



Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

by W.K. Ting¹, A. Hasan¹

Affiliation:

¹The Department of Civil Engineering,
Universiti Malaysia Sarawak,
Malaysia

Correspondence to:

A. Hasan

Email:

halsidqi@unimas.my

Dates:

Received: 3 Sept. 2024
Revised: 12 Jan. 2025
Accepted: 31 Oct. 2025
Published: January 2026

How to cite:

Ting, W.K., Hasan, A. 2026. Guide memoire:
Temperature-elevated hydration effect on
stress behaviour of cemented paste backfill.
*Journal of the Southern African Institute of
Mining and Metallurgy*, vol. 126, no. 1,
pp. 1–12

DOI ID:

<https://doi.org/10.17159/2411-9717/3557/2026>

ORCID:

W.K. Ting:
<https://orcid.org/0000-0001-5067-7659>
A. Hasan:
<https://orcid.org/0000-0001-7543-096X>

Abstract

Mine stope is typically backfilled with cemented paste backfill, which provides a regional underground stability and also a reduction of aboveground tailings accumulation. During backfilling, a phenomenon known as arching occurs and affects the stress distribution of the cemented paste backfill. The change in temperature due to uncontrolled heat transfer from the surrounding rock mass and/or generation from hydration process complicates the stress distribution development of cemented paste backfill. This paper presents results of the investigation on the effects of hydration to cemented paste backfill behaviour when backfilled into a narrow wall model using uncemented paste backfill as controlled sample. The parameters considered include backfill type (cemented paste backfill vs uncemented paste backfill), curing temperature (30°C–60°C), and stress evolution during pouring, consolidation, and curing stages. Results show that uncemented paste backfill re-establishes arching effects more readily, with lower peak stresses and greater stress relaxation than cemented paste backfill, of which its behaviour is significantly influenced by hydration under elevated temperatures. The main outcome of this work is that hydration critically controls the stress-temperature response of cemented paste backfill, and the balance between hydration-driven strength gain and stress relaxation can be leveraged to optimise backfill mix design for safer and more efficient stope filling.

Keywords

narrow stopes backfill, arching effect, hydration, temperature, uncemented paste backfill

Introduction

The exhaustion of surface-level deposits due to the rising global demand for minerals necessitates deeper mining operations, which create narrow underground voids (mine stopes) (Asr et al., 2019; Cao et al., 2021). Such a condition presents significant challenges in maintaining underground stability, which directly affects both ore recovery rates and mine safety (Ngwenyama, De Graaf, 2021). Also, substantial volume of extracted earth becomes waste in the form of tailings (Rahmat et al., 2022).

Cemented paste backfill (CPB) was introduced as a technique to mitigate issues of underground instability and accumulation of mine waste by utilising dewatered tailings and cement as a binding agent to fill up the mined-out voids generated from mining activities, thereby facilitating further ore extraction (Fall et al., 2008). Despite its benefits, CPB is a complex material with properties influenced by various factors (Yan et al., 2021). Inadequate understanding of CPB behaviour can lead to issues such as structural failure, which indirectly increases safety risks and operational costs (Agboola et al., 2020).

One critical aspect of backfill design in narrow stopes is the phenomenon of arching, where the stress distribution of the backfill material along the stope walls is governed by the frictional properties of the fill (Fang, Fall, 2018). Unlike in fully confined conditions, the stress-strain behaviour in semi-confined stopes differs due to the allowance for vertical deformation (Li, 2024). Theoretical models have been developed to predict stress distribution based on stope geometry and material properties (Cui, Fall, 2017; Yilmaz, 2018; Pagé et al., 2021; Porathur et al., 2022; Fang et al., 2023; Vlachogiannis et al., 2024), while recent numerical studies have considered additional effects such as temperature influences on barricade stability (Wu et al., 2025) and the coupled hydro-mechanical response of CPB under varying load-bearing conditions (Yan et al., 2025). As the performance of the fill material and its interaction with stope boundaries are central to backfill stability, new approaches to material enhancement have also emerged. For instance, the incorporation of sustainable additives such as recycled microplastics has been shown to

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

improve the toughness and ductility of CPB (Samiratou Yaya et al., 2025). Nevertheless, experimental validation in realistic geometries remains scarce (Ile, Malan, 2023), with multiple studies reporting unexpected patterns of stress propagation, including stress increases during rest periods contrary to theoretical predictions (Doherty et al., 2015; Oke et al., 2021).

Full-scale study of mine backfill in the actual stope is challenging and costly. Some mechanical behaviour of mine backfill in actual mine stopes can be investigated using a laboratory scale model (Wu et al., 2016; Chen et al., 2022). In such a model, boundary conditions that replicate the full-scale backfill environment need to be comparable.

The effect of temperature changes on CPB backfilled into an experimental model has been discussed (Ting, Hasan, 2023) but the impacts of hydration on backfill stress propagation are yet to be understood. Temperature variations and the nature of the backfill are hypothesised to play a role in the overall behaviour. It is possible to redefine mine backfill material design by re-evaluating the targeted strength while controlling the stress generation of the backfill at different stages of curing (Jafari, Grabinsky, 2021). Such understanding will ultimately lead to safer designs and potentially reduce the overall cost of backfilling operations.

Materials and methods

Materials

Laboratory-made CPB and UCPB, which reflect the material properties and behaviour of actual backfill material were used in this research. Both mixes are primarily composed of silica flour and water, with CPB additionally containing cement as its binding agent. Local tap water used in mix design was tested with PCSTestr35 EUTECH Instruments, which showed a pH of 6.84, total dissolved solids at 74.3 ppm, and salinity at 0.0627 ppt. Ordinary Portland cement (OPC) from Cahya Mata Sarawak (CMS), meeting the Malaysian Standard MS EN 94 197-1 was used as binder for the CPB sample. Both water and binder were selected based on its local availability and its similarity to actual CPB practices, provided that the final mix design produced a paste with strength and flowability requirements comparable to those used in mine backfilling.

Silica flour is selected as the tailing replacement material due to its similarity in particle size distribution (PSD) towards the tailing average size (Nasir, Fall, 2008). Table 1 provides detailed findings on its PSD characteristics, while Figure 1 shows its distribution curve. According to a mine fill handbook (Potvin et al., 2005), the silica flour complies with a minimum of 15% passing of 20 μ m particles

for paste fill. Silica flour is chemically inert and possesses resistance to strength retrogression at temperatures below 110°C, which makes it particularly suitable for this research. Its geotechnical properties were identified using respective standard testing methods, and it complies with the technical specifications provided by its manufacturer (Sibelco, SILVERBOND® PG20) and comparable related research utilising silica flour (Fall et al., 2010). This ensures good accuracy and reproducibility for all samples prepared in this research.

Sample preparations

To ensure similar sample behaviour, a suitable mix design is needed along with using comparable materials to recreate the paste. The mechanical properties such as yield stress, compressive strength, and shear behaviour were assessed through slump tests, unconfined compressive strength (UCS) tests, and direct shear tests with temperature control. When the backfilling space is narrow in geometry, controlling the mix design is crucial, as it directly affects arching intensity and initial stress distribution. Table 2 provides a summary of the sample's mix design and its corresponding mechanical behaviour. The selection of 5% binder content and 72% solids was based on preliminary UCS and slump tests, targeting 300 kPa UCS at 3 days of curing, in line with common mine practice (Sheshpari, 2015; Ghirian, Fall, 2016). At this solid content, the yield stress of 115 Pa satisfies the flowability criterion of less than 200 Pa for pipeline transport (Cooke, 2008). According to the mix design, all sample is mixed at the same speed until it is homogenous to control its rheological properties prior to immediate backfilling into the narrow wall model.

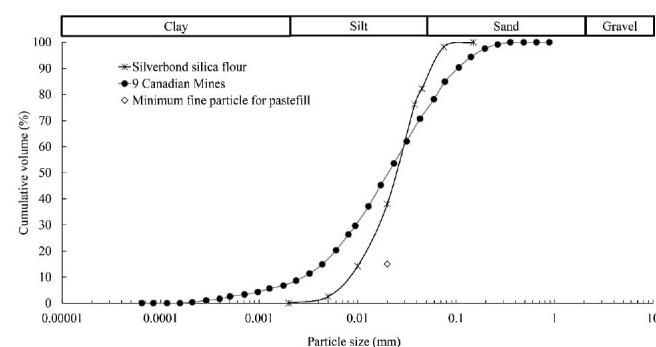


Figure 1—The PSD of silica flour and the average PSD from 9 Canadian mines

Table 1

The properties of silica flour

Physical properties	Result	Specification	Literature
Specific gravity, G_s	2.67	2.65	2.7
Particle size distribution	Silt	-	Silt
Coefficient of uniformity, C_u	3.66	3.65	16.2-16.6
Coefficient of gradation, C_c	1.17	-	1.3
Initial water content	< 0.2%	0.2%	-
Liquid limit, LL	23.83%	-	-
Plastic limit, PL	22.22%	-	-
Plasticity index, PI	1.61%	-	-
Shrinkage limit, SL	5.31%	-	-
USCS classification	Low plasticity silt	-	Low plasticity silt

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

Table 2

The mix design of CPB and relevant mechanical properties

Sample	Binder content (%)	Solid mass content (%)	Water content by total (%)	Water content by solid (%)	Water to cement ratio	Slump height (mm)	UCS (kPa)	Yield stress (Pa)
CPB	5	72	28	38.9	7.7	17	314	115
UCPB	0	72	28	38.9	-	21	-	70

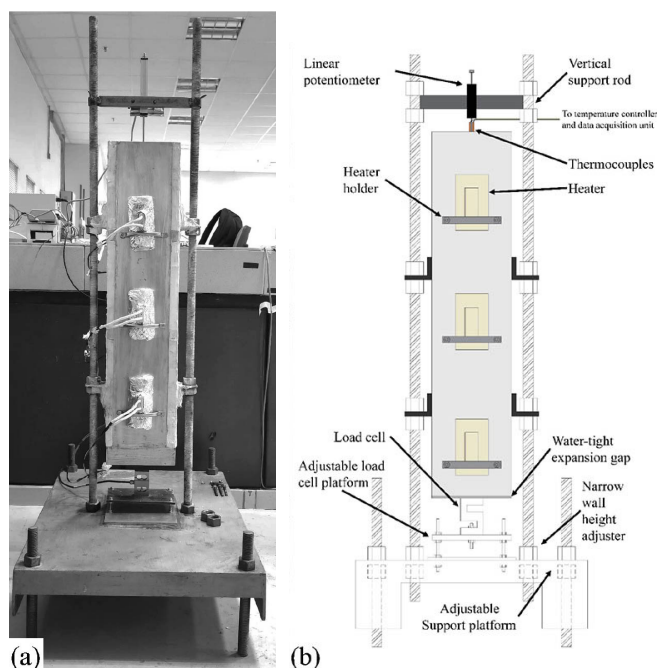


Figure 2—Narrow wall (a) photo and (b) schematic design

Temperature-controlled narrow wall model

Figure 2 illustrates the narrow wall schematic that has been designed based on related literature (Goodey et al., 2006; Li, Aubertin, 2010; Widinghe, Sivakugan, 2014; Yan et al., 2019) with a modification made to enable the capability required for this study. Most factors affecting this study, such as the curing temperature, aspect ratio of backfill, confining condition, and adjacent wall stiffness were considered in the narrow wall model design while others, such as filling rate of sample, interface shear between sample and wall, and drainage were controlled for consistent results (Helinski et al., 2011; Walkse, 2014; Cui et al., 2023). The narrow wall model functionality and the steps taken to ensure its accuracy were discussed (Ting et al., 2020).

Arching effects in a narrow wall occur when the height is more than twice its width (Fahey et al., 2009). In order to investigate

the arching effects over the temperature change, the narrow wall is designed to exclude overly stress induced by the adjacent wall. The narrow wall model has dimensions of 0.8 metres in height, 0.15 metres in width, and 0.05 metres in depth. It was built using aluminium plates with an elastic modulus of 70 GPa that is similar to mining rock masses (Belem, Benzaazoua, 2008). Aluminium plate of sufficient thickness prevents deformation under stress, ensures efficient heat transfer, and is sufficient for multiple cleaning to control surface properties. To control water evaporation, an impermeable film is used to cover the top opening of the narrow wall after completion of backfilling. To maximise stress generation, a single pour with filling rate around 0.00015 m³/s is used. The same volume of sample is prepared for all tests to ensure consistent passive interface loading and stress generation (Cui et al., 2023).

The vertical stress (σ_v) was measured on the bottom plate using an OMEGA load cell (LCM101) while the unconfined sample's expansion was measured from the top opening of the narrow wall via an OMEGA potentiometer (LP804). The test temperature was measured using an OMEGA Type J Thermocouple where it is also wired to an OMEGA data acquisition unit (DAQ-USB-2401) and to an OMEGA temperature controller (CN7233). The temperature controller regulated heating according to set temperatures and thermocouple measurements. The data acquisition unit is initiated before the commencement of backfilling for instruments checking and offsetting purposes. In addition, the monitoring of thermocouple allows proper preheating to be performed onto the narrow wall model.

The selected temperature range (30°C to 60°C) was chosen to simulate the diverse subsurface thermal regimes found in underground mines. These conditions are influenced by factors such as depth and the local geothermal gradient, with in situ rock mass temperatures often reaching or exceeding 50 °C (Thompson et al., 2012; Oke et al., 2021). Both CPB and UCPB samples were heated (ramp) at a constant rate, held at a fixed temperature (soak), and then cooled (dwell) according to the temperature pattern outlined in Table 3. Test 1 analysed the impact of temperature variations on the consolidated sample, as indicated by stable stress readings from the load cell. This demonstrates that any temperature change after this stage is purely due to temperature effects on the sample's behaviour. Meanwhile, Test 2 to Test 5 assess the impact

Table 3

List of tests for both CPB and UCPB

Test	1					2	3	4	5
Step	1	2	3	4	5	-	-	-	-
Ramp	RTP-30	30-40	40-50	50-60	30-60	RTP-30	RTP-40	RTP-50	RTP-60
Soak	30	40	50	60	60	30	40	50	60
Dwell	-	-	-	60-30	60-30	-	40-30	50-30	60-30

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

of immediate temperature changes immediately after backfilling. In practical mine backfilling contexts, the stope wall temperature is not controlled, which allows direct temperature shifts after pouring. While fixed temperature tests give better correlation to actual mine backfill behaviour, Test 1 data is essential for understanding the direct effects of temperature and serves as a fundamental reference to eliminate the effects of temperature from the fixed temperature tests.

The controlled temperature profile test was conducted in duplicate, and the results showed a high degree of consistency between runs. Due to the extensive duration of each experiment (2–3 weeks per test), a single representative test was performed for the uncontrolled (fixed temperature) profiles. The figures show the data from these representative tests.

Results and discussions

To understand the effect of hydration on the stress-strain-temperature of backfill within narrow wall, UCPB sample is tested with the same temperature profile as CPB reported by Ting and Hasan (2023). The stress-time and strain-time evolution of UCPB is discussed and the effect of temperature change at all stages was analysed to be compared to the behaviour of CPB.

Post-consolidation tests

For post-consolidation tests, the UCPB sample follows the temperature pattern outlined in Test 1. Prepared sample was backfilled at a constant filling rate and allowed to consolidate at a controlled temperature of 30°C. Figure 3 shows the monitoring of stress-strain-temperature behaviour of UCPB against the elapsed time from the initiation of backfilling until 54 hours after.

During consolidation, a significant reduction in σ_v from 15 kN/m² to 7.5 kN/m² was observed. This densification and frictional property development are evidenced by the reduction in volumetric strain (ϵ_v) during consolidation. As the sample consolidates, arching effects where σ_v is transferred horizontally to the adjacent wall developed progressively. This phenomenon was also observed in full-scale monitoring, which underscores the need to isolate stress-altering factors before studying the temperature response in a semi-confined narrow wall.

When σ_v readings plateau (t_{90}), temperature change is introduced. Upon ramping by 10°C to 40°C, an increase in σ_v reading is observed. However, the σ_v dropped when the sample

was not gaining any heat during the soaking phase. This behaviour repeats itself over the subsequent ramping and soaking phase. Based on its ϵ_v behaviour, it behaves similarly to the stress behaviour over the applied temperature pattern. Such phenomenon did not occur in the CPB samples. Such behaviour is speculated to be due to a phenomenon, namely relaxation, which occurs due to the accumulation of thermal stress during the ramping phase. This reduces the potential and magnitude of effect from a phenomenon namely creep. It is undeniable that creep may occur with the presence of thermal stress as hydration commences, which damages the strength obtained from hydration and possibly resulting in lower ultimate strength. Such is proven by Xue et al. (2018) by keeping a constant application of stress onto a cohesive sample and relaxation is observed. As the narrow wall model is a semi-confined space, UCPB is free to relieve the thermal stress by allowing particles to rearrange and to relieve the stress generated over time. This relaxation phenomena are not instant and the net σ_v remains slightly higher than the initial σ_v before any ramping, indicating that thermal stress is not fully relieved due to the frictional properties of UCPB. If the backfill material is entirely frictionless and cohesionless, thermal stress concentration will not occur and thus, the material will be able to expand freely without generating any stress during the ramping stage.

When the sample is dwelled from 60°C to 30°C, both σ_v and ϵ_v show reduction in response to the temperature drop. During dwelling, the material shrinks in response to the temperature drop and thus relieving additional stress generated over the ramping period. However, the net σ_v after dwelling back to 30°C is slightly lower than the net σ_v recorded at 30°C prior to any ramping. Any relaxation that occurs during the ramping and soaking period reduces the total σ_v at that time. As the backfill stabilised during the soaking phase, any dwelling afterward is speculated to first reduce any remaining thermal stress within the backfill that is held by its frictional properties and then only reduction due to the contraction of particles due to temperature drop. Interestingly, the net volume of the backfill recorded at the open end of the narrow wall showed some increases if compared to the net volume prior to temperature change. This is likely due to the unconfined end of the narrow wall where the backfill is free to expand when ramped but could not fully consolidate during soaking and shrink during dwelling due to any forms of cohesion and concurrent re-establishment of arching effects towards narrow wall.

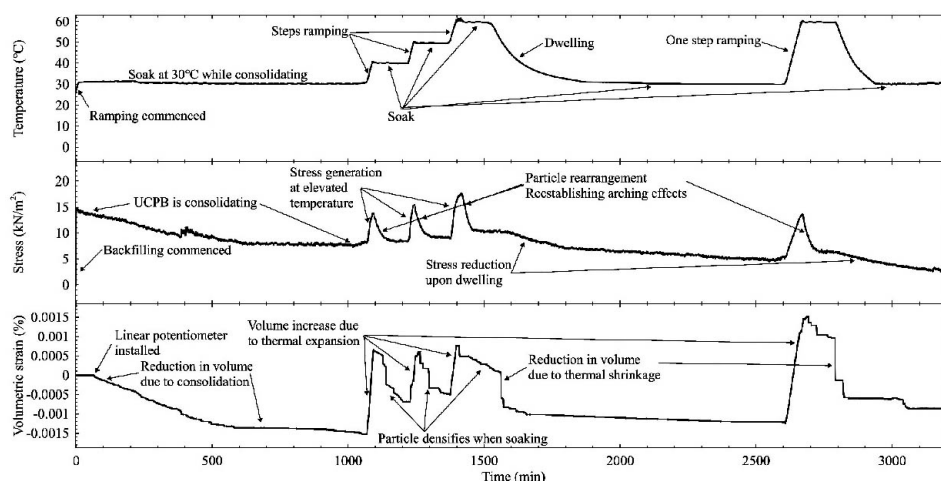


Figure 3—Stress-strain-temperature monitoring of UCPB via Test 1 temperature profile

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

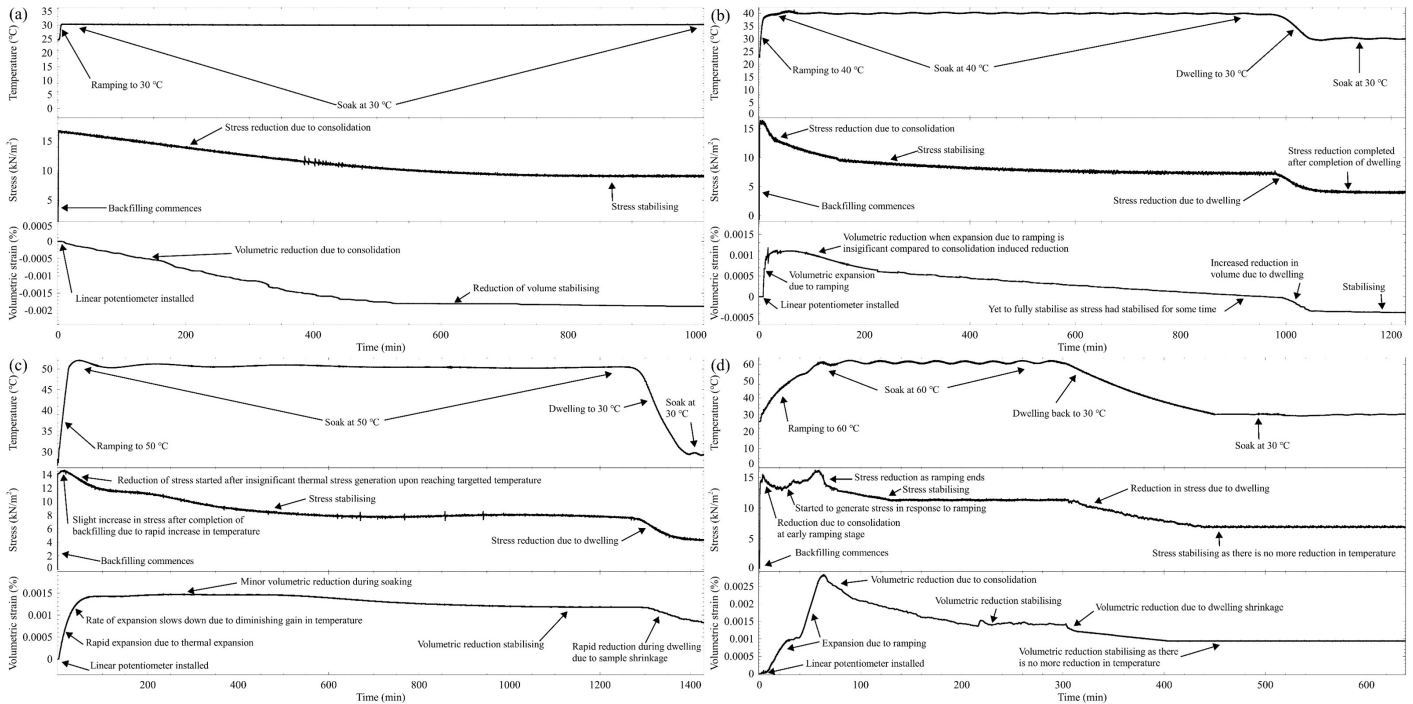


Figure 4—Stress-strain-temperature of unconsolidated fixed temperature tests for (a) UCPB 30, (b) UCPB 40, (c) UCPB 50, (d) UCPB 60

Upon stabilising, the backfill sample is ramped to 60°C, soaked at 60°C until the σ_v reading stabilised, and finally dwelled back to 30°C. This attempt shows that UCPB behaves similarly, even if the ramping steps are increased from 10°C to 30°C. As UCPB should remain in paste form after an extended period of study, the instability of ϵ_v observed, which became more significant after multiple temperature change cycles, may be due creep. Continuous ramping cycle leads to repeated drying of paste due to the hot adjacent wall and wetting of paste due to osmotic suction from dried-up paste across the perimeter (Gao et al., 2023). This leads to the growth of a weak, yet brittle shear strength, which hinders volumetric consolidation during soaking and dwelling.

Ting and Hasan (2023) conducted a similar test to Test 1, using the same samples following the same temperature profile. Both tests generally showed similar behaviour in response to variations in temperature, though there were minor differences in the σ_v and ϵ_v . These datasets were used in the analysis section; the cited data is labelled as UCPB1, while data from Test 1 is referred to as UCPB2 for clarity.

Unconsolidated fixed temperature tests

Figure 4 shows the behaviour of UCPB samples ramped to target temperature of 30°C, 40°C, 50°C, and 60°C right after backfilling until σ_v and ϵ_v stabilised, then the samples were dwelled back to 30°C. UCPB 30 behaved similarly to the consolidated test with a maximum σ_v of 16.8 kN/m², which reduces by 46% after 900 minutes, and ϵ_v reduces by 0.002%. UCPB 40 σ_v remained stable due to self-weight consolidation, with a 0.0011% volumetric expansion observed during ramping. As insignificant heat did not affect much of σ_v or ϵ_v , σ_v and ϵ_v reductions were noted right after reaching 40°C. Upon dwelling back to 30°C, σ_v reduces at a rate of 0.4 kN/m² per degrees celcius, and volume decreased by 0.0005%.

For UCPB 50, ramping took 40 minutes due to a 25°C temperature difference. The sample expanded by 0.0014%, which is comparably higher, and σ_v reduced by 6.5 kN/m², which is comparably lower than both UCPB 30 and UCPB 40 tests. The

smaller decrease in σ_v was due to thermal stress and arching effect development. When the influence of thermal expansion from ramping diminished, consolidation-induced reductions in both σ_v and ϵ_v were observed. Upon dwelling back to 30°C, the σ_v reduces at a rate of 0.175 kN/m² / °C while the volume further reduced by 0.00045%, indicating material contraction. For UCPB 60, a 35°C temperature increase led to notable σ_v and ϵ_v changes. During ramping, the initial volumetric gain is at a lower rate until 45 minutes where a sudden expansion was observed. This can be observed from the σ_v , where the σ_v started to increase as the volumetric expansion recorded slows down before the 45 minutes mark. Initial consolidation and thermal expansion resulted in rapid packing and thus densify the backfill, which intensifies arching effects. Beyond 45 minutes, ϵ_v became prominent while σ_v continues to increase until the target temperature is reached. During soaking, significant σ_v and ϵ_v reductions resembled Test 1 soaking behaviour. Dwelling to 30°C reduced σ_v from 11.5 kN/m² to 7 kN/m² and ϵ_v from 0.0012% to 0.0009%, respectively.

Data analysis

Based on the backfill test data, each phase (backfilling, consolidating, ramping, soaking, and dwelling) was thoroughly analysed to understand how temperature affects the stress-strain behaviour of hydrating and non-hydrating backfill. Over time, UCPB and CPB shall vary in material state and shear behaviour, differing their stress-strain-temperature behaviours. The impact of temperature changes, initial curing temperature, and the type of backfill sample were explored.

Initial stress of backfill

The σ_v equals to the horizontal stress (σ_h) when internal angle of friction, ϕ is near 0. Geostatic stress ($\sigma_{geostatic}$), caused by the gravitational pull exerted on the backfill material, is represented by Equation 1.

$$\sigma_{geostatic} = \sigma_v = \sigma_h = h\gamma \quad [1]$$

where, h represents backfill height, and γ is its unit weight.

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

Pirapakaran and Sivakugan (2007) validated their findings on the stress distribution of UCPB using FLAC and then formulated a σ_v theorem that considers the friction angles of the backfill, as shown in Equation 2.

$$\sigma_v = \gamma l w \frac{1 - \exp\left\{-2K \tan \phi \frac{h(l+w)}{l w}\right\}}{2K \tan \phi (l+w)} \quad [2]$$

where, h stands for the height of the backfill, γ denotes backfill unit weight, l represents narrow wall length, w signifies narrow wall width, ϕ denotes backfill friction angle, and K is the coefficient of lateral earth pressure at rest. Figure 5 shows the σ_v solved from Equation 2. Both the UCPB and CPB sample correspond similarly to the predicted σ_v , as the sample was still in slurry state where sufficient arching effect is yet to be established at the first 40 seconds of backfilling. Ultimately, the establishment of arching effects primarily depends on the rheological properties of the backfill sample and the cross-section of the narrow wall (Liu et al., 2020; Zhang et al., 2023). In this case, the effect of hydration is yet to be noticeable.

With precise specification of input parameters, the current equation reliably estimates the initial σ_v within a narrow wall. Generally, granular materials kept in any narrow space, such as a silo, usually do not experience substantial temperature changes or hydration. Though, in mine backfill, temperature changes and alterations in the state of the backfill material do occur. Consequently, it is essential to understand the behaviour of UCPB and CPB not only during the backfilling stage but also throughout the curing period. Analysing the non-hydrating UCPB sample helps clarify the impact of hydration in CPB, offering key insights into the isolating effects of temperature changes.

Backfill stress behaviour during consolidation

The observed decrease in σ_v after backfilling at a constant temperature can be due to the consolidation driven by the self-weight of the backfill material. This happens because the backfill is initially a slurry with minimal flow resistance. While cement hydration affects consolidation with duration, this analysis examines the immediate stage following backfilling, without temperature changes.

Figure 6 shows the σ_v behaviour of the UCPB30, UCPB 1, UCPB 2, CPB 30, CPB 1, and CPB 2 tests. The finding reveals consistent post-backfilling behaviour primarily due to self-weight consolidation, which is similarly reported by Zheng and Li (2019).

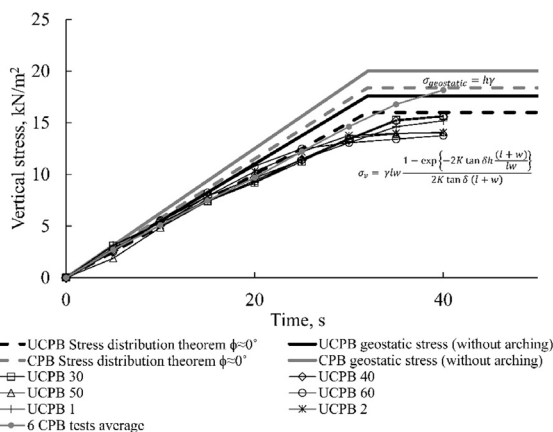


Figure 5—Comparison of actual and predicted data of σ_v generation during deposition

The key difference lies in the time required to balance σ_v transfer during consolidation, with UCPB taking a longer period to achieve the same σ_v reduction as CPB samples. As the frictional properties of CPB develop more rapidly than UCPB, optimal arching effects are established in a shorter timeframe. This consistency of consolidation data across all UCPB and CPB samples permits the application of Equation 3.

$$\Delta \sigma_v(t) = \sigma_{v(peak)}(A - 1)(1 - e^{-ct}) \quad [3]$$

where, $\sigma_{v(peak)}$ represents the peak vertical stress at the end of backfilling, A denotes the average factor of residual stress after consolidation relative to the peak stress, c denotes the coefficient describing the rate of stress reduction over time, and t denotes elapsed time. Figure 6 provides the best-fit representation of the empirical relationship between the change in vertical stress ($\Delta \sigma_v$) and the elapse of time (t). Table 4 presents the parameters corresponding to both backfill samples with respect to Equation 3.

Backfill stress behaviour over temperature variations

The σ_v responses of UCPB and CPB were examined across different temperature phases, including ramping, soaking, and dwelling. This analysis considered the effects of temperature change in both controlled post-consolidation tests and uncontrolled fixed-temperature tests where the effect of consolidation is not omitted. An uncontrolled fixed-temperature test serves as a good reference for a more realistic behaviour of a sample towards the actual backfilling works. Relationships derived from the controlled test data can be applied to the uncontrolled tests to validate their adequacy.

Impact of temperature variations on the stress behaviour of stabilised backfill

Figure 7 shows the $\Delta \sigma_v$ over the change in temperature (ΔT) at 10°C step for UCPB and CPB, respectively. The UCPB samples show a gradual increase in σ_v with rising temperature. However, the σ_v

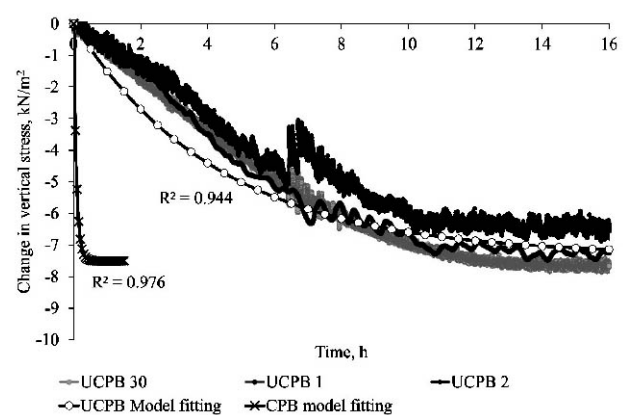


Figure 6—Stress behaviour of CPB and UCPB at controlled temperature of 30 °C

Table 4

Corresponding parameter for Equation 5.3

Backfill material	$\sigma_{v(peak)}$, kN/m ²	A	c
UCPB	16	0.542	0.23
CPB	17.6	0.574	12.12

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

increase is less prominent when compared to CPB. The smaller σ_v increment in UCPB is attributed to the absence of significant hydration, which means it lacks the additional binding and stiffness provided by the hydration process in CPB. This enhanced stiffness in CPB is a direct result of cement hydration, which is the chemical reaction between cement particles and water. This process forms a nano-structured gel known as calcium-silicate-hydrate (C-S-H), which acts as the primary binding agent. The C-S-H gel coats the tailings particles and progressively fills the pore spaces, creating a solid, cohesive matrix that offers far greater resistance to thermal expansion compared to the purely frictional particle-to-particle contact in UCPB. The σ_v increase for UCPB is primarily due to thermal expansion resisted by the arching effect in the semi-confined environment. In comparison to the predicted σ_v in fully confined conditions, part of the thermal stress is converted to slight material expansion towards the unconfined direction (top opening), which reduces the overall stress generated.

Figure 8 shows the $\Delta\sigma_v$ over the ΔT at a 30 °C step. Generally, the rise in σ_v with temperature increase is more linear because of the extended duration of ramping. Though UCPB gives almost linear relationship between σ_v generation and temperature increase, the magnitude of σ_v generated is only half of CPB, which indicates simultaneous occurrence of a stress alleviating mechanism namely relaxation. Over time, as CPB continues to hydrate, its stiffness and cohesive properties will increase, leading to even higher σ_v

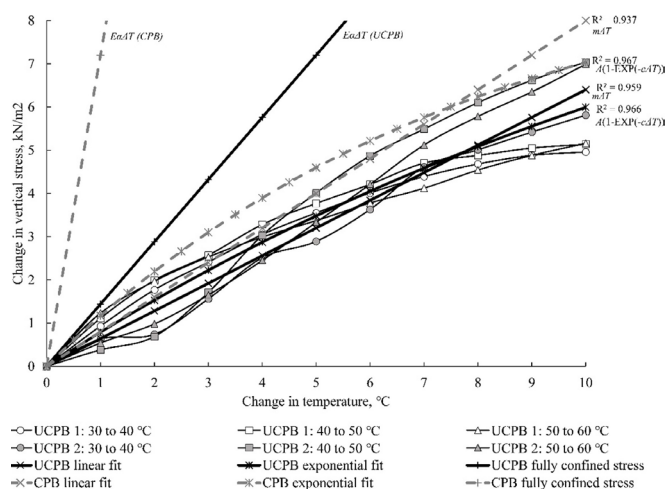


Figure 7—Stress behaviour of UCPB and CPB at every elevation of 10 °C

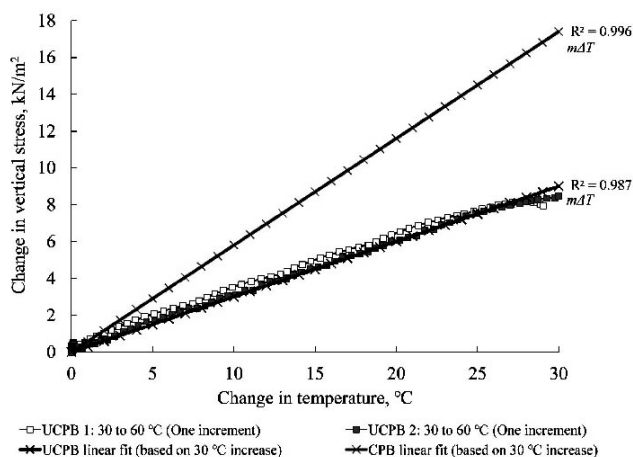


Figure 8—Stress behaviour of UCPB and CPB at an elevation of 30 °C

responses to temperature changes. The more pronounced stress response in CPB is attributed to thermally accelerated hydration kinetics. As temperature increases, the rate of C-S-H formation is significantly enhanced. This concept is well-established in cement chemistry, where elevated curing temperatures are known to accelerate early-age strength development (Sindhunata et al., 2006). As the data in Figures 7 and 8 only discuss the ramping stage, the relaxation phenomena and the differences across the UCPB and CPB sample became obvious when additional heat was not induced during the soaking phase.

The graphs in Figure 9 illustrate the stress behaviour at constant temperatures for both UCPB and CPB samples after experiencing temperature changes of 10 °C and 30 °C. The CPB samples experience a slight decrease in σ_v , as evidenced by dispersed data presenting an average reduction of 1.2 kN/m². As the backfill material had attained full consolidation at 30 °C before any temperature variations took place, it could imply that the material was compactly packed. Upon ramping, the backfill experienced thermal expansion, yet arching limited this expansion to some extent, which generated additional internal pressure within the backfill. After ramping, soaking at a constant temperature led to a gradual decrease in excessive thermal stress because of limited relaxation or in another word, creep in the case of CPB. The distinct difference in relaxation behaviour during the soaking phase highlights the microstructural evolution of the CPB. In UCPB, stress dissipates primarily through particle rearrangement and sliding. In contrast, the CPB's behaviour is governed by its developing solid skeleton. The C-S-H bonds, as noted by Yilmaz et al. (2010), create a continuous, semi-rigid framework connecting the tailings particles. This framework resists particulate-level rearrangement, transforming the dominant stress-relief mechanism from simple relaxation to time-dependent creep of the solid matrix itself. Figure 9 shows the fitted data, which reflect relaxation as a time-dependent process where thermal stress is progressively reduced over time.

During the dwelling phase, the backfill material's volume decreased as the temperature dropped. The σ_v levels recorded were significantly lower than those at the end of the consolidation phase at 30 °C for both UCPB and CPB due to the varying level of relaxation that occurred during the soaking period after ramping. Figure 10 illustrates the dwelling behaviour for both UCPB and CPB by a reduction of 30 °C.

After the time spent to ramp and soak the sample at 10 °C and 30 °C increments, the CPB sample had undergone hydration for at least 1 day, which causes the material to behave elastically in

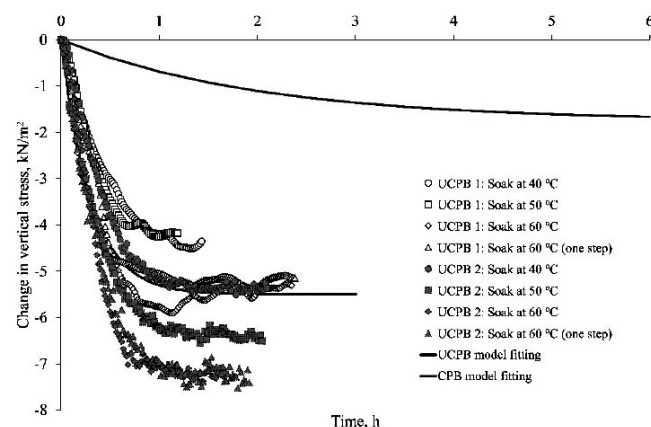


Figure 9—Change in the vertical stress of UCPB and CPB over time during soaking

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

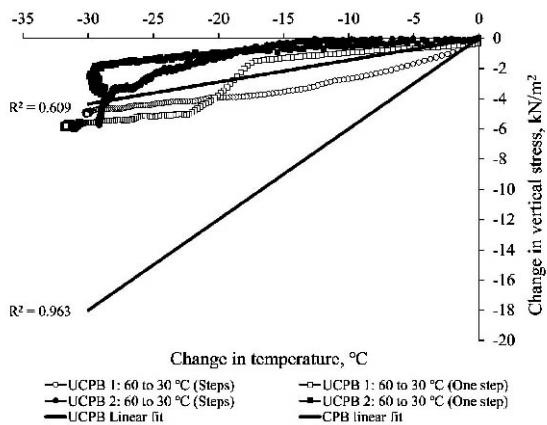


Figure 10—Stress behaviour of UCPB and CPB during dwelling by 30 °C

response to temperature change. Hence, the σ_v change recorded was almost linear with the temperature change. Meanwhile, UCPB exhibited inconsistent σ_v behaviour during dwelling, although a general reduction in σ_v was observed. This inconsistency might stem from the combined effects of particle strain caused by thermal shrinkage and irregular relaxation as equilibrium states are disturbed. In this scenario, the internal pressure acts as a normal force, enhancing shear behaviour between UCPB and the surrounding narrow wall, as demonstrated in the UCPB interface shearing study (Hasan, Ting, 2022).

The σ_v reduction in UCPB during dwelling was on average 3 times less than CPB, since much of the thermal stress had already dissipated through relaxation during soaking. Thus, only the residual thermal stress was reduced during dwelling. From Figure 3, it is evident that the final net σ_v after UCPB was dwelled back to 30°C was lower than the net σ_v after initial consolidation at 30°C. This pattern was consistent for both UCPB 1 and 2 Tests.

In summary, the divergent stress behaviours of UCPB and CPB under thermal loading are fundamentally governed by the presence and temperature-dependent evolution of the cementitious microstructure. The formation of a C-S-H network in CPB transforms the material from a frictional, granular assembly into a cohesive solid. The rate of this transformation is accelerated by temperature, leading to higher stress generation during heating and a more elastic, less plastic response during cooling. While not explicitly investigated in this study, the long-term performance and densification of such a matrix could be further enhanced by pozzolanic reactions, where materials like fly ash react to form additional C-S-H, further filling pores and strengthening the backfill (Alp et al., 2009; Bernal et al., 2016; Cavusoglu et al., 2021).

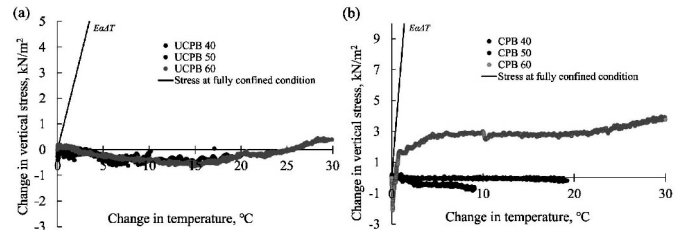


Figure 11—Initial stress behaviour of (a) UCPB (b) CPB when backfilled into the narrow wall at a controlled temperature

Impact of immediate elevated temperature on backfill stress behaviour

Figure 11 illustrates UCPB and CPB stress behaviour after directly backfilled at controlled target temperatures. This allows the backfill to be ramped right after backfilling, which could represent the actual mine backfill condition. Generally, the backfill material exhibited different σ_v changes depending on the target temperature. Though it is rather inconsistent for UCPB, higher curing temperatures generally resulted in greater final σ_v levels for both samples upon reaching the target temperature.

The σ_v generated from fixed temperature tests is very much lower than the σ_v generated from consolidated UCPB and CPB samples reported in Figure 7. During the early stage of deposition, proper arching effects had not been established in the UCPB tests. The time required for UCPB to fully consolidate was around 16 hours (as indicated in Figure 6), while ramping UCPB up to 60°C took at most 1 hour, showing insufficient time for proper arching development. Consequently, the slurry state of UCPB had less constraint from thermal expansion compared to fully consolidated UCPB, resulting in minimal σ_v generation at the early stage. This is especially true for UCPB 40 and UCPB 50 samples where no additional stress is generated from ramping. However, as the temperature approached 60°C for UCPB 60, there was some gain in σ_v , likely due to the rapid establishment of arching caused by the material's swift expansion at higher temperatures, which constricted smooth expansion within a narrow wall and generated thermal stress. As elevated temperature promotes hydration, the presence of binder in the hydrating sample establishes arching quicker than UCPB due to its rapid rheological development, which results in a clearer correlation between stress generation and rate of ramping.

Figure 12 illustrates the stress behaviour over time when soaked at a constant temperature. Since consolidation had not been allowed before the temperature change, all samples continued to establish an arching effect when soaked at the target temperature. For UCPB, the combined effects of self-weight consolidation, thermal

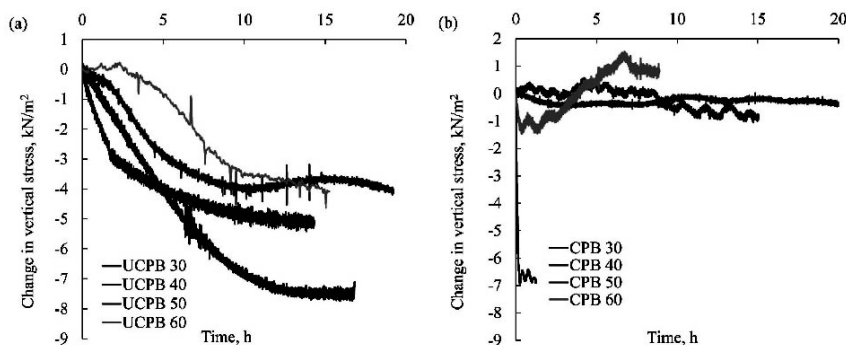


Figure 12—Change in vertical stress over time for (a) UCPB and (b) CPB

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

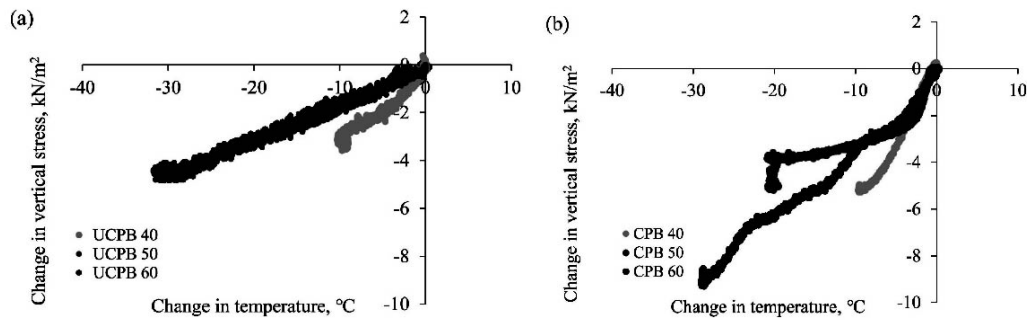


Figure 13—Change in stress while dwelling (a) UCPB and (b) CPB

expansion, and relaxation occurred simultaneously, resulting in significant σ_v reduction for all UCPB samples. Stress reduction was less pronounced at higher temperatures, which complexly affects the development of arching, and thermal stress generation and relaxation mechanics of the backfill.

Both UCPB and CPB 30 experienced the largest σ_v reduction as they rapidly attained the target temperature while still in a slurry state, permitting consolidation and arching effects to take place. This finding reflects the observation reported in Figure 6 with a similar magnitude of σ_v reduction and similar consolidation time. Some gain in stress for CPB samples were noted as testing at higher temperatures can enhance mechanical properties due to accelerated hydration. Consequently, UCPB that is experiencing a drop in stress across all temperatures continues to reduce during the soaking phase. This highlights that backfilling samples with higher workability or inferior frictional properties are beneficial to backfill work conducted at a temperature elevated stope.

Figure 13 illustrates the change in stress in response to temperature drop for both UCPB and CPB. Generally, the σ_v readings for all samples decreased, with UCPB showing less reduction in σ_v over the temperature decrease in comparison to CPB. CPB 60 exhibited a significant drop in σ_v , likely because of thermal stress relieved over soaking phase. The stress reduction behaviour in the dwelling phase differed in magnitude when compared to post-consolidation tests shown in Figure 10. Despite UCPB 50 experiencing a doubled temperature reduction compared to UCPB 40, UCPB 40 showed similar σ_v reduction. This may be due to the higher heat applied to UCPB 50, which gives greater thermal stress but is alleviated as the CPB sample might still be in slurry state, which allows a certain degree of relaxation to occur. This resulted in lower final σ_v during soaking and thus, lower relievable σ_v during dwelling. This further highlights the importance of conducting a test after the sample had stabilised.

The unconsolidated tests conducted at fixed temperatures simulate real stope conditions, where heat exchange begins immediately after pouring. However, these tests introduce greater complexity in data analysis due to the simultaneous influence of multiple factors on the observed stress variations. While the tests conducted after consolidation allow the material to fully stabilise before any temperature change, they offer more consistent behaviour in response to temperature variations. The differences between backfill material's behaviour affect the stress propagation over the evolution of backfill material across time, which, in this case, would be the hydrating effects. Hydration primarily affects the backfill material by altering the workability during the initial stage where arching develops, and stiffness at the later stage. Beyond hydration, uses of additive beyond typical CPB mix such as fibre-reinforced CPB, which affects stiffness and workability,

can be investigated to optimise backfill design by understanding its stress propagation (Cao et al., 2019). As noted in recent case studies of deep mining regions like the Zonguldak basin in Türkiye, understanding the in situ thermal environment is crucial, as it directly influences the mechanical and rheological behaviour of backfill materials (Bilen et al., 2025).

Conclusions

This study presents experimental findings on the impact of hydration on stress behaviour of backfill within a semi-confined narrow wall under varying temperature conditions from 30°C to 60°C. UCPB, serving as the controlled sample, was analysed alongside CPB, which yields the following conclusions:

- The novel narrow wall model can accurately capture stress-strain-temperature behaviour of both UCPB and CPB by reflecting the stress-strain behaviour throughout the pouring stage, self-weight consolidation stage, and curing stage with respect to temperature change.
- In the backfilling stage, hydration did not cause any difference to the gain of stress during pouring until the peak stress was attained at the end of pouring. Both samples behave like a flowable slurry, which did not generate any significant arching effects during the first 1 minute of testing.
- During the consolidation stage, CPB established stable stress transfer quicker than UCPB, though the magnitude of transferred stress did not differ much. Hydration does not affect the magnitude of stress transfer during consolidation without temperature alteration. However, the effect of hydration is significant if the sample is backfilled and cured at elevated temperature.
- An increase in temperature leads to linear increase in stress for both the CPB and UCPB samples. The magnitude of increase in stress for UCPB is lower than CPB due to the lack of hydration, which also allows UCPB to experience a greater relaxation effect during ramping. The relationship between temperature increases and stress generation is not linear for samples that were cured directly at a higher temperature.
- Stress reduction is observed for all samples during the soaking phase but reduces over time for CPB as it hydrates and becomes more resistant to thermal stress relaxation. UCPB experiences similar stress reduction during soaking, regardless of time, due to the lack of hydration. The presence of hydration in unconsolidated tests greatly affects the stress propagation during the soaking phase, which requires attention in optimising backfill mix design when backfilled to a temperature-elevated stope.

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

- The effect of hydration extends to the dwelling phase where UCPB experiences less reduction in stress from the effects of dwelling due to the thermal stress lost over relaxation during the ramping and soaking phases. CPB behaves more elastically due to hydration as the time elapses, leading to a stronger linear relationship between the change in stress towards the change in temperature. Effects of hydration on the unconsolidated tests show lower stress reduction during dwelling due to the possibility of relaxation of CPB at slurry state.

By understanding hydration as one of the contributing factors, this study improves knowledge of stress–temperature behaviour in narrow wall backfill systems. However, the present narrow wall apparatus is limited to capturing stress–strain–temperature responses in real time through the equipped sensors. Based on the UCPB finding, the difference in its behaviour due to speculated factors such as strength development, hydraulic conductivity evolution, progressive densification, localised stress concentrations, and relaxation zones could not be directly identified with the current setup. Future studies may therefore benefit from integrating non-invasive monitoring techniques, which can be correlated with mechanical measurements through extensive calibration. Such approaches would provide a more comprehensive picture of CPB behaviour and enable the development of safer and more efficient stope backfilling strategies.

Acknowledgements

The authors acknowledge the financial support from the Ministry of Higher Education Malaysia through Fundamental Research Grant Scheme (FRGS) No. FRGS/1/2023/TK06/UNIMAS/02/2, with a title: Behavior of thermal contraction on cemented paste backfill in mine stope. The authors also would like to thank the technical support and facilities provided by the Geotechnical Engineering Laboratory, The Department of Civil Engineering, University of Malaysia Sarawak.

Disclosure statement

The author(s) declare that no potential conflict of interest exists.

Credit author statement

W.K. Ting: Conceptualisation, methodology, software, investigation, validation, formal analysis, writing – original draft, project administration.

A. Hasan: Conceptualisation, methodology, software, validation, resources, writing – review and editing, supervision, project administration, funding acquisition.

Data availability statement

The data that support the findings of this study are available from the corresponding author, Alsidiqi Hasan, upon reasonable request.

References

- Agboola, O., Babatunde, D.E., Isaac Fayomi, O.S., Sadiku, E.R., Popoola, P., Moropeng, L., Yahaya, A., Mamudu, O.A. 2020. A review on the impact of mining operation: Monitoring, assessment and management. *Results in Engineering*, vol. 8, p. 100181. <https://doi.org/10.1016/j.rineng.2020.100181>
- Alp, I., Deveci, H.A., Sungun, Y.H., Yilmaz, A., Kesimal, A., Yilmaz, E. 2009. Pozzolan characteristics of a natural raw material for use in blended cements. *Iranian Journal of Science and Technology Transactions of Civil Engineering*, vol. 33, no. 4, pp. 291–300. <https://doi.org/10.22099/ijstc.2009.707>
- Asr, E.T., Kakaie, R., Ataei, M., Tavakoli Mohammadi, M.R. 2019. A review of studies on sustainable development in mining life cycle. *Journal of Cleaner Production*, vol. 229, pp. 213–231. <https://doi.org/10.1016/j.jclepro.2019.05.029>
- Belem, T., Benzaazoua, M. 2008. Design and application of underground mine paste backfill technology. *Geotechnical and Geological Engineering*, vol. 26, no. 1, pp. 147–174. <https://doi.org/10.1007/s10706-007-9154-3>
- Bernal, S.A., Rodríguez, E.D., Kirchheim, A.P., Provis, J.L. 2016. Management and valorisation of wastes through use in producing alkali-activated cement materials. *Journal of Chemical Technology and Biotechnology*, vol. 91, no. 9, pp. 2365–2388. <https://doi.org/10.1002/jctb.4927>
- Bilen, M., Toroglu, İ., Yilmaz, E. 2025. Power plant ash as a backfill material for subsidence mitigation and mining district recovery: A review and case study in Zonguldak, Türkiye. *International Journal of Mining, Reclamation and Environment*, vol. 1–19. <https://doi.org/10.1080/17480930.2025.2565498>
- Cao, S., Yilmaz, E., Song, W. 2019. Fiber type effect on strength, toughness and microstructure of early age cemented tailings backfill. *Construction and Building Materials*, vol. 223, pp. 44–54. <https://doi.org/10.1016/j.conbuildmat.2019.06.221>
- Cao, S., Xue, G., Yilmaz, E., Yin, Z. 2021. Assessment of rheological and sedimentation characteristics of fresh cemented tailings backfill slurry. *International Journal of Mining, Reclamation and Environment*, vol. 35, no. 3, pp. 319–335. <https://doi.org/10.1080/17480930.2020.1826092>
- Cavusoglu, I., Yilmaz, E., Yilmaz, A.O. 2021. Sodium silicate effect on setting properties, strength behavior and microstructure of cemented coal fly ash backfill. *Powder Technology*, vol. 384, pp. 17–28. <https://doi.org/10.1016/j.powtec.2021.02.013>
- Chen, S., Wang, W., Yan, R., Wu, A., Wang, Y., Yilmaz, E. 2022. A joint experiment and discussion for strength characteristics of cemented paste backfill considering curing conditions. *Minerals*, vol. 12, no. 2, p. 211. <https://doi.org/10.3390/min12020211>
- Cooke, R. 2008. *Pipeline design for paste and thickened tailings systems*. 1st ed. USA, CRC Press.
- Cui, L., Fall, M. 2017. Multiphysics modeling of arching effects in fill mass. *Computers and Geotechnics*, vol. 83, pp. 114–131. <https://doi.org/10.1016/j.compgeo.2016.10.021>
- Cui, L., Singalreddy, S.P., Guo, G. 2023. Geomechanical behavior and properties of cemented paste backfill under passive interface loading and their influences on field-scale stability. *Acta Geotechnica*, vol. 18, no. 4, pp. 3927–3945. <https://doi.org/10.1007/s11440-023-01798-4>
- Doherty, J.P., Hasan, A., Suazo, G.H., Fourie, A. 2015. Investigation of some controllable factors that impact the stress state in cemented paste backfill. *Canadian Geotechnical Journal*, vol. 52, no. 12, pp. 1901–1912. <https://doi.org/10.1139/cgj-2014-0321>
- Fahey, M., Helinski, M., Fourie, A. 2009. Some aspects of the mechanics of arching in backfilled stopes. *Canadian Geotechnical Journal*, vol. 46, no. 11, pp. 1322–1336. <https://doi.org/10.1139/T09-063>
- Fall, M., Benzaazoua, M., Saa, E.G. 2008. Mix proportioning of underground cemented tailings backfill. *Tunnelling and Underground Space Technology*, vol. 23, no. 1, pp. 80–90. <https://doi.org/10.1016/j.tust.2006.08.005>
- Fall, M., Célestin, J.C., Pokharel, M., Touré, M. 2010. A contribution to understanding the effects of curing temperature on the mechanical properties of mine cemented tailings backfill. *Engineering Geology*, vol. 114, no. 4, pp. 397–413. <https://doi.org/10.1016/j.enggeo.2010.05.016>
- Fang, K., Fall, M. 2018. Effects of curing temperature on shear behaviour of cemented paste backfill-rock interface.

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

- International Journal of Rock Mechanics and Mining Sciences*, vol. 112, pp. 184–192.
<https://doi.org/10.1016/j.ijrmms.2018.10.024>
- Fang, K., Zhang, J., Cui, L., Ding, L., Xu, X., Timms, W. 2023. Mathematical modelling and simulation for hydrating backfill body under cemented paste backfill/rock interface loading. *International Journal of Mining, Reclamation and Environment*, vol. 37, no. 1, pp. 87–109.
<https://doi.org/10.1080/17480930.2022.2142423>
- Gao, Y., Jiang, S., Xie, J., Wei, W., Jiang, Q. 2023. Experimental study on the shear creep characteristics of joints under wetting-drying cycles. *International Journal of Rock Mechanics and Mining Sciences*, vol. 169, p. 105458.
<https://doi.org/10.1016/j.ijrmms.2023.105458>
- Ghirian, A., Fall, M. 2016. Strength evolution and deformation behaviour of cemented paste backfill at early ages: Effect of curing stress, filling strategy and drainage. *International Journal of Mining Science and Technology*, vol. 26, no. 5, pp. 809–817.
- Goodey, R.J., Brown, C.J., Rotter, J.M. 2006. Predicted patterns of filling pressures in thin-walled square silos. *Engineering Structures*, vol. 28, no. 1, pp. 109–119.
<https://doi.org/10.1016/j.engstruct.2005.08.004>
- Hasan, A., Ting, W.K. 2022. Temperature effect on Mohr–Coulomb's effective strength parameters of paste backfill. *Frontiers in Materials*, vol. 8, p. 794089.
<https://doi.org/10.3389/fmats.2021.794089>
- Helinski, M., Fahey, M., Fourie, A. 2011. Behavior of cemented paste backfill in two mine stopes: Measurements and modeling. *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 137, no. 2, pp. 171–182.
[https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0000418](https://doi.org/10.1061/(ASCE)GT.1943-5606.0000418)
- Ile, D., Malan, D.F. 2023. A study of backfill confinement to reinforce pillars in bord-and-pillar layouts. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 123, no. 5, pp. 223–234.
<http://dx.doi.org/10.17159/2411-9717/2452/2023>
- Jafari, M., Grabinsky, M. 2021. Effect of hydration on failure surface evolution of low sulfide content cemented paste backfill. *International Journal of Rock Mechanics and Mining Sciences*, vol. 144, p. 104749.
<https://doi.org/10.1016/j.ijrmms.2020.104749>
- Li, D. 2024. A new analytical model for stress distribution in the rock bolt under axial loading. *International Journal of Rock Mechanics and Mining Sciences*, vol. 176, p. 105690.
<https://doi.org/10.1016/j.ijrmms.2024.105690>
- Li, L., Aubertin, M. 2010. An analytical solution for the nonlinear distribution of effective and total stresses in vertical backfilled stopes. *Geomechanics and Geoengineering*, vol. 5, no. 3, pp. 237–245. <https://doi.org/10.1080/17486025.2010.497871>
- Liu, N., Cui, L., Wang, Y. 2020. Analytical assessment of internal stress in cemented paste backfill. *Advances in Materials Science and Engineering*. Vol. 2020, 6666548.
<https://doi.org/10.1155/2020/6666548>
- Nasir, O., Fall, M. 2008. Shear behaviour of cemented pastefill-rock interfaces. *Engineering Geology*, vol. 101, no. 2, pp. 146–153.
<https://doi.org/10.1016/j.enggeo.2008.04.010>
- Ngwenyama, P.L., De Graaf, W.W. 2021. Risks and challenges affecting opencast pillar mining in previously mined underground bord and pillar workings. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 121, no. 12, pp. 623–633. <http://dx.doi.org/10.17159/2411-9717/1675/2021>
- Oke, J., Hawley, K., Belem, T., Hashemi, A. 2021. Paste backfill continuous pour: Red Lake operations case study. *Proceedings of the 24th International Conference on Paste, Thickened and Filtered Tailings*, Australian Centre for Geomechanics, Western Australia. pp. 381–396.
https://doi.org/10.36487/ACG_repo/2115_31
- Page, P., Yang, P., Li, L., Simon, R. 2021. A semi-empirical solution for estimating the elastic stresses around inclined mine stopes for the Mathews-Potvin stability analysis. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 121, no. 8, pp. 405–414.
<http://dx.doi.org/10.17159/2411-9717/690/2021>
- Pirapakaran, K., Sivakugan, N. 2007. Arching within hydraulic fill stopes. *Geotechnical and Geological Engineering*, vol. 25, no. 1, pp. 25–35. <https://doi.org/10.1007/s10706-006-0003-6>
- Porathur, J.L., Sekhar, S., Godugu, A.K., Bhargava, S. 2022. Stability analysis of a free-standing backfill wall and a predictive equation for estimating the required strength of a backfill material – a numerical modelling approach. *Journal of the Southern African Institute of Mining and Metallurgy*, vol. 122, no. 5, pp. 227–234.
<http://dx.doi.org/10.17159/2411-9717/1544/2022>
- Potvin, Y., Thomas, E., Fourie, A. 2005. *Handbook on mine fill*. Perth, Australia: Australian Centre for Geomechanics.
- Rahmat, M.A., Ismail, A.F., Aziman, E.S., Rodzi, N.D., Mohamed, F., Abdul Rahman, I. 2022. The impact of unregulated industrial tin-tailing processing in Malaysia: Past, present and way forward. *Resources Policy*, vol. 78, p. 102864.
<https://doi.org/10.1016/j.RESOURPOL.2022.102864>
- Samiratou Yaya, N., Cao, S., Yilmaz, E. 2025. Innovative reinforcement: Assessing strength features of waste microplastics reinforced backfills in sustainable mine waste management. *Construction and Building Materials*, vol. 460, p. 139744. <https://doi.org/10.1016/j.conbuildmat.2024.139744>
- Sheshpari, M. 2015. A review of underground mine backfilling methods with emphasis on cemented paste backfill. *Electronic Journal of Geotechnical Engineering*, vol. 20, no. 13, pp. 5183–5208.
- Sindhunata, Van Deventer, J.S.J., Lukey, G.C., Xu, H. 2006. Effect of curing temperature and silicate concentration on fly-ash-based geopolymerization. *Industrial and Engineering Chemistry Research*, vol. 45, no. 10, pp. 3559–3568.
<https://doi.org/10.1021/ie051251p>
- Thompson, B.D., Bawden, W.F., Grabinsky, M.W. 2012. In situ measurements of cemented paste backfill at the Cayeli Mine. *Canadian Geotechnical Journal*, vol. 49, no. 6, pp. 755–772.
<https://doi.org/10.1139/t2012-040>
- Ting, W.K., Hasan, A., Sahdi, F., Taib, S.N.L., Sutan, N.M., Aziz, B.A., Fourie, A. 2020. A narrow wall system to capture temperature stress-strain behavior in paste backfill. *Geotechnical Testing Journal*, vol. 43, no. 2, pp. 310–324.
<https://doi.org/10.1520/GTJ20170383>
- Ting, W.K., Hasan, A. 2023. Stress behaviour of cemented paste backfill within temperature controlled stope model. *International Journal of Mining, Reclamation and Environment*, vol. 37, no. 7, pp. 996–1015.
<https://doi.org/10.1080/17480930.2022.2142423>
- Vlachogiannis, I., Benardos, A. 2024. Proposed formulas for pillar stress estimation in a regular room-and-pillar pattern. *International Journal of Rock Mechanics and Mining Sciences*, vol. 180, p. 105826.
<https://doi.org/10.1016/j.ijrmms.2024.105826>
- Walske, M.L. 2014. An experimental study of cementing paste backfill. PhD thesis, The University of Western Australia, Australia.
- Widisinghe, S., Sivakugan, N. 2014. Vertical stresses within granular materials in confinements. *International Journal of Geotechnical Engineering*, vol. 8, no. 4, pp. 431–435.
<https://doi.org/10.1179/1939787913Y.00000000031>
- Wu, A., Wang, Y., Zhou, B., Shen, J. 2016. Effect of initial backfill temperature on the deformation behavior of early age cemented paste backfill that contains sodium silicate. *Advances in Materials Science and Engineering*, vol. 2016, p. 8481090.
<https://doi.org/10.1155/2016/8481090>

Temperature-elevated hydration effect on stress behaviour of cemented paste backfill

- Wu, D., Liu, L., Yilmaz, E., Zheng, S. 2025. Numerical prediction of strength and temperature changes within cemented paste backfill considering barricade stability. *Engineering Science and Technology, an International Journal*, vol. 62, p. 101966. <https://doi.org/10.1016/j.jestch.2025.101966>
- Xue, Y., Mishra, B., Gao, D. 2018. Laboratory study on the time-dependent behavior of intact and failed sandstone specimens under an unconfined condition with the relaxation test. *International Journal of Rock Mechanics and Mining Sciences*, vol. 110, pp. 210–217. <https://doi.org/10.1016/j.ijrmms.2018.08.011>
- Yan, B.X., Jia, H.W., Liu, Y.L., Liu, P.H., Yilmaz, E. 2025. Revealing cooperative load-bearing mechanisms between mine backfill and rock pillar using a bonded-block modeling approach. *Minerals*, vol. 15, no. 3, p. 210. <https://doi.org/10.3390/min15030210>
- Yan, B., Lai, X., Jia, H., Yilmaz, E., Hou, C. 2021. A solution to the time-dependent stress distribution in suborbicular backfilled stope interaction with creeping rock. *Advances in Civil Engineering*, vol. 2021, p. 5533980. <https://doi.org/10.1155/2021/5533980>
- Yan, B., Zhu, W., Hou, C., Guan, K. 2019. A three-dimensional analytical solution to the arching effect in inclined backfilled stopes. *Geomechanics and Geoengineering*, vol. 14, no. 2, pp. 136–147. <https://doi.org/10.1080/17486025.2019.1574031>
- Yilmaz, E., Belem, T., Benzaazoua, M., Bussi re, B. 2010. Assessment of the modified CUAPS apparatus to estimate in situ properties of cemented paste backfill. *Geotechnical Testing Journal*, vol. 33, no. 5, pp. 351–362. <https://doi.org/10.1520/GTJ102689>
- Yilmaz, E. 2018. Stope depth effect on field behaviour and performance of cemented paste backfills. *International Journal of Mining, Reclamation and Environment*, vol. 32, no. 3, pp. 273–296. <https://doi.org/10.1080/17480930.2017.1285858>
- Zhang, C., Liu, G., Tian, S., Cai, M. 2023. Passive soil arching effect in aeolian sand backfills for grillage foundation. *Sensors*, vol. 23, no. 19, 8098. <https://doi.org/10.3390/s23198098>
- Zheng, J., Li, L. 2019. A solution to estimate stresses in backfilled stopes by considering self-weight consolidation and arching. *Proceedings of the 8th International Congress on Environmental Geotechnics Volume 3, ICEG 2018*. Environmental Science and Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-13-2227-3_22 ◆



With more than thirty years of mining industry experience, we're experts in:

- Tailings & Mine Waste Handling
- Concentrate & Long-distance Pipelines
- Mine Backfill
- Mineral Processing
- Mine Services
- Bulk Water Supply Pipelines
- Dredging & Marine Pipelines
- Metallurgical Laboratory & Process Test Work

patersoncooke.com

Paterson & Cooke
KNOWLEDGE | EXPERIENCE | PASSION