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Waste glass powder as a partial replacement of binder in improving the performance of cemented paste backfill

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Abstract

This study investigates the potential of Waste Glass Powder (WGP) as a sustainable replacement material in Cemented Paste Backfill (CPB) for metal mining operations. The primary objective is to explore WGP's capacity to reduce operational costs and environmental impacts associated with CPB, particularly by addressing the significant cement consumption that drives up costs. The research focuses on evaluating WGP as a cost-effective binder, examining its effects when partially replacing cement in CPB with three average particle sizes: 75 µm, 90 µm, and 125 µm. Laboratory tests were conducted on CPB samples incorporating varying WGP dosages of 10%, 20%, 30%, and 40% by weight of cement. The performance of these samples was assessed through a series of tests, including X-ray fluorescence (XRF), moisture content analysis, rheology testing, and mechanical testing. These tests aimed to evaluate the influence of WGP particle size on pozzolanic activity, compressive strength, and overall stability of the CPB. The results demonstrate that partial replacement of cement with WGP can significantly enhance CPB performance. Notably, the particle size of WGP plays a significant role in influencing pozzolanic activity, compressive strength, and mitigating expansion due to alkali-silica reactions (ASR). XRF analysis revealed a high silica content of approximately 76.4% in the WGP, further supporting its reactivity. For instance, at a 10% WGP dosage with a particle size of 125 µm and a curing age of 28 days, the compressive strength of CPB samples increased by an average of 13.8% compared to the reference sample. These findings highlight WGP's potential as a sustainable and cost-effective binder material for CPB in mining operations.

Keywords: *Cemented Paste Backfill; Waste Glass; Waste Glass Powder; Calcium Silicate Hydrate; Compressive Strength; Silica Content*

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Introduction

Recently, Cemented Paste Backfill (CPB) has seen growing adoption in numerous global metal mines due to its economic and environmental merits (Li, 2021). The primary constituents of CPB encompass dewatered mine tailings (constituting 70-85% of the paste's weight), hydraulic binders (comprising 3-7% of the dry paste weight), and mixing water, which can be either fresh or treated (Fall *et al.,* 2005). According to Deb *et al.,* (2017), CPB offers various advantages, including mitigating the adverse environmental impact of waste accumulation. CPB also minimizes the risks associated with tailing dam failure and provides ground support and stability for underground structures. The major deterrent of CPB is highly attributed to cement costs which account for up to 75% of the backfilling costs and 20% of total mining operating costs (Jiang *et al.,* 2019; Edraki *et al.,* 2014).

However, it is often challenging to reduce backfilling costs without incorporating a binder agent or pozzolanic materials such as silica fumes, fly ash, sea shells, glasses, polymers and a few others. These resources may contribute to pozzolanic reactions with cement and by doing so they can partially replace cement (Gomaa and El-Nagdy, 2023). Hence the investment cost of CPB may be reduced by exploring the best alternative and cheapest binder agent to be incorporated into a CPB, which must offer both economic sustainability and reduce environmental implications (Fang and Fall, 2020).

Waste glass is a pozzolanic material which itself is cementitious and can defined as the amorphous substances which contain large quantities of silicon and calcium (Shi and Zheng, 2007). The use of crushed waste glass powder (WGP) as a partial replacement for cement has proven to have a positive influence in improving both the mechanical performance of concrete and minimizing environmental pollution (Chand *et al.,* 2023).

The global generation of waste glass has surged to over 130 million tons, with only 21% being recycled (Ferdous *et al.,* 2021). In Tanzania, over 600,000 tons of waste glass are produced annually, yet only 10% is recycled (Atin and Siddhart Ghanshyam, 2021; Palfreman, 2014). Compared to other solid waste, the low recycling rate is mainly due to supply chains and technical barriers (Bristogianni and Oikonomopoulou, 2023). As a result, the amount of waste glass has rapidly increased in recent years, driven by the growing use of glassware (Tamanna *et al.,* 2013). The landfilling of waste glass is particularly problematic due to its non-biodegradable nature, leading to significant environmental pollution (Al-jburi Najad *et al.,* 2019).

The fine particles of WGP can potentially undergo pozzolanic reactions. These particles provide additional silica, which reacts with cement hydrates (Ca-OH) to form secondary Calcium Silicate Hydrate (CSH) gel (Islam *et al.,* 2017; Anwar, 2016). This CSH gel enhances the binding properties of cement paste, ultimately improving the mechanical performance of CPB (Ahmad, 2022).

The existing body of literature predominantly focuses on the utilization of WGP in concrete mortars while studies on the use of waste glass in CPB are limited (Abdelli *et al.,* 2020; Okeke and Adedeji, 2016). The previous studies conducted by Du and Tan., (2013), indicated that concrete having coarse particles of waste glass contained a significant content of alkali and active SiO2. This content was prone to Alkali-Silicon-Reactions (ASR). The ASR resulted in the detrimental expansion by forming an alkali-silicic acid gel (Na(K)–Si–H(gel)). This resulted in the cracking of concrete having a coarse particle size of Waste glasses. Therefore, it is suggested that waste glass with a particle size of less than 150 µm can be used for up to 40% without any negative effects on the performance of concrete (Cyr *et al.,* 2012).

This study, therefore, focuses on the use of WGP as a partial replacement for binders in improving the flow properties and mechanical performance of CPB. Also, this study addresses how mining industries can contribute to the mitigation of environmental pollution by reducing the quantity of waste glasses disposed in landfills. Henceforth, this study utilized waste glasses with a particle size of 75 µm, 90 µm and 125 µm.

Materials and Methods

This research utilized multi-coloured waste glasses as the partial replacement material for the binder. These materials were collected from dump sites found in Majengo market at Dodoma City. The chemical composition of waste glasses, class CEM II 42.5 N Portland and grouped mineralogical composition of Wet tailings are presented in

Table 1. Additionally, this research utilized process plant water from the Mine Site.

Table 1

Chemical composition of WGP, cement and grouped mineralogical composition of wet tailings

Chemical composition of WGP

Compound	SiO2	Al2O3	Fe2O3	MgO	SO3	CaO	TiO2	Na2O	Others
% Composition	76.4	8.67	0.5	1.66	0.67	4.15	0.4	4.31	3.24

Chemical composition of class CEM II 42.5N Portland Cement

Compound	SiO_2	Al_20_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
% Composition	22.42	3.98	3.5	65.4	1.48	2.6	0.07	0.55

Grouped mineralogical composition of mine tailings

Compound	SiO_2	Al_20_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
% Composition	22.42	3.98	3.5	65.4	1.48	2.6	0.07	0.55

Methods

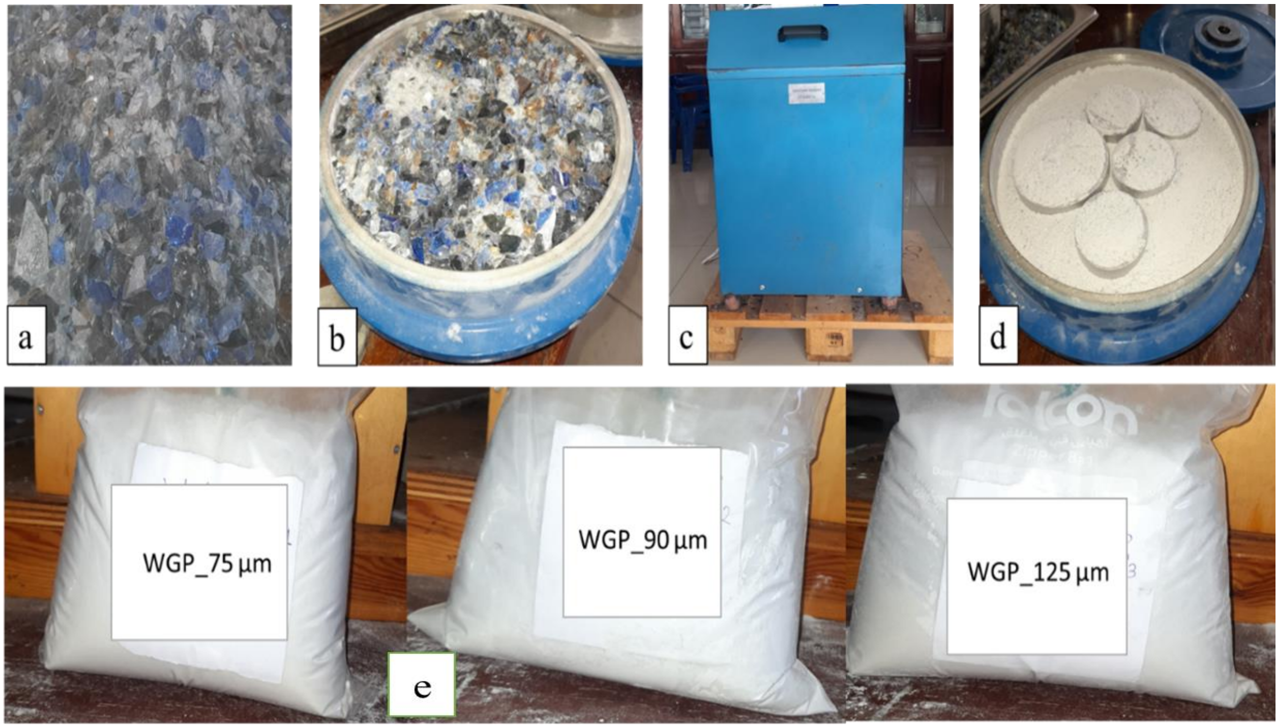
To evaluate the performances of WGP in cemented paste backfill, XRF analysis, moisture content measurements, and rheology and Uniaxial Compressive Strength (UCS) tests were performed. The purpose of conducting these measurements, tests, and analysis was to determine the effect of WGP replacement on workability or flowability and compressive strength development in both the early and late curing ages. The test procedures included WGP sample preparation, moisture content measurements, CPB mix design, rheology and compressive strength tests.

WGP sample preparation

Multi-coloured waste glasses were first cleaned using fresh water and dried for 24 hours in direct sunlight. The cleaned waste glasses were then crushed using a jaw crusher for about 5 min as shown in Figure 1a. The products from the jaw crusher were fed in a sample pot and pulverized for about 10 minutes as shown in Figure 1b. A pulverizing machine is shown in Figure 1c. After pulverizing, WGP specimens were further sieved at -150 µm + 125 µm, -125 µm +106 µm, -106 µm + 90 µm, -90 µm + 75 µm and 75 µm as indicated in Figure 1d. After sieving, three samples of WGP having an average particle size of 75 µm, 90 µm and 125 µm were prepared and separately packed as shown in Figure 1e. The selection of particle sizes of WGP followed the optimal size which is sufficiently enough to mitigate the detrimental expansion of concrete as a of the formation of alkalic-silic acids (Cyr *et al.,* 2012). From WGP-sized specimens, a composite sample was prepared for XRF analysis.

Figure 1

WGP sample preparation; (a) coarse products of waste glasses (b) coarse waste glasses fed in a sample pot (c) sample pulverizer (d) crushed WGP from a pulverizer and (e) Sized sample of WGP consisting of 75 µm, 90 µm and 125 µm after preparation



Moisture content testing

The moisture content testing of wet tailings followed (ASTM D226). A representative sample mass was placed in a tared container and the mass of the sample (M_1) was recorded as 328 g. This sample was then placed in an oven drying machine and heated for 24 hours at a temperature of 105°C. The mass (M_2) after drying was recorded as 246 g.

CPB Mix design

CPB samples were prepared using water, wet tailings and binder (cement + WGP). The moisture content of tailings was measured as 25%, water content in a paste was 34% and solids concentration was measured as 66% by weight. CPB mix was prepared by a dry mixing of wet tailings and binder for about 40 seconds followed by adding water and further mixing for about 7 minutes. Notably, the mix design parameters of CPB are listed in **Table 2**.

Table 2

Mix design parameters for CPB incorporated WGP of an average particle size of 75µm, 90 µm and 125 µm

Dosage of WGP (%)	Cement (C) (g)	WGP (g)	Water (W) (g)	W/C ratio	Wet tailings (kg)	Binder Content (%)
0	830	0	3100	3.73	19.59	3.5
10	750	80	3100	4.13	19.59	3.5
20	660	170	3100	4.7	19.59	3.5
30	580	250	3100	5.34	19.59	3.5
40	500	330	3100	6.20	19.59	3.5

Rheology test

The slump test was performed as an alternative approach for determining the rheology of CPB. The procedures of conducting the slump test followed ASTM C143. The experimental procedures in the slump test involved filling a fresh CPB into the cone in three layers, with each layer compacted by tamping it 25 times using a bullet-nosed metal rod measuring 16 mm in diameter and 600 mm in length. Once the third layer was added, the excess CPB was levelled with the top of the mold Carefully, the mold was lifted vertically upwards to avoid disturbing the CPB cone. Subsequently, the CPB naturally settles or slumps. The slump height was then determined by measuring the vertical distance between the top of the slumped CPB and the level of the top of the slump cone as shown in **Figure 2**b.

Compressive Strength Test

Cylindrical plastic molds of diameter of 100 mm and height of 200 mm were used for casting samples for studying the early and late compressive strength development as shown in **Figure 2**a. Mold selection followed the American Standards of Testing and Materials which state that the height of a cylindrical mold must be twice the diameter (Ulusay, 2014; Astm, 2005).

These molds were filled with cement paste, and sealed as shown in **Figure 2**c.

The casted samples were then cured in an underground temperature exhibiting 36°C and relative humidity of 90% as shown in **Figure 2**d.

To evaluate the strength development at different ages, the samples were set to cure for 3, 7, 14 and 28 days. After ageing, the specimens were subjected to UCS tests using a MATEST machine. The samples were compressed at a maximum load of 15 KN until failure occurred, and strength at failure was then recorded as shown in **Figure 2**e.

Figure 2

Sample preparation for Compressive Strength test (a) Cylindrical plastic mold for casting CPB (b) Casted CPB in cylindrical molds (c) Curing of casted CPB samples and (d) Compressing of cured CPB sample to attain 15 KN

The mean of the three measurements was calculated in these experiments. Further statistical measures including standard deviation (SD) and coefficient of variation (CV), as given by equations (1) and (2) respectively, were used to analyze the data. A higher CV value indicates a greater degree of variation in the data, while a lower value suggests more accurate results.

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}{n}} \qquad (1)$$

Where; X_i is the i^{th} value in the data sample, $\overline{X}$ is the mean value of the data and $'n'$ is the number of data values in the sample.

$$\mathrm{CV} = \frac{\mathrm{SD}}{\overline{\mathrm{X}}} * 100\% \qquad (2)$$

Results

The results for the effects of WGP replacement on the workability of CPB, effects of partial replacement of WGP particle sizes of 75 µm on compressive strength development, effects of partial replacement of WGP particle sizes of 90 µm on compressive strength development and effects of partial replacement of WGP particle sizes of 125 µm on compressive strength development are presented in **Table 3**,**Table 4**,**Table 5** and **Table 6** respectively.

Table 3

Effects of WGP replacement on the workability of CPB

Dosage of WGP (%)	WGP at 75 µm		WGP at 90 µm		WGP at 125 µm	
	Slump (mm)	SG (g/ml)	Slump (mm)	SG (g/ml)	Slump (mm)	SG (g/ml)
0	265	1.84	-	-	-	-
10	267	1.85	266	1.84	265	1.84
20	268	1.84	266	1.85	264	1.86
30	269	1.83	267	1.85	264	1.87
40	272	1.80	268	1.84	263	1.88

Table 4

Effects of partial replacement of WGP particle sizes of 75 µm on Compressive Strength development

MIX	Dosage of WGP (%)	3-days curing			7-days curing			14-days curing			28-days curing		
		Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)
WGP_0 (ref.)	0	0.27	0.02	7.41	0.36	0.04	11.11	0.45	0.02	4.44	0.58	0.02	3.45
WGP_1	10	0.23	0.07	30.43	0.3	0.03	10.00	0.38	0.08	21.05	0.47	0.03	6.38
WGP_2	20	0.19	0.04	21.05	0.28	0.03	10.71	0.38	0.02	5.26	0.5	0.01	2.00
WGP_3	30	0.18	0.01	5.56	0.30	0.01	3.33	0.43	0.02	4.65	0.56	0.01	1.79
WGP_4	40	0.12	0.02	16.67	0.21	0.02	9.52	0.31	0.03	9.68	0.43	0.01	2.33

Table 5

Effects of partial replacement of WGP particle sizes of 90 µm on Compressive Strength development

MIX	Dosage of WGP (%)	3-days curing			7-days curing			14-days curing			28-days curing		
		Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)
WGP_0 (ref.)	0	0.27	0.02	7.41	0.36	0.04	11.11	0.45	0.02	4.44	0.58	0.02	3.45
WGP_5	10	0.26	0.03	11.54	0.34	0.04	11.76	0.42	0.03	7.14	0.55	0.03	5.45
WGP_6	20	0.22	0.02	9.09	0.32	0.02	6.25	0.4	0.02	5.00	0.56	0.01	1.79
WGP_7	30	0.17	0.02	11.76	0.26	0.03	11.54	0.34	0.02	5.88	0.49	0.02	4.08
WGP_8	40	0.14	0.02	14.29	0.25	0.01	4.00	0.35	0.02	5.71	0.51	0.02	3.92

Table 6

Effects of partial replacement of WGP particle sizes of 125 μm on Compressive Strength development

MIX	Dosage of WGP (%)	3-days curing			7-days curing			14-days curing			28-days curing		
		Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)	Average UCS (MPa)	SD	CV (%)
WGP_0 (ref.)	0	0.27	0.02	7.41	0.36	0.04	11.11	0.45	0.02	4.44	0.58	0.02	3.45
WGP_9	10	0.26	0.02	7.69	0.38	0.01	2.63	0.51	0.01	1.96	0.66	0.02	3.03
WGP_10	20	0.21	0.02	9.52	0.3	0.02	6.67	0.4	0.02	5.00	0.53	0.01	1.89
WGP_11	30	0.15	0.02	13.33	0.25	0.01	4.00	0.34	0.02	5.88	0.45	0.03	6.67
WGP_12	40	0.16	0.01	6.25	0.23	0.02	8.70	0.3	0.01	3.33	0.39	0.01	2.56

Discussion

Effects of WGP replacement on the workability of CPB

As indicated in **Table 3**, the results of the slump test show that the workability of CPB progressively increased with increasing WGP replacement, reaching 272 mm and 268 mm at 40% of WGP dosage in samples having WGP particle sizes of 75 µm and WGP particle sizes of 90 µm respectively as compared to 265 mm for reference samples. However, from **Figure 3**, it may be noted that the workability of CPB progressively decreased with increasing WGP replacement reaching 263 mm at 40% of WGP dosage in samples having WGP particle sizes 125 µm as compared to reference CPB with 265 mm.

The improvement of workability as a result of increasing in WGP dosage to 40% in both WGP particle sizes of 75 µm and WGP particle sizes of 90 µm may be attributed to the effects of fine aggregates in glasses which act as a micro filler that fills the voids between paste ingredients, resulting in a more cement paste being available for lubrication and flowability (Ismail and Al-Hashmi, 2009). However the progressive decrease in workability as a result of the increase in WGP dosage to 40% in WGP particle sizes of 125 µm may be influenced by the physical nature of waste glasses having large and rough surface areas which increased internal friction of paste ingredients, resulting in a less flowable CPB. (Ahmad *et al.*, 2021).

Effects of particle size of WGP on compressive strength development

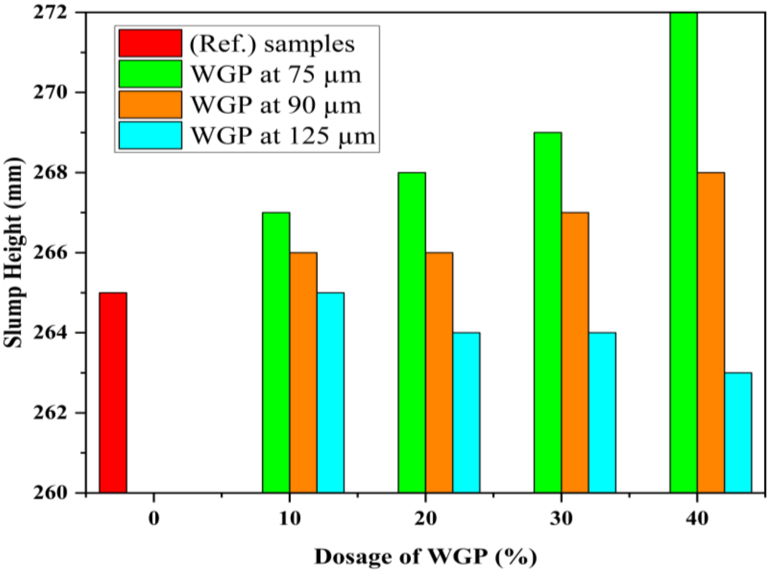
WGP particle sizes of 75 µm

As indicated in **Table 4**, the results of 3, 7 and 14 days progressively decreased with increasing WGP dosage from 0% to 40%, reaching 0.12 MPa, 0,21 MPa and 0.31 MPa for 3, 7 and 14 days respectively as compared to 0.27 MPa, 0.36 MPa and 0.45 MPa for the reference samples.

However, **Figure 4** (a), shows the improvement in compressive strength as a result of increasing WGP dosage reaching 30% at 7, 14 and 28 days of curing. The improvement in compressive strength may be attributed to a progressive increase in the rate of pozzolanic reactions of WGP while the low improvement in Compressive Strength may be influenced by pozzolanic responses at the early age of curing are very slow. (Hussain and Chandak, 2015). Additionally, the compressive strength was observed to decrease at a higher dosage of WGP regardless of the increasing age of the samples. This may be attributed to the particle agglomeration effects which are highly influenced by a significant reduction of cement in a binder (Shao *et al.,* 2000).

Figure 3

Influence of WGP replacement on the workability of CPB



WGP particle sizes of 90 µm

As indicated in **Table 5**, the compressive strength results for 3, 7, 14 and 28 days progressively decreased with increasing WGP dosage reaching 0.14 MPa, 0.25 MPa, 0.35 MPa and 0.51 MPa at 40 % replacement as compared with 0.27 MPa, 0.36 MPa, 0.45 MPa and 0.58 MPa for reference sample respectively. However, the compressive strength development was achieved by increasing in WGP dosage up to 20% at 28 days of curing as shown in **Figure 4** (b). The strength improvement may have been influenced by a pozzolanic reaction that appears to offset this trend at a later stage of hardening and such contributes to an improvement in the compressive strength at 28 days (Metwally, 2007).

Additionally, the lower compressive strength at higher dosages greater than 20% of WGP particle size of 90 µm may be attributed to a significant reduction in cement hydrates responsible for pozzolanic activity between silica from waste glass and Ca-OH from cement. Hence this resulted from weak bond formation between cement paste ingredients due to the particle agglomeration effect (Aliabdo *et al.,* 2016).

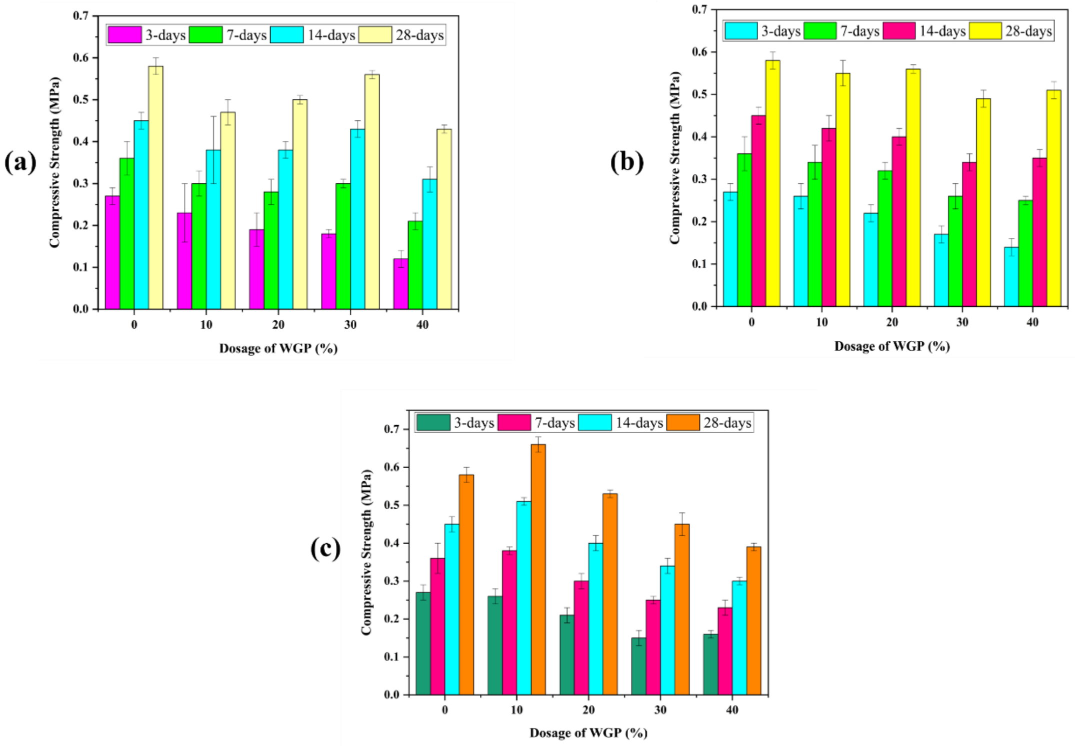
WGP particle sizes of 125 µm

As indicated in **Table 6**, the Compressive Strength results for 3, 7, 14 and 28 days progressively decreased with increasing WGP dosage of 20%, 30% and 40 % reaching 0.16 MPa, 0.23 MPa, 0.30 MPa and 0.39 MPa respectively. These results indicated a decreasing trend when compared with 0.27 MPa, 0.36 MPa, 0.45 MPa and 0.58 MPa for reference at 3, 7, 14 and 28 days.

However, **Figure 4** (c) shows that at 10% of WGP dosage, the Compressive Strength progressively increased by 5.5%, 13.3% and 13.8% at 7, 14 and 28 days of curing when compared with the Compressive Strength for reference samples. The reason for this strength improvement may be influenced by the high contribution of silica content which resulted in the additional formation of C-S-H gel responsible for enhancing the binding properties between cement paste ingredients. (Abdallah and Fan, 2014).

Figure 4

Influence of different particle sizes of WGP on compressive strength development; (a) 125 µm, (b) 90 µm, and (c) 125 µm



Effects of curing age on compressive strength development

3 days of curing

The compressive strength results of CPB obtained by partial replacement of WGP particle sizes of 75 µm, 90 µm and 125 µm after a curing time of 3 days are presented in **Table 4**, **Table 5** and **Table 6** respectively. The compressive strength results progressively decreased with increasing WGP replacement reaching 0.12 MPa, 0.17 MPa, and 0.16 MPa at 40% replacement compared with 0.27 MPa for the reference samples.

However, **Figure 5** (a), shows the significant compressive strength improvement in samples having both WGP particle sizes of 90 µm and 125 µm reaching 0.26 MPa at 10%. The improvement in compressive strength as a result of the 10% partial replacement of WGP particle sizes of 90 µm and 125 µm may be attributed to the early hardening of cement paste which led to gradual improvement in pozzolanic activity between cement paste ingredients and WGP. This might significantly improve the workability of CPB. (Ahmad *et al.*, 2021). Conversely, the lower compressive development as observed in samples having WGP particle sizes of 75 µm might be influenced by a slow formation in interfacial bonding between cement paste and glass aggregates at an early age. The lack of crack arrestors in glass aggregates may influence the propagation of cracks within glass aggregates (Shehata *et al.*, 1996).

7 days of curing

The compressive strength results of CPB obtained by partial replacement of WGP particle sizes of 75 µm, 90 µm and 125 µm after a curing time of 7 days are presented in **Table 4**, **Table 5** and **Table 6** Respectively. The compressive strength results progressively decreased with increased dosage of WGP particle sizes 90 µm reaching 0.34 MPa, 0.32 MPa, 0.26 MPa and 0.25 MPa at 10%, 20%, 30% and 40% respectively as compared with 0.36 MPa for the reference samples.

However, **Figure 5** (b), shows the increase in compressive strength by 5.5 % at 10% partial replacement of WGP particle sizes of 125 µm as compared with the Compressive Strength of reference samples. The improvement in compressive strength may attributed to an increase in pozzolanic activity as a result of high silica content which reacted with Calcium hydrates from cement by forming a secondary C-S-H gel. (Ahmad *et al.,* 2021). Additionally, the lower compressive strength improvement as observed in samples having WGP particle sizes of 75 µm and 90 µm may be influenced by a decrease in micro filling tendency of void spaces during cement paste mixing. (Shekhawat and Aggarwal, 2014).

14 days of curing

The compressive strength results of CPB obtained by partial replacement of WGP particle sizes of 75 µm, 90 µm and 125 µm after a curing time of 14 days are presented in **Table 4**, **Table 5** and **Table 6** Respectively. The compressive strength results progressively decreased with increasing dosage of WGP particle sizes of 75 µm and 90 µm reaching 0.31 MPa and 0.35 MPa respectively at 40% replacement as compared with 0.45 MPa for the reference samples. However, **Figure 5** (c), shows the increase in compressive strength by 13.3 % at 10% partial replacement of WGP particle sizes of 125 µm as compared with those of reference samples.

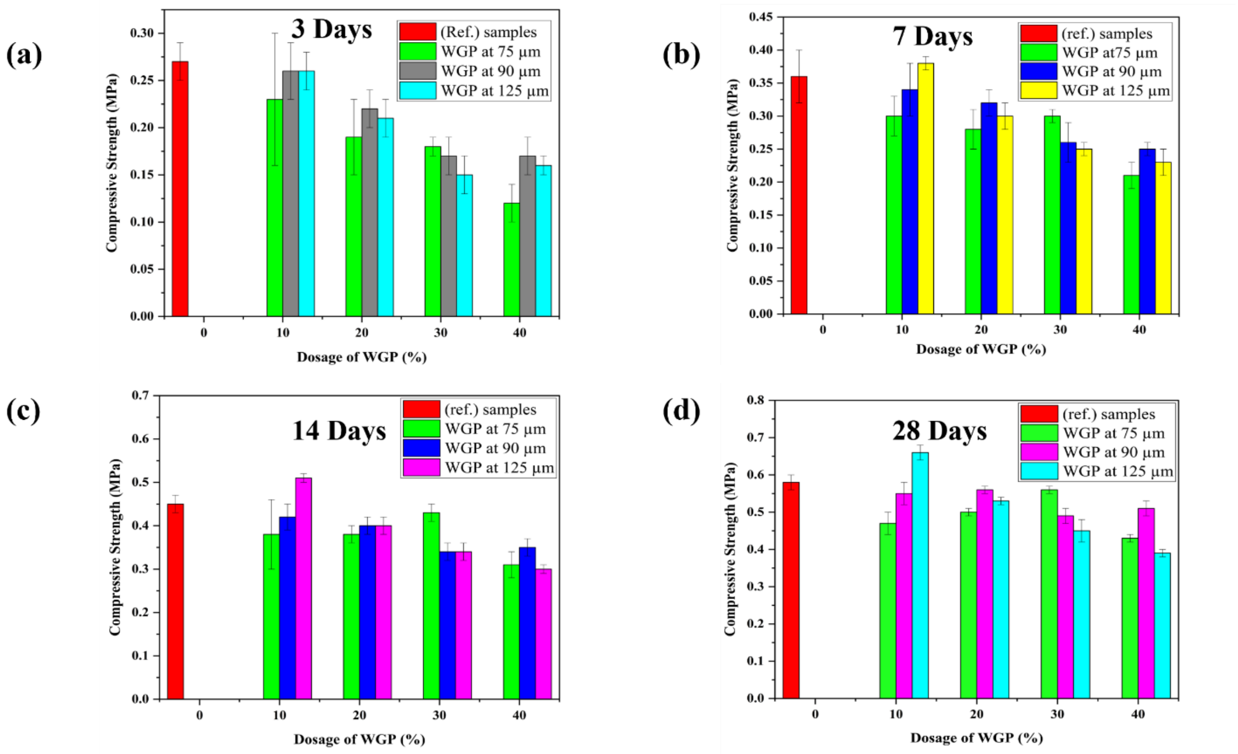
This improvement in strength observed in samples having WGP particle sizes of 125 µm may be attributed to a significant improvement in micro-filling tendency and workability as a result of a significant increase in CPB density at a low dosage of WGP. The compressive strength progressively decreased with an increase in partial replacement of WGP particle sizes of 125 µm reaching 0.30 MPa at 40% replacement. The reason for this trend might be the fact that high CPB density reduced compaction enhancement between WGP and cement paste ingredients leading to the formation of a less workable paste (Ahmad *et al.,* 2021; Ahmad *et al.,* 2022).

28 days of curing

Table 4, **Table 5** and **Table 6** respectively show the compressive strength results obtained by partial replacement of WGP particle sizes of 75 µm, 90 µm and 125 µm after a curing time of 28 days. From these results, the compressive strength of WGP samples closely approached the reference samples with increasing dosages of WGP particle sizes of 75 µm, 90 µm and 125 µm reaching 0.50 MPa, 0.56 MPa and 0.53 MPa respectively at 20% partial replacement. However, **Figure 5** (d), shows the increase in compressive strength by 13.80 % at 10% partial replacement of WGP particle sizes of 125 µm as compared to reference samples. The improvement in compressive strength as observed in samples WGP particle sizes of 125 µm may be due to a significant improvement in micro filling tendency of void spaces which densified the cement paste resulting in an increase in bond strength between WGP particles and the surrounding cement paste due to irregular geometry of glass (Abdallah and Fan, 2014; Ismail and Al-Hashmi, 2009).

Figure 5

Influence of curing age on compressive strength development; (a) 3 days, (b) 7 days (c) 14 days, and (d) 28 days



Conclusion

The study demonstrates that Waste Glass Powder (WGP) can be an effective and sustainable partial replacement for cement in Cemented Paste Backfill (CPB) applications, particularly in metal mining operations. The incorporation of WGP not only helps in reducing the operational costs associated with CPB by lowering cement consumption but also mitigates environmental impacts by repurposing waste glass that would otherwise contribute to landfill waste. The findings reveal that WGP, especially at particle sizes less than 150 µm, enhances the workability and compressive strength of CPB, making it a viable alternative to traditional cement binders. However, the effectiveness of WGP is influenced by its particle size and dosage, with optimal results observed at specific levels of replacement. The study underscores the potential of WGP as a cost-effective, environmentally friendly material that supports sustainable mining practices while maintaining the structural integrity and performance of CPB.

Based on the key findings from this study, the use of Waste Glass Powder (WGP) as a partial replacement for cement in Cemented Paste Backfill (CPB) provides several significant insights into the potential benefits and limitations of this approach in mining operations.

The research demonstrated that incorporating WGP into CPB can effectively enhance its performance. Specifically, the study found that the partial replacement of cement with WGP, especially at lower dosages (such as 10% and 20%), resulted in improved compressive strength. For instance, CPB samples with 125 µm

WGP at a 10% dosage exhibited a 13.8% increase in compressive strength compared to the control sample after 28 days of curing.

The particle size of WGP plays a crucial role in the pozzolanic activity and the resulting compressive strength of CPB. Finer WGP particles (75 µm and 90 µm) were more effective in improving the workability and strength of CPB compared to coarser particles (125 µm). This suggests that optimizing particle size is critical for maximizing the benefits of WGP in CPB formulations.

The study observed an improvement in the workability of CPB with the addition of finer WGP particles. CPB mixes with 75 µm and 90 µm WGP particles showed increased slump values, indicating better flowability and ease of application. However, the workability decreased with larger particle sizes (125 µm), likely due to increased internal friction within the paste.

The use of WGP as a partial cement replacement offers significant economic benefits by reducing the cost associated with cement consumption in CPB. Additionally, utilizing waste glass in this manner contributes to environmental sustainability by diverting glass waste from landfills and reducing the carbon footprint associated with cement production.

While the study highlighted the benefits of WGP, it also noted limitations, particularly at higher dosages (30% and 40%). At these levels, the compressive strength of CPB decreased, possibly due to particle agglomeration and reduced cement content. This suggests that there is an optimal range (10% to 20% WGP) where the benefits are maximized without compromising the material's structural integrity.

Based on findings from this study, it may be concluded that multi-coloured waste glasses have a potential application in improving the mechanical performance of CPB if ground at a finer size of less than 150 µm. The main discoveries of this study are outlined below:

WGP has shown great potential as a replacement material for cement and can offer adequate strength for backfilling and support purposes

Due to the potential for binder replacement, it offers an opportunity for the safe disposal of solid wastes generated from waste glasses

WGP use in partial replacement can reduce the costs of using additives as it has shown improvement in backfill workability at high dosages.

Recommendation

The study on using Waste Glass Powder (WGP) as a partial cement replacement in Cemented Paste Backfill (CPB) offers several key recommendations to optimize the use of WGP for enhancing CPB performance. These recommendations are aimed at both improving the mechanical properties of CPB and maximizing the economic and environmental benefits.

The study suggests that the optimal dosage of WGP for CPB applications lies between 10% and 20% replacement of cement by weight. To achieve the best balance between enhanced compressive strength and workability, practitioners should consider using WGP at dosages within this range. Specifically, a 10% WGP dosage with finer particle sizes of 125 µm is recommended to maximize strength gains without compromising the workability or stability of the CPB.

The size of WGP particles has a significant impact on both the pozzolanic activity and the overall mechanical performance of the CPB. For optimal results, finer WGP particles (75 µm to 125 µm) should be used. These particle sizes are more reactive, leading to better integration with the cement matrix, improved compressive strength, and enhanced workability. It is advisable to avoid coarser particles (150 µm).

The study provides insights into the short-term performance of CPB with WGP, the long-term effects, especially in terms of durability and resistance to environmental factors, require further investigation.

The incorporation of WGP offers potential environmental benefits by reducing waste and the carbon footprint associated with cement production. Mining companies and construction industries should conduct a detailed environmental and economic impact analysis to fully quantify the benefits of using WGP in CPB. This analysis should include considerations of local availability of waste glass, transportation costs, and the environmental benefits of reducing cement use.

The findings of the study are based on laboratory-scale experiments, which may not fully represent the complexities of large-scale CPB applications in mining. Before widespread adoption, pilot-scale trials and field tests should be conducted to validate the laboratory findings under real-world conditions. These trials should assess the scalability of the process, the practical challenges of implementation, and the overall effectiveness of WGP in large-scale CPB operations.

scope of this study did not delve much into the chemical behaviors of backfill materials. Further studies should be conducted on WGP, tailings and Cement chemistry.

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