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Coarse tailings backfill design considerations and optimisation: a case study from Malanjkhand Copper Project

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Abstract

Hindustan Copper's Malanjkhand Project is a 2.5 Mtpa copper operation that has transitioned from open pit to underground sublevel open stoping with paste backfill. The existing mill produces a very coarse tailings material with an average D20 of 13 µm and periods of even coarser grind. Laboratory testing indicated that the resulting paste backfill was not stable, exhibited high friction factors and was prone to pipeline plugging. A study was performed which evaluated options to improve the pipeline transportation properties of the tailings such as regrinding or harvesting legacy fine tailings from an existing tailings management facility. However, due to the close proximity of iron blast furnace operations and the low local cost of ground blast furnace slag (GBFS), the study selected the option of adding a 90/10 binder blend of GBFS/cement with an overall concentration of 10% by weight of binder. The GBFS provides the additional fines needed to improve the paste stability as well as providing the majority of the cementitious material to give the backfill its strength. The plant was commissioned in 2025 and optimisation efforts are underway to minimise binder consumption while meeting the target strength requirements and rheological constraints of pipeline transport. This paper discusses the process of selecting the preferred option, commissioning experience and optimisation efforts.

Keywords: *paste backfill, coarse tailings, rheology, optimisation*

1 Introduction

Hindustan Copper Ltd. (HCL) Malanjkhand Copper Project, India's largest open pit copper mine, is undergoing a transition to underground mining to extend the mine life. Sublevel open stoping with paste backfill was selected as the preferred mining method to ensure safe ground conditions, maximise ore recovery, and reduce surface tailings disposal.

A key challenge was the nature of tailings generated by the concentrator. Unlike fine-grained tailings that are easily made into paste, Malanjkhand produces relatively coarse tailings with limited fines. Initial assessments indicated that the material was prone to segregation, exhibited high friction factors, and increased the risk of pipeline plugging. A study was conducted to determine how to address the constraints incurred by the presence of coarse tailings.

2 Process design

2.1 Options evaluation and selection

Mother tailings samples were collected from the single point discharge of the tailings line depositing to the existing Malanjkhand tailings storage facility (TSF) in 2019. 'Mother tailings' are the site term used to describe

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unclassified tailings that are discharged to the TSF. A second sample of cyclone overflow tailings was also sampled from the TSF which represents the fine fraction of the mother tailings and stored inside a perimeter dam constructed with cyclone underflow.

The tailings that were received were coarser than historical norms being experienced by the site and therefore the mother tailings were further milled in the laboratory to achieve a particle size distribution (PSD) that reflected the mill's actual design grind.

The PSD of the ground mother tailings used in the test work program is shown in Figure 1.

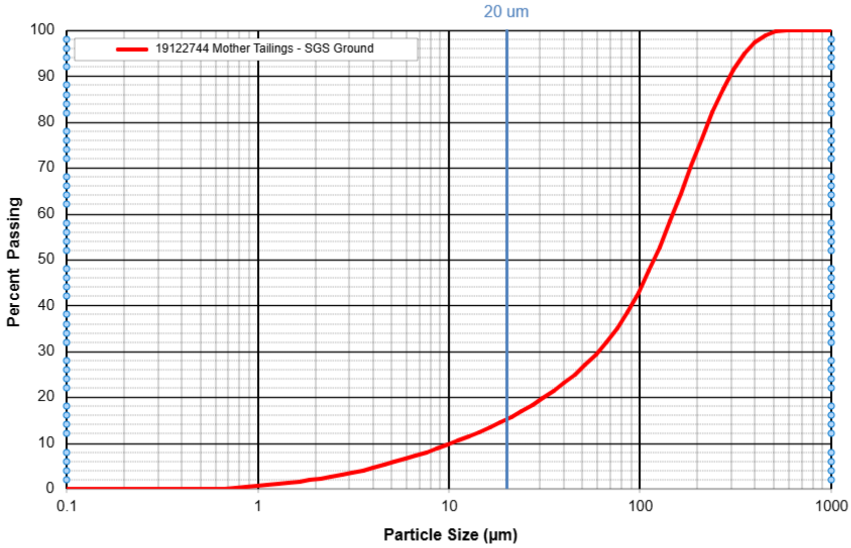

Figure 1 Ground mother tailings particle size distribution

A typical rule of thumb for the minimum amount of fines required to produce a stable paste backfill that does not bleed excessive amounts of water or segregate when at rest is 15% passing 20 µm. While this rule of thumb is a good starting point, the differences in mineralogy and particle shape can shift this criterion somewhat.

Throughout the testing it was observed that the ground mother tailings exhibited high amounts of water bleed (greater than 15% by weight in 24 hours) and developed strength rapidly when left at rest. These indicators pointed towards potential problems during typical paste backfill system operations since it is not unusual for a short-term problem in the paste plant to result in a momentary stoppage of flow in the pipeline. In general, the paste should be stable enough that the operators can respond to a short-term stoppage in the system and have enough time to either restart or flush the system before the paste becomes immovable in the pipeline.

Even if the paste is kept moving in the pipeline and is not subjected to a stoppage in flow, the friction losses in a paste pipeline with excessively coarse tailings are generally much higher. This effect was seen during the flow loop testing of the mother tailings. The flow loop test is performed on paste backfill mixtures in the laboratory to determine what the pipeline friction losses are for a given mix design. In this case, the flow loop is composed of 75 and 50 mm straight piping sections and four pressure transmitters that allow the pressure losses in straight sections of 75 and 50 mm pipe to be determined. These pressure losses are then extrapolated to larger pipe sizes that reflect the ultimate size of the paste backfill pipeline (200 and 250 mm in the case of Malanjkhand).

The danger of excessively coarse tailings material was further compounded by the understanding that the mill periodically would produce material that was coarser than the normal design PSD. This potential was reinforced by the sample that was taken from the tailings pipeline at the TSF exhibiting coarser PSD than the design mill PSD. To provide some buffer between the minimum amount of fine material required for a stable paste and PSD being received from the mill, it was decided that the target PSD for the paste would require a minimum of 20% passing 20 µm.

Figure 2 shows the plugged laboratory flow loop pipeline that resulted during the development of the mix design for the Malanjkhand paste plant.

Figure 2 Plugged flow loop pipeline

Although some of the void that can be seen above the paste in Figure 2 is related to the paste flowing out of the pipeline during disassembly, there is also a substantial amount of that void that consisted of separated water, indicating a lack of paste stability.

When the paste is moving through the pipeline, this segregation of water is minimal due to the constant remixing of water with the paste resulting from the shear forces acting on the paste from the walls of the pipe. However, the moment the paste stops flowing, that remixing effect is lost and segregation as well as consolidation of the particles at the bottom of the pipe begins.

Figure 3 shows a section of the flow loop elbow that was disconnected for cleaning. Due to the way it was disconnected, some of the segregated water can be seen on top of the paste.

Figure 3 Water segregating from the paste

As the laboratory testing program developed, options were evaluated for improving paste stability. These options included:

- grinding the mother tailings to increase the amount of minus 20 µm particles to 20%
- adding cyclone overflow to the mother tailings or removal of some of the coarse material from the mother tailings to result in a blended tailings of 20% passing 20 µm
- extracting old, fine tailings from the TSF and trucking or pumping those tailings back to the mill to be combined with the mother tailings stream being pumped to the TSF to achieve a blended tailings of 20% passing 20 µm
- adding other fine components such as increased amounts of cement and/or ground blast furnace slag (GBFS) where the fine component of the cement/GBFS would increase the amount of fines to reach the 20% passing 20 µm threshold.

The increased amount of grinding required for the mother tailings was evaluated purely from a backfill point of view and the benefits of increased grinding on mill recovery was not assessed. However, the practicality of upgrading the existing mill to provide the additional grinding and downstream processing capability was considered too disruptive and had a much higher capital cost than some of the other options.

Addition of cyclone overflow to the mother tailings was considered problematic due to the lack of tailings required to do this. Since the replacement ratio for tailings used for backfill versus ore tonnes milled is approximately 60% and since a typical backfill plant utilisation rate is about 60%, the paste plant essentially takes all of the mill tailings when it is running. If part of the mother tailings stream needed to be discarded as cyclone underflow, then the utilisation of the paste plant would need to increase beyond practical limits which are typically 70–75% utilisation maximum.

Extraction of old, fine tailings was an interesting option however the practical aspects of fine tailings extraction from an existing and operational TSF made this option unattractive. Obtaining the correct PSD of tailings reliably from historic tailings deposits is difficult due to the variable spigotting arrangements, flowrates, dam raises, TSF expansions, etc., and the extraction, pumping, and quality control challenges were not attractive.

The addition of fine cement or binder materials is an unusual but not unknown method for addressing the rheological challenges of excessively coarse tailings. For example, the ‘super paste’ solution (Betancourt et al. 2024) addressed a short-term lack of reclaimed tailings materials that met the required PSD at Newmont’s Hoyle Pond and is a case study for how the fines in cementitious binders can take the place of fines that are missing from the tailings. Since the fines content available is 60% passing 20 µm for General Use (GU) cement and 68% passing 20 µm for GBFS, these binder materials can be used to provide the shortfall in fines from the mother tailings.

While the ‘super paste’ example was a short-term solution to address excessively coarse tailings, the Malanjkhand mine has some advantages that make the permanent use of binder as a source of fines attractive:

- The Malanjkhand mine is located within 200 km of several iron blast furnaces which means that there is a substantial local supply of GBFS.
- To reach a 20% passing 20 µm PSD, a dosing rate of 10 wt% of 90/10 GBFS/Portland Cement is required.
- The 1 MPa at 28 days minimum strength requirement for the backfill required a certain amount of binder already. The additional cost associated with using cement/GBFS to make up the fines shortfall is only the gap between the amount of binder that would be required to reach the target strengths versus the binder that would be required to provide adequate paste stability. A dosage of 5 wt% binder (90/10 blend of GBFS and Portland Cement) was required to meet the 1 MPa

strength requirement. The additional cost for adding binder to bridge the gap is therefore the cost of an additional 5% binder to reach the 10% binder total.

- It should also be noted that this 5% additional binder is considered a minimum since the test work was conducted using Lafarge GBFS available in Canada rather than the GBFS that would be sourced near Malanjkhand since the supply chain for GBFS was not developed at the time of the completion of the study. There was some uncertainty related to the quality of the GBFS and therefore it was considered likely that the actual production requirement for binder to meet the 1 MPa target could be higher than 5%. This turned out to be the case and binder requirements needed to meet the strength target are closer to 10% instead of 5%.

It should also be noted that, at the time of the process selection, the cost of the GBFS in the Malanjkhand area was extremely inexpensive (less than USD 16.92/tonne) and the current price of GBFS is closer to USD 47.38/tonne. However, the relative cost of GBFS addition versus the other options is still attractive since GBFS cost in Malankhand is much lower than in other parts of the world.

2.2 Design implementation

The Malanjkhand paste plant was constructed in 2023 and 2024, and final commissioning occurred in December 2024.

The plant design capacity is for 260 m^3/hr of cemented paste backfill. The mother tailings are pumped from the existing mill tailings system to the paste plant via a pipeline that is 834 m long. At the paste plant, the tailings are thickened in a 22 m diameter high rate thickener that produces a 65 wt% solids underflow. The thickener underflow is pumped to one of two filter feed tanks and the filter feed pumps supply tailings slurry to one of the two 143 m^2 horizontal vacuum belt filters installed in a duty/standby arrangement. A filter cake at 81 wt% solids is discharged from the operating filter onto a transfer conveyor which, in turn, discharges onto an inclined weigh conveyor that discharges into the paste mixer.

Portland cement and GBFS are stored separately in 2 250 tonne day silos. Additional storage for GBFS is provided in 2 large 1,118 tonne silos. The GBFS is transferred from the large silos to the GBFS day silo as required. The large storage is used to accommodate the higher tonnage requirements for the GBFS and the intermittent delivery.

Filter cake, tailings slurry, cement and GBFS are all mixed together in the paste mixer and discharged to either an operating or standby paste pump that pumps 400 m through a 250 mm diameter pipeline to a surface borehole that drops to the -290 mrl level (a vertical distance of 296 m). From the -290 mrl, the 250 mm diameter pipeline continues for 130 m to the footwall drift on -290 mrl and then the pipeline changes to 200 mm diameter and extends approximately 500 m south in the footwall drift and 700 m north in the footwall drift to reach the furthest stopes. Levels below the -290 mrl are reached by interlevel boreholes fanning out from the -290 mrl to reach each, successive footwall drift below -290 mrl.

Figure 4 shows the discharge of filter cake from the horizontal vacuum belt filter and Figure 5 shows the paste pumps that are used to pump the paste backfill to the stopes.

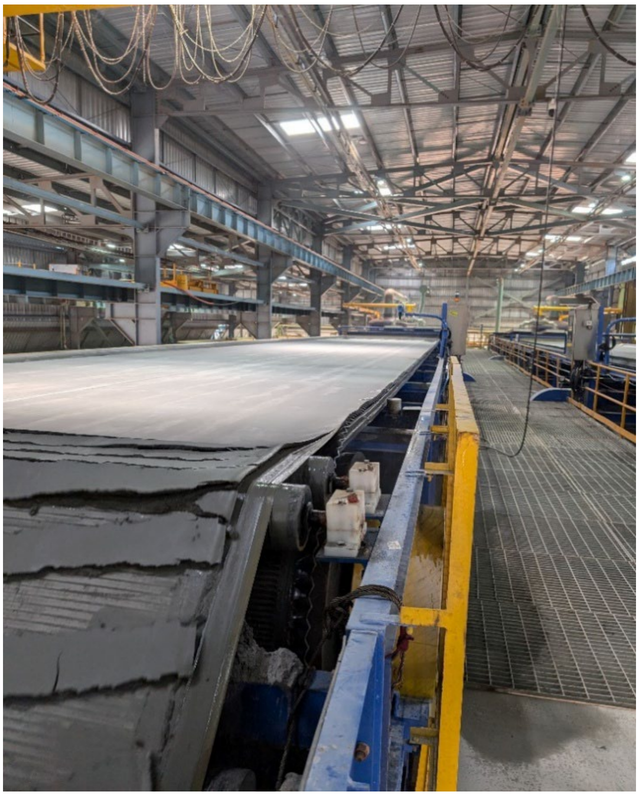

Figure 4 Horizontal vacuum belt filter discharge

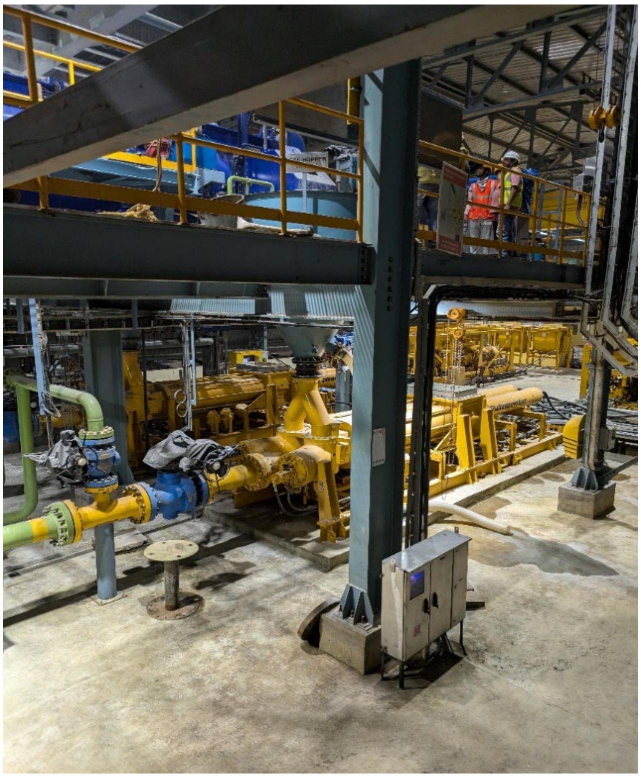

Figure 5 Paste pumps

2.3 Commissioning experience

The commissioning of the Malanjkhand paste plant was finalised in December 2024. During the commissioning period, the use of cement/GBFS to achieve reasonable friction factors was somewhat validated in the sense that the design friction factors were relatively close to the actual observed friction factors. Although it was confirmed that the friction factors were roughly in line with expectations with the design blend, there were some limitations on the ability to test the impact of fines reduction since the plant was under demand to place backfill as expeditiously as possible. Subsequently, there was minimal appetite during the commissioning process to experiment with fines reduction or anything else that could jeopardise the ability of the plant to deliver fill.

Nevertheless, some interesting observations were made during the commissioning process that help validate the process design and focus on potential future optimisation:

- The flow rate of tailings to the paste plant was sometimes interrupted due to operational issues resulting in the tailings line from the mill to the paste plant draining backwards to the mill (the pipeline is continuously sloped towards the mill). In those cases, it was observed that, during the subsequent start-up, the torque in the thickener would increase to a higher value than normal and pressures were seen to be slightly higher in the paste pipeline. It is hypothesised that the back draining of the tailings pipeline to the mill down a relatively shallow slope resulted in the deposition of significant amounts of coarse tailings which were subsequently remobilised and delivered to the thickener when the pipeline was restarted. Although the effect of this slug of coarse tailings was buffered somewhat by the contents of the filter feed tank, the rheological performance of the paste clearly was affected by the excessive amount of coarse tailings.
- During the initial commissioning period, the paste plant was delivering paste via the surface pipeline to the open pit rather than down the borehole to the -290 mrl level. This alternate deposition location was used to minimise the risk of plugging the pipeline while the plant process control was fine tuned. During this period, the rotary valve feeder for the GBFS jammed on several occasions which stopped the flow of GBFS into the paste mixer. Although this was not a planned test to observe the effect of removing a large portion of the fines content being added to the paste, it did allow the commissioning team to observe the effect. The ability to fully assess the impact of the removal of these fines from the mix was somewhat reduced because, when the GBFS stopped flowing into the system, the cement addition was adjusted to supply enough fine material to meet the shortfall. However, due to differences in grind size (the cement is slightly coarser than the GBFS) and due to limitations on the cement feeder flow rate (which cannot supply the same amount of GBFS as the GBFS feeder could) the quantity of fines being added into the mix was approximately half of the design amount. Although it was expected that a reduction in fines would increase friction loss and pipeline pressures, the measured pressures exhibited no substantial differences with or without the reduction of fines. This indicates that the effects of inadequate fines is not a hard line after which friction factors increase exponentially. An additional explanation is that the combination of tailings PSD being produced at that time, plus the additional cement in the mix resulted in an overall fines content that was still above the inflection point where friction factors would increase noticeably.
- Due to the observation that friction factors did not increase noticeably during a period of fines reduction, there was some optimism that it would be possible to decrease the gap between the amount of binder required to achieve the design strength requirements and amount of binder required to meet the rheological requirements. This is the focus of the optimisation work described in the next section.

3 Optimisation materials and methods

3.1 Objective

The use of 10% binder (10% cement and 90% GBFS) to supply the fines for the backfill is effective; however, challenges related to the availability of GBFS and the quality control of the supplied GBFS have made it attractive to HCL to evaluate mix designs that use less binder overall and less GBFS in particular.

An optimisation plan was developed during the commissioning phase of the project to investigate the potential for reducing the overall binder content while still achieving the required strength, paste stability and friction factor targets.

An overall binder content reduction of 1% was targeted as an initial step in the optimisation process. In addition, the ratio of cement versus GBFS was changed to reduce the amount of GBFS and make the mix design less reliant on the variable GBFS properties. A mix design of 7:2 (7% GBFS and 2% cement) was proposed to replace the current 9:1 (9% GBFS and 1% cement) mix design.

The method for evaluation of the binder reduction potential was to simply change the mix design at the paste plant and observe the performance of the plant at both the 7:2 and 9:1 mix designs. Additional test work for paste stability and unconfined compressive strength (UCS) was also conducted on laboratory scale for the two mix designs.

3.2 Tailings characterisation

Prior to conducting the optimisation trials, it was desired to baseline the tailings material PSD . This was done so that comparisons with historical results from the original testing program performed by WSP in 2019 and the mine's ongoing QA/QC program could be made without unknown variables being introduced because of PSD variability. To this end, a sample was taken in 2025 and PSD determined by the National Metallurgical Laboratory (NML).

The PSD comparison between the original WSP 2019 SGS ground tailings and the current mill tailings sample is presented in Figure 6. The current tailings exhibit a noticeably coarser gradation compared to the 2019 sample. At the 20 µm size fraction, approximately 13% of the 2019 sample passes, while only about 10–11% of the current sample is finer than this size.

This shift toward coarser particles suggests potential worsening of the paste stability and an even higher requirement for additional fines from the added binder.

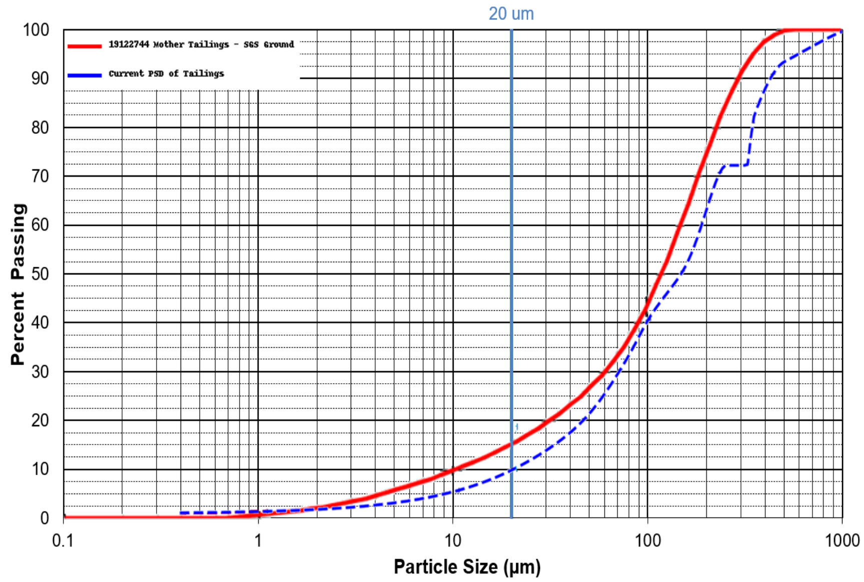

Figure 6 2019 WSP design particle size distribution (PSD) versus current tailings PSD in 2025

3.3 Detailed comparative analysis of operational trends: 7:2 versus 9:1 ground blast furnace slag: cement paste fill recipes

Continuous trend monitoring of the 7:2 and 9:1 GBFS:cement paste fill blends under full-scale operating conditions for one hour provided valuable insight into the interrelationship between binder content and friction factors in the Malanjkhand paste fill plant.

3.3.1 Mixer power behaviour

mixer power draw control is used as a proxy for viscosity control. When paste flowrates are kept at a consistent value, the mixer power draw control is also a proxy for pipeline friction factors and pump pressures. Mixer power remained stable throughout the observation period for both binder ratios, with mean values of 58.5 kW (7:2) and 59.6 kW (9:1). The low standard deviations (2.7 kW and 1.5 kW, respectively) confirm minimal rheological fluctuation during operation. With all other characteristics equal, the slightly higher average power draw for the 9:1 mix design should result in a slightly higher friction factor.

The paste plant production rate was slightly different for the two mix designs and the 7:2 mix recorded a higher average paste flow of 230 m^3/h, compared to 215 m^3/h for the 9:1 mix. Although this difference is minor, it does have an impact on the friction factor in the pipeline and it would be expected that if all other characteristics were equal, the friction factor for the 7:2 mix design should be higher than for the 9:1 mix design.

3.3.2 Pipeline Pressure Trends

Average surface pipeline pressures at the discharge of the paste pump were recorded at 13.1 bar for the 7:2 mix and 14.0 bar for the 9:1 mix, while corresponding underground pressures at the pressure indicating transmitters (PIT) located near the bottom of the surface borehole averaged 17.7 bar and 15.5 bar, respectively. Although there is a slight difference between the pressures recorded using the 7:2 and 9:1 mixes, the differences are minor and essentially the friction factor is the same between the 2 mix designs.

The recorded trends also show that transient fluctuations in pressure and power draw were minor and within expected operational tolerance. These short-term variations can be attributed to small pulsations in paste feed rate or binder dosing adjustments, rather than genuine rheological instability. Therefore, while the instantaneous ΔP values of the 7:2 mix appear higher, they do not represent a significant or sustained increase in friction factor.

3.3.3 Binder Flow and Feed Stability

Binder flow control closely matched design targets. The 7:2 mix delivered higher cement flow (7.1 t/h) corresponding to its formulation, while the 9:1 mix maintained higher GBFS dosing (31.0 t/h). While the GBFS binder control loop tuning appeared to have some greater variability than normal, the large size of the mixer and the homogenising effect of the 5 minute residence time largely buffer out the fluctuations in GBFS addition.

These operational findings validate the laboratory results, showing that binder optimisation (7:2 versus 9:1) influences friction factors only slightly. This insight provides a sound basis for selecting mix proportions based on cost efficiency and targeted fill cycle requirements. Results are shown in Table 1 and Figures 7 and 8.

Table 1 Summary of key operational metrics (average over 1 hour)

Metric	Average (7:2)	Minimum (7:2)	Maximum (7:2)	Standard deviation (7:2)	Average (9:1)	Min (9:1)	Max (9:1)	Standard deviation (9:1)
Mixer power (kW)	58.51	52.20	64.40	2.69	59.57	55.40	65.40	1.50
Surface pressure (bar)	13.14	4.42	21.74	2.64	14.02	5.46	21.99	2.39
Underground pressure (bar)	17.66	12.02	20.46	1.96	15.54	14.02	16.74	0.65
GBFS flow (t/h)	25.82	8.97	60.17	6.51	31.03	6.26	62.97	7.08
Cement flow (t/h)	7.11	1.57	20.72	2.29	3.37	0.24	32.43	2.29
Total paste flow (m^3/h)	230.79	151.21	281.89	14.99	214.80	144.36	284.66	14.65

GBFS = ground blast furnace slag

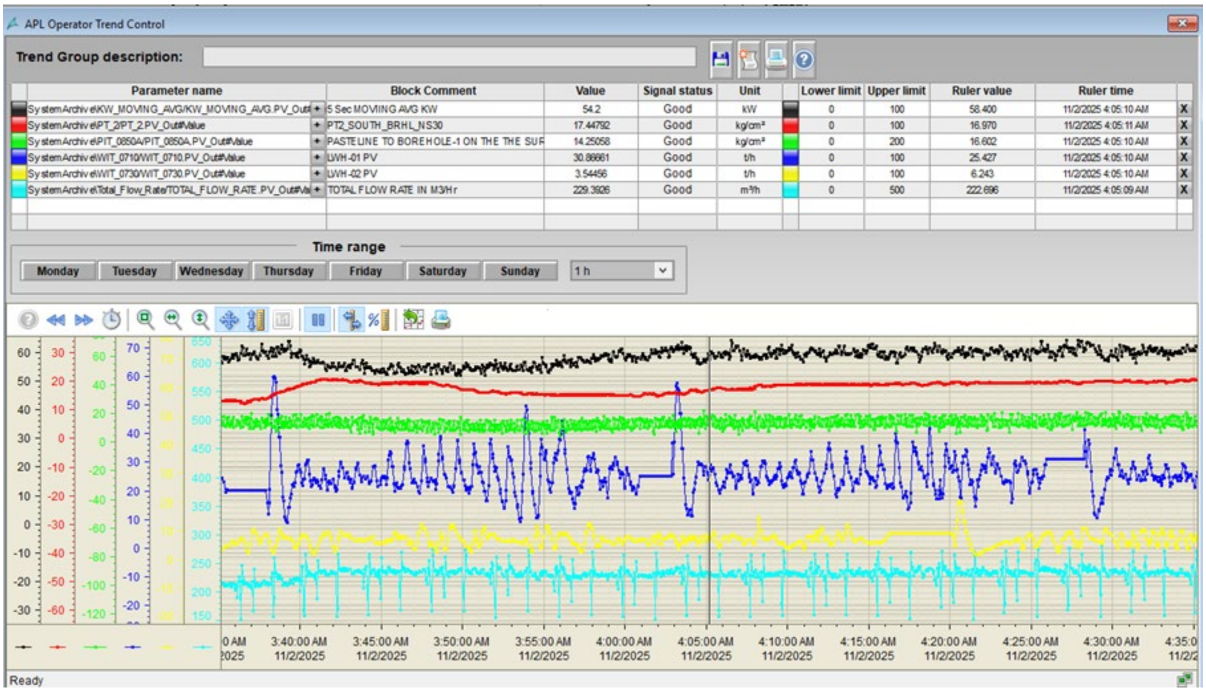

Figure 7 Trends of 7:2 ratio operation (mixer power = black, pressures = red/green, binder = blue/yellow)

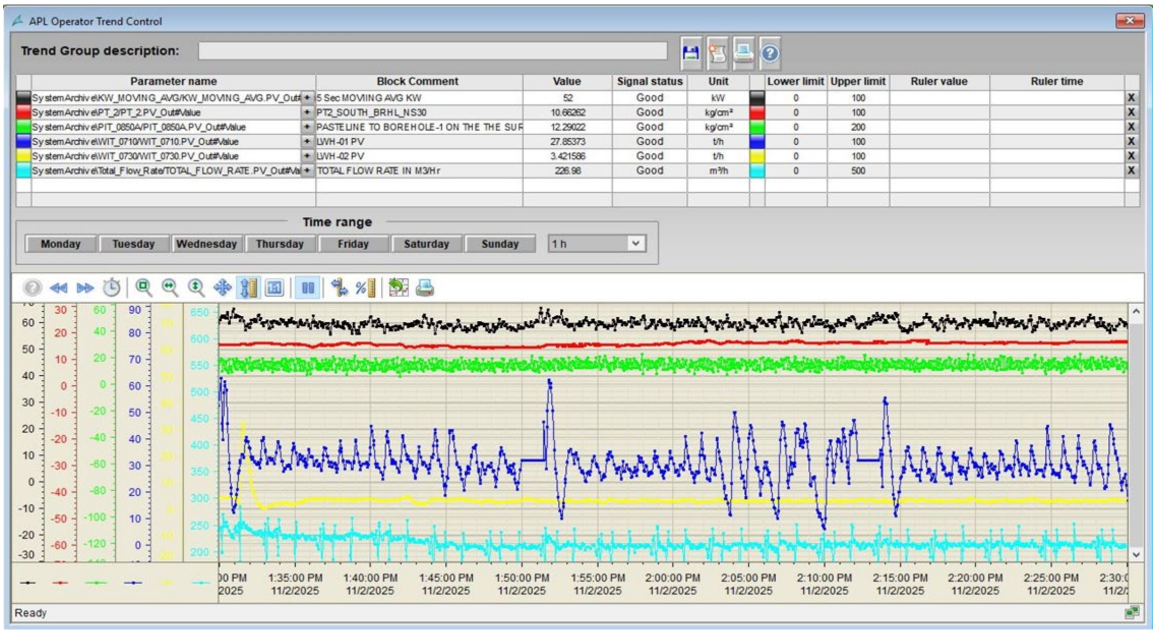

Figure 8 Trends of 9:1 ratio operation (mixer power = black, pressures = red/green, binder = blue/yellow)

3.4 Binder selection trials

To confirm that the optimised mix design would meet the strength targets, testing of the 7:2 mix design was conducted. Cylindrical samples were prepared with 91% tailings, 7% GBFS, and 2% cement, corresponding to 9% total binder addition. This modified binder ratio of ~7% GBFS and ~2% cement was chosen to evaluate whether increased cement dosage would enhance early strength development while slightly reducing overall binder consumption compared to the design mix.

3.4.1 Sample preparation and curing

Cylindrical samples were prepared with a tailings and binder ratio of: 91:7:2

Samples were cast into standard test cylinders and cured underground near filled stopes to replicate environmental conditions.

3.4.2 Testing program

Tests were performed on the samples including:

- Slump test: measured workability for pipeline transport
- Density test: determined bulk density of fresh mixes
- UCS: measured at 7, 14, and 28 days using standard testing procedures.

3.4.3 Water bleed results

The water bleed testing was conducted in the Malanjkhand paste fill laboratory to evaluate the drainage and stability characteristics of tailings and paste mixtures under static conditions. The study included 2 uncemented tailings samples, 2 paste samples with an optimised 7:2 GBFS:cement binder ratio, and one paste sample with a designed 9:1 GBFS:cement ratio. All mixtures were prepared at 79 wt% solids with slump values ranging between 220 and 240 mm. Water separation was monitored at time intervals of 0.5, 1, and 2 hours, and the percentage of bleed water was calculated based on the separated volume of free water over time.

The results, summarised in Table 2 and Figure 9, showed that the tailings-only samples exhibited considerably higher water separation, reaching nearly 10% after 2 hours, indicating low stability and higher drainage potential. In contrast, paste samples with GBFS:cement binders showed significantly lower bleed, remaining below 3.5% at 2 hours. The designed paste mix (9:1 GBFS:Cement) demonstrated early stabilisation and uniform performance, while the optimised mix (7:2 GBFS:Cement) exhibited even better water retention within the first two hours. This improvement is attributed to the increased cement fraction, which enhances early hydration and matrix cohesion.

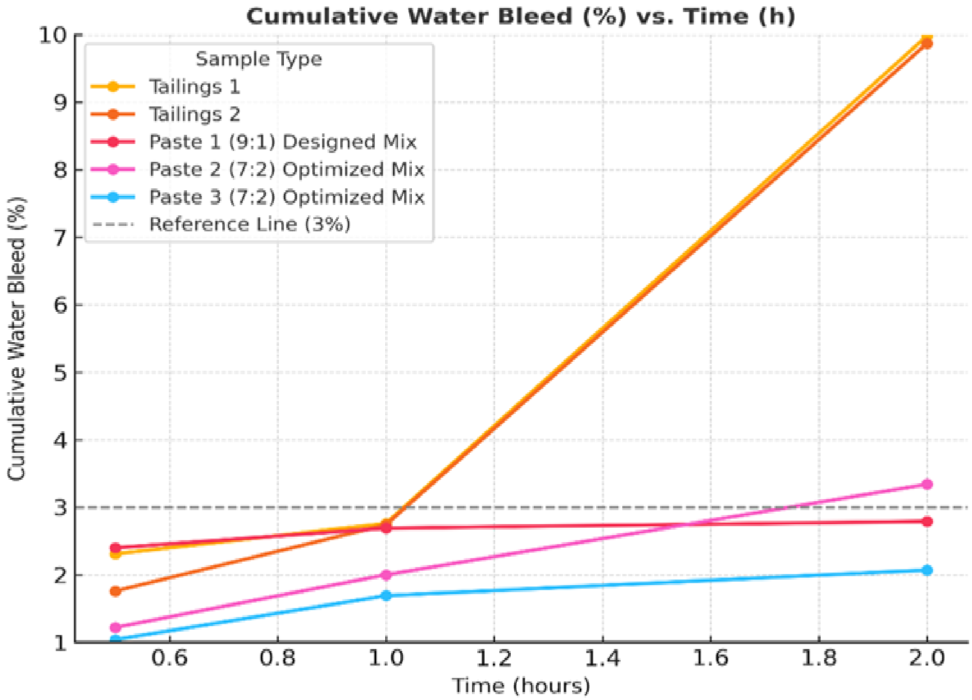

Figure 9 Cumulative water bleed versus time

The cumulative water bleed (%) versus time (h) relationship shown in Figure 9 highlights the distinct difference in drainage behaviour between uncemented tailings and binder-treated pastes. The results confirm that binder addition effectively improves paste stability, reduces free water release, and ensures consistent flow characteristics, making the optimised and designed mixes suitable for reliable underground backfill applications.

Table 2 Water bleed test results

Sample ID	Mix Type	GBFS:cement Ratio	Slump (mm)	% Solids	Water bleed (%) at 0.5 h	1 h	2 h
Tailings 1	Tailings	–	230	79	2.31	2.76	9.98
Tailings 2	Tailings	–	220	79	1.76	2.74	9.87
Paste 1	Designed mix	9:1	240	79	2.40	2.69	2.79
Paste 2	Optimised mix	7:2	230	79	1.22	2.00	3.34
Paste 3	Optimised mix	7:2	230	79	1.04	1.69	2.07

GBFS = ground blast furnace slag

3.4.4 Unconfined compressive strength results

UCS tests were performed on paste samples containing binder (7:2 GBFS:cement) and binder (9:1 GBFS:cement) at curing ages of 7, 14, and 28 days. The results are summarised in Figure 10.

At 7 days, the UCS of the 7:2 mix was 0.78 MPa, slightly higher than the 0.75 MPa recorded for the 9:1 mix, indicating good early strength even with lower binder content. By 14 days, both mixes achieved significant strength gain. The 7:2 mix exhibited UCS values ranging between 0.68–0.96 MPa, while the 9:1 mix ranged between 0.69–0.92 MPa, averaging around 0.85 MPa.

At 28 days, the UCS values reached 1.08 MPa for the 7:2 mix and 1.1 MPa for the 9:1 mix, both exceeding the target of 1 MPa required for underground paste fill stability. These results demonstrate that the 7:2 mix with 9% binder can achieve comparable strength to the 9:1 mix with 10% binder, providing a potential binder optimisation opportunity with reduced cement consumption and cost.

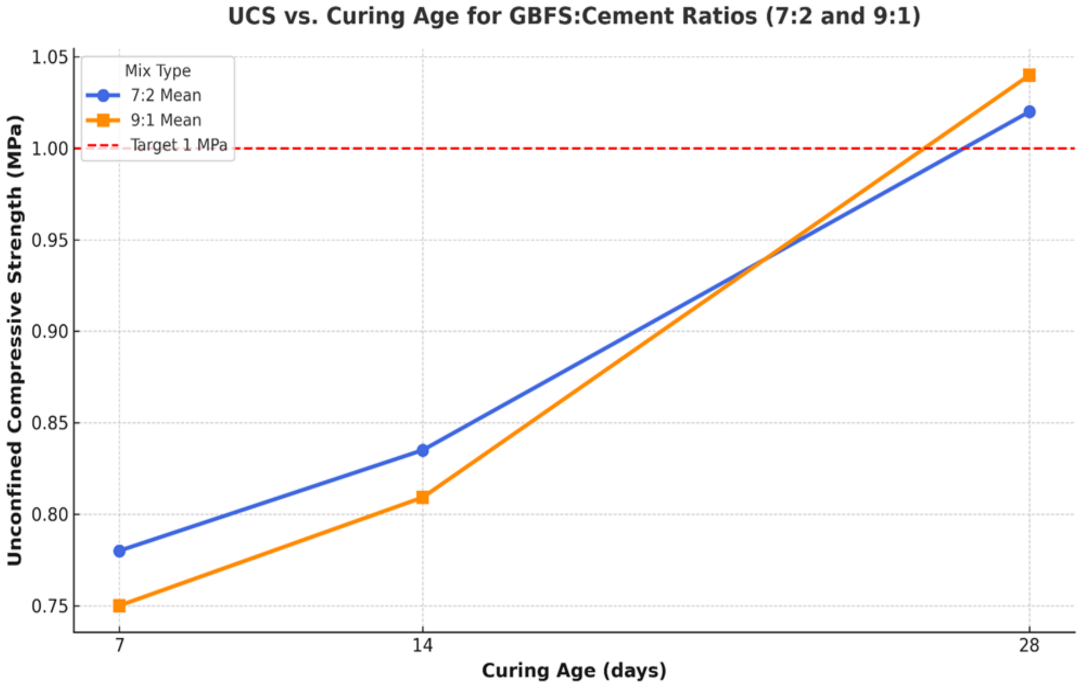

Figure 10 Unconfined compressive strength result versus curing days

3.4.5 Discussion

The study confirms that different mix designs with less binder can be used to achieve the desired outcome of paste stability and strength requirements at HCL's Malanjkhand mine.

PSD results from WSP and NML analyses confirm that the tailings are coarse, with less than 20% of the tailings finer than 20 µm below the optimal threshold for paste stability. The GBFS:cement binder compensates for this deficiency, introducing finer, reactive particles that enhance water retention, reduce permeability, and improve paste strength.

Water bleed testing reinforced this assessment. Uncemented tailings released nearly 10% of their water within 2 hours, indicating moderate drainage and limited stability when left uncemented. In contrast, binder-treated paste samples exhibited substantially lower water bleed, remaining below 3.5% during the same period. The optimised 7:2 GBFS:cement mix demonstrated a much lower early water release in the 0.5 and 1 hour range whereas the 9:1 GBFS:cement mix had a surprisingly high water release in this early period and appeared similar to the tailings alone. This behaviour of the 9:1 sample is considered a discrepancy and the interpretation of the results at the 2 hour period is considered a more accurate representation of the water release characteristics of the different mix designs. The 2 hour period represents a point where there has been minimal removal of free water from the paste matrix due to reaction with the cement and therefore the lack of high quantities of bleed water indicates a limited amount of free water separation from the tailings.

Strength development results further validate the suitability of the 7:2 mix design. Both 9:1 and 7:2 binder ratios achieved ~1 MPa UCS at 28 days, meeting stope stability requirements while reducing binder usage from 10% to 9%. The higher binder demand compared to previous studies (1 MPa at 5% binder) may reflect lower reactivity of the local GBFS and cement used at Malanjkhand.

4 Conclusion

This study demonstrates that Malanjkhand's coarse tailings, though initially deficient in fine material, can be effectively transformed into stable and pumpable paste backfill through an optimised GBFS–cement binder system.

The comparative analysis of PSD data confirmed that the tailings contain less than 20% material finer than 20 µm, indicating a shortage of fines needed for matrix cohesion. The binder, therefore, serves a dual role: providing strength and supplying the additional fine fraction required for paste stability. The testing confirmed that the 7:2 mix design achieved better paste stability with lower water release than the 9:1 mix design.

Both the designed 9:1 and optimised 7:2 GBFS:cement ratios achieved satisfactory strength development (~1 MPa at 28 days), adequate for stope support in sublevel open stoping operations. Although higher binder contents generally increase strength, the study confirms that a moderate reduction in total binder from 10% to 9% does not compromise the strength performance due to the higher proportion of cement versus GBFS. Slightly lower UCS values compared to earlier laboratory results (1 MPa at 5% binder) may reflect differences in GBFS and cement reactivity or particle fineness at Malanjkhand.

Operational trends during commissioning validated these laboratory observations of acceptable paste stability. The optimised 7:2 mix showed similar pipeline pressures. The successful full-scale implementation of this mix confirms that coarse tailings can be safely and economically utilised when binder systems are engineered to increase fines content.

5 References

Betancourt, L, Veenstra, R, Kraft, T & Mensah, E 2024 'Super paste: case study of the use of binder in cemented paste fill to support the role of fines in paste mix designs', *International Symposium on Mining with Backfill*, Canadian Institute of Mining, Metallurgy and Petroleum, Vancouver.