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Ultrafines dewatering: converting field and laboratory test work results into process design criteria

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Abstract

The mineral sands industry faces challenges from lower-grade deposits with higher ultrafine clay content. Operations previously reliant on free-flowing sands must adopt new technologies to maintain throughput and mine life. Regulatory constraints demand innovative methods for safe ultrafine residue disposal that promote post-mining agricultural land rehabilitation while preventing production bottlenecks.

To minimise land sterilisation and operational risks, mining companies are exploring alternative dewatering techniques beyond conventional market solutions. This study examines frequently overlooked technologies through laboratory and field trials, developing robust process design criteria for design of effective mine tailings management processes in these challenging conditions.

Keywords: *accelerated mechanical consolidation, residue dewatering, polymer-assisted co-disposal, rehabilitation*

1 Introduction

This study is an amalgamation of test work performed on 2 distinct kaolinite rich mineral sand deposits.

Retained moisture in clay-rich ultrafines critically determines post-mining soil viability. Excessive water creates safety and accessibility risks lasting years after closure, hindering agricultural rehabilitation. Effective dewatering strategies are essential, directly impacting agricultural accessibility and soil aeration – both compromised by water trapped in deposited clays.

Rehabilitation studies on reconstituted, hydraulically deposited mine tailings, such as Smith et al. (2016) highlight the criticality of optimal soil water to allow sufficient aeration – “soil water contents throughout the reconstituted soil profile were so high that soil aeration was below critical levels for plant growth.”

Clay-rich ultrafines are predominantly the drivers of water-retentive behaviour of soils due to their small particle size, and high surface area and charge. The clays are typically smaller than 20 um, while this report refers to ‘metallurgical process fines’ as being any particle passing into a cyclone overflow operating at a cut point of 45 µm. The coarse fraction is classified as the cyclone underflow fraction passing 2,000 µm and retained on a 45 µm screen.

The author acknowledges that thickening and pumpability of the various mixtures are key parameters to be evaluated in the overall project feasibility program. These aspects are however not detailed in this study.

Effective tailings dewatering maximises storage capacity in tailings facilities while recovering water for re-use. Reduced moisture content increases material strength and bearing capacity, enabling earthmoving, shaping, and agricultural activities. Higher undrained strength also mitigates liquefaction risks, preventing catastrophic facility failures and enhancing overall safety.

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2 Methodology

2.1 Transportable moisture limit and flow moisture point

A major consideration in the decision to apply specific dewatering technologies is the ability to transport the dewatered products. This is detailed by Chrystal & Jansen (2024) – "there is a balance between having a low enough yield stress (higher water content) to economically transport and place the material per the stacking plan versus maximising water recovery (lower water content) ahead of deposition to minimise the water loss through purposeful evaporation."

The industry accepts that the material flow moisture point (FMP), and the subsequent calculation of the transportable moisture limit (TML) allows for the selection of appropriate dewatering and transportation methods without introducing risk and spillage during transportation. ALS (2026) indicates a comprehensive explanation of the flow moisture point.

Work performed in accordance with ISO12742 (International Organization for Standardization 2020), were standard test procedures to determine the FMP and TML values for the various simulated slurries. Table 1 shows the results of this test work.

Table 1 Transportable moisture content results for various blends of fines and coarse tailings

Material	Transport moisture limit (TML*) – (90% of FMP)	
	Mine site 1	**Mine site 2**
Fines 100%/sand 0%		34.5% (65.5 %m/m solids)
Fines 85%/sand 15%		26.6% (73.4 %m/m solids)
Fines 50%/sand 50%		21.9% (78.1 %m/m solids)
Fines 35%/sand 65%	24.9% (75.1 %m/m solids)	20.7% (79.3 %m/m solids)
Fines 30%/sand 70%	20.8% (79.2 %m/m solids)	
Fines 20%/sand 80%	18.6% (81.4 %m/m solids)	

*Note: flow moisture point (FMP) and transportable moisture limit (TML) moisture content is metallurgical (m_{water}/m_{slurry}) definition

2.2 Phase 1: technology scanning and 'best-fit' evaluation

Despite both projects having engineered tailings storage facilities (TSFs) available as disposal options, it was prioritised to minimise tailings volume to reduce farmland and community disturbance. This study, conducted on material for both mine sites, focused on dewatering mechanisms for clay-rich fines and co-disposed tailings, addressing water retention sensitivity to optimise to minimal disposal volumes.

2.2.1 Mechanical dewatering options evaluated

2.2.1.1 Pressure filtration

The test work found that filtration performance was made difficult by the very low permeability of the ultrafine clays. The coefficient of permeability (k_T) of a dispersed slurry bed of kaolinitic ultrafines, was measured at 3.39 × 10^{-06} m/s.

The most successful ultrafines pressure filtration laboratory result achieved with an original equipment manufacturer's (OEM's) laboratory filter press, equipped with a special lining membrane, performing a 15 minute, 15 bar squeeze, achieved a 72.5 %m/m solids cake with a 15 kg dry solids/hour/m^2 throughput. The required instantaneously available area to treat the slurry at 30% solids was calculated to be 51 × 10^3 m^2 of filtration surface area.

The addition of sand as a ballast to promote filtration rates did little to enhance capillary suction time. It was therefore concluded that the coarse sand and fines streams should be dewatered separately, optimising the filtration equipment requirements and infrastructure capital spend.

Figure 1 represents a typical result of repeated pressure filtration campaigns by OEMs and accredited laboratories. The filter cakes typically only lost moisture on the outer surfaces, and the centres of the cakes remain relatively unchanged even when form times, air-blow times, membrane squeeze times and feed pressures are extended.

Excessive capital cost requirements of this technology meant that the option was not investigated further.

Figure 1 Typical filter cake generated by filter presses on the kaolinite rich ultrafines material

2.2.1.2 Vacuum filtration

Vacuum filtration was evaluated on a laboratory scale with the addition of polymer. Several filter screen sizes were tested.

Figure 2 from the paper presented by Gardolinski et al. (2000) provides a clear contrast between 'dispersed' and 'undispersed' kaolinite plate-like clays. The dispersed clay, typically generated by hydraulic pumping and high shear processes, indicated on the left photograph, would clearly have a lower permeability than the stacked plate-like formations indicated on the right.

A polymer-assisted, flocculated slurry would more-closely resemble the photograph on the right as the plate-like structures are aligned and ordered by the charged sites provided by the polymer.

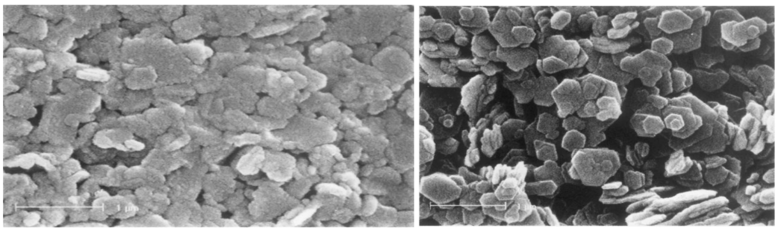

Figure 2 Scanning electron micrograph indicating plate-like structures of dispersed and undispersed kaolinite

Beveridge et al. (2015) found that the addition of Rheomax® ETD 9050 to kaolinites and fine smectite-containing tails was able to improve both the consolidation coefficient and permeability. The polymer “induced substantial changes in permeability that were approximately 2 orders of magnitude above that of the untreated ore.”

The benefit of monomer-enhanced polyacrylamide addition allows for the re-ordering of the dispersed kaolinite discs to facilitate separation of these particles from the suspension medium.

In Figure 3, da Silva (2011) displays a conceptual explanation of the effects of polymers on clay particles and their binding to larger silica particles. The use of the coarse particles provides a scaffold onto which the flocculated clay fines can attach.

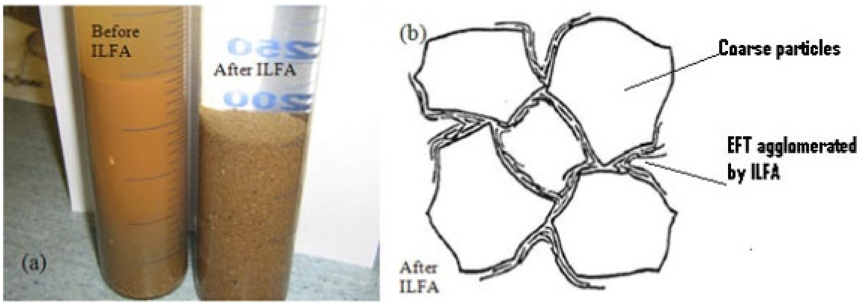

Figure 3 A conceptual example of the effect of inline flocculation polymers on kaolinitic clays

Note:

- EFT is defined as ‘extrafine tailings’ or ultrafine tailings.
- ILFA is defined as ‘in-line-flocculated-addition’.

The polymer-assisted vacuum filtration option showed promise, as depicted in Figure 4, in terms of water-removal efficiency and the structure of the cake. However, inability to reach the requisite TML, excluded this option from consideration for further studies.

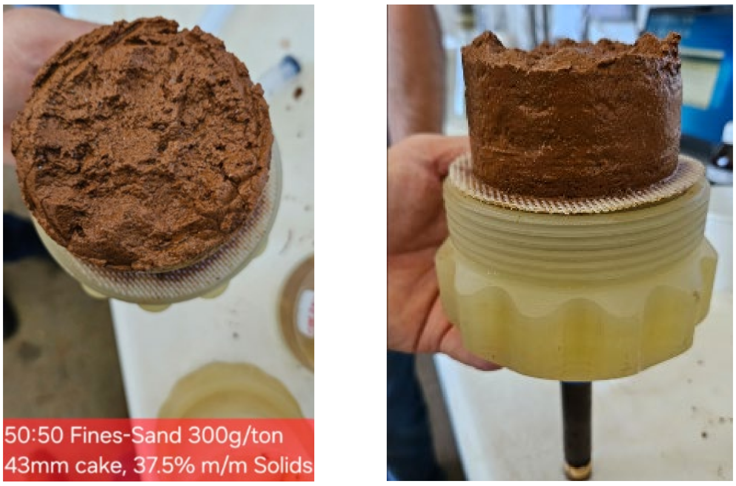

Figure 4 Effect of 300 g/tonne polymer addition on 50% fines, 50% coarse mixture subjected to vacuum filtration

2.2.1.3 Centrifugation

Inability to attain the TML by OEM laboratories meant that centrifugation was excluded from further studies.

2.2.1.4 Accelerated mechanical consolidation or mud farming

The use of amphibious scrolling machines combined with low-ground-pressure earth-moving vehicles has had decades of success in the bauxite industry and is being explored in mineral sands tailings management processes. Munro & Smirk (2012) highlight the benefits thereof.

The advantage of accelerated mechanical consolidation (AMC) is that dewatering happens post deposition in engineered tailings facilities and is not subject to the need to achieve post-treatment TML/FMP constraints.

The standard tailings facility design, reliant on sub-aerial deposition and evaporative desiccation processes, is typically hamstrung by the entrainment of water in the deposited flocculated structures. These structures limit the strength gain and volumetric reduction of the residue post deposition.

Żbik et al. (2008) detail this mechanism as follows:

> *"flocculant addition to kaolinite suspensions, "freezes", the pre-existing particle structure and orientation. It has important implications for final bed density and dewatering without disruption of floc structures because both inter- and intra-aggregate water remains locked in the pre-flocculant structures. In practice, raking the flocculated bed is normally used to release some of this retained water but the % solids is still low in most tailings' disposal."*

The AMC dewatering process is a sequence of events that can be summarized in the following repeatable steps

1. Mechanical methods introduce extra shear, compression and stirring energy via gentle disturbance, that overcomes "inter- and intra-aggregate" structures while liberating bleed water.
2. Liberated bleed water permeates to the beach surface, making it available for removal either by gravity or by evaporation processes.
3. The amphibious machine, as it travels through the mud, introduces channel-like pathways in the scroll depressions (indicated in Figure 5) which accelerate the drainage of bleed water from the mud.

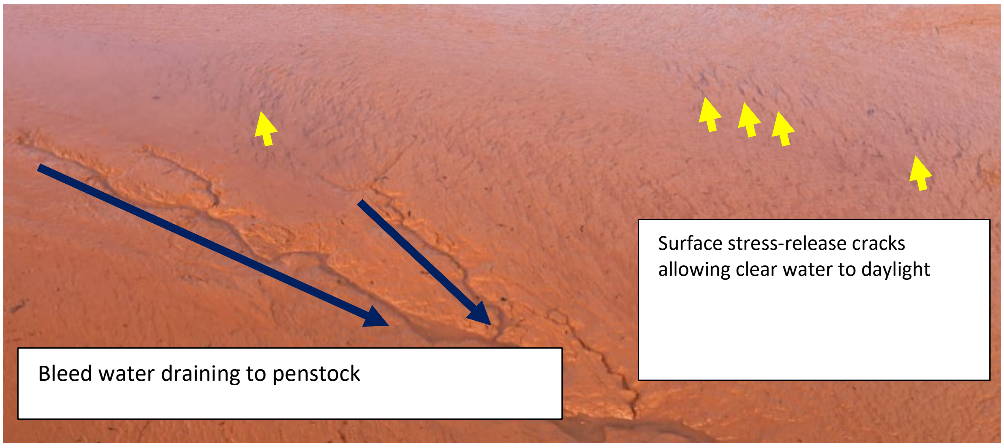

Figure 5 Close-up of the surface of a recently scrolled tailings storage facility paddock indicating stress-release cracks

4. The ridged elevations between the scroll depressions in Figure 6 are squeezed, displaced and raised vertically, standing proud of the surface of the TSF beach. This elevated surface promotes cracking and significantly improves beach angles off which the water can more effectively be removed by bleed and evaporative processes.

Figure 6 Typical accelerated mechanical consolidation raised ridges and scroll depressions indicating surface cracking Cocks (2019)

5. As free-draining bleed ceases, evaporation takes over as the primary dewatering mechanism; the clay-rich fines begin to crack along the surface stress-release cracks, accelerating the surface area available for further evaporation.
6. The scrolling process is repeated to re-initiate the bleeding and evaporative process.
7. Once the desiccated tailings approach a moisture content that renders an undrained strength of at least 35 kPa (Santiago et al. 2024), through the top 100 cm of material, it is suitable to introduce low-ground-pressure machines, increasing consolidation pressures and surface area for evaporative desiccation.
8. Self-weight consolidation is enhanced as each raise increases the pressure subjected to the underlying tailings layers, squeezing unevaporated water vertically to the TSF surface.

3 Results

3.1 Tailings physical characteristics

Figure 7 indicates the particle size distributions of fines from 2 mine sites with predominantly kaolinitic-rich fines compositions. It is evident that mine site 1 (MS1) has higher −2 um ultrafines/clay content, and elevated −20 um content compared to mine site 2 (MS2). Mineralogical analysis has since revealed that MS1 has significant fractions of illite and smectite in association with the kaolinite, while MS2 material is predominantly kaolinite clay with minor amounts of muscovite and mica.

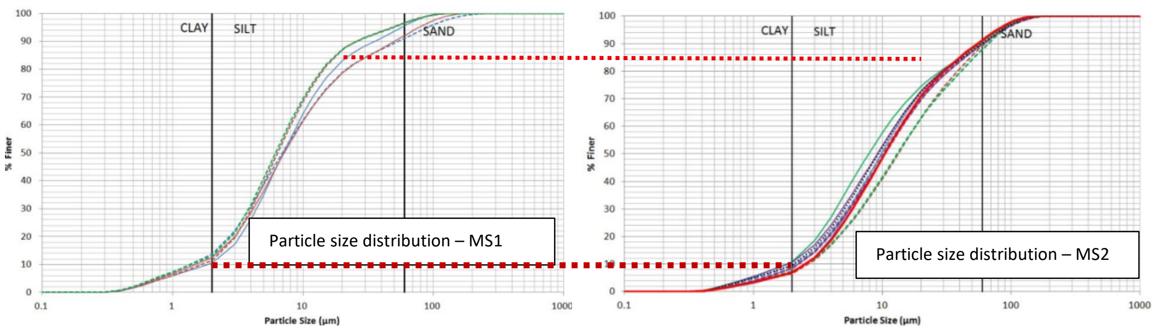

Figure 7 Particle size distribution of typical kaolinite-rich −45 um (cyclone overflow) fines fractions

Table 2 indicates the physical and Atterberg characteristics provided in reports by Paterson & Cooke (n.d.), of the metallurgical fines characteristics of the 2 mines referenced in this study.

Table 2 Clay fines key characteristics

Parameter	Unit	MS1	MS2
Specific gravity	t/m^3	2.7	2.7
D_{20}	um	3	4.8
D_{50}	um	6	13
D_{80}	um	15	48
Liquid limit (% solids m/m)	%	101.2 (48.1%)	64.6 (60.7%)
Plastic limit (% solids m/m)	%	38.4 (71.4%)	43.5 (69.7%)
Plasticity index	%	62.8	21.1
Linear shrinkage	%	19.7	9.9
Shrinkage limit	Mw/Ms (%)	Not measured	20
	m/m (%)		83

According to ASTM International (2017), mine site 1 would be defined as a ‘CH’ or “inorganic fat clay of high plasticity”, while mine site 2 would fall into the category of ‘MH’ which is “elastic inorganic/micaceous or diatomaceous fine sands or silts”. This is indicated in Figure 8.

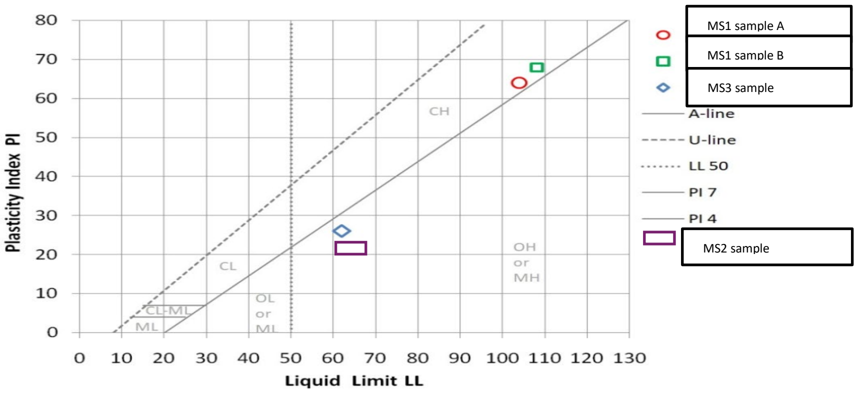

Figure 8 Comparative plot of the Atterberg limits of kaolinitic-clay-rich tailings samples on the plasticity chart

3.2 Accelerated mechanical consolidation simulations and field trials

The first step in developing a model to predict performance of AMC was to simulate the consolidation behaviour after stirring and shearing the tailings material.

The buckets used in the mechanical stirring simulation are indicated in Figure 9. This test measures the rate of water liberation from the flocculated particles, when sheared, to attain consolidation.

Figure 9 Buckets used to perform mechanical consolidation utilising varied mechanical stirring frequencies

Buckets filled with fine tailings were stirred at different intervals. Solids concentration and the resultant forced mechanical consolidation curves were inferred by measuring the daily removed mass of supernatant water. These tests were performed in-doors in cool 15–20°C conditions, and thus evaporative losses were assumed to be negligible.

Self-weight-consolidation curves were also established using 9 m high, 0.46 m diameter polyvinyl chloride pipe columns for mine tailings 2. This data is plotted to establish the long-term deep consolidation behaviour with time.

Figures 10 and 11 indicate the comparative effect of stirring on the MS1 and MS2 tailings samples.

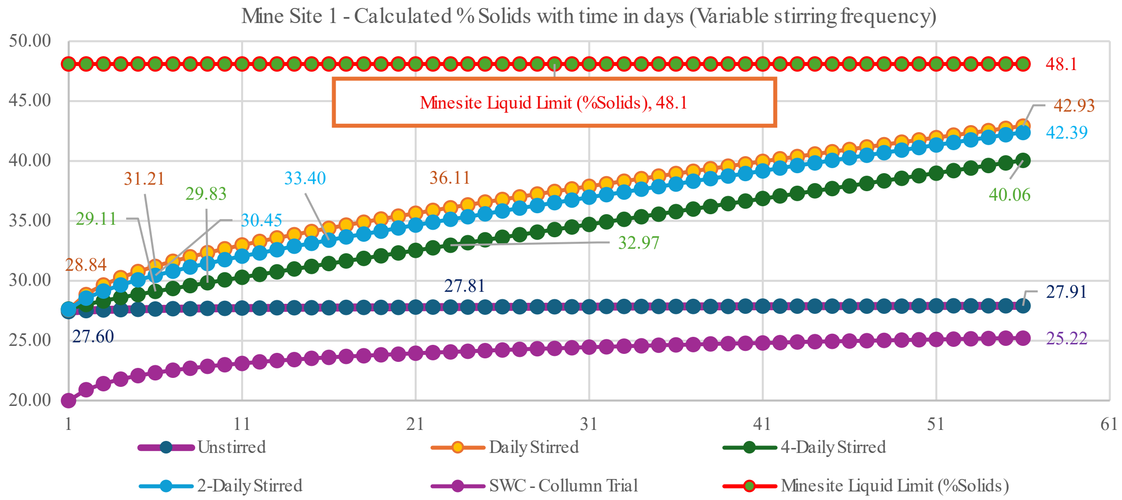

Figure 10 Solids content of mine site 1 with time after deposition as a function of varied stirring frequencies

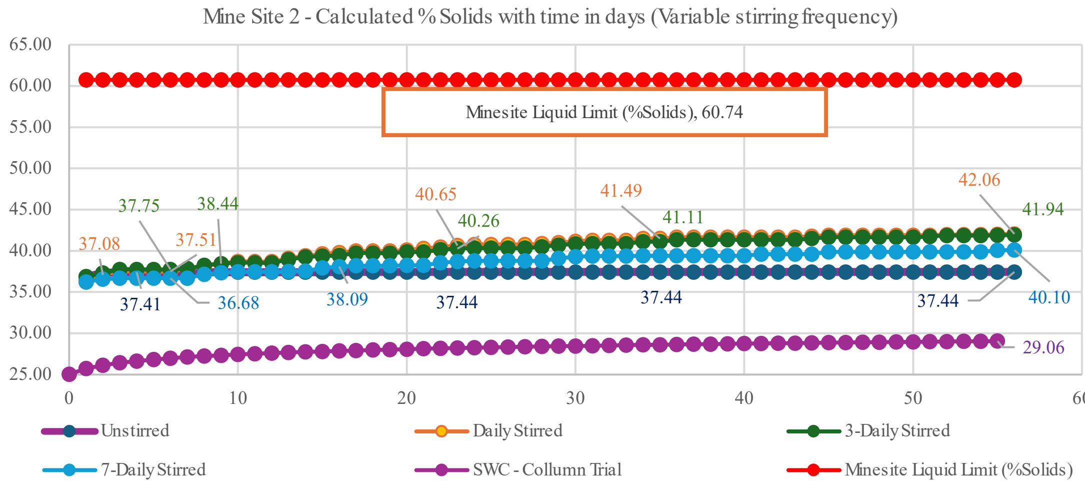

Figure 11 Solids content of mine site 2 with time after deposition as a function of varied stirring frequencies

The respective tailings' liquid limits have been plotted to provide context of how far the material must dewater to reach the point of transition into its plastic state. Both mine site 1 and 2 had different initial deposition states, and this is driven by the respective material's C_{bMax}[1] which influences how effective the thickener can dewater the settled solids.

[1] C_{bMax} is defined as the maximum solids packing volumetric concentration, simulating a stirred thickener.

Mine site 1's solids mass concentration at its liquid limit (48% solids) is considerably lower than that of mine site 2 (61%), and this proximity to the material's liquid limit drives the efficiency of the mechanical consolidation process. The data indicated no noticeable improvement when stirring frequency is increased from 3-daily to daily stirs.

3.2.1 Mud-farming field trials

An industrial-scale field trial was conducted on mine site 1 between 10 April and 3 June 2025, where a single amphibious scrolling machine performed dewatering trials on polyacrylamide flocculated, thickened tailings deposited using a positive displacement pump system feeding an overland pipeline distributed into a ring main deposition system designed to deposit sub-aerially around the TSF perimeter.

The trial was undertaken using a newly established TSF designed to perform sub-aerial deposition. The selected trial paddock of 7.1 ha was prepared by establishing temporary earthen bund walls around the perimeter and inserting 1 m depth marker pegs placed 25, 50 and 100 m from the tailings discharge points around the perimeter to enable visual pour depth and consolidation height measurements.

Thickened residue was placed using discharge spigots tapping off a main perimeter ring supply line. Pegs were used to visually control pour depth. Figure 12 indicates the areas that required more scrolling and more machine time due to the depth of the deposited residue.

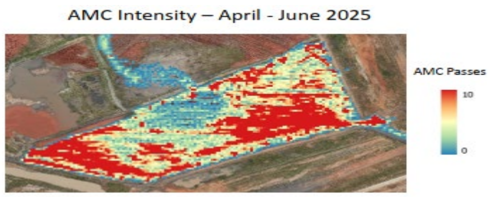

Figure 12 Amphibious scroller travel heat map indicating working intensity and number of machine passes

Topographical correction was required with an initial pour, which, in places, was more than 1 m in depth. Figure 13 indicates moisture analysis data taken from the mud-farmed area as a function of time and the number of mud-farming passes (times the scroller worked in the vicinity of a pre-defined marker peg). The duration of this simulation was a total of 54 days between initial pour and final moisture reading. The average fines slurry deposition relative density measured using inline slurry density meters during the duration of deposition was 1.21 t/m^3, equivalent to 28.5% solids slurry composition on a mass basis.

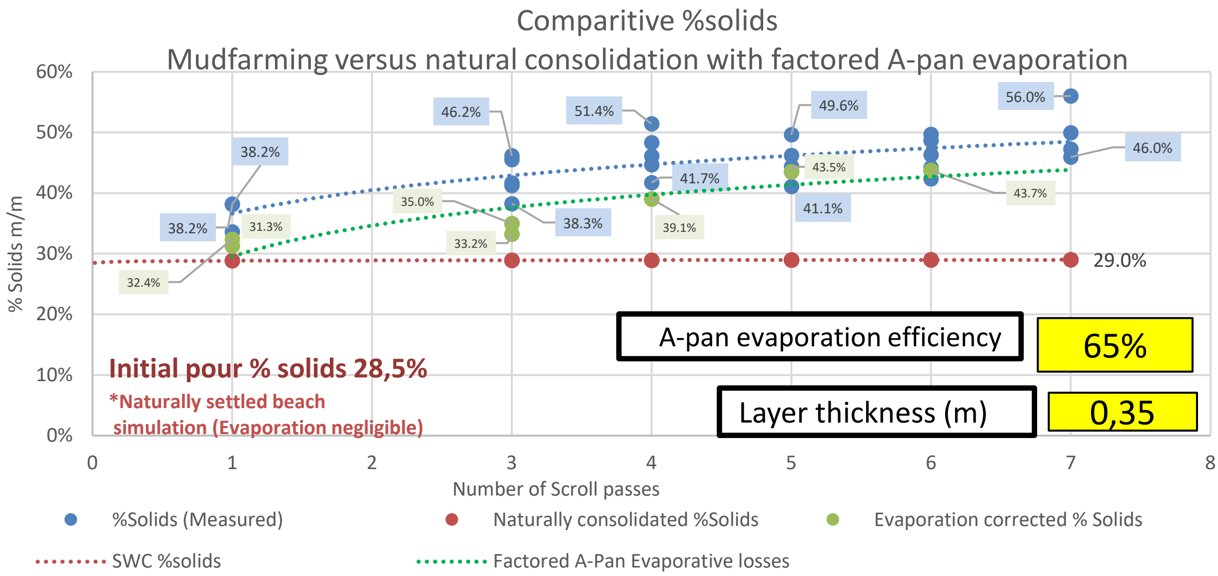

Figure 13 Comparison of mud farming with self-weight consolidation with evaporative solar drying

Literature normally applies a factor to the A-pan evaporation rate to predict the evaporation off the surface of the fines beach surface. Cooling & Glenister (1992) report the use of a factor of 50% applied to the A-pan evaporation rate to predict the actual residue surface evaporation.

Daily A-pan data was recorded onsite by mine employees, and a factored A-pan rate of evaporation was used to calibrate the evaporative moisture losses from the surface of the mud. The A-pan evaporation factor that predicted the sampled residue moisture was 65%. The average depth of pour over the 7.1 ha paddock surface was equivalent to 35 cm.

It was observed that, at a certain clay consistency and in absence of a competent high-strength base layer, the residue would bind onto the machine scrolls, covering the flights and result in hindered progress. This stickiness was observed in areas where the machine began to experience propulsion issues. Figure 14 indicates the scroll build-up and the apparent layering being sloughed off the scrolls as they rotate in the material.

Figure 14 Paste build-up on the amphibious machine scrolls

The solids content (indicated in Figure 15), at which the following are noticed, seems to correspond to the material's liquid limit value.

1. moisture losses stabilise
2. travel speeds drop
3. build-up is noticed on the scrolls.

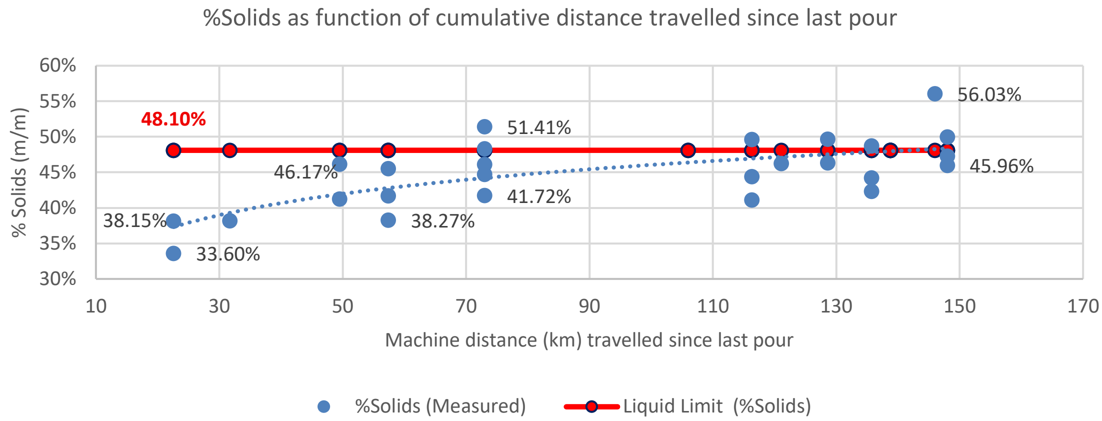

Figure 15 Deposited residue %solids (m/m) relationship with AMC machine distance travelled

It was deduced that using the typical 80–100 cm Munro & Smirk (2012) pour cycle depth, the AMC scrolling process would be effective in material below its liquid limit. Once the material approaches its liquid limit, the clay fines layers become resistant to scroller travel and would have to be subjected to evaporative desiccation to improve its moisture content and strength beyond their liquid limit.

A management alternative was developed to pour thinner layers more frequently to allow the scroller machine to maintain its travel rate (speed) due to lower resistances and cleaner, less-caked scrolls, and to improve desiccation and strength beyond its liquid limit.

An acceptable underfloor layer undrained strength of 10 kPa has been found to provide enough strength for forward propulsion of the machine while being strong enough to clear the 'layers' of viscous material accumulating on the scrolls.

Geotechnical laboratory work on the mine site (MS1) material, enabled the development of a correlation between the shear vane undrained strength readings and the %solids content. This relationship allowed inference of mud 'dry density' at different depths using a hand-held shear vane tool.

Figure 16 indicates the relationship between repeated scrolling and inferred final dry density of the tailings material at 20, 50 and 100 cm sample depths. There was no correlation between the pass number (1–7) and the calculated dry density on the surface, but there was a marked relationship of an improvement in the final dry density with depth.

It is hypothesized that, due to continuous vertical migration of moisture to the beach surface as lower layers consolidate and displace inter-particular water upwards, the mud surface remains wet for longer allowing more bleed and evaporative water removal. The repeated mechanical scrolling of the AMC machine shears, compresses and displaces water out of the lower layers as it repeatedly re-establishes the consolidation curves indicated in Figures 10 and 11.

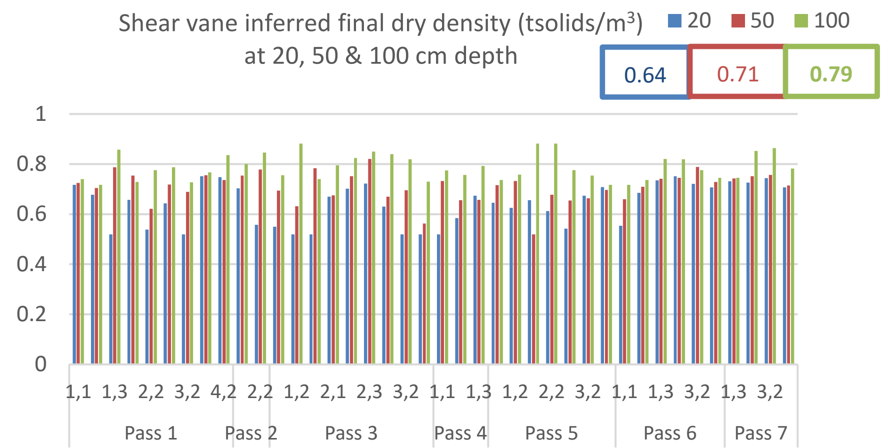

Figure 16 Final dry density of fines inferred by the shear vane readings at different depths

3.3 Polymer co-disposal results

3.3.1 Polymer screening and optimal mixing conditions

Delchem (Pty) Ltd's KT220 polymer was screened as the most effective polymer. It is described as a medium-chain, monomer-equipped, branched polymer to facilitate optimal clay orientation. This polymer is shorter than typical thickener-type flocculants as it allows for easier mixing at higher slurry viscosities.

The ability of the polymer to bind the flocculated clay to the coarse 'ballast' solids is driven by the polymer's ability to overcome viscosity effects of the suspended clay fines as well as its charge and molecular structure.

Revington & Wells (2025) detail the need to quantify the macro, meso and micromixing effects to optimise effective polymer performance when blending with clay containing tailings. There is a balance between getting effective mixing while minimising harmful shear effects to prevent the degradation of the floccules once created.

Beaker-scale test work found that the effective mixing of polymer was reliant on the slurry solids content, especially at elevated clay fines levels and higher solids concentrations. It was established that a minimum water-to-fines ratio (mass ratio of water to the −45 micron fraction of solids in the slurry) of 4.5 allowed for low-enough viscosities to facilitate proper mixing and contact of the polymer with the ultrafines to facilitate structure formation and rapid water separation.

The optimal mixing outcomes established in both the lab and field trials were confirmed by those established in the paper by Revington & Wells (2025).

It is recommended that any future polymer-assisted co-disposal test work starts with the methylene blue test to gain insight into the reagent surface demands of the specific clays and the 'pain index' referred to in Kaminsky et al. (2024).

3.3.2 Intermediate bulk container deposition trials

One-cubic-metre intermediate bulk containers (IBCs) were used to evaluate the potential of the selected polymer in removing excess water from mixtures of varying fines-to-coarse sand ratios.

The coarse sand layer depicted in the 'before' photograph in Figure 17 was mechanically placed to create a permeable pathway facilitating removal of released water. Water was drained periodically and the mass recorded to construct the consolidation curve. Solids consolidation was measured using the depth marker.

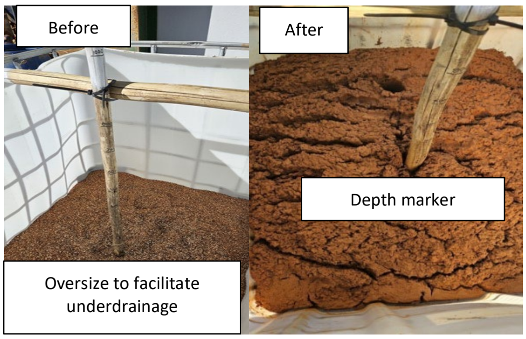

Figure 17 Intermediate bulk containers fed with 50% fines, 50% coarse sand co-disposed with polymer fed inline

An important outcome of this trial was the tendency of the unsaturated, well drained material to dewater to a water-to-fines ratio of 1.53, independent of the mass of coarse solids in the mixture. This ratio, plotted for the IBC trials in Figure 18 below, indicated that a specific amount of water is associated with the clay fines and points to the relationship highlighted in Equation 2 of Kaminsky et al. (2024). It could also point to the efficacy of polymer mixing to re-align the clay particles while displacing excess trapped water.

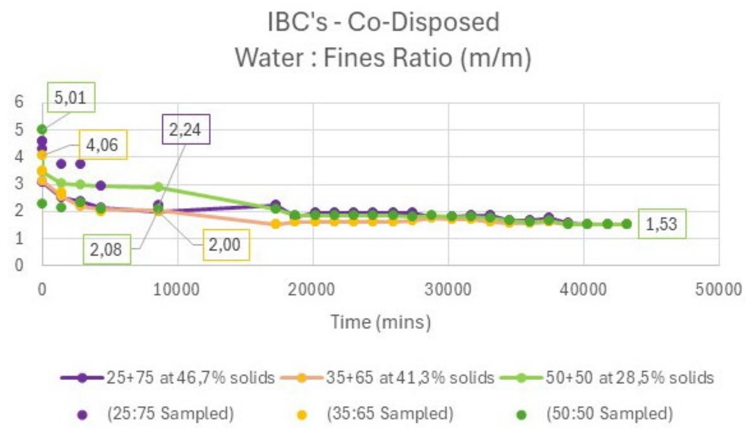

Figure 18 Polymer-assisted co-disposal effects on water-to-fines ratio when deposited inline

3.3.3 Field trial results

Mine site 2 performed a large-scale mining and rehabilitation field trial in Q4 2024. Co-disposed pits were deposited, and periodic core samples were taken to monitor key variables.

Push-tube core samples were taken after 6,050 hours (252 days) of cessation of deposition to determine the final dry density behaviour of the co-disposed mixtures. Figure 19 displays how the push-tube core results deviated from the calculated dry densities (assuming saturated soil conditions). This indicates the presence of air entry into the soil matrix.

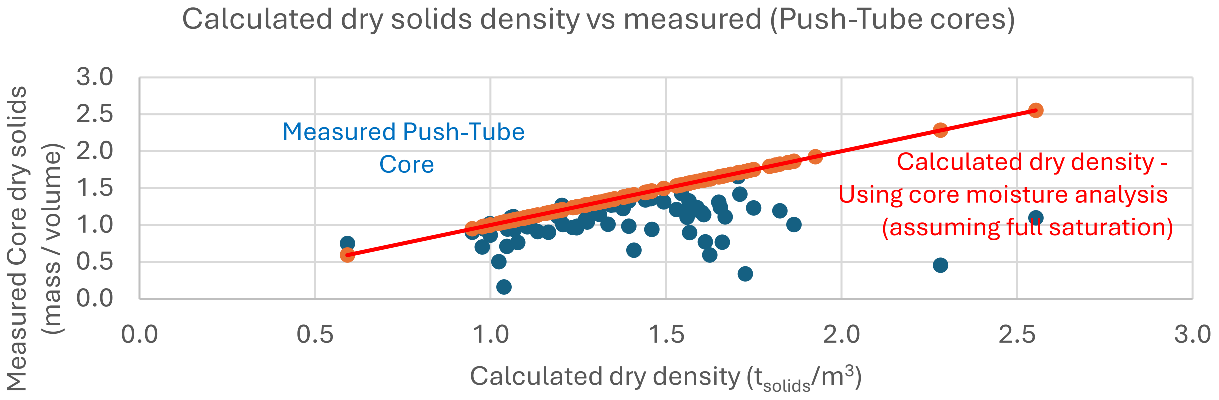

Figure 19 Indication of air ingress – deviation of measured drillcore versus calculated dry densities

Polymer dosages recorded in the laboratory and IBC trials of 500 g/tonne of metallurgical fines were confirmed in the larger-scale field trials and allowed confidence into the detailed design process.

Figure 20 indicates the measured solids composition and volumetric consolidation (excluding bleed water in the first 24 hours) after cessation of deposition.

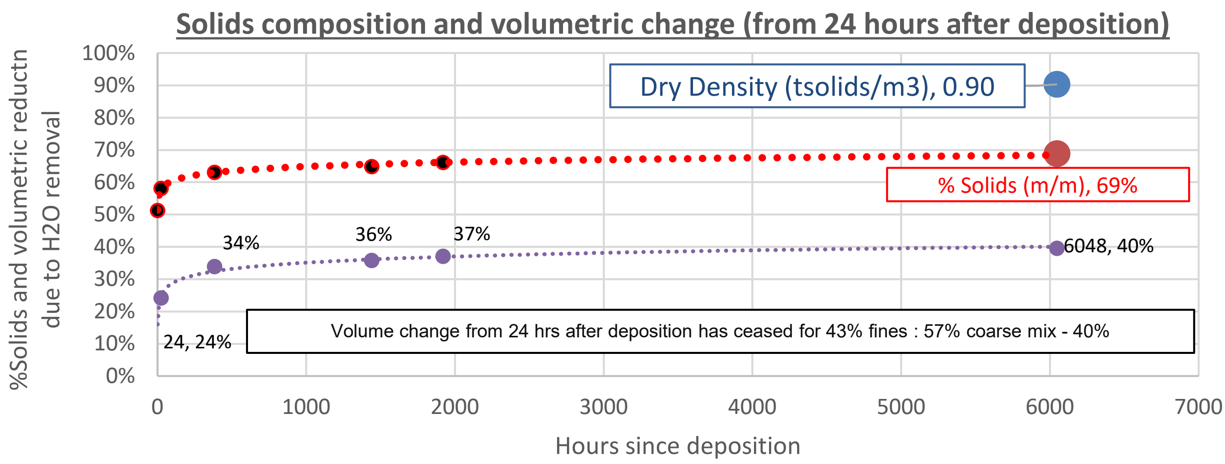

Figure 20 Co-disposed field trial consolidation, solids concentration and final dry density measurements

4 Conclusion

Optimal mixing of co-disposal mixtures and polymers became limiting as the fines-to-water ratio increased and slurry viscosity influenced effective mixing.

Dewatered polymer-assisted co-disposed material seemed to tend towards a constant water-to-fines ratio in the consolidated mixture after deposition. This relationship seemed independent of varying compositions of fines and coarse material. The water-to-fines ratio points to the retained or associated water on the clay fines particles. It is noted that a water-to-fines ratio of 3 was achieved during field trials compared to the laboratory findings of 4.5. This points to efficiency of mixing of the fines and polymer during inline dosage. Future work would include the determination of the methylene blue index as a measure of the polymer demand and to quantify expected clay associated surface water.

The mine site 2 field trials using the Delchem KT220 polyacrylamide, were able to dewater a mixture of 43% fines and 57% coarse tails to 0.9 t/m^3 dry density after 252 days, and yet still have enough inter-particular voidage to promote air entry. Excluding removal of free bleed water in the first 24 hours, the solids volumetric consolidation post deposition was found to be 40%.

The polymer consumption was determined to be 500 g/tonne metallurgical fines.

The mine site 1 AMC field trials indicated improved mechanical consolidation of fines at depths of at least 1 m with inferred final dry densities of 0.79 t/m^3.

The fines material liquid limit is a key parameter when determining the extent to which material can be dewatered without accumulation of viscous layering on the scroll surfaces. The material in the MS1 field trials indicated that a period of evaporative desiccation would be required to dewater the material beyond its liquid limit.

MS1 material subjected to site-specific A-pan evaporative conditions indicated that the optimum pour depths of 35 cm with 4–5 passes per pour ensured the maximum distance and speed utilisation of the scroller.

The benefits of multiple thin-layer deposition cycles are that, as the scroller imparts stresses into the mud at depths of at least 100 cm, it repeatedly facilitates the restoration of multiple consolidation events on each pass.

The AMC field trials confirmed the stirred bucket trial findings of an expected solids content improvement from 28 to 40 %m/m, attributable only to the mechanical consolidation process over a period of 52 days.

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