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Research Article

Recycling Dam Tailings as Cemented Mine Backfill: Mechanical and Geotechnical Properties

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As a result of developing technology and scientific studies, employing dam tailings as critical raw material and vital economic reserve has become widespread recently. Employing dam tailings as a main ingredient of CPB (cemented paste backfill) can offer benefits to mining operations. This study deals with the use of dam tailings in CPB, considering the mechanical and geotechnical aspects. CPB was prepared at fixed solid and cement contents (72%, and 5%, respectively) and tested for different cure ages varying from 3 to 56 days. The results disclosed that the strength of filling increased over time, with the exception of 56-day cured CPB having high sulfur minerals where strength decreased sharply. The reasons behind these strength surges could be clarified by CPB's basicity, which quickens the hydration of cement. Voids between tailings grains are also occupied by hydration products, resulting in the high strengths. Due to the fact that higher sulfate contents can cause lower pH values within CPB, this is one of the factors that should be considered for the backfill's strength performance. The cement tends to increase the backfill's pH in short term, but pH of long-term cured backfills decreases because of dam tailings which is inclined to acid formations and erosions. This is a sign that the deformation properties of CPB are deteriorated. Depending on curing time, CPB's water content and void ratio decrease, but their surface areas increase. The resulting data will endow to better apprehend the effects of dam tailings on CPB quality integrating cost and quality.

1. Introduction

The major amounts of tailings are inevitably created on account of the processing of valuable minerals in the mining sector [1, 2]. They are mostly cumulated in surface tailings impoundments/dams and refilled into underground stopes where the ore is extracted [3, 4]. In particular, pyritic tailings stored on surface occupy and possibly contaminate large fertile lands or soils and surface-ground water, creating the development of acid mine drainage in prevalence of H_2O and O_2 [5, 6]. These risks continue during and after the mining operation by posing a serious threat to the environment [7, 8]. Although these problematic tailings are seen as economically worthless, nowadays they are used as raw material, such as in geopolymer [9], mine backfill [10], ceramics manufacture [11], and brick production [12] and to reestablish plant fertility in polluted soils [13]. Valorization of the tailings appears to be not only a source of invaluable raw materials but also a capable substitute to cut their ecological impacts [14, 15]. In recent years, the effective reuse of the tailings produced after active mining operations in different sectors such as construction and civil engineering causes a major reduction in the amount of the generated tailings which need to be treated properly [16, 17]. However, the continuous storage of tailings into the dams might create capacity problems and hence pose a serious risk such as failure and leakage [18, 19].

In addition, when compared to low-grade ores, the tailings received from dams can contain many valuable elements and present a remarkable commercial value [20, 21]. Taking into account the elements in tailings accumulated in the dams, they can be used either for backfill (acidified tailings) or for raw materials (nondamaged tailings) [22]. Nevertheless, the current study will consider acidified dam tailings for mine fill applications, especially for cemented paste backfill (CPB), while the nondamaged dam tailings are out of the scope of this study. Being an innovative tailings disposal system, CPB allows mine operators to send 65–80% of pyritic tailings back to underground stopes as backfill (it helps to build for ground support) or disposal purposes [23, 24]. Unlike concrete materials, CPB has unique properties such as finer (at least 15% under 20 μm) grain size, higher (typically more than 5) water/cement ratio, and lower (typically less than 10%) cement content [25, 26]. As a result of these characteristics, CPB increases the neutralization potential of pyritic tailings and ensures secure storage in an alkaline environment with low permeability [27]. Consequently, CPB has been frequently preferred in the mining industry targeting both sustainable development and circular economy [28, 29].

Numerous researchers have so far focused on CPB's key components such as physical [30], chemical [31], rheological [32], and mechanical properties [33]. However, the mining-induced environmental problems have led rethinking mine operators to reduce or eliminate the presence of pyritic tailings accumulated in the dams [34–37]. Aldhafeeri and Fall [38] experimentally investigated the effect of cemented paste tailings (CPT) on the reactivity of the initial sulfate content by conducting O2 consumption tests on backfill samples and observed that CPT's reactivity augmented with growing sulfate concentration. Dong et al. [7] explored sulfate effect on CPB's long-term stability and found that high amounts of sulfur minerals like pyrite caused severe erosion between 90 and 360 days of curing times, decreasing the backfill strength by 11–32%. Li et al. [39] evaluated the short-term strength of CPB with variable sulfur content (6–25wt.%) and found that a significant loss of strength (~21%) occurred in 14-day cured samples. Liu et al. [40] examined the influence of sulfur content on CPB's strength characteristics and stated that sulfur content plays a vital role in these properties of backfilling. Zheng et al. [41] explored experimentally the potential of employing slag activated with reactive MgO as a binding agent within the backfill with sulfidic tailings and found that pH values (11.5) increased before 14 days by reason of acid/sulfate attacks while they decreased to 9.8–10.5 after 14 days (from 28 to 360 days).

The above-mentioned literature has mainly focused on short- and long-term effects of pyritic tailings generated from ore processing plant. However, the impact and potential use of already-deposited dam tailings which can have different pH values have not been totally investigated yet. In this study, the effect of dam tailings with different pH values (4.2, 5.9, 6.8, and 10.5–control sample) on quality and performance of CPB was investigated experimentally. Three tailings samples (pH: 4.2, 5.9, and 6.8) are collected from the different regions of a selected tailings dam site, while one tailings sample (pH: 10.5) is received from the filter of a flotation based ore processing plant. Mine fill specimens were manufactured by employing a fixed binder dosage of 5wt.% and solid content of 72wt.% and later exposed to several mechanical (e.g., uniaxial compressive strength, stress-strain behavior, and elastic modulus) and geotechnical (e.g., water content, porosity, specific surface area, and degree of saturation) characteristics of mine fill specimens. In addition, how diverse pH tailings affect the overall performance and behavior of mine fills was thoroughly discussed in the current paper.

2. Materials and Methods

2.1. Properties of Ingredients

2.1.1. Tailings. Pyritic tailings experimented in this work were supplied from an active underground copper mine. Two types of concentrate are produced in the concentrator facility of the tested mine: Copper concentrate with 17–18wt.% Cu content and pyrite concentrate with 47–48% S content. In addition to these concentrates, the mine also generates processing tailings which are noneconomical and managed sustainably in different places. Nearly 80% of the generated tailings are deposited into tailings dams, while the rest (20wt.%) are used as cemented paste backfill (CPB). The primary target of the current work is to recycle dam tailings as CPB. Accordingly, three samples were collected from different points of the tailings dam (DTS1, DTS2, and DTS3), while one sample was collected from the filter (PTS, it will be also evaluated as control sample). The dam tailings were sampled from a close distance of 3 to 5 m and a depth of 15–25 cm with the help of auger and shovel-up. The sample collection points are clearly shown in Figure 1.

Physical characteristics of four tailings samples are listed in Table 1. Specific gravity (G_s) of tailings differs from 3.57 to 3.81, while their specific surface areas (S_s) vary in the range of 2.68–2.89 m^2/g. The highest maximum dry density value (2.55 kg/m^3) and moisture content value (13.4%) were obtained from DTS1 sample. Tailings' chemistry was also detected using PANalytical Epsilon 5 energy dispersion XRF (X-ray fluorescence) spectrometry, and the achieved outcomes are presented in Table 2. According to the oxide analysis results, it was determined that Fe_2O_3 was the most dominant compound, varying from 33.45% to 43.06%.

2.1.2. Binder and Mixing Water. Ordinary Portland cement (OPC) type I 42.5R was employed as a principal binder within diverse CPB mixtures. The G_S and S_S values of OPC were found as 3.11 and 0.39 m^2/g, respectively. The contents of CaO and SiO_2, which are OPC's main components, were found to be 63.76% and 17.76%, respectively. Only tap water was used in CPB mixtures. It is kept in mind that the influence of mixing water on CPB's chemistry was not definitely aimed at in the current work.

2.2. Experimental System

2.2.1. Backfill Manufacturing. A total of 36 CPB specimens were smoothly manufactured in the geotechnical, waste management, and backfill laboratory (Table 3). Since the goal of this work is to experimentally measure the influence of mechanical and geotechnical parameters on backfill's

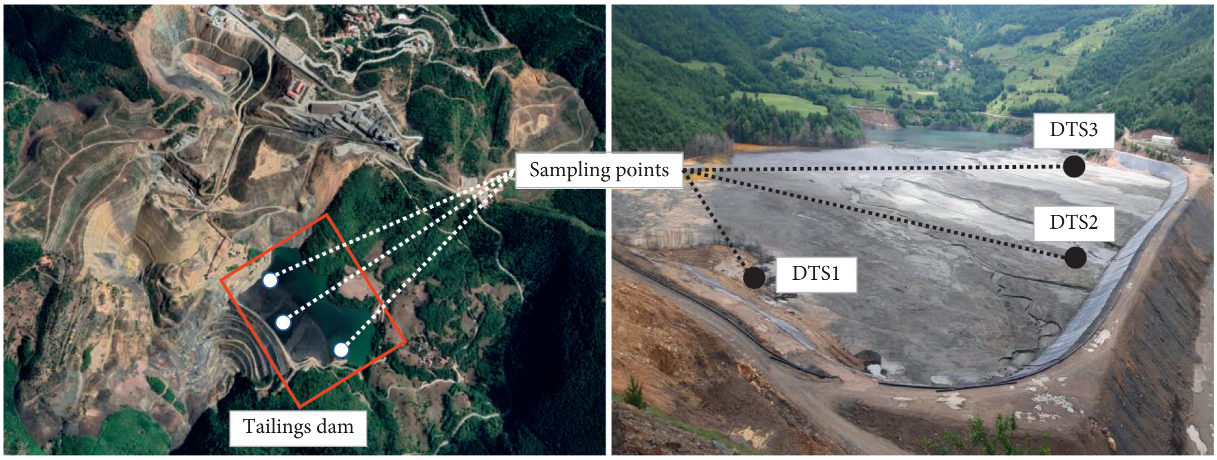


Figure 1: The sample collection points in the tailings dam: (a) satellite view and (b) dam view.

Table 1: Tailings' physical properties.

Samples	Specific gravity (GS)	Specific surface area (SS, m^2/g)	Maximum dry density (kg/m^3)	Optimum moisture content (%)
DTS1	3.81	2.89	2.55	13.4
DTS2	3.75	2.83	2.49	12.9
DTS3	3.67	2.77	2.42	12.4
PTS	3.57	2.68	2.37	12.3

Table 2: Tailings' chemical properties (oxide analyses).

Composition	DTS1 (%)	DTS2 (%)	DTS3 (%)	PTS (%)
Fe_2O_3	33.45	37.11	40.75	43.06
Mn_3O_4	0.13	0.14	0.13	0.07
BaO	0.01	0.01	0.01	0.01
TiO_2	0.20	0.19	0.25	0.31
CaO	4.81	4.01	3.99	2.60
K_2O	0.45	0.44	0.32	0.26
SO_3	0.38	0.33	0.34	0.34
P_2O_5	0.09	0.07	0.07	0.05
SrO	0.01	0.01	0.01	0.01
SiO_2	34.31	30.11	25.44	23.16
Al_2O_3	6.13	6.99	7.07	7.78
MgO	1.66	1.88	1.82	2.46
Na_2O	0.06	0.05	0.06	0.11
LOI	18.32	20.11	20.17	20.23

Table 3: Different mixture recipes of CPB materials manufactured with dam tailings.

CPB-ID	Tailings type	Binder content (%)	Solid content (wt.%)	Pyrite/sulfide content (%)	pH value	Slump (cm)	Curing time (days)
CPB-D1	DTS1	5	72	46/34	4.2	25	3, 14, 28, 56
CPB-D2	DTS2	5	72	39/25	5.9	25	3, 14, 28, 56
CPB-D3	DTS3	5	72	35/21	6.8	25	3, 14, 28, 56
CPB-P	PTS	5	72	32/16	10.5	25	3, 14, 28, 56

quality and behavior, solid (72wt.%) and cement (5wt.%) contents of CPB samples were kept constant. Firstly, the blending ratios were determined for each CPB sample, and samples were thoroughly mixed for 7–10 minutes with the help of the UTEST lab mixer until the mixture got homogeneous. To remove air within the backfill, a steel rod stick was used by tamping 25 times. The prepared backfill materials were cast in a cylindrical plastic mold ($D \times H$:

50×100 mm) in one-third length increments. The casting backfill molds were then closed by using plastic covers to prevent air and water from evaporating and oxidizing in the course of curing time. Finally, backfills were put in the cure room until target curing of 3, 14, 28, and 56 days. The curing box was adjusted to be at $20 \pm 3^{\circ}$C temperature and 90 ± 5% humidity. Figure 2 shows some stages of the backfill sample preparation. Three CPB backfills were manufactured for a given mine backfill recipe and their mean value was considered as a main result in this paper.

2.2.2. Determination of Mechanical Parameters. The backfill's mechanical parameters (e.g., uniaxial compressive strength (UCS), stress-strain behavior, and elastic modulus E50) were experimentally investigated. A servo controlled UTEST Multiplex machine having 50 kN nominal capacity and 1 mm/min replacement rate was used for characterizing the backfill's mechanical parameters. Once CPB samples reached the target curing time, they were removed from the plastic molds placed within cure box and sample dimensions were measured by caliper and assay balance. The upper/lower sections of hardened fill samples to be placed between the platens were smoothed by a sharp instrument (cutter). The UCS tests of cylindrical backfill samples prepared in $D \times H$: 5×10 cm (a length/diameter ratio of 2) were performed by following the ASTM C39 standard.

2.2.3. Determination of Geotechnical Parameters. After mechanical testing, CPB's specific surface area S_s, specific gravity G_s, water content w, void ratio e, and saturation degree S_r parameters were measured by using different methods. The BET technique (using a Micromeritics Gemini 2375 volumetric analyzer) was employed to determine samples' S_s values. To measure the backfill's w values, sample pieces were oven-dried at nearly 50°C for 2 days. The G_s value was explored with the aid of the Micromeritics AccuPyc 1330 helium pycnometer. CPB's pore structures were detected by employing a Micromeritics Autopore III 9420 Hg intrusion porosimeter. Accordingly, void ratio e was calculated by using equation (1). The degree of saturation S_r parameter was also estimated by employing already-known parameters w, G_s, and e (see equation (2));

$$e = \frac{n}{1-n}. \tag{1}$$

$$S_r = \frac{wG_s}{e}, \tag{2}$$

where G_s is the specific gravity; n is the porosity (%); e is the void ratio; w is the water content (wt. %); and S_r is saturation degree (%).

3. Results and Discussion

3.1. Influence of Dam Tailings on Mine Backfill Strength. Figure 3 displays the strength development of mine backfills being cured after 3, 14, 28, and 56 days. UCS values of all backfill samples (CPB-D1, CPB-D2, CPB-D3, and CPB-P) increased during the first 28 days of curing. However, at 56-day curing time, a 3.9% decrease in the strength acquisition of CPB-D1 (compared to 28-day curing time) was observed. The 56-day cured backfills (CPB-D3, CPB-P, and CPB-D2) provided, respectively, 19.4%, 11.1%, and 4.9% higher strengths than the 28-day cured ones. CPB-P had the highest strength (0.582 MPa), while CPB-D1 had the lowest strength (0.221 MPa). CPB-D1 produced 55.0%, 60.1%, 56.1%, and 62.0% lower strengths than control sample (CPB-P) for curing times of 3, 14, 28, and 56 days, respectively. These values were 42.9%, 47.5%, 40.0%, and 43.3% for CPB-D2 and 18.9%, 27.0%, 19.7%, and 13.8% for CPB-D3, respectively. The key reason behind the strength changes in different CPB samples as a function of pH can be explained by cement hydration. At early curing ages (3–28 days), calcium oxide (CaO) being produced because of cement hydration increased due to the alkalinity of the medium. This led to an increase in alkalinity which caused increasing the strength of CPB samples.

In the long term (56 days), the decrease in pH values and the gradual increase in sulfate content slowed down the rate of cement hydration and decreased the alkalinity of the internal system by producing acid. The strength of CPB-P, CPB-D3, and CPB-D2 samples which reached high pH values was not affected greatly although pH of the medium decreased. However, the strength of 56-day cured CPB-D1 decreased mainly due to the pH value below 7, which indicates an acidic environment. In addition, the decrease in ambient alkalinity during long curing times caused slight erosions on samples. The decrease in the pH value of CPB not only created an unfavorable environment for cement hydration but also caused the deterioration of other backfills. The acidic property of tailings is a parameter that directly affects the strength of CPB. This issue was well discussed in every single aspect in the literature works [7, 39].

3.2. Influence of Dam Tailings on CPB's Stress-Strain Curves. Figure 4 displays the stress-strain relationship of 28- and 56-day cured CPB samples. Stress-strain curves can be assessed in four stages (i.e., pore compaction, elastic deformation, plastic flow, and rupture-fracture). Samples at the pore compaction stage had many voids due to the loose nature of tailings. After the first load is applied, the microcavities of CPB samples began to close and a bowl-shaped stress-strain curve formed. At second stage, as compressive stress increases, strain increases equivalently and CPB samples arrived at the stage of elastic deformation. Thus, the stress-strain curve goes to a straight line and the microcracks form within CPB. At the next stage (plastic flow stage), elastic deformation turned into plastic one. Then the internal cavities and cracks of CPB gradually expanded and the curve reached the maximum (peak) strengths. The highest strengths and slopes of the curve were observed in CPB-P samples, while the smallest ones were observed in CPB-D1. As the compressive stress continued to be applied, the stress gradually decreased and all CPB samples had certain residual strengths after failure. It was found that the CPB-P and CPB-D3 samples showed high brittleness after stress reached the

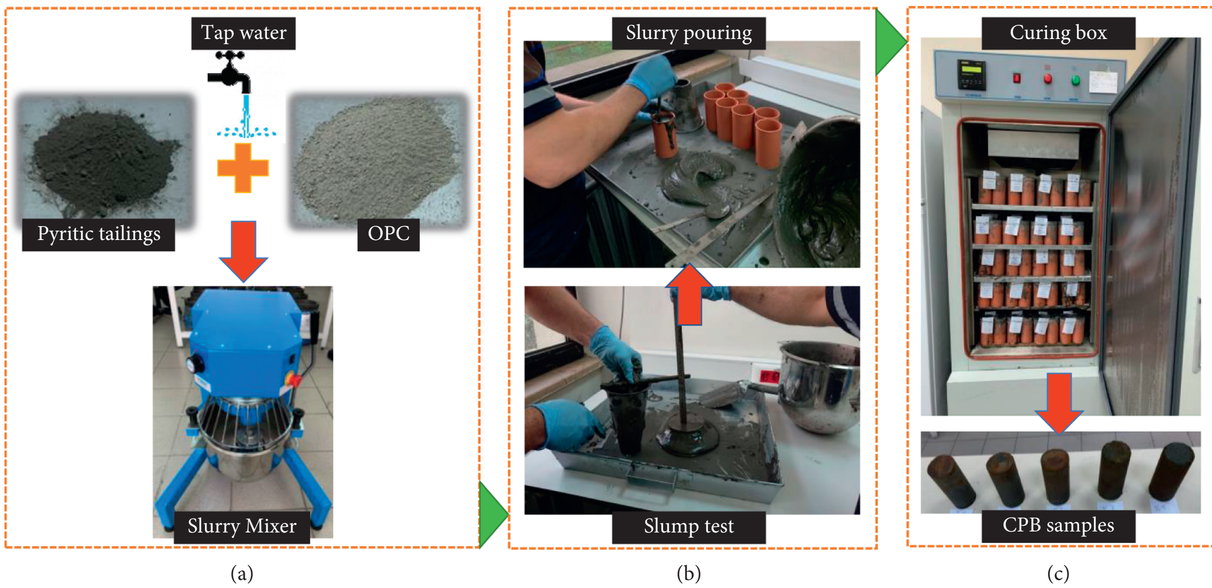


Figure 2: Manufacturing stages of backfill mixtures: (a) blending, (b) slump measurements, and (c) curing.

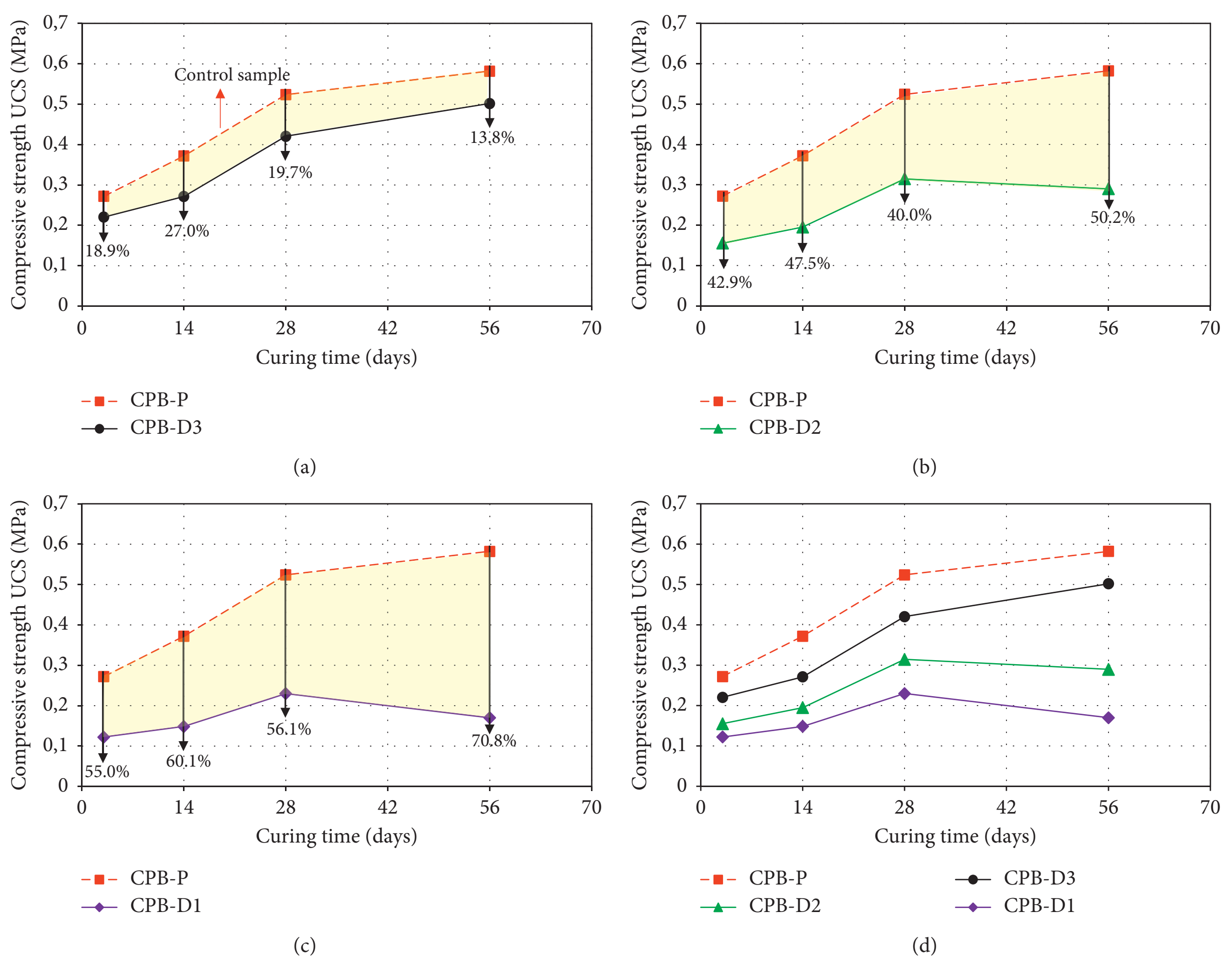
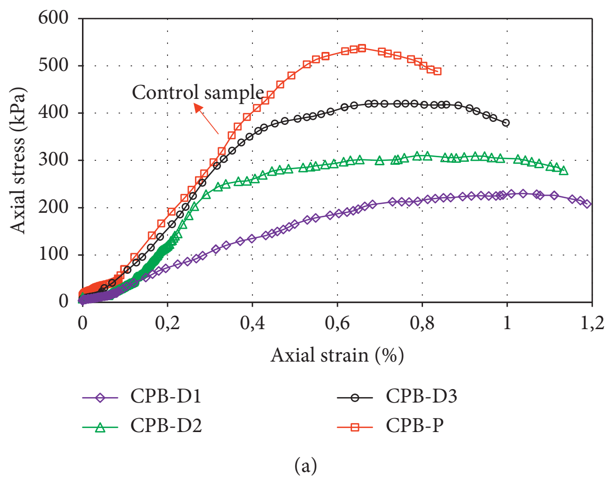


Figure 3: Change in UCS with time for diverse mine backfills.

peak values. However, CPB-D1 and CPB-D2 samples had larger strain values compared to other samples. Since the pH values of these samples are very low, an acidic medium (causing lower pH values) formed and CPB indicated ductile behavior. Similar stress-strain behavior was observed in the literature [32, 42]. One can also observe from Figure 4 that



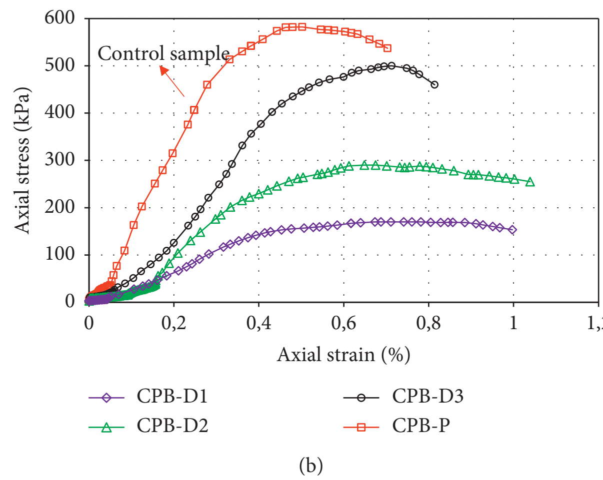


Figure 4: Change in axial stress with axial strain for diverse mine backfills: (a) 28 days and (b) 56 days.

56-day cured backfills had higher peak and residual strengths in comparison with 28-day cured ones.

3.3. Influence of Dam Tailings on CPB's Elastic Modulus. Elastic modulus is a vital factor to better clarify the resistance of mine backfills to elastic deformation. While it reflects the compressive capacity of mine backfills, it is attentively connected to bearing capacity in upper layers of the backfills placed in subsurface voids. Three methods, tangent modulus ($E_{\max}$), secant modulus (E_s), and mean modulus (E50), are mostly used to determine the elastic modulus values according to the ASTM D3148 standard. The E50 value which is equivalent to 50% of the failure stress is used to determine the service condition of geotechnical structures like CPB during their service life [43]. In this study, the E50 values obtained from stress-strain curves, based on UCS testing, were used. Figure 5 shows the relationship between E50 and cure time for diverse mine backfills. Overall, elastic modulus of CPB samples varies between 10 and 20 MPa at early ages and between 100 and 1200 MPa at later ages [42, 44]. The E50 values obtained for all backfill samples range from 14 to 115 MPa, which shows that the values found are in agreement with earlier studies.

E50 values of all mine backfills increase over time as a consequence of chemical reactions that take place inside CPB. The increase in the backfill's density due to the hydration products (C-S-H gels) which fill CPB's pores can trigger creating a harder material with a higher elastic modulus [45]. This is the reason why the control sample CPB-P in particular exhibits high E50 values. In comparison, the samples CPB-D1, CPB-D2, and CPB-D3 (acidic samples) prepared with dam tailings have lower E50 values by 22.1% to 78.7%. The main reason for this significant decrease is related to the corrosion effect that occurs in CPB samples after 28 days. The corrosion effect (lowering of the pH in CPB) in the backfill pointedly affects the resistance of backfilling to elastic deformation [46]. Moreover, this situation promotes the formation of corrosive ions in CPB, which prevents the reactions between hydrated gels and affects CPB's rigidity. In addition, a large amount of expansion crystals is expected to form in CPB with low pH values (high sulfate concentration) after 56 days, causing the formation of cracks in mine backfills and thus a drop in the elastic modulus. As mentioned earlier, the long-term deterioration of the structural integrity of CPB prepared with dam tailings is directly related to acidity. Acidic tailings directly lead to sulfate attack and corrosion formation, which prevents CPB's pore structure and the cement's hydration formation. As a result, developing elastic modulus is directly influenced by acidic dam tailings.

3.4. Geotechnical Parameters

3.4.1. Assessment of Water Content. Index properties like water content w (%), specific surface area S_s (m^2/g), saturation degree S_r (%), and void ratio e strongly govern CPB's stability. In cementitious materials like CPB, cement and water content directly affect the curing time [47]. Figure 6 displays the disparity in CPB's water content over time. Although the water content of all cured samples varies between 7% and 20.5%, the water content decreases with increasing cure time. The lowest water content (7%) was observed in reference sample (CPB-P), while the highest water content (20.5%) was observed in CPB-D1 sample. However, the water content of 56-day cured samples lessened in the range of 20.3–52.4% in comparison with 3-day curing time. The water contents of 56-day cured CPB-D1 and CPB-D2 samples only showed an increase (4.95% and 2.13%, respectively) when compared to 28 days. In general, the decrease in the water content increased CPB's performance. Basically, the free water required for CPB's cement hydration governs the amount of final water [48].

The water used within the mixture has two main functions on CPB, such as workability and initiating the hydration process. However, the drainage of CPB pore waters over time causes a serious decrease in total void ratio, increasing the strength [49]. In addition, the drainage of pore water contributes to the hydration process [50]. This leads to CPB with

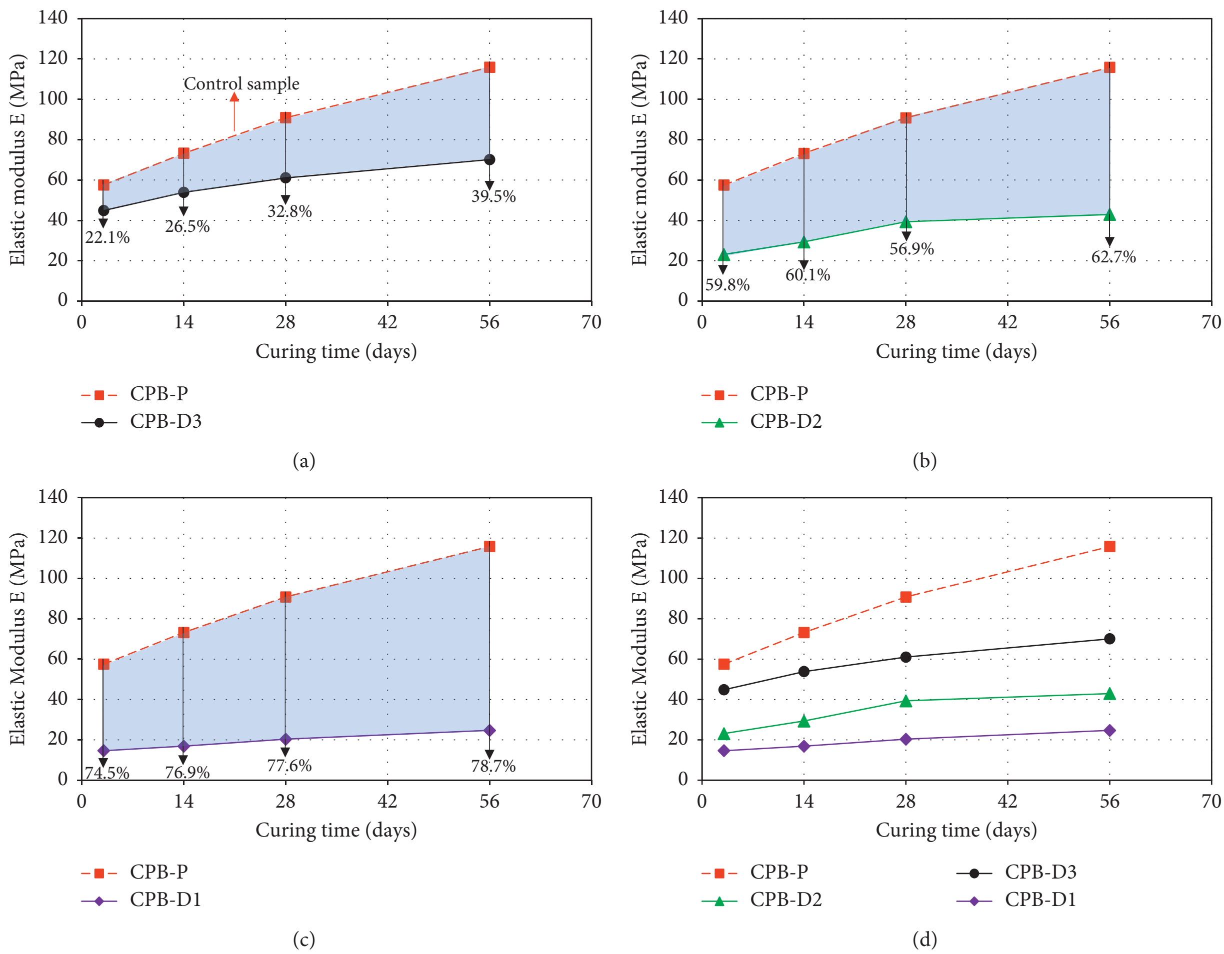


Figure 5: Change in elastic modulus with time for diverse mine backfills.

pores formed as a result of hydration (contributed to the hardening process in CPB samples) [51]. The main reason for the increase in water content in CPB-D1 and CPB-D2 samples during the 56-day curing period can be explained by the low ambient pH compared to other samples [49]. The decrease in pH provides acidic properties and stops the chemical reactions in CPB. This causes excess water to remain in sample. Therefore, excess water that does not participate in hydration can be considered as a reason for the strength reduction of CPB.

3.4.2. Assessment of Void Ratio. Figure 7 indicates that void ratio (e) of CPB samples significantly decreased over the entire curing time. Note that void ratios of all backfill samples differ from 0.49 to 0.87. However, the void ratios of 56-day cured samples decreased between 2.30% and 25.8% when compared to 3-day curing time. The lowest void ratio (0.49) was observed in the reference sample (CPB-P), while the highest void ratio (0.87) was observed in the CPB-D1 sample. The curing time is closely related to CPB's total void ratio. The drop in e value causes the water drainage and a sharp rise in the fill's density. This causes the continued hydration process to generate bigger quantities of hydration product that fills the spaces between particles, thus significantly reducing the void ratio [52]. This is not the case for CPB-D1 and CPB-D2 samples, although the void ratios were noticeably reduced in all samples. In general, when compared to 3 days, the void ratio in 56-day cured CPB-D3 and CPB-P samples decreased by 20.3% and 25.8%, respectively, while these values were reduced by 2.30% and 5.88% for CPB-D1 and CPB-D2 samples, respectively.

Void ratio is greatly increased by evaporation of excess chemically unreacted water (low pH samples) [53]. As the curing times of CPB-D1 and CPB-D2 samples increase, the decrease in ambient pH causes an increase in the void ratio by preventing the chemical reaction (hydration) that fills the voids of the mixture [54]. In addition, void ratio is closely related to the grain size. When fine grains are undue (the grain size of acidic samples is small), coarse grains will be repelled by fine grains, significantly increasing the sum of water requested for filling the spaces between the particles. On account of this situation, the absence of sufficient water for hydration or the presence of acidic water will increase the void ratio in CPB [55, 56]. The 56-day cured CPB-D1 and CPB-D2 have the highest void ratios, increasing by 2.41% and 1.27%, respectively, when compared to 28 days. In addition, since CPB-D3 and CPB-P samples showed basic

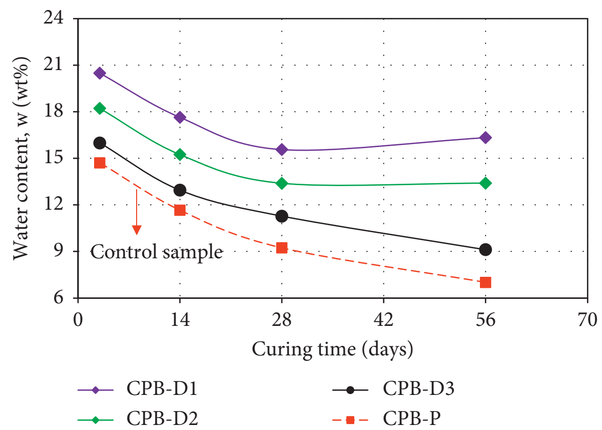


FIGURE 6: Change in water content with time for diverse mine backfills.

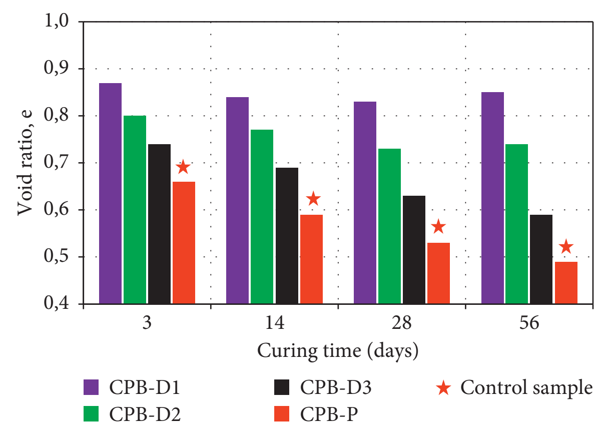


FIGURE 7: Change in void ratio with time for diverse mine backfills.

properties in the long term, hydration reactions were partially prevented and void ratios were low.

3.4.3. Assessment of Specific Surface Area. SSA is interrelated by the setting development and final strength of CPB. As can be seen from Figure 8, fill's S_S performance increases with increasing cure time. The S_S values of all samples varied in the range of 4.11–12.0 m^2/g, and the lowest S_S value was observed in CPB-D1 sample, while the highest S_S value was observed in reference sample (CPB-P). In addition, after 28-day curing time, S_S of samples increased, while S_S of CPB-D1 sample alone decreased by 1.26%. Although S_S is directly related to microstructure and grain size, it determines the reactivity of samples [53].

It is clear that fine-grained materials have larger S_S values than large-grained ones. As a result, a higher S_S means more surface to be cemented (escalated hydration products and decreased free water) [54]. This directly affects the performance of CPB positively. In addition, S_S changes in direct proportion to the packing density. Increasing the surface area increases the packing density, filling the spaces between the large particles in CPB and providing a more compact structure. As a result, the increase in packing density

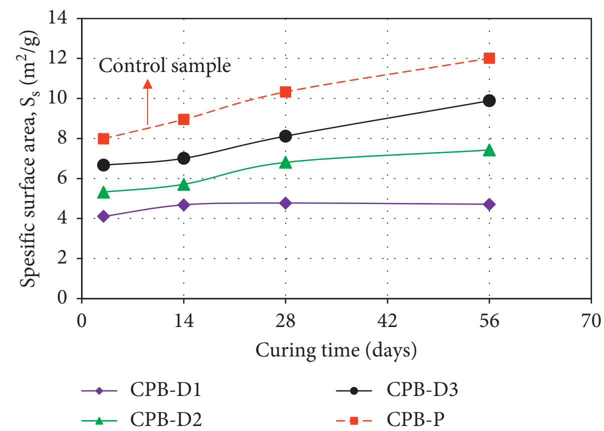


FIGURE 8: Change in S_s values with time for diverse mine backfills.

contributes to fill's strength increase [55]. However, S_S effect on CPB performance can be complex. In other words, although CPB grains with small surface areas are less reactive, grains with large surface areas show high reactivity due to high water retention [57]. As a result, oxygen diffusion and sulfide oxidation rate are affected. Increasing S_S (reducing grain size) increases the degree of liberation of harmful minerals such as sulfide and decreases pH of the environment [58]. Equally, a decrease in pH and the existence of harmful minerals such as sulfites cause an increase in S_S [59].

3.4.4. Assessment of Degree of Saturation. Figure 9 displays variation in fill's saturation depending on cure time. S_r decreases with curing times of 3.14, 28, and 56 days. These reductions for 56-day cured CPB-D1, CPB-D2, CPB-D3, and CPB-P samples were 17.0%, 18.4%, 27.3%, and 33.1%, respectively, when compared to 3-day curing time. Fill's water consumption from completely saturated to incompletely saturated state can be clarified by cement hydration. S_r is greatly affected by fill's drainage ability. In particular, the bottom-perforated plastic containers increase the drainage ability of CPB and reduce its saturation over time. The smaller the degree of saturation, the larger the performance and stability of CPB [60]. The water consumption by cement hydration in CPB causes larger absorption (adsorption is directly related to CPB's pore structure) [61].

The increase in the suction force strengthens the bonds between CPB particles and contributes to the improvement of their strength and fracture resistance [62]. The saturation of all samples varied between 55.9% and 95.4%; the lowest S_r value was observed in CPB-P sample, while the highest S_r value was observed in CPB-D1 sample. Although the S_r values in samples continued to decrease after the 28-day curing period, the saturation degrees of 56-day cured CPB-D1 and CPB-D2 samples showed a small increase of 1.98% and 0.86%, respectively, when compared to 28-day curing time. Until the 28-day curing period, the amount of free water in samples is consumed due to the hydration process, but the saturation decreases.

However, after 28-day curing period, the oxidation of CPB-D1 and CPB-D2 samples damages the products created

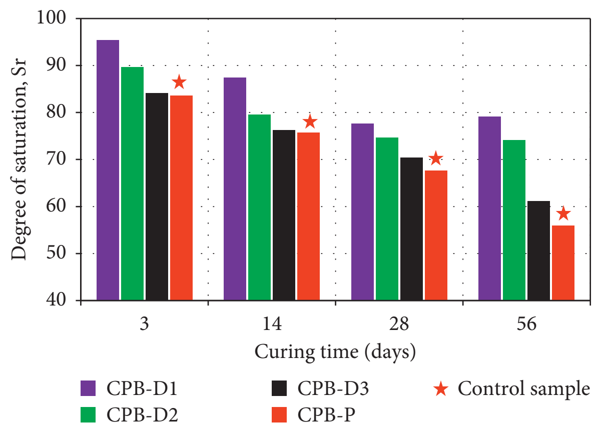


Figure 9: Change in the degree of saturation with time for diverse mine backfills.

by means of hydration. In particular, the mixing of sulfide minerals such as pyrite into pore waters breaks up C-S-H gels. The hydration's weakening causes water in the environment not to be consumed for the hydration process, which increases the saturation of CPB [63]. In addition, this high saturation or free water content allows the hydration products to crystallize [64]. Excess water remaining in sample cavities will evaporate over time, causing samples to have a hollow structure. This will cause strength losses in CPB as well as a decrease in toughness.

3.5. Interpretation on the Effect of Dam Tailings. When the variation of pH in the tested CPB samples is explored, it is apparent that there are serious differences between process tailings and the tailings collected from the dam. When the physical properties of CPB samples were examined, the increase in pH values supported the alkaline environment, causing an increase in hydration products and thus filling the voids in CPB with these products, thus reducing the porosity. The fill's water content decreased owing to void reduction and the consumption of pore water in hydration processes, as proven by Wang et al. [65]. Likewise, the degree of saturation decreased in parallel with the water content. The decrease in the amount of voids increases the strength of CPB [66]. The recent works done by Lopes et al. [67] clearly show the effect of pH on water content and void ratio. At the same time, acidification on the samples with the decrease of pH values caused direct erosion, reducing the grain size and causing structural deterioration. Considering the above-mentioned parameters, the effect of pH of samples on CPB performance was clearly observed. As a result, one can conclude that it is important to take into account the effects of acidic or basic while evaluating dam tailings as CPB.

4. Conclusions

The current work assesses the influence of pH of diverse tailings (e.g., dam and process) on quality and performance of CPB samples. Dam tailings are collected from three different locations of the dam while processing tailings are collected from the discharge of filter. CPB samples were prepared by using these four tailings (three of them are in acidic condition, while one is basic condition). After curing for 3–56 days, all mine backfills were subjected to both UCS and geotechnical index tests. From the executed laboratory test works, some key assumptions can be made below:

(i) Regardless of the tailings type (dam or process tailings), the strengths of all CPB samples increased until 28 days. However, in comparison with 28-day cured backfills, the strength gains of 56-day cured CPB-D1 and CPB-D2 samples decreased by 6.5% and 26.1%, respectively.

(ii) According to stress-strain behaviors of 28-day and 56-day cured backfills, CPB-P had the highest stress value with brittle behavior, while CPB-D1 samples had higher strain and ductile behavior than others. The minimum E50 values of CPB-D1 were found to be 15 MPa, while the maximum E50 value of CPB-P samples was found to be 115 MPa for a given curing time.

(iii) The backfill's water contents reduced in the range of 20.3% to 52.4% during the 56-day curing time (compared to 3-day curing time). Similarly, after 56 days, fill's void ratios decreased between 2.30% and 25.8%, while their surface areas decreased by 14.6%–50.3%. Degree of saturation decreases between 16.6% and 33.1% after 56 days.

(iv) The geotechnical test results show that dam tailings should be treated with basic materials to reduce their harmful effects and, accordingly, to be refilled into underground mined-out stopes as a ground support element.

Finally, this study shows that tailings present in the dam can be very different from one to another because of climate and deposition conditions. Therefore, to prevent the negative effect of dam tailings, pH of the environment in the dam must be taken under control for sustainability. In the future works, the authors will consider CPB samples by adding different additives with various substitution ratios especially for problematic tailings such as acidic dam tailings.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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