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Optimising paste backfill at the LZ5 plant, LaRonde Complex

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Abstract

This paper presents the optimisation process of the paste backfill system at the LZ5 plant of LaRonde Complex, operated by Agnico Eagle Mines in Abitibi-Témiscamingue, Quebec, Canada. In collaboration with Sika Canada, a customised admixture was developed and fully integrated into the plant's dosing system. Since implementation, several trials have demonstrated significant improvements in performance, overall operating cost and sustainability of the paste backfill.

Sill plug fill trials achieved a significant binder reduction of 17–33%, while simultaneously reducing pipeline pressure onsurface by up to 62% and underground by up to 29%. This binder reduction translates to a reduction in global warming potential of up to 348 tonnes CO_2 eq per year, supporting the mine's efforts to reduce its environmental footprint while reducing over 8% in net annual binder costs. Additionally, the substantial pressure reduction trials allowed an increase in backfill throughput of up to 49% in complex long horizontal pumping areas. During those trials, the pumping pressure observed was lower than those estimated by an engineering pressure simulation model. The admixture demonstrated its efficiency at low dosages, with only 1% by mass of binder addition required to achieve the observed effects even when working with mixes having binder contents as low as 2.2%.

This optimisation has provided LaRonde Complex with a cost-effective and scalable solution to backfill remote and previously inaccessible areas. As the mine continues to extend both vertically and horizontally, this advancement supports operational continuity and resource recovery, while aligning with cost and environmental objectives.

Keywords: *paste backfill, sustainable mining, admixture optimisation, binder reduction, CO_2 emissions reduction, throughput increase*

1 Introduction

The LaRonde Complex, located in the mineral-rich Abitibi region of northwestern Quebec, is a flagship operation of Agnico Eagle Mines Limited and a cornerstone of Canadian gold production. The complex comprises several underground zones: LaRonde mine (West and East), 11-3, and LZ5, that collectively feed ore to 2 mills. Since the start of commercial production in 2018, LZ5 has rapidly developed into a high-performing asset. Its integration into the LaRonde Complex in 2020 enabled operational efficiencies through shared infrastructure, advanced automation, and environmentally responsible practices, including the use of paste backfill to reduce surface tailings storage.

Backfilling operations are supported by 2 dedicated paste plants: LaRonde paste plant (200 tonnes per hour, tph) and LZ5 paste plant (150 tph). While the complex operates 2 milling circuits, the paste fill tailings material is fed only from LaRonde mill. These tailings are strongly influenced by hydrothermal alteration, particularly the abundance of phyllosilicates such as chlorite, kaolinite, pyrophyllite and minerals from the mica group.

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High phyllosilicate contents are known to increase viscosity, water demand, and binder consumption, thereby affecting the rheology and placement efficiency of paste fill mixtures (Belem & Benzaazoua 2008; Fall et al. 2009; Benzaazoua et al. 2004). Because of the limited availability of good quality, low-phyllosilicate tailings, that are easier to pump, the mine was obliged to evaluate the 3 available tailings sources and optimise their blending, along with water-to-solid ratios, to balance pumpability and mechanical strength.

This project, conducted in collaboration with Sika Canada, was initiated to address challenges in paste fill rheology, which is strongly influenced by variable water demand arising from the mineralogical changes. The main objectives were to improve rheological performance, increase throughput, and enable transport over longer and more complex piping networks without resorting to additional water that would compromise the final compressive strength. A further priority was the optimisation of binder consumption. Binder production is a major contributor to CO_2 emissions, accounting for nearly 8% of global anthropogenic output. According to the 14th edition of the *Global Cement Report* (International Cement Review 2020), approximately 400 million tonnes of binder are produced and consumed annually. In mining, binder is predominantly used in paste backfill, where it can represent 75–80% of the total operating cost of a paste fill plant (Hassani & Bois 1989; Potvin et al. 2005; Li et al. 2019). This makes binder consumption a focal point not only for cost reduction but also for emission mitigation strategies, particularly since purchased binder is reported as Scope 3 emissions. At the LZ5 paste plant alone, annual binder consumption is approximately 24,500 tonnes, a figure expected to increase as production expands. The introduction of chemical admixtures in paste fill is therefore motivated by both performance, cost and sustainability objectives. While admixtures represent a key step toward reducing costs and environmental impact, the longer-term strategy should also explore alternative low-carbon binder technologies.

2 Geology

The Cadillac Fault is a major east–west crustal structure that defines the southern boundary of the Abitibi Greenstone Belt, one of the most mineral-rich regions in Canada. This fault zone has played a pivotal role in the localisation of gold and polymetallic deposits across the Abitibi region. Acting as a deep-seated conduit for hydrothermal fluids, the Cadillac Fault facilitated the formation of extensive mineralisation zones, a volcanic-sedimentary sequence that hosts several world-class deposits.

Geologically, LaRonde Complex is situated within the Blake River Group of the Abitibi Greenstone Belt, along the structurally active LaRonde-Bousquet deformation corridor. This corridor hosts gold-rich volcanogenic massive sulfide (VMS) mineralisation formed by ancient submarine volcanism. The LaRonde mine itself is hosted within high-grade polymetallic VMS lenses, formed in a submarine back-arc basin environment (Galley 2013), and is notable for its deep, high-tonnage production of gold, zinc, copper, and silver.

While LZ5 shares some lithological similarities with VMS environments such as its felsic volcanic host rocks, it is more accurately classified as a structurally controlled gold deposit. The gold-bearing zones at LZ5 occur as lenses, or stringers of disseminated to semi-massive, locally massive aggregates of fine to coarse pyrite, with traces of pyrrhotite and chalcopyrite. These mineralised zones are concentrated within sericite silica altered felsic rocks and are closely associated with deformation structures, reflecting the corridor's dynamic tectonic evolution.

The 11-3 zone at LaRonde is a VMS lens hosted in the same Bousquet Formation stratigraphy as the main LaRonde orebody, but it is geologically distinct – it is shallower, more heterogeneous, and shows stronger local variability in alteration, sulfide textures, and mechanical behaviour (Agnico Eagle Mines Limited 2022).

3 Methodology

3.1 Mineralogy and particles size distribution

To assess the mineralogical composition and particle size distribution of the tailings, samples were sent to Paterson & Cooke for analysis. Mineralogical analysis was conducted using a Bruker D8 ADVANCE X-ray diffraction (XRD) system. The scanning parameters included a 2θ angle range of 5–75°, a step size of 0.0197°, and a time per step of 1 second. Particle size distribution was measured using a Malvern Mastersizer 3000E laser diffraction instrument. For the analysis, the tailings were dispersed in distilled water to ensure proper suspension of particles.

3.2 Unconfined compressive strength

Cemented paste backfill 3 × 6" cylinders were cast following ASTM C31/C31M 03a (ASTM International 2022) and cured in a humidity chamber at 22 ± 2°C and a relative humidity higher than 90%. Three cylinders per curing age were tested using the MTS 10/GL electromechanical press with a capacity of 50 kN, at a constant compression rate of 1 mm/min, in accordance with ASTM D2166–06 (ASTM International 2010). The samples were tested after the mine-specified curing ages.

3.3 Water-reducing admixtures and binder optimisation process

Water-reducing admixtures in paste backfill systems can improve workability (i.e. decreasing primarily yield stress and, in certain instances, the viscosity), allowing the water content of the paste to be reduced, and thereby allowing either a decrease in binder for the same strength or an increase in strength for the same binder content. To achieve these, the selected admixture must be capable of producing a pronounced rheological response, specifically, a significant decrease in yield stress. This rheological modification typically manifests as an increase in slump, indicating improved flowability and reduced resistance to pumping (Figure 1). This enhanced workability permits a reduction in the paste water content while counteracting the increase in yield stress that typically results from higher solids content (Silva 2017; Sofra 2017). The increase in solids concentration contributes to an increase in unconfined compressive strength (UCS), thereby supporting a reduction in binder dosage while maintaining the required early-age strength and workability performance.

(a) (b) (c)

Figure 1 Visual comparison of the reference mix versus the impact of different admixture dosages, one causing a major plasticising effect as observed in Figure 1c, used then to increase the solids

For the LZ5 paste plant, Sika Canada's mine backfill team conducted a detailed analysis of the tailings and subsequently formulated a customised water-reducing admixture tailored to the material's rheological and performance requirements. For the trials at the plant, dosages ranging from 0.25 up to 2.6% by mass of binder (bmob) were tested for different purposes presented in this article.

3.4 Global warming potential

The global warming potential of industry materials are nowadays declared in environmental product declarations (EPDs). The average cradle-to-gate global warming potential (GWP) is expressed in kg CO_2 equivalent and is associated with the production of 1 kg of the material. Table 1 presents the GWP for the high-range water-reducing (HRWR) admixture and the binders evaluated in this study. The reported values account for life cycle stages A1 to A3, which include raw material extraction and upstream processing (A1), transportation to the manufacturing facility (A2), and product manufacturing (A3).

The GWP for HRWR admixtures was obtained from declared values provided in the EPD for Sika concrete admixtures and binder additives in Canada. The GWP for the HRWR admixture EPD was extracted from Sika Canada (2022) EDP, published in June 2022. For the binder used in this study, 80/20 ratio, the GWP was extracted from the EPD reports for the binder manufacturer and production plant. For the Portland-limestone (general use limestone) binder, its GWP was extracted from the Holcim-Lafarge (2022) EPD issued in July 2022. For the slag binder, the GWP was extracted from the Slag Cement Association (2021) issued in July 2021. All these EPDs were developed in compliance with ISO 14025:2006 and ISO 21930:2017 (International Organization for Standardization 2006, 2017).

Table 1 Environmental product declaration of the binder and admixture materials used at the mine for the trails

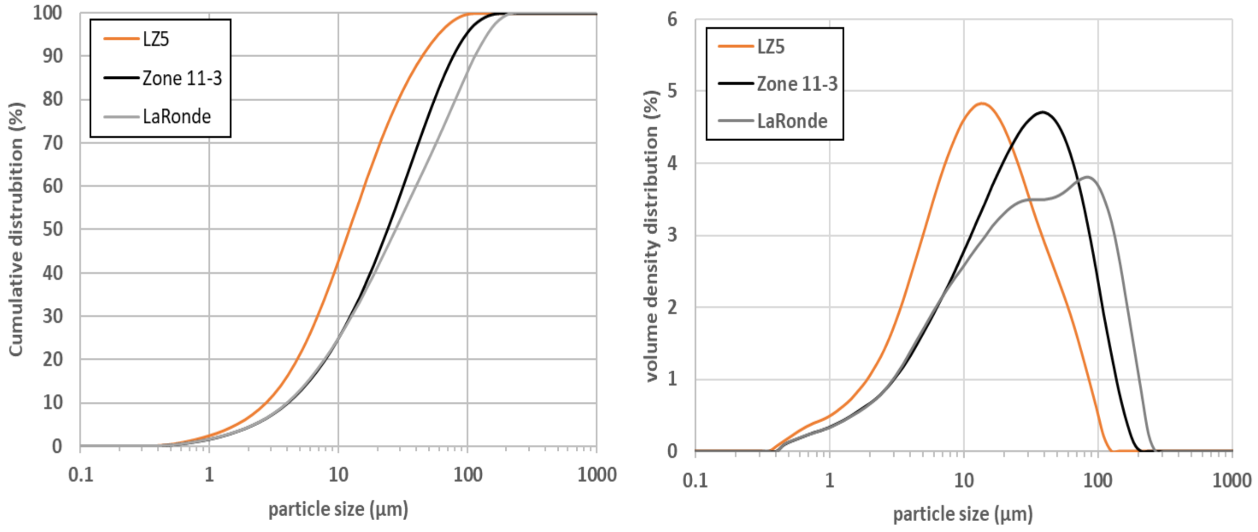
Component	Global warming impact (kg CO_2 eq/tonne)
Water-reducing admixture	1,360
General use limestone (GUL, type IL)	830
Slag binder	143

4 Results

4.1 Characterisation of the tailings used at LZ5 paste plant

At LZ5 plant, combinations of 3 tailings sources are used in varying ratios. Two composite ore blends were evaluated. One blend combined LaRonde and LZ5 ores at a 2:1 ratio, while a second blend comprised LaRonde, 11-3, and LZ5 ores in a 3:1:2 ratio, respectively. As summarised in Table 2, all 3 tailings are quartz-rich (53–66%) but differ primarily in their contents of phyllosilicates, sulfide, and carbonates. Carbonates are present only in the LZ5 tailings. Variations in phyllosilicate and sulfide concentrations significantly influence paste rheology. Phyllosilicates, characterised by their platy structure, low Mohs hardness, and tendency for delamination, increase water demand and yield stress. Their concentrations range from 18.1% in 11-3, 20.6% in LaRonde, to 30.4% in LZ5. In contrast, pyrite, a high-density mineral, tends to increase the apparent specific gravity and enhance slump or slump flow. Pyrite contents are 4.8% in LZ5, 13.5% in LaRonde, and 26.3% in 11-3, corresponding to paste specific gravities of 2.8, 3.1, and 3.5, respectively.

Particle size distribution (PSD) data (Figure 2 and Table 3) are variable, and adjustments need to be done daily. A study performed by the Mineral Technology Research and Service Unit lab in Canada on these mines showed LaRonde tailings being coarser, with 38% passing 20 µm (ultrafine fraction) and 76% passing 80 µm (fine fraction). The 11-3 tailings were slightly finer with passing 40% ultrafine and 88% fines, while LZ5 tailings were the finest with 64% ultrafine and 97% fines. However, neither PSD nor mineralogy can be considered constant daily. Variations in ore source, hydrothermal alteration, and grinding conditions generate fluctuations in key minerals such as muscovite, chlorite, and pyrite, directly influencing water retention, slump behaviour, density, and strength development (Gélinas & Alcott 2023). The combined effects of PSD and mineralogy on paste behaviour are best evaluated by comparing each tailing at identical solids content and observing the resulting paste texture and flow characteristics, as presented in Figure 3.



(a) (b)

Figure 2 (a) Cumulative and (b) volume density particle size distribution analysis for the 3 tailings

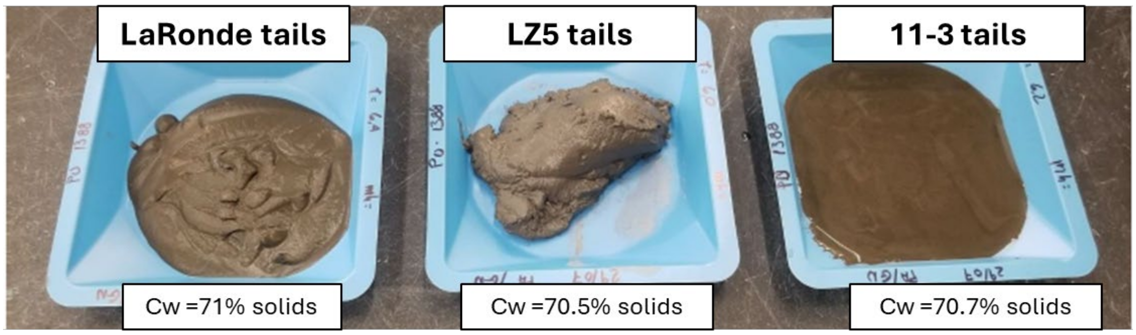


Figure 3 Comparative water-demand variation of the 3 mines at 70–71% solids (Noirant et al. 2023)

Table 2 X-ray diffraction analysis of the 3 tailings

Mineral group	Mineral	LaRonde (%)	LZ5 (%)	Zone 11-3 (%)
Silicates	Quartz	65.9	53.1	55.6
Silicates	Muscovite	12.4	14.4	5.7
Silicates	Paragonite	1		1.2
Silicates	Chlorite	7.2	16	1.4
Silicates	Kaolinite			
Silicates	Pyrophyllite			8.6
Silicates	Plagioclase		1.1	
Sulfide	Pyrite	13.5	4.8	26.3
Carbonates	Calcite		1.2	
Carbonates	Dolomite	Trace	9.4	
Oxides	Ilmenite		Trace	
Total		100	100	100
Total phyllosilicates		20.6	30.4	18.1

Table 3 Properties of the 3 tailings and their mineralogy description from X-ray diffraction analysis

Parameters	Units	LaRonde	LZ5	Zone 11-3
D_{10}	µm	4.6	3.1	4.6
D_{30}	µm	14.3	7.8	14
D_{50}	µm	31.4	13.7	27.1
D_{60}	µm	45.2	17.9	35.9
D_{80}	µm	91.1	32.9	62.5
D_{90}	µm	130	50.1	87
$Cu = D_{60}/D_{10}$		9.9	5.7	7.8
$Cc = D_{30}^2/(D_{60} \times D_{10})$		1	1.1	1.2
$U = (D_{90} - D_{10})/D_{50}$		4	3.4	3.5
Specific gravity		3.07	2.64	3.52
% ultra-fines or P_{20} µm (d < 20 µm)	%	38	64	40
% fines or P_{80} µm (d < 80 µm)	%	76	97	88

4.2 Sika lab results

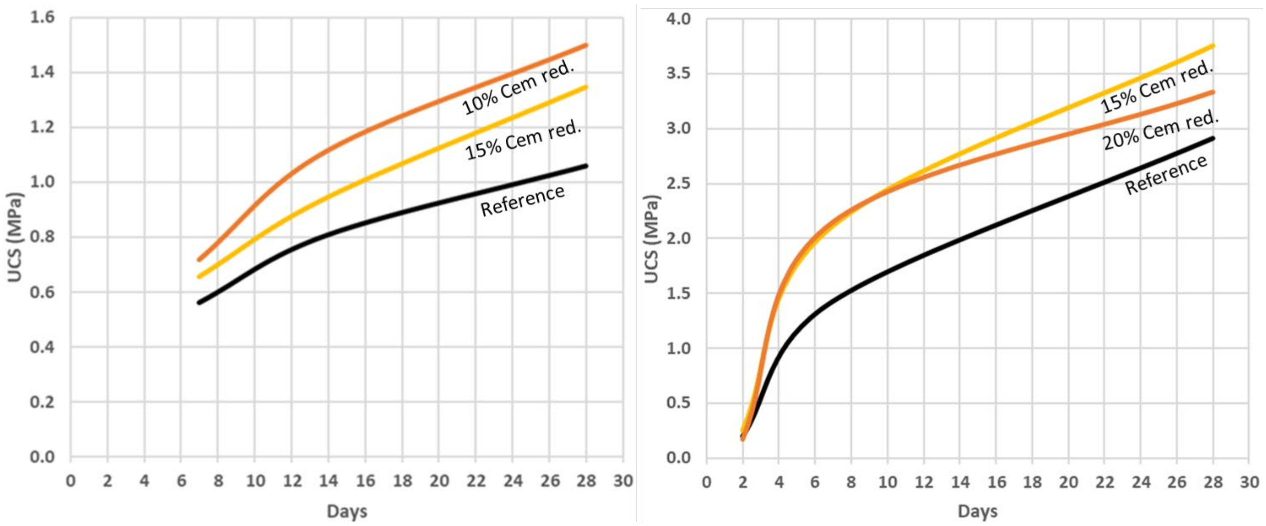
Sika Stabilizer-3XXMBF was presented by Sika as a product having a great reactivity with the blend combining LaRonde and LZ5 ores at a 2:1 ratio used and compatible with both GU/GUL binders.

Two mix designs were tested in the lab: the sill plug fill (9% binder), and the main fill (4.2% binder). Triplicate cylinders were produced for each breaking age.

Lab results (Figure 4) showed that, for a starting reference solid content of 73%, the binder optimisation potential for each fill was:

- Sill plug fill (9% binder): 1% bmob admixture allowed to reduce between 15–20% binder and increase the solids by 2–3% while maintaining similar workability.
- Main fill (4.2% binder): 2.6% bmob admixture allowed to reduce between up to 15–20% binder and increase the solids by 2–3% while maintaining similar workability.

The results suggested lower dosages of admixture might improve the rheology while reducing the pumping pressure or compensate for the higher water demand when a high content of phyllosilicates was present.



(a) (b)

Figure 4 UCS results for main and plug fills, show over 15% binder reduction potential by increasing solids from 73% to 75–76%, using (a) 2.6% bmob for main and, (b) 1% bmob admixture for sill plug

4.3 Stope underground distribution for field trials

Figure 5 provides a schematic overview of the underground stope distribution used in the full-scale trials. The illustration highlights the areas targeted for different objectives: binder reduction (purple), pumping pressure reduction (orange), and paste tonnage increase (red). This visual serves as a guide to understand the spatial arrangement for the trials presented in the following sections.

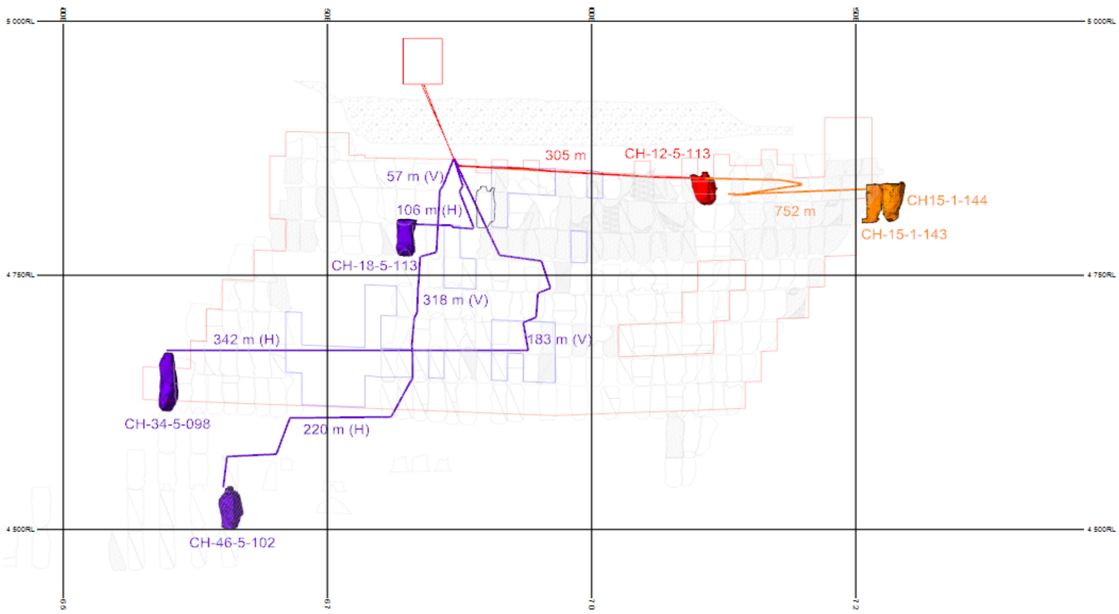


Figure 5 Stopes filled for testing binder reduction (purple), pumping pressure reduction (orange) and paste tonnage increase (red). Distances are the total distance from the plant to the stope

4.3.1 Sill plug: binder optimisation and pressure reduction

During November 2023, the reduction of binder for the sill plug fill was tested for the first time filling the stope 18-5-113 located 57 m vertically and 106 m horizontally in relation to the paste plant (Figure 5). The testing sequence started at 9% binder (called LZ5-9-0-0), reduced to 7.5% binder (LZ5-7-1-0) and finally reduced to 6% binder (LZ5-6-1-0). During the binder reduction process, the baseline throughput was raised from 130 to 140 tph (7% increase) at 11:20 am to evaluate the effect of a 10 tph increase on pumping pressure. This adjustment resulted in a 100 psi increase, prompting future interest in exploring and validating this operating potential. The test continued at 140 tph. Regarding the effect of the binder reduction, the observed loss in UCS was compensated by progressively increasing the admixture dosage and reducing the water content, resulting in a higher solid content.

Figure 6 shows the surface pressure trend during the trial. It can be observed that each change in admixture dosage induced a pressure drop. The pressure gradually went back up as the water content was reduced. For the 7.5% binder mix, dosages of 0.22, 0.78 and 1.45% by mass of binder (bmob) of admixture was added. For the 6% binder, a dosage of 1.8% bmob of admixture was used. The admixture addition and the water reduction allowed an increase in solid content from 72.6 up to 75.2%. Nine cylinders were taken per admixture dosage change or binder change to monitor the effect of each change on the UCS.

Figure 7 presents the UCS results from that trial. Unsurprisingly, decreasing the binder from 9 to 7.5% and to 6% results in a UCS loss of over 700 kPa (25% decrease) for the 7.5% binder and over 1,000 kPa (37% decrease) for 6% binder, when compared to the reference. Using an admixture dosage of 1.45% bmob at a binder content of 7.5%, the water content was reduced, resulting in the UCS exceeding the reference strength by over 400 kPa (a 15% increase). When dosing 1.8% admixture at 6% binder, some minor additional water reduction was achieved and the UCS showed that the strength came back to the reference strength. This reflects that over 17% binder reduction, estimated at 22%, could be achieved with 1.45% bmob of admixture, and 33% of binder reduction could be achieved with 1.8% bmob of admixture. This test was repeated starting at lower solids of 71.4% and achieving 73.8% solids, confirming over 17% and the 33% binder reduction, while maintaining lower pumping pressures, suggesting potential for further operational efficiency optimisation by increase paste throughput tonnage.

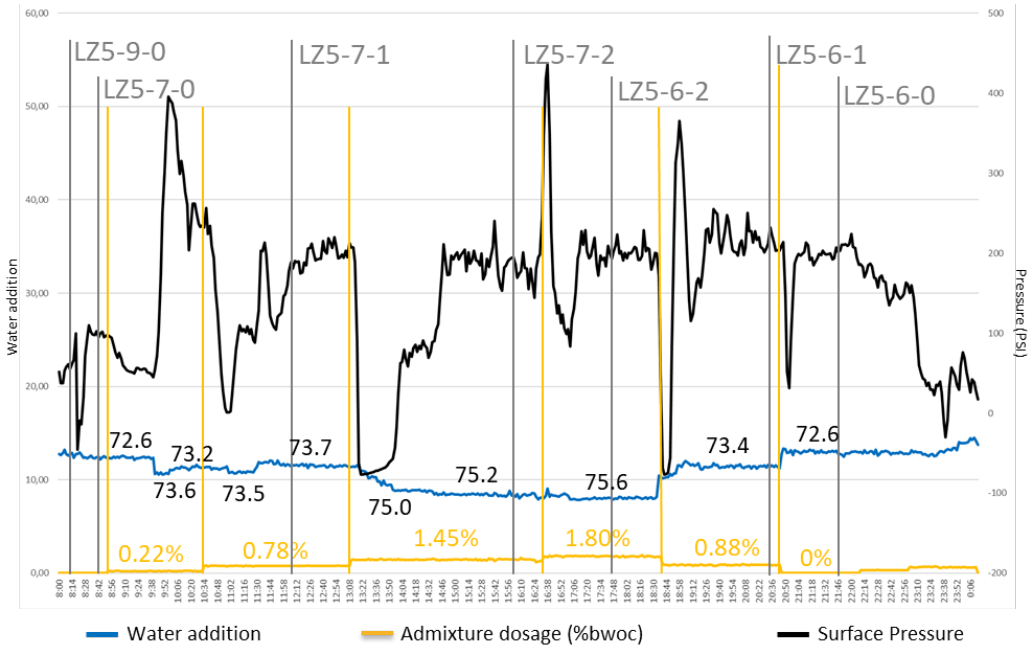


Figure 6 Field trials test for the plug fill showing the surface pressure drops and water addition reduction when increasing the admixture dosage and while optimising the binder from 9% down to 6.5%

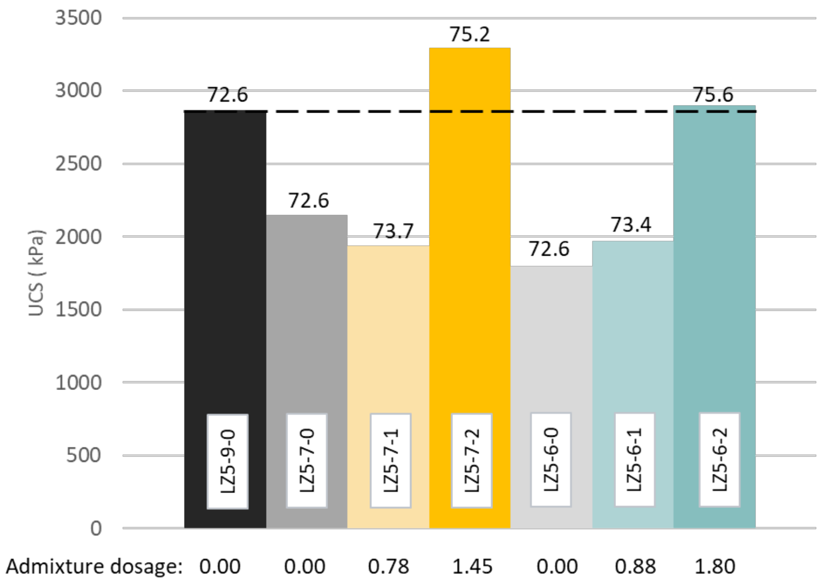


Figure 7 Unconfined compressive strength results of plug fill mixes with binder contents of 9, 7.5, and 6%, showing that the binder content could be reduced from 9% down to 6% by using an admixture to lower the water content while maintaining comparable compressive strengths

4.3.2 Main fill: binder reduction trial

Two main fill trials were conducted to optimise binder usage and improve backfill performance. The first trial, carried out in 2023 in stope CH-34-5-098 (183 m vertically and 342 m horizontally in relation to the paste plant, Figure 5), focused on reducing an already low binder content of 3.3%. Admixture dosage was gradually increased by increments until a dosage of 2.6% bmob. Each admixture increment resulted in a significant reduction in pumping pressure, enabling an increase in solids content from 70.9 to 73.3% at 2.6% bmob admixture dosage. Despite the 2.4% increase in solids, no change in UCS was observed.

The second trial, conducted in 2025 in stope CH-46-5-102 (318 m vertically and 220 m horizontally in relation to the paste plant Figure 5), aimed to optimise binder content in a mix with higher binder content (4.4% versus 3% for the first trial), with a solid content of 74.2% for the reference mix. Admixture was again incrementally added, reaching 2.5% bmob and increasing solids content to 76.4%. This time, UCS was increased by 34% (Figure 8).

A subsequent reduction in binder content to 3.6% (18% binder reduction), combined with 2.6% bmob admixture, maintained the target strength, achieving 1,056 kPa compared to the reference strength of 1,094 kPa. In terms of placement pressure, increases were noted both at the surface and on level 9. However, all pressures remained within normal operational ranges.

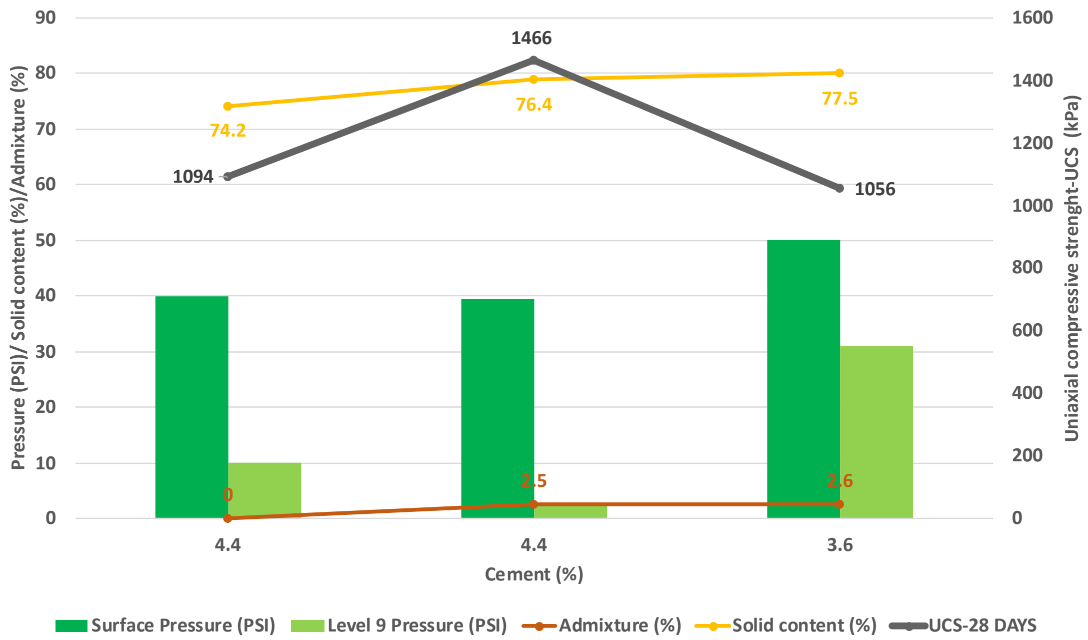


Figure 8 Main fill trial results showing strength gain through water reduction and binder optimisation

4.3.3 Pressure decrease and tonnage increase trials

4.3.3.1 Test 1

After confirming that binder content optimisation was possible for both fills, the next objective was to evaluate the potential for increased paste throughput. LZ5, stope 12-5-132 near the surface (Figure 5) was considered, at the time of the trail, a complex 305 m horizontally stopping area due to minimal head pressure or gravity assistance. To ensure successful delivery, an engineering pressure simulation model developed by an external engineering firm based on rheology testing with and without admixture was applied.

Figure 9 presents the measured versus the externally modelled pressure variation as a function of tonnage increase with incremental admixture dosages. The reference mix solid content was 71 with 2.5% binder. At 155 tph, we were essentially operating at the upper limit of what the system could tolerate, as higher throughputs led to significant hammering issues in the underground. Stepwise admixture additions of 0.28, 0.5, 0.75, and 1% bmob were tested while increasing throughput. At 1% bmob, surface pressure was reduced by 62% (214 down to 81 psi) and level 9 pressure by 24% (282 down to 213 psi). The pronounced pressure drops between the 0.75 and 1% bmob admixture dosage suggests that the saturation point for optimal admixture performance had been reached.

These reductions enabled throughput to increase from 155 to 189 tph. Further increases were not possible as 100% of the available disk filter cake was consumed (half of total filter capacity was used), and 99% of pump capacity was reached. Nonetheless, achieving a 22% throughput increase in such a challenging area, while markedly reducing hammering, represented a significant operational improvement.

Model-to-measurement comparisons showed strong agreement at lower admixture dosages (0–0.5% bmob). Beyond the saturation point, however, the model failed to capture the observed pressure drop, predicting pressures 115% higher than measured at 1% bmob (174 versus 81 psi). To achieve these low pressures, the model had estimated that a 2% bmob dosage would be required. Table 4 presents the simulated pressure values from the model for comparison to the Figure 9 field results.

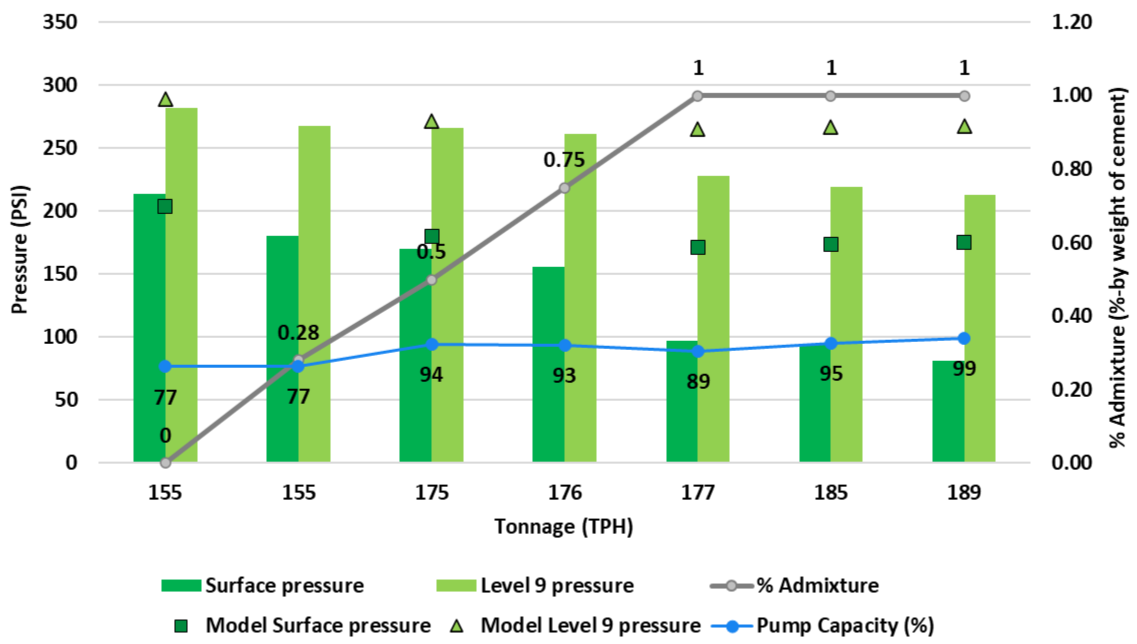


Figure 9 **Tonnage increase test at LZ5 mine. Measured pressures at the surface (dark green) and level 9 (light green) compared with simulation model values (dark green squares, light green triangles). Admixture dosage (grey) and pump capacity (%) also displayed**

Table 4 **Modelled surface and level (Lvl.) 9 pressures for different tonnages and admixture contents**

Admixture (%)	0		0.5		1		1.5		2	
Tonnage (tph)	Surface	Lvl. 9	Surface	Lvl. 9	Surface	Lvl. 9	Surface	Lvl. 9	Surface	Lvl. 9
155	204	289	180	272	165	261	131	237	85	204
175	211	294	187	277	171	265	137	241	90	207
185	215	297	190	279	174	267	140	243	92	209
190	217	298	192	280	175	268	141	244	93	209

4.3.3.2 Test 2

Following the encouraging results obtained with the admixture at a low binder content and the 305 m horizontal pumping distance, further testing was conducted later under one of the most challenging operational scenarios anticipated, located in Zone 1 of the LZ5 mine, near the surface, but where the pipeline does a loop, corresponding to a total pumping distance of 752 m horizontally (more than doubled vertical distance). This configuration significantly increases the pumping distance and elevation, resulting in elevated pressure demands on the system. To assess the performance of the admixture under these conditions, tests were carried out on 2 adjacent stopes: 15-1-144 and 15-1-143 (Figure 5). For stope 15-1-144, the plug was poured before the admixture setup was fully operational, so no admixture was used. For stope 15-1-143, operational issues occurred during the plug pour, making the data unreliable for comparison. Only the main fill in both stopes was completed with admixture under proper conditions.

Figure 10 illustrates the high pumping pressures encountered when operating in that complex zone with a slurry composition of 71% solids and 4% binder for the plug, without the use of admixtures. Under these conditions, pressures reached 300 psi at the surface and 420 psi at level 9, with a maximum throughput of 80 tph. Once in the main fill (3% binder), an admixture dosage of 2% by mass of binder (bmob) was introduced, causing a significant reduction in pumping pressure. Surface pressure dropped to 150 psi, a 50% decrease, and pressure at level 9 decreased to 300 psi, representing a 29% reduction. Additionally, throughput was increased to 96 tph, marking a 20% tonnage improvement. Further optimisation was achieved in stope 15-1-143, where the solids content for the main fill was increased to 72%, and the admixture dosage was reduced to 1.5% bmob. Although the tonnage was increased to 119 tph, reflecting a 49% increase compared to the initial plug baseline, the pumping pressures remained as low as the 14-1-144 with admixture.

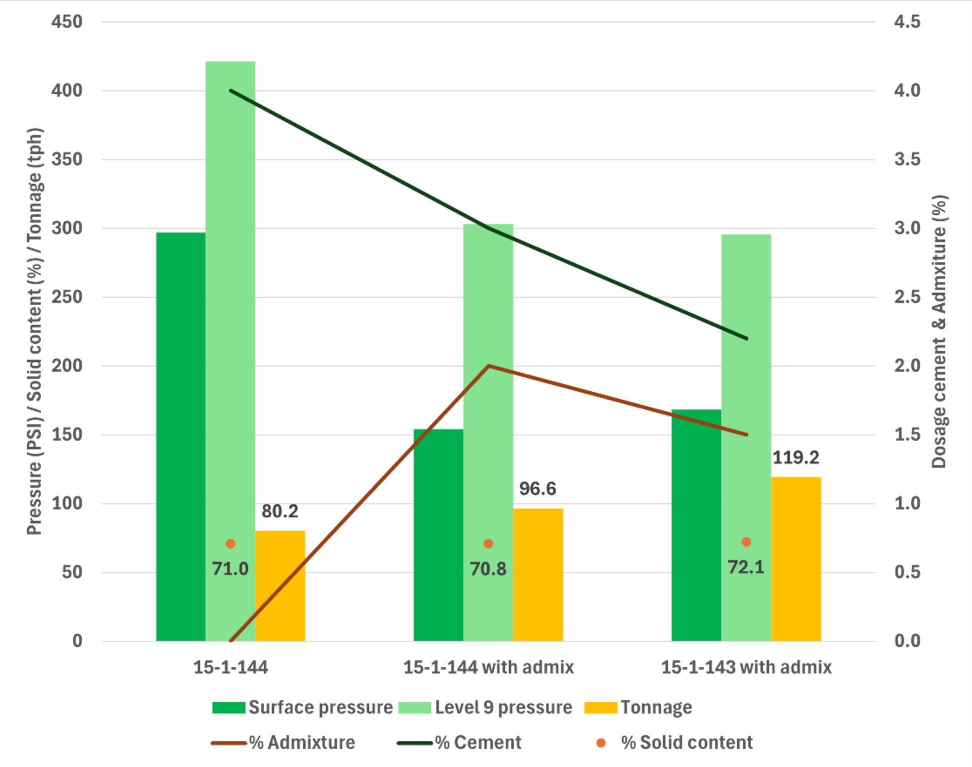


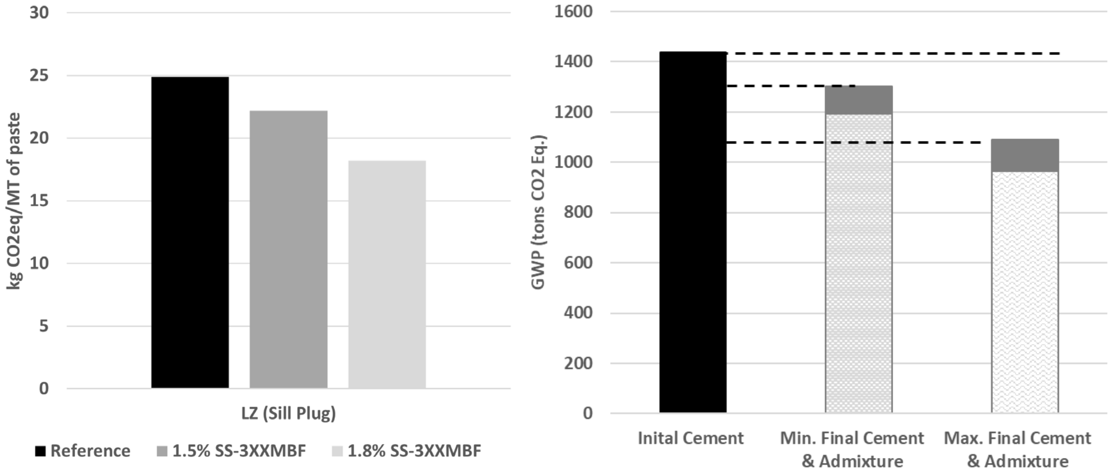
Figure 10 Trials showing a pressure decrease in the surface (dark green) and in level 9 (light green), as well as tonnage (orange) increase when adding admixture

5 Discussion

This collaborative project provided a valuable opportunity for both parties to explore the broad applicability of the admixture in paste fill systems. Its consistent use in operations demonstrates that, once a compatible product is developed that interacts well with the mine water, binder, and the phyllosilicate minerals present in the tailings, the variability of the tailings during operation has minimal impact on dosage rates. This enables the mine to adopt more standardised mix designs. Nevertheless, the training of the operators and continuous monitoring of the tailing's characteristics remain critical for responding to any major changes in performance.

Comparing lab and field performance, the plug and main trials revealed notable differences. In the lab, a 1% bmob admixture dosage enabled a 14–20% reduction in binder. Field results show that increasing the admixture dosage from 1.5 to 1.8% (bmob) markedly improves binder efficiency. At 1.5%, binder use can be reduced by 17%, while 1.8% enables a 33% reduction with no loss in strength. This small 0.3% increase in admixture therefore delivers an additional 16% binder reduction, highlighting a strong non-linear optimisation effect, which makes it very economically interesting for the mine site. This means that 1 kg of admixture can reduce up to 18.3 kg of binder. This 33% binder reduction translates into a potential annual binder cost saving of over 8%.

To assess the GWP associated with binder reduction strategies, Figure 11a illustrates the CO_2 equivalent (kg CO_2 eq) emissions optimisations achieved per metric tonne of paste. The comparison includes scenarios without admixture and with admixture dosages of 1.5 and 1.8%, demonstrating the environmental benefits of admixture-assisted binder optimisation. Given that approximately 5,200 tonnes of binder are used annually for sill plugs composed of 80% slag and 20% GUL (277 kg CO_2 eq/tonnes), this represents a baseline GWP of roughly 1,440 tonnes CO_2 eq per year. Figure 11b graphically illustrates how 17% binder reduction at 1.5% bmob (minimum case) and 33% reduction at 1.8% bmob (maximum case) correspond to savings of about 900–1,700 tonnes of binder, equivalent to 245–475 tonnes CO_2 eq per year. The carbon footprint of the admixture itself, at dosages between 1.5 and 1.8% bmob, is estimated to range from 106–127 tonnes CO_2 eq per year. Therefore, when combining the effects of binder reduction and admixture use, the overall net decrease in emissions is estimated between 138 and 348 tonnes CO_2 eq annually. Although transportation emissions are not included in these calculations, logistics also favour admixture use. Replacing 1,717 tonnes of binder with only 93 tonnes of admixture (at 1.8% bmob) significantly reduces transport emissions. In practical terms, this corresponds to approximately 43 fewer 40 tonnes binder trucks per year (87 instead of 130 trucks), replaced by 4 trucks of 22 tonnes carrying the admixture. This assessment does not consider the consumption of admixture for throughput and pressure reduction.



(a) (b)

Figure 11 Theoretical average optimisation of the global warming potential (GWP) of the sill plug. (a) Carbon footprint per tonnes of paste without and with 1.5 and 1.8% admixture; (b) In black is the GWP associated with initial binder consumption (no binder reduction). The other histogram bars represent the GWP associated with a 17% (minimal) and 33% (maximal) binder reduction. The GWP associated to the addition of the water-reducing admixture is dark grey top addition

Main fill trials presented greater challenges due to the reference mix binder contents of 3.3 and 4.4%. While lab tests achieved a 15–20% reduction, initial field trials at 3.3% binder showed no improvement. This outcome aligned with observations by Erismann & Hansson (2021), who identified an exponential correlation between solids content and uniaxial compressive strength. Specifically, between 65 and 74% solids, strength gains are minimal. However, once solids approach exceeds 74%, strength increases exponentially. For the sill plug, we achieved slightly over 75% solids which resulted in significant UCS gain. With that thinking, the second main fill test was conducted in an area with a reference mix of 4.4% binder and 74% solids. By increasing solids to over 74–75%, in this specific case to 77.5% using 2.6% admixture bmob, an 18% binder reduction was achieved. Although this dosage is not economically viable, the strength gains validated Erismann & Hansson (2021) observations. Further testing would be needed to define the limits of this observation. The suggested hypothesis is that lower binder content requires higher initial solids content to optimise performance, necessitating a more potent and cost-effective admixture to make this approach economically viable.

Engineering model comparisons showed strong alignment with measured data at low admixture dosages (0–0.5% bmob). However, beyond the saturation point, the model failed to predict the observed pressure drops, overestimating the required dosage (2 versus 1% bmob). This discrepancy underscores the need for collaboration with engineering firms to refine modelling approaches and fully leverage the admixture's potential.

Integrating the admixture into paste fill formulations has a direct and positive impact on pump maintenance and operational efficiency. Increased fluidity reduces internal friction and pumping pressure, minimising mechanical stress on components such as seals, valves, and pistons. This leads to reduced wear, fewer blockages, and less downtime. Enhanced slump and consistent delivery rates also contribute to smoother pumping cycles, lower energy consumption, and extended equipment lifespan. Overall, admixture use not only enhances paste fill performance but also translates into lower maintenance costs, fewer operational disruptions, increased reliability of the pumping system, and other operational and economic benefits.

Finally, this set-up allowed for a comparative analysis of binder influence under high-pressure pumping conditions. The results will inform operational strategies for admixture deployment in zones with elevated hydraulic constraints. These results support the hypothesis that admixture use, even at low binder content, can significantly improve flow characteristics and operational efficiency under high-pressure conditions.

6 Conclusion

This collaborative project exemplifies the value of strong partnerships between mining operations and product suppliers like Sika, demonstrating the transformative potential of admixture integration in paste fill systems. Field trials confirmed that, while lab testing provides important insights, real-world applications are essential to fully understand performance and benefits. Among the most impactful outcomes was a 33% binder reduction in sill plug fills, where 1 kg of admixture replaced 18.3 kg of binder, resulting in a net annual GWP reduction of up to 348 tonnes CO_2 eq and over 8% savings in annual binder costs. In main fill applications, the trials highlighted the critical role of solids content in achieving strength and binder reductions, emphasising the need for more potent and cost-effective admixtures to make these gains economically viable.

Operationally, admixture use led to pumping pressure reductions of up to 62% onsurface and 29% underground, enabling backfilling in previously challenging areas and increasing throughput by up to 49%. These improvements also led to reduced hammering, smoother operations, enhanced safety, reduced equipment wear, and lowered energy consumption. This optimisation has provided LaRonde Complex with a cost-effective and scalable solution to backfill remote and previously inaccessible areas, which could also be tested at LaRonde paste plant in the future. As the mine continues to extend both vertically and horizontally, this advancement supports operational continuity and resource recovery, while aligning with cost and environmental objectives.

To fully unlock the potential of admixture-enhanced paste fill systems, continued collaboration with engineering partners is essential, particularly to refine predictive models for high-pressure conditions. Overall, this study lays a strong foundation for broader adoption of admixture technologies, supporting more efficient, cost-effective, and sustainable mining practices. While admixtures represent a key step toward reducing costs and environmental impact, the longer-term strategy should also explore alternative low-carbon binder technologies.

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