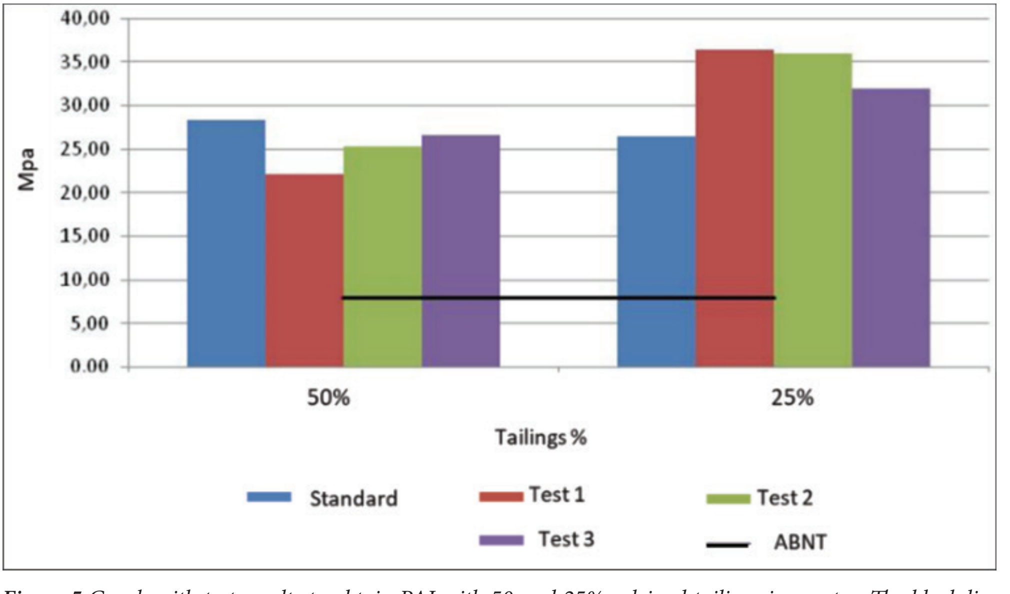

Figure 5 Graph with test results to obtain PAI with 50 and 25% calcined tailings in mortar. The black line represents the Brazilian Standard (ABNT).