Operational Backfill Challenges in a Mature Mining Complex with Variable Tailings Mineralogy

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Abstract

The increase of mining tonnage throughput and the variation of tailings mineralogy in a mature mining complex can bring new challenges to underground operations that depend on cemented paste backfill (CPB). The LaRonde mining complex in the Abitibi region (Quebec, Canada) is facing this challenge, as the mill throughput includes an increasing proportion of satellite zone material with the Volcanic-Massive-Sulphides (VMS) ore. The inclusion ore from the LZ5, 11-3 and Frange zones introduced new geometallurgical tailings signatures that can vary daily. These variations affect the backfill operation and the overall CPB strength development.

Historically, LaRonde VMS tailings mineralogy consisted of various tectosilicate (quartz, anorthite, microcline), sulphates (gypsum) and a large proportion of sulphides, with up to 27.5% of pyrite. This tailings mineralogy did not significantly affect CPB quality prior to 2018. This mineralogy was inert at early curing age and did not affect the hydration dynamics of cementitious reactions. In mid 2018, the LaRonde mill started introducing a low proportion of LZ5 ore in its millfeed,; following this, there was a significant increase in phyllosilicate mineral (mica and clay) content whose impact was not caught initially. This new tailing mineralogy containing a larger concentration of muscovite, clinochlore and chlorite affected CPB strength development. Depending on the ratio of LaRonde and LZ5 material making up the tailings, the required binder percentage had to be modified to achieve the same UCS strength for the same curing time.

This paper considers how tailings mineralogy variability in a mature mining complex can impact CPB quality, operational lessons-learned, and how data analytics are used to maintain backfill quality.

Key words: backfill, mineralogy, lab testing, data analytics, operational lessons

LaRonde complex backfilling context

The LaRonde mining complex is located in the Abitibi mining district between Rouyn-Noranda and Val-D'Or in western Quebec. The ore body is an Au-rich volcanogenic massive sulfide lens composed of Au-Ag-Cu-Zn. The LaRonde complex currently produces gold, copper and zinc concentrates. The tailings produced can be used to produce CPB that is essential for mining in all zones. The tailings characteristics have varied over the years. For example, in 2004, the overall annual specific gravity of ore (G_s) was 4.00 kg/m^3 and in 2023, it was 3.05 kg/m^3. This is mainly due to the reduction of sulphide content in the ore and the changing characteristics of the deposit as the mining progresses deeper.

There are two CPB plants at the LaRonde complex, the LaRonde and the LZ5 plants. Simplified schematic flowsheets of the plants can be seen on Figure 1. Both CPB plants are supplied with tailings from the LaRonde mill. The LaRonde plant produces batch gravity fed CBP for the LaRonde East and West mines. In 2023, the LaRonde plant produced on average 1750 t per day of CPB at an average solid content of 72.5%. The main recipe for CPB is prepared with a mix of slag and general use limestone cement (GUL) in a proportion of 90:10%, respectively. The deepest backfilled stope to date was at 3.2 km depth. This CPB plant has been in operation since 2000.

The LZ5 continuous CPB plant uses a positive displacement pump to backfill the LZ5 and 11-3 mining horizons. In 2023, the LZ5 average daily CPB production was 1900 t per day at an average solid content of 71%. As with the LZ5 plant, the main recipe for CPB is prepared with a mix of slag and general use limestone cement (GUL) in a proportion of 90:10%, respectively. The deepest backfilled stope to date was at 340 m. This CPB plant has been producing since 2018.

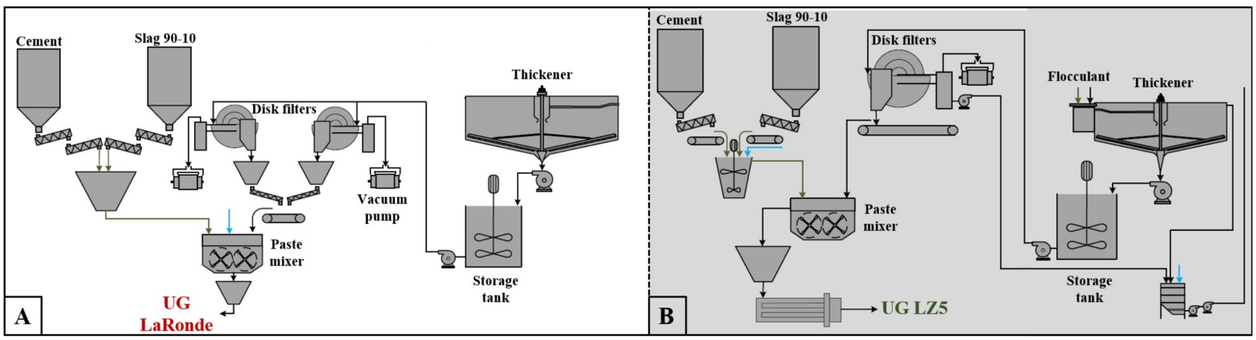


Figure 1. A) Simplified LaRonde batch CPB plant flowsheet, and B) simplified LZ5 continuous CPB plant flowsheet.

Paste backfill operational challenges at the LZ5 cemented backfill paste plant

Tailings mineralogy evolution at the LaRonde mining complex brought new challenges as soon as LZ5 ore was included in the mill throughput. Prior to 2018, tailings source material came largely from the LaRonde VMS mining lenses. In contrast, LZ5 ore zone is composed of gold-rich disseminated to stringer sulphide mineralization. Initially, following the inclusion of LZ5 material, no changes were made to the CPB operational guidelines. However, the quality control uniaxial compressive strength (UCS) values obtained at the LaRonde and the LZ5 CPB plants were flagged as lower than expected. To better understand the factors influencing these UCS values, the variations of tailings characteristics, physical and geochemical aspects will be described. *In situ* testing and general backfill performance show that stopes at LaRonde perform better than stopes at LZ5. For this reason, the data presented in the paper will concentrate on the LZ5 CPB plant.

Particle size distribution of tailings

Particle Size Distribution (PSD) curves can be described using different parameters, such as P80 preferred by metallurgists and P20 preferred by backfill engineers. Over the years, the LaRonde mine has refined the optimal PSD curves for the mineral recovery. While CPB preparation and quality depends on the mill generated tailings, it is rare that backfill design is a key consideration when optimizing mineral recovery relative to grinding size. The PSD curve will be optimized to maximum gold recovery and economics. Depending on the geomechanical characteristics of the millfeed, the comminution process is complex and targeting the optimum PSD is challenging (Parapari et al., 2020). Ideally, a comminution circuit with stable throughput should produce a relatively consistent PSD. At LaRonde, variations in ore throughput and feed-source mineralogy result in PSD variations. In general, it was noted that lower tonnage per day generated higher fines content. The influence of throughput on fines generation is related to the comminution circuit. The load of balls in the ball mill is not varied for lower throughputs, so there is more grinding energy in the system at lower throughput and more fines are produced.

In advance of increasing the LZ5 ore throughput, multiple lab tests were completed in attempts to mimic the expected CPB characteristics. Different proportions of LaRonde and LZ5 tailings were combined by an external lab (URSTM, 2022) to produce overall PSD curves. The variation in fines (< 20 µm) was quite large, between 40–70% depending on the blends (Figure 2). Other sampling campaigns have shown similar variations (URSTM, 2018, 2019, 2020, 2022).

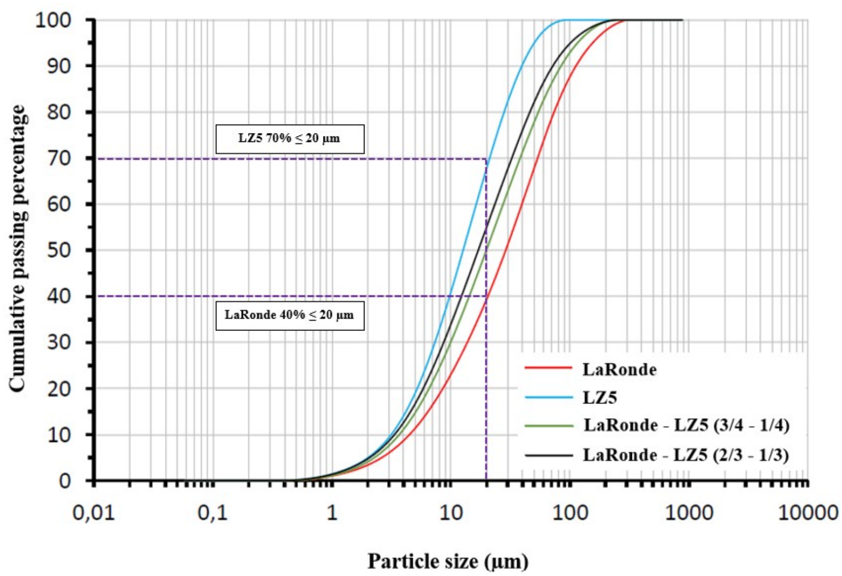


Figure 2. PSD curve with different blends of ore coming from LZ5 and LaRonde prepared in an external laboratory.

Figure 3 shows tonnage per day and fines generated depending on the content of LZ5 ore for a two-and-a-half-year period. The fines content determination is based on material passing the last dry sieve of 38 µm for a composite sample made up of subsamples taken every 30 mins. Data show significant scatter and highlight the challenge of the LaRonde complex with variation of ore tonnage and its origin. During this period, general trend indicate the average fines content (< 38 µm) increased from 57.2% to 61.2% with an increase of the LZ5 contribution to ore throughput from 17% to 25%. However, the relationship between fines content, throughput and ore source composition is more complex than this general trend indicates. There are outliers which include the blue dots at the beginning of the time series (17% LZ5) that have essentially the same fines content as the highest grey points at the end of the time series (25% LZ5) for different LZ5 throughputs. Some days show no fines due to missing data. These variations can affect the backfill operation and the overall CPB strength development (UCS).

Currently, data are still being gathered and analysed. Multiple factors influence the relationship between daily PSD and CPB UCS, and work is continuing to better understand this and the impacts on CPB strength. However, this dataset and the analysis work are important steps in the continuing development of the operation backfill team's understanding of the effects and importance of variations or changes in ore throughput and ratio on CPB performance. A strategy is under-evaluation to try and better stabilize fines generation by limiting large variations of ore throughput or drastic changes in the ore source blend ratio.

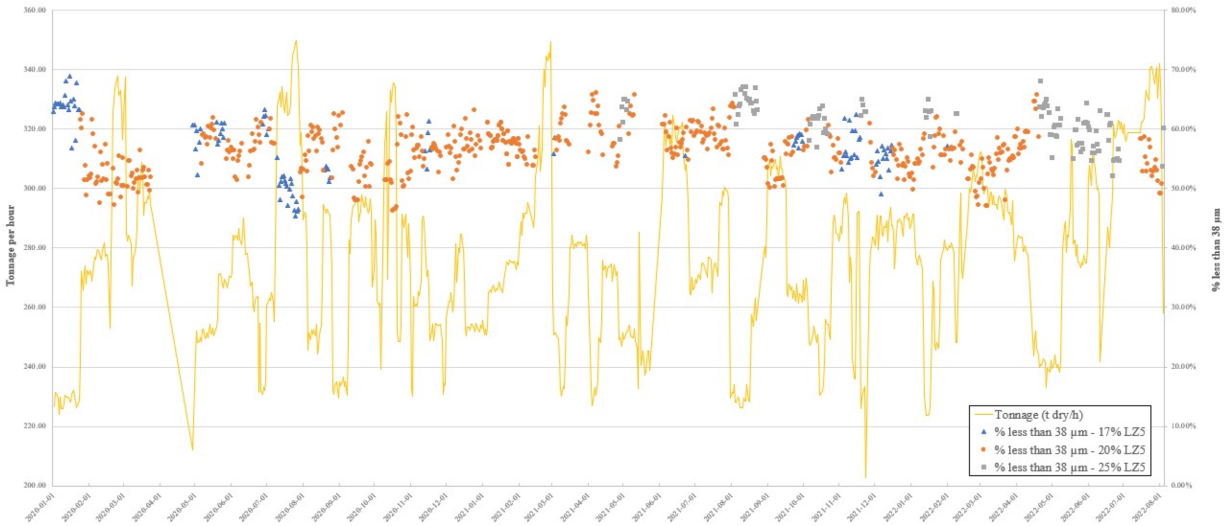


Figure 3. Average daily tonnage per hour, daily fine particles content and ore throughput percentage (LZ5 vs LaRonde)

Fall et al. (2005) showed that the CPB water demand increases with increasing fineness of the tailings material used and affects the overall UCS resistance of CPB. The optimum fines content for any CPB is generally between 20–30% of particles of < 20 µm (Belem, 2015). For the LaRonde complex, LaRonde VMS material contains approximately 40 % of particles of < 20 µm. Increasing LZ5 material in the mill feed further increases fines content. To better track these variations, in addition to daily PSD composites samples are now taken minimally on a monthly basis and analysed with a Malvernsizer laser combined with the dry sieve analysis. Variations in mineralogy and the tonnage throughput make it almost impossible to maintain a constant fines content. Despite efforts to stabilize the throughput tonnage and the LaRonde and LZ5 material blend in the feed, there are still variations in the fines content and PSD curves. To address these variations, the internal CPB QA/QC database also tracks and forecasts the ratio of LaRonde and LZ5 ore throughput to help the backfill engineer to better anticipate the UCS resistance expected with different recipes. There is also ongoing testing to try and reduce the fine generation without affecting mineral recovery.

More recently, laboratory work is part of the strategy to get a clearer understanding of factors controlling optimal CPB strength development (Gélinas, 2023a). Figure 4 shows samples that were prepared with a tailings source ratio of 1:1 (LaRonde: LZ5), but where the fines content was modified to create five sets of tailings samples that varied from the initial 55% fines (≤ 25 µm) to 15% fines. UCS results at 7 and 28 days show that for 5% binder (90% slag:10% GU), the optimal fines content is 25%. In the operational context it is not currently possible to generate tailings with these optimal fines content. However, this work shows that reducing fines without affecting recovery is an effective strategy for stabilizing UCS. Below the optimal 25% fines content that there is no additional gain in UCS, and in some cases UCS values are lower.

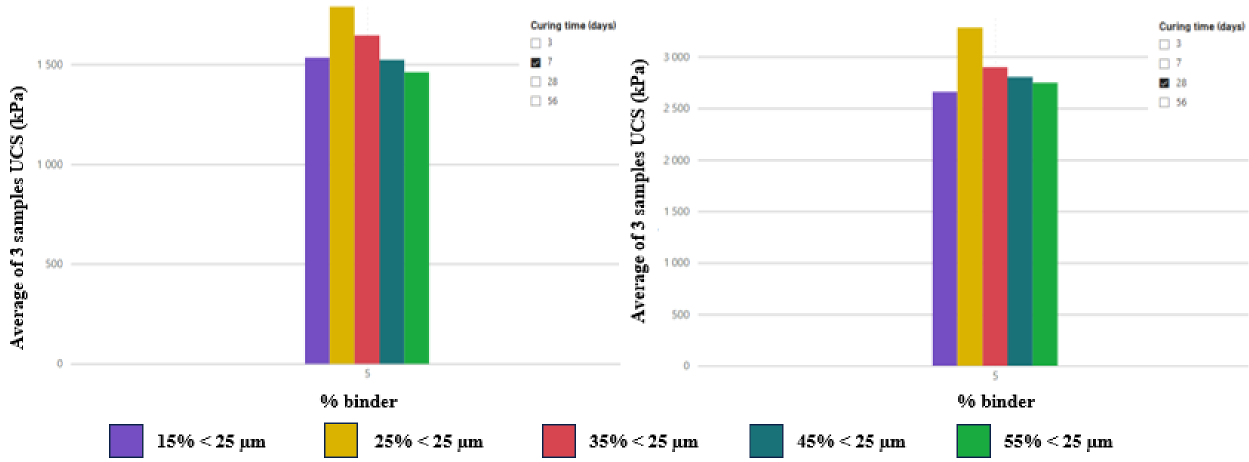


Figure 4. UCS of CPB samples with variation of fines < 20 um at 5% binder (90% slag:10% GUL) (Gélinas, 2023a)

Mineral characterization

A compilation of mineralogical test results for LaRonde and LZ5 material is presented in Table 1. While both mineralogies are similar, there are important differences in the relative proportions of components. The LaRonde tailings are mainly composed of quartz (46.7–65.6%), pyrite (9.7–27.5%), chlorite (0–10%) and muscovite (5.4–7%). The LZ5 tailings remain dominated by quartz (35.7–55.3%), muscovite (9.8–24.3%), chlorite (0–20%) and pyrite (3.6–8.5%). The total phyllosilicate content (ie, clay and micas) varies from 9.3–4.3% at LaRonde to 19.8–44.3% at LZ5.

The ratio in which these ore sources are combined can also vary, which further complicates the variations in mineralogy of tailings. The last column of Table 1 presents a sample taken for a LaRonde/LZ5 ore feed at a 4:1 ratio. This sample exhibits surprisingly high proportions of pyrite and muscovite for a LaRonde/LZ5 mixture and indicates that despite controlling the LaRonde/LZ5 material blend, mineralogical variability remains in the resulting tailings. Studies (URSTM, 2017, 2018, 2019, 2020, 2022) have attempted to better define the mineral characteristics of both deposits. However, they do not adequately capture the daily mineralogical variation to allow for reliable operational forecasting.

Table 1. Mineral composition of LaRonde and LZ5 tailings used for CPB.

Mineral group	Mineral	LaRonde	LaRonde	LaRonde	LZ5	LZ5	LZ5	4:1 LaRonde et LZ5
Tectosilicate	Quartz	46.7	50.0	65.6	35.7	38.0	55.3	42.0
Tectosilicate	Anorthite		3.0	8.8			1.3	2.5
Tectosilicate	Oligoclase					7.0		
Tectosilicate	Microcline		2.6	2.6			7.0	
Amphibole	Actinolite							1.1
Inosilicate	Aegirine					2.0		
Inosilicate	Wollastonite				1.0			
Feldspath	Albite	3.5			4.8		2.5	
Feldspath	Orthoclase							1.3
Mica	**Siderophyllite**					**3.0**		
Mica	**Biotite**	**4.3**						
Mica	**Muscovite**		**7.0**	**5.4**	**24.3**	**19.0**	**9.8**	**18.0**
Clay	**Chlorite**	**10.0**			**20.0**			
Clay	**Chamosite**		**3.5**			**6.4**		**5.3**
Clay	**Clinochlore**		**1.5**	**3.9**		**7.0**	**10.0**	
Clay	**Montmorillonite**							**3.0**
Carbonate	Aragonite		8.0					
Carbonate	Ankerite		0.8			5.0		1.6
Carbonate	Calcite					2.7	2.5	0.5
Carbonate	Dolomite				9.5	1.0	4.5	
Sulphide	Pyrite	27.5	22.5	9.7	3.6	8.5	4.6	22.6
Sulphide	Chalcopyrite		0.1			0.1		0.1
Sulphide	Sphalérite		0.2			0.01		0.2
Sulphide	Arsenopyrite		0.02					0.0
Sulphide	Magnetite			1.7			1.4	
Sulphide	Galena		0.01					0.0
Sulfate	Barite		0.1			0.1		0.1
Sulfate	Ettringite							1.0
Sulfate	Gypsum	5.9		2.4			2.1	
Oxide	Anatase		0.3			1.0		0.5
Oxide	Corundum				1.1			
Arsenate	Brassite	2.0						
Total phyllosilicates (Mica + clay)		**14.3**	**12.0**	**9.3**	**44.3**	**35.4**	**19.8**	**26.3**
Reference		URSTM (2017)	URSTM (2020)	Sika (2022)	URSTM (2017)	URSTM (2020)	Sika (2022)	URSTM (2020)

For CPB, monitoring sulphide and phyllosilicate mineral content is critical. Figure 5 shows a snapshot of muscovite and pyrite content over time and as a function of ore feed source. In general, pyrite (FeS_2) content is higher in the LaRonde tailings (≤ 27.5%) and lower in the LZ5 tailings (≤ 8.5%). The lower sulfur content is the main reason why LZ5 tailings have a lower relative density (specific gravity) than LaRonde tailings. Sulphide content is important to monitor because these very dense minerals strongly influence the tailing density.

As the proportion of LaRonde ore feed is anticipated to decrease in the future, the relative density will also decrease. Depending on the LaRonde/LZ5 mixtures, it will be necessary to adjust the relative density value used for the cement dosing. Depending on the range of variations, a change in density will influence the CPB recipe since all formulas assume a fixed density. An increase in density will result in overdosing the CPB recipe, which will not negatively impact resistance but will increase cost. A decrease in density will result in underdosing, which will negatively impact resistance as neither the targeted recipe nor the design resistances will be achieved. Therefore, the density value is being tracked weekly to ensure proper dosing of the CPB recipes. Calibration of the load cells and cross validation of binder usage calculated in the mill compared to the binder delivery report are also done automatically by aggregating data.

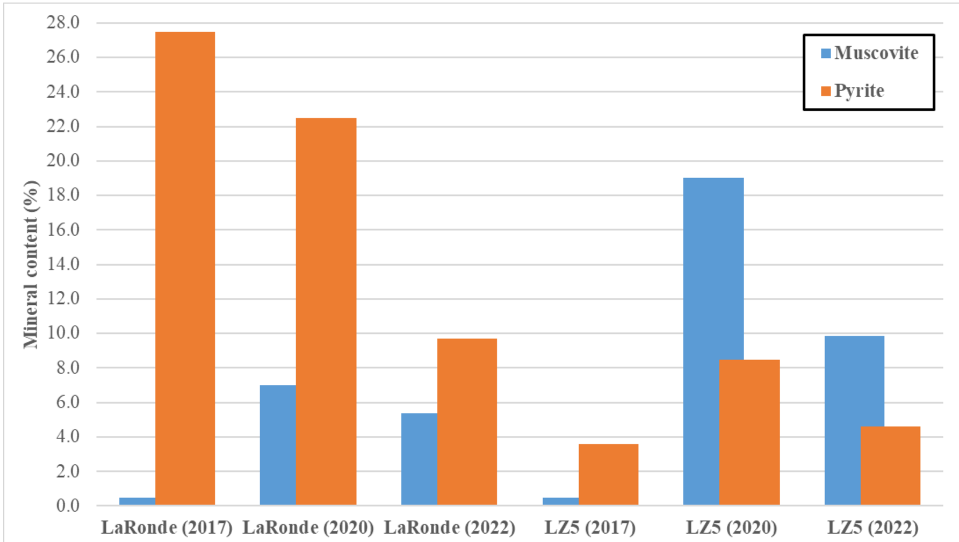


Figure 5. Proportion of muscovite and pyrite at LaRonde and LZ5 (2017, 2020, and 2022).

Silicates (quartz, anorthite, oligoclase, microcline, aegirine, wollastonite), amphibole (actinolite), feldspathoids (albite and orthoclase), oxide (anatase, corundum), carbonate (aragonite, ankerite, calcite, dolomite), sulfate (barite, ettringite, gypsum) and even arsenate (brassite) are reported in the LaRonde/LZ5 tailings' mineralogy. These minerals are generally inert and should not negatively affect the hydration dynamics of the cementitious reactions in backfill applications. For CPB, the main problematic minerals are phyllosilicates. This family of minerals is divided into three groups:

1. Clay group containing chlorite, clinochlore, chamosite, illite, kaolinite, montmorillonite, and talc
2. Mica group with biotite, siderophyllite, muscovite and phlogopite
3. Serpentine group (not found at LaRonde complex)

The phyllosilicates are sheet-structured minerals that have weak internal bonding between the planes (Benzaazoua et al., 2005). This mineralogy can allow failure planes and crack propagation to develop under loading. Phyllosilicate content of > 5% can negatively impact the strength development of the CPB (P&C, 2023).

Based on Figure 5, for a combined LaRonde/LZ5 millfeed the muscovite content is primarily from LZ5 ore, and pyrite content is mainly from LaRonde. At the LaRonde complex, the muscovite has a large effect on water retention and may pose significant challenges during the adjustment of the solid percentage by increasing slump value. The impact of phyllosilicates is better understood in the concrete and mortar industry (Lagerblad et al., 2007, Loorents et al., 2020). Recent research is attempting to show similar behaviours with CPB and, therefore, a negative impact in terms of the resistance gain (UCS) of the CPB (Belem, 2022). Mineralogy has multiple effects on CPB, especially regarding mechanical strength (UCS). The same percentage binder at the same water/cement ratio can generate a large variability of UCS values depending on tailings' mechanical (PSD) and chemical (mineralogical) characteristics (Benzaazoua et al., 2002, 2010).

Slump and solid percentage

Figure 6 shows CPB samples prepared from the LaRonde, LZ5 and 11-3 zones. While there are variations in the solids content of these samples, the slump variations can be quite drastic and do not vary directly with solids content. Historically, the LaRonde site targeted an Abrams cone slump of approximately 7 in (178 mm). By varying the sources and relative contributions to millfeed, water retention varies greatly, even if the targeted slump remains the same. The water/cement ratio may vary quite a lot for a constant 7 in slump. Two extreme cases are 100% LZ5 tailings which has 65.8% solids content with a slump of approximately 7 in and 100% Zone 11-3 tailings which has a solids content of 77% for a slump of approximately 7 in. Images in Figure 6 indicate the clay-like behaviour of the LZ5 material, especially at 70.6% solids. The yield stress of these mixes will vary greatly, introducing operational pumping challenges as well.

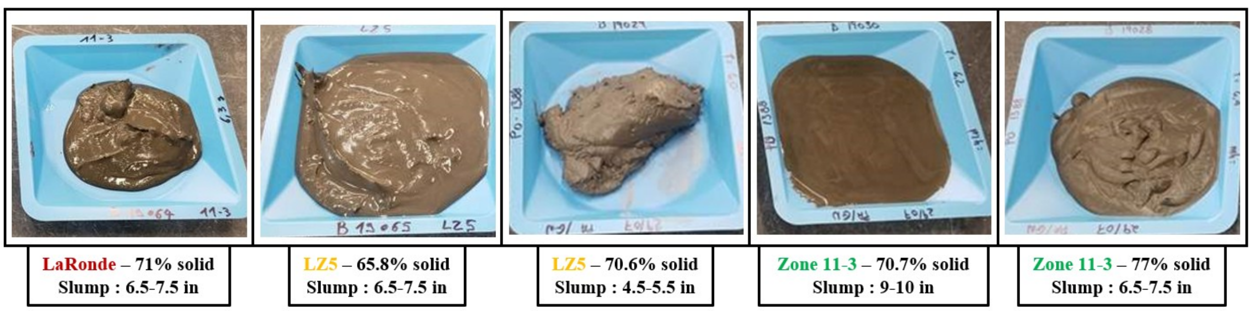


Figure 6. Solid percentage vs slump of various mixes prepared at the URSTM lab (pictures from URSTM, Gélinas, 2022).

Table 2 summarizes the detailed recipe and the 3-sample average UCS after 28 days of curing, corresponding to batches shown in Figure 6. The 100% LaRonde tailings sample had the highest UCS (981 kPa) at almost twice that of LZ5 (580 kPa) and close to four times higher than the Zone 11-3 sample. Both the LaRonde and 11-3 samples had approximately 71% solids content (981 kPa vs 234 kPa). These samples were prepared in the lab at the same time, cured in the same conditions, and the used the same testing equipment. This demonstrates that by strictly adhering to operation practices, regardless of tailings material source, and targeting a slump between 6.5–7.5 in, significant variations can be measured in 28 day UCS values (LaRonde: 981 kPa; LZ5: 442 kPa; Zone 11-3: 527 kPa). Although this testing was conducted using an 80/20 Slag/GU binder, the tendencies are expected to be similar for other binders.

Table 2. Various CPB batches and UCS results from the LaRonde complex

#Batch	Tailings	Binder type Slag/GU	% Binder	Slump (in)	Solid (%)	Curing time (days)	UCS (kPa)
19028	LaRonde	80/20	3.5%	6.5 – 7.5	71.0%	28	981
19064	LZ5	80/20	3.5%	4.5 – 5.5	70.5%	28	580
19029	LZ5	80/20	3.5%	6.5 – 7.5	65.8%	28	442
19065	Zone 11-3	80/20	3.5%	9.0 – 10.0	70.7%	28	234
19030	Zone 11-3	80/20	3.5%	6.5 – 7.5	77.0%	28	527

QA/QC practices and data analytics

The challenges of bringing new ore zones to the mill and variable-composition tailings at the CPB plants has required increasing the robustness of QA/QC practices at the LaRonde complex. For plug pours, a minimum of 9 samples are taken, which includes triplicate cylinders to be tested at 7, 14 and 28 days curing time. For mass pours, a minimum of 6 samples are taken, which includes triplicates of cylinders to be tested at 28 and 56 days of curing time. Sampling data and testing results are centralized in an operational and UCS database where relevant operational KPIs are tracked and available to backfill team members. Figure 7 demonstrates how this kind of data integration is essential for the operation. The graph shows UCS results from CPB samples tested at 7, 14 and 28 days of cure. For constant binder content and slump, there is a wide range of UCS values. At 7 days, the difference between the minimum and maximum resistance values is 534 kPa ; it is 705 kPa at 14 days and 568 kPa at 28 days. This variability represents an engineering challenge to ensure the required design strength is met. Each UCS value represents a complex, multivariable relationship.

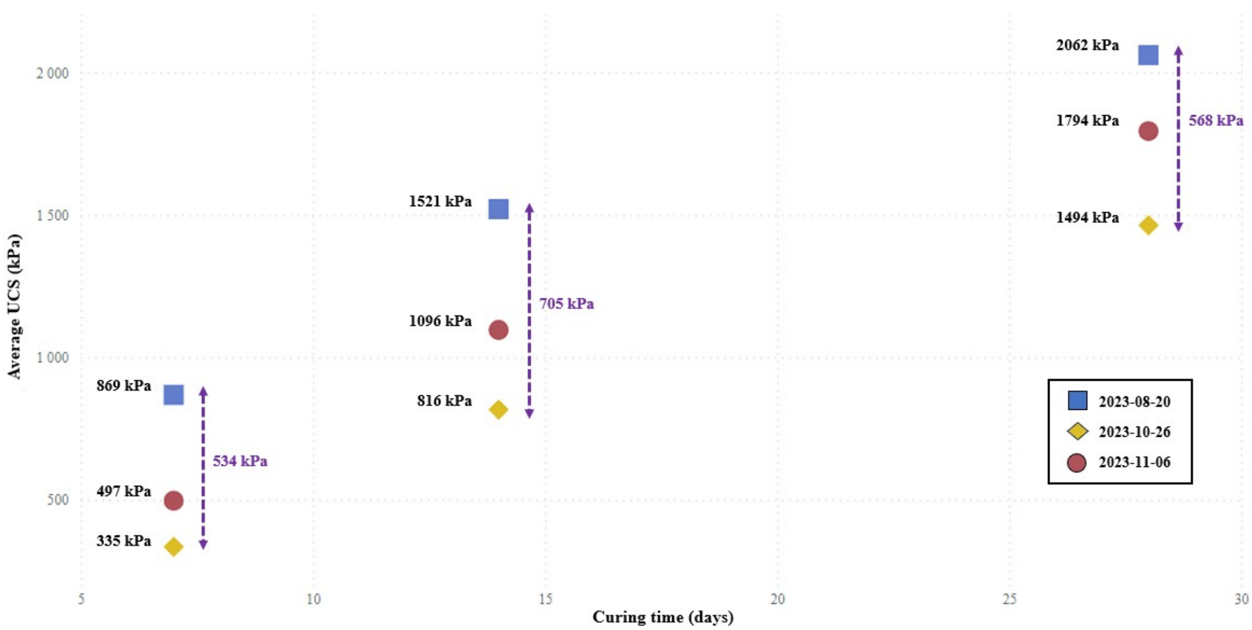


Figure 7. Average UCS (kPa) vs curing time (days),7 in (6% Terraflow).

To reduce risk and better understand variation in CPB UCS resistance, a Power BI report has been developed for both the LaRonde and the LZ5 CPB plants where relevant data from operations are extracted from PI and linked with the laboratory UCS results. Figure 8 shows an example of LZ5 target resistance for various binder content and laboratory UCS values for the 2023 period. The backfill engineer can click on any data point representing samples from a specific stope and then start an advanced parametric analysis.

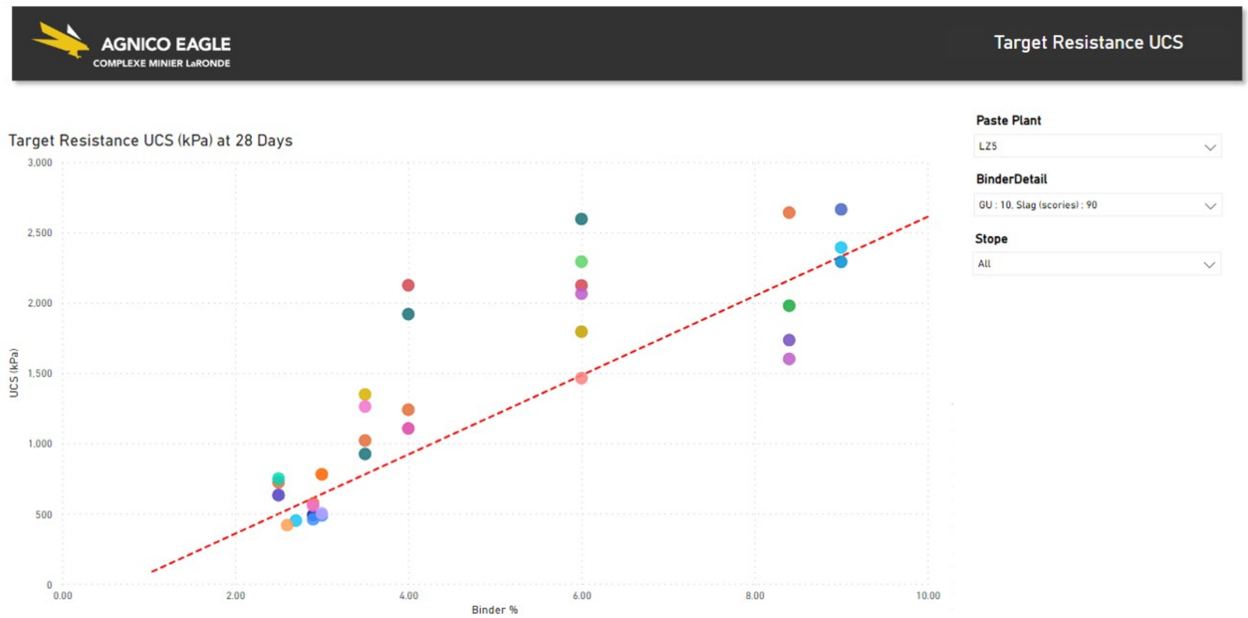
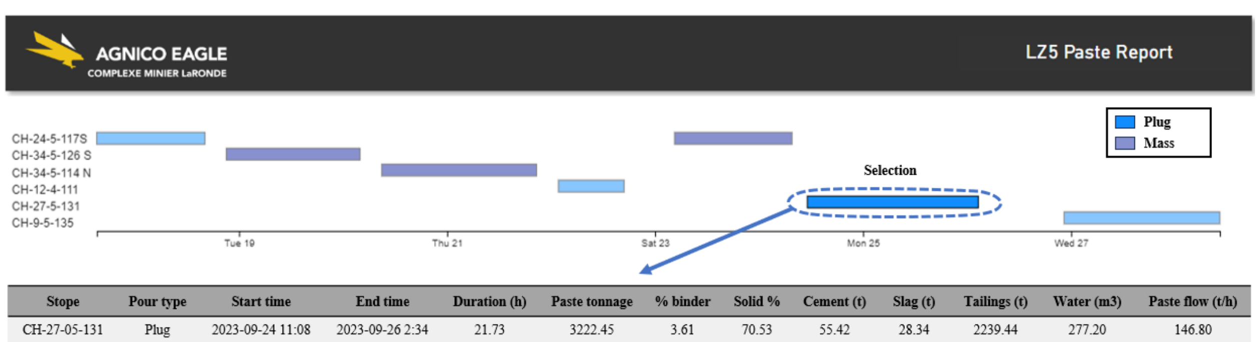


Figure 8. Overview of the target UCS resistance graph from the LaRonde complex, updated weekly.

Figure 9 shows another data display that is available to the backfill team. For this specific stope, the CH-27-05-131, the resistance was slightly lower than expected. Upon validation of the plug pour, the average corrected binder percentage was lower than planned at 3.61% vs 4%, which resulted in a 70.53% solid content instead of 71%. These automated reports and easy access to data allow for efficient validation from any member of the backfill group and have led to multiple optimization and innovation initiatives.



Stope	Pour type	Start time	End time	Duration (h)	Paste tonnage	% binder	Solid %	Cement (t)	Slag (t)	Tailings (t)	Water (m3)	Paste flow (t/h)
CH-27-05-131	Plug	2023-09-24 11:08	2023-09-26 2:34	21.73	3222.45	3.61	70.53	55.42	28.34	2239.44	277.20	146.80

Figure 9. Detailed stope by stope schedule

Another example of data now being tracked at LaRonde is the tailings' PSD. As previously mentioned, the P20 of tailings is obtained with a Malvernsizer laser monthly. For a constant blend of LZ5 and LaRonde tailings (50/50), a range of P20 values varying from 33–44% was measured in 2023. A portion of these data are presented in Figure 10. This illustrates the point that variations in mineralogy and the tonnage throughput make it almost impossible to maintain a constant fines content. An internal study showed that at LaRonde, a 10% increase in particles of < 20 µm can reduce CPB strength ≤ 12% (Gélinas, 2023b). The PSD is now a physical property that is being followed and studied at LaRonde complex and in all AEM sites producing CPB.

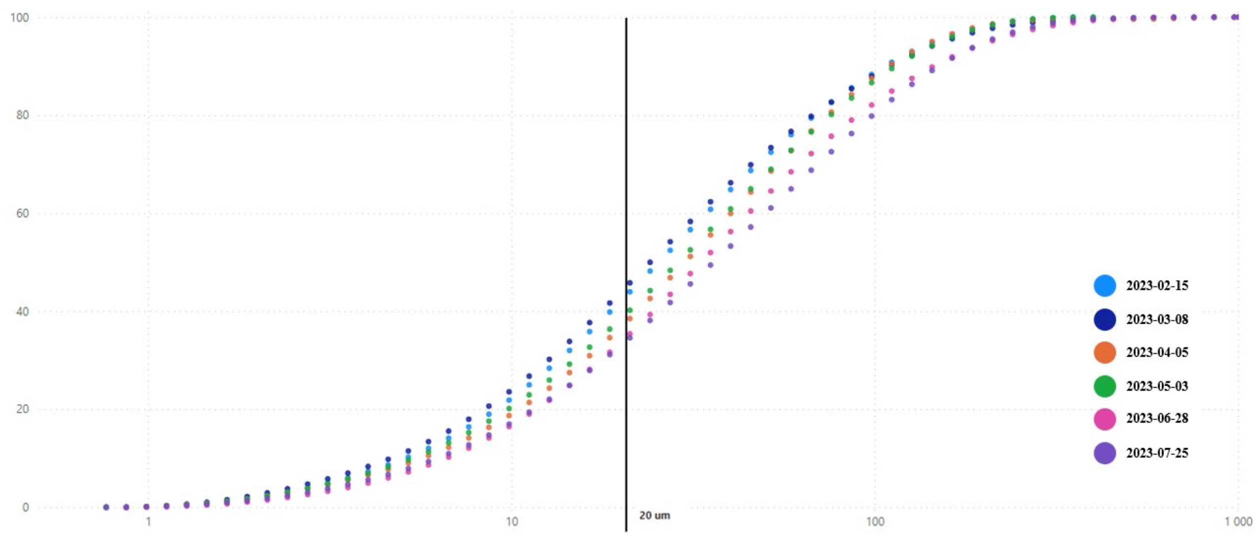


Figure 10. Monthly PSD tailings results from 2023.

2023 was a pivotal year which saw the tracking of many parameters and complex backfill data analysis become possible at the LaRonde Complex. Figure 7 shows that for CPB produced using the same recipe (ie, binder content) and a similar water/cement ratio in different months (ie, August, October, November) can generate large variations in UCS resistance. Results presented and described in this paper demonstrate the importance of tracking and understanding variations in mineralogy and PSD which can affect the strength development of CPB in a mature mining complex such as LaRonde. A yearly review of QA/QC practices is essential for the LaRonde complex as the millfeed composition continues to evolve rapidly with the emergence of new satellite zones.

Conclusion

Lessons learned at LaRonde complex can be summarized as follows:

- The importance of tracking the evolving mineralogy of tailings in a mature mining complex is essential. Annual investigations are now being planned to continue updating the mineralogical database for the LaRonde complex.
- Using advance data aggregation software, updated data policy and easy access to data, (eg, data democratization) has contributed to an evolving understanding of controlling parameters for strength (UCS) development of CPB at LaRonde. Different departments are now sharing information and generating and exploring optimization opportunities.
- Laboratory work with limited variations of factors affecting CPB strength development is essential to explore new optimization objectives.

- As demonstrated in this paper, the CPB strength development can be affected by mineralogy and PSD. Additional factors and data that have not been discussed here are being measured and analysed daily such as temperature of the water and the CPB.

AEM participates actively in university research project to better understand the impact of minerals on backfill strength. Being able to share easily a large and clean database makes collaboration between industry and research institutions simpler than ever.

Based on these findings and tools, backfill engineers from LaRonde and LZ5 adjust frequently the planning to consider mineralogical changes in the tailings and adjust the cement content in order to achieve design CPB strength (UCS) requirements. Team members understand that daily variations in the millfeed source blend and/or large variations in throughput tonnage can impact backfill quality and affect the overall performance of the mine. Based on this, efforts are made daily to stabilize millfeed or to plan for millfeed changes to limit their impact on the backfill operation. AEM continues to research technologies to accelerate mineralogical analysis from months to days.

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