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Evaluating The Durability Properties Of Gold Mine Tailings Geopolymeric Mortars: A Circular Economy Perspective

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The present investigation evaluated the comparison from a linear economy to a circular one, taking into consideration the uniaxial compression resistance of geopolymeric mortars from gold mining tailings against Portland cement mortars, to present comparative data analysis of costs, percentage of circular material and simulated conditions at different weather conditions (such as air with salinity saturation, humidity, dryness and normal air). The evaluation that was carried out was to work the geopolymers in different weather conditions using a closed system for 24 hours in the following way: dry air that conditioned the environment by injecting air with 0% humidity, also with 5% saline air with chloride sodium, humid air at 99% humidity and normal air. Subsequently, the mechanical resistance at room temperature was evaluated, in addition to carrying out a comparative analysis of costs and circularity of the resources used.

As a result, it was obtained that the conventional Portland cement mortar obtained an average maximum resistance of 77 Mpa, under normal air conditions. It should be noted that the water consumption is much greater than the geopolymers and it does not contain any percentage of circular material in its elaboration process. However, the geopolymeric mortars at room temperature and under normal atmospheric conditions had better performance with respect to resistance with a maximum average of 13 MPa.

It was observed that the geopolymeric mortar from tailings from informal mining had a higher performance compared to that from formal mining, probably due to the homogenization of the sample, silicate concentrations and lower porosity, thus allowing the spaces in the structure to be reduced. of the mortar, obtaining greater mechanical resistance.

Geopolymeric mortar made from formal mine tailings contains 26.023% and informal tailings mortar contains 24.855% circular material. Tailings are considered circular material, since they are waste from the mining industry, thus providing a transition from a linear economy to a circular economy.

Finally, these geopolymeric mortars could be reused for the production of prefabrication elements in masonry, allowing them to be an alternative to conventional mortar, generating a contribution to the circular economy in the mining and construction industry.

KEYWORDS: geopolymeric mortars, gold mining tailings, thermoresistance, circular economy

1] Introduction:

The mining sector in Peru has always presented notable growth and a potential economic model. The importance of highlighting the production of gold in Peru in the period from January to October 2023 amounted to 80,972 kg (2.6 million ounces) of fine gold, the regions that occupy the places give Arequipa as the second producing city, allowing to evaluate how much waste is generated as a result (MINEM, 2023) [1].

In extraction activities within the mining sector, tailings are the main waste generated, these by their nature contain metals in the surrounding environment due to exposure to water or wind dispersion, these wastes are not degradable so their presence in the environment is a problem. for health and the ecosystem. According to (Fashola et al., 2016) [2], the amount of residual material generated in mining activities that does not meet the economic standards to be processed is between 2 and 12 tons, per processed ton of economic value, as evaluated by the authors. (Shehata et al., 2022) [3]. The current focus in the mining sector is to develop sustainable processes to extract low-grade metals and evaluate treatments to minimize (bioprocesses) or recycle, that is, use waste as resources to obtain new products. (Jaiswal and Srivastava, 2024) [4].

The development of pilot-scale laboratory tests of geopolymeric mortars in addition to the evaluation of climatological conditions (humid, dry, normal environment) to evaluate their mechanical resistance, evaluation of environmental aging and good processing, looking for materials that face extreme climatological changes, in comparison with conventional materials such as Portland cement (Cong & Cheng, 2021) [5]. Therefore, this research aims to develop a transition from the linear economy in the disposal of all industrial waste to giving added value by being a contribution to the development of new geopolymeric materials from the reuse of mine tailings, reducing their environmental impact, in addition to giving it an economic value, seeking a circular economy transition.

2] Materials and Methods:

(a) Preparation of geopolymeric mortars

The following variations of mortars were manufactured (03):
Tailings were prepared and conditioned, which were collected from informal and formal gold mining tailings dams.
To prepare the geopolymeric tailings mortars, first the separation of solid particles of different sizes was carried out using a #100 sieve (150 microns), then the dry materials were mixed, such as the material, stirring for a time of 5 minutes, 26 g of silica material (tailings) and 74 g of fine sand, then an alkaline activating solution is prepared by dissolving the alkaline agent in water, adding 12 ml (with 12 M NaOH solution). Finally, the mixture of all the components gave a liquid phase/solid material ratio of 0.6. It was stirred for a period of 5 minutes. As a result of the mixture, a plastic paste was obtained as shown in Figure 1(a).

Figure 1 (a) Processing steps for making geopolymers

Source: Author's own work

The nomenclatures used for geopolymer mortars from informal mining, which were extracted from an informal mining tailings in the Arequipa region, in the district of Chala (GI) and geopolymers from formal mining of a formalized company also located in the district of Chala (GF).

(b) Conventional Type 1 Portland cement was prepared and conditioned

Once the previous mixture is obtained, it is poured into steel molds.
To model.
The mortars need a curing period in water for the chemical reaction between the components to be completed. In the case of Portland cement, a 15-day cure was applied and in the case of geopolymeric mortars, the curing is without water but it was conditioned. a humidity system for a period of 15 days and then dried in an oven for 72 hours at 100°C, to accelerate the process and complete the chemical reaction.

(c) Characterization of mechanical resistance

For the evaluation of the physical resistance properties, it is important to take into account the real density of the initial elements and the prepared mortars, for which it was evaluated in a Micromeritics brand helium pycnometry equipment. The evaluation of the mechanical resistance properties consisted of compression tests in a single direction at a constant compression speed of 0.05 mm/minute until the material cracked. The compression tests were carried out on materials in the shape of 5 x 5 x 10 mm3 parallelepipeds.
To evaluate the resistance to mechanical compression, microtest tests were carried out, where different simulation climatological conditions were used, which are described below:
-Saline air flow in continuous system for 24 hours: A salt solution containing a 5% concentration of sodium chloride with pH: 7.8 was prepared and placed in 2 500 ml flasks, where air outlets were placed. with hoses to the closed system where the sample was located, a system of humidity conditions where the mortar reached a humidity of 99%.
-Humid air flow in a continuous system for 24 hours: It was prepared in two flasks with a volume of 500 ml with water, reaching a humidity of 99%, entering compressed air through the flasks into the continuous system for 24 hours.
-Dry air stream in a continuous system for 24 hours: it was prepared in two 500ml silica gel flasks, reaching zero humidity, entering compressed air through the flasks into the discontinuous system for 24 hours.
-Normal air flow in continuous system for 24 hours: compressor air was used; through connections it entered the system continuously for 24 hours, as shown in Figure 2 (b).

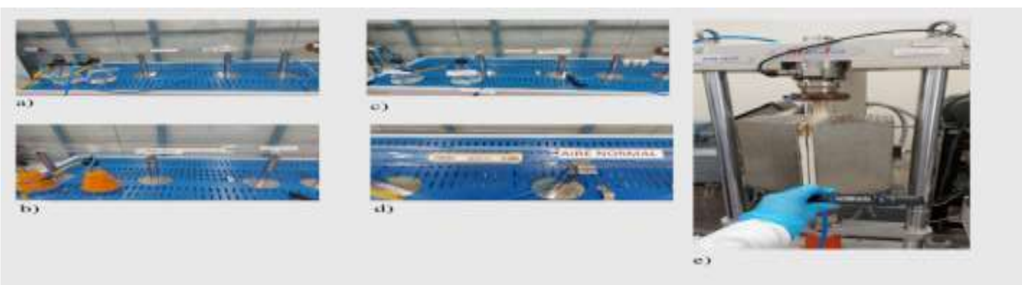

Figure 2 (b) It shows the systems developed: a) humid air conditions, b) dry air conditions, c) saline air conditions, d) normal air conditions, e) the mechanical test.
Source: Author's own work

(d) Circular Economy Assessment

The comparison of materials used for the production processes of geopolymeric mortars compared to conventional mortar was evaluated to see the contribution to the circular economy, where the comparison of the material balance for the production of a geopolymeric mortar compared to a conventional mortar was carried out. Detailing the quantities of input components, durability, % circularity of resources and output products.
The costs were taken into account from the preparation of a conventional mortar and geopolymer from mine tailings.

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3] Results :

(a)Physical characterization of mortars

Table N°1 are the results of the determination of the real, apparent density and porosity of control and geopolymeric mortars, which showed that the control mortar has lower porosity and a direct relationship with the real density. The density and porosity as shown in the Table1.

Table 1. Real, apparent density and porosity data

TYPE OF SAMPLE	ACTUAL DENSITY AVERAGE (G/CM^3)	APPARENT DENSITY AVERAGE (G/CM^3)	POROSITY (%)
CONTROL	2.46	1.99	19
GI	2.62	1.79	32
GF	2.71	1.73	36

Source: Author's own work

This agreed with the results of greater uniaxial compressive strength in all atmosphere conditions evaluated.

(b) Mechanical Characterization

Compression tests in a single direction in normal atmosphere with different flows of saline air in a continuous system, humid air flow in a continuous system, dry air flow in a continuous system, normal air flow in a continuous system for 24 hours (saline air, humid air, dry air).

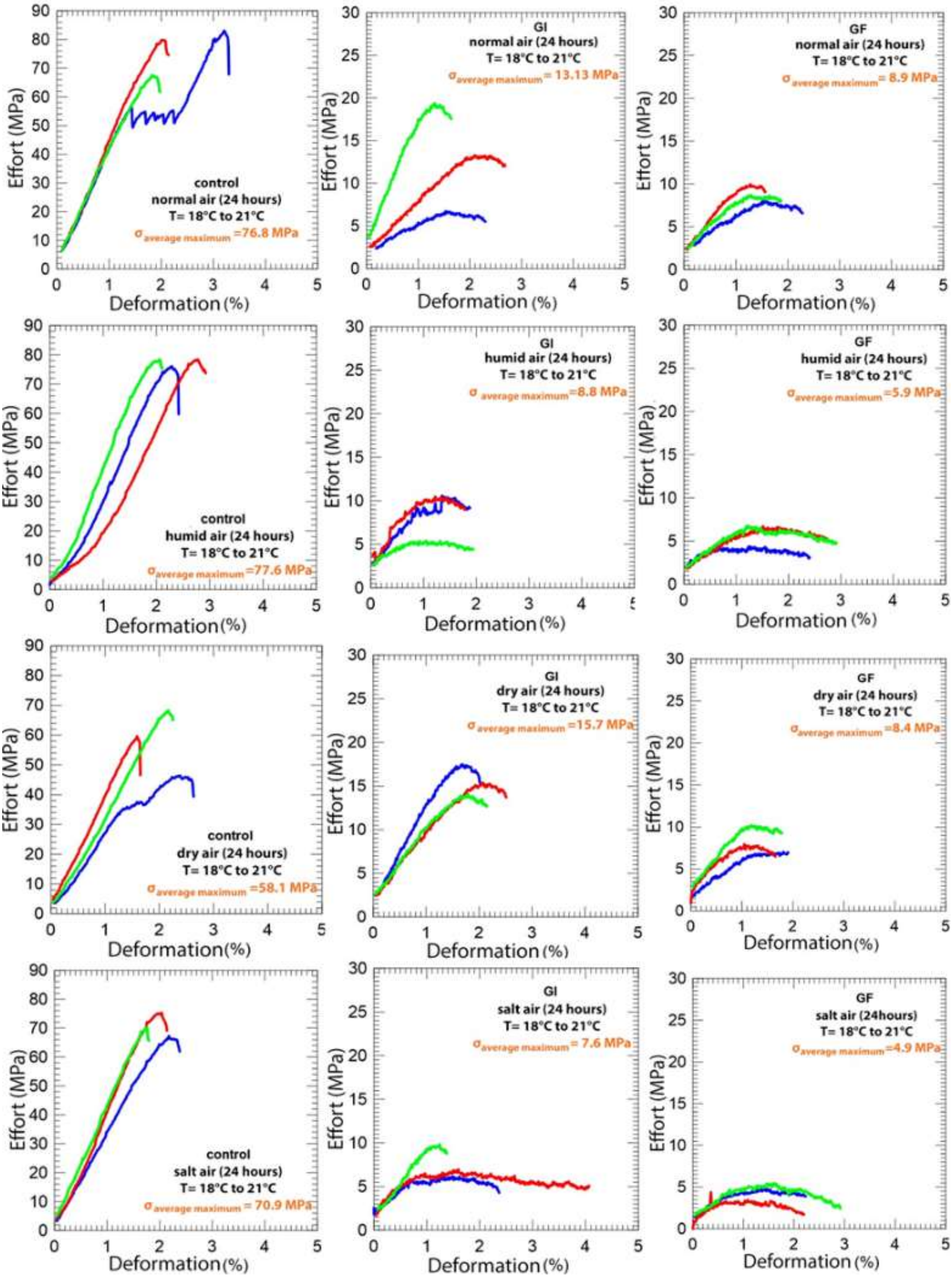
control
normal air (24 hours)
T= 18°C to 21°C
σ average maximum =76.8 MPa
GI
normal air (24 hours)
T= 18°C to 21°C
σ average maximum = 13.13 MPa
GF
normal air (24 hours)
T= 18°C to 21°C
σ average maximum = 8.9 MPa
control
humid air (24 hours)
T= 18°C to 21°C
σ average maximum =77.6 MPa
GI
humid air (24 hours)
T= 18°C to 21°C
σ average maximum =8.8 MPa
GF
humid air (24 hours)
T= 18°C to 21°C
σ average maximum =5.9 MPa
control
dry air (24 hours)
T= 18°C to 21°C
σ average maximum =58.1 MPa
GI
dry air (24 hours)
T= 18°C to 21°C
σ average maximum =15.7 MPa
GF
dry air (24 hours)
T= 18°C to 21°C
σ average maximum =8.4 MPa
control
salt air (24 hours)
T= 18°C to 21°C
σ average maximum = 70.9 MPa
GI
salt air (24 hours)
T= 18°C to 21°C
σ average maximum = 7.6 MPa
GF
salt air (24hours)
T= 18°C to 21°C
σ average maximum =4.9 MPa
Effort (MPa)
Deformation (%)

Figure 3 (b) Validation curves of the stresses on the material in relation to the deformations that for conventional cement mortars (Control), geopolymeric tailings from informal mining (GI) and geopolymeric tailings from formal mining (GF) in different air conditions. As shown in Figure 3(b). Source: Author's own work

(c)Circularity Assessment

To make a contribution to the circular economy, it was important to develop mass balances, detailed in the flow chart for calculating the percentage of circular material. Table 2 presents costs per material to prepare the functional unit of each mortar, it also shows the quantities of resources used, as well as the outputs of each activity, for 1 mortar whose functional unit is 10 cm3, approximate weight between 15 to 19g.

Table 2. nput and output components for the mortar production process

Type of material	Input components	Unit	Quantity	Quantity	Output Components	Cost Soles / cm^3 mortar (includes VAT)	Thermoresistance durability (Mpa)	% circular material
Portland cement mortar	Portland cement type I	g	5.48	5.48	-	0.01	77	-
	Fine sand (150 microns)	g	14.518	14.518	-	0.03	-	-
	Water (mixture)	ml	3.2	3.2	-	0.0003	-	-
	Water (cured)	ml	55	55	water steam	0.004	-	-
Geopolymeric mortar derived from formal mining	Mining tailings derived from formal mining	g	5.2	5.2	-	-	13	26.023
	Fine sand (150 microns)	g	14.782	14.782	-	0.03	-	-
	Water (mixture)	ml	-	-	-	-	-	-
	Water (cured)	ml	-	-	water steam	-	-	-
	12M NaOH alkaline solution	ml	1.5	1.5	-	0.0576	-	-
	Electric power (optional drying	kwh	417.6	417.6	-	3.25	-	-

	process) 5.8kwh							
Geopolymeric mortar derived from informal mining	Mining tailings derived from informal mining	g	4.97	4.97	-	-	9	24.8549
	Fine sand (150 microns)	g	15.026	15.026	-	0.03	-	-
	Water (mixture)	ml	-	-	-	-	-	-
	Water (cured)	ml	-	-	water steam	-	-	-
	12M NaOH alkaline solution	ml	1.44	1.44	-	0.0576	-	-
	Electric power (optional drying process) 5.8kwh	kwh	417.6		-	3.25	-	-

Source: Author's own work

4] Discussion:

Figure 3 (b), at a temperature of 18°C to 21°C and normal atmosphere, shows that the average maximum compressive strength in the Portaland cement mortars (Control) obtaining a maximum compression load of 77 MPa , with respect to the geopolymeric mortars from informal mine tailings (GI), a maximum resistance was obtained under an average compression load of 13 MPa and in the geopolymeric mortars from formal mine tailings (GF), a maximum load resistance of average compression of 9 MPa. The geopolymeric mortars revealed to be more fragile to compression, this is due to the presence of empty spaces (pores) present in a material, values between 32 and 36% porosity were obtained. This result coincides with previous research (Borges et al., 2019) [6].

Compression tests in a single direction in an atmosphere with a relative humidity of 99% and a saline atmosphere gave the lowest results in mechanical stress, probably having been structurally damaged by salinity, presenting surface epifluorescence. The simulated weather conditions, where it could perform better mechanically, is in a normal, dry environment.

Work to evaluate the resistance of mortars is best to apply humidity variations, which makes them suitable for various climatic conditions. This study applied different atmospheric conditions, such as dry air, saline air, normal air and humid air. By using geopolymeric mortars that can handle different climates, it allows for optimal construction materials in durability over time.

The samples prepared as mortars which were extracted from gold mining tailings from both formal and informal mining would allow an application in the construction sector but adjustments would need to be made in the research of the process to be able to compete economically with conventional cement, allowing reduce the environmental impact it generates and use circular material, reducing the amount of waste that must be stored, reducing the space where it could be used to provide added value or mineral production.

The geopolymer mortar in Table 2 made from formal mine tailings contains 26.023% and the informal tailings mortar contains 24.855% circular material. Tailings are considered circular material, as they are waste from the mining industry, thus providing a transition from a linear economy to a circular economy. These geopolymeric mortars could be reused for the production of prefabrication elements in masonry, allowing them to be an alternative to conventional mortar, generating a contribution to the circular economy in the mining and construction industry.

5] Conclusion:

The Portland cement mortars (Control) obtained their real densities of 2.42 g/cm3 and average porosities of 19%. Unlike geopolymers from informal mining (GI), they obtained real densities of 2.62 g/cm3 and average porosities of 32%. The geopolymers from informal mining (GF) had real densities of 2.71 g/cm3 and average porosities of 36%.

• The conventional Portland cement mortar presented better load capacity (resistance), obtaining a maximum average of 77 MPa, compared to geopolymeric mortars from formal mining tailings with a maximum average of 13 MPa, and finally, the comparison with mine tailings from informal mining. mining with a maximum average of 9 MPa.

• The simulated climatic conditions, in which it could have better mechanical behavior, is a normal, dry atmosphere. And the conditions that most affect mechanical performance are saline and high humidity conditions, structurally damaging the geopolymers.

• It is recommended to use these materials for prefabricated elements in the construction sector, working under type I pavers NTP:399.611.

European Standards (EN):

EN 998-1: Specifies the requirements for mortars for plastering and rendering. The compressive strength of mortar is classified into categories (e.g. CS I, CS II, CS III, CS IV), and the CS IV category could include mortars with a strength of 13 MPa.

EN 998-2: Specifies the requirements for masonry mortars. The compressive strength of mortars is classified in a similar way to EN 998-1.

American Standards (ASTM):

ASTM C270: Specifies requirements for mortars for masonry units. Mortars are classified into types (M, S, N, O), with type S requiring a compressive strength of at least 12.4 MPa (1800 psi), approaching 13 MPa.

• Develop an economic viability plan for geopolymeric mortars, optimizing the drying process, so that they are economically viable and competitive in the market.

6] Acknowledgement:

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8] Data Availability:

"No new data were created or analyzed in this study. Data sharing is not applicable to this article".