Paste 2025 – AB Fourie, A Copeland, V Daigle & C MacRobert (eds)
© 2025 Australian Centre for Geomechanics, Perth, ISBN 978-1-7636842-2-5
doi:10.36487/ACG_repo/2555_34

Assessment of the flowability and compressive strength of cemented paste backfills composed of muscovite-rich tailings: impact of admixtures

Ikram Elkhoumsi [a,*], Tikou Belem [a], Mostafa Benzaazoua [b], Sara Arcila-Gut [c]

[a] *Université du Québec en Abitibi-Témiscamingue, Canada*

[b] *Mohammed VI Polytechnique University, Morocco*

[c] *Sika Canada Inc, Canada*

Abstract

The increased prevalence of phyllosilicates such as muscovite in mine tailings and their adverse effects on the compressive strength of cemented paste backfills (CPBs) have recently attracted significant attention. This issue presents challenges for underground backfilling operations, underscoring the necessity for a comprehensive understanding and effective solutions.

Admixtures can mitigate the increased water demand and loss of uniaxial compressive strength (UCS) by influencing the binder hydration process and the microstructure of the CPB, which are critical for determining the type and quantity of hydrates formed.

This study examines the compatibility of selected admixtures in CPB containing different proportions of muscovite (0, 3, 8 and 18%) and evaluates their effectiveness in enhancing fluidity and compressive strength. The experimental program aims to reveal significant alterations in the mechanical properties of CPB with admixture (A1) at varying dosages (up to 3% by weight of cement). The investigation utilises one type of binder – general use Portland limestone cement (Type GUL) at a fixed binder rate (Bw) of 7%.

The findings provide valuable insights into the application of admixtures to counteract the adverse effects of muscovite (phyllosilicate) on: 1) the water demand by decrease it to zero-water demand for low to medium muscovite-rich CPBs and up to 55.4% for high muscovite-rich CPB, 2) compressive strength by helping to gain up to 136% of UCS and, 3) the yield stress by decreasing it up to 58.5% .This article presents the potential of admixture to optimise complex and phyllosilicate-rich CPB mix formulations.

Keywords: *muscovite-type phyllosilicates, cemented paste backfill, flowability, compressive strength, admixtures dosages*

1 Introduction

The heightened content of phyllosilicates in mine tailings can significantly wane cemented paste backfill's (CPB's) mechanical strength, risking the stability and weakening underground mining structures. Their layered structure and high adsorption properties are responsible for both water demand increase and microstructural changes in the cemented paste matrix (Mshali & Visser 2014; Xing et al. 2014). Additional to the mechanical impact, the presence of phyllosilicates changes in the rheological behaviour of the paste, creating serious challenges during its transportability (high yield stress which results in high pumping pressures).

Few research studies have recognised this phenomenon, spotting strength decline (Dewar 1963; Leemann et al. 2023; Mshali & Visser 2012; Muller 1971), workability decrease (Lagerblad et al. 2014) and water demand growth (Maregesi & Salaam 2021; Mshali & Visser 2014) in several cementitious materials with rising mica

---

[*] Corresponding author. Email address: ikram.elkhoumsi@uqat.ca

content. For instance, studies indicate that incorporating mica into concrete can reduce compressive strength by 8–23% and increase water demand by up to 16% (Maregesi & Salaam 2021). Additionally, high mica content negatively affects engineering properties such as the plasticity index and the compactability of cemented aggregates (Mshali & Visser 2014). In the same study, an increase in water absorption capacity with mica addition was reported. Water absorption increased from three to over 10% by mass when mica content reached 10%.

These insights point out significant challenges in CPB mixture preparation, transport and placement, which could be addressed using admixtures as has been reported in several studies (Ouattara et al. 2018a; Ouattara et al. 2017; Saedi et al. 2021; Yang et al. 2018). The incorporation of admixtures within CPB mixture preparation can enhance its rheological and mechanical properties (Aguilar Sánchez et al. 2024; Arcila Gut et al. 2023; Erismann & Hansson 2021; Ouattara et al. 2018a; Ouattara et al. 2017; Saedi et al. 2021). Superplasticisers (SPs) and water-reducing admixtures, for example, reduce water demand and improve flowability without compromising workability (Govin et al. 2019; Yang et al. 2018). They can increase slump (Ercikdi et al. 2010; Ouattara et al. 2017) and reduce the yield stress of CPB (Fan et al. 2014; Simon & Grabinsky 2013). The use of SPs in CPB has improved workability and strength properties by decreasing water requirements without compromising fluidity (Yang et al. 2018). Phyllosilicates-rich tailings are commonly found within the Abitibian mining district and the compatibility of admixtures in backfill mixtures utilising these types of tailings is still a matter of debate. In the field of concrete and mortars it is believed that clay minerals, including muscovite, negatively impact the dispersion of SPs (Chi et al. 2024; Ma et al. 2020; Muzenda et al. 2020) and reduce their effectiveness as fluidity modifiers due to the competitive adsorption between clay minerals and cement particles (He et al. 2022; Lei et al. 2022; Ma et al. 2022).

In light of these challenges, this study investigates the potential of water-reducing admixtures (A1) to offset muscovite's adverse effects by modifying hydration behaviour and enhancing CPB microstructure. The focus in this study is on the effects of tested admixtures on both fresh-state properties, including flowability and hardened-state properties like, specifically uniaxial compressive strength (UCS).

2 Methodology

The experimental program aims to evaluate the compatibility of one selected admixture (A1) with muscovite by analysing the workability and strength development of CPB mixtures prepared with a solids content of 68 and 72% and a fixed binder content of 7% general use Portland limestone (Type GUL) cement. Compatibility of the admixture was evaluated through empirical tests, including slump tests, rheological measurements and UCS tests.

2.1 Materials characteristics

The study uses tailings (T1) from a hard rock gold mine in the Abitibi district, Quebec, Canada, with an initial water content (ω) of 20%, specific gravity (G_s) of 2.81, and fine particle content ($P_{20\mu m}$) of 42%. To increase the phyllosilicate content in T1, high-purity muscovite (M80, > 99% purity) was sourced from Arctic Minerals LLC. This muscovite, mined in North Carolina and processed in Indiana (USA), was specifically selected for its granulometric compatibility with T1, as confirmed by cumulative particle size distribution (PSD) curves (Figure 1). Internal data, along with previous studies (Loorents et al. 2007; Lagerblad et al. 2005) indicate that muscovite concentrates in the fine fractions of tailings ranging in size between d < 20–38 µm.

General use Portland limestone cement (GUL) cement was chosen for its widespread global use in backfilling operations (Tariq & Yanful 2013) and tap water (TW) was used to subtract the influence of water chemistry on CPB behaviour (Benzaazoua et al. 2002). One selected admixture (A1) provided by Sika Inc. was selected based on its compatibility with both muscovite and GUL-binder (primitive cementitious paste). Figure 3 presents the flowability results of the different admixtures screen.

Prior to CPB preparation, T1 (initial 14.5% muscovite), M80, GUL and muscovite-enriched tailing (T1M80, with additional 18% muscovite) were characterised physically, chemically and mineralogically. Specific gravity measurements revealed values of 2.85 for M80 and 2.81 for both T1 and muscovite-enriched tailings (T1M80, additional 18% muscovite). PSD analysis confirmed that the fine fractions (P20 µm) ranged from 34–52%, with specific surface areas (Ss) between 0.49 m^2/g for T1 and 2.48 m^2/g for M80. and 0.62 m2/g for T1M80 (Table 1). Figure 1 present the PDS of all ingredients and shows the very similar PSD curve between T1 and T1M80 mixture.

Chemical composition analysis using X-ray fluorescence (XRF) spectrometry (S2 Ranger, Bruker AXS) and inductively coupled plasma mass spectrometry (ICP-MS) revealed that T1 and M80 are rich in SiO_2 and Al_2O_3, with M80 containing a high K_2O content (10.5%). GUL cement was dominated by CaO (61.86%). Mineralogical analysis using a Bruker D8 Advance X-ray diffractometer (Bruker AXS, Billerica, MA, USA), of tailings (T1) identified already approximately 14.3% muscovite and 5% clinochlore (Table 3; another phyllosilicate mineral) for a total of almost 20% phyllosilicates. These detailed characterisations were made to ensured compatibility and are summarised in Tables 1–3 and Figures 1–2.

Table 1 Physical characteristics of raw materials

Parameter	Unit	M80	T1	T1M80	GUL
Specific gravity, Gs	(–)	2.85	2.81	2.81	3.17
Specific surface, Ss	m^2/g	2.48	0.49	0.62	2.17
Gravimetric water content, ω	%	< 0.4	20.8	20.8	< 0.5
D_{10} (10% weight of passing)	μm	7.38	4.62	5.1	4.42
D_{50} (50% weight of passing)	μm	31.98	27.2	33.2	19.2
$C_u = D_{60}/D_{10}$(coefficient of uniformity)	(–)	5.59	8.4	9.65	5.38
$C_c = (D_{30}^2/D_{60} *D_{10})$ (coefficient of curvature)	(–)	1.07	1.02	0.98	1.17
P_{20} (percentage of particles finer than 20µm)	%	34	42	34	52
P_{80} (percentage of particles finer than 80µm)	%	86	78	76	98

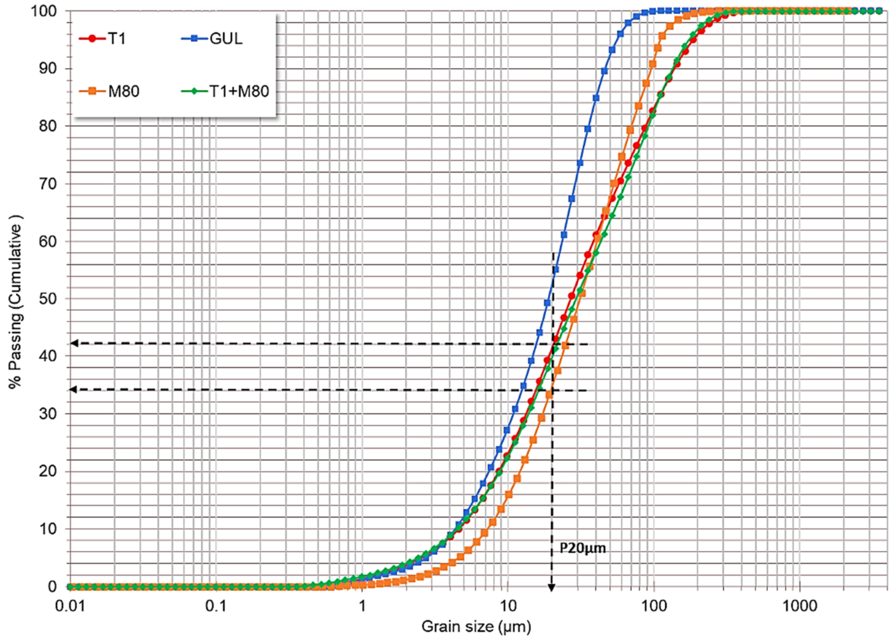


Figure 1 **Cumulative particle size distribution of raw materials (grain size in micrometres versus %-passing)**

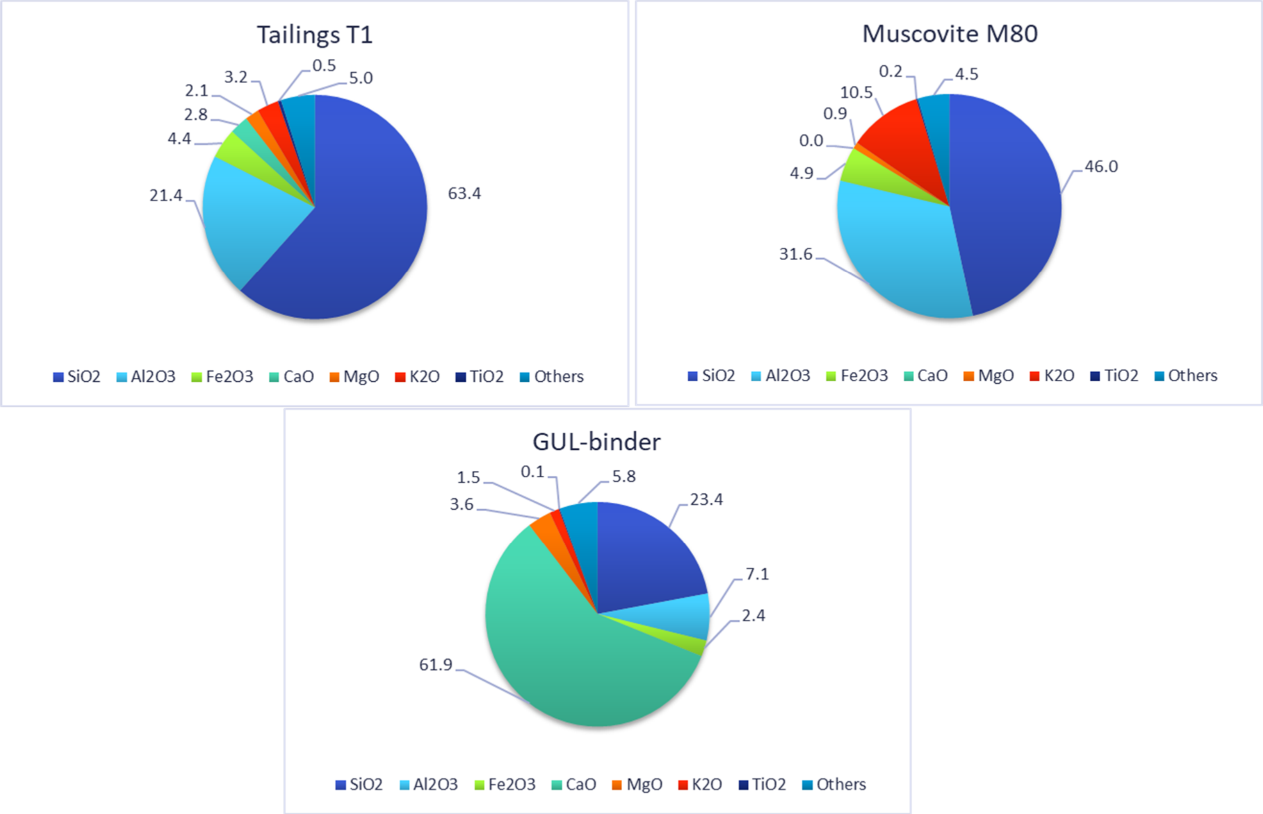


Figure 2 Chemical composition of raw materials

Table 2 Chemical composition of mixing water

Chemical element	pH	EC*	Eh**	Ca	K	Cl	Mg	Si	Al	Cu	Fe	Na	S
Unit	–	µS/cm	V	mg/l-1									
TW	7.6	0.0009	0.4	0.18	0.27	n/a	0.09	n/a	0.04	0.01	0.00	0.58	n/a

* EC: electric conductivity

**Eh: Redox potential

Table 3 Mineralogical composition (%) of tailings (T1) and muscovite (M80)

Mineral (%)	Quartz	Albite	Muscovite	Augite	Clinochlore	Pyrite	Calcite	Gypsum
T1	45.8	19.0	14.3	10.0	5.0	2.6	2.3	1.0
M80			100					

2.2 Admixture selection

The A1 admixture was selected based on a systematic series of workability experiments designed to identify admixture compatibility with primitive cementitious pastes (PP) composed solely of GUL binder and muscovite. Initial trials focused on evaluating the performance of various admixtures for muscovite-rich tailings (Figure 3). PP were prepared using M80 muscovite, GUL-binder and TW at solids content (C_w) of 72%.

A total of six PP mixtures were prepared and their flow diameters were compared to a reference paste (REF) without admixture. Notably, the reference primitive paste (without admixture) was not workable, exhibiting a very low flow diameter of approximately 25 mm. Six admixtures (A1 to A6) were tested at a dosage of 5%, and workability was assessed using a small, truncated cone that is 37 mm highest and 12.6 mm in diameter at the top (scale 1:3). Admixtures were considered suitable if they increased the paste flow diameter (F) beyond 50 mm, which corresponds to the double of the reference paste flow.

Results showed that all admixture where capable of doubling or more the reference flow. Specifically, admixtures A1 (the diameter grew by over 5.5 times its original size) followed in performance by A6 (4.6 times flow growth) demonstrated the highest flow diameters in PP mixtures, confirming their good compatibility with both muscovite and GUL-binder (Figure 3). Consequently, A1 was selected for further investigation in CPB mixtures, with its characteristics summarised in Table 4.

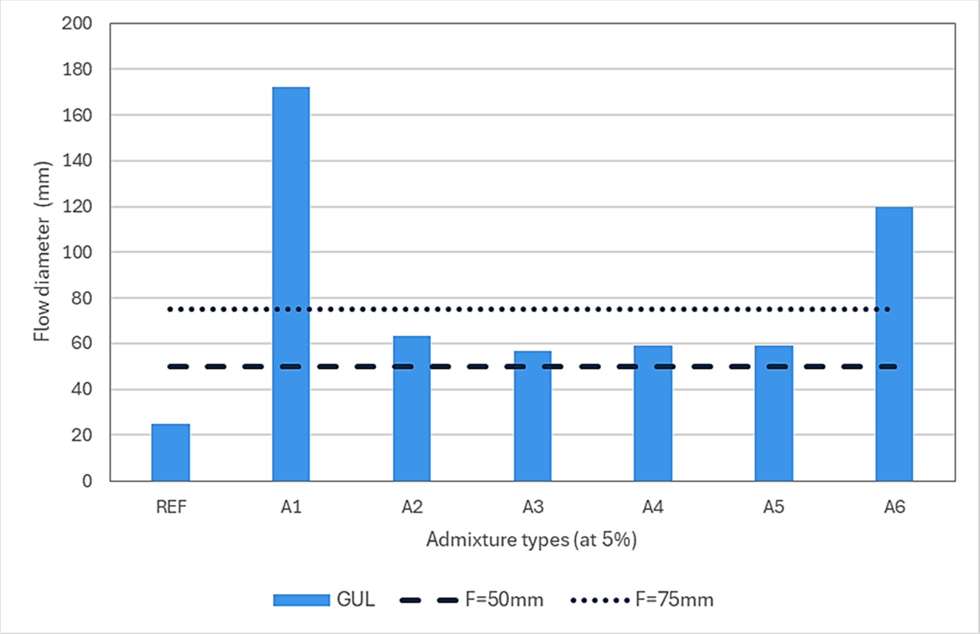


Figure 3 **Flow diameter primitive pastes incorporating different admixture types at a fixed dosage of 5% by weight of cement**

Table 4 **Characteristics of the selected A1 admixture type investigated with cemented paste backfill, provided by Sika ($C_{w\text{-}Ad}$ = solid content of the super-plasticising admixture)**

Admixture	G_s	pH	$C_{w\text{-}Ad}$ (%)
A1	1.11	5.7	45

2.3 Cemented paste backfill preparation and conditioning

Two CPB blends were proportioned at 72 and 68% solids concentration. The GUL cement content was fixed to 7% by weight to dry tailings. the only variable changing is the muscovite content incorporated within T1 (0, 3, 8 up to 18% M80). It is important to highlight that this muscovite addition represents to an actual 23 to 38% total phyllosilicate content in the different mixes (considering the initial phyllosilicates content of the tailings). Aiming to compensate the expected negative effect of the muscovite addition, different A1 dosages up to 3% by weight of cement, were tested. The target slump value was established at approximately 30 mm ±2 mm (~1.18 inches ±0.07), measured using a small, truncated cone (1:3 scale). When translated to the Abrams small cone (1:2.5 scale), this slump measurement equates to 84 mm ±2 mm, ensuring consistency with conventional testing protocols.

All ingredients, including the selected admixture A1 (immediate addition), were combined simultaneously and mixed using a Heidolph mixer (RZR 2012 model) at a speed of 750 rpm for 2.5 minutes. The admixture's dosage (*D*) is defined as the mass ratio of the dry admixture $M_{dA}$to the dry mass of tailings M_{dT} as denoted in the Equation 1 (Ouattara et al. 2018a; Ouattara et al. 2018b; Ouattara et al. 2017):

$$D = \frac{M_{dA}}{M_{dT}} = B_w \times \frac{M_{dA}}{M_B} \tag{1}$$

where:

B_w = the binder percentage

M_B = the mass of the binder.

Once blended, the resulting CPB mixtures were homogenised and both slump and flow diameter were measured according to the American Society of Testing Material ASTM C143. For this purpose, preliminary mixtures underwent slump tests using the Abrams small cone (SSC 1:2.5) and the small, truncated cone (SSC 1:3). A conversion factor of 2.83 (Figure 4) was identified to convert the measured slump values(s) into the corresponding values for the Abrams small cone (scale 1:2.5).

Finally, CPBs were poured into small cylinder-shaped moulds (d × h: 60.96 × 30.48 mm) in a single layer, tapped and shaken sideways to expel air bubbles from the backfill cast. Prepared moulds are hermetically sealed and kept in a controlled atmosphere chamber with a relative humidity of around 90% and a temperature of 25°C ± 2°C. Each recipe was produced in triplicate for each curing time (7 and 28 days) to ensure the reliability of experimental results and reduce bias. Table 5 present CPB mixtures recipes.

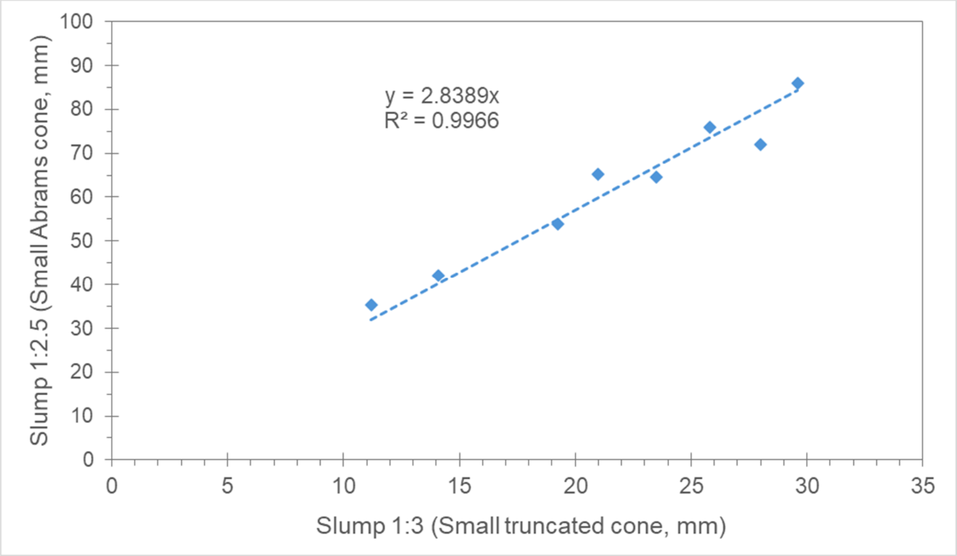


Figure 4 Conversion factor between Abrams small cone (1:2.5) and truncated small cone (1:3)

Table 5 Mixture proportions of cemented paste backfill

Admixture type	Admixture dosage *D*	Solids content C_w	Binder type	Binder content B_w	Water binder ratio w/b	Muscovite content %M80	Curing time
A1	0	72	GUL	7%	6	0, 3, 8 & 18	7, 28
	0.75					0, 3, 8 & 18	7, 28
	1.5					0, 3, 8 & 18	7, 28
	3					0, 3, 8 & 18	7, 28
	0	68			7	0, 3, 8 & 18	7, 28
	0.75					0, 3, 8 & 18	7, 28
	1.5					0, 3, 8 & 18	7, 28
	3					0, 3, 8 & 18	7, 28

2.4 Testing methods

2.4.1 Water demand test

Control mixtures containing 0% muscovite were first prepared to establish the reference water mass M_{w0}, required to reach the target slump. The effect of varying muscovite content on water demand (%W_D) was evaluated by preparing progressively higher muscovite content CPB mixtures while incrementally adjusting the water content to achieve the 84 mm ±2 mm target slump. The increase in water demand (%W_D) was calculated as follows (Equation 2):

$$\%W_D = \frac{M_{w1}-M_{w0}}{M_{w0}} \tag{2}$$

where:

M_{w1} = the water mass added to the mixture to achieve the target slump.

2.4.2 Workability tests

The impact of admixtures was assessed by testing the flowability and fluidity of designed CPBs. The flowability was quantified in accordance with both the slump test and the flow diameter measurements. The fluidity of pastes was evaluated through rheological measurements of fresh CPB blended with and without admixtures. Tests were performed using a shear rate-controlled rotational AR2000 rheometer (TA instruments, USA) with a four-blade vane geometry of 28 mm diameter and 42 mm height. Measurements were conducted at a fixed temperature of 21°C using a Peltier temperature control system through water circulation. Each sample was subjected to a shear rate ($\dot{\gamma}$) ranging from 1 to 100 s^{-1}, which was subsequently dropped from 100 s^{-1} to 1 s^{-1} over a period of two minutes. Data were recorded in terms of CPB flow curves $\tau\ (\dot{\gamma})$ (where τ is the shear stress (Pa) and $\dot{\gamma}$ the shear rate [1/s]), and the dynamic viscosity curve $\mu\ (\dot{\gamma})$, where μ is the dynamic viscosity ($\mu = \frac{\tau}{\dot{\gamma}}$).

2.4.3 Unconfined compression tests

After curing for 7 and 28 days, CPB mixtures were subjected to unconfined compression tests carried out using an MTS 10/GL mechanical press with an axial loading capacity of 50 kN and a minimum strain rate of 1 mm/min. UCS test were conducted in accordance with ASTM C39 Standards (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens). Each test was performed in triplicate, and the average values were taken as the final compressive strengths. The impact of admixtures on mechanical strength was evaluated as follows in Equation 3:

$$\frac{UCS_1-UCS_0}{UCS_0} \tag{3}$$

where:

UCS_1 and UCS_0 = the measured mechanical strengths of CPB mixtures incorporating 3% A1 and CPB mixtures of control (without the A1 addition).

3 Results and discussion

3.1 Water demand and target slump

The influence of muscovite on water demand and the potential use of admixtures to improve flowability without water addition were assessed in this study. Figure 5 shows a sharp increase in water demand for muscovite-rich CPB mixtures. The water demand for the reference mix (0% A1) to obtain the target slump is 14%. The water demand increased progressively to 26, 42 and 81.3% for 3, 8, and 18% muscovite addition, respectively.

Generally, the introduction of admixtures like A1 in mining industry was meant to reduce the amounts of water required to reach a target slump. The selected A1 admixture was tested at a muscovite M80 content of 3, 8 and 18%. Figure 5 shows the impact of 0.75, 1.5 and 3% A1 dosage by weight of cement. At 0 and 3% M80, a 0.75% dosage already decreases the water demand down to zero, thanks to its plasticising effect. Increasing the A1 percentage beyond a specific threshold does not yield additional benefits, as the target slump is already achieved. This observation underscores the importance of identifying the minimum effective dosage of A1 to achieve the desired performance while minimising material costs. In the paste plant, higher dosages are however sometimes used to decrease further the yield stress, resulting in lower pumping pressures or for increasing the paste throughput. At 8% M80, the A1 dosage required for a zero-water demand increases to 1.5% A1. For a 18% muscovite addition, using 3% A1, the admixture doesn’t manage to compensate the full water demand, but still drops significantly from 81.3% without A1 to 36.2% with 3% A1, highlighting the admixture’s effectiveness in mitigating the increased water demand caused even at such high muscovite content (representing 38% total phyllosilicate content).

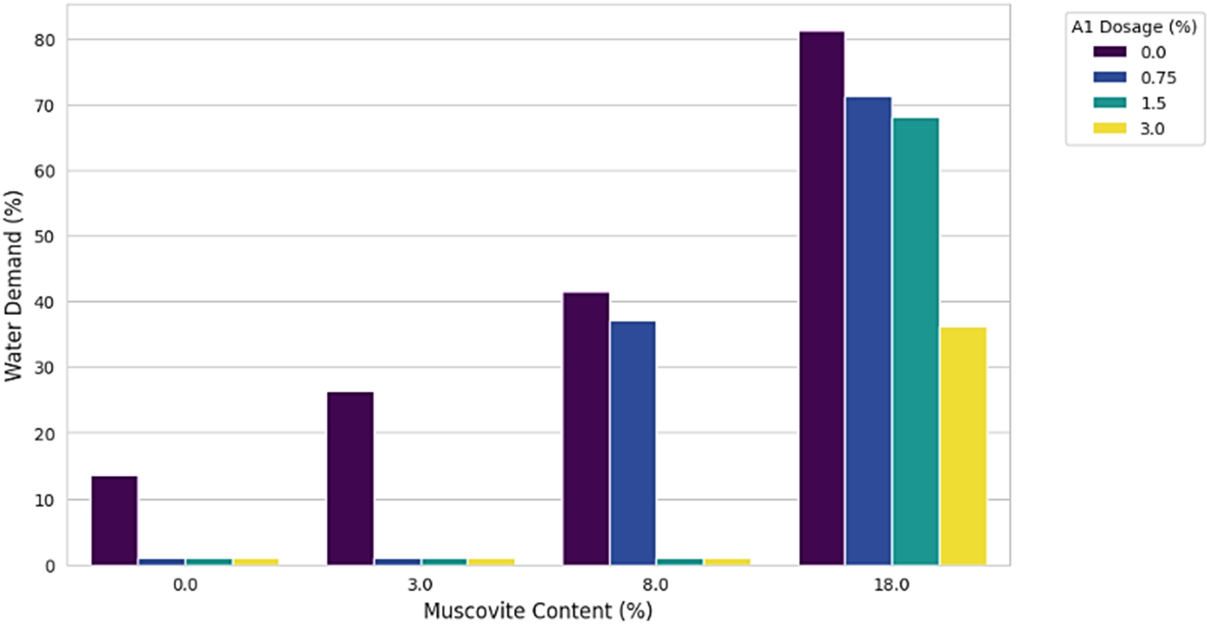


Figure 5 The effect of A1 admixture on water demand. A1 significantly reduces water demand, especially at higher muscovite contents.

3.2 Effect of A1 dosages on slump and flow diameter

The effect of A1 dosages on slump (using the small cone scale 1:2.5) for CPB mixtures containing 0, 3, 8 and 18% M80 at C_w = 72% and C_w = 68% are illustrated in Figures 6a and b, respectively. Small slump for the control CPB mixtures (0% M80 addition) grew by using 1.5% *wt*% A1 from 93.8 to 162.4 mm at C_w = 72% (65.2% growth) and from 115.4 mm to 162.4 mm at C_w = 68% (40.7% growth). Increasing the A1 dosage rate from 0.75 to 3% *wt*% increases the small slumps of CPB mixtures at both solid concentrations tested, regardless of the M80 content, with exception of the CPB mix at72% C_w and 18% M80. This specific mix showed a different trend where A1 provided limited performance and the slump remained low (s~7 mm) regardless of dosage. It should also be noted that the muscovite content is remarkably high (up to 32% muscovite and 38% phyllosilicate) in this specific mix and that the prepared CPB was not workable, proving the achievement of limiting conditions. Therefore, increasing the M80 content in the T1 tailings requires decreasing its solid content under 72% C_w to ensure its flowability. This is observed by improved flow at 68% C_w (Figure 6b).

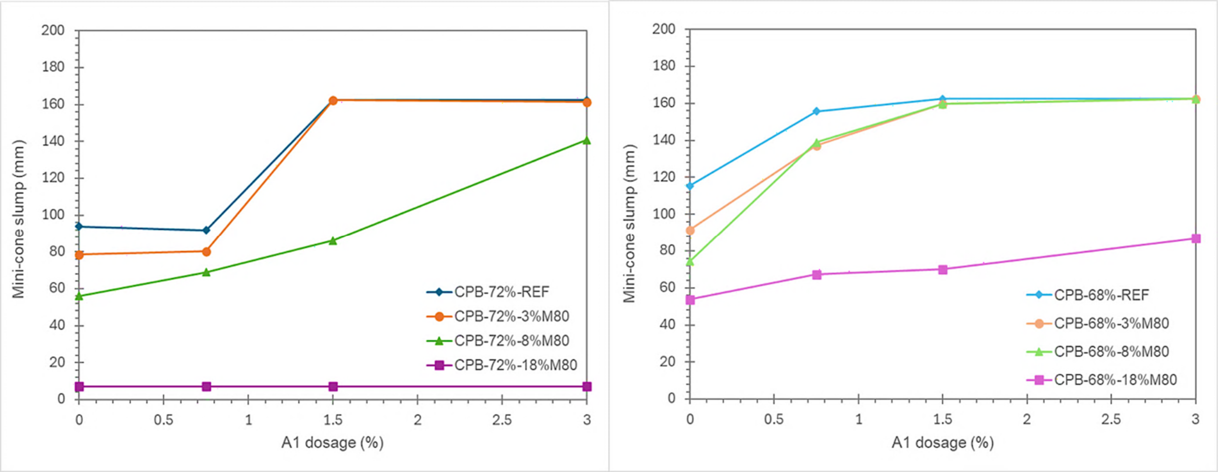
For CPB mixtures at 68% C_w, the 0.75% *wt%* A1 dosage showed a great plasticising effect of 140 mm and reach its maximum slump of about 160mm using 1.5% *wt%* A1 dosage for mixtures enriched with 3 and 8% of muscovite. This dosage can be assumed to be the saturation dosage for these formulations, as further increases in A1 dosage did not significantly improve slump. For mixtures with 18% *wt%* M80 at 68% C_w, the slump started at around 58 mm and grew only up to 80 mm at 3% *wt%* A1 dosage, suggesting that a dosage above 3% will be required to achieve the same maximal slump of 160 mm.

For CPB mixtures at 72% C_w, minimal plasticising effect is observed when using 0.75% A1, proving that the saturation dosage required is higher compared to the 68% C_w mixes. For 3% M80, with 1.5% A1 dosage the 162 mm small slump was achieved but for 8% M80 a 3% A1 only reached 140 mm, suggesting that way over 3% dosage is required to achieve the targeted slump.

The slump of mixtures with 18% M80 remained extremely low (7 mm) regardless the A1 dosage, highlighting the challenges of achieving adequate workability in high M80-rich mixtures. The A1 admixture is most effective in improving slump for mixtures with low to moderate muscovite content, while its effectiveness diminishes significantly at higher M80 content.

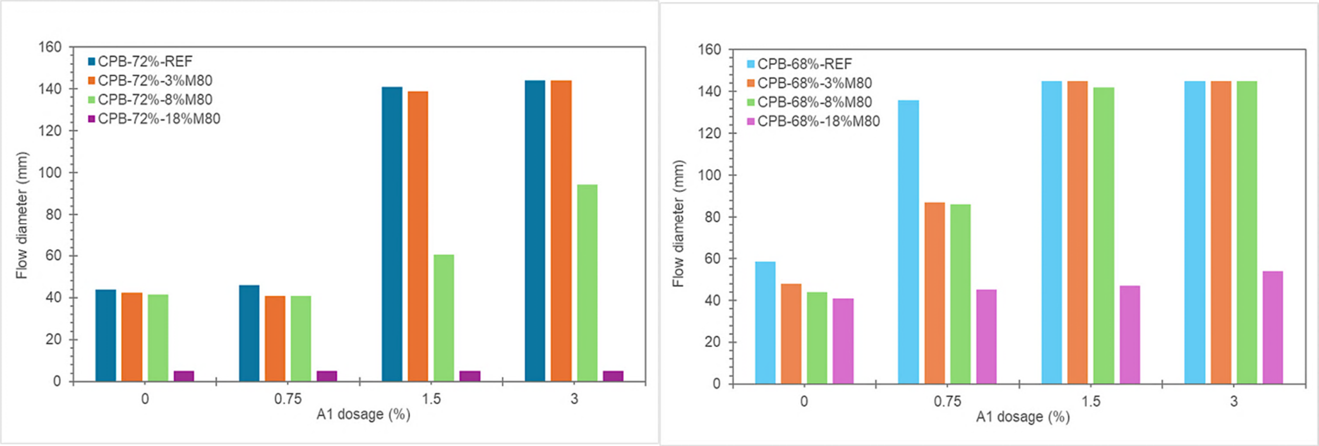
To confirm the estimated saturation dosages, the variation of flow diameter using 0–3% *wt%* A1 for CPB mixtures containing 0, 3, 8 and 18% M80 at 72 and 68% C_w is illustrated in Figures 7a and b, respectively. Control mixtures (0% additional M80), exhibit the highest flow diameters. The higher muscovite content significantly reduces the flow diameters of CPB mixes and limits the positive effect of A1 on improving flowability. The addition of A1 improves the flow diameter for CPB mixtures with low to moderate muscovite content (3 and 8% *wt%*) at both solid contents, demonstrating its performance in enhancing workability. However, for high M80 content (18%), the influence of A1 becomes limited as the flow remains consistently low, indicating that muscovite adversely affects the workability of CPB at such high solid contents.

The incorporation of admixture A1 significantly enhances the flowability of CPBs, as evidenced by notable increases in both the flow diameter and slump. For example, at a dosage of 3% A1, the flow diameters of CPBs with 72% C_w increased by 3.3, 3.4 and 2.3 times the control diameter (without A1) for muscovite (M80) contents of 0% (control CPB), 3 and 8%, respectively. Similarly, at a lower solids content (68% C_w), the rates of flow diameter increase were comparatively lower, reaching 2.5, 3, 3.3 and 1.3 times the control diameter for muscovite contents of 0, 3, 8 and 18%, respectively. These results highlight the substantial impact of A1 on improving workability, particularly for formulations with lower to moderate muscovite content and higher solid concentrations.



(a) (b)

Figure 6 **Variation of a small slump with A1 dosage for cemented paste backfill mixtures proportioned with: (a) 72%; (b) 68% solid contents**



(a) (b)

Figure 7 Flow diameter of cemented paste backfill (CPB) mixtures versus A1 dosage for CPB proportioned with: (a) 72%; (b) 68% solid contents

Figures 8a and b illustrate the rheological properties of CPB mixtures with 0% *wt%* A1, and Figures 9a and b at 3% *wt%* A1 dosage, at varying muscovite contents. The rheological curves plotted in Figures 8a and 9a exhibit a discernible pattern corresponding to the Herschel–Bulkley rheological model (Herschel & Bulkley 1926) represented by Equation 4:

$$\tau = \tau_0 + K\dot{\gamma}^n \tag{4}$$

where:

τ = the shear stress (Pa)

τ_0 = the yield stress (Pa)

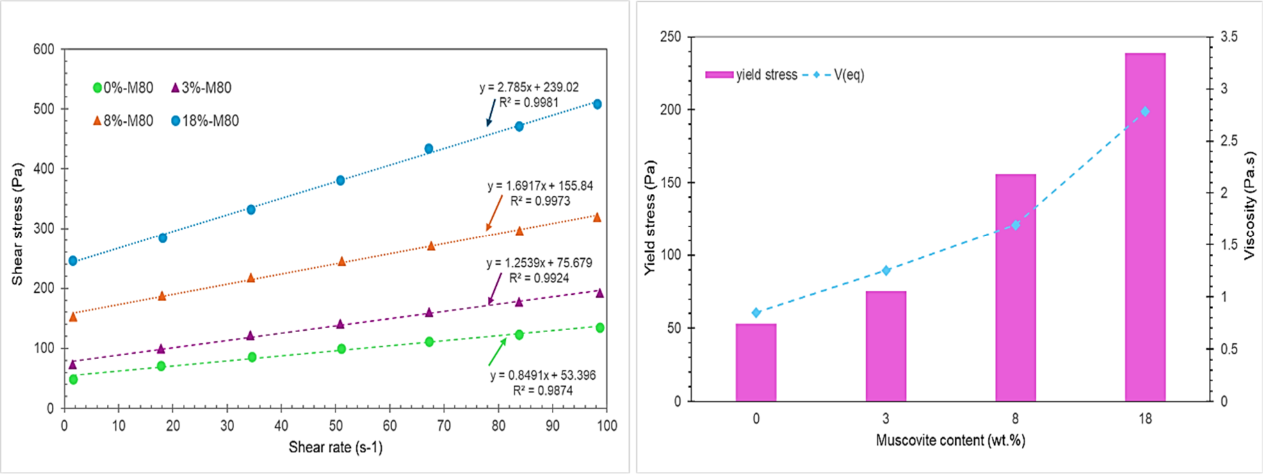
K = the consistency index (Pa.sn)

$\dot{\gamma}$ = the shear rate (s-1)

n = the flow index.

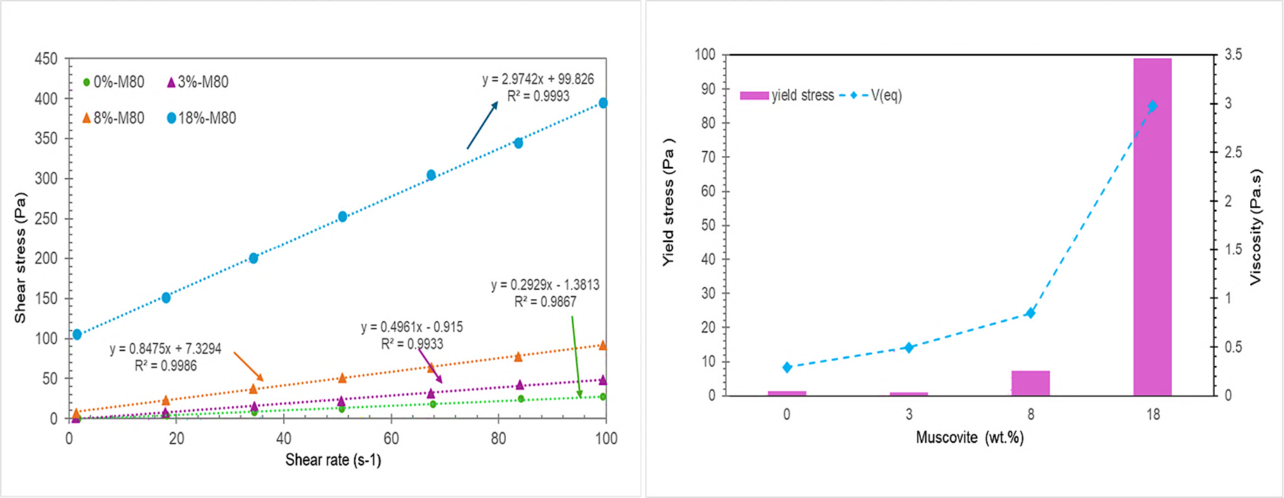
Figures 8a and 9a show a significant increase in shear stress at all tested share rates with increased M80 content. This indicates a linear relationship with a high correlation coefficient. After the introduction of A1, shear stress becomes consistently lower across all shear rates, suggesting its positive effect on decreasing particles agglomeration, leading to smoother flow and reduced resistance to deformation under applied shear. Figures 9a and 9b show that the highest impact of A1 admixture is observed in the lower range of shear rate. For example, the addition of 3% *wt%* A1 to the 18% M80 mix helps decrease that interaction by 57.1% at low shear rates and by 16.2% at 100s^{-1}. This suggest that even though the admixture works to compensate part of the increase of fines, the slope value for 18% M80 is higher, reflecting increased viscosity due to stringer interactions between these fine particles added into the mix, mostly at higher rates. In summary, at high shear rates, the rheology is mostly controlled by the particles interactions and the fines/phyllosilicate content.

Figures 8b and 9b show that yield stress increases significantly with a higher muscovite content, indicating the impact of muscovite on flow initiation. The CPB paste becomes more resistant to flow. For CPB mixtures without admixture, the yield stress reached its highest value of 239 Pa at 18% M80, which was four times higher compared to CPB control at 0% M80. The introduction of A1 decreases yields stress values across all muscovite contents, reaching minimal yield values for 0, 3 and 8%. For 18% M80, 3% *wt%* A1 reduced by 58.5% the yield stress. This demonstrates the impact of the admixture in reducing the force required to initiate flow and thus its potential to improve the pumpability, even at higher M80 content. Similarly, the viscosity of the mixture increases dramatically with muscovite content, indicating reduced flowability and a higher energy requirement for pumping. This trend is visible at both conditions (0 and 3% *wt%* A1). However, the introduction of A1 to CPB mixtures shows a decrease in viscosity down to minimal viscosity values for 0, 3 and 8% muscovite content when compared to CPB mixtures without A1. At 18% M80, the viscosity stayed unchanged by the admixture addition. Therefore, considering the cumulative effect on shear stress, yield stress, and viscosity, A1 effectively counteracts the thickening effect and enhances the pumpability of low to high muscovite-rich CPB mixtures.



(a) (b)

Figure 8 Effect of muscovite on the: (a) rheological properties; (b) yield stress and viscosity of the cemented paste backfill control proportioned with 72% solids content and 0% A1 dosage



(a) (b)

Figure 9 Effect of muscovite on the: (a) rheological properties; (b) yield stress and viscosity of the cemented paste backfill proportioned with 72% solids content and 3% A1 dosage

3.3 Effect of admixtures on compressive strength

Figures 10 and 11 plot the UCS at 7 days and 28 days of curing for CPB mixtures at 68 and 72% solids contents and 7% GUL, with varying M80 contents. Results confirm a decreased UCS with increased M80 content. The highest UCS was measured at the reference CPB (0% M80). This indicates the negative impact of muscovite on hydration characteristics, through inhibiting cement hydration and bonds formations due to its high-water demand and retention capacity as observed already in Figure 5.

The introduction of 0, 0.75, 1.5 and 3% *wt%* A1 admixture showed also an impact on the UCS (Figures 10 and 11) for the various muscovite contents at both curing times (7 and 28d). For example, at 68% C_w and 0% muscovite, the UCS increased after 7days from 185.89 kPa (without A1) to 226.86 kPa (with 3% A1), representing a 22% improvement. Similarly, the UCS rose after 28 days from 287.11 kPa to 424.07 kPa, marking a 48% increase. This trend is consistent across varying M80 proportions. Even at higher muscovite contents, such as 18% M80, the UCS at 7 days increased from 150.80 kPa (without A1) to 211.6 kPa (with 3% A1), a 40% improvement, and the UCS at 28 days for that mix rose from 169.83 kPa to 373.05 kPa, a 120% increase. These results demonstrate that the A1 admixture not only accelerates early strength development but also significantly enhances long-term strength, regardless of the muscovite content. The admixture's effectiveness is more significant after 28 days of UCS compared to 7days of UCS due to the progressive nature of cement hydration and microstructural development.

It is important to highlight two key observations:

1. In the 72% solid mixes, the increase in UCS with 3% admixture was significant enough to compensate for the UCS loss caused by adding 3 and 8% M80, as well as a substantial portion of the 18% M80 at 7 days, bringing it closer to the reference strength values (0% M80). In the 68% solid mixes, any addition of admixture improved and compensated for the strength loss compared to the reference at 7 days.
2. At 28 days, the 68% solid mixes with 0, 3, and 8% M80 showed such significant improvement that they not only compensated for the UCS loss but, with a 3% A1 dosage, reached or even exceeded the UCS of the 72% solid reference. Additionally, the 18% M80 mix with a 3% A1 dosage at 68% solids recovered almost 80% of the 72% solid reference strength.

These findings demonstrate the effectiveness of admixtures in optimising mix designs and mitigating the adverse effects of muscovite.

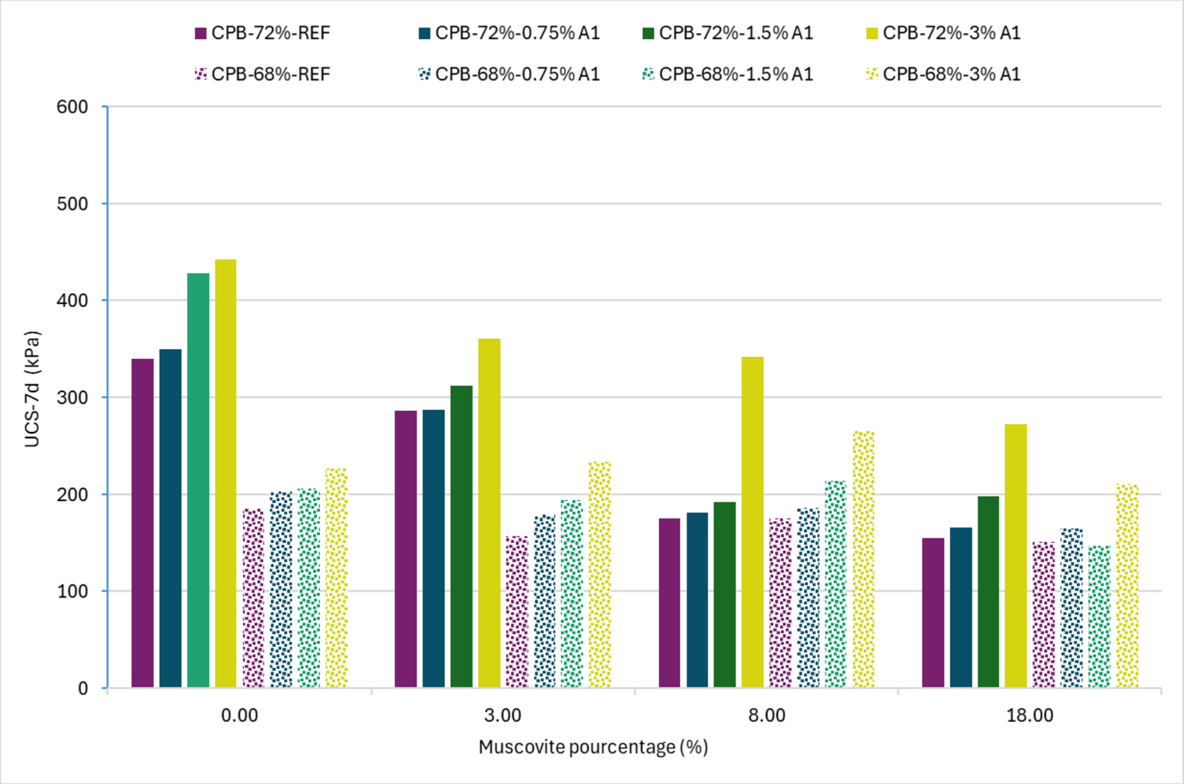


Figure 10 Variation of 7-days UCS for CPB mixtures with 72 and 68% solids contents and 7%GUL incorporating A1 dosages of 0, 0.75, 1.5 and 3% *wt%*.

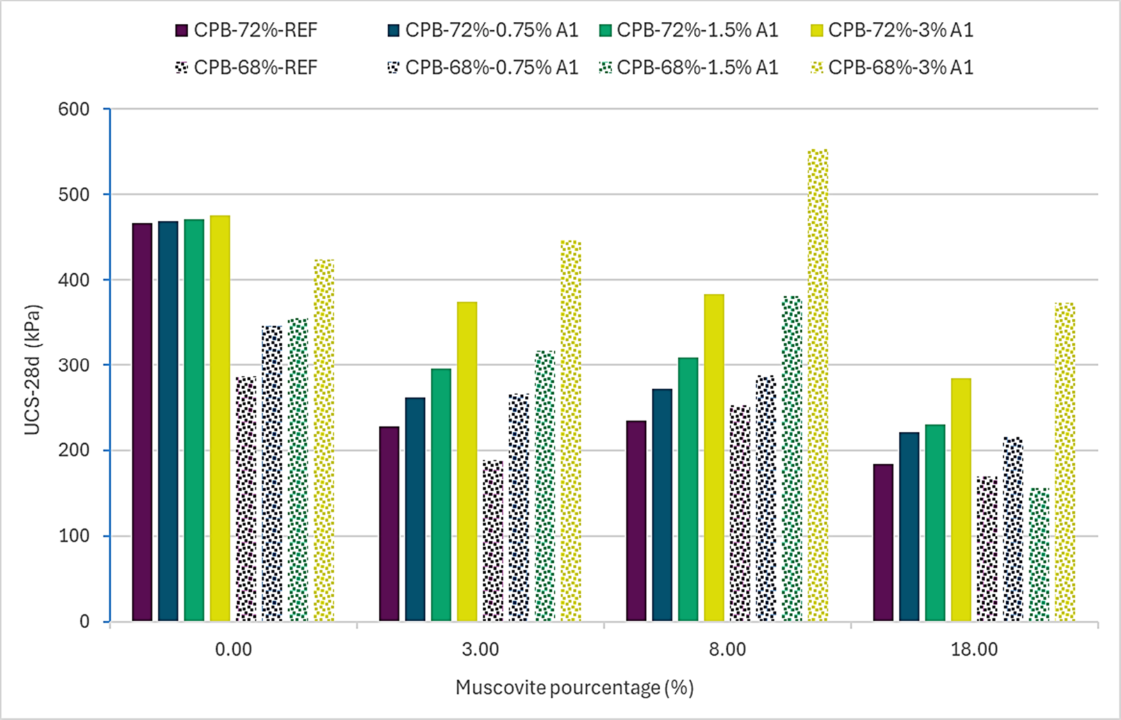


Figure 11 **Variation of 28- days UCS for CPB mixtures with 72 and 68% solids contents and 7%GUL incorporating A1 dosages of 0, 0.75, 1.5 and 3% *wt%*.**

4 Conclusion

This study explores the substantial impact of muscovite content on both the rheological and mechanical properties of CPB. High muscovite percentages, particularly at 18%, significantly increase yield stress and viscosity -up to four times higher than CPB without muscovite – indicating a pronounced negative effect on workability.

The addition of an admixture (A1) mitigates these adverse effects by reducing water demand, yield stress, shear stress and viscosity, for all muscovite contents investigated in this study. At low to moderate muscovite contents (0-8% M80), A1 eliminates water demand entirely at optimal dosages (0.75–1.5% *wt%* A1) and reduces yield stress by up to 97.1%, significantly easing flow initiation and pumpability. Even at high muscovite content (18% M80), A1 achieves a 55.6% water demand reduction and a 58.5% yield stress decrease. Shear stress reductions are most pronounced at low shear rates (~57%), where particle agglomeration dominates, while high shear rates see smaller reductions (~16%) as inertial forces prevail. These improvements demonstrate the A1 admixture effectiveness in modifying particle interactions, improving particle dispersion and reducing internal friction, thereby enhancing flowability and pumpability.

In addition to its rheological benefits, A1 contributes to substantial strength gains at both 7-days and 28-days curing stages, proving its dual role in improving workability and mechanical performance. At 68% solids content, UCS growth ranges from 22 to 51% at 7 days and 48 to 136% at 28 days with 3% A1. For 72% solids content, gains are slightly lower but still substantial, ranging from 26.1 to 94.8% at 7 days and 2 to 64% at 28 days. Notably, the highest gains occur in lower-solids formulations (68% Cw), where A1 maximises strength development even at elevated muscovite levels, reaching up to 136% UCS improvement after 28 days.

This study highlights also the effectiveness of admixtures in optimising mix designs, as they not only compensate for UCS loss in both 68 and 72% solid mixes but also enhance strength recovery, with 3% A1 dosage enabling 68% solid mixes to approach or even exceed the UCS of the 72% solid reference while mitigating the adverse effects of the various muscovite additions.

These findings underscore the critical role of admixtures in optimising CPB formulations and mitigating the adverse effects of phyllosilicate minerals like muscovite. By balancing workability and strength, such admixtures can contribute to more effective and sustainable backfill solutions in mining applications.

Acknowledgement

The authors would like to acknowledge the Fonds de recherche du Québec, Nature et technologies (FRQNT) (Research Fund of Quebec, Nature and Technologies), Programme de recherche en partenariat sur le développement durable du secteur minier - Volet valorisation des résidus miniers (Partnership Research Program on Sustainable Development of the Mining Sector-Mining Waste Vaporisation Component) (grant number: 20220MN-301195), Agnico Eagle Mines Ltd, IAMGOLD Corporation and the Research Institute of Mines and Environment (RIME UQAT-Polytechnique) for their financial support. Also, the authors extend their gratitude to Sara Arcila for her assistance in obtaining admixtures from Sika Inc. and Vanda Melko for support in selecting the appropriate admixture for this study.

References

Aguilar Sánchez, I, Bellver Baca, MT, Barahona, W, Arcila-Gut, S, Erismann, F, Avilés, E … & Contador, R 2024, 'Enabling sustainability in mining case study: mine backfill', in AB Fourie & D Reid (eds), *Paste 2024: Proceedings of the 26th International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Perth, pp. 373–384, https://doi.org/10.36487/ACG_repo/2455_30

Arcila Gut, S, Erismann, F & Ting, B 2023, 'A review of modern paste admixture technology and its effect on cement reduction in paste mix designs', in GW Wilson, NA Beier, DC Sego, AB Fourie & D Reid (eds), *Paste 2023: Proceedings of the 25th International Conference on Paste, Thickened and Filtered Tailings*, University of Alberta, Edmonton, and Australian Centre for Geomechanics, Perth, pp. 244–256, https://doi.org/10.36487/ACG_repo/2355_18

Benzaazoua, M, Belem, T & Bussiere, B 2002, 'Chemical factors that influence the performance of mine sulphidic paste backfill', *Cement and Concrete Research*, vol. 32, no. 7, pp. 1133–1144.

Chi, H, Wang, C, Tian, Y, Xie, Z, Yuan, Q, Chen, Z, & Zhu, X 2024, 'Unraveling polycarboxylate superplasticizer (PCE) compatibility in muscovite-blended cement paste through aggregation mechanisms', *Journal of Building Engineering*, vol. 95.

Dewar, J 1963, *Effect of Mica in the Fine Aggregate on the Water Requirement and Strength of Concrete*, Cement and Concrete Association, London.

Ercikdi, B, Cihangir, F, Kesimal, A, Deveci, H & Alp, İ 2010, 'Utilization of water-reducing admixtures in cemented paste backfill of sulphide-rich mill tailings', *Journal of Hazardous Materials*, vol. 179, no. 1–3, pp. 940–946.

Erismann, F & Hansson, M 2021, 'Efficient paste mix designs using new generation backfill admixtures–perception versus reality', *Minefill 2020-2021,* CRC Press, London, pp. 3–12.

Fan, ZP, Zhang, ZH, He, Q, Cai, MQ & Shi, C 2014, 'Effects of naphthalene-based super plasticizer on the performances of whole tailings backfill materials', *Applied Mechanics and Materials*, vol. 608-609, pp. 962–965.

Govin, A, Bartholin, M-C, Schmidt, W & Grosseau, P 2019, 'Combination of superplasticizers with hydroxypropyl guar, effect on cement-paste properties', *Construction and Building Materials*, vol. 215, pp. 595–604, https://doi.org/https://doi.org/10.1016/j.conbuildmat.2019.04.137

He, D, Lu, Z, Liang, X, Liu, R & Sun, G 2022, 'A study to improve the compatibility of PCE with cement paste containing clay', *Materials Letters*, vol. 308, https://doi.org/https://doi.org/10.1016/j.matlet.2021.131111

Herschel, WH & Bulkley, R, 1926, 'Konsistenzmessungen von gummi benzolloesungen', *Kolloid-Zeitschrift*, vol. 39, pp. 291–300.

Lagerblad, B, Gram, H-E, & Westerholm, M 2014, 'Evaluation of the quality of fine materials and filler from crushed rocks in concrete production', *Construction and Building Materials*, vol. 67, pp. 121–126. https://doi.org/10.1016/j.conbuildmat.2013.10.029

Lagerblad, B, Westerholm, BLM, Gram, MWHE, Westerholm, M, Gram, HE, Attenius, E & Fjällberg, L 2005, *Krossad Berg som Ballast till Betong* (*Crushed Rock as Concrete Aggregate),* report from the Swedish national project*,* MinBaS (Compilation of 6 project reports)*,* CBI, Stockholm.

Leemann, A, Lothenbach, B, Münch, B, Campbell, T & Dunlop, P 2023, 'The "mica crisis" in Donegal, Ireland – A case of internal sulfate attack?', *Cement and Concrete Research*, vol. 168.

Lei, L, Hirata, T & Plank, J 2022, '40 years of PCE superplasticizers - history, current state-of-the-art and an outlook', *Cement and Concrete Research*, vol. 157, https://doi.org/https://doi.org/10.1016/j.cemconres.2022.106826

Loorents, K-J, Johansson, E & Arvidsson, H 2007, 'Free mica grains in crushed rock aggregates' *Bulletin of Engineering Geology and the Environment*, vol. 66, no. 4, pp. 441–447, https://doi.org/10.1007/s10064-007-0091-4

Ma, Y, Sha, S, Zhou, B, Lei, F, Liu, Y, Xiao, Y & Shi, C 2022, 'A study on the interactions between polycarboxylate ether superplasticizer and montmorillonite', *Cement and Concrete Research*, vol. 162, https://doi.org/https://doi.org/10.1016/j.cemconres.2022.106997

Ma, Y, Shi, C, Lei, L, Sha, S, Zhou, B, Liu, Y & Xiao, Y 2020, 'Research progress on polycarboxylate based superplasticizers with tolerance to clays - a review', *Construction and Building Materials*, vol. 255, https://doi.org/https://doi.org/10.1016/j.conbuildmat.2020.119386

Maregesi, GR & Salaam, DE 2021, 'Some engineering properties of Udzungwa scarp soil', *Advanced Engineering Solutions Journal*, vol. 1.

Mshali, M & Visser, AT 2012, 'Influence of mica on unconfined compressive strength of a cement-treated weathered granite gravel', *Journal of the South African Institution of Civil Engineering*, vol. 54, no. 2, pp. 71–77.

Mshali MR & Visser AT, 2014, 'Influence of mica on compactability and moisture content of cement–treated weathered granite gravel', *Proceedings of the 33rd Southern African Transport Conference*, University of Pretoria, Pretoria.

Muller, O 1971, 'Some aspects of the effect of micaceous sand on concrete', *Civil Engineering*, vol. 1971, no. 9, pp. 313–315.

Muzenda, TR, Hou, P, Kawashima, S, Sui, T & Cheng, X 2020, 'The role of limestone and calcined clay on the rheological properties of LC3', *Cement and Concrete Composites*, vol. 107, https://doi.org/https://doi.org/10.1016/j.cemconcomp.2020.103516

Ouattara, D, Belem, T, Mbonimpa, M & Yahia, A 2018a, 'Effect of superplasticizers on the consistency and unconfined compressive strength of cemented paste backfills', *Construction and Building Materials*, vol. 181, pp. 59–72. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.05.288

Ouattara, D, Mbonimpa, M, Yahia, A & Belem, T 2018b, 'Assessment of rheological parameters of high density cemented paste backfill mixtures incorporating superplasticizers', *Construction and Building Materials*, vol. 190, pp. 294–307.

Ouattara, D, Yahia, A, Mbonimpa, M & Belem, T 2017, 'Effects of superplasticizer on rheological properties of cemented paste backfills', *International Journal of Mineral Processing*, vol. 161, pp. 28–40, https://doi.org/https://doi.org/10.1016/j.minpro.2017.02.003

Saedi, A, Jamshidi-Zanjani, A& Darban, AK 2021, 'A review of additives used in the cemented paste tailings: Environmental aspects and application', *Journal of Environmental Management*, vol. 289, https://doi.org/https://doi.org/10.1016/j.jenvman.2021.112501

Simon, D & Grabinsky, M 2013, 'Apparent yield stress measurement in cemented paste backfill', *International Journal of Mining, Reclamation and Environment*, vol. 27, no. 4, pp. 231–256.

Tariq, A & Yanful, EK, 2013, 'A Review of binders used in cemented paste tailings for underground and surface disposal practices', *Journal of Environmental Management*, vol. 131, pp. 138–149.

Xing, JQ, Zhan, SL, & Li, XY 2014, 'Effect of mica content in stone powder of manufactured sand on performance of cement mortar', *Advanced Materials Research*, vol. 1044-1045, pp. 624–628.

Yang, L, Yilmaz, E, Li, J, Liu, H & Jiang, H 2018, 'Effect of superplasticizer type and dosage on fluidity and strength behavior of cemented tailings backfill with different solid contents', *Construction and Building Materials*, vol. 187, pp. 290–298. https://doi.org/https://doi.org/10.1016/j.conbuildmat.2018.07.155