Super Paste: Case Study of the use of Binder in Cemented Paste Fill to Support the Role of Fines in Paste Mix Designs

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Abstract

Cemented paste fills (CPF) are composed of full-stream (usually) tailings, water, and a cementitious binder. The fines in the tailings and binder create a matrix which supports the coarser particles allowing the CPF to be transported to an underground stope via a mine's underground reticulation network. However, what happens when the usual supply of tailings is disrupted and the only viable source of 'tailings' aggregate is significantly coarser than the usual tailings? This paper summarizes observations of a project conducted as part of an operational necessity to replace tailings fines with binder.

The project was conducted at Newmont Porcupine's Hoyle Pond (HP) mine in Timmins, Canada. Tailings for HP are harvested during the summer and a surplus is stockpiled for use during the winter. Due to operational constraints, insufficient tailings were stockpiled. To keep up with mine production, HP utilized a CPF whose mix consisted of silty sand, binder, and water. This paper explores the development of the blend in comparison to the operation's usual blend, operational observations during the CPF pours, and provides a comparison of the performance between its standard paste mix design and the project's colloquially named "super paste."

Key words: cemented paste fill, particle size distribution, rheology

Introduction

Newmont's Hoyle Pond Underground mine (HP) is located 18km east from Timmins, Canada and is part of the Porcupine Gold Mines (PGM) complex. The Porcupine Gold Mines (PGM) complex was formed in 2007 and was acquired by Newmont in April 2019. Mines that have comprised PGM date back to 1910, when the Dome Mine began commercial production. The PGM complex has been comprised of more than 25 mines including the Dome, McIntyre and Pamour mines. It has produced more than 67M oz gold for which ~ 60% of the gold produced is attributed to HP Underground (Henning and Wojtus, 2004). Today, the PGM complex incorporates Hollinger Open Pit in Timmins, Borden Lake Underground in Chapleau, and HP Underground in Porcupine, Canada. PGM's mineral processing occurs at the Dome processing facility in South Porcupine.

HP began production in 1985 and mines a system of flat laying veins in the southwestern Abitibi Greenstone Belt of the Superior Province in the Canadian Shield. HP's underground workings are accessed by two ramps and two shafts. Historically, four different mining methods have been implemented at HP: conventional cut and fill, shrinkage stoping, panel stoping, and long hole stoping. Today, the mine extends to approximately 1940 m below surface and the most common mining method employed is a bottom-up longhole stoping. Typical longhole stope blocks have a strike length between 20–45 m and widths vary between 4–15 m depending on the vein dip and width. Main haulage levels are driven at 60 m intervals and cross-cuts to stopes are driven from the ramp at 15–20 m vertical intervals.

Backfill at Hoyle Pond Underground

The methods of backfill implemented at HP are uncemented run of mine waste rock fill and cemented paste fill (CPF). Of the two methods, CPF is the most common. The CPF is manufactured at the surface batch paste plant and then reticulated to voids via the paste underground distribution system.

Paste plant
HP's CPF system began with a modified batch concrete plant. In 1998, the plant was modified as part of an effort to incorporate additional controls to ensure adherenece to the paste recipe and plant monitoring. The plant consists of two hoppers that are fed from stockpiles located next to the plant. Constituent materials (tailings, sand, binder, water, admixture) are fed into a paddle mixer and then to a hopper. HP's paste system is gravity fed. The paste in the hopper flows through a borehole box to remove rock and catch clay balls and then flows down the borehole to the underground workings. Samples of the paste are taken from the hopper where ASTM slump tests are used (along with pressure sensor data from the pipeline sensors) to guide usage of water to maintain flow and prevent potential plugging events.

Underground distribution system
Like the paste plant, the underground distribution system (UDS) at HP has undergone modifications to streamline and control paste delivery to underground workings. The original reticulation system at HP used a 150 mm pipeline designed as close to vertical as possible with no level loops. The system was designed with two main backbone lines branching out to five different zones. In 2017, the paste UDS was updated to a 200 mm pipeline with pipe specifications that were adjusted to fit the site's operational requirements based on hydraulic modeling of the paste. From surface to the underground workings, the paste travels 120 m of vertical height via borehole and then travels through a series of drives and boreholes. At 1060 m of vertical depth, the UDS branches into four different ore zones reaching varying depths. Today, the UDS at HP exceeds 1900 m in vertical depth and consists of over 4600 m of active pipelines.

Tailings
Every year, HP must manage harvesting logistics for the excavation and screening of tailings based on the mine plan. Several contracts are established to excavate the tails, haul the material to a screening plant, and then to screen the tailings.

Screened tailings are then stockpiled and delivered to the paste plant as needed due to the limiting footprint of storage capacity at the HP paste plant. During the screening process it is possible for material to be rejected. Rejections are typically due to the high moisture content in the material preventing it from being screened and can be as high as 20%. However, the usual rejection rates are 15%. Material that is rejected is left to dry and is re-processed once it has dried, typically the following year.

In addition to the management of tailings logistics, HP's harvesting timeline is limited by winter. HP experiences six months of sub-zero temperatures with an estimated seven months of the year with snow on the ground. Screening is halted in winter months due to the freezing of the tailings. Tailing harvesting typically occurs from May until November (or until the annual paste backfill requirements are met) and additional processed tailings material are then stockpiled onsite for use during the winter period.

Due to a series of unplanned difficulties in 2022, harvesting of tailings to prepare for the 2023 mine plan was delayed and the harvesting season was shortened due to earlier than expected snowfall. The shortened harvesting season also created a downstream situation due to the increased *in situ* tailings moisture content (caused by limited dewatering time post-harvest and pre-screening) which caused screen rejection rates to exceed 90% (Figure 1).

Figure 1. Screen reject tailings with high *in situ* moisture content.

As a result, the harvested tailings that were processed for CPF were insufficient to meet the needs of the mine plan in 2023. It was decided to identify a path forward where HP could continue to produce a CPF without utilizing its harvested tailings.

Mix Design Proposal

HP's standard mix design blends silty sand and tailings, binder, plasticizer, and water. As such, each constituent material in CPF impacts its rheological and strength properties. Changing to a completely different set of constituent materials would obviously be a big change to HP's operation.

The first step was to secure samples from nearby (and not so nearby) borrow sources in order to complete particle size analysis. From this analysis, a silty sand, located near Sudbury, Ontario, was identified as the preferred choice as it was the finest material available that could be obtained in sufficient quantities. HP's binder would then be blended with this sand to increase the fines content sufficiently to create a CPF-like material with similar flow characteristics as the standard HP paste mix design.

To minimize operational system issues and reduce the impact to the mine plan caused by insufficient CPF volumes, refining a solution had to be done quickly. This meant that there would be a limited timeline for laboratory testing. It was understood that this would be an expensive solution. However, the solution would only be required until the stockpile of frozen harvested tailings thawed sufficiently to be screened.

Mix design test work

To achieve minimal impact to the backfill system, the rheology of the new CPF mix design was required to be similar to HP's standard mix design. It was expected that the HP strength requirements would be easily reached by the proposed mix design, but this assumption would need to be verified. The majority of the laboratory test work was undertaken by Paterson and Cooke out of their Sudbury office (Paterson and Cooke, 2023).

As mentioned previously, the standard HP recipe utilizes a blend of silty sand and tailings (50/50). This blend's standard PSD (red line in Figure 2) contains 43% fines passing < 20µm and 63% passing < 40µm.

HP's binder had contained 62% find passing < 20µm while the selected silty sand was significantly coarser with only 6% of the material passing <2 0µm.

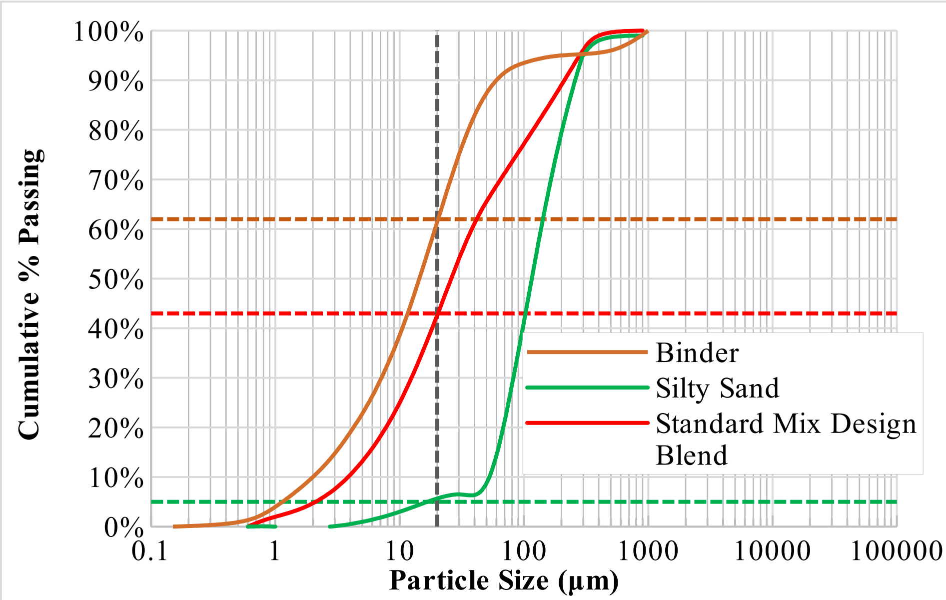

Figure 2: Particle Size Distribution curves for HP's available constituent materials.

In order to determine the performance of the sand/binder blend, the sand and binder were blended at 95/5, 90/10, 85/15, 80/20, and 75/25 ratios (by mass). The PSD of each blend was determined and compared with the standard HP CPF PSD curve referred to as the 'Standard Mix Design Blend' (Figure 3).

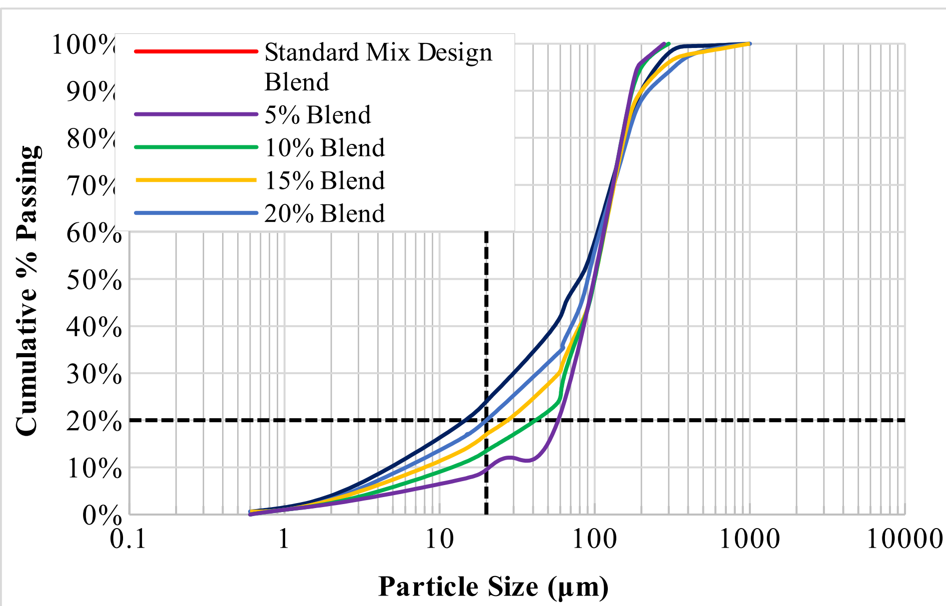

Figure 3. Sand-Binder Blend PSD curves.

The next step was to complete a rheological assessment on the different binder content blends. The HP paste plant is typically run at 75–76% solids to obtain a conical slump of 11 in. Previous studies of the standard mix design have shown the recipe to result in an estimated yield stress of 75–95 Pa. The yield stress of the standard HP mix design could be achieved by the 80/20 and 75/25 blends at 73–74% solids (Figure 4).

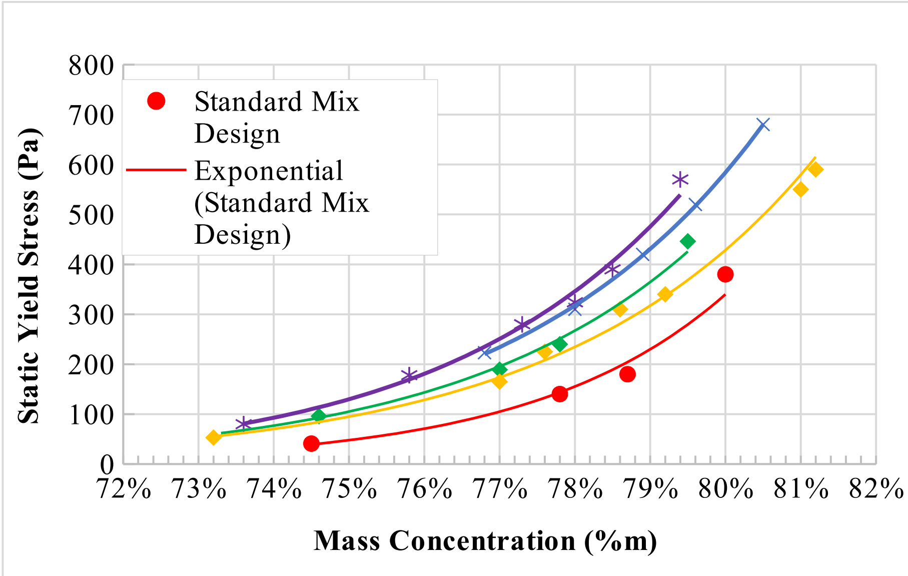

Figure 4. Blend Static Vane Yield stress curves.

While the HP plant runs ASTM slumps it was decided to run Boger slump tests to understand the rheology. The 90/10 and 85/15 mixtures (particularly the 90/10 blend) were unstable at the lower percent solids, characterized by these blends self-consolidating within the Boger sump cylinder and exhibiting bleed water. Blends that met the minimum guideline for the PSD curves were able to retain water and created slump profiles (Figure 5).

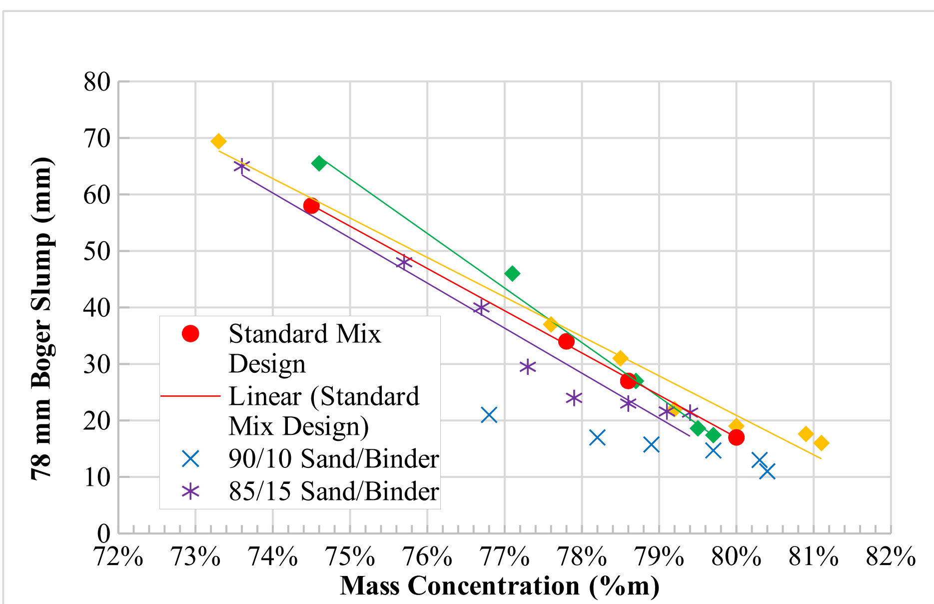

Figure 5. Blend Boger slump curves.

Based on these results, it was decided to pursue the 80/20 sand/binder. The 80/20 blend did not exhibit consolidation or water bleed and would be more cost effective than the 75/25.

HP has historically utilized an admixture to allow an increase in its CPF density in order to reduce binder consumption. While it was not necessary to utilize an admixture with this recipe, the paste plant contractor felt more comfortable to continue running with the admixture. Figures 6 and 7 demonstrate that the admixture shifts the rheology lines allowing HP to achieve higher percent solids paste while achieving a similar yield stress as the standard mix design.

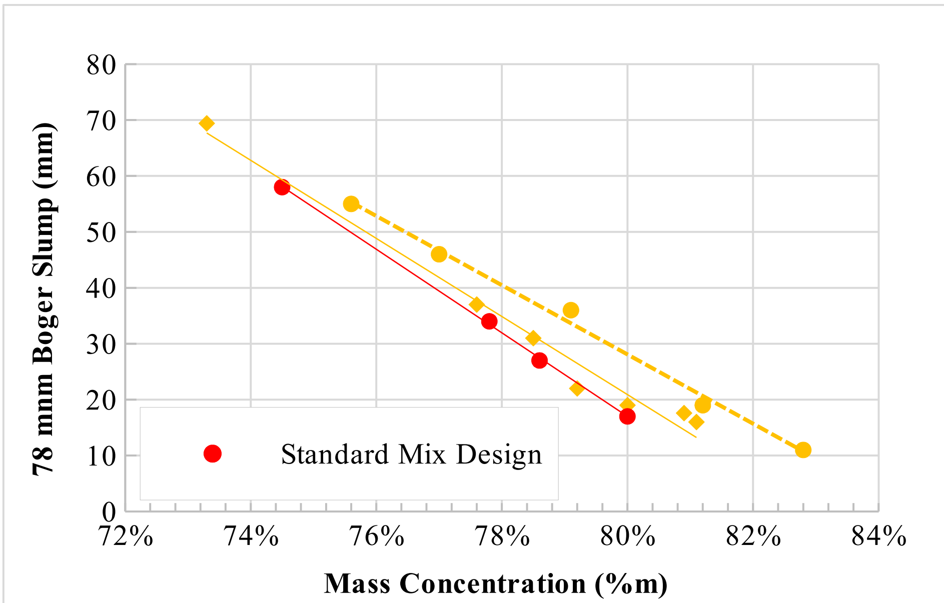

Figure 6. Static yield stress vane curves with and without admixture.

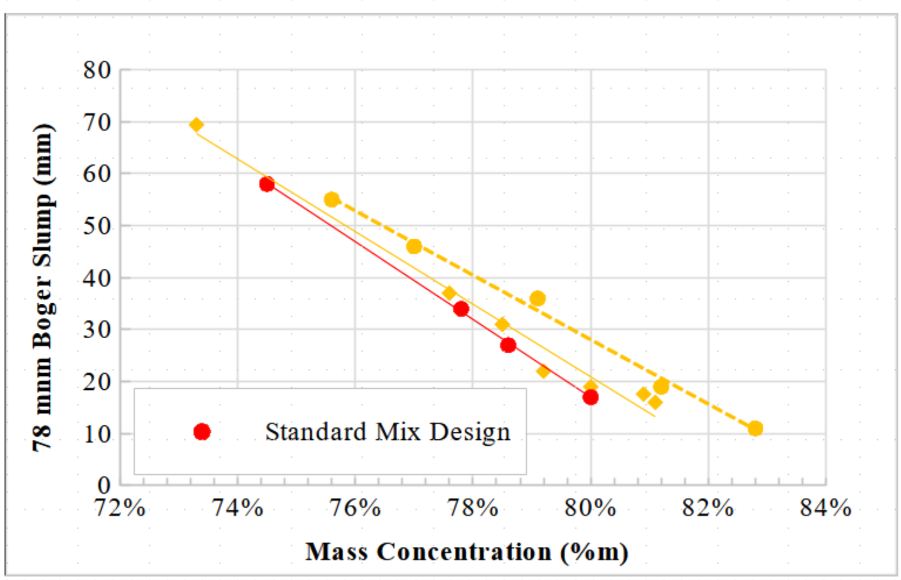

Figure 7. Boger slump curves with and without admixture.

To reduce operational stress, the mine wanted the new recipe accommodated HP's plant specific standard of an 11 in conical slump. Figure 8 provides results of conical slump testing done with the 80/20 blend including admixture. Review of conical slump cones indicate that similar results would be encountered with the 80/20 and admixture blend and would provide the plant with a familiar operating standard.

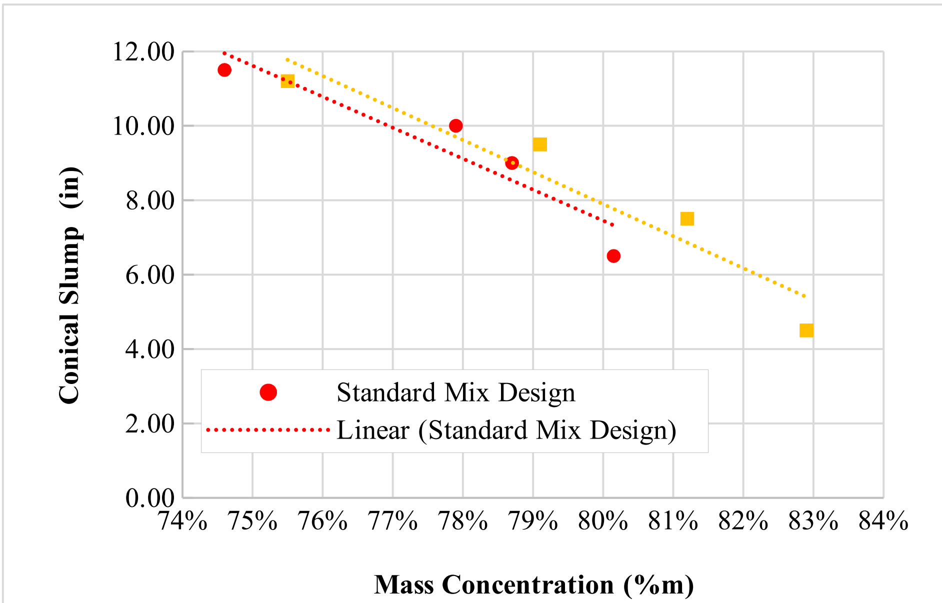

Figure 8. Conical slump results with and without admixture.

Based on the laboratory assessment, it was determined that the 80/20 Sand/Binder blend would perform sufficiently to meet HP's backfill requirements. It was decided to proceed to an operational basis with the new HP 'super paste'.

Risk Assessments of Super Paste

HP completed an assessment comparing the costs of utilizing the costs of using a high binder (ie, high cost) paste to not backfilling with CPF. This comparison found that not backfilling with CPF would have had catastrophic consequences for mine planning and sequencing at HP, and would have created unsafe geotechnical scenarios (ie, too many voids left open for too long). Given this, it was decided to proceed with the super paste and the assessment focus moved to implementing its use along with risks associated with paste quality and operation.

HP ran out of its stockpiled tailings while the super paste laboratory test work was being completed. This severely limited HP's ability to institute quality checks for the new mix design. Therefore, it was not possible to determine the content of the silty sand's PSD used in the new mix design. In addition, the short implementation timeline meant that no baseline laboratory strength results were determined prior to utilizing the super paste. While it was expected that the super paste would exceed strength requirements, mine sequencing could have been affected if test results did not meet strength requirements.

Scheduling and operational risks included logistics regarding supplying constituent materials, testing plant equipment capacity and potential line restrictions/plugging risks. Logistically, the operation had to manage the delivery of sand and binder at significantly higher rates than previously attempted. For example, the plant binder storage capacity was designed for sustained paste production at much lower binder contents, typically between 0–3.5 %. This required the coordination of binder deliveries to be monitored and planned to reduce standby or emptying of the silos during pours. There was also a risk that the higher binder content would require higher dosing rates than what could be handled by the dosing system, potentially slowing the paste flow rates. Reticulation blockages were also a concern as the higher binder content would make unblocking the system more difficult.

Finally, there was a safety risk to both the backfill plant and UG backfill operators if they were required to handle the super paste given its higher binder content (eg. cleaning the plant). To this end, information sessions were held with the operators to inform them of the increased risk and specialized PPE was made available.

Operational Results
Overall, the operational implementation of the super paste at HP was successful. It was manufactured over two months of 2023 and accounted for approximately 15% of the CPF tonnage poured during that year. In practice, the biggest challenge was logistics as both binder and sand used were imported from outside of the Timmins area. To manage sand supply, the plant used the available stockpile area at the plant. However, the binder deliveries had to be coordinated with usage and available storage capacity in silos. During the two months of super paste usage, the plant encountered four pour interruptions due to the lack of binder. These interruptions were caused by delivery trucks breaking down or arriving late. Communication between the delivery company and the paste plant was important to manage and prepare for interruptions during the pours.

One of the key risks highlighted during the assessment period was the potential for blocking and cleaning the reticulation network. However, there were no blockage or plugging events over the two months where the super paste was utilized.

Comparison of standard and super paste performance
Comparisons were made between performance of the super paste (Pour 1) and standard (Pour 2) mix designs. Pour 1 was used in April 2023 while Pour 2 was used in August 2023. The stopes being filled during the pours were located on the same mining level in approximately the same area. Both pours used the same reticulation network configuration, and the paste for both systems had similar conical slump cone results and ran at similar flow rates (Table 1).

Table 1. Pour statistics for rheology comparison between HP's standard and super paste mix designs.

	Pour 1 – Super Paste	Pour 2- Standard
Location	1060 SDF1 BL4	1060 SDF1 BL3
Binder Content (%)	20.2	5
Flow Rate (tph)	103	100
Conical slump (in.)	11	10.65
Tonnes Placed	779	1008
Approx. Density	1.91 t/m^3	1.98 t/m^3

Pressure Trends
Figures 9 and 10 show the pressure instrumentation trends from both pours. These pours exhibited slug flow throughout the system. Slug flow is a function of the backfill plant's batch mixing system and the

low density of the CPF. As each batch is released from the mixer it flows through the UDS. As the slug of CPF flowed past the pressure sensor it caused a pressure spike.

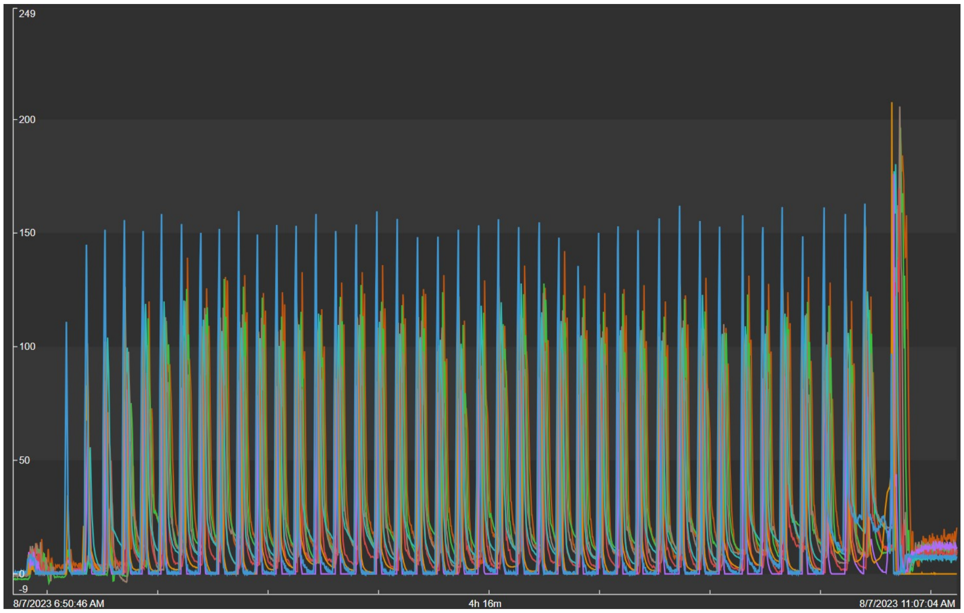

Figure 9. Pour 2: Standard Mix design overall pressure trends.

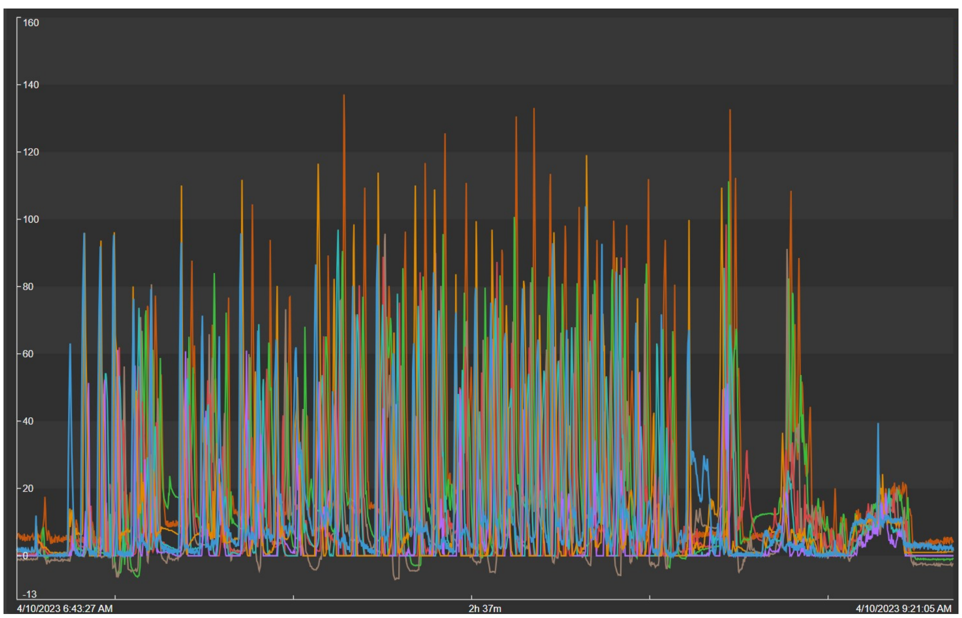

Figure 10. Pour 1: Super Paste Mix design overall pressure trends.

A comparison of pipeline pressure trends for each pour shows that Pour 2 design had very consistent slug flow behavior. The pressure magnitude change at each pressure sensor was similar as each CPF batch moved through the line (Figure 9). Figure 11 provides a closeup view of one CPF batch as it moved through the pipeline past each pressure sensor.

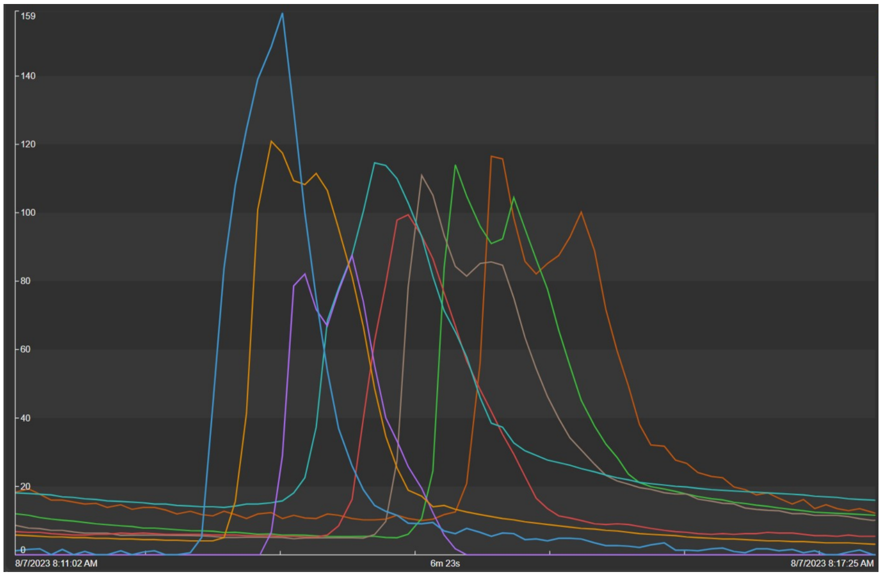

Figure 11. Pipeline pressure trends associated with a Pour 2 slug of standard HP CPF moving through the reticulation network.

Pour 1 pressure trends, in comparison, exhibited lower magnitude pressure increases than the standard CPF mix, partially explained by its lower density values. It also showed higher pressures at different sensors than the standard CPF mix. For example, the standard mix trends (Figure 9) show that the highest pressure was consistently measured at the blue pressure location (pressure sensor at the bottom of the surface delivery borehole). However, Pour 1 trends (Figure 10) show the highest pressures being recorded at other instruments (mainly light and dark orange instruments). Additionally, the super paste trends showed that the slug movement was not as uniform as the standard mix, most likely a result of a less homogeneous mix. There is also more evidence of increased CPF buildup within the pipeline. An example of this is shown in Figure 12, which highlights the pressure trend from the pipeline pressure instrument located at the bottom of the surface delivery borehole. This shows an increase in pressure above this instrument, indicating that the CPF level was increasing in the borehole.

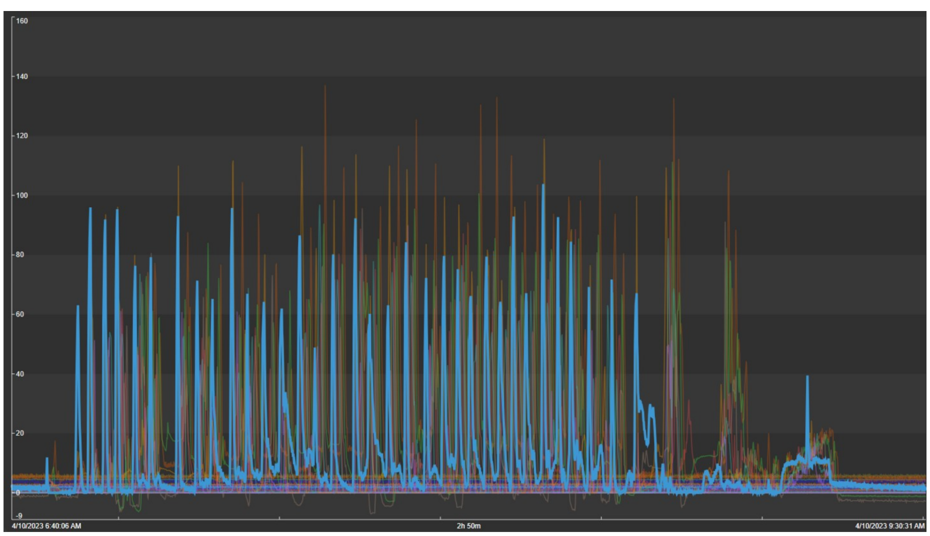

Figure 12. A highlighted pressure trend from the pressure sensor at the bottom of the surface delivery borehole showing CPF buildup within that borehole.

More chaotic pressure response of Pour 1 pressure behavior is shown in Figure 13, in contrast to the trend shown in Figure 11 (both plots have similar trend length periods).

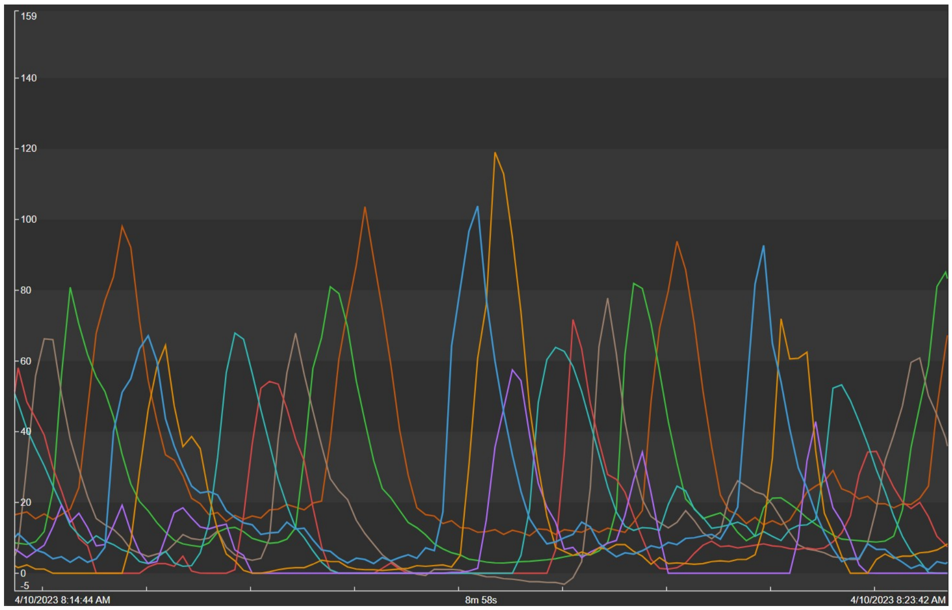

Figure 13. Pour 1 pressure trends from a tighter trend time period (compare with Figure 11).

The pressure results from both pours were correlated to the site hydraulic model. This was done by attempting to correlate the hydraulic model to the pressure sensor data taken at different times. The work showed that the pressures from the super paste pour were harder to correlate given their inconsistent behavior (Figure 14) while the standard paste pressures were more tightly clustered (Figure 15).

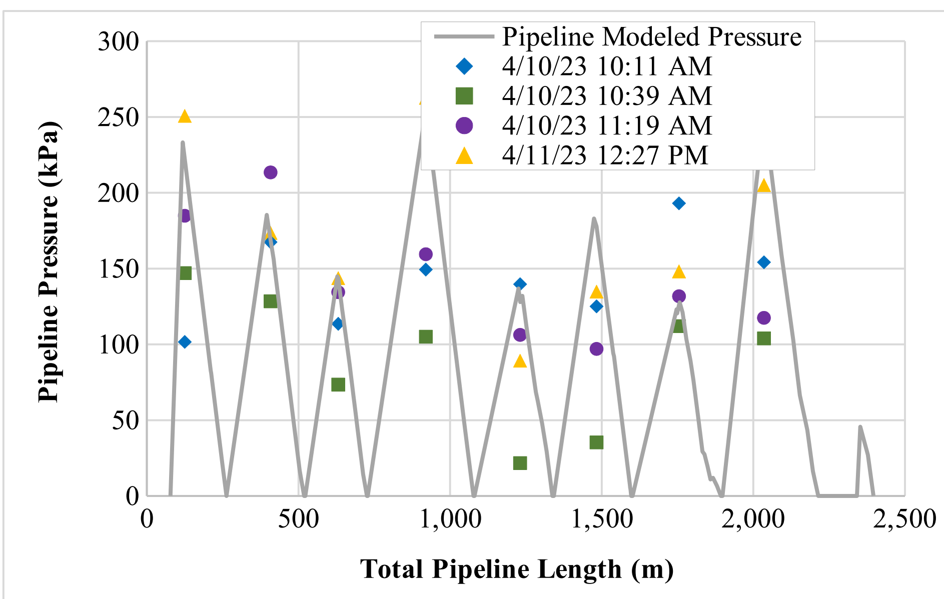

Figure 14. Pour 1 super paste pressure trends reconciled with modeled pressures.

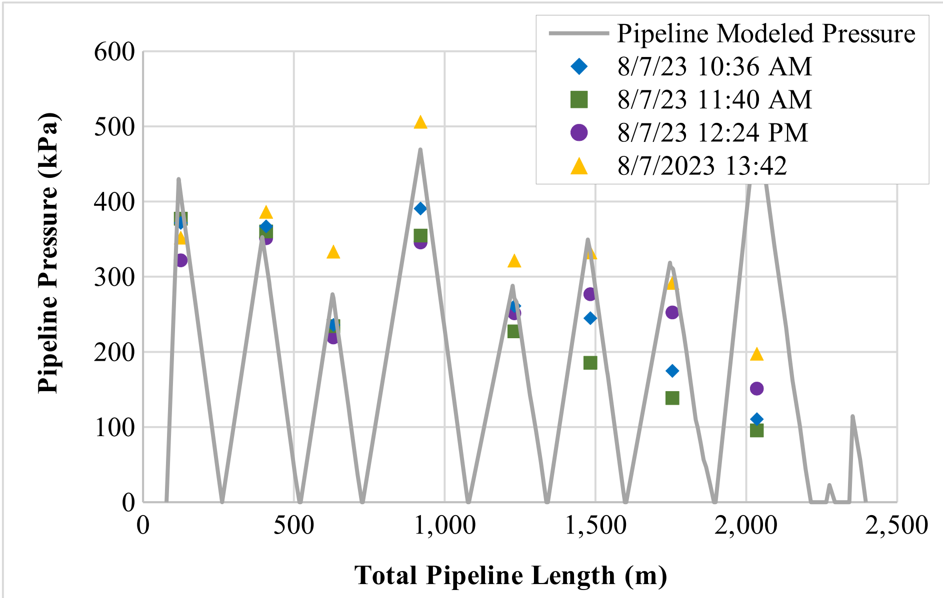

Figure 15. Pour 2 standard paste pressure trends reconciled with modeled pressures.

The super paste was designed to have similar rheological characteristics to that of HP's standard CPF mixes. However, the super paste needed to have a higher pressure-loss gradient than HP's standard CPF blend in order to explain the field observations, eg, an overall more chaotic system, CPF build up within the boreholes, higher pressures at different instruments, and overall lower system pressures.

Paste UCS Strength Comparison

During the operational risk assessment of the super paste, it was assumed that the super paste strengths would easily achieve the target paste strengths. However, as these strengths could not be determined prior implementing the super paste given the timeline constraints, it was important to validate this assumption.

Samples were taken during the pour process as per HP's quality control (QC) program. This program specifies unconfined compressive strength (UCS) testing at 3, 7, 14, and 28 days. Figure 16 provides a summary comparison of the average strength results between the standard paste and super paste. HP has three standard mix design recipes with binder contents at 3.5, 5, and 10%.

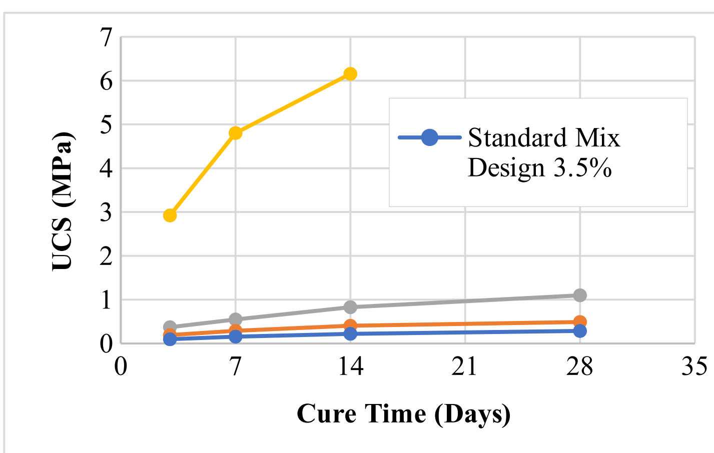

Figure 16. UCS strength comparison between super and standard pastes.

As shown in Figure 16, the super paste's 3 day strength was much higher than the standard recipes and increased rapidly, exceeding 6 MPa after a 14 day cure. It was not possible to test the 28 day strengths as the on-site UCS machine was unable to break the samples past 6 Mpa. Needless to say, the super paste exceeded the operation's strength requirements. It is expected that these strengths would cause further operational issues if this backfill ever needs to be excavated (excavation of super paste has not yet been required).

Cost

The cost of the super paste was significant. As seen in Figure 17, CPF production decreased dramatically from January to March when existing tailings were depleted and the schedule was changed to prioritize backfilling that allowed further production. The use of super paste was able to bridge the material shortfall in April and May. In June, HP was able to reinstate the standard mix design. The super paste's production cost per CPF tonne was 43% more than budgeted cost. This highlights that the use of the super paste was a short-term option.

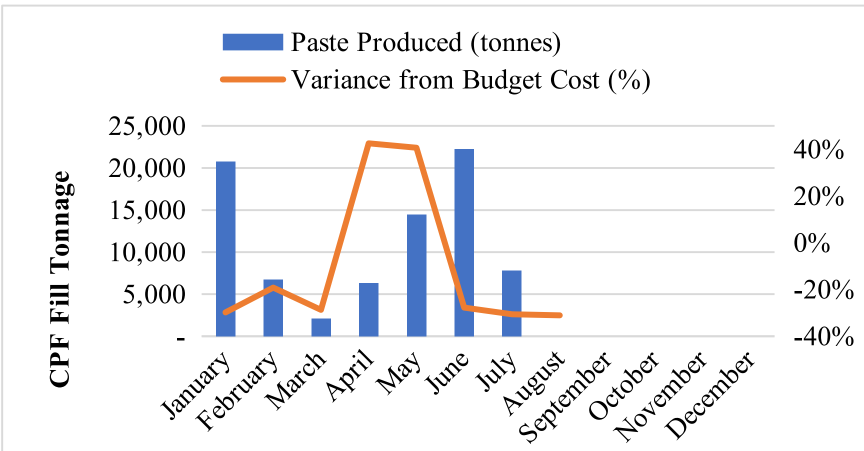

Figure 17. CPF costing.

Conclusion

The use of CPF to fill UG voids according to the schedule is a fundamental component of HP's mining operation. This makes the management of the CPF constituent materials required for the backfilling operation vital to the success of the mine. However, due to a disruption in HP's harvested tailings supply, it was necessary for the operation to develop an alternate CPF material that would allow the operation to continue backfilling over a short period until HP's harvested tailings supply could be reinstated. In order to bridge the production gap, a CPF was created utilizing blended silty sand and binder (at an 80/20 ratio) to create a material that had similar rheological characteristics to HP's standard CPF mixes. Given the high binder content required, this CPF was called super paste. The super paste's rheological field performance showed that it behaved differently than the standard mix, despite basing super paste rheological characteristics on HP's standard mix. However, these differences were not large enough to cause any issues from an operational sense. The super paste also generated significantly higher strengths than the standard mix. Overall, implementation of the super paste was a successful, if expensive, solution and allowed the operation to maintain its production schedule.

Note: Mcintyre tails are mined for Glencore, the primary purchaser.

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