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ATA® treated tailings for underground backfill: a Harmony Gold case study

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Abstract

Harmony Gold's Kusasalethu mine is a deep-level underground gold mine located 90 km west of Johannesburg, South Africa. Kusasalethu utilises woven geotextile contained backfill for underground support. The operation currently requires tailings to be classified and densified with a hydrocyclone, with only hydrocyclone underflow utilised for backfill.

This paper demonstrates how the full tailings stream can be used as backfill via the ATA® rapid dewatering technology. ATA is a three-component system in which the fines and coarse fractions of a split tailings stream are each treated with complementary polymeric reagents and recombined to create anchored particles that capture fine particles whilst increasing dewatering rate.

A pilot test was conducted at Kusasalethu in 2023, treating 25 tph of tailings with ATA and dewatered in 1 m^3 geotextile bags, simulating underground containment. Dewatered and contained solids were subjected to compression testing to confirm the maximum load carried at incremental displacement, simulating backfill compression by a hanging wall. The load-bearing capacity at a given displacement was markedly better compared to classified backfill.

Supplementary lab-scale ATA tests were conducted to confirm the geotechnical properties of ATA treated gold tailings from an Australian operation compared to tailings treated with conventional flocculation. Results from this study showed that ATA treated tailings produced materially higher hydraulic conductivities at a given solids concentration compared to conventional flocculation. This study also showed that fines capture and released water clarity was markedly improved in ATA treatment compared to conventional flocculation. Shear yield stresses and dewatering rate after ATA treatment were significantly increased over untreated material, reflecting development of an open, inter-particle structure.

The use of ATA for backfill enables incorporation of fine tailings underground. This lessens the load on existing wet tailings storage facilities whilst also producing higher stability backfill with an increased dewatering rate.

Keywords*:* *backfill, polymer treated backfill, geotechnical properties, geotextile dewatering, flocculation, new technologies, case studies*

1 Introduction

1.1 ATA introduction

Dewatering of fine tailings is a complex challenge and the problem is rapidly growing as increasing tonnages are processed at finer grind sizes, and more operations are moving towards stackable tailings. ATA® offers a novel approach by separately treating coarse and fine fractions (produced using conventional technology such as hydrocyclones, or already existing in an operation) with pairs of complementary polymeric reagents (see, for example, Berg et al. 2013). The fine stream is treated with an activator, while the coarse stream is treated with a tether, creating anchor particles, hence ATA (Figure 1). 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. The agglomerate network has a rigid, open structure that rapidly dewaters through a porous medium such as a screen, geotextile, or filter. Due to the attractive forces between the fine and coarse particles, exceptionally low turbidity water is released and fines capture (and recapture) can be dramatically improved compared to conventional flocculation with a single reagent.

ATA has been demonstrated at laboratory scale on tailings from a wide variety of commodities including gold, copper, diamond, phosphate, iron ore and mineral sands, and piloted on diamond, gold and phosphate tailings. The aims of this work were to quantify the observed properties and benchmark performance relative to conventional flocculation, to correlate the laboratory and pilot-scale behaviour, and to demonstrate the benefits of ATA in a specific application (underground backfill of gold tailings in geotextile bags).

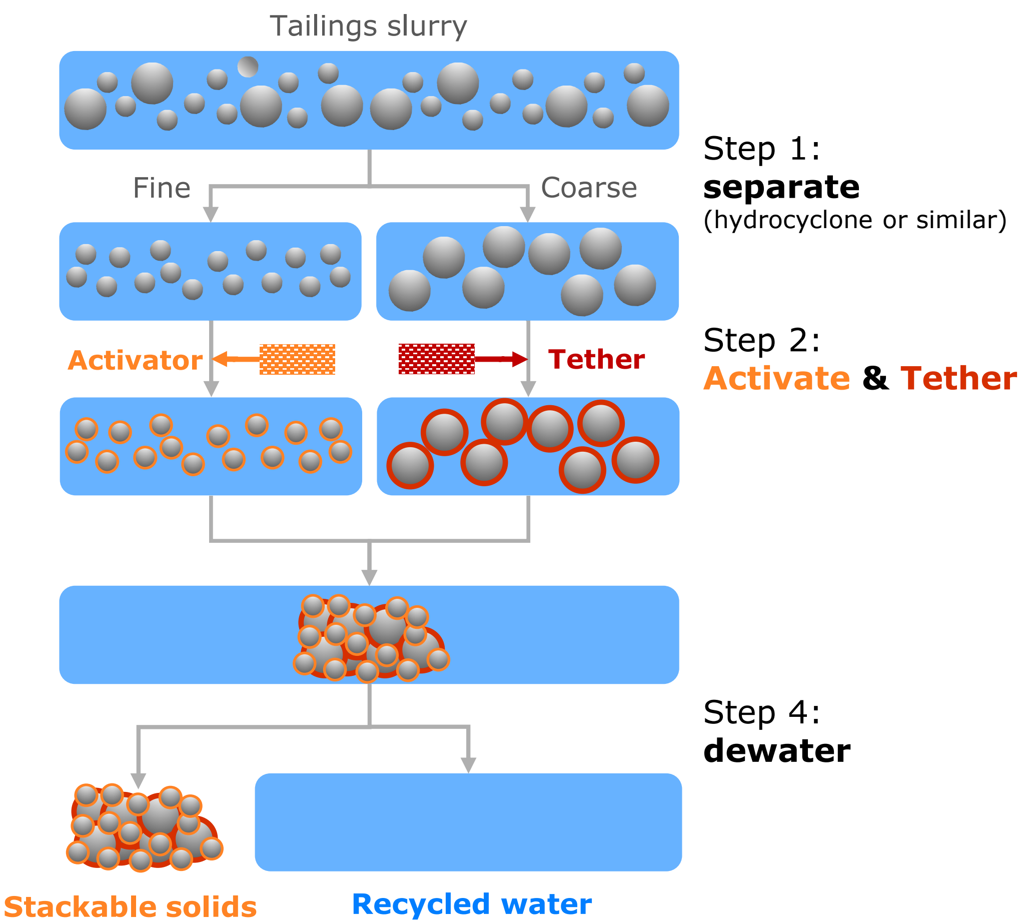


Figure 1 Schematic of ATA process

1.2 Overview of current backfill at Harmony Gold

Harmony Gold's Kusasalethu mine is a deep-level underground gold mine located 90 km west of Johannesburg, South Africa. Mining infrastructure consists of twin vertical and twin sub-vertical shaft systems. Mining at Kusasalethu is conducted using a sequential grid layout, with current mining depth at 3.3 km below surface.

Typically, underground backfill is required to be self-supporting, with the key requirement being that the backfill has sufficient shear strength to support its own weight. This requirement is applicable for cemented backfill, where backfill placement occurs in large excavations.

At Kusasalethu, underground stopes are in the order of 1 to 1.4 m high and typically 35 m in length. Mining occurs at deep-level, in excess of 3 km below surface. These narrow excavations mean that the self-supporting weight of backfill is negligible in comparison to the stress imposed by the narrow excavations at deep-level (Fourie et al. 1994). In the case of these deep-level and narrow stopes, backfill experiences confined compression and therefore compressibility and its relationship to shear strength is the overriding concern.

Backfill at Kusasalethu involves the pumping of a classified backfill slurry into a large geotextile bag, allowing the slurry to be retained and dewatered, as illustrated in Figure 2. Dewatering and consolidation of the slurry allows the backfill to become self-supporting before subsequent blasting can occur.

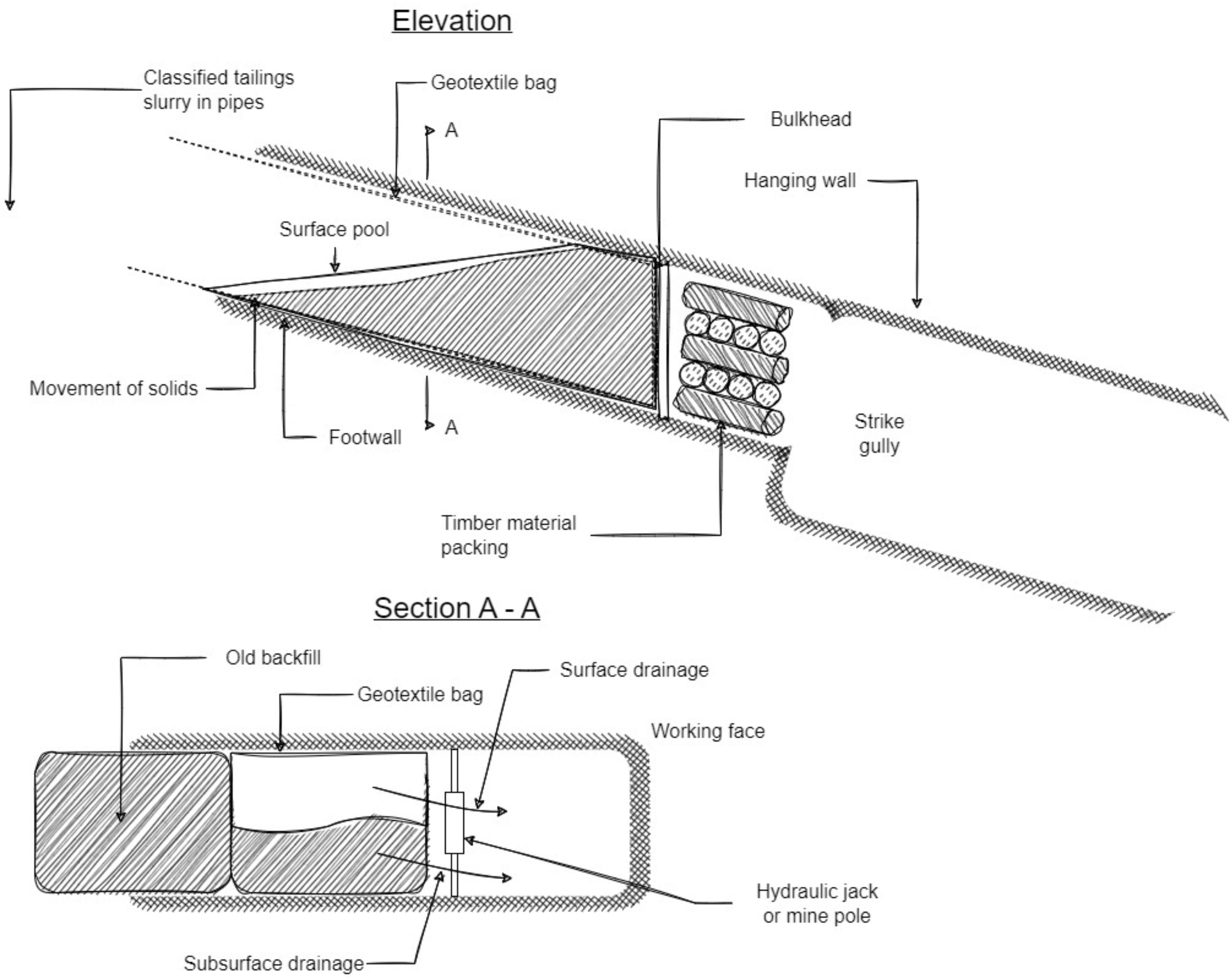


Figure 2 Schematic of current backfill operation (paddock width range 1.6–4.0 m; paddock length up to 30 m; stope width range 0.8–1.6 m)

Backfill preparation at Kusasalethu involves classification of tailings using hydrocyclones. The hydroyclone underflow is densified to a relative density (RD) of 1.7 and stored in surface tanks before being pumped underground. This classification process ensures that the backfill slurry pumped into the geotextile bags contains minimal fines. The presence of fines within the backfill slurry limits the hydraulic permeability of the backfill which in turn reduces the ability of backfill to become self-supporting within the required 24-hour period. Backfill that has not been sufficiently dewatered within the geotextile bag is referred to as unconsolidated backfill. When blasting of a nearby stope face occurs whilst backfill remains unconsolidated, backfill may liquefy, creating hazardous conditions. Furthermore, under current conditions, the presence of fines in the backfill may lead to solids losses through the geotextile when slurry placement occurs. This leads to mud accumulation in the working areas of the stope, blocking drains and creating further hazardous working conditions.

The particle size distribution (PSD) of current plant tailings at Kusasalethu has become less coarse over time, with the introduction of a blend of run of mine and re-mined tailings as feed to the process plant. This has resulted in declining backfill quality. It was therefore recommended that the utilisation of full plant tailings (i.e. unclassified tailings) be investigated as an alternative.

1.3 Objective of the study

The variables that affect the application of ATA to a given tailings include the chemistry and dosages of the ATA reagents, the PSD, RD of the coarse and fine streams, and the coarse to fine mass ratio (CFR). The aim of this study was first to develop a quantitative and reproducible assessment method to support the findings of the pilot-scale testing, by measuring rheological and hydraulic properties at laboratory scale, and benchmark the performance of ATA against conventional flocculation with anionic polyacrylamide (PAM). The laboratory scale study was conducted on gold tailings from a large porphyry copper gold deposit in New South Wales, Australia. The Harmony Gold Kusasalethu pilot test was run concurrently with the laboratory scale study. The outcomes of the laboratory scale rheological study allowed for interpretation of the results achieved during the pilot, enabling an assessment of the ATA performance and backfill quality produced during the pilot.

2 Experimental procedures

2.1 Materials

2.1.1 Polymeric reagents

The ATA activator and tether reagents are proprietary polymers. Solid polymers were dissolved at 0.2% w/w in deionised water while solution polymers were diluted to 0.2% w/w with deionised water. Dosages were optimised based on visual observation of agglomerate formation and settling behaviour.

2.1.2 Australian gold tailings

The samples (cyclone overflow and cyclone underflow) were received after filtering and drying. The retained filtrate (process water) was also shipped and was used to reconstitute the tailings. Upon receipt, the solid and water samples were subject to initial characterisation as presented in Table 1. Note that the solid specific gravity was determined only on a mix of the coarse and fine particles at the design CFR of 0.583. A check of the dissolved solids level in the cyclone overflow process water indicated a low level of 0.29% w/w. As this level was low, it was not deemed necessary to undertake corrections to oven dried solids concentration measurements quoted within this paper. PSDs of the components and mix shown in Figure 3 were measured by laser diffraction using a Malvern Mastersizer 3000.

Table 1 As-received sample properties (Australian gold tailings)

Sample	As-received concentration (% w/w)	Process water conductivity (mS/cm)	Process water pH	0.583 CFR mixture solids specific gravity
Fines (cyclone overflow)	99.7	3.44	7.7	2.833
Coarse (cyclone underflow)	99.8	3.15	7.8	

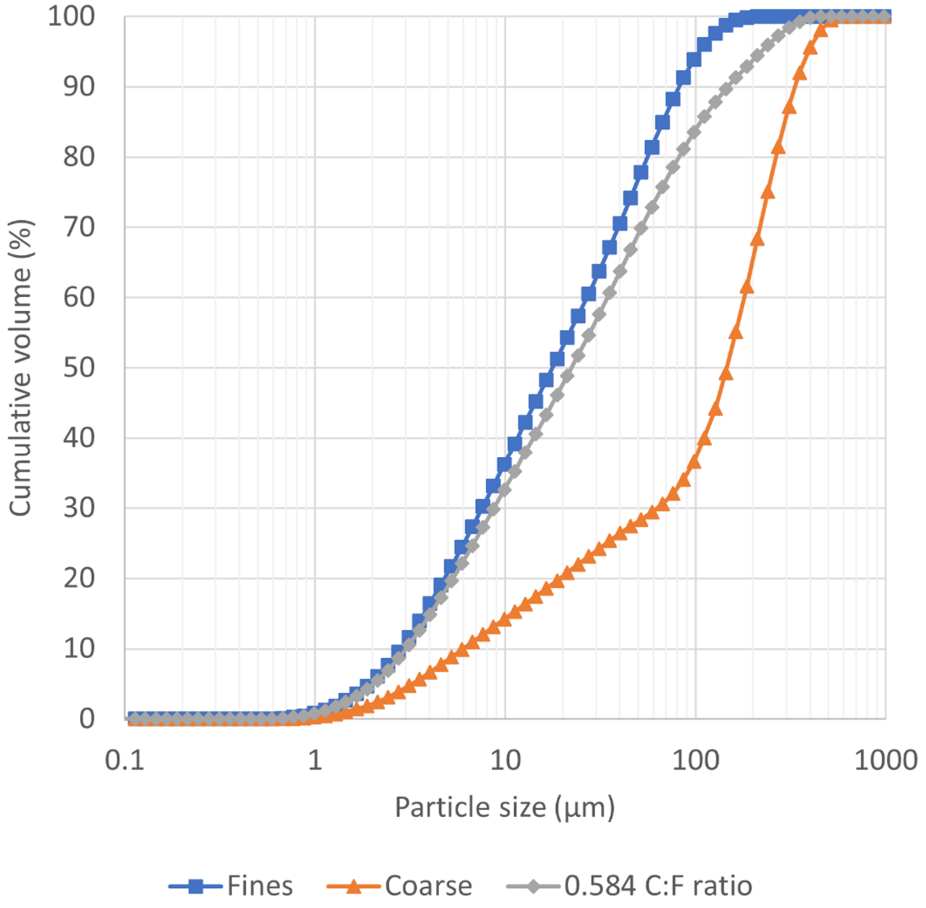


Figure 3 Particle size distribution data for the fines, coarse and 0.583 CFR mixture (Australian gold tailings)

2.1.3 South African gold tailings

The pilot plant at Harmony Gold Kusasalethu was fed with full plant tailings with a PSD, as shown in Figure 4. The PSD of the cyclone underflow and overflow is shown in Figure 4. Lab-scale optimisation was conducted utilising a dried sample. The sample was sieved using a 75 µm mesh in order to create a dry fines and coarse fraction. Coarse and fines slurries were reconstituted using potable water.

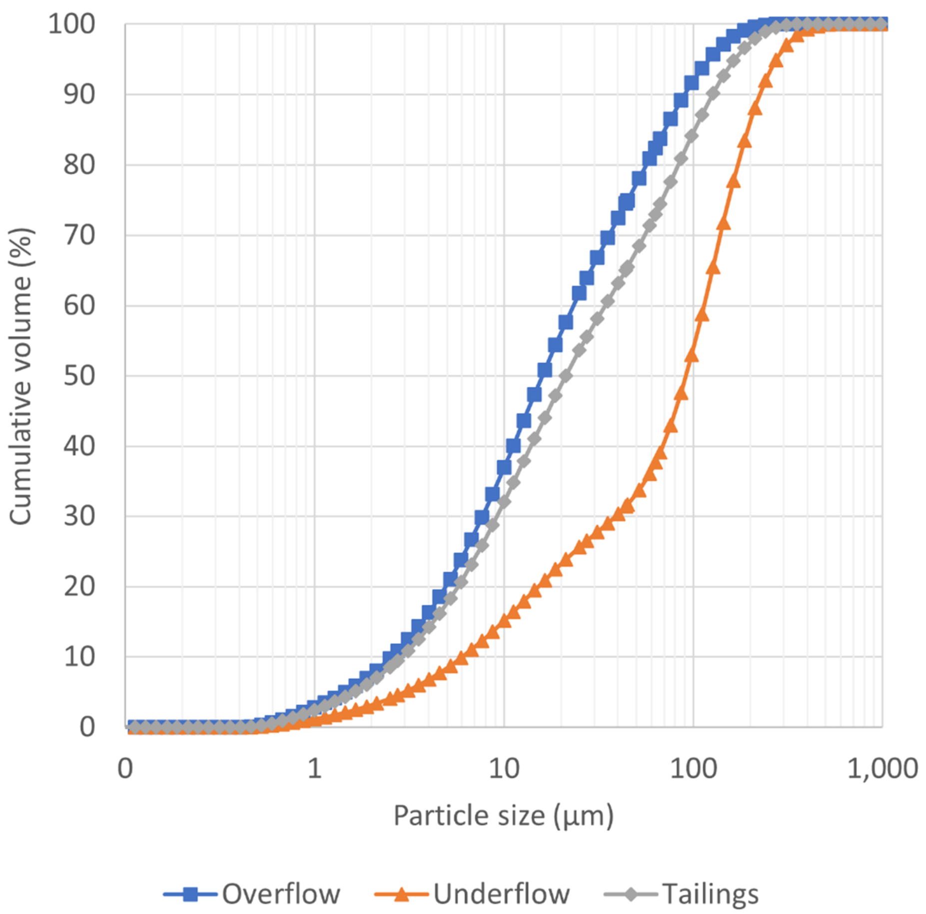


Figure 4 Particle size distribution of cyclone underflow, cyclone overflow, and full plant tailings at Harmony Gold

2.2 Rheological study

2.2.1 Undrained and drained water release

After conditioning by ATA or PAM flocculation, the slurry was gently deposited into a two-segment cylinder and allowed to settle in an undrained state. The undrained sediment height was recorded for 15 minutes after deposition after which the supernatant was decanted and weighed. The top segment of the cylinder was then removed and the settled tailings yield stress (see Section 2.2.3) in the undrained state was then measured.

The base of the bottom cylinder segment was then removed allowing drainage of the flocculated or ATA conditioned tailings. The mass of drained water was monitored for 60 minutes. After overnight drainage, the yield stress of the drained sample was measured. Further water release was assessed by gentle compaction of the surface of the sample with a plunger, and 40 gentle compactions were applied across the entire sample surface. Any released water was removed and weighed, after which the yield stress was again measured. The final dewatered solids concentration was then measured.

2.2.2 Compression-permeability

Compression-permeability (C-P) test data were obtained using a laboratory scale automated pressure filtration apparatus at the University of Melbourne (de Kretser et al. 2001). The piston-driven pressure filtration apparatus characterises the filtration and compressive behaviour of substrate filter cakes.

The C-P data were determined in the pressure filtration rig by applying a range of increasing applied pressures and either:

- For unconditioned slurries: measuring the filtration rate during filter cake formation (which is used to calculate the cake permeability) and measuring the final cake solids after completion of compaction (which is used to determine the stress-density behaviour). Through the application of a range of pressures, the C-P behaviour was determined.
- For conditioned slurries: measuring the final cake solids after completion of compaction (which is used to determine the stress-density behaviour) and the rate of percolation of fluid through the compacted filter cake (which is used to calculate the cake permeability). Through the application of a range of pressures, the C-P behaviour was determined.

Sample slurries were generated for the C-P testing using an agitated beaker method to carry out the conditioning by ATA or PAM flocculation. After settling of all the solids, including any residual turbidity, the released water was decanted. The conditioned tailings were then subsampled into the C-P testing equipment.

2.2.3 Shear yield stress

Single point yield stress testing of the conditioned tailings samples was also conducted in their undrained settled state, drained state and compacted and drained state, using a Haake VT550 controlled rate viscometer. Yield stress measurements were conducted according to method by Nguyen & Boger (1985).

2.3 Laboratory scale ATA testing

2.3.1 Jar test procedure

An amount of fines slurry was added to a suitable sized jar, activator (at 0.2% w/w) was dosed in using a syringe, and the jar was capped and then inverted by hand. A similar procedure was followed for adding tether to the coarse slurries. The activated fines slurry was then poured into the tethered coarse slurry and further mixed by hand. The combined solids were poured onto a screen or geotextile, and the moisture content of the dewatered slurry was measured by oven drying a representative sample.

2.3.2 Lab-scale dosage optimisation for piloting

Preparatory lab-scale work was conducted using a dried sample received from Kusasalethu. Activator and tether dosage was optimised using the jar test procedure described in Section 2.3.1 at varied solids concentrations. Cyclone inefficiencies at each feed solids concentration were modelled using a cyclone mass balance and the fines carry-over into the underflow was simulated at lab-scale by adding the proportional amount of dried fines to the reconstituted coarse slurry.

2.4 Pilot-scale ATA testing

2.4.1 Pilot plant overview and operation

A schematic of the ATA pilot situated at Kusasalethu is shown in Figure 5. The operating conditions of the pilot are summarised in Table 2.

Table 2 Pilot plant operating conditions

Process condition	Units	Value
Feed slurry flow rate	m^3/h	35
Feed relative density (RD)	–	1.4
Feed solids concentration	% (w/w)	44
Feed solids flow rate	t/h	25
Cyclone underflow RD	–	1.76
Cyclone overflow RD	–	1.38
Coarse-to-fines ratio		2.2
Activator dosing	g/t	400
Tether dosing	g/t	300

The pilot plant was fed at an average rate of 35 m^3/h at an average feed RD of 1.4. RD and flow rate of the feed was measured with an inline magnetic flow meter and an inline density meter. The RD of the cyclone overflow and underflow was measured by sampling during operation and measurement with a pulp density flask and scale.

The feed slurry was split with a hydrocyclone into a coarse and a fines stream at a cut point of 75 µm. This results in an operating CFR of 2.2. The cyclone overflow and underflow were fed to their respective baffle boxes. Photographs showing the pilot plant setup can be seen in Figures 6 and 7. The baffle boxes were dosed with activator polymer for the fines stream and tether polymer for the coarse stream. Both polymers were made up to an active concentration of 0.2% (w/w). Following mixing of the respective polymers in the two initial baffle boxes, the activated fines and tethered coarse streams were fed into a third baffle box (blend box) where the two streams were mixed and the ATA material was formed. From this blend box, the ATA treated material was fed by gravity to the geotextile bags. A 20 m^3 geotextile bag in tubular form was used for excess material, whilst four 1 m^3 geotextile bags were filled with ATA treated material.

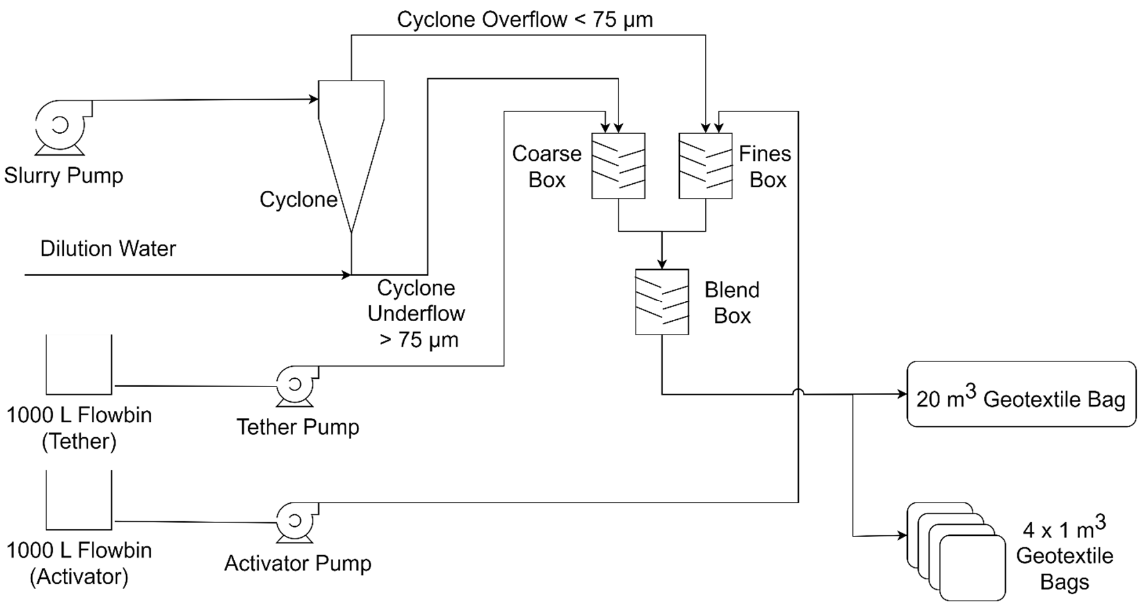


Figure 5 Schematic of ATA pilot plant constructed at Kusasalethu

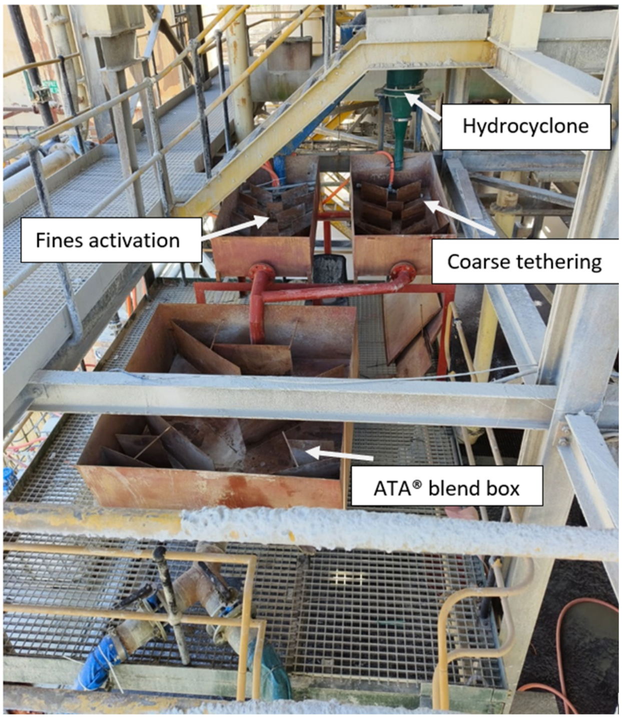


Figure 6 Photograph of pilot plant installation at Kusasalethu

Figure 7 Photograph of pilot showing ATA feed to 1 m^3 geotextile bags at Kusasalethu

2.4.2 Dewatering efficiency

Once filled, the 1 m^3 geotextile bags were left for six days to dewater through undisturbed drainage and consolidation. Material from the bag was sampled every 24 hours by inserting a 30 mm diameter perspex pipe into the bag in order to extract a sample. The pipe was pushed straight through the width of the bag and then removed to collect a representative sample of the full width of the bag. Samples were collected at pre-marked positions at the top, middle and bottom of the bag. Moisture content of each collected sample was measured by the gravimetric method, utilising oven drying at 110°C for six hours. The moisture content results for the top, middle and bottom samples were averaged to estimate the average moisture content for the bag on a given day.

Samples of filtrate were collected during the initial filling period and turbidity was measured using a Thermo Scientific Orion AQ3010 turbidity meter.

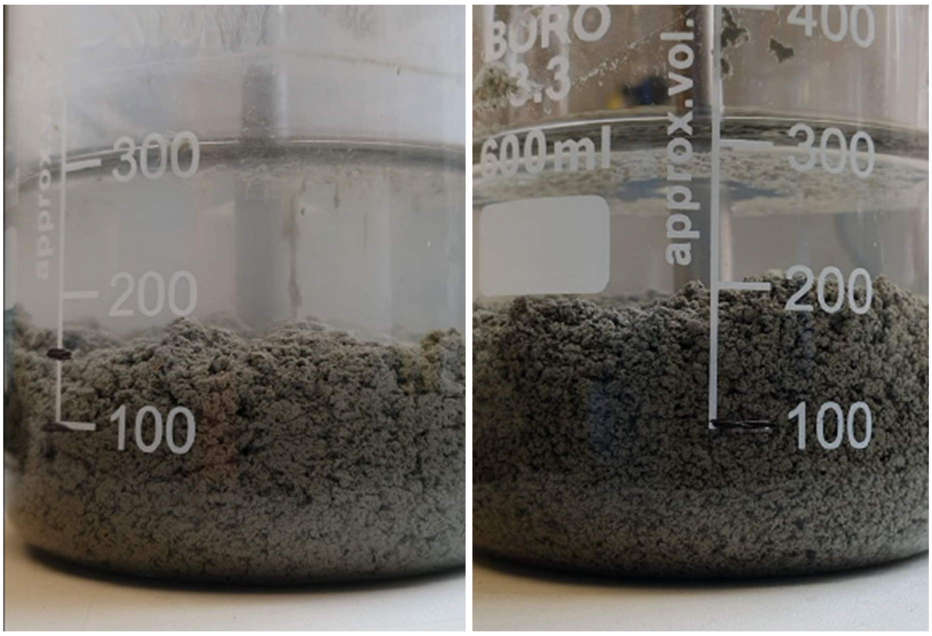
2.4.3 Load compression

Load compression tests were conducted to simulate hanging wall compression on the consolidated geotextile bag after six days of standing time. Load compression was tested using a Mohr & Federhaff 8,896 kN compression testing machine. The bag was removed from its support stand and placed in between the plates of the compression testing machine. The dimensions of the bag before compression were noted in order to calculate percentage displacement from the starting height. A gradually increasing load was applied to the bag at a rate of 10 kN/min.

3 Results and discussion

3.1 Rheological and dewatering study on Australian gold flotation tailings

Conventional and ATA treatment was initially carried out in 600 mL beakers with overhead stirring. Figure 8 shows the difference in the structure generated by each approach. The ATA-conditioned tailings produced a more uniform aggregate structure and a sediment composed of smaller aggregates with less macroscopic interlinkages. Furthermore, the supernatant clarity of the ATA-conditioned tailings (62 NTU) was improved relative to conventional conditioning with anionic PAM (432 NTU), indicative of better fines capture.



(a) (b)

Figure 8 Illustration of the different network structures. (a) Conventional PAM; (b) ATA treatment (Australian gold tailings)

Figure 9 shows that the shear yield stress after ATA treatment was significantly increased over the as-received tailings while also reflecting the development of higher network strength when compared to standard flocculation at a given solid %. Figure 10 shows that the ATA conditioned material was more rigid, with a lower density compared to PAM flocculated material, for the same applied compressive stress.

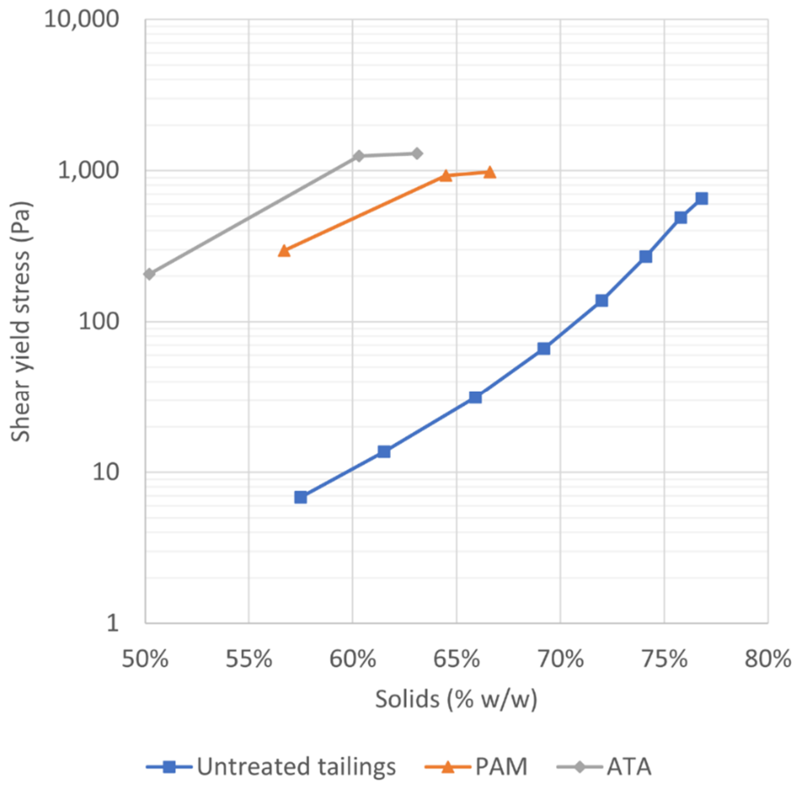


Figure 9 Yield stress versus solids concentration for Australian gold tailings slurry illustrating the impact of PAM and ATA treatment on yield stress

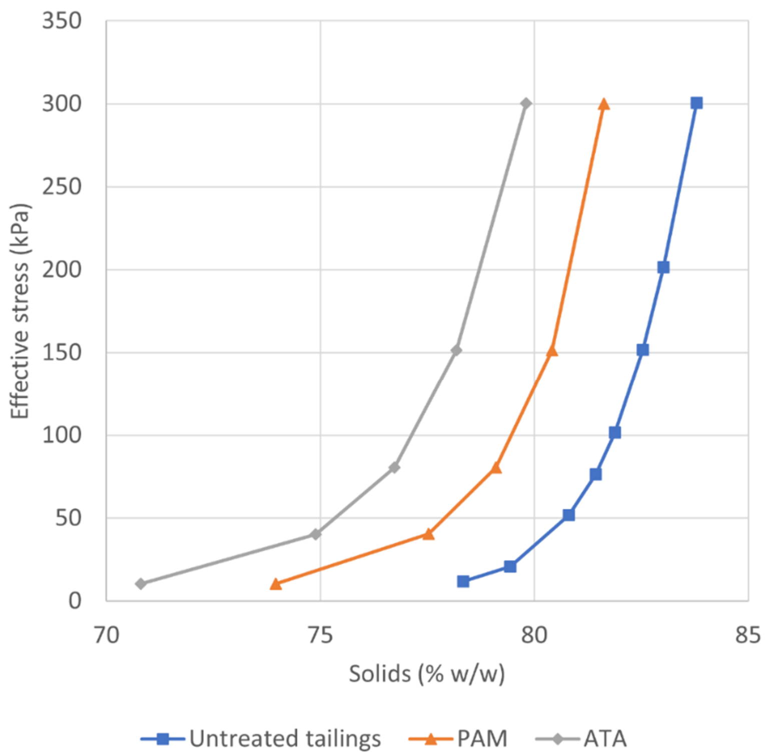


Figure 10 Effective compressive stress for Australian gold tailings versus solids concentration

Figure 11 shows that the ATA material exhibited enhanced permeability over PAM treated tailings, suggesting there is a fundamental difference in the nature of the porous network generated via ATA conditioning. This may be a result of a more optimal distribution of micro and macro pores, and more uniform distribution of fine particles within the aggregated sample.

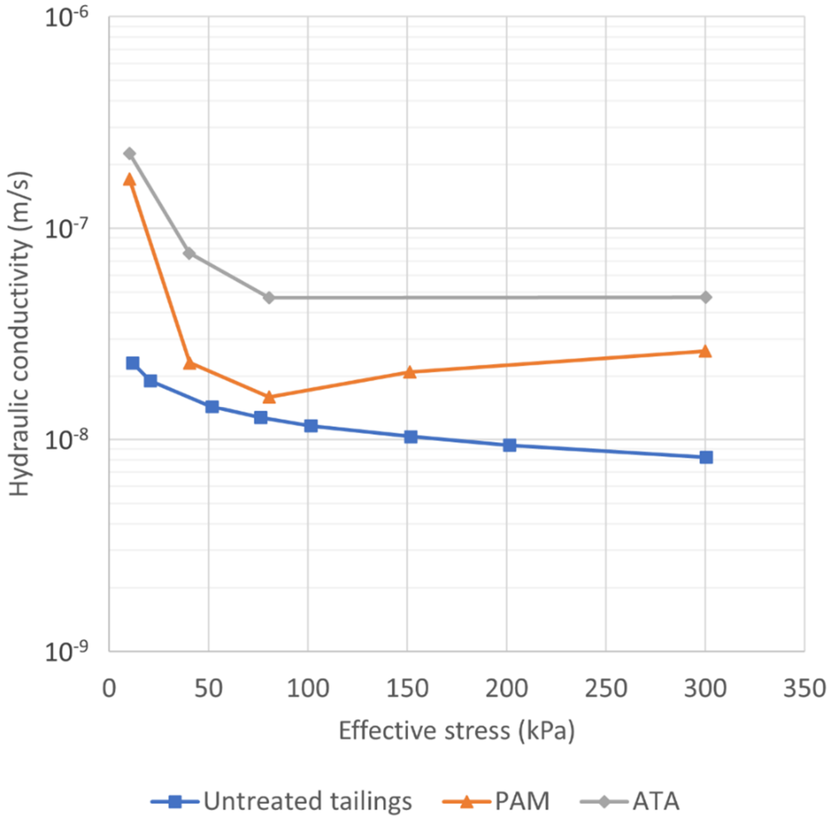


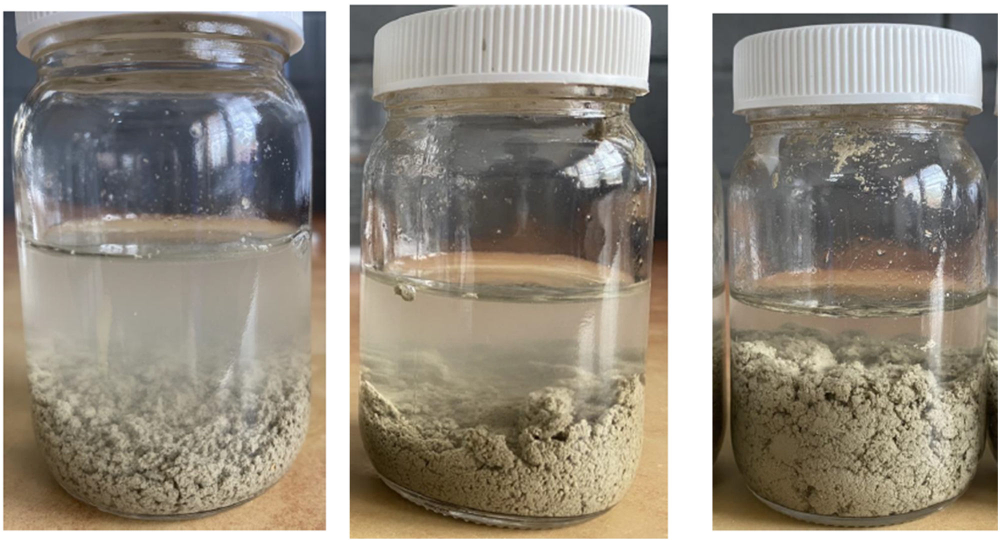
Figure 11 Hydraulic conductivity versus solids concentration for Australian gold tailings

In summary, the rheological and dewatering laboratory scale study suggests that ATA generates a more uniform aggregate structure and a sediment composed of smaller aggregates with less macroscopic interlinkages. Whilst this leads to a more open sediment with lower settled density, it is extremely permeable with faster dewatering rates. While the ultimate density achieved by ATA treatment may be lower compared to conventional PAM flocculation, the rate of dewatering to reach that density is materially improved. The higher permeability appears to be driven by a more optimal pore size distribution. Finally, fines capture and released water clarity was markedly better with ATA treatment, which would be expected to reduce blinding of filter media by mobile fines.

The following sections on the application of ATA to a South African gold tailings underground backfilling operation demonstrate that the properties measured at laboratory scale on a similar material (gold flotation tailings) translate to pilot-scale dewatering by gravity drainage in geotextile bags.

3.2 Laboratory study on Harmony Gold tailings using ATA

Photographs of the resultant ATA treated tailings at 20, 30 and 40% solids concentration can be seen in Figure 12. Figure 13 summarises the outcomes of the lab-scale polymer dosage optimisation at varying feed solids concentrations. The required dosages of both activator and tether polymer were found to increase proportional to the increase in solids concentration.



(a) (b) (c)

Figure 12 ATA treated tailings (Kusasalethu) at varying solids concentrations. (a) 20% (w/w); (b) 30% (w/w); (c) 40% (w/w)

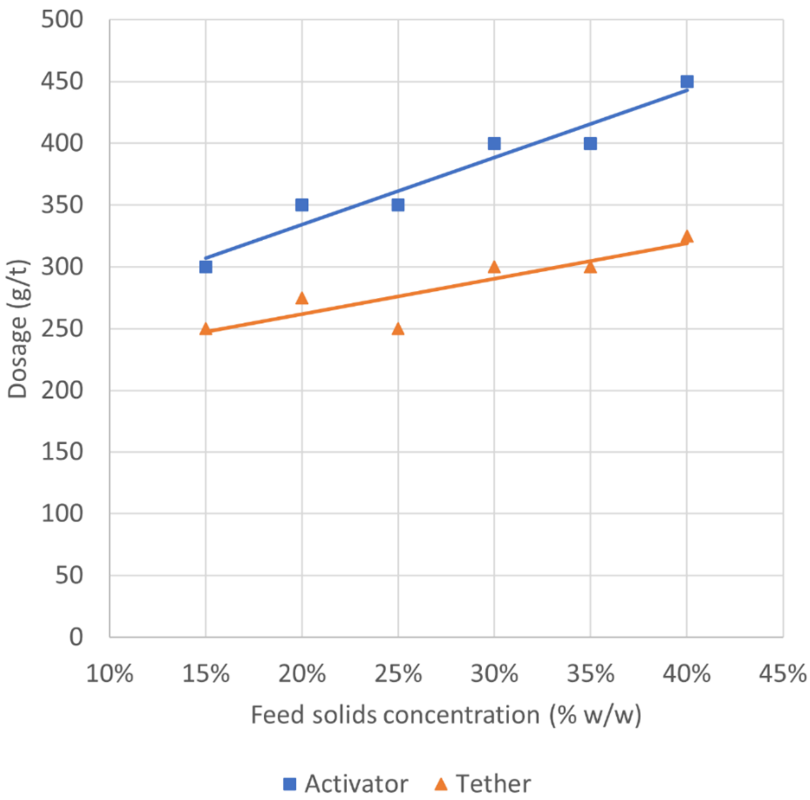


Figure 13 Optimised lab-scale ATA dosages at varying solids concentrations (Kusasalethu)

3.3 Pilot testing of Harmony Gold tailings using ATA

3.3.1 Correlation with lab-scale results

The pilot trial enabled the demonstration of ATA at pilot-scale on a representative tailings feed stream. The RD of the feed to the pilot plant varied between 1.33 and 1.4, which equates to feed solids concentrations between 39 and 44% (w/w). The pilot plant was operated with activator and tether dosages of 400 g/t and 300 g/t, respectively, which correlates well with the optimised dosages found at these solids concentrations during the lab-scale work.

3.3.2 Dewatering efficiency results

The results for the dewatering efficiency of four different geotextile bag fills are summarised in Figure 14. The majority of the dewatering occurs in the first 24 hours. The final dry solids concentration after six days were measured as 73% (w/w) for bag 1 and 72% (w/w) for bag 2. Bags 3 and 4 were initially sampled after 18 hours and were able to achieve 71% (w/w) dry solids concentration within this period. Bags 3 and 4 were only sampled up until day four with the final average dry solids concentration at day four measured at 72% for both. For comparison, a baseline test was completed using unclassified tailings without ATA, the baseline, which is shown as the control in Figure 14, illustrated that the untreated tailings dewaters to 66% (w/w) in the first 24 hours. The untreated tailings reach a higher final dry solids concentration after six days, with a final dry solids concentration of 76% (w/w). During sampling, it was also noted that the geotextile bag containing untreated tailings sample did not maintain stability, whereas the bags filled with ATA-treated tailings held their shape very well, as shown in Figure 15. The operation currently aims for 70–72% dry solids concentration before blasting can occur and this currently requires a minimum 24 hour consolidation period with classified tailings. The rapid dewatering of ATA-treated tailings will lead to rapid consolidation of the backfill in the stope and in turn, enable blasting and stope advancement within a period shorter than 24 hours. Furthermore, ATA also enables the incorporation of fines underground and the utilisation of full plant tailings. The control results in Figure 14 show that utilisation of full plant tailings without ATA treatment would not be possible, as dewatering to the required dry solids concentration only occurs after two days.

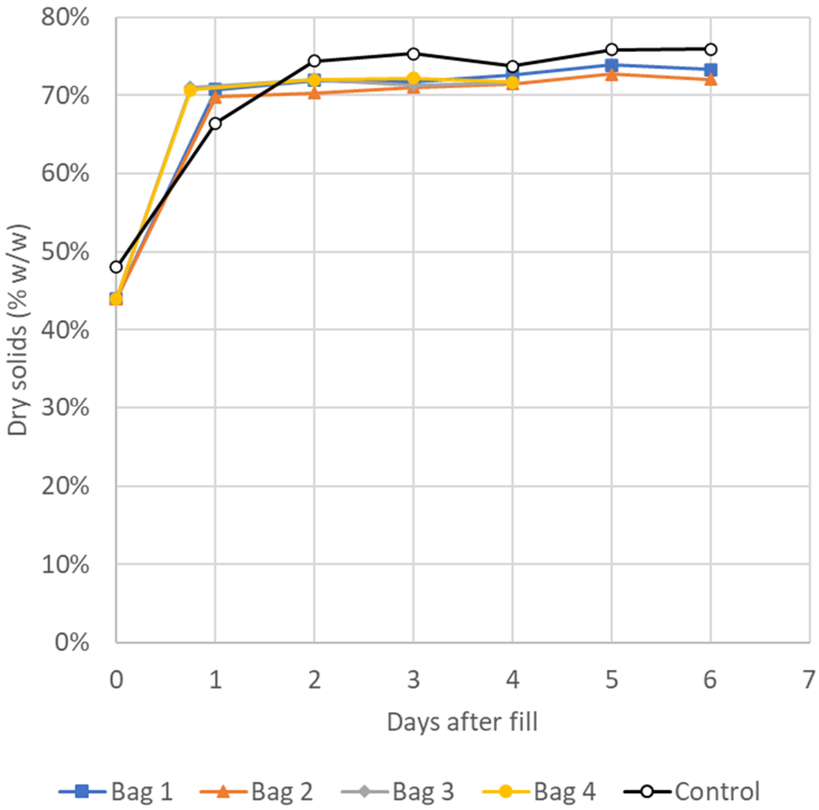


Figure 14 Dry solids concentration of geotextile contained ATA tailings over six days of standing time (Kusasalethu)

(a) (b)

Figure 15 Core samples taken from the geotextile bag after 24 hours of dewatering for (a) ATA treated and (b) untreated tailings

Solids losses with ATA treatment are also minimal, even with the presence of fines. Classification of tailings is typically conducted in conventional backfill to minimise fines losses through the geotextile as it can result in mud accumulation in active workings (as well as to maintain acceptable drainage rates). Samples of filtrate collected from the geotextile during the initial filling period with ATA treatment ranged between a minimum value of 14 NTU and a maximum value of 196 NTU, showing minimal fines losses. Significant fines losses were evident during the control test, as visually represented in Figure 16, which explains the improved free drainage of the untreated tailings, resulting in a higher final dry solids concentration after six days. It also further reinforces the need for either classification or ATA treatment of full plant tailings to avoid unacceptable mud accumulation within the active workings.

The lab-scale rheological study on Australian gold tailings showed that ATA treatment creates a uniform, almost granular structure with less macroscopic interlinkages. In the context of the Kusasalethu application, this more open pore distribution results in improved dewatering rates whilst reducing fines mobility, as evidenced from the rapid dewatering that occurred in the first 24 hours after filling the geotextile dewatering bag with minimal solids losses even with the presence of fines (contrary to classified backfill, where fines are purposefully limited).

(a) (b)

Figure 16 Fines losses during filling of geotextile bag, comparing (a) ATA treated and (b) untreated tailings

3.3.3 Load compression results

Figure 17 shows compressive stress with respect to percentage closure for the ATA treated tailings and classified backfill. Percentage closure is calculated as a percentage of the displacement of the bag from the start of load compression. ATA treatment of the tailings lead to higher compressive strength at higher closure percentages above 25%. Compared to classified backfill, ATA-treated backfill can support higher applied stress at reduced compressibility. This shows that the incorporation of full plant tailings, enabled by ATA, improves the load-bearing capacity of the backfill at higher closure percentages. The ability to utilise full plant tailings underground in turn will reduce capacity requirements of the surface tailings storage facility.

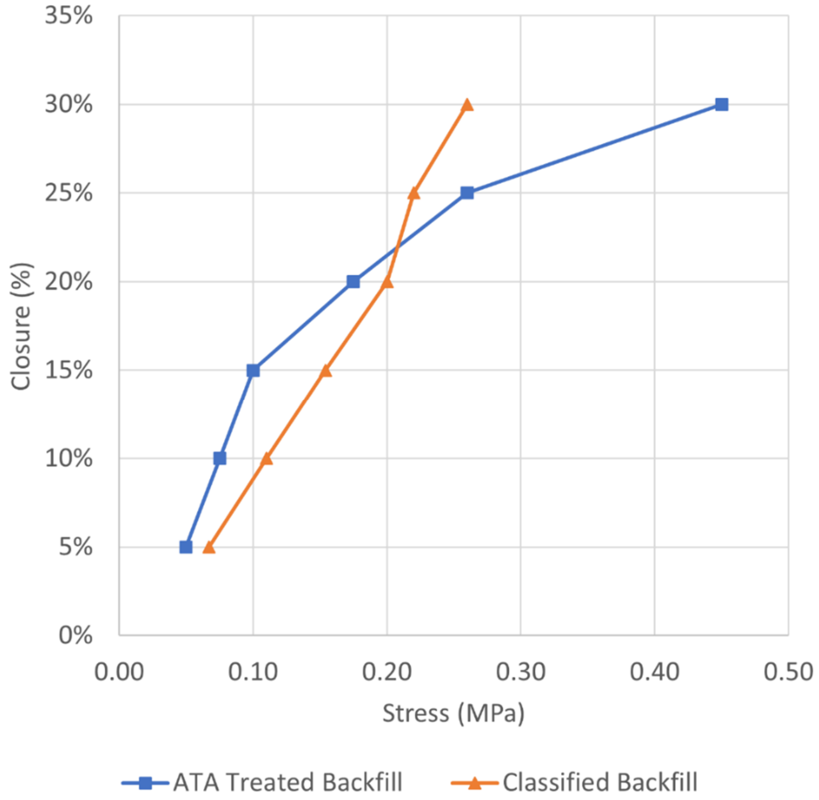


Figure 17 Load compressive stress with respect to closure percentage (Kusasalethu)

4 Conclusion

The results from this study show that ATA treatment of tailings creates a more uniform aggregate structure with improved fines capture. This in turn leads to an improved permeability and dewatering rate which translated to an improved consolidation and fill rate during the geotextile dewatering pilot utilising ATA on full plant tailings. Fines were less mobile, which led to reduced solids losses. The lab-scale rheological study enabled interpretation and validation of these results at pilot-scale. It was also shown that optimised dosages from lab-scale work translated to pilot-scale. The pilot study demonstrated ATA treatment enables the use of full plant tailings with high fines concentration for backfill when dewatered through a geotextile, with improved load-bearing capacity of the ATA-treated backfill compared to classified tailings at higher closure percentages.

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