Recovery of Sands from Gold Mining Tailings for Clinker Manufacture

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Abstract

Gold mining in Antioquia, Colombia, is prominent, especially in Bajo Cauca and Nordeste. This study, a collaboration between the National University of Colombia and the University of Oviedo, used materials from the "El Molino" plant. It aimed to optimize gold mining sands for clinker manufacture by identifying waste parameters affecting production, determining optimal raw material proportions using Bogue's moduli, and comparing the mechanical performance of cement from mining waste with conventional Portland cement. Results indicated the necessity of thermal pre-treatment to reduce contaminants and highlighted the high energy input required for effective silica reaction.

Keywords: Mining waste, clinker, circular economy, environment

Introduction

Mining operations have been identified as a significant source of environmental liabilities, defined as abandoned mining activities (Yurupari, 2003; Cruzado-Tafur *et al.*, 2021). The inadequate management of these liabilities is associated with the generation of acid drainage, which can be detected between 2 and 5 years after the commencement of mining operations (Abiahu, 2019).

In the context of gold mining, these liabilities, otherwise known as tailings, are constituted of a mixture of crushed rock and processing fluids from mills and concentrators (Kossoff, 2014). It is noteworthy that these tailings frequently contain elevated concentrations of toxic elements and compounds, including cadmium, copper, zinc, lead and chromium (Abiahu, 2019; Okereafor, 2020).

The properties of these waste materials vary according to the protolith from which they originate, but they generally exhibit high angularity and abundance of grains with sizes between 0.625 mm and 2.0 mm, and variable densities between 2.5 g/cm³ and 2.6 g/cm³ (Kossoff, 2014). Mineralogically, they are classified into three groups: gangue (mainly quartz and plagioclase), sulfides (such as pyrite, pyrrhotite and arsenopyrite) and secondary minerals formed by interaction in the depositional medium. The waste-to-concentrate production ratio is high, sometimes around 200:1, and can increase as the market price of metal rises (Lottermorser, 2010; Kossoff, 2014).

A number of studies have explored potential new applications for these by-products. However, the process of obtaining gold follows a linear design where the ore is beneficiated and the residue is discarded or stored in dams, sometimes used as backfill material without adequate knowledge of its physical, chemical and mineralogical characteristics (Kossoff, 2014). This has resulted in these tailings being considered as inefficient materials, with a low impact on waste reduction

In Colombia, gold mining is active in approximately 17 departments and 80 municipalities across diverse scales (Casallas & Martinez, 2014). In 2023, the department of Antioquia ranked as the leading gold producer, with the municipalities of Caucasia and Buriticá reporting gold yields of 9,365.7 kg and 6,501.9 kg, respectively (UPME, 2024). This suggests that Antioquia, as the largest gold producer in the country, has a significant amount of mining waste in its territory.

Cement production requires a carefully balanced chemical composition in the raw mix to ensure optimal clinker mineralogy and performance. The main components – lime, silica, alumina, and iron oxide – must be present in specific ratios to form desirable phases such as alite and belite. However, naturally occurring raw materials often lack this ideal composition, particularly in terms of reactive silica and alumina contents. Considering that the raw materials for cement production are not chemically ideal, it is necessary to add corrective materials. These include silica-rich materials such as quartzites and quartz sandstones, although softer minerals or amorphous silica like opal are preferred due to their higher reactivity during sintering (Tobón & López, 2007). Mining waste has potential for clinker production due to its high silica content and significant amounts of iron and alumina, which are essential components for clinker manufacturing.

This study, a collaborative endeavor between the National University of Colombia and the University of Oviedo, explores the utilization of mining waste from the 'El Molino' facility for the fabrication of clinker. The objective is to propose a sustainable alternative for the management of gold mining waste in the region, in alignment with the 2030 Sustainable Development Goals and the principles of the circular economy

Materials and Methods

Materials

The material used in this research corresponded to samples taken from the gold mining waste storage ponds at the 'El Molino' processing plant. The plant is located in the rural area of the village of Santa Rita, located 10 km northwest of the municipality of Andes in the department of Antioquia – Colombia (Fig. 1).

Artisanal miners in the area travel to the plant to process the material extracted from the mines. The concentrate is marketed and the tailings from the process are stored in storage yards within the plant. Finally, the tailings from the artisanal miners' beneficiation process that was stockpiled become the raw material for processing at the "El Molino" beneficiation plant.

Sampling points were randomly selected and with the help of a sampling shovel, approximately15 kilograms of material was extracted and packed in bags. XRD, XRF and SEM were used for characterization.

X-Ray Diffraction (XRD)

The XRD test confirmed the presence of quartz, plagioclase and magnetite. A content of micas such as Illite and Muscovite was also detected (Fig. 2).

***Figure 1** El Molino Mine.*

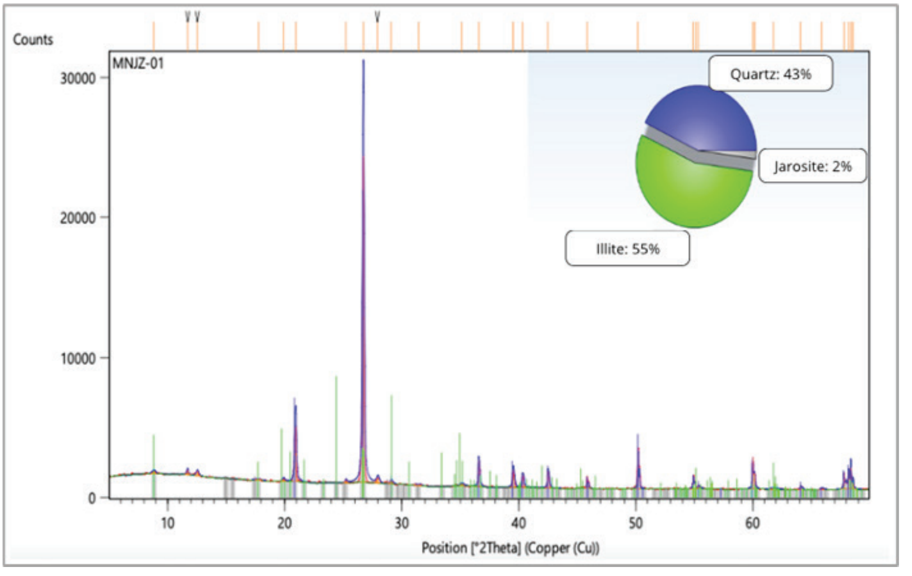


Figure 2 *Diffractogram of the mining residue.*

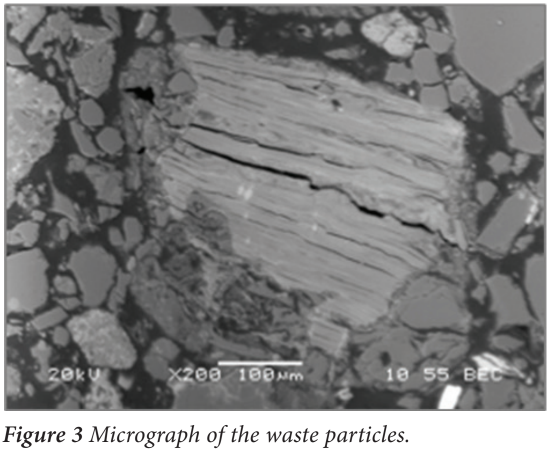
Table 1 *XRF results of the mining waste.*

	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Mn	Fe	Cu	Zn	As	V
%	6,49	11,71	57,97	0,86	4,31	0,25	1,94	0,55	0,518	0,03	11,25	0,04	0,17	2,45	0,03

Scanning Electron Microscopy (SEM)

Scanning electron microscopy (SEM) confirmed the presence of quartz, arsenic and sulfur in the form of pyrite and arsenopyrite. The quartz grains (QZ) were identified surrounded by arsenopyrite (As).

The complementary raw material for clinker production came from different sources located in Asturias. The calcite was supplied by the La Belonga mine located in the city of Oviedo, the silica sand was obtained from the company 'Sílices La Cuesta' where it is used for glass production and the alumina from the company 'Arciresa', Arcillas Refractarias S.A. located in Lugo de Llanera. These raw materials were all characterised by their high purity.



Element	Weight%	Atomic%
O K	36.21	56.82
Mg K	3.10	3.20
Al K	9.09	8.46
Si K	17.83	15.94
Cl K	0.25	0.18
K K	0.88	0.57
Ti K	2.26	1.18
Fe K	30.38	13.66
Totals	100.00	

Figure 3 *Micrograph of the waste particles.*

Table 2 Contribution to clinker meal from gold mining waste sands.

CaO (%)	Al_2O_3	Fe_2O_3	SiO_2
0,1	0.0	94.7	5.2

Table 3 Dosage of complementary materials to clinker meal.

Calcite (g)	Alumina (g)	Silica (g)	Sand (g)
0,1	0.0	94.7	5.2
MH (%)	**MS (%)**	**MA (%)**	**LFS (%)**
1.9	1.6	1.2	90.85

Method:

Using Boggue's method for the calculation of the dosage of the raw materials in the manufacture of Clinker, the calculations of the necessary dosages of both the mining waste Table 2 and the rest of the material necessary to reach the values required to obtain the Clinker with the modules presented in Table 3.

After the compression of the tablets with the prepared mixture, the specimens were subjected to different heating ramps from room temperature with a ramp of 10 ºC per minute until they reached maximum temperature and were kept at this constant temperature for 45 minutes. After this time, the clinked specimen was removed from the furnace. The maximum temperatures used were 1250 ºC and 1300 ºC.

Results

After the clinkering tests, the sample did not reach a complete reaction at 1250ºC, as granules and pores of different sizes and colors were found inside the sample without showing homogeneity of the firing and therefore in the final coloring. Fig. 4a

Similarly, the product shown in Fig. 4b showed a darker color due to the interaction of the raw materials in the sintering process in the kiln, however, some unreacted particles were still observed, which led to an additional test with a ramp to ensure the decarbonation process of the flour.

As a result of testing the sample with the stepped ramp at a maximum temperature of 1300ºC, the product shown in Fig. 4c was obtained, which exhibits a more intense brown color, less unreacted granules and a higher reaction of the components. For the step ramp, the equipment was programmed with a ramp of 10 ºC per minute until 800 ºC was reached. At this temperature remained constant for 30 minutes and at the end of this time it was increased again at 10 ºC per minute until it reached a maximum temperature of 1300 ºC, remaining constant for 45 minutes.

Each of the products obtained from the sintering process in the linear heating ramps at 1250 ºC and 1300 ºC, as well as the product from the stepped ramp at 1300 ºC, were characterized by XRD and SEM in the equipment of the University of Oviedo in order to verify in greater detail the formation of the mineral phases of the clinker.

Figure 4 Specimens obtained at 1250 ºC (a), 1300 ºC linear (b) and 1300 ºC staggered (c).

Table 4 XRD identification.

Phase name	Identification COD	Identified 2θ peaks	2θ correlated reference peaks
	Heating ramp to 1250 ºC		
Larnite	96-901-2790	32,6017º y 32,0288º	32,598º y 32,075º
Gehlenite	96-101-1003	31,3307º y 29,0424	31,347º y 29,061º
Calcite	96-900-9668	29,390º y 47,1236º	29,390º y 47,092º
Merwinite	96-900-0286	33,4894º	33,409º y 33,568º
	Heating ramp to 1300 ºC		
Larnite	96-901-2790	32,1361º y 32,6338º	32,598º y 32,075º
Gehlenite	96-900-6114	31,3702º y 29,1217º	31,347º y 29,061º
Merwinite	96-900-0286	33,4978º	33,409º y 33,568º
	Heating ramp to 1300 °C Stepped		
Larnite	96-901-2790	32,6345º y 32,1475º	32,598 y 32,170
Gehlenite	96-900-6114	31,384º y 29,083º	31,347 y 29,061
Merwinite	96-900-0286	33,4953º	33,409º y 33,568º

Scanning Electron Microscopy (SEM)

On the matrix, there is a growth of grains with an approximate size of 1µm and a lighter color than the matrix, forming in some sectors agglomerations in the form of rosettes. The presence of gehlenite is observed in the form of well-defined needles with sizes between 1µm and 5µm, as well as cracks due to the cooling process.

Conclusions

This study addresses the possibility of reusing gold mining waste, a major environmental liability, for application as a raw material for clinker production. The study identified the critical parameters affecting clinker production, concluding that waste cannot fully replace raw materials and requires high purity supplements. Therefore, not all deposits are suitable; a complete mineral characterization of the waste to be used in each case is needed.

On the other hand, once the final clinker obtained has been studied, it is concluded that controlling the temperature, the amorphous phases and promoting the formation of belite during sintering could improve the properties of the final product.

This study highlights the potential of gold mining waste for clinker production, contributing to sustainable waste management and circular economy

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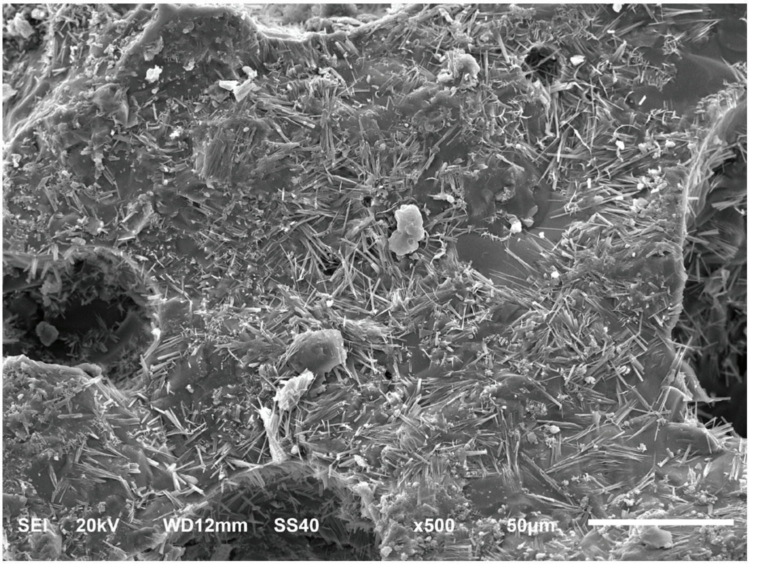

Figure 5 *Micro grains of gehlenite with belite in sintering product at 1300°C.*

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