Experimental assessment of strength and durability of copper tailings-blended cement mortars

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***Abstract*—Copper tailings are fine-grained waste material that are left over after the extraction of copper from ore. It is commonly disposed of in large tailing ponds, posing environmental concerns such as soil and water contamination. Reuse of copper tailings in concrete and mortar production is meant to achieve sustainable development, environmentally friendly construction practices, and industrial waste management, and environmental protection and safety. This paper reports the experimental study on the strength and durability of mortar incorporating copper tailings-blended cement. To reduce CO2 emissions associated with cement production and avoid serious environmental pollution caused by mining waste deposition, the research investigated the potential of using copper tailings (CT) as a supplementary cementitious material to enhance the mechanical and durability properties of traditional cement-based materials. The effects of CT on the properties of ordinary Portland cement mortars were investigated by mortar samples made of binder-to-sand ratio of 1:2.75 as specified by the ASTM C109 and water to binder ratio of 0.55. Copper tailings were added to partially replace cement at 10%, 20%, 30% and 40% of the binder weight, while the control specimen had a zero CT content. Durability of the samples were comparatively evaluated by curing demoulded mortar specimens both in potable water and in 5% sodium sulphate solution and subsequently tested for the compressive, split tensile and flexural strengths at different test ages. The findings showed that the compressive, flexural, and split tensile strengths increased with CT content up to an optimal value of 20% and subsequently declined towards 30% to 40%.**

***Keywords*—Copper tailings, supplementary cementitious materials, cement-based mortar, waste management, additives, compressive strength, tensile strength, flexural strength, durability.**

I. INTRODUCTION

Supplementary cementitious materials (SCMs) are finely ground substance added to concrete in a partial replacement of ordinary Portland cement to improve its properties (strength, durability, workability) and sustainability by reducing cement use, lowering costs. Typical SCMs are primarily industrial by-products including but not limited to fly ash [1, 2, 3], slag [4, 5, 6], silica fume [7, 8, 9], limestone [2, 10] and metakaolin (Mobili et al. 2025) often through beneficial pozzolanic or hydraulic reactions, making concrete greener and stronger.

Fly ash is a by-product of coal combustion in power plants that has gained attention as a supplementary cementitious material (SCM) in the construction industry [2, 3]. It is a fine powder that can be used as a partial replacement for Portland cement in mortar and cement paste. The use of fly ash as an SCM can lead to a decrease in carbon dioxide emissions by up to 60%. This makes fly ash a sustainable option for the construction industry, aligning with global efforts to mitigate climate change [8, 12]. Utilization of fly ash as an SCM have been found to enhance the strength, durability, and workability of concrete and mortar. This is particularly important for infrastructure projects, where the long-term performance of concrete is crucial [13].

Slag cement, also known as ground granulated blast-furnace slag (GGBFS), is a byproduct of iron ore smelting process in blast furnaces [5]. It is a cementitious material that has been widely studied and used in construction applications due to its numerous advantages [6]. The use of slag cement as a cementitious material has been extensively studied in recent years [1]. Cheah et al. [4] reported recent advances in slag-based binders and chemical activators extracted from industrial by-products. Ahmad et al. [14] presented a comprehensive review on ground granulated blast furnace slag (GGBS) in the production of cement-based concretes and mortars. Lee & Lee [15] investigated the durability and engineering performance evaluation of the lime content and the ratio of binary blended concrete containing GGBFS. Several studies have revealed that concrete incorporating slag cement exhibited improved strength, durability, and resistance to chemical attacks compared to ordinary Portland cement concrete. These findings highlighted the potential of slag cement as a sustainable and high-performance cementitious material for various construction applications.

Copper tailings are a type of solid waste yielded during the beneficiation process of copper mine. Several studies have investigated the chemical composition, particle size distribution, and mineralogical characteristics of copper tailing to understand its potential as a supplementary cementitious material. Interestingly, recent research has shown that copper tailing can be utilized as a cementitious material due to its pozzolanic and hydraulic properties especially as a supplementary addition for cement in concrete and mortars [16-22]. The addition of copper tailing has been shown to improve the mechanical properties and durability of concrete, leading to reduced environmental impact and cost savings [23-24]. Additionally, studies have focused on optimizing the dosage of copper tailing to achieve desired performance and compatibility with other cementitious materials, such as fly ash and slag [11, 25]. The use of copper tailing in cementitious systems offers several environmental and economic benefits. By reducing the consumption of traditional cement, the carbon footprint of construction projects can be significantly lowered. Furthermore, the utilization of copper tailing can mitigate the environmental impact of mining activities by repurposing waste material. Economic advantages include potential cost savings and improved resource utilization, making it an attractive option for sustainable construction practices [18].

Despite the promising results of using copper tailing as a cementitious material, several challenges and opportunities for future research exist. The long-term behavior and durability of concrete containing copper tailing need further investigation, particularly in harsh environmental conditions. Furthermore, the development of standardized guidelines and specifications for incorporating copper tailing into cementitious systems is essential for widespread adoption in the construction industry. Future research should also focus on the environmental impact and life cycle assessment of using copper tailing in construction materials to provide comprehensive.

This study presents the experimental assessment of the mechanical properties and durability of copper tailings blended cement mortar at different copper tailings contents of 0% to 40% at an interval of 10%. The copper tailings were sourced from the BCL Open Cast Copper Mine located in Selebi-Phikwe, Botswana. The suitability of CT as a supplementary cementitious material (SCM) in mortar is a function of its physical and chemical properties. This would play a three-fold role of waste management, environmental protection, saving of cement cost via economic and technical reuse of copper tailings as blended cement in concrete and mortar. The physical, chemical and mineralogical properties of CT were reported, and the influence of varying CT contents on the properties mortar under normal and aggressive curing conditions was presented.

II. Description of the Study Area

Botswana is one of the Africa's topmost producers of mineral producers including South Africa and the Democratic Republic of Congo [26]. Its mining industry provides employment for scores of thousands Batswana and is the mainstay of the economy with 38% contribution to GDP. Diamond, soda ash, gold and Ni-Cu are the anchor of the mining industry in Botswana [27]. However, there is an increasing demand for sustainable and environment-friendly mining activities, which generate an increase in tailings and other contaminants that threathen environmental health as shown in Fig. 1.

The Selebi Phikwe Copper-Nickel mine, founded by Bamangwato Concessions Limited (BCL) founded the mine, is located geographically between longitudes 27°47′ E and 27°53′ E, and latitude 22°55′ S and 22°00′ S [28].

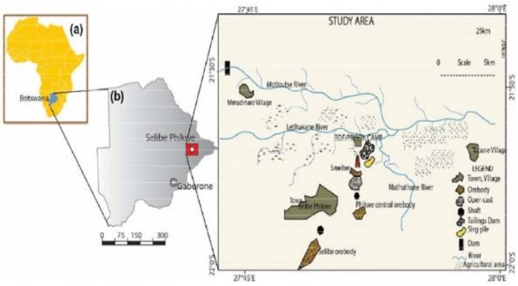
The Selebi Phikwe climate is semi-arid with an annual temperature of 21° C. The tailings dam which covers about 4 km^2 of land, has generated waste from decades of processing nickel, copper, zinc and cobalt sulphide ore. The tailings from the processing ore plant consists of about 35% of solid material. The material consist of about 12.5% of metal sulphides, horneblende and feldspar as major gangue minerals. Pyrrhotite occupies about 88% volume of the sulphide fraction, while pyrite (6%), pentlandite (4%) and chalcopyrite (2%) of the remainder volume [26-27, 32].

III. Experimental Programme

A. Cement

This CEM 1 ordinary Portland cement of 52.5 N grade strength was used in the study. The physical properties of the cement are tabulated in Table 1. The specific gravity was 3.15 and the Blaine fineness was 3880 cm^2/g which provided a greater surface area to be wetted resulting in an acceleration of the reaction between cement and water causing an increase in the rate of heat liberation at early ages.

The chemical composition of CEM I used in the study is as presented in Table 2. OPC consists of clays or aluminum silicates in the form of clays and shales and lime carbonate or calcium carbonate in the form of limestone, chalk and marl, a mixture of clay and calcium carbonate. Lime (66.0%) and silica (20.2%) are the most dominant oxides. The main components of OPC are tricalcium and dicalcium silicates, tricalcium aluminate and tetracalcium aluminium ferrite, and calcium sulfate in the form of gypsum. All the parameters are within the acceptable limits of SANS 50196-1.



(a) Location map showing Africa, Botswana and BCL mine at Selebi Phikwe

(b) Acid mine drainage from tailings dump in BCL mine

(c) Tailings dam in BCL mine in Selebi Phikwe

Fig. 1: Location of BCL mine and tailings dump and dams in Selebi Phikwe

Table 1: Physical properties of cement

Standard Consistency (%)	30
Specific gravity	3.15
Initial setting time (min) - minutes	200
Final setting time (max) - minutes	280
Fineness (cm^2/g)	3880
Compressive strength (N/mm^2)	
2 days	29.9
28 days	61.5

Table 2: Chemical composition (by weight) of ordinary Portland cement (CEM I) and copper tailings

Compound	CEM I – 52.5 N	Copper tailings (%)
SiO_2	20.18	52.407
MgO	1.58	7.841
Fe_2O_3	2.84	8.141
Al_2O_3	4.56	15.497
CaO	66.01	5.406
K_2O	0.11	1.633
Na_2O	0.183	1.742
Cl	0.027	
TiO_2		0.382
SO_3	2.42	2.192
P_2O_5		0.078
MnO		0.084
Cr_2O_3		0.032
SrO		0.007
ZrO_2		0.02
LOI	2.09	4.538
Total	**100**	**100**

B. Copper tailings

The chemical composition as presented in Table 2 using XRF analysis showed that the tailings are pozzolanic with the cummulative percentage composition by weight of SiO_2 (52.4%), Al_2O_3 (15.5%) and Fe_2O_3 (8.1%) exceeding the 70% threshold.

The X-ray diffraction (XRD) spectra that analyzed the mineralogical composition of the copper tailings to identify crystalline materials and study their atomic structure is shown in Fig. 2. The mineralogical composition of the mine tailings their order of the percentage composition by weight from the highest to the lowest was Andesine – 28.3%, Pargasite – 27.5%, Quartz low – 20.5%, Annite-siderophyllite – 20.1%, Greenalite – 2.5%, and Zeolite Y (Ni-exchanged) – 1.0%.

Andesine is a sodium-rich plagioclase feldspar mineral commonly found in volcanic rocks, and prized as a gemstone for its range of colors (white, gray, green, red) and potential color-change effects, often created by copper diffusion for vibrant hues in jewelry. Pargasite is a complex, calcium-rich amphibole mineral found in high-temp metamorphic rocks and some igneous rocks, appearing green to brownish-black, and serving as a significant water-storage site in the upper mantle. Quartz low is the low-silica engineered quartz, a material with significantly reduced crystalline silica content, making it safer for manufacturers (less silicosis risk from dust) and more eco-friendly. It allays the concerns regarding health concerns and environmental impact, offering similar performance with improved sustainability and safety. Annite-siderophyllite is a solid solution series or compositional range within the biotite mica group, representing iron-rich (annite) to aluminum-rich (siderophyllite) varieties.

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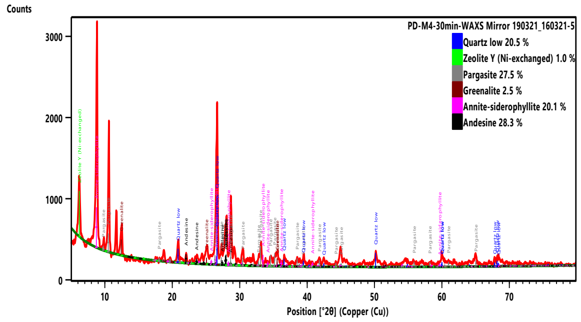


Fig. 2: XRD test results of copper tailings

Greenalite is a silicate mineral rich in iron (Fe) and magnesium, with a complex layered structure. It has an earthly green appearance and often occurs as small granules or in oolitic (small, spherical) forms. Its structured surfaces provided grooves that could align and help build complex organic molecules, acting as a crucial template for early life's building blocks. Zeolite Y is a crucial aluminosilicate microporous material. It features high surface area, tunable acidity, and stability, and its properties are often enhanced through modifications like dealumination or ion exchange to improve thermal stability and catalytic performance.

C. Aggregate and water

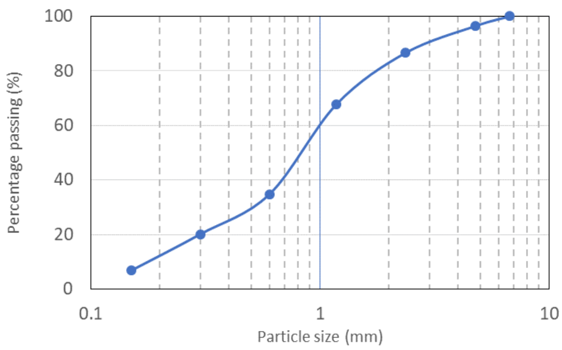
Fine aggregate was crushed stone dust from Kgale Quarries Pty (Ltd), Gaborone of maximum nominal size of 4.75 mm. It is obvious from the particle size distribution in Fig. 3 that the fine aggregates utilized in the mix are well-graded. The properties of fine aggregates are presented in Table 3. The fineness modulus of 3.0 for crusher dust implies that it falls within the range of coarse sand. Fineness modulus is an index number representing the mean size of particles in sand or fine aggregate. It was calculated by performing sieve analysis and is the sum of the total percentages retained on each specified sieve divided by 100.

Table 3: Properties of fine aggregate

	Quarry dust
Specific Gravity	2.64
Bulk Density (kg/m^3)	1240
Moisture content	4.09
Fineness modulus	3.0

Potable water of pH of 7.1 conforming to the requirements of BS 3148 [29] was used in mixing the fine aggregates and cement. The aggregates were free from deleterious materials and the physical properties were carried out in accordance with BS 812 [30].

(a) Crushed stone dust as fine aggregate



(b) Particle size distribution of fine aggregate

Fig. 3: Stockpile and particle size distribution of fine aggregate

D. Mix proportioning and casting of mortar specimens

Five different mortar mix proportions designated M0, M1, M2, M3 and M4 corresponding to 0, 10%, 20%, 30% and 40% CT contents in partial replacement of cement (CEM-1) at a constant water-binder ratio of 0.55 and binder-fine aggregate ratio of 1:2.75. Mortar with zero CT content represented the control specimen. For each mortar mix, the water content was 2.37 litres and the fine aggregate was 11.83 kg.

Table 4: Mixture proportions for mortar

Mixture No.	Mix Designation	Cement (kg)	Copper tailings (kg)
Control	M0	4.3	0
10% CT	M1	3.87	0.43
20% CT	M2	3.44	0.86
30% CT	M3	3.01	1.29
40% CT	M4	2.58	1.72

For the preparation of hardened mortars, mortar cylinders of 50 mm dia × 100 mm length were used for the compressive and split tensile strength tests, while prisms of dimension 50 × 50 × 200 mm for the flexural strength tests. These are depicted in the test setup shown in Fig. 4.

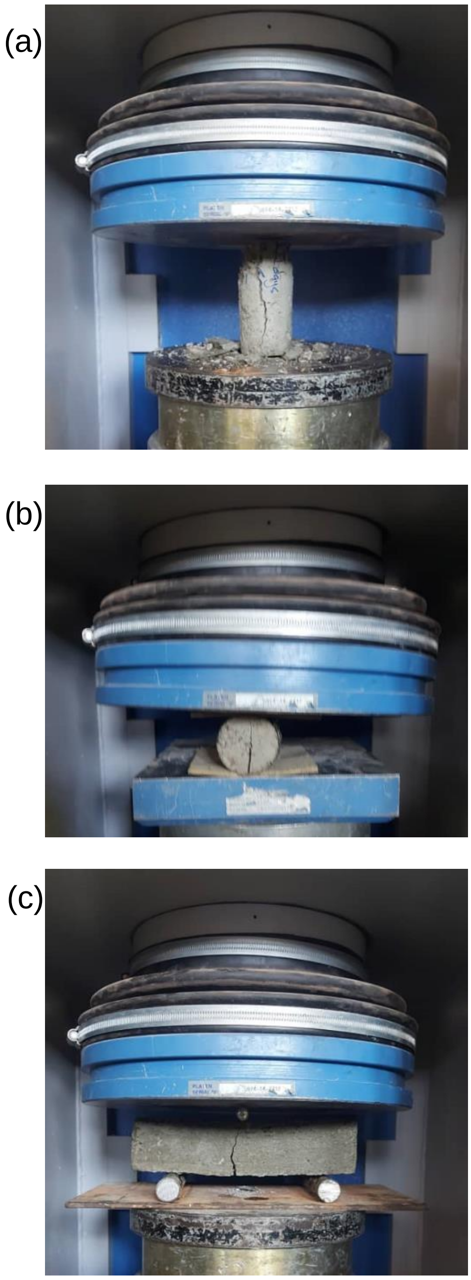


Fig. 4: Test setup for the compressive, split tensile and the flexural strength tests of mortar specimens.

For normal strength test, the specimens were cured in drinkable water tank, while durability assessment was performed by curing the specimens in 5% sodium sulphate solution. The cured specimens are tested at 7, 14, 21 and 28 test days in accordance with ASTM C39, ASTM C496 and BS EN 1015-11 using the universal testing machine for the compressive, split tensile and flexural test.

A total of 240 cylinder specimens of mortars were cast, cured and tested for the compressive and split tensile test procedures. 60 mortar cylinder specimens each were cast, cured and tested for the compressive and split tensile strength test of normal and 5% sulphate solution curing procedure. For the flexural strength test, 60 prisms of size 50 × 50 × 200 mm were cast, cured and tested for the normal curing in water and durability assessment when cured in 5% sulphate solution at 21 days and 28 days curing ages.

IV. Results and Discussion

A. *Compressive, split tensile and flexural strength of mortars cured in water*

The compressive strength of mortar specimens cured in water for the control mortars M0 and mortars M1, M2, M3 and M4 corresponding to copper tailings content of 10%, 20%, 30% and 40% is shown in Fig. 5a. It is obvious from the test results that for the control mix and every copper tailings content (i.e. $0 < c_t \leq 40\%$) that the compressive strength increased with curing age in water.

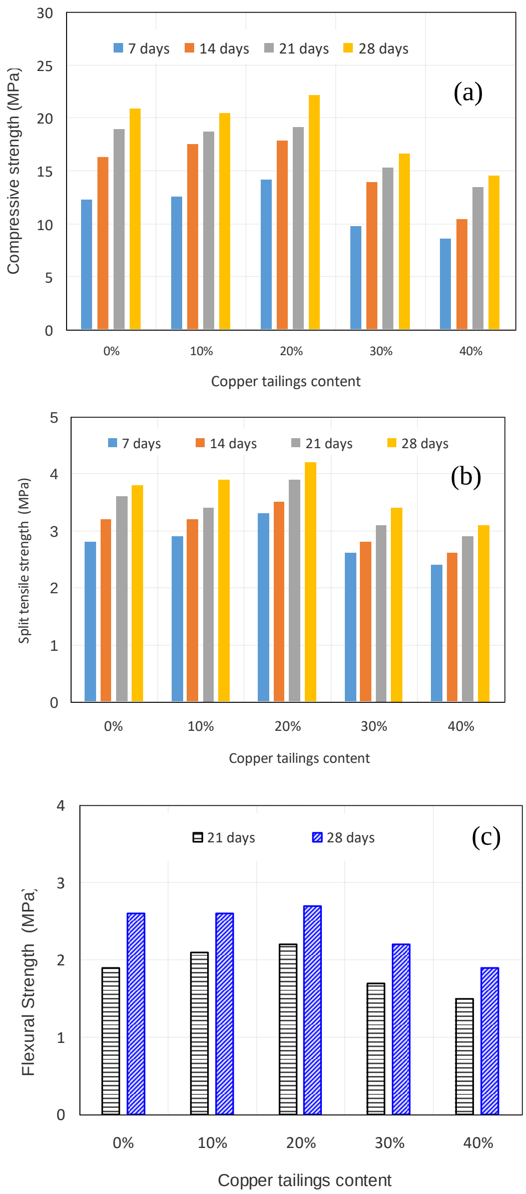


Fig. 5: Compressive, split tensile and the flexural strength results of mortar cured in water.

In addition, for virtually all the mixes, the compressive strengths increased with CT contents and attained optimal values at 20% CT contents and dropped slowly for 30% and 40% CT addition in the mixes. The highest compressive strength was 22.1 MPa at 28 days occurred for 20% CT content. The compressive strength has a quadratic relationship with the CT contents. The findings agreed with existing literature [16-17].

Similar trend was observed for the split tensile strength for the control mix M0 with zero copper tailings content and mortars M1, M2, M3 and M4. The split tensile strength increased with the curing ages in water as shown in Fig. 5b. The optimal tensile strength values was 4.2 MPa at the curing age of 28 days and at 20% CT content. The relationship between the compressive strength and the CT contents was quadratic. This is in agreement with the submission of various literature [10, 25, 31].

Furthermore, for the flexural strength of the prisms tested at curing ages 21 days and 28 days are as shown in Fig. 5c. Flexural strength increased with curing age. The strength increased slowly with the CT contents from the control mortar, M0 and attained the optimal flexural strength at 20% copper tailings content.

The statistical summary of the compressive, split tensile and flexural strengths of mortars cured in water and sulphate solutions is presented in Table 5 to Table 7. The percentage loss of compressive, split tensile and flexural strengths is as plotted in Fig. 7. The maximum loss of compressive strength was 4.6% corresponding to 7th day strength of 40% CT content. The 20% optimal CT contents a maximum of 4.3% strength loss at 7 days and 3.2% loss at the 28th day test day.

B. Compressive, split tensile and flexural strength of mortars cured in sulphate solution

Even though the compressive strength of the mortal cylindrical specimens cured in the sulphate solution for days 7, 14, 21 and 28 days curing ages. There was a general loss of compressive strength due to the relative harsh effect of sulphate compared to water curing. For all the mortal mixes, there was a consistent increase in compressive strengths as the CT contents increased and attained optimal values at 20% CT contents and dropped slowly for 30% and 40% CT addition in the mixes. The highest compressive strength was 20.6 MPa at 28 days occurred for 20% CT content. The compressive strength has a quadratic relationship with the CT contents as shown in Table 5. This aligns with the submission of Cristelo et al. [19].

The split tensile strength for the control mix M0 with zero copper tailings content and mortars M1, M2, M3 and M4,which was comparable to the rest results for the normal curing in water. The maximum split tensile strength was 3.9 MPa at 20% CT contents at age 28 days as shown in Fig. 6b. The relationship between the tensile strength and the CT contents was also quadratic.

Furthermore, for the flexural strength of the prisms tested at curing ages 21 days and 28 days are as shown in Fig. 6c. Flexural strength increased with curing age. The strength increased slowly with the CT contents from the control mortar, M0 and attained the optimal flexural strength of 2.7 MPa at 20% copper tailings content.

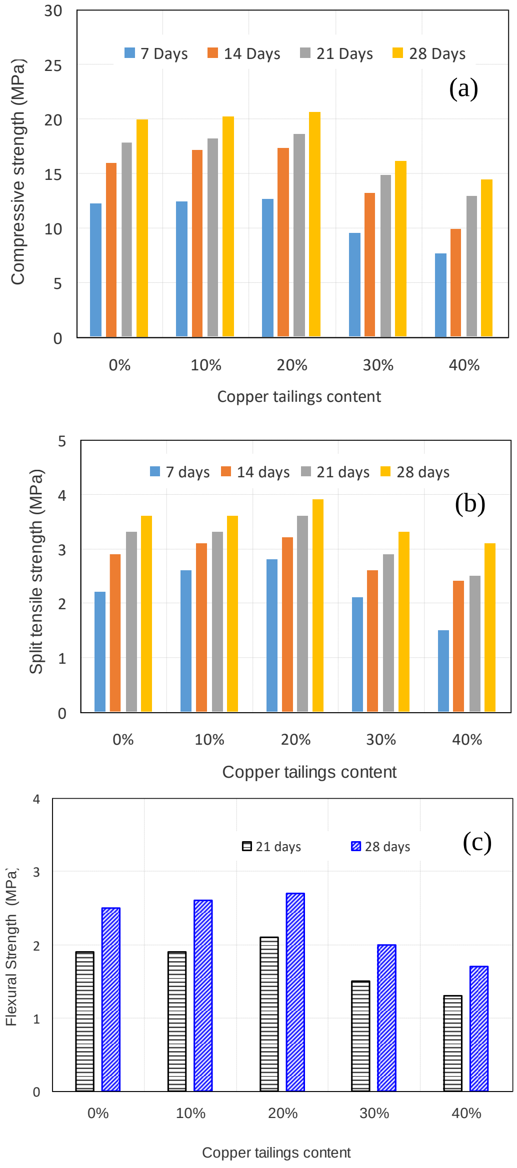


Fig. 6: Compressive, split tensile and the flexural strength results of mortar cured in 5% Na_2SO_4 solution.

C. Durability assessment of influence of sulphate on compressive, split tensile and flexural strength of mortars

Fig. 7 shows the influence of sulphate environment on the compressive, split tensile and flexural strength of mortar for durability assessment. Table 5 also summarizes the percentage loss of strength at different CT content. The maximum compressive strength loss was 4.7% at 7 days curing age for 40% CT content. However, the 20% optimal CT content lost 4.3%, 2.8%, 2.6% and 3.2% at 7, 14, 21 and 28 days curing ages respectively.

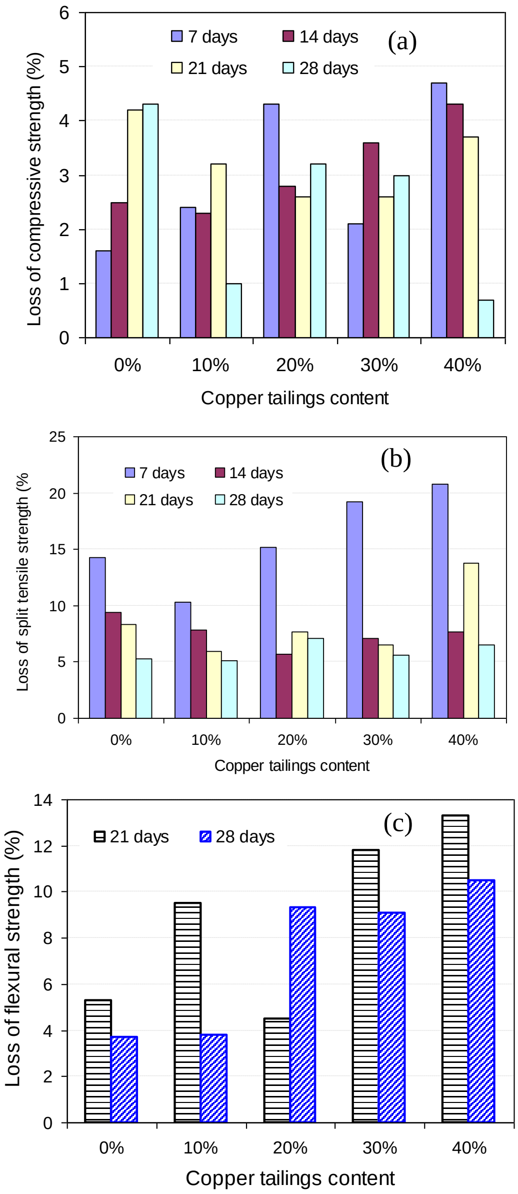


Fig. 7: Percentage loss of strength of mortar specimens in compression, split tension and flexure between curing in water 5% and Na_2SO_4 solution.

For the split tensile strength results, there was a maximum of 20.8% tensile strength loss at 7 days of 40% CT content. Specifically, for the optimal 20% CT content, there were tensile strength losses of 15.2%, 5.7%, 7.7% and 7.1% corresponding to the 7, 14, 21 and 28 days curing ages respectively.

Like the compressive and split tensile strength assessment of mortars, there were loss of flexural strength to the sulphate environment. There was a maximum strength loss of 13.3% corresponding to the 21 days curing age for 40% CT replacement of cement. However, for the 20% optimal CT content, there were flexural strength losses of 4.5% and 9.3% to sulphate attack at ages 21 and 28 days respectively.

Table 5: Statistical summary compressive strength and percentage loss of strength in sulphate solution

Test day	Equation	COD (R^2)
Compressive strength of mortars cured in water		
7-d	$f_c = -0.6429c_t^2 + 2.8371c_t + 9.96$	0.7921
14-d	$f_c = -0.9714c_t^2 + 4.2886c_t + 13$	0.9721
21-d	$f_c = -0.5357c_t^2 + 1.7643c_t + 17.66$	0.9244
28-d	$f_c = -0.7571c_t^2 + 2.9029c_t + 18.5$	0.857
Compressive strength of mortars cured in Na_2SO_4 solution		
Test day	Equation	COD (R^2)
7-d	$f_c = -0.5357x^2 + 2.0043x + 10.74$	0.9485
14-d	$f_c = -0.9571x^2 + 4.1229x + 12.8$	0.9644
21-d	$f_c = -0.6214x^2 + 2.4186x + 16.02$	0.9214
28-d	$f_c = -0.6357x^2 + 2.3043x + 18.32$	0.9037
Percentage loss of compressive strength of mortars due to curing in Na_2SO_4 solution		
Test day	Equation	COD (R^2)
7-d	$f_c = 0.3083x^3 - 2.8107x^3 + 8.081x - 4.18$	0.6315
14-d	$f_c = -0.0667x^3 + 0.75x^3 - 1.9833x + 3.8$	1.0
21-d	$f_c = 0.0583x^3 - 0.1821x^3 - 0.8405x + 5.16$	0.9993
28-d	$f_c = -0.6333x^3 + 5.6714x^3 - 15.295x + 14.44$	0.8984

Table 6: Statistical summary split tensile strength and percentage loss of strength in sulphate solution

Split tensile strength of mortars cured in water		
Test day	Equation	COD (R^2)
7-d	$f_t = -0.1214c_t^2 + 0.6186c_t + 2.28$	0.7118
14-d	$f_t = -0.1c_t^2 + 0.44c_t + 2.84$	0.7734
21-d	$f_t = -0.0929c_t^2 + 0.3871c_t + 3.24$	0.6524
28-d	$f_t = -0.1357c_t^2 + 0.6243c_t + 3.3$	0.8273
Split tensile strength of mortars cured in Na_2SO_4 solution		
Test day	Equation	COD (R^2)
7-d	$f_t = -0.2071x^2 + 1.0529c_t + 1.36$	0.9503
14-d	$f_t = -0.1071x^2 + 0.4929c_t + 2.54$	0.8534
21-d	$f_t = -0.1286x^2 + 0.5714c_t + 2.82$	0.8673
28-d	$f_t = -0.0929x^2 + 0.4271c_t + 3.24$	0.7624
Percentage loss of Split tensile strength of mortars due to curing in Na_2SO_4 solution		
Test day	Equation	COD (R^2)
7-d	$f_t = 0.7357c_t^2 - 2.2243c_t + 14.54$	0.8015
14-d	$f_t = 0.5643c_t^2 - 3.7957c_t + 12.72$	0.8607
21-d	$f_t = 1.1714c_t^2 - 5.8686c_t + 13.16$	0.8268
28-d	$f_t = -0.092\ c_t^2 + 0.8471c_t + 4.4$	0.333

Table 7: Statistical summary flexural strength and percentage loss of strength in sulphate solution

Flexural strength of mortars cured in water		
Test day	Equation	COD (R^2)
21-d	$f_f = -0.1c_t^2 + 0.48c_t + 1.54$	0.8659
28-d	$f_f = -0.0857c_t^2 + 0.3343c_t + 2.34$	0.928
Flexural strength of mortars cured in Na_2SO_4 solution		
Test day	Equation	COD (R^2)
21-d	$f_f = -0.0857c_t^2 + 0.3543c_t + 1.62$	0.8307
28-d	$f_f = -0.1143c_t^2 + 0.4657c_t + 2.16$	0.9012
Percentage loss of flexural strength of mortars due to curing in Na_2SO_4 solution		
Test day	Equation	COD (R^2)
21-d	$f_f = 0.4929x^2 - 1.1271x + 6.84$	0.6103
28-d	$f_f = -0.2214x^2 + 3.2186x + 0.06$	0.8529

V. Conclusion

This work has confirmed the potentials of copper tailings as a supplementary cementitious material in mortal. Also confirmed was the fact that copper tailings blended cement mortar also possesses acceptable resistance against 5% sulphate in curing environment. The following conclusions were drawn from the experimental study conducted on the suitability of copper tailings as supplementary cementitious addition in mortars.

1. The copper tailings from the BCL mines is pozzolanic (combined contents of SiO_2 (52.4%), Al_2O_3 (15.5%), and Fe_2O_3 (8.1%) exceeding 70% threshold.
2. The mineralogical composition of the mine tailings their order of the percentage composition by weight from the highest to the lowest was Andesine – 28.3%, Pargasite – 27.5%, Quartz low – 20.5%, Annite-siderophyllite – 20.1%, Greenalite – 2.5%, and Zeolite Y (Ni-exchanged) – 1.0%.

3. For copper tailings ($0 \leq c_t \leq 40\%$) replacement of cement that the compressive, split tensile and flexural strength increased with curing age in water and sulphate solution.
4. The optimal copper tailing content was 20% for compressive, split tensile and flexural strength assessment.
5. For the 20% copper tailings supplementary addition in mortar, the highest compressive, split tensile and flexural strengths at 28^{th} day curing age were 22.1 MPa, 4.2 MPa and 2.7 MPa, respectively.
6. The maximum percentage compressive and split tensile strength losses were 4.7% and 20.8% at 7 days curing age for 40% CT content.
7. The maximum percentage flexural strength loss was 13.3% corresponding to 21 days curing age of 40% copper tailing content.
8. For the 20% optimal mine tailings content, the compressive, split tensile and flexural strength losses at the 28^{th} day curing age were 3.2%, 7.1% and 9.3%.
9. Copper tailings from the BCL mine are good candidates for supplementary cementitious additions for the production of mortars and concrete.

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References

[1] Das, P., Cheela, V.R.S., Mistri, A., Chakraborty, S., Dubey, B., Barai, S.V. (2022). Performance assessment and life cycle analysis of concrete containing ferrochrome slag and fly ash as replacement materials – A circular approach, Construction and Building Materials, 347, 128609.

[2] Jiang, F., Zhou, J., Wang, J. (2025). Regulating the rheological properties of cement paste with fly ash and limestone powder, Construction and Building Materials, 504, 144680.

[3] Samantasinghar, S., Singh, S.P. (2018). Effect of synthesis parameters on compressive strength of fly ash-slag blended geopolymer, Construction and Building Materials, 170, 225-234.

[4] Cheah, C.B., Tan, L.E., Ramli, M. (2021). Recent advances in slag-based binder and chemical activators derived from industrial by-products – A review. Construction and Building Materials, 272, 1216572.

[5] Nieświec, M., Chajec, A. & Šavija, B. (2025). Effect of ground copper slag on the fresh properties of 3d printed cementitious composites. Scientific Reports, 15, 18117.

[6] Rohini, I., & Padmapriya, R. (2023). Properties of Bacterial Copper Slag Concrete. Buildings, 13(2), 290.

[7] Cavusoglu, I. (2024). Superplasticizer Dosage Effect on Strength, Microstructure and Permeability Enhancement of Cementitious Paste Fills. Minerals, 14(12), 1242.

[8] Monteiro, P.J.M, Geng, G., Marchon, D., Li, J., Alapati, P., Kurtis, K.E., Qomi, M.J.A. (2019). Advances in characterizing and understanding the microstructure of cementitious materials, Cement and Concrete Research, 124, 105806.

[9] Muslim, F., Wong, H.S., Choo, T.H., Buenfeld, N.R. (2021). Influence of supplementary cementitious materials on microstructure and transport properties of spacer-concrete interface, Cement and Concrete Research, 149, 106561.

[10] Tu, Z., Shi, C., Farzadnia, N. (2018), Effect of Limestone Powder Content on the Early-Age Properties of CO2-Cured Concrete. Journal of Materials in Civil Engineering, 30(8), August.

[11] Mobili, A., Blasi, E., Maqbool, Q., Tittarelli, F. (2025). Copper mine tailings and metakaolin as precursors for sustainable alkali-activated mortars, Journal of Building Engineering, 103, 112134.

[12] Mehta, P. K., & Monteiro, P. J. M. (2018). Concrete: Microstructure, Properties, and Materials. McGraw-Hill Education.

[13] Gou, M., Zhou, L., Then, N.W.Y. (2019). Utilization of tailings in cement and concrete: A review, Science and Engineering of Composite Materials, 26(1), 449-464.

[14] Ahmad, J., Kontoleon, K. J., Majdi, A., Naqash, M. T., Deifalla, A. F., Ben Kahla, N., Isleem, H. F., & Qaidi, S. M. A. (2022). A Comprehensive Review on the Ground Granulated Blast Furnace Slag (GGBS) in Concrete Production. Sustainability, 14(14), 8783.

[15] Lee, J., & Lee, T. (2020). Durability and engineering performance evaluation of CaO content and ratio of binary blended concrete containing ground granulated blast-furnace slag. Applied Sciences, 10(7), 2504.

[16] Adiguzel, D., Tuylu, S., Eker, H., (2022). Utilization of tailings in concrete products: A review, Construction and Building Materials, 360, 129574.

[17] Arunachalam, K.P., Avudaiappan, S., Maureira, N., Filho, F.D.G., Monteiro, S.N., Batista, I.D., de Azevedo, A.R.G. (2023), Innovative use of copper mine tailing as an additive in cement mortar, Journal of Materials Research and Technology, 25, 2261-2274.

[18] Chen, S.C., Gao, M.Y., Lin, W.T., Liang, J.F., Li, D.W. (2022). Effects of incorporating large quantities of copper tailings with various particle sizes on the strength and pore structure of cement-based materials, Construction and Building Materials, 329, 127150.

[19] Cristelo, N., Coelho, J., Oliveira, M., Cesar Consoli, N., Palomo, Á., & Fernández-Jiménez, A. (2020). Recycling and application of mine tailings in alkali-activated cements and mortars—Strength development and environmental assessment. Applied Sciences, 10(6), 2084.

[20] Esmaeili, J., Aslani, H. & Onuaguluchi O. (2020). Reuse Potentials of Copper Mine Tailings in Mortar and Concrete Composites, Journal of Materials in Civil Engineering, 32(5).

[21] Ghazi, A.B., Jamshidi-Zanjani, A., Nejati, H. (2022). Utilization of copper mine tailings as a partial substitute for cement in concrete construction, Construction and Building Materials, 317, 125921.

[22] Ghazi, A.B., Jamshidi-Zanjani, A., Nejati, H. (2022). Clinkerisation of copper tailings to replace Portland cement in concrete construction, Journal of Building Engineering, 51, 104275.

[23] Sigvardsen, N. M., Nielsen, M. R., Ottosen, L. M., & Jensen, P. E. (2017). Utilization of mine tailings as partial cement replacement. Academic Journal of Civil Engineering, 35(2), 272-277.

[24] Thomas, B.S., Damare, A., Gupta, R.C. (2013). Strength and durability characteristics of copper tailing concrete, Construction and Building Materials, 48, 894-900.

[25] Pei, C., Chen, P., Tan, W., Zhou, T., Li, J.(2023). Effect of wet copper tailings on the performance of high-performance concrete, Journal of Building Engineering, 74, 106931.

[26] Gabasiane, T., Bhero, S., & Danha, G. (2019). Waste Management and Treatment of Copper Slag BCL, Selebi Phikwe Botswana: Review. 2nd International Conference on Sustainable Materials Processing and Manufacturing, 35, 495-496.

[27] Ekosse, G., Van Den Heever, D.J., De Jager, L. & Totolo, O. (2004). Mineralogy of Tailings Dump around Selebi Phikwe Nickel-Copper Plant, Botswana. Journal of Applied Sciences and Environmental Management, 8 (1) 37 - 44.

[28] Darkoh, B. M. (2015). Socio Economic and environmental impacts of mining in Botswana: A case study of the Selebi Phikwe copper-nickel mine. Eastern Africa Social Science Research Review.

[29] BS 3148, Methods of test for water for making concrete. British Standard Institution, London, 1980.

[30] BS 812, Methods for sampling and testing of mineral aggregates, sands and fillers. Part 103. British Standard Institution, London, 1995.

[31] Gutiérrez, MV, Gómez, R, Alcayaga, A, Avudaiappan, S & Betancourt, F (2024). Potential of copper tailings as fine aggregates in cement mortar, Proceedings of the International Conference & Exhibition on Mass Mining, Luleå University of Technology, Luleå, pp. 1130-1139.

[32] Hu, l., Wu, H., Zhang, L., Zhang, P., Wen, Q., (2017). Geotechnical Properties of Mine Tailings, Journal of Materials in Civil Engineering, 29(2).