

Copper And Zinc Mining Tailings as A Partial Replacement for Cement to Increase the Compressive Strength of Concrete

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Abstracts: This study uses copper and zinc mining waste from mining activity as a partial substitute for cement in the concrete mix. This initiative seeks to strengthen the compressive strength of concrete. Copper and zinc waste can partially replace the cement content in concrete due to meeting the necessary physical and chemical requirements. In addition, these residues promote the formation of binders that improve the hydration of Portland cement. This approach improves the physical and mechanical properties of concrete and its durability. It also has economic and environmental advantages, as it uses copper and zinc waste from mining operations. Obtaining copper involves processing minerals from mines, which may contain copper oxides or sulfides. The rock is milled to obtain copper and zinc; these elements are separated using water, air, and other chemicals. The resulting by-products are stored in mining waste deposits that comply with current regulations. As for the research methodology, a deductive approach with applied orientation and a quantitative approach is followed. A retroactive data collection instrument is used to describe and explain the process. The optimal percentage of joint incorporation of copper and zinc residues from mining activity is around 10% and 5%, respectively. If you want to use only copper waste, you could reach up to 30%, while zinc waste can be incorporated in a maximum of 5%. In addition, it is observed that incorporating lead and zinc residues by 40% instead of cement increases compressive strength by 18%.

Keywords: Mining Tailings, Copper, Zinc, Cement, Resistance to Comprehension, Concrete.

1. INTRODUCTION

Mining and the cement industry produce waste that harms the natural environment. Mining generates significant volumes of debris, which can be a source of pollution for surrounding areas, hurting the environment and human health. A radiological risk is associated with exposure to the natural radionuclides contained in mining waste, which are sometimes used to manufacture building materials [1]. For its part, cement is essential in the construction of buildings, but its production emits large amounts of carbon dioxide (CO₂) into the atmosphere, contributing to climate change and environmental deterioration. Ever-increasing mining activity also leads to a constant accumulation of waste and debris, which requires proper handling and disposal. The proliferation of this waste around mines and its dispersion into the natural environment can lead to serious ecological problems. To address these problems, it is essential to consider the reuse and recycling of materials from mining waste in construction projects and civil works as non-structural components in buildings or road construction. This can help mitigate environmental impacts and conserve natural resources [2].

Mine tailings, also known as tailings or mining residues, are the materials and waste left behind as a byproduct after mineral processing in mining operations. These materials typically consist of fine particles of rock, sludge, water, and chemicals used in mineral extraction and concentration processes. When minerals are extracted from the earth, such as gold, silver, copper, or zinc, it is necessary to crush and grind the rock to release the valuable minerals. During this process, large amounts of waste are generated in the form of sludge and fine particles that do not contain minerals of economic interest. These wastes are transported and stored in repositories known as tailings or tailings deposits. Mine tailings can pose a significant environmental challenge, as they often contain toxic chemicals or heavy metals that can leach into soil or water if not properly managed. Proper tailings management is essential to prevent environmental pollution and minimize negative impacts on surrounding ecosystems and human health. Various techniques and technologies are used to collect and, in some cases, recycle or reuse tailings materials to reduce their environmental impact.

Proper mining waste management requires applying various techniques, including cemented paste-filling. However, it is essential to note that these wastes are processed with additives that can harm the environment, so examining their impacts and considering alternatives is crucial [3]. Mine tailings as a replacement for cement in concrete processing is a highly efficient method of reducing environmental pollution from tailings accumulation, including toxic elements, acid mine drainage, and dust emission. The safe management and precise reuse of tailings is therefore necessary. Substitute copper and zinc tailings, respecting international standards for proper dosage and development of concrete, optimizing durability levels with copper and zinc tailings components under adverse weather conditions to freeze and thaw cycles without affecting durability or resistance. Tailings contain hazardous pollutants, such as heavy metals, which pose environmental and public health risks. The mining activity for the extraction of underground minerals, the fine contents of the spill, called mine tailings, with scattered traces of residual minerals, generates severe threats to the surrounding ecosystems due to the presence of various toxic, primary, and secondary elements in the form of organic/inorganic pollutants [4].

In this context, it has been proposed in this work to analyze and evaluate the mining tailings of copper and zinc as a complement to cement to increase the resistance to concrete compression.

2. DEVELOPMENT

2.1. Concrete

Concrete, also known as concrete in some places, is a widely used building material worldwide due to its durability, versatility, and strength. It consists mainly of three ingredients: cement, aggregates (such as sand and gravel), and water, although additives are sometimes added to improve specific properties.

Cement: Cement is a fine powder that, when mixed with water, forms a paste that acts as a binder to bind aggregates. The most common type of cement used is Portland cement, produced by heating a mixture of limestone and clay to high temperatures. Portland cement is essential in the production of concrete.

Aggregates: Aggregates are composed of sand, gravel, or crushed stone mixed with cement to create a solid concrete mass. Aggregates provide strength and durability to concrete and reduce costs by replacing part of the cement.

Water: Water mixes with cement to form a paste that chemically reacts and hardens over time. The amount of water used in the mixture affects the workability and strength of the concrete. An adequate amount of water is essential to achieve the desired consistency.

Additives: In some situations, additives can be added to concrete to improve its properties. Depending on project needs, these additives can accelerate or delay setting time, improve water resistance, increase compressive strength, or provide other benefits.

Concrete is widely used to construct buildings, bridges, roads, dams, sidewalks, and other structures. Its advantages include its compressive strength, long-term durability, and ability to adapt to various shapes and sizes. However, concrete can also be vulnerable to corrosion and cracking over time, so proper maintenance is essential to ensure its longevity.

In addition, developing sustainable technologies has led to the exploration of greener alternatives to traditional concrete, such as recycled concrete or high-performance concrete with lower cement content, to reduce its environmental footprint.

2.2. Copper and Zinc Tailings

Copper and zinc tailings are by-products generated in mining operations extracting and processing copper and zinc ores, respectively. These tailings contain various materials, including unwanted minerals, fine rock particles,

water, and often chemicals used in mineral concentration and separation processes. Specific information on copper and zinc tailings is provided below:

2.2.1. Copper Tailings

Copper tailings are mainly generated in copper ore mining operations. The mined ore is processed to separate copper from other ores, and during this process, large amounts of waste are generated, including rock particles, sludge, and chemical solutions. Copper tailings can contain various substances, such as unrecovered copper, other unwanted metals and minerals, and chemicals used in flotation and leaching processes. These tailings must be appropriately managed and stored to prevent the seepage of toxic substances into the surrounding soil and water. This is because they may contain heavy metals such as arsenic, which pose significant environmental risks if released into the natural environment.

2.2.2. Zinc Tailings

Zinc tailings are produced in zinc ore mining and processing operations. The process involves crushing and grinding the ore to release the zinc, and during this process, the waste is generated that becomes tailings. Zinc tailings may contain unrecovered zinc and other unwanted metals and minerals. In addition, they may contain chemicals used in zinc separation and purification processes. Like copper tailings, zinc tailings must be appropriately managed to prevent environmental pollution. Zinc can be toxic to aquatic life, and zinc tailings can contain other potentially harmful metals.

The management and disposal of mine tailings is a critical issue in the mining industry due to the associated environmental risks. Tailings management regulations and practices vary by country and mining operation, but the primary goal is to minimize negative impacts on the environment and human health. This may include safely storing tailings in dams or reservoirs, rehabilitating affected areas, and implementing advanced technologies to reduce tailings generation and recover valuable minerals.

3. METHODOLOGY

The research was based on a documentary, bibliographic, and descriptive study. In addition, it is a deductive methodology, which collects information from articles, thesis works, and academic and research material associated with the subject to perform content analysis and make deductions about it. The type of orientation is applied because the study aims to analyze the improvement of the resistance to concrete compression by partially replacing cement with copper and zinc mining tailings. The type of approach is quantitative since the data are expressed in calculations and statistical tables. Laboratory results were also collected to evaluate the influence of mining tailings as a complement to cement on the compressive strength of concrete, making a descriptive and explanatory analysis. Table 1 shows the methods used in this study and the techniques developed.

Table 1. The methods and techniques developed.

Method or technique	Normative or standard
Unit weight of aggregates	ECWM 203-2000
Bending strength test	ASTM C78
Granulometric analysis of coarse aggregate	ECWM 204-2000
Specific gravity and absorption of coarse aggregates	ECWM 206-2000- NTP 400.021
Determination of cracking potential	ASTM1579
Specific weight, absorption, and moisture of aggregates	MTC E 205-2000
Granulometric analysis of the aggregate	MTC E 204-2000
Axial compressive strength tests	ASTM C39
Temperature test	ASTM C1064 and NTP 339. 184
Revenence	ASTM C-143 and NTP 339.035
Elaboration of these test tubes	ASTM C-31 and NTP 339.033
Mix design	ICA

Ahmari & Zhang [5] studied the feasibility of improving physical and mechanical properties and durability with

geopolymer based on copper mine tailings with cement kiln dust. They conducted the following tests:

- Effects of copper content CKD (0-10%).
- Sodium hydroxide (NaOH) concentration (10 and 15 M).
- Initial water content (12-20%) on unconfined compressive strength.
- Water absorption and weight and strength losses after immersion in water.

To shed light on the mechanism for CKD's contribution to geopolymerization, they use:

- Microscopic and spectroscopic techniques, including scanning electron microscopy/energy dispersive X-ray spectroscopy (SEM/EDX).
- X-ray diffraction (XRD)
- Fourier transform infrared (FTIR) spectroscopy to investigate geopolymer samples' micro/nanostructure and elemental and phase composition.

4. RESULTS

4.1. Findings Found in The Literature Search

Table 1 shows the previous works where the incorporation of copper and zinc tailings has been considered as a complement to cement for concrete production. These works are recent and present an essential contribution to the research work carried out.

Table 1. Previous work has considered the partial incorporation of copper and zinc in cement.

Study and Author	Abstract
Chen et al., [6]	They studied the efficacy of modified granulated copper slag as a partial replacement of ordinary Portland cement cemented paste for lead/zinc mine tailings cemented paste filling using Na ₂ SO ₄ (CSN) and CaO (CSC) as alkalis-activated material. They promote the circular economy in the lead/zinc mining and copper industries.
Saedi et al., [7]	They state that the production of acid mine drainage and the emission of heavy metals from tailings, especially sulfur tailings, into the environment is one of the severe challenges in the management of copper mine tailings. They advocate using cementation and replacing cement with mining tailings in concrete manufacturing as practical solutions.
Kundu et al. [8]	It partially replaces 10% and 15% of copper mine tailings in concrete, which results in acceptable and effective strength to immobilize leachable elements in tailings and stabilize waste.
Esmaeili et al. [9]	The partial replacement of 0%-30% of cement in paste, mortar, and concrete mixtures with copper mine tailings entails a slight increase in water demand and a delay in setting but meets the minimum UPS requirements of 75% in the 28 and 90 days in the case of mortar modified with copper mining tailings.
Agrawal et al. [10]	They suggest that it is feasible to use 10% mechanically treated copper tailings waste and 5% untreated zinc waste as a substitute for cement in concrete to reduce adverse environmental impact.
Escobar et al. [11]	X-ray fluorescence analyses have revealed variations in copper and zinc grades in waste rock and tailings concentrations. They suggest that both mining wastes have potential for the recovery of base metals and as non-metallic raw materials for construction.

Table 2 shows the effects of incorporating copper and zinc tailings into cement, indicating that the results are positive and offer some advantages for the construction process.

Table 2. Effects of partial incorporation of copper and zinc in cement

Author	Tailings	Activated materials	Replacement	Effects
Chen et al. [6]	Lead/zinc	Na ₂ SO ₄ (CSN) and CaO (CSC)	Modified granulated copper slag	Positive in the copper industry
Saedi et al. [7]	Sulfide tailings	CuSO ₄ + Zn = ZnSO ₄ + CuSe	Copper mining tailings management	Practical approaches to mine tailings management
Kundu et al. [8]	Copper mining tailings	Cu	10% and 15% of copper mining tailings	Immobilize leachable elements
Esmaeili et al. [9]	Copper mining tailings	Cu of 75%	0%-30% copper mining tailings	Meets minimum requirements
Agrawal et al. [10]	Zinc tailings	Zn	10% copper tailings and 5% zinc residues	Positive effect on concrete properties
Escobar et al. [11]	Copper and zinc tailings	Cu and Zn	0.6% and 1.3% copper and zinc	Recovery of metals (tailings) or non-metallic raw materials for construction.

4.2. Effects Of Copper and Zinc On The Properties Of Concrete

Sheikhhosseini Lori et al. [12] have pursued producing and utilizing new materials with acceptable mechanical properties and lower environmental costs. Geopolymers are new binders likely to outperform Portland cement due to their excellent strength and low greenhouse gas emissions. The results indicated that mine tailings-based geopolymer could improve mechanical properties efficiently without harming the environment. Statistical analysis illustrated that potassium hydroxide concentration was the most influential parameter for the compressive strength of samples.

Saedi et al. [13] state that compressive strength after 28 and 90 days of curing increases strength from 16.9 MPa to 19.8 MPa. However, by extending the curing time from 28 to 90 days, the compressive strength of concrete samples with 20% cement replacement increased from 28.35 MPa to 45.5 MPa. The results showed that mechanically activated lead-zinc mine tailings, up to 40% (by weight), can be a suitable substitute for cement in concrete production.

Lu et al. [14] state that copper slag storage and uniaxial compressive strengths at 3d, 7d, and 28d curing ages reached uniaxial compressive strengths of 3.55 MPa, 9.48 MPa, and 32.43 MPa, respectively.

Esmaeili et al. [9] reused copper tailings as a partial substitute for 0% to 30% cement in paste, mortar, and concrete mixtures. Copper mine tailings were first characterized, and then its effects on paste and mortar yield were evaluated by normal consistency, setting time, resistance activity index, X-ray diffraction, scanning electron microscopy analysis, and autoclave expansion. The mechanical resistances incorporating 5% to 20% of copper tailings in concrete were superior to the standard mixture. X-ray diffraction results also gave positive effects.

Xie et al. [15] successfully prepared a high-strength concrete material with copper tailings as the primary feedstock, with a 28-day compressive strength of 85.35 MPa, flexural strength reached 12.46 MPa, and a tailings utilization rate of 60%.

Lan et al. [16] indicated that compressive strength can reach 20 Mpa after consolidating heavy metals and leaching toxicity meets international standards at 60 days.

4.3. Design and Proportions of The Mixture of Concrete with Copper and Zinc

Dai et al. [17] obtained a mixture for cement paste filling with a mass concentration of 76.75%, a copper and

zinc/rock tailings ratio of 3.35, a cement/(tailings + rock) ratio of 0.1, and a pumping agent addition of 1.24%. The optimal mixture's collapse and uniaxial compressive strength were 24.1 cm and 1.59 MPa, respectively.

Külekcçi [18] prepared lightweight concretes using copper mine tailings, clay brick dust, and fly ash instead of fine aggregates. Some mechanical tests were performed. Tests revealed that samples with the addition of copper mine tailings produced the best energy absorption at all levels. Absorption decreased as the energy level increased and mass attenuation coefficients decreased.

4.4. Hydration of Concrete: Curing and Mixing Water with Incorporation of Copper and Zinc

Barzegar Ghazi et al. [19] concluded that the cement hydration process and C-S-H crystal growth were higher in samples containing 10% to 70% cement-replacing mine tailings than in the control sample. Resistance to chloride ion penetration increased at 28 days in samples containing 10% to 40% copper mine tailings as cement replacement but decreased in samples containing 50% to 70% mine tailings.

Ahmari & Zhang [5] significantly improve unconfined compressive strength and durability when using copper contents. Water absorption, however, increases slightly due to Ca hydration in added CKD. The improvement of unconfined compressive strength and durability is attributed to improving copper content in the dissolution of aluminosilicate species, forming CaCO_3 , and integrating Ca in the geopolymer gel.

Xie et al. [15] incorporate copper tailings as the primary hydration of $3\text{CaO} \cdot \text{SiO}_2$ (C_3S) and $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ (C_3A) in cement and the secondary hydration reaction induced by copper tailings and silica fume. These mechanisms combine to form a dense suspension microstructure, which incorporates exceptionally high mechanical properties at the macroscopic scale, providing a reference role for the mass utilization of copper tailings.

Kasap et al. [20] mention that the types of tailings (aged and fresh) and hydration products that are formed due to the interaction of these tailings mixed with cement decrease after 56 days due to acid formations and erosions, an essential function of physical, chemical and microstructural deterioration.

Bull & Fall [21] analyzed the leaching protocol (ASTM-C-1308) to determine the leachability of cemented paste filler samples subjected to different curing temperatures (2, 20, and 35 °C). This dependence of cemented paste on curing temperature is attributable to temperature-induced changes in the pore structure of cemented paste, the formation/development of hydration products, and the pH in cemented paste fillers during the curing process.

5. DISCUSSION

In the study by Chen et al. [6] on the partial incorporation of lead/zinc, the effect obtained by its mechanical and physical properties of concrete was positive. On the other hand, for Saedi et al. [13], Sulfide tailings had practical approaches in the fabrication, cementing process, and replacing cement with copper mine tailings. Kundu et al. [8] studied copper mine tailings to immobilize leachable elements, verify treatment efficiency, and estimate the potential impact of mine tailings on concrete properties. Esmaeili et al. [9] stated that the composition of minerals in copper mine tailings meets the minimum requirements in concrete curing set out in the standards. Agrawal et al. [10] studied zinc tailings and indicated that the particulate composition of these tailings is beneficial to the properties of concrete. Escobar et al. [11] state that copper and zinc tailings, both for recovering base metals (tailings) and as non-metallic feedstocks, can be used to manufacture building materials.

The effects of mine tailings-based geopolymers improve mechanical properties efficiently without harming the environment, and potassium hydroxide concentration being the most influential parameter for compressive strength of samples [12], [13] indicated that lead and zinc mine tailings improve mechanical properties and that it is a good substitute for cement in concrete production. Lu et al. [14] studied copper smelting slag and mentioned that it positively affects the mechanical properties of concrete. Esmaeili et al. [9] say that copper mine tailings improve the mechanical properties of concrete and are a partial substitute for cement in mixtures of paste, mortar, and concrete. Xie et al. [15] successfully prepared a high-strength concrete material with copper tailings as the primary feedstock,

and the effects were favorable to the mechanical properties. Lan et al. [16] established that after consolidating heavy metals, compressive strength increases, and leaching toxicity meets international standards.

CONCLUSIONS

The combined optimal percentage of copper and zinc tailings incorporation from mining activity would be 10% and 5% respectively. If you only want to incorporate copper tailings, it would be up to 30% and zinc waste up to 5%. Lead and zinc tailings with a 40% cement replacement increase compression strength by 18%. Adding copper tailings improves absorption and decreases as the energy level increases and the attenuation coefficients decrease. Curing and mixing water incorporating copper and zinc increases resistance to chloride ion penetration when containing 10% to 40% copper tailings but decreases when ordering more than 50% mining tailings.

Incorporating copper and zinc tailings in concrete manufacturing offers an environmentally beneficial solution by providing an alternative use to these mining by-products. Instead of storing large quantities of tailings in waste disposal facilities, they are given a useful purpose in building infrastructure. This reduces the accumulation of mining waste and decreases pressure on natural resources by reducing the need to extract additional materials for cement production.

The use of copper and zinc tailings in concrete manufacturing can contribute to the sustainability of the construction and mining industry. By reducing dependence on natural resources and decreasing carbon dioxide emissions associated with cement production, a more efficient and environmentally friendly approach to infrastructure construction is encouraged. In addition, the environmental risks associated with tailings disposal can be minimized by harnessing these mining byproducts safely.

Recommendations

Considering aspects of chemical composition, particle size, and variation in physical and mechanical properties, regardless of additives, improves resistance to understanding by incorporating mining tailings such as copper and zinc. Add bentonite to increase compressive strength and improve strength in tailings mixtures with cement after a wet curing period. Incorporate cement-stabilized mining tailings into road construction to meet strength requirements and tailings treated with bentonite as a covering material as they meet strength requirements in the base and subbase layers.

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