

Utilisation of an engineered calcium aluminosilicate binder for cemented paste backfill with challenging mineralogy

Nikolas Romaniuk ^{a,*}, Lucas McFarlane ^b, Narain Hariharan ^b

^a Graymont, Canada

^b Graymont, USA

Abstract

Buoyed by high gold prices and demand for critical minerals like copper, miners are increasingly exploiting underground reserves, often with decreasing ore quality. In underground mining, the utilisation of mine tailings in cemented paste backfill (CPB) is key to maximising extraction and improving economics, while reducing external tailings footprints, providing social license to operate. As new ore bodies are exploited, resulting tailings possess challenging mineralogy that can contain considerable amounts of iron sulphides and/or expansive phyllosilicate minerals, which present significant challenges for CPB operations. Portland cements, such as general use limestone cement, lack the physical and chemical characteristics necessary to achieve strength targets in CPB systems containing elevated sulphate or phyllosilicate minerals, thus forcing operators to rely on alternative binders, such as primarily slag cements, to manage binder cost. The production of ground granulated blast furnace slag (GGBFS), key to producing slag cements, has plateaued and is set to decline as the blast furnaces that produce these slags are replaced with lower carbon intensity electric arc furnaces. Lack of GGBFS poses an existential risk for many CPB operations and necessitates the development of new binder alternatives. This study builds on previous investigations into the development of an engineered calcium aluminosilicate (CAS) binder designed to provide comparable strengths to slag cements in these challenging CPB systems, while maintaining a low embodied carbon footprint and a local supply chain. Key developments further demonstrate beneficial interactions with admixtures, such as plasticisers, commonly employed in challenging CPB operations.

Keywords: cemented paste backfill, pozzolanic reactions, low carbon, slag alternative, rheology, uniaxial compressive strength

1 Introduction

As critical minerals become increasingly exploited to satisfy the demands of the energy transformation and artificial intelligence (AI) and the price of gold reaches all-time highs, the role of cemented paste backfill (CPB) to support underground mining is becoming increasingly important. Data centres used to support AI alone require significant inputs of copper, silver, platinum, and tin, and a single wind farm to power a data centre (Malakoff 2025) with green energy requires between 2,000–7,000 tonne of copper (SFA Oxford 2025). To secure these resources, mine operators are faced with the reality of chasing mineral veins deep underground as deposits exploitable by open pit mining become fewer and the concerns about the environmental footprint of mining operations heighten in the wake of successive tailings dam failures (Williams 2021). To support underground mine operations, many rely on the method of CPB which has the added advantage of limiting the size of external tailings facilitates by the deposition of tailings into underground stopes.

CPB itself is an integrated system where the mill tailings are dewatered through a combination of thickeners and filters to create a low-moisture cake. The cake is then mixed with water, binder, and potentially

* Corresponding author.

admixtures to create a slurry that is hydraulically transported to the mined-out stopes where it is finally deposited and cemented in place (Belem 2004). There are many variations of CPB processes including different filter types to dewater the tailings and different mechanisms of hydraulic transport (e.g. gravity versus pumped) (Lee 2025). Crucial to the success of the backfill matrix are the different types of cementitious binders used to stabilise the tailings. These binders are typically composed of reactive calcium, alumina, and silica in the form of hydraulic cements, e.g. general use limestone (GUL) cement or alternative cementing materials (ACM) such as ground granulated blast furnace slag (GGBFS) (Sheshpari 2015). ACMs are distinct in their usage compared to supplementary cementitious materials (SCM) for their ability to replace a majority of general use (GU)/GUL cement binder (Smith 2022). ACM and SCM binders have different efficacies depending on mineralogy of the tailings themselves and are frequently blended to optimise performance.

The mineralogy of mine tailings is intrinsic to each resource and can contain a plethora of minerals and chemistries that are known to interfere with the performance of cementitious binders. Two of the most common challenging components frequently found within tailings for CPB are sulphate (Benzaazoua 2002), typically from the oxidation of iron sulphides, and high-alkali phyllosilicates (Wu 2018), such as clay minerals like kaolinite or illite. Challenges of sulphate minerals in structural cemented systems are characterised by the latent formation of expansive hydrated minerals like ettringite that can have negative impacts on strength and durability (Harris 2004). Phyllosilicate-rich CPB systems are typically marked with impeded flow and challenging rheology. Backfill systems that experience these difficult components usually respond poorly to ordinary Portland cements and have a significant reliance to blend with ACMs – particularly GGBFS – provided to mine operators as pre-blended ‘slag-cements’ (SC).

While SCs are used effectively today, many operators cannot regionally secure the ACM and the long-term outlook is negative due to declining worldwide availability of GGBFS (U.S. Geological Survey 2025). The greenhouse gas (GHG) intensive blast furnaces that generate the GGBFS necessary to produce SC are rapidly being replaced with ‘greener’ electric arc furnace (EAF) ‘mini-mills’ as steel producers strive to meet climate goals and obligations. The use of GGBFS is also preferred to miners for its ability to assist in meeting their scope 3 GHG emissions targets as it is a co-product and is attributed a negligible GHG footprint. Ironically, it is the extreme energies provided through the GHG intensive use of coal and coke in blast furnaces that impart the cementitious performance benefits to GGBFS and the use of lower energy directly reduced iron and recycled materials used in EAF results in a slag that has minimal cementitious activity. Worldwide production of GGBFS is estimated to have plateaued and is expected to decline. This decline in availability is expected to be acute in developed economies such as Canada, as is illustrated by Algoma steel’s commitment to convert their Sault Ste. Marie plant to EAF with plans to shut down their blast furnace operations in 2027 resulting in the permanent loss of local GGBFS (McGee 2025). Imports from eastern Asia are compensating to support current industry needs but are prone to supply chain disruption and, in any case, the increase worldwide demand for SCs pose an existential risk to economic and technical feasibility of the future of CPB operations.

This paper presents a newly developed alternative calcium aluminosilicate (CAS) binder system for CPB that demonstrates significant promise to provide a resilient solution for CPB operations, especially those with problematic mineralogy. This binder system leverages a low GHG footprint while providing similar chemistry profile to common SCs. The hydrated products of SCs are not well understood and difficult to characterise for even the most advanced laboratories. Observably, SC is differentiated from GUL with characteristically high concentrations of silica and alumina. By using highly reactive calcium and aluminosilicate sources in the CAS binder for CPB, similar hydration patterns may be achieved in relation to SC. We postulate the higher active alumina content found in the CAS binder is similar to SC with an inherent ability to generate beneficial reactions with sulphate along with enhanced hydration mechanisms that improve strength and durability. The paper explores the performance of the CAS binder for CPB with 2 unique tailings profiles: one with high sulphate and one enriched with fine phyllosilicates. In both binders, it is evaluated as a substitution for SC and as a ‘standalone’ ACM with GUL.

2 Experimental study

All experiments were completed at Graymont's Central Laboratory in Sandy, Utah. The CAS binder was tested using an 80% CAS/20% GUL and a 40% CAS/60% SC blends. Two different sources of mine tailings were used to analyse the performance of the binders: high fines (HF) tailings and high sulphur (HS) tailings. Both physical and chemical properties of the tailings are compared.

X-ray diffraction (XRD) mineralogy was completed using a Bruker D8 Endeavor with LynxEye XE-T detector. PDF-5+ and Diffrac.EVA software was used in conjunction with TOPASv6 for diffraction data collection and refinement. A JEOL IT200 scanning electron microscope (SEM) with electron dispersive spectroscopy (EDS) were used to confirm the morphology of selected CAS-cemented binder matrices.

X-ray fluorescence of the binder samples were completed using a Bruker S8 Tiger. Refractory elemental analysis for the tailing samples were carried out using a lithium tetraborate flux and a Perkin-Elmer Optima 7300 Radial view ICP-OES. A LECO 744 carbon/sulphur infrared analyser was used to measure the CO₂ and sulphur values. A loss on ignition test at was performed in accordance with ASTM C25-19 to 'balance-check' the summation of the measured elements. A laser-method CILAS 1190 particle size analyser was used to analyse a size distribution of the tailings.

2.1 Material properties

2.1.1 Binder properties

The elemental compositions for GUL cement, SC, and the novel CAS-cement are shown in Table 1.

Table 1 Elemental composition of general use limestone (GUL), slag cements (SC), and the calcium aluminosilicate (CAS) cement binder

| Binder sample | % mass | | | | | | | | |
|---------------|--------|-----|--------------------------------|--------------------------------|------------------|------------------|-------------------|-----|-----------------|
| | CaO | MgO | Fe ₂ O ₃ | Al ₂ O ₃ | SiO ₂ | K ₂ O | Na ₂ O | S | CO ₂ |
| GUL cement | 60.2 | 2.7 | 3.0 | 4.3 | 18.8 | 0.8 | 0.3 | 1.8 | 4.5 |
| Slag cement | 45.3 | 5 | 1.2 | 10.9 | 35.1 | 0.4 | 0.2 | 0.9 | 0.4 |
| CAS cement | 45.5 | 1.2 | 1.6 | 13.6 | 32.9 | 0.9 | 0.1 | 0.4 | 1.4 |

2.1.2 Mine tailings properties

Each tailings source was mixed and sampled into 12 representative containers. Each aliquot was tested for moisture analysis. Represented as an average, the HS tailings had a solids concentration of 82% versus the HF tailings solids concentration of 75%.

Six out of 12 aliquots from each tailing were randomly sampled for quantitative chemical analyses. The average elemental composition of the 2 types of tailings is outlined in Table 2. HS tailings display high concentrations of iron and sulphur, alluding to its pyrite concentration. The HF tailings show a more complex tailing sample with higher concentrations of alkali, silica, and calcium.

Table 2 Elemental composition of the major constituents in the mine tailings

| Tailings sample | % mass | | | | | | | | |
|-----------------------|--------|-----|--------------------------------|--------------------------------|------------------|------------------|-------------------|------|-----------------|
| | CaO | MgO | Fe ₂ O ₃ | Al ₂ O ₃ | SiO ₂ | K ₂ O | Na ₂ O | S | CO ₂ |
| High sulphur tailings | 1.7 | 1 | 21.1 | 10 | 48 | 1.76 | 0.6 | 15.1 | 1.0 |
| High fines tailings | 4.7 | 9 | 7.3 | 11.8 | 55 | 2.3 | 3.1 | 0.5 | 2.5 |

A random sample of each tailings source was taken for XRD analysis. The mineralogical composition of the mine tailings is shown in Table 3. The HS tailings exhibit phases of quartz, pyrite, and muscovite compared to the HF tailings' larger amorphous phase, along with high instances of chabazite (a zeolite), clinocllore, albite, and actinolite. The HF tailings' mineralogical profile presents greater complexity.

Table 3 Mineralogical composition of the major constituents in the mine tailings

| Tailings sample | % phase | | | | | | | | | | |
|-----------------------|---------|-----------|------------|-----------|-------------|------------|-----------|--------|--------|---------|-----------|
| | Albite | Anorthite | Actinolite | Chabazite | Clinocllore | Phlogopite | Muscovite | Pyrite | Quartz | Calcite | Amorphous |
| High sulphur tailings | – | 4.7 | – | – | – | – | 22 | 23.5 | 46.2 | – | 8.2 |
| High fines tailings | 34.4 | – | 13.4 | 10.8 | 8.1 | 7.6 | – | <1 | 19.2 | 5.5 | 17.6 |

Figure 1 shows the comparative laser particle size analysis of the two types of tailings. The left-shifted curve of the HF tailings confirms more concentrated fines compared to the broader curve of the HS tailings. The steepened, finer curve of the HF tailings may be attributed to phyllosilicate minerals; however, it is noted that the prevalence of zeolite in these tailings may cause interference in laser diffraction methods due to their unique crystal structure and porous nature.

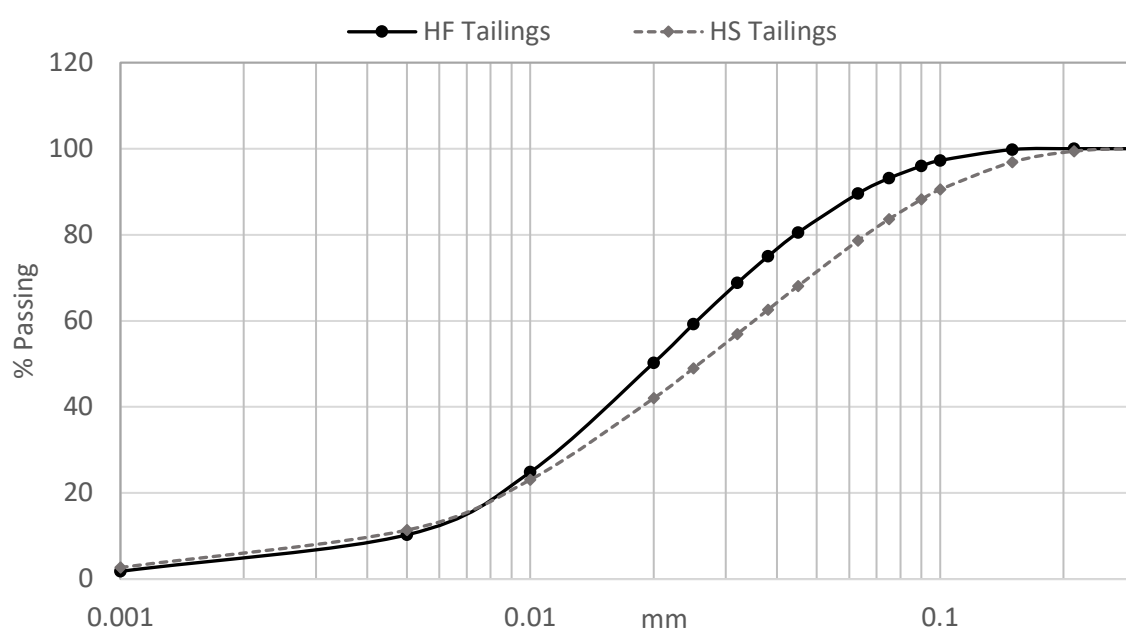


Figure 1 Particle size distribution of high sulphur (HS) tailings and high fines (HF) tailings analysed by laser using a CILAS 1190 particle size analyser

2.2 Performance testing program

A performance testing program was carried out to test the rheology and strength performance of the CPB mixtures at the Graymont Central Laboratory in Sandy, Utah, USA. The testing methods were developed in-house in collaboration with the mine operators that provided the tailings. CPB mixing was completed using a 4.7 litre Kitchen-Aid® Pro stand mixer with a paddle attachment. Strength testing was conducted using a Karol-Warner 90 kN load frame with a 22 kN load cell. All rheology results were collected using a Brookfield RST-SST rheometer with a vane spindle. Strength specimens were cast using 51 × 101.6 mm HDPE cylinder

moulds. The chosen plasticising admixtures were previously optimised for each CPB mixture by the supplier and considered proprietary.

2.2.1 Cemented paste backfill matrices

Although there are many similarities in design of the CPB matrices, each CPB operation has unique characteristics to the CPB design. The upper limits of binder concentrations were used for this study – the HF CPB used a 6.5% binder concentration by dry mass whereas the HS CPB used a 6% binder concentration. The CPB matrices of the HF and HS CPB are available in Table 4 and 5, respectively. Enough water was added to the CPB mixtures such to reduce the yield stress of the CPB slurry to a rheological yield stress of 250 Pascals, which yielded slight variations in the water concentration.

Table 4 Cemented paste backfill (CPB) matrix of high fines (HF) tailings. Samples A, B, and C were tested without the use of plasticising admixtures. Samples D, E, and F use the same binders as A, B, and C with plasticisers

| CPB sample | Tailings (g) | CAS binder (g) | GUL cement (g) | Slag-cement (g) | Water (g) | Plasticiser (g) | Total binder (%) | Total solids (%) |
|------------|--------------|----------------|----------------|-----------------|-----------|-----------------|------------------|------------------|
| HF-A | 3,900 | 0 | 204 | 0 | 469.3 | 0 | 6.5 | 65.9 |
| HF-B | 3,900 | 0 | 0 | 204 | 479.2 | 0 | 6.5 | 65.8 |
| HF-C | 3,900 | 81.6 | | 122.4 | 573.1 | 0 | 6.5 | 64.9 |
| HF-D | 3,900 | 163.2 | 40.8 | 0 | 545.1 | 0 | 6.5 | 64.9 |
| HF-E | 3,900 | 0 | 200 | 0 | 248.9 | 4 | 6.5 | 70.6 |
| HF-F | 3,900 | 0 | 0 | 200 | 218.8 | 4 | 6.5 | 71.1 |
| HF-G | 3,900 | 80 | | 120 | 192.5 | 4 | 6.5 | 71.5 |
| HF-H | 3,900 | 160 | 40 | 0 | 254.4 | 4 | 6.5 | 70.5 |

CAS = calcium aluminosilicate; GUL = general use limestone

Table 5 Cemented paste backfill (CPB) matrix of high sulphur (HS) tailings. Samples A, B, and C were tested without the use of plasticising admixtures. Samples D, E, and F use the same binders as A, B, and C with admixtures

| CPB sample | Tailings (g) | CAS binder (g) | GUL cement (g) | Slag-cement (g) | Water (g) | Plasticiser (g) | Total binder (%) | Total solids (%) |
|------------|--------------|----------------|----------------|-----------------|-----------|-----------------|------------------|------------------|
| HS-A | 3,900 | 0 | 204 | 0 | 492.5 | 0 | 6 | 73.8 |
| HS-B | 3,900 | 0 | 0 | 204 | 542.5 | 0 | 6 | 73 |
| HS-C | 3,900 | 81.6 | 0 | 122.4 | 544.4 | 0 | 6 | 73 |
| HS-D | 3,900 | 163.2 | 40.8 | 0 | 572.4 | 0 | 6 | 72.6 |
| HS-E | 3,900 | 0 | 204 | 0 | 277.9 | 4.1 | 6 | 77.5 |
| HS-F | 3,900 | 0 | 0 | 204 | 250.2 | 4.1 | 6 | 78.0 |
| HS-G | 3,900 | 81.6 | 0 | 122.4 | 311.2 | 4.1 | 6 | 76.9 |
| HS-H | 3900 | 163.2 | 40.8 | 0 | 361.3 | 4.1 | 6 | 76.0 |

CAS = calcium aluminosilicate, GUL = general use limestone

2.2.2 Tailings mixing

Both the HS and HF tailings were received in 200 L drums. The individual tailings were well-mixed and aliquoted into 12 19 L buckets each. When the tailings were sampled for CPB mixing, they were re-mixed and tested for solids concentration before confirming the CPB recipes.

2.2.3 Cemented paste backfill mixing

After confirming the solids concentration, the tailings were weighed out with an accuracy of ± 0.1 g into a stainless-steel mixing bowl. All binder components were massed into a weigh boat with the same precision. The initial water addition was also massed into a beaker using tap water to the nearest 0.1 g. After amassing, all components were placed into the mixing bowl and hand mixed using a spatula to incorporate for 1 minute. If plasticiser is being used, it is added at this point. Once incorporated, the bowl of CPB slurry was transferred to the stand mixer for more vigorous mixing. The paddle attachment was started on low speed for 30 seconds, then increased to a medium speed for 1 minute. The mixer was stopped and lowered to scrape the sides and have any unmixed material incorporated. The mixer was returned to medium speed for an additional 2 minutes.

After initial mixing, the bowl was lowered and the CPB mixture sampled for rheological yield stress. Yield stress was analysed using a 2-slope intersection technique. If the resulting yield stress was recorded to be within 250 ± 10 Pa, the CPB mixture was caste into cylinders. If the resulting CPB mixture was above 260 Pa, additional water was added to mix, recorded, and mixed for an additional 1 minute. The sampling process and rheology test was repeated until the CPB slurry was at the correct rheology – typically within the first or second sequential water addition. If under 240 Pa, the CPB mixture was discarded.

2.2.4 Cylinder casting

Once CPB mixing was completed, strength specimens were caste into the HDPE cylinder moulds with an approximate 25 mm collar extension at the top of each mould, secured with duct tape around the seam where the collar meets the cylinder. A primary lift was deposited into each cylinder to fill approximately half of the volume and was tamped 25 times. A second lift was then deposited to fill the remaining volume to approximately halfway up the collar extension. The second lift was tamped 25 times so that the tamping rod would penetrate about 12.5–25 mm into the first lift. Each cylinder was capped and transferred to a humidity chest kept a $23 \pm 2^\circ\text{C}$ and $98 \pm 2\%$ humidity to be demoulded at the indicated testing intervals. Figure 2 displays how the cylinders are stored during curing.

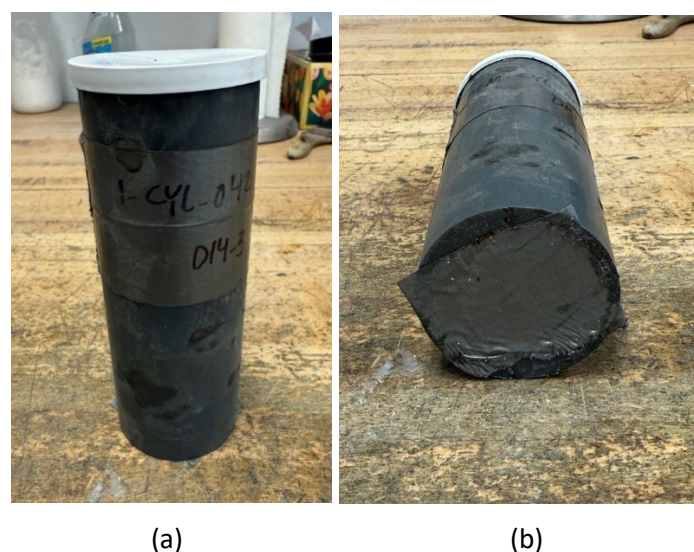


Figure 2 (a) Example of cylinder mould in vertical that displays the seam between the mould and collar; (b) Sealed with duct tape and bottom view that displays a 2 mm hole sealed with duct tape

2.2.5 Cylinder unconfined compressive strength testing

Each cylinder was removed from the humidity chest and demolded at the specified uniaxial compressive strength (UCS) intervals. The collar of each cylinder was removed to reveal excess cemented CPB at the top of the mould. This excess CPB was removed carefully using a mortar knife so that the contained CPB cylinder was level with the mould. The tape at the bottom of each cylinder, shown in Figure 2b, was removed to reveal a 2 mm hole. Pressurised air at 2.1 bar was pushed into the bottom of the cylinders through the hole to push the CPB cylinders out from the moulds.

Each cylinder was individually placed into the UCS load frame. The lower platen was jogged so that the upper platen was approximately 1 mm away from the top of the CPB cylinder. The testing program began using a strain rate of 1.3 cm/min. Each test was stopped once the specimen exhibited a 10% drop in strength from the peak strength. The UCS average maxima were recorded.

3 Results and discussion

3.1 High sulphur cemented paste backfill binder uniaxial compressive strength performance

SC is the most used binder in CPB because it produces the strongest resulting CPB material. This is due to many reasons with a primary rational being the ability of SC to convert greater amounts of water in the CPB matrix into 'bound' water hydration products versus Portland cements. Another enhancing characteristic of SC is its ability to generate sulphate resistivity, making this binder a stand-out choice for CPB systems that contain pyrite or other 'sulphidic' minerals.

3.1.1 High sulphur cemented paste backfill binder performance without plasticiser

Figure 3 shows the comparative UCS performance of the binder systems compared in this study. Considered a latent-hydraulic cementitious material, SC develops most of its strength between 3-days and 28-days. GUL cement does not perform as well as the 80% CAS/20% GUL binder blend; both develop over 50% of their overall strength by 7 days of curing. Replacing 40% of SC with the CAS binder generates less strength than the SC alone but may prove usable for CPB plant operations.

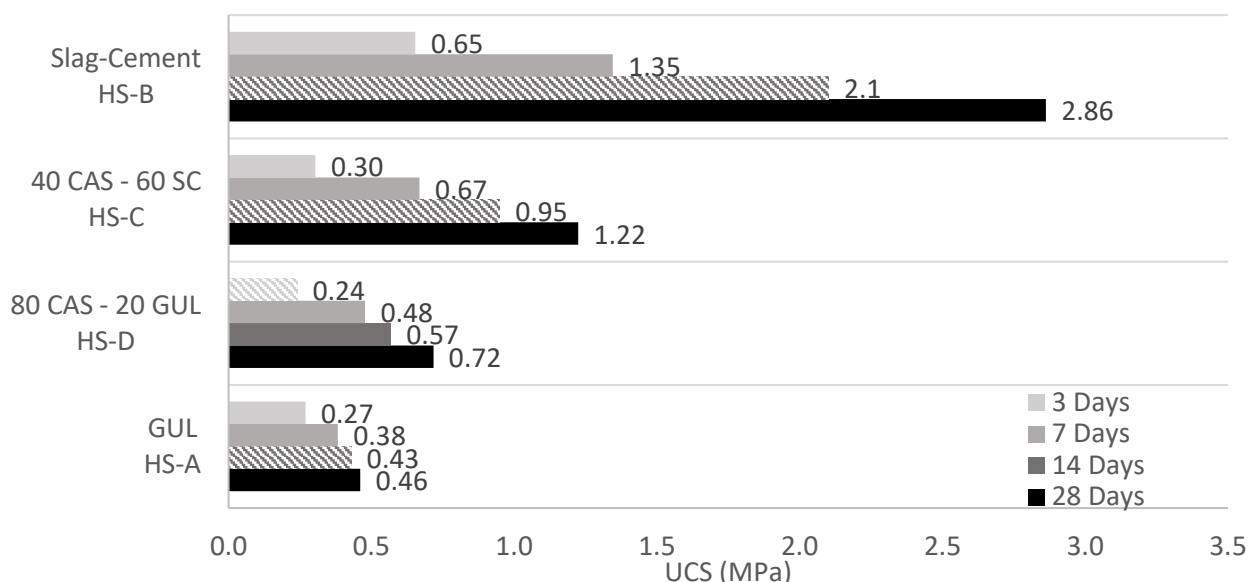


Figure 3 Uniaxial compressive strength (UCS) of high sulphur (HS) cemented paste backfill using binder blends without plasticisers. Columns shaded with diagonal lines indicate regression-projected data points. CAS = calcium aluminosilicate, GUL = general use limestone

3.1.2 High sulphur cemented paste backfill binder performance with plasticiser

The UCS performance of the binder blends in the HS tailings using plasticiser are shown in Figure 4. The plasticiser was dosed at 2% by weight of binder. All binder systems were positively impacted with the use of plasticising admixture; however, CAS-incorporated binder systems experienced the greatest UCS increase. The use of plasticiser showed variable performance at the 3-day interval.

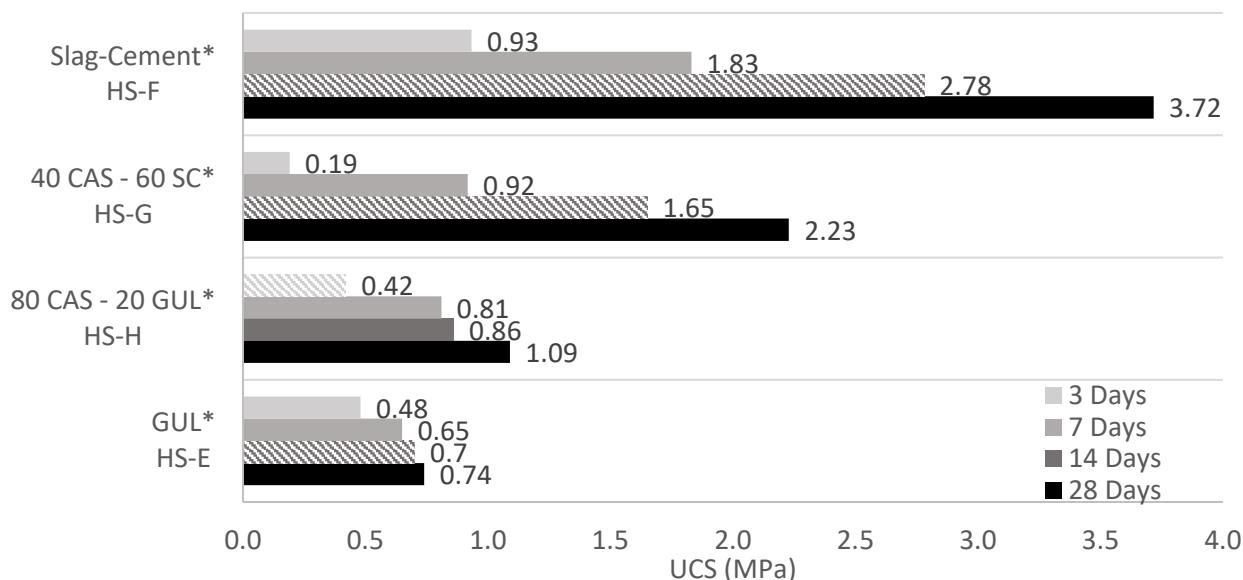


Figure 4 Uniaxial compressive strength (UCS) of high sulphur (HS) cemented paste backfill using binder blends with plasticisers. Blends using plasticiser are notated with an asterisk (*). Rows shaded with diagonal lines indicate regression-projected data points. CAS = calcium aluminosilicate, GUL = general use limestone

The 40% CAS/60% SC blend experienced an increase of 82% in strength when using plasticising admixture, as seen in Table 6. The improvements in strength performance confirm the largest benefits of the plasticiser are most likely to occur in the CAS binder blends.

Table 6 Comparison of uniaxial compressive strength change in high sulphur (HS) cemented paste backfill at 7-day and 28-day intervals with percentage increase using plasticising admixture. CAS = calcium aluminosilicate, GUL = general use limestone

| Sample | 7-day strength (MPa) | | 7-day % increase w/ admix | 28-day strength (MPa) | | 28-day % increase w/ admix |
|--------------------------|----------------------|----------|---------------------------|-----------------------|----------|----------------------------|
| | No admix | W/ admix | | No admix | W/ admix | |
| GUL (HS-A/E) | 0.38 | 0.65 | 70% | 0.46 | 0.74 | 61% |
| 80% CAS/20% GUL (HS-D/H) | 0.48 | 0.81 | 69% | 0.72 | 1.09 | 52% |
| 40% CAS/60% SC (HS-C/G) | 0.67 | 0.92 | 37% | 1.22 | 2.23 | 82% |
| SC (HS-B/F) | 1.35 | 1.83 | 36% | 2.86 | 3.72 | 30% |

3.2 High fines cemented paste backfill binder uniaxial compressive strength performance

A finer tailings source in CPB systems creates an especially challenging environment for Portland cements like GUL. Fine particles can surround the nucleation sites of cement particles and create a 'blinding' effect, thereby reducing the percolation of the cementitious network in CPB. SC's performance in CPB that contains HF is expected to be due to the forementioned proclivity towards enhanced hydration products.

3.2.1 High fines cemented paste backfill binder uniaxial compressive strength performance without plasticiser

Figure 5 shows the comparative UCS performance of the binder systems in HF CPB. UCS performance is lower among all binders compared to the HS CPB. When indexed against SC, the CAS binder develops more strength in the HF CPB than the HS CPB. GUL underperforms all binders and would require much higher binder concentrations for successful use in the HF tailings.

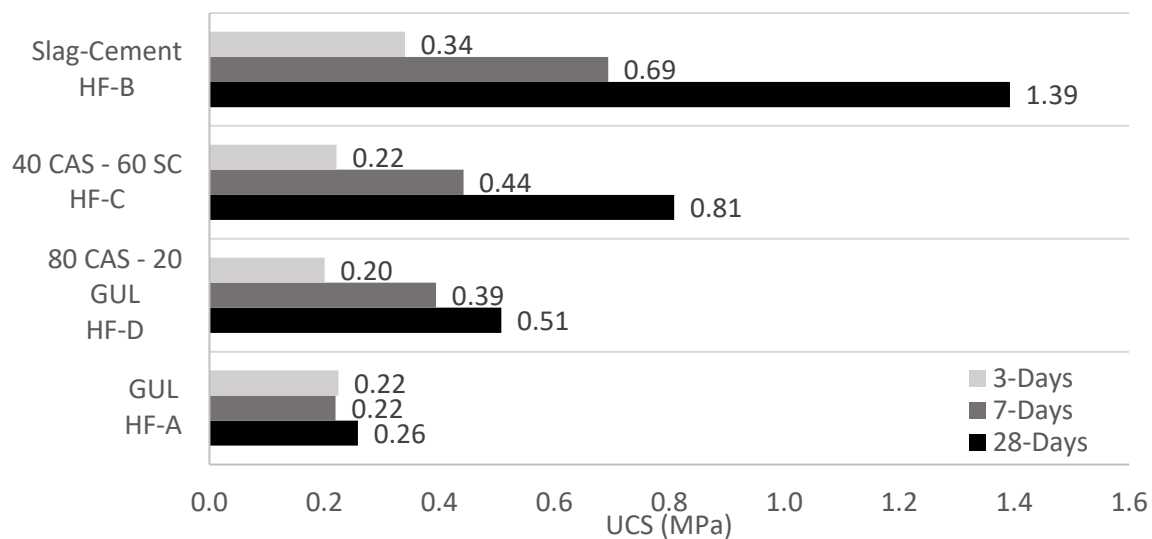


Figure 5 Uniaxial compressive strength of high sulphur (HS) cemented paste backfill using binder blends without plasticisers. CAS = calcium aluminosilicate, GUL = general use limestone, HF = high fines

3.2.2 High fines cemented paste backfill binder uniaxial compressive strength performance with plasticiser

The UCS performance of the binder blends in the HF CPB using plasticiser are shown in Figure 6. The plasticising admixture added to the CPB at 2% dosage by binder mass increases the performance of every binder at every UCS interval. Like the plasticiser results in the HS CPB, the greatest increase in UCS strength when using plasticiser is exhibited by the 40% CAS/60% SC binder.

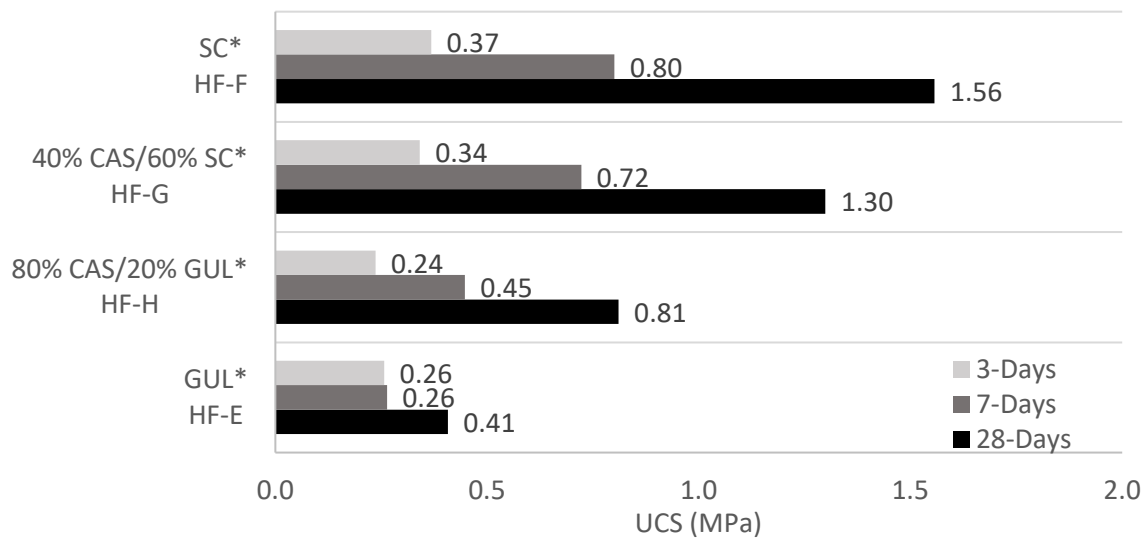


Figure 6 Uniaxial compressive strength of high sulphur (HS) cemented paste backfill using binder blends with plasticisers, notated with asterisks (*). CAS = calcium aluminosilicate, GUL = general use limestone, HF = high fines

When evaluating UCS strength, the CAS binder shows more usability in the HF tailings than in the HS tailings. Using plasticiser in the HF tailings enables the 60% CAS – 40% SC binder to exceed the 7-day UCS of SC without plasticiser in HF CPB and only lags the 28-day UCS of SC without plasticiser. Table 7 shows the performance increase in HF CPB after using plasticiser.

Table 7 Comparison of UCS change in HS cemented paste backfill at 7- and 28-day intervals with percentage increase using plasticising admixture. CAS = calcium aluminosilicate, GUL = general use limestone, HF = high fines, SC = slag-cement

| Sample | 7-day strength (MPa) | | 7-day % increase w/ admix | 28-day strength (MPa) | | 28-day % increase w/ admix |
|--------------------------|----------------------|----------|---------------------------|-----------------------|----------|----------------------------|
| | No admix | W/ admix | | No admix | W/ admix | |
| GUL (HF-A/E) | 0.22 | 0.26 | 20% | 0.26 | 0.41 | 58% |
| 80% CAS/20% GUL (HF-D/H) | 0.39 | 0.45 | 13% | 0.51 | 0.81 | 60% |
| 40% CAS/60% SC (HF-C/G) | 0.44 | 0.72 | 64% | 0.81 | 1.30 | 61% |
| SC (HF-B/F) | 0.69 | 0.80 | 15% | 1.39 | 1.56 | 12% |

3.3 Scanning electron microscopy of calcium aluminosilicate-general use limestone cemented paste backfill

The primary mode of evaluation for the mineral phases of the different CPB samples was SEM. SEM was used to compare the amorphous and unique structures formed using the 80% CAS/20% GUL (HS-D and HF-D) without plasticiser in an attempt to better understand the cementitious phases formed in the CPBs. The samples chosen were cured for 7-days. SEM images of the selected samples are shown in Figure 7.

Comparison of the cemented phases in the CPB matrices is challenging. Quantitative methods such as XRD lack the resolution to draw strong relationships between diffraction peak intensity and phase concentration. This is exacerbated by high amorphous phases in GUL, SC, and CAS CPBs. Further, XRD as a quantitative technique should be carefully considered in low-binder structural systems like CPB, as detection limits may give skewed data.

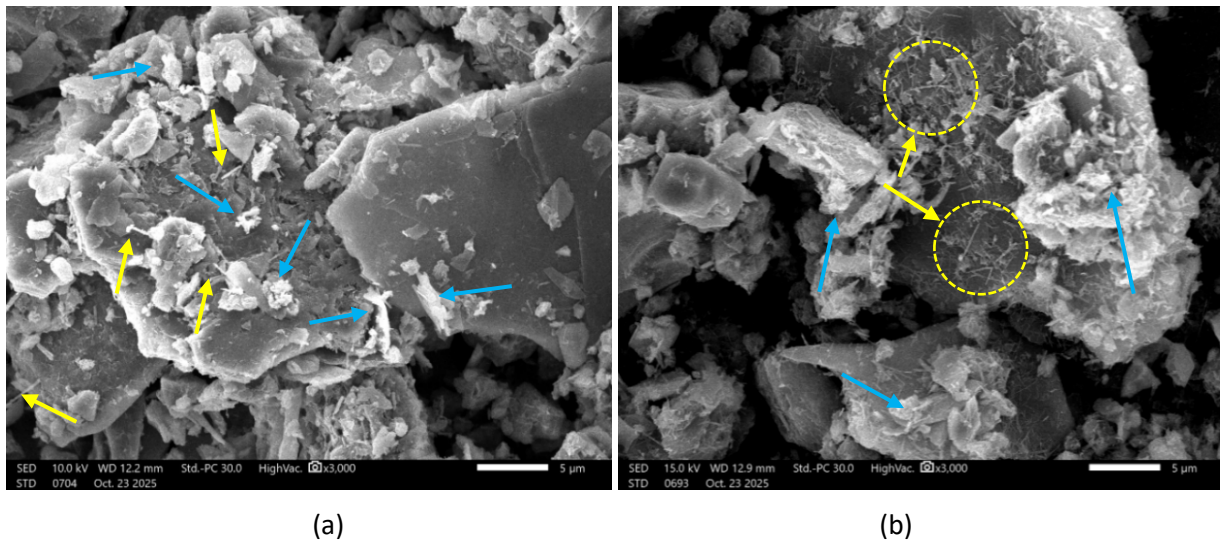


Figure 7 JEOL JSM IT200 (SED) scanning electron microscopy imaging of 80% CAS/20% GUL in CPB samples (a) HF-D and (b) HS-D. Arrows and circles marked in yellow indicate instances of rod-like ettringite. Arrows of blue indicate areas of hydrated calcium silicates and/or calcium aluminosilicates

The SEM imaging shown in Figure 7 shows likely instances of ettringite in both samples, with higher concentrations in the HS CPB. The HS CPB sample exhibits ‘clustering’ of ettringite compared to the dispersed rods in the HF CPB. This finding is expected, due to the higher concentrations of sulphur in the HS tailings. The development of well-ordered ettringite by day 7 suggests this is beneficial and strength building ‘primary ettringite’ rather than deleterious latent ettringite (Taylor 2000). Higher-density areas appear on the SEM scan as brighter compared to lower-density tailings particles that appear darker. The high-density, globular/amorphous areas correspond to cemented phases within the individual CPB matrices. The formation of beneficial ‘primary ettringite’, which is calcium sulphoaluminate phase, requires active alumina content in the binder, which is enriched in the newly developed CAS binder.

3.4 Rheology impact using different binders and plasticiser

Deviation of solids content for the different binders without plasticiser ranged from 0.5% in HS CPB to 0.7% in HF CPB to achieve 250 ± 10 Pa. When using plasticiser, deviation ranged from 0.4% in HF CPB to 0.8% in HS CPB. Given the precision for the prescribed yield stress method, the deviation in solids content is within error in determining whether certain binders require statistically significant increases in water demand.

A relationship was made between the use of plasticiser in the HS and HF CPB systems by normalising the yield stress (YS) in Pascals to solids concentration (%s). The resulting value gives YS per unit of solids. The values for the normalised data are plotted in Figure 8. Both systems exhibit an inverse linear relationship between solids concentration and normalised YS. However, the slope magnitude of the HF CPB is much steeper than the HS CPB, suggesting the HF CPB to be more sensitive to solids dilution as a driver towards the reduction of rheological YS.

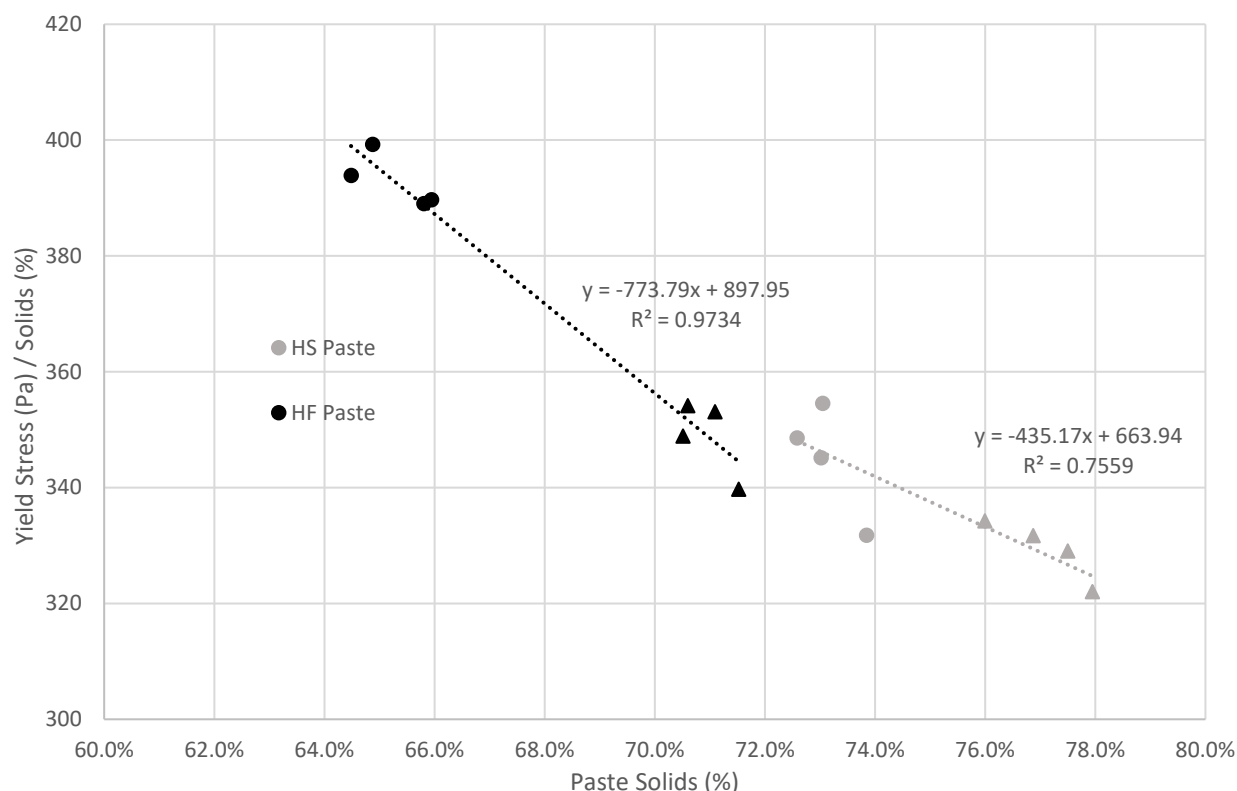


Figure 8 Normalised yield stress versus percent solids of the high sulphur (HS) and high fines (HF) cemented paste backfill systems. Cemented paste backfill slurries using plasticiser are shown using triangles

The higher R^2 value in the HF CPB may indicate a more structural response versus that of the HS CPB. A consideration for this effect is the quantity and combination of phyllosilicate and zeolite content in the HF tailings and their potentially higher geotechnical plasticity index – the solids difference between liquid limit and plastic limit.

4 Conclusion

4.1 Performance of calcium aluminosilicate binder blends in cemented paste backfill

The CAS binder presents a modern, high-range ACM suitable for integration into SC systems for CPB. The CAS binder's chemistry highlights the importance of the alumina phase in backfill binders as it provides a similar elemental composition compared to SC, which contains high proportions of GGBFS, that is extensively used in modern CPB. Results indicate that up to 40% of SC can be replaced with CAS while still achieving operational UCS targets – around 40–80% of the strength activity of SC, depending on the use of admixture – enabling backfill operators to extend the use of limited SC supplies without compromising on strength performance. The use of a 90%/10% SC system blended with CAS offers a practical option to maintain process throughput, lower clinker demand, and reduce associated CO_2 emissions.

Furthermore, the development of a slag-free CAS-cement binder presents a realistic, low carbon alternative to traditional SC CPB systems. Although SC outperforms CAS in both the HS and HF CPB systems, the 80% CAS/20% GUL blend demonstrated superior performance compared to GUL cement alone. This CAS binder is commercially available and offers a viable option for operations unable to secure reliable SC supply, providing a sustainable pathway toward lower carbon backfill design in modern mining.

4.2 Comparison of the calcium aluminosilicate binder in high sulphur and high fines cemented paste backfill systems

The results of this study show that the disparity in UCS between conventional 90%/10% SC and CAS-based binder blends is notably smaller in the HF tailings than in the HS tailings. This suggests a positive synergy between the CAS binder and CPB systems containing elevated fines content, leading to improved strength development versus GUL cement with zero compromise on rheological performance. Given that HF concentrations often pose challenges to all facets of tailings management, the CAS binder demonstrates promising potential as a functional alternative for fine-grained tailings, offering enhanced compatibility and reduced performance penalties relative to traditional SC systems.

4.3 Future work

We are further optimising the CAS binder formulations by investigating the mineralogy of the produced cementitious phases, with a focus on calcium sulphoaluminates, to support the observation seen in our SEM analysis. The goal is to build a model that will correlate strength development in CPB to the identified formation of beneficial cementitious phases. We are also actively working with market partners to advance this effort and seeking further collaborations to provide a mutually beneficial CAS binder for the benefit of the mining industry.

Acknowledgements

This work made use of Nanofab EMSAL shared facilities of the Micron Technology Foundation Inc. Microscopy Suite sponsored by the John and Marcia Price College of Engineering, Health Sciences Center, Office of the Vice President for Research.

References

- Belem, T & Benzaazoua, M 2004, 'An overview on the use of paste backfill technology as a ground support method in cut-and-fill mines', in E Villaescusa & Y Potvin (eds), *Proceedings of the Ground Support in Mining Underground Construction*, Perth, pp. 28–30.
- Benzaazoua, M, Belem, T & Bussière, B 2002, 'Chemical factors that influence the performance of mine sulphidic paste backfill', *Cement and Concrete Research*, vol. 32, no. 7, pp. 1133–1144.
- Harris, P, Scullion, T & Sebesta, S 2004, *Hydrated Lime Stabilization of Sulfate-Bearing Soils in Texas*, FHWA technical report.
- Lee, C & Veenstra, R 2025, 'Cemented paste mine fill system design', in Y Potvin & R Veenstra (eds), *Comprehensive Handbook on Mine Fill*, Australian Centre for Geomechanics, Perth, pp. 224–239.
- Malakoff, E 2025, *Key Minerals in Data Centers Infographic*, U.S. Geological Survey, viewed 10 October 2025, <https://www.usgs.gov/media/images/key-minerals-data-centers-infographic>
- McGee, Niall 2025, 'Algoma Steel pivots early to electric future after securing \$500-million in government loans', *The Globe and Mail*, viewed 10 October 2025, <https://www.theglobeandmail.com/business/article-algoma-steel-government-loans-trade-steel-tariffs/>
- SFA Oxford 2025, *Copper Market and Copper Price Drivers*, viewed 10 October 2025, <https://www.sfa-oxford.com/battery-metals-and-materials/markets/copper-market-and-copper-price-drivers/>
- Sheshpari, M 2015, 'A review on types of binder and hydration in cemented paste backfill (CPB)', *Electronic Journal of Geotechnical Engineering*, vol. 20, no. 13, pp. 5949–5963.
- Smith, M 2022, *Low Carbon Cement*, Climate Action Reserve, viewed 10 October 2025, https://climateactionreserve.org/wp-content/uploads/2023/03/Low-Carbon-Cement-Protocol-Draft_v3-track-changes.pdf
- Taylor, HFW, Famy, C & Scrivener, KL 2000, 'Delayed ettringite formation', *Cement and Concrete Research*, vol. 31, no. 5, pp. 683–693, [https://doi.org/10.1016/S0008-8846\(01\)00466-5](https://doi.org/10.1016/S0008-8846(01)00466-5)
- U.S. Geological Survey 2025, *Mineral Commodity Summaries*, Reston, viewed 10 October 2025, <https://pubs.usgs.gov/periodicals/mcs2025/mcs2025-iron-steel-slags.pdf>
- Williams, DJ 2021, 'Lessons from tailings dam failures—where to go from here?', *Minerals*, vol. 11, no. 8, p. 853.
- Wu, AX, Wang, J, Wang, S, Yang, X & Zhou, F 2018, 'Application of clay-rich full plant tailings paste backfill technology', in RJ Jewell & AB Fourie (eds), *Paste 2018: Proceedings of the 21st International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 351–360, https://doi.org/10.36487/ACG_rep/1805_27_Wang