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Improving tailings dewatering with ATA® for paddocked buttress formation: A pilot study

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Abstract

The St. Helena tailings storage facility, operated by Harmony Gold, receives tailings from several Harmony Gold processing plants in the Welkom area of the Free State, South Africa. To improve structural integrity and extend the operational life of the tailings storage facility, a tailings paddock buttressing method is currently being implemented. In this method, the buttress is constructed using deposited tailings in paddocks, with walls typically shaped and placed by an excavator. Whilst this method provides the necessary structural integrity, it is a time and resource intensive method that is limited by the drainage rate of the ultra-fine tailings, equipment availability, and weather conditions.

This paper demonstrates the use of Clean TeQ Water's ATA® rapid dewatering technology as an alternative approach, utilising woven geotextile dewatering bags in combination with the ATA® technology to construct and fill the paddock buttress. ATA® is a three-component system where the tailings stream is separated into fines and coarse fractions utilising a hydro-cyclone. These fractions are treated separately with complementary polymeric reagents and recombined to create anchored particles. These anchored particles enhance dewatering performance by capturing the fines and creating a granular agglomerate structure that promotes improved free drainage and rapid water release. A 9 t/h pilot plant was operated on site, benchmarking the ATA® enhanced paddocking method with the current method. The results from the pilot demonstrated that the use of ATA® offers significant advantages, including higher homogeneity in the buttress, higher permeability, and faster settling rates. The moisture content of the ATA®-treated material is lower and trafficability was achieved at an accelerated rate, reducing turnaround time between lifts and enabling more efficient and safer tailings facility management.

Keywords

polymers, buttressing, permeability, trafficability, phreatic line, direct deposition

Introduction

Stability of tailings storage facilities (TSF) has become a significant focus following disastrous tailings dam failures worldwide. To manage mining facilities responsibly, there is much emphasis on the urgent need for improved safety standards and measures to control and reduce risks of failure. TSFs often require stability interventions. For a TSF with low stability or uncontrolled seepage, one such stabilisation method is through the construction of a buttress against the existing side slopes. A buttressing solution can increase slope stability, improve the safety factor, and prevent catastrophic failures, therefore improving against a number of the key guidelines prescribed in the Global Industry Standard on Tailings Management (GISTM) (ICMM, 2020). Buttressing involves one basic principle: To provide sufficient dead weight near the toe of a slope to prevent movement, thereby increasing the resisting force and increasing stability (Crous, Jacobsz, 2023).

Harmony Gold's St. Helena Mine currently operates a surface retreatment operation. The site reprocesses gold-bearing tailings and waste rock from the Free State region in South Africa. The site continues to operate an active TSF to manage the tailings produced in the retreatment operation. To improve structural integrity and extend the operational life of the TSF, St Helena has implemented a tailings paddock buttressing method. In this method the buttress is constructed using deposited tailings in paddocks, with walls typically shaped and placed by an excavator (upstream construction). The construction material and method of constructing the buttress play a major role in the geotechnical properties of the buttress and its stability. Properties such as particle size, density, moisture content, permeability, and homogeneity of the placed material influence how well the material will drain and how it behaves under stress, affecting the dam's overall stability.

Using the same deposition technique as within the dam to form the buttress is considered acceptable, provided it has the required geotechnical properties to support the dam and significantly improve the slope stability. Constructing stable embankments that have the required geotechnical properties is dependent on material quality and method of deposition. These properties should be present within the buttress to ensure its own stability and to provide support and drainage to improve the dam's embankment stability.

Clean TeQ Water's ATA® rapid dewatering technology, a concept that uses novel dual polymer conditioning, can be used to improve the geotechnical properties of the TSF by enabling the placement of homogeneous, high strength conditioned tailings (Spagnuolo et al., 2024) within the paddock buttress with increased permeability, allowing for an advanced dewatering rate, resulting in a lower phreatic surface within the TSF itself.

During the ATA® process, the tailings stream is split into fine and coarse fractions, using a hydrocyclone. The fine and coarse fractions are then treated separately with a pair of complementary polymeric reagents. The fines stream is treated with an activator polymer, while the coarse stream is treated with a tether polymer, creating anchor particles. When the activated fines are combined with the tethered coarse material (anchors), the fine particles are attracted to the anchors, form large agglomerates, and rapidly settle. This process is illustrated in Figure 1. The agglomerate network has a rigid, open structure that rapidly dewaters through a porous medium such as a screen, woven geotextile, or filter. Due to the attractive forces between the fine and coarse particles, low turbidity water is released, and fines capture (and recapture) can be dramatically improved. The deposited material is therefore a homogeneous rigid, open structure material with attractive forces between the fine and coarse particles that could provide an increase in the long-term stability of the tailings buttress.

Objective of the study

This paper demonstrates the application of Clean TeQ Water's ATA® rapid dewatering technology as an alternative to the conventional paddock buttressing method. The study included operation of a 9 t/h ATA® pilot plant on site, along with tests aimed at characterising the hydraulic and geotechnical properties of materials produced, using both methods in order to compare them.

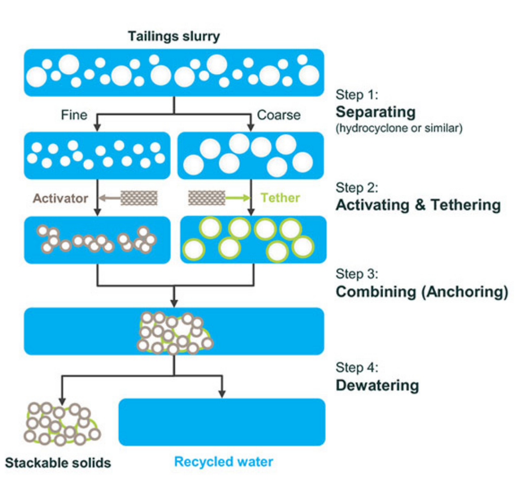

Figure 1—Schematic of the ATA® process

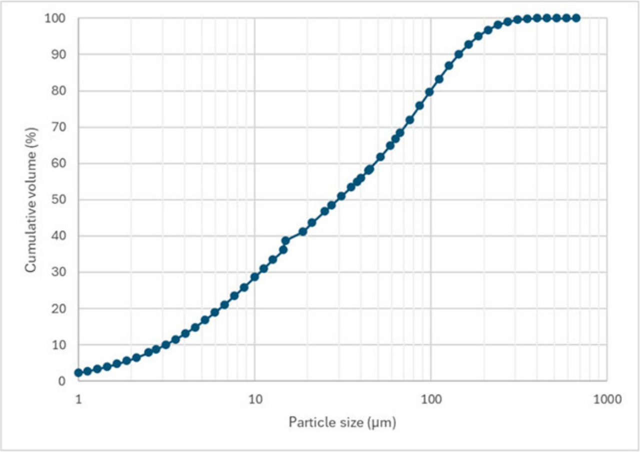

Figure 2—Particle size distribution data for the St. Helena tailings material

Experimental procedures

Materials

Polymeric reagents

The ATA® activator and tether reagents are proprietary polymers received in a fully desaturated powder form. The polymers were dissolved at 0.2% w/w in return water from the tailings facility. Polymer dosages were optimised based on visual observation of agglomerate formation and settling behaviour.

St. Helena tailings material

The St. Helena TSF is fed with the full plant tailings at a solids flow rate ranging from 700 t/h to 800 t/h with a density ranging between 1.3 kg/m^3 and 1.45 kg/m^3. The particle size distribution (PSD) of the tailings material is shown in Figure 2. The material is relatively fine, with a P80 of 100 µm.

Conventional buttressing

The conventional buttressing method entails the construction of paddocks at the toe of the dam's embankments. Using material from within the buttress, paddock walls are constructed and shaped with an excavator throughout the buttressing process when walls need to be raised. The paddocks are then filled with tailings slurry at roughly 21 t/h to obtain 300 mm layers through a subaerial deposition technique, as illustrated in Figure 3. The filling of the paddocks is done by a spigotting technique, discharging tailings through small pipes (spigots) from multiple points at regular intervals along the outer wall of the paddock (Lighthall, 1989). While filling, a beach is formed, where the coarsest fraction deposits close to the discharge points and the finer fraction deposits progressively further away from the discharge points, allowing water to be drained via the penstock drains (Vick, 1990). Each 300 mm layer is given sufficient time to drain and dry out before the next layer is placed. This layer-by-layer process ensures that the placed material reaches sufficient strength and trafficability for the excavator to move across the placed material in order to construct the walls for the next lift.

On-site ATA® treatment and deposition

Figure 4 shows a schematic of the St. Helena pilot plant while Table 1 shows a summary of the average operating conditions, with conditions varying depending on the output from site and the position of deposition in the main TSF.

A bleed stream from the full feed to the TSF was redirected to a hydrocyclone at around 9.8 t/h, to be split into fine and coarse

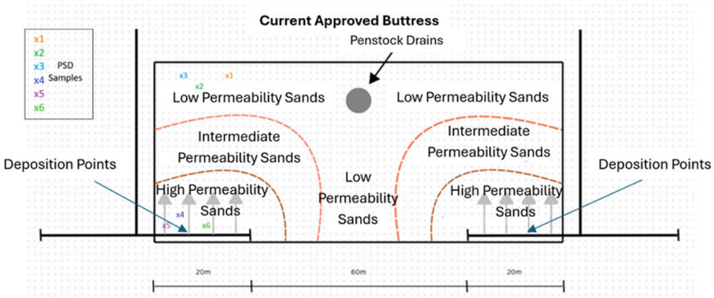

Figure 3—Conventional buttress layout

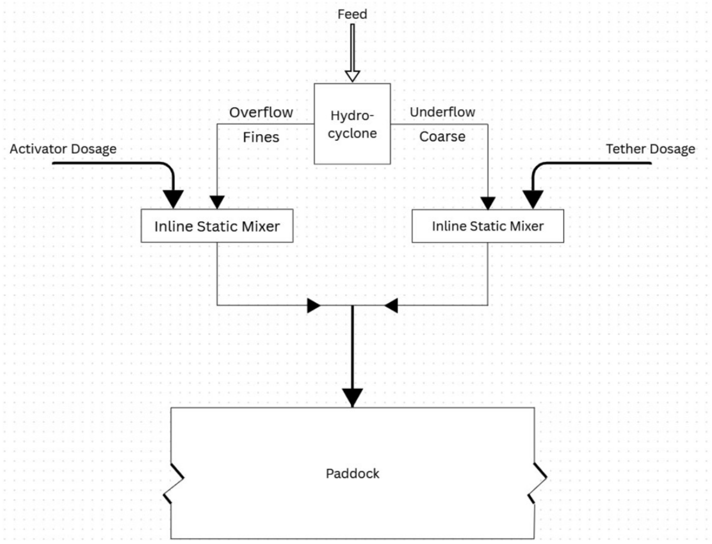

Figure 4—Block flow diagram of ATA® system on site

Table 1

Average operating conditions of the St. Helena pilot plant

Process condition	Units	Value
Feed solids flow rate	t/h	9.8
Overflow solids flow rate	t/h	6.0
Underflow solids flow rate	t/h	3.8
Coarse to fines ratio (CFR)	-	0.6
Activator dosage	g/t	470
Tether dosage	g/t	300

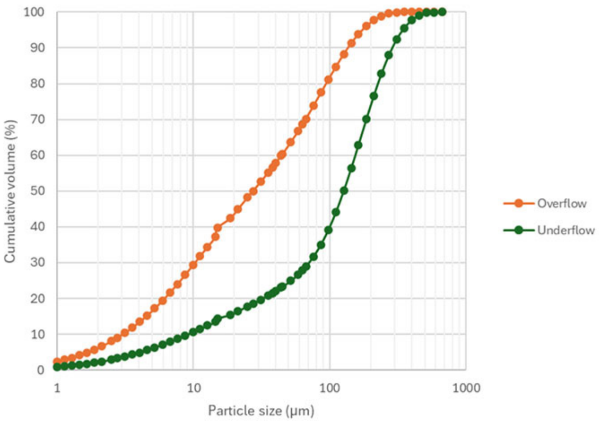

Figure 5—Particle size distribution of the cyclone overflow and underflow

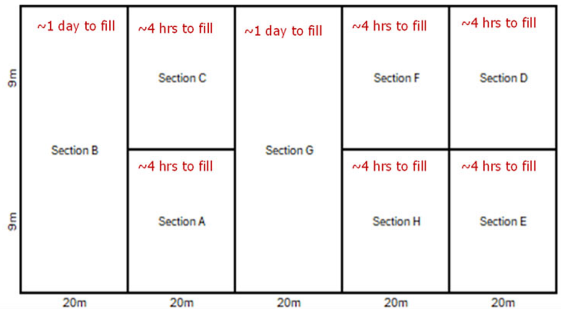

Figure 6—ATA® buttress divided into eight sections

streams. The fine stream (cyclone overflow), with a flow of 6 t/h, was treated with the activator polymer in an inline mixer, and the coarse stream (cyclone underflow), with a flow of 3.8 t/h, was treated with the tether polymer in another inline mixer. Thereafter, the two streams were re-combined into a single pipe and deposited into the paddocks that form the buttress. The average PSD of the cyclone overflow and underflow can be seen in Figure 5.

The ATA® paddock was divided into eight different sections using woven geotextile bags, filled with ATA® treated material. This was done to accommodate the reduced capacity of the ATA® pilot plant (9.8 t/h) compared to the fill rate of the conventional buttress (21 t/h). The different sections can be seen in Figure 6. For simplicity and brevity, the paper will focus on the results from Sections A, B, and E.

Sampling and analysis

The following tests were conducted on the samples collected from the different sections of the ATA buttress, as illustrated in Figure 6, in order to compare these properties to the samples collected from the conventional buttresses:

- Moisture content (SANS 3001-GR20:2010) (*Civil Engineering Test methods. part GR20, determination of the moisture content by oven-drying*, 2010)
- Turbidity (ISO 7027-1:2016) (*Water quality — Determination of turbidity — Part 1: Quantitative methods*, 2021)
- Particle size distribution (SANS 3001-GR1:2013) *(Civil Engineering Test methods. part GR1, wet preparation and particle size analysis, 2013)*
- Permeability (K.H. Head Method) (Head, Epps, 2011)

Moisture analysis

The samples were taken at varying timeframes after deposition and weighed immediately after collection to prevent any loss of moisture. The moisture content of each collected sample was measured by the gravimetric method, utilising oven drying at 110 ˚C for six hours.

Turbidity analysis

Slurry samples from the conventional buttressing method and ATA® treated method were collected in 20 L buckets at the deposition point. The samples were allowed to settle, and supernatant turbidity was measured at timed intervals. This provides an indication of the difference in settling velocity between the two buttressing methods. Supernatant water was sampled from each bucket and tested for turbidity using a Hanna HI98703 turbidity meter.

Particle size distribution (PSD)

Dried samples were screened to determine the PSD of the samples across the paddocks. Screen sizes of 75 µm, 106 µm, 150 µm, and 425 µm were used for the PSD analysis.

Permeability

Hydraulic conductivity, also known as soil permeability, measures how easily water can flow through the soil's pore spaces. This property is expressed by the permeability coefficient (k). The permeability tests were conducted using the triaxial permeability method (Head, Epps, 2011). This method is performed under a constant hydraulic gradient, utilising automated pressure controllers to regulate confining, inlet, and outlet pressures and to monitor volume changes.

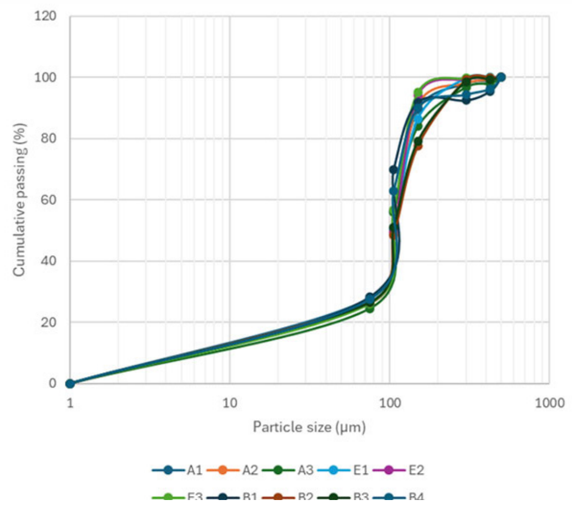

Figure 7—PSD of the three ATA® sections at different sampling points

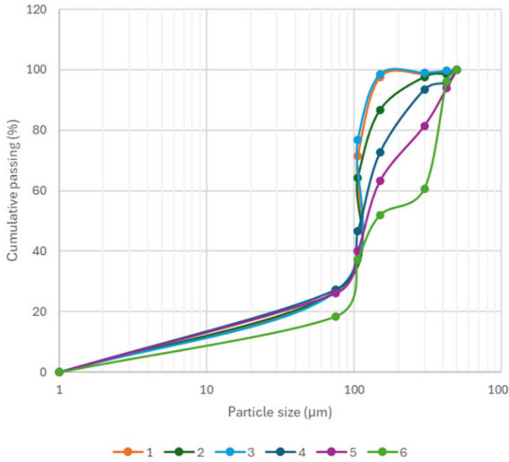

Figure 8—PSD of six different sampling points in the conventional buttress

Results and discussion

PSD homogeneity throughout the buttresses

Upon deposition of the conventional buttress, natural segregation of the coarse and fines material was observed from the deposition point to the drainage point in the buttress. To confirm this, PSD analyses were conducted on both the ATA® buttress and the conventional buttress. Figure 7 shows the PSDs for the three selected ATA® sections.

As seen in Figure 7, the PSD of the three ATA® sections are similar across the different sampling points. This shows homogeneity throughout the ATA® buttress and confirms the strength of particle-particle interaction between the fine and coarse material.

Figure 8 shows the PSD at six different sampling points in the conventional buttress, where sampling points 1 – 3 are further from deposition and sampling points 4 – 6 are closer to the deposition point.

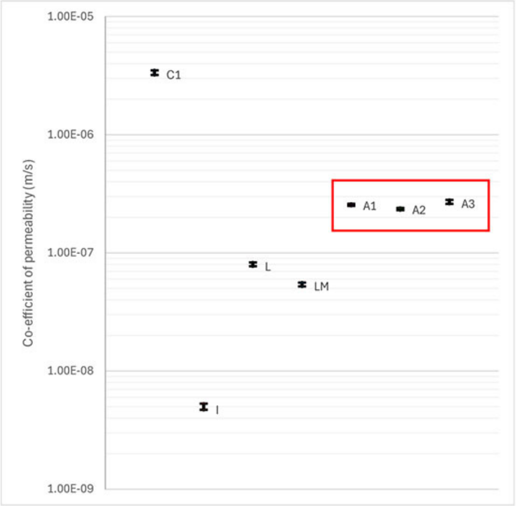

Figure 9—Permeability coefficient after deposition

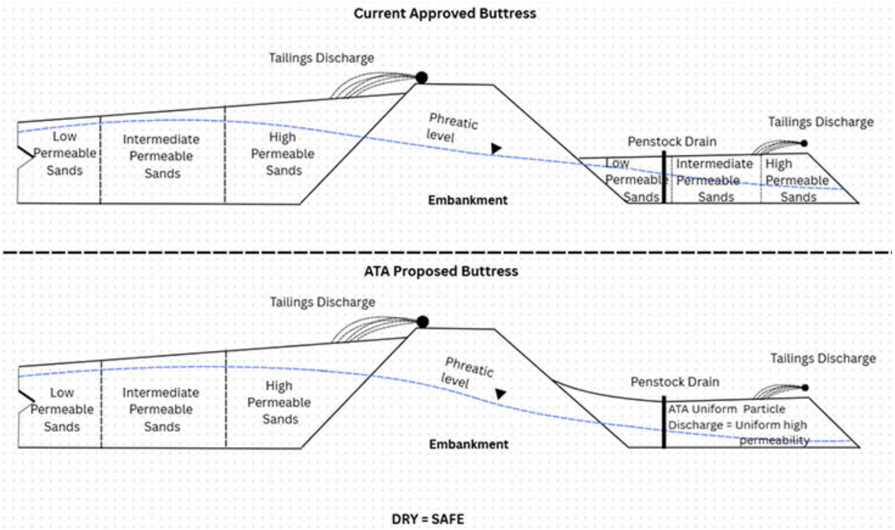

Figure 10—Difference between ATA® and conventional buttressing expected phreatic lines due to permeability differences

Figure 8 demonstrates a significant difference in PSDs between six different sampling points in the conventional buttress (see Figure 3). Coarser material was found in the area closest to the deposition point and finer material was found in the area sampled further away from the deposition point, as expected (see Figure 3). This shows that there are areas within the conventional buttress with relatively coarser PSDs and areas with relatively finer PSDs. Undisturbed samples from these different areas were used to test for a permeability difference between these areas, as low permeability areas within the buttress will reduce its ability to drain moisture and, therefore, its ability to support the dam efficiently.

Permeability of buttresses after deposition

As mentioned, undisturbed samples were taken for permeability testing from three areas in Section A of the ATA® buttress and from four areas in the conventional buttress, as shown in Error! Reference source not found. With reference to Figure 3, C1 refers to samples taken from the high permeability sands area, I refers to samples taken from the intermediate permeability sands area, L refers to samples taken from the low permeability sands area, and LM refers to samples taken from the low permeability sands area near the penstock drain.

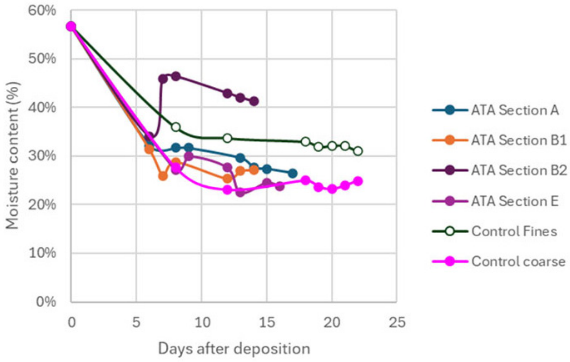

Figure 11—Moisture content over time after deposition in the buttress

All ATA® samples exhibited higher permeability coefficients than the conventional buttress samples, with the exception of the coarse sample from the conventional buttress taken closest to the deposition point. This sample exhibits the highest permeability coefficient. The ATA® buttress samples exhibited consistency in permeability coefficients, which is indicative of the homogenous and granular nature of the ATA®-conditioned material across the entire buttress.

The conventional buttress samples show decreasing permeability coefficients with increasing distance from the deposition point. This, together with the PSD results, further indicates the occurrence of natural segregation within the buttress, with evident areas of high permeability sands (coarser PSD in Figure 8), areas of intermediate permeability sands, and areas of low permeability sands (Finer PSD in Figure 8). Low permeability areas within the buttress reduces its ability to drain water and therefore its ability to lower the dam's phreatic line. Additional constructed drainage may be required in areas of low permeability in the conventional buttress; however, implementation of ATA could potentially eliminate the need for this supplementary drainage. Future monitoring studies of the phreatic surface are also recommended to verify the conceptual illustration presented in Figure 9.

Moisture content

Samples for moisture content analyses were taken periodically from the three sections in the ATA® buttress and compared to samples taken from the areas of coarse material and areas of fine material in the conventional buttress, as shown in Figure 4.

Figure 11 shows that ATA® Section A performed better than the fines area of the conventional buttress and is trending toward moisture results recorded for the coarse area of the conventional buttress. ATA® Section E achieved a lower moisture content than the fines area of the conventional buttress and reached the same moisture level as the coarse section of the conventional buttress after 13 days. The significant difference in moisture content between the control coarse and control fines in the conventional buttress further indicates that there is natural segregation of material occurring within the buttress, as the zones with coarser material drained more rapidly than those with the finer material.

Table 2

Comparison of turbidity of supernatant after different settling durations for ATA and conventional deposition

Treatment method	Turbidity (NTU)				
	30 seconds	60 seconds	120 seconds	900 seconds	1200 seconds
ATA®	5.23	5.12	4.06	NM	NM
conventional	Too high to measure	Too high to measure	Too high to measure	Too high to measure	228

NM = not measured


Figure 12—The ATA® buttress could support a vehicle being driven onto and off the buttress 13 days after deposition

ATA® Section B was divided into two different categories. The samples of Section B1 were taken close to the outer wall of the buttress, away from the penstock drain. Section B2 samples were taken adjacent to the geotextile bags used for sectioning the ATA® buttress, closer to the penstock drain. There is an unusual spike in the moisture content in Section B2 due to water that is unable to drain through the geotextile bags used in this section of the paddock. The water that drained from Section B1 accumulated in Section B2. This indicates that the geotextile bags restricted drainage within the buttress and may not be suitable for this method of buttress construction at full-scale.

Trafficability was achieved after 13 days throughout the entire ATA® buttress (as seen in Figure 12) whereas, after the same duration, the fines area of the conventional buttress was still saturated and not trafficable. This demonstrates that the next layer of deposition can be placed sooner when ATA®-conditioning is used, compared to the current conventional buttressing method.

Turbidity

The turbidity of the supernatant water after varying settling durations is shown in Table 2. The supernatant turbidity of the ATA®-conditioned material was significantly lower than that of the conventional buttress material taken at the deposition point. Samples taken from the conventional buttress that were allowed to settle for up to 900 seconds were found to have excessive suspended solids, preventing measurement of the turbidity. This confirms that ATA® treatment's rapid fines capture, re-capture, and settling rate are far greater when compared to the conventional buttress. This rapid settling resulted in cleaner and faster water drainage and improved water recovery, which could be returned to the site's water circuit.

Conclusion

The results from this study show that ATA® leads to a more homogenous and potentially geotechnically stable buttress, compared to the conventional buttressing method. ATA®-treated material settles faster, without segregation. The agglomerate structure formed is more permeable and allows for faster dewatering, leading to the buttress being trafficable sooner. Due to the decrease in segregation of ATA®-treated material, zones of low permeability were not observed. This results in more uniform drainage behaviour across the structure. This, in turn, lowers the phreatic line in the buttress, reduces moisture accumulation in the TSF wall, and enhances overall slope stability. Additionally, the rapid fines capture and accelerated dewatering achieved with ATA® improve water recovery efficiency, providing potential operational and environmental benefits through reduced water losses and shorter deposition cycles. Overall, ATA® conditioning results in a more consistent, rapidly dewatering and trafficable buttress, leading to increased TSF strength, improved operational efficiency, and safer tailings management.

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