

# Development of slag alternatives for paste backfill operations

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## Abstract

*Paste backfilling, a critical step of the underground mining cycle which enables both increased resource recovery and provides a resilient tailings storage solution, is increasingly challenged by limited availability of industrial byproduct binders such as ground granulated blast furnace slag (GGBFS). The use of high quality GGBFS has proven to be critical for operators to address challenges posed by unique and complex ore compositions such as high sulphate ores while also contributing towards reducing the scope 3 greenhouse gas (GHG) emissions, especially as traditional cement binders can be responsible for up to 70% of the GHG emissions in the backfill process. This paper focuses on the development of a versatile engineered lime-based binder for paste backfill which maintains a low GHG footprint and can be made adaptable to various mine conditions, such as high sulphate ores, without compromising strength and other performance requirements. The novel binder has been tested in laboratory conditions by monitoring the unconfined compressive strength development over time using a sulphate-rich paste tailings provided by a commercial mining operation in Canada and has shown promising progress as a slag alternative.*

**Keywords:** *paste fill, paste backfill, sulphate, GHG reduction, binder, slag alternative*

## 1 Introduction

There is no denying the numerous benefits of backfill in underground mining operation, especially the paradigm shifting advancement of paste backfilling. While traditional backfilling methods like cemented rockfill provide stability and improve resource recovery, the utilisation of milled tailings in backfill virtually eliminates the need for external tailings facilities and provides geochemical stability, reducing sulphidic pollution (Belem & Benzaazoua 2004; Sheshpari 2015; Tariq & Yanful 2013). The benefits of paste backfill are accentuated in metal ores that have high waste-to-product ratios, such as those that are encountered in gold and copper mining. The waste-to-product ratios of many critical metals can approach 1,000,000 to 1, as lower-grade ore bodies are mined to support industrial and consumer demand (Qi & Fourie 2019). Avoiding large surface tailings deposits is of increasing importance due to recent high-profile tailing impoundment failures that have resulted in significant loss of human life and environmental damage (Williams 2021). The safe extraction of critical metals, like copper and nickel, is in no small part due to the use of paste backfill and these key resources are required for the energy transition to electrified automobiles and transport critical to achieve greenhouse gas (GHG) reduction goals worldwide (Azevedo et al. 2022).

While the importance of mining's role to provide the materials to support the energy transition is well known and highlights the importance of mining to develop a decarbonised future, mining operations are under increased environmental scrutiny (Azadi et al. 2020). A significant cohort of international mining operators recognise the need to improve environmental performance, especially with respect to GHG emissions, and have made aggressive promises to stakeholders, such as commitments to net-zero GHG operations. These GHG emissions are broadly divided into three categories: scope 1 covering direct emissions from operations, scope 2 covering indirect emission resulting from operations such as electricity and fuel, and scope 3 covering indirect emissions through the supply and value chains, which includes backfill binders like cement. Much of the GHG reduction successes enjoyed by mining operations are a result of adopted new technologies to lower scope 1 emissions or conversion to cleaner energy sources to lower scope 2 emissions,

but there has been limited attention on reducing scope 3 emissions. The lack of focus on reducing scope 3 emissions is in no part due to complexity of getting accurate emissions data from suppliers and standardised accounting methods that address the full cradle-to-grave lifecycle of these products and services (Patchell 2018). The increased usage and acceptance of independently verified Environmental Product Declarations (EPD) is a critical step for mining operators to fully understand their scope 3 emissions. In mine backfill, understanding the scope 3 emissions is of the critical importance as traditional binders, such as Portland cement, can be responsible for up to 70% of the total GHG emission in the entire process (Safari & Lim 2023); a theoretical paste plant using 40,000 tonnes of cement a year would produce nearly 37,000 tonnes of CO<sub>2</sub> based on the 922 kg/tonne of cement published by the Portland Cement Association (2021). Reducing the scope 3 emissions from mine backfill binders will be critical for mine operators to meet their net-zero GHG commitments.

The binders used in mine backfill rely primarily on the development of strength from calcium silicate hydrate (CSH) minerals and to a lesser extent calcium aluminate hydrate (CAH) minerals. These CSH minerals are traditionally produced through hydraulic cements, like Portland cement; however, there is an alternate mechanism to produce CSH minerals relying on pozzolanic reactions. These pozzolanic reactions require the alkaline activation of reactive silicates and aluminates, typically through their reaction with calcium hydroxide (i.e. slaked lime) to produce the CSH and CAH minerals (Walker & Pavia 2011). The use of pozzolanic cements has existed for millennia, used extensively by the Roman empire where volcanic ashes were made to react with lime to produce resilient cements that still exist to this day, such as in Rome's Parthenon. The pozzolanic cements, noted for their ability to self-heal, are typically slower to set and cure when compared to modern Portland cement formulations (Seymour et al. 2023). The requirement of lime to activate the pozzolan can be problematic in high sulphate systems, such as can be encountered in sulphide rich tailings, producing gypsum and ettringite mineral phases that can limit strength development (Harris et al. 2004). There are many potential sources of pozzolans, which can be broadly divided into manufactured natural products, such as calcined clays and volcanic ashes, and industrial co-products, such as fly ashes and slags.

Mine backfill operations make great use of industrial co-products to improve the economics, performance, and environmental footprint of the binders. In high sulphide paste tailings, the use of ground granulated blast furnace slag (GGBFS), a byproduct of pig iron production, is a preferred binder as it has been shown to impart sulphate resistance (Benzaazoua et al. 2002). However, the best co-products, such as GGBFS and fly ash, are associated with high GHG emission industrial processes, such as blast furnaces and coal-fired energy generation, which are being rapidly replaced with more efficient processes, such as directly reduced iron and natural gas fired energy production. As the industrial processes required to generate these co-products decline, the co-product availability is expected to plateau and then decline as has been seen with the precipitous decline of fly ash due to closure of coal-fired power stations across the United States. In the case of GGBFS, the US Geological Survey has identified a plateau in worldwide GGBFS slag production with a local decline in North America (US Geological Survey 2023). This plateau in production has corresponded with an increase in demand in GGBFS throughout the construction industry, resulting in significant escalation in price and shortages in supply. This paper investigates the use of a new engineered cement alternative, developed by Graymont, that is produced by combining lime products and naturally occurring pozzolanic materials to provide a low GHG footprint, security of supply (i.e. not reliant on other industrial processes like GGBFS), and customizability to optimise the binder composition for different paste tailings chemistries.

## 2 Experimental study

All experiments were completed at Graymont's Central Laboratory in Sandy, Utah.

### 2.1 Material properties

Refractory elemental analysis for the tailing and binder samples were carried out according to ASTM C1301-95 using a lithium tetraborate flux and a Perkin-Elmer Optima 7300 Radial view ICP-OES. A LECO 744 carbon/sulphur IR analyser was used to measure the CO<sub>2</sub> and sulphur values. A loss on ignition test was

performed in accordance with ASTM C25-19 to ‘balance-check’ the summation of the measured elements. Soluble sulphate was analysed using a Dionex ICS-2100 Ion Chromatographer with a sodium hydroxide eluent and an IonPac AS-15 column.

### 2.1.1 Sand and tailings properties

The HM107 sand was purchased from Gilson Company and is a rounded silica sand containing nearly pure quartz mined from Ottawa, Illinois. The HM107 sand is manufactured to pass a no. 20 sieve but be retained on a no. 30 sieve meeting the specification in ASTM C 778.

The low and high sulphate paste tailings were obtained from two gold mining operations in North America. The properties of the elemental properties of these tailings are presented in Table 1.

The particle size analysis of the sand and both paste tailings is presented in Table 2. Adherence to ASTM E3340-22, particle size analysis was carried out using a CILAS 1190 laser particle size analyser in a wet state with ultrasonic dispersion.

**Table 1 Paste tailings elemental properties**

Material	CaO	MgO	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	S	CO <sub>2</sub>	Soluble sulphate ppm
	% Mass									
Low sulphate	15.2	5.8	1.8	4.1	48.0	1.1	0.0	1.8	15.6	2187
High sulphate	1.9	1.3	17.3	11.5	56.1	1.6	0.5	10.6	1.1	9794

**Table 2 Paste tailings particle size properties**

Material	Diameter at 10%	Diameter at 50%	Diameter at 90%
	µm		
Low sulphate	6.9	35.1	157.2
High sulphate	2.0	13.3	52.7

### 2.1.2 Binder properties

Examples of the binders used in the work are detailed in Table 3. The GB-PASTE and standard Portland type ½ cement were used in both the ‘mortar cube’ and ‘low sulphate paste’ testing. The general use cement, ‘GU cement’, and GGBFS, were used for the ‘high sulphate paste’ testing. Three proprietary GB-PASTE binders namely, GB-P-A, GB-P-B, and GB-P-C were used for ‘high sulphate testing’.

The estimated greenhouse gas footprints are presented in Table 3. The GB-PASTE values were based on Graymont’s internal environmental performance data available in our sustainability report and partner supplier’s EPDs. The cement and slag values were found in the cited literature.

**Table 3 Binder elemental and estimated greenhouse gas (GHG) properties**

Binder		Elemental composition (% mass)								Estimated GHG footprint	
Class	Type	CaO	MgO	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	S	(CO <sub>2</sub> <sub>eq</sub> kg/tonne)	
GB-PASTE	Low lime	52.6	0.7	1.0	5.0	33.9	2.9	0.9	0.0	176	
	Mid lime	54.9	0.8	1.0	4.8	32.1	2.8	0.9	0.0	237	
	High lime	57.2	0.9	0.9	4.5	30.3	2.6	0.8	0.0	298	
Cement	GU cement	60.2	2.7	3.0	4.3	18.8	0.8	0.3	1.8	922 <sup>A</sup>	767 <sup>B</sup>
Slag	GGBFS	44.4	5.7	0.9	9.6	35.0	0.4	0.2	1.0	147 <sup>C</sup>	459 <sup>B</sup>

<sup>A</sup> Portland Cement Association (2021); <sup>B</sup> Kawai et al. (2005); <sup>C</sup> Slag Cement Association (2020)

## 2.2 Testing program

### 2.2.1 Test matrix and cube/cylinder preparation and curing

The test matrices used to prepare the cube or cylinders are presented in Table 4 for the ‘mortar cube’ testing, Table 5 for the ‘low sulphate paste’ testing, and Table 6 for the ‘high sulphate paste’ testing. The ‘mortar cube’ and ‘high sulphate paste’ testing used 2 in cubes, whereas the ‘low sulphate paste’ testing used a 3 × 6 in cylinders.

**Table 4 Mortar cube test matrix**

Test condition	Sand (g)	Binder (g)		Water (g)	Target W:B ratio	Make-up water	Effective W:B ratio	Total binder (% solids)
	HM107	GB-PASTE	Type 1/2 cement					
No lime	1,600	200	200	200	0.50	0	0.50	20
Low lime	1,600	200	200	200	0.50	31	0.58	20
Mid lime	1,600	200	200	200	0.50	30	0.58	20
High lime	1,600	200	200	200	0.50	21	0.55	20
Cement control	1,600	0	400	200	0.50	0	0.50	20

**Table 5 Low sulphate paste test matrix**

Test condition	Paste tailings (g)	Binder (g)		Water (g)	Total (g)	W:B ratio	Total binder (% solids)
		GB-PASTE	Type 1/2 cement				
Cement control	8,480	0	493	700	8973	1.42	5.5
Low lime	8,480	247	247	700	8973	1.42	5.5
Mid lime	8,480	247	247	700	8974	1.42	5.5
High lime	8,480	247	247	700	8973	1.42	5.5

**Table 6 High sulphate paste test matrix**

Condition	Paste tailings (g)*	Binder (g)			Total water (g)	Yield stress (Pa)	W:B Ratio	Total binder (% solids)
		GB-PASTE	GGBFS	GU cement				
Cement/GGBFS control	2,250	0	122.3	16.7	336.43	253	2.42	7.5%
GB-P-A	2,250	61.1	61.2	16.7	323.62	249	2.32	7.5%
GB-P-B	2,250	61.1	61.2	16.7	287.28	254	2.06	7.5%
GB-P-C	2,250	61.2	61.2	16.7	321.32	256	2.31	7.5%

\*The high sulphate paste tailings contain 17.4% moisture, thus 2,250 g of wet paste contains 1,858.5 g of dry solids

Mortar cube testing was developed internally with Graymont and its partners to model the unique programs underway at different backfill operations. Mortar cube testing was performed with 2" × 2" cubes using a 1:4 binder to sand ratio, HM 107 '20–30' sand matrix, a 0.5 water to binder ratio, and a make-up water step. The low binder content and poorly graded aggregate size distribution better represent the CRF backfill operation of witness. It was found through testing that with a 100% cement binder with the given parameters for the mortar procedure, the cement blend typically produces a 9% moisture after complete blending. A secondary water addition was developed targeting a 9% moisture content after complete blending of GRAYBOND mortar mixes. This step was found necessary to balance the increased water demand of GRAYBOND against the cement control.

High sulphate paste cube testing was also developed internally within Graymont to better model the unique paste backfill programs underway. Binder concentration was controlled to measure 7% by weight of total solids and a variable water to binder to target a rheological consistency defined by a yield stress of 250 Pa.

Low sulphate paste mixing was carried out in 3 × 6 in cylinders. Binder concentration was 5.5% by weight of total solids with a controlled water to binder ratio of 1.42. This paste cylinder campaign had no rheological control.

### 2.2.2 Mortar cube mixing, casting, and storage

All dry components as presented in Table 4 were massed into a steel mixing bowl for attachment with a Kitchen-Aid™ stand mixer. A paddle attachment was used to blend the dry ingredients at a low speed for 1–2 minutes, taking care to minimise air loss of the powder. The initial amount of water was added and the mortar was mixed for 2 minutes at a low speed. After mixing, the mortar was sampled in triplicate to determine the initial moisture of the material using a moisture balance at 200°C. The required amount of water make-up determined was subsequently added and the mortar was mixed for an additional 30 seconds at a slightly faster rate. The mortar cubes were cast into moulds in accordance with ASTM C109/109 M-20 and moved to a moist cabinet at 95% humidity.

After 24 hours, the mortar cubes were removed from their moulds, labelled, and returned to the moist cabinet for testing at the designated intervals.

### 2.2.3 High sulphate paste cube mixing, casting, and storage

A 200 L drum of paste tailings was mixed to homogeneity and separated into 10 buckets. The average moisture content of the tailings was found to be 17.4% ± 0.4%. Tailings were massed in a steel mixing bowl and binder powders were added as presented in Table 6. The tailings and binder were mixed for one minute at low speed using a paddle mixer to incorporate the dry components. The initial water mass was slowly added over 3–5 minutes to the paste mixture while mixing to avoid splashing. After all water was added, the blend was mixed on a medium speed for one minute. After mixing, the material was sampled and tested for yield stress using a Brookfield RST-SST rheometer. If the yield stress fell within 250 ± 10 Pa, no more water

was added. If the yield stress was above these bounds, additional water was added and the mixture was retested.

Once finished, the paste was placed into 2 × 2 in cube moulds in two separate lifts. After the first lift was placed, the cube mould was firmly tapped on the table 15–20 times to compact the paste and expel air bubbles. The second lift was placed and the compaction was repeated. The mortar cubes were then moved to the humidity chest and demolded after 24–48 hours depending on qualitative plasticity whereas the cubes could be safely removed from the moulds without deforming the paste cubes.

Once demolded, the cubes were returned to the moist cabinet for testing at the designated intervals.

#### **2.2.4 Low sulphate paste cylinder mixing, casting, and storage**

Tailings were massed in a steel mixing bowl and binder powders were added as presented in Table 5. The tailings and binder were mixed for one minute at low speed using a paddle mixer to incorporate the dry components. The initial water mass was slowly added over 3–5 minutes to the paste mixture while mixing to avoid splashing. After all water was added, the blend was mixed on a medium speed for one minute.

After mixing, the material was carefully poured into a 3 × 6 in cylinder in two separate lifts. Between each lift, the cylinder was firmly tapped on the table 15–20 times to compact the paste and expel air bubbles. Each cylinder was labelled, sealed, and stored in a humidity chest to be demolded and tested at the designated intervals.

#### **2.2.5 Uniaxial compression strength testing**

Uniaxial compressive strength (UCS) testing was carried out at designated intervals in accordance with ASTM C109/109 M-20 using a Humboldt™ ‘20,000 lbs load frame’ and ‘20,000 lbs load cell’. The platens used were of brass material with the top platen on a ball joint below the load cell. The test specimen was centred between the top and bottom platen and the jog switch was applied to move the platens together until the digital display read 4.5–5 kg of force. The test recording software was set to ‘record’ and the testing toggle was switched on. Strain rate for all testing remained at 1.27 mm/min. Each test was performed until the strength of the specimen fell by 10% from its peak and visual failure was apparent. The maximum UCS was recorded for the sample.

### **3 Results and discussion**

#### **3.1 Mortar cube results**

The initial screening program using a fine ASTM sand (HM-107) was used to understand the lime requirements to effectively react with the pozzolans and maximise strength at a typical 28 day target. The testing uses a higher binder content than typical backfill to better elucidate the differences in strength and an aggressive 50% substitution of cement with the new ‘GB-PASTE’ alternative binder blends. The UCS measured at 7 and 28 days are presented in Table 7. As is expected, the pozzolanic reactions from the GB-PASTE binder occur at a slower rate compared to pure hydraulic cement, so the strengths observed at day 7 are all lower than the cement control, with a typical strength activity index of 73–78%. However, by day 28 the strength from the pozzolanic reactions exceeds the strength of hydraulic cement by up to 20%. The amount of lime in the binder is critical to optimise strength. No improvement is seen compared to the control when using no lime, relying only on the free lime produced from hydraulic cements, which indicates supplemental lime is necessary to optimise for the higher alternative binder substitution rate. The mid and high lime binder blends produce essentially the same strength, 15 MPa, at day 28.

**Table 7 Mortar cube strengths**

Binder type	Total binder	Portland type 1/2 cement	GB – PASTE	UCS strength (MPa)	
				Day 7	Day 28
High lime	20%	10%	10%	10.3	15.2
Mid lime	20%	10%	10%	10.5	15.1
Low lime	20%	10%	10%	9.8	13.7
No lime	20%	10%	10%	10.3	12.8
Cement control	20%	20%	0%	13.3	12.7

### 3.2 Low sulphur paste results

The new binder blends developed in the mortar cube work were tested using real paste tailings. These paste tailings were low in soluble sulphur, with only about 2,000 ppm found in leachate testing and the total sulphur was reasonably low at 1.8% by weight. The miner who supplied the tailings was primarily interested in strength generation at two different time points where a minimum UCS must be achieved: 0.1 MPa at 20 hours and 0.9 MPa at 28 days. The cylinder strengths for the different binder blends are presented in Table 8 where, unlike the mortar cubes, a typical backfill binder design was used (i.e. 5.5% by weight). Again, the substitution of the GB-PASTE binder provided lower strength than the cement control; however, all of the experiments met the 0.1 MPa target. At 28 days the GB-PASTE binders gained strength approaching or exceeding the cement control; however, unlike the mortar cube testing, the low lime binder provided the highest strength at 0.94 MPa. The med lime binder at 0.88 MPa nearly met the 0.9 MPa target and the high lime binder had significantly lower strength at 0.70 MPa.

**Table 8 Low sulphur paste strength results**

Binder type	Total binder	Portland type 1/2 cement	GB-PASTE	UCS strength (MPa)	
				20 hours	28 days
High lime	5.5%	2.75%	2.75%	0.10	0.70
Mid lime	5.5%	2.75%	2.75%	0.10	0.88
Low lime	5.5%	2.75%	2.75%	0.10	0.94
Cement control	5.5%	5.5%	0.0%	0.20	0.90

### 3.3 High sulphur paste results

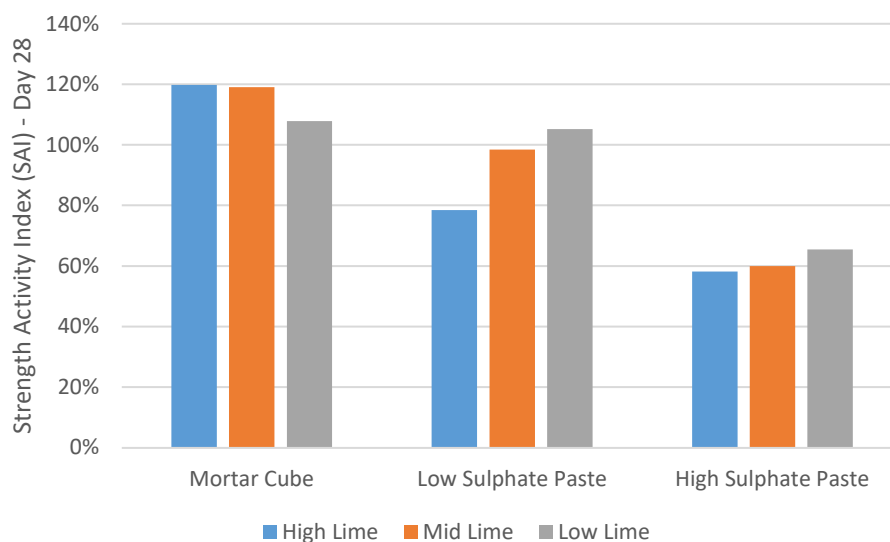
Unlike the previous test conditions, the high sulphur paste system requires a GGBFS, rather than cement alone in the binder blend to mitigate the high sulphur and achieve strength. This high sulphur paste tailings contains nearly five-times the amount of soluble and total sulphur when compared to the low sulphur paste tailings. The initial target in this system is to replace at least half of the GGBFS. Initial results of our investigations are shown in Table 9. The UCS results are relatively lower when compared to the low sulphur tailings, with the best result from GB-P-A providing 0.76 MPa compared to about 1.3 MPa for the control system. The GB-P-A contains a lower relative lime content compared to GB-P-B and C.

**Table 9 High sulphur paste strength results**

Binder type	Total binder	GB-PASTE	GGBFS	GU cement	UCS strength (MPa)	
					Day 7	Day 28
GB-P-A	7%	3.08%	3.08%	0.84%	0.32	0.86
GB-P-B	7%	3.08%	3.08%	0.84%	0.40	0.79
GB-P-C	7%	3.08%	3.08%	0.84%	0.36	0.76
Cement/GGBFS control	7%	0%	6.16%	0.84%	1.34	1.31

### 3.4 Comparison of test conditions

Comparing the results from the different test conditions is achieved by indexing the results to a control, i.e. the test strength divided by the control strength at day 28, to derive a strength activity index (SAI) which are presented in Figure 1. The GB-PASTE binder used in the ‘mortar cube’ and ‘low sulphate paste’ testing are identical in composition; however, the GB-P-A, -B, and -C used in the ‘high sulphate paste’ has different proprietary chemistry, with increasing lime content from A to C.

**Figure 1 Comparison of strength activity index at day 28 across all test systems**

The ‘mortar cube’ system was initially designed as a test method for development of product for cemented rockfill and does not contain any sulphate minerals, which are typical in many paste backfill applications. Unsurprisingly, the GB-PASTE binder performed best in the ‘mortar cube’ system with the high lime concentration that maximises the rate and efficiency of the pozzolanic reactions at 28 days curing. As soon as the system contains soluble sulphate a reverse in the SAI trend is seen where the lower concentration of lime provides the best relative performance. The GB-PASTE binders at the lower lime concentration enjoyed success when used in the ‘low sulphate paste’ system, meeting the strength of the cement control after 28 days of curing. The initial investigation into the ‘high sulphate paste’ system has been challenging for the GB-PASTE binders and requires refinement beyond adjusting the lime content.

### 3.5 Potential impact on scope 3 GHG emissions

Potential reduction of scope 3 emissions from the alternative binders is presented in Table 10. The GB-PASTE binder is estimated to produce 68 to 81% less GHGs when compared to traditional Portland type ½ cement.



In the ‘low sulphate paste’ system, where 50% replacement of cement with of the low lime GB-PASTE reached performance targets, a backfill operator could achieve an estimated 40% reduction in scope 3 emissions. If the backfill operator typically uses 40,000 tonne of binder per year in their backfill production, this can represent avoidance of nearly 15,000 metric tonnes of CO<sub>2</sub> per year. The GHG values in this exercise are based on the averages reported by the Portland Cement Association and do not represent individual cement operations which may have significantly higher actual emissions, potentially exceeding 1,200 kg CO<sub>2</sub> eq. per tonne of cement produced. In the case of a backfill binder comprised of 1:1 low lime GB-PASTE and 1,200 kg CO<sub>2</sub> eq. per tonne Portland cement, the GB-PASTE itself has an 85% lower GHG footprint to the cement and the 1:1 blend would provide a 43% potential reduction in scope 3 emissions, equating to avoidance of just over 20,000 metric tonnes of CO<sub>2</sub> per year. The variations in cement production means that it is critical to complete a lifecycle analysis of cement used as backfill binders, such as detailed in the recently published International Council on Mining and Metals framework document (International Council on Mining and Metals 2023).

**Table 10 Estimated greenhouse gas (GHG) footprint and potential for scope 3 GHG reduction**

Binder type	Estimated GHG footprint (CO <sub>2</sub> eq kg/tonne)			Potential scope 3 GHG reduction compared to cement only	
	GB-PASTE	Portland cement	1:1 binder blend	%	Metric tonnes (presuming 40,000 tonnes of binder use per annum)
Low lime	176	922	549	40	14,920
Mid lime	237	922	580	37	13,700
High lime	298	922	610	34	12,480

## 4 Conclusions and future work

The development of alternative binders to cement for backfill operations is critical for mining operators to achieve their GHG commitments and has been propelled further by the diminishing availability of traditional co-products, such as fly ash and GGBFS. The engineered lime-based binder introduced in this study showed promise to replace up to 50% cement in both cemented rockfill and paste backfill processes by tailoring the binder composition based on the mineralogy of the backfill materials. Initial investigation using the new binder to treat a high sulphate (i.e. approximately 10,000 ppm soluble sulphate concentration) paste tailings system achieved about 60% the uniaxial compressive strength of the cement control at day 28. However, the adaptability of the alternative binder allowed for adjustment of the lime content which demonstrated success in a lower sulphate (i.e. approximately 2,000 ppm soluble sulphate concentration) paste tailings system. Most significantly, use of the new GB-Paste binder in the binder formulations showed potential to provide a sizable reduction (i.e. approximately 40%) in scope 3 GHG emissions compared to a traditional cement binder. Significant further testing is underway to target full cement replacement by pairing the new binder with admixtures, potentially resulting in up to 80% reduction in the binder related GHG footprint. Work is also underway with multiple market partners to advance the binder development efforts and to validate the performance GB-PASTE binder through pilot scale lab and field trials.

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