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A New Approach to Bauxite Residue Dry Stacking: Utilizing Ciba® RHEOMAX™ ETD Technology

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1 INTRODUCTION

Most mineral tailings are transported as slurry via a pipeline to a designated storage area. In principle, the aims of above ground tailings storage are to contain the tailings, consolidate these tailings to maximise storage efficiencies, aid rehabilitation, and maximise water recovery via efficient drainage and decant systems. Recent advances in tailings management have focussed on thickening of the tailings prior to deposition in the storage area to aid both consolidation and water recovery (Jewell et al, 2003). This is commonly referred to as "thickened tailings disposal" or "sloped deposition". These systems rely on thickened slurry, which can be deposited in relatively thin layers on a sloped bed, allowing consolidation via both gravity drainage and solar drying.

Over the past decade, significant advances have been made in the technology associated with thickening dilute slurries (Arbuthnot et al., 2005; Crozier et al., 2005). Thickeners have become more efficient and flocculants more effective. These advances have aided the development of thickened tailings disposal, making the process more affordable. Many new tailings storage facilities are now adapting the process to their specific needs.

Ciba Specialty Chemicals has developed a range of rheology modifying products, which could play an important role in this type of tailings management process. These products modify the surface properties of the tailings when added to a slurry at point of discharge. The application known as Ciba® RHEOMAX™ ETD technology has been investigated on a range mineral of ore types at both laboratory and operational scale.

Alcoa World Alumina Australia (Alcoa) currently produces bauxite tailings (referred to as residues), which are separated into coarse and fine fractions by cyclones. The coarse sand fraction is used for drainage layers, perimeter embankments, and final capping of the storage areas. The fine mud fraction is stored via a method of thickened residue disposal called "dry stacking". This utilises a large diameter super thickener to dewater the fine residue, producing a high density underflow slurry of around 45 to 50% solids w/w. The thickened residue slurry is pumped to one of a number of drying beds and deposited in layers of up to 0.5m in depth. The yield stress of the mud and the slope of the bed are designed to allow for an even distribution of slurry across the bed.

The fine residue dewaters through a combination of drainage and evaporative drying to a final dry density of around 70% solids w/w. Alcoa also routinely plough the mud with machinery to speed up the rate of moisture loss to evaporation and reduce the dusting potential from the drying beds. This process, sometimes referred to as "mud farming", is generally done using a swamp dozer or amphirol (Cooling et al., 2002).

This paper provides an overview of testing with Ciba® RHEOMAX™ ETD technology at Alcoa World Alumina Australia's Western Australian refineries, and describes how this rheology modifier might be used to enhance the current storage processes.

2 APPLICATION TO BAUXITE RESIDUE

The technology involves the addition of rheology modifier in the form of a polymeric solution prepared in a way similar to that of conventional polymers for use in thickening applications. The rheology modifier is added to a dilute residue slurry and mixed under low shear to form large solid aggregates surrounded by free liquor. The process produces free liquor which can be rapidly decanted or drained forming a high density settled slurry.

Ciba Specialty Chemicals conducted the following small-scale rheology modifier trials at Alcoa's Western Australian operations:

- Superthickener bypass at the Wagerup residue area – testing was on a dilute slurry of the fine mud residue only.
- Sand separation plant bypass at the Pinjarra residue area – testing was on a slurry consisting of a combined sand and fine mud residue stream.

The aim of the trials was to modify the dilute slurry such that it would settle rapidly, producing a layer of settled residue that would consolidate and dry as well or better than thickened residue, thus allowing a dilute slurry to be deposited directly into the drying beds without compromising the normal drying bed operation. The following were key parameters of the trial:

- Determine the effect of rheology modifier dose rate, concentration and mixing dynamics.
- Determine the rate of increase in density and strength of the material deposited in the drying bed.
- Observe the clarity of decant water produced.

2.1 Scope of the trial – Wagerup superthickener bypass

Testing on a dilute stream of fine mud residue was done at Alcoa's Wagerup refinery. Slurry was treated and deposited for a period of 24 hrs at an average mass flow rate of 157 tonnes/hr. A walkway extending into the deposition area was constructed from scaffolding to allow for progressive sampling and shear vane testing after deposition.

The rheology modifier was added into the discharge pipe 10m before deposition allowing for the formation of large aggregates. Two dosage points in the main feed line were used to precondition the mud as shown in Figure 1. The batching equipment used for the trial is shown in Figure 2. A schematic layout of the process is shown in Figure 3. The dosage of rheology modifier averaged 177 g/tonne dry solids over the duration of the trial.

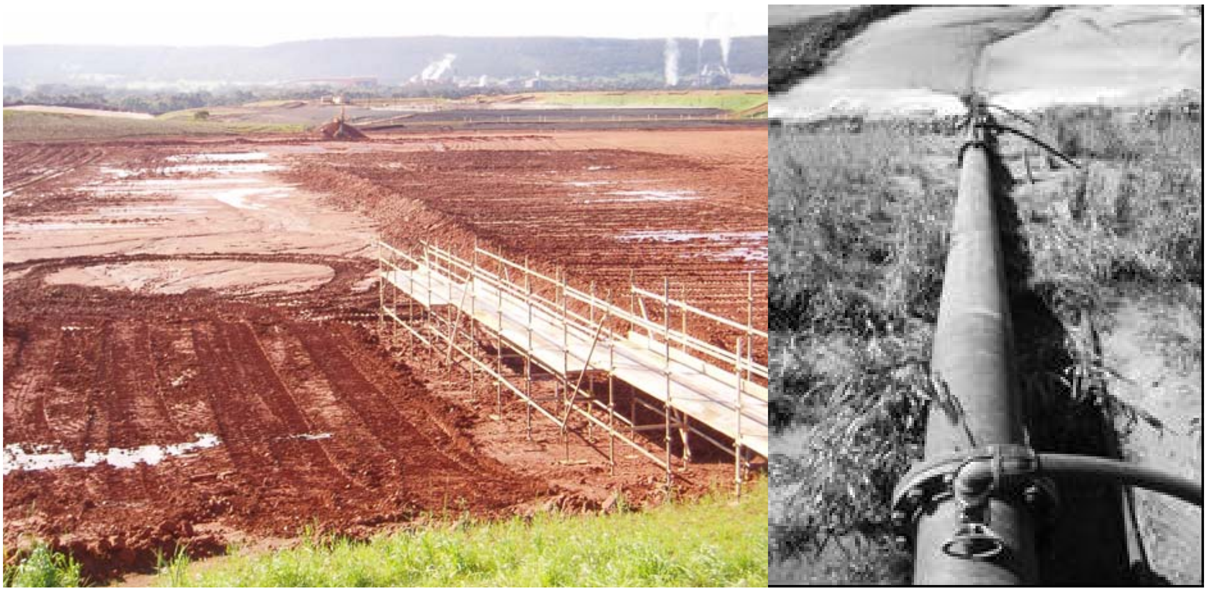

Figure 1 Deposition bay and dosing points in main feed line

Figure 2 Rheology modifier batching equipment

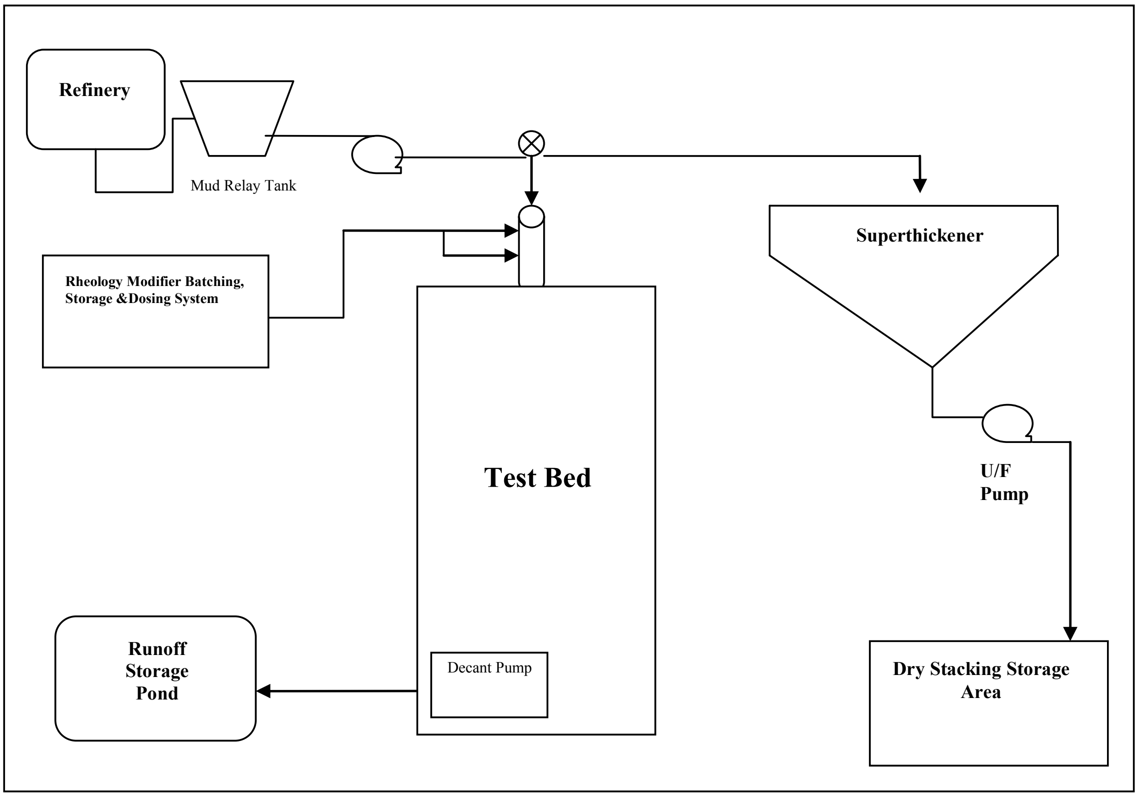

Figure 3 Schematic layout of rheology modifier test area at Wagerup

2.2 Scope of the trial – Pinjarra sand plant bypass

Testing was also done on dilute slurry consisting of both coarse residue and fine mud at Alcoa's Pinjarra refinery. A small test area measuring 30 m x 80 m x 3 m deep was constructed for this co-deposition trial. The duration of the trial was 38hrs at an average mass flow rate of 50 tonne/hr. The rheology modifier was added into the discharge pipe 10m before deposition allowing for the formation of large aggregates. The rheology modifier dosage averaged 140 g/tonne dry solids over the duration of the trial. Deposition was staged which allowed the deposit to drain overnight. The longest continuous run was on the last day with dosing for 28 hrs uninterrupted. Figure 4 shows a schematic layout of the process.

3 RESULTS

3.1 Trial details - Wagerup superthickener bypass

The rheology modifier was added into the dropper near the open launder discharge. Given the short duration of the trial, alternative dosing points were not investigated; however the dosing point was determined from prior experience on a similar application. A split dosing arrangement was used with the first addition point 5m from the end of the pipe and the second point was a further 5 m away. The average mixing time was approximately 3 to 5 seconds.

It was noted that formation of aggregates appeared to improve when the residue was discharged into a plunge pool, situated at the end of the launder. It is possible that addition of rheology modifier even closer to the end of the pipe, or into the plunge pool directly, would reduce reagent consumption. Figure 5 shows the effect of mixing in the plunge pool and the large aggregates and clear decant formed upon dosing. Solids settled from the slurry at the deposition point providing a slope for increased liquor drainage. Clean clear liquor was observed to be skimming the surface when the correct dosage was applied. At the toe of the deposited residue, clean decant was exiting the decant pump. During normal bypass into the same area, the decant would contain a considerable amount of suspended solids.

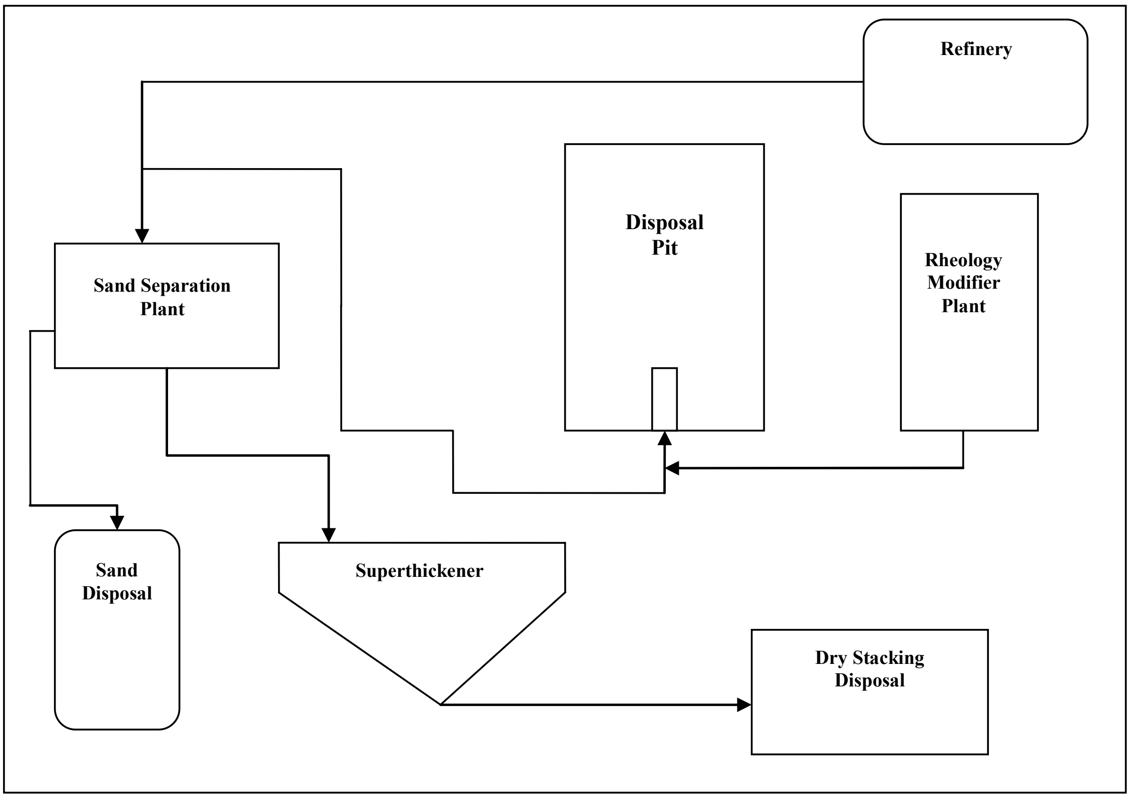

Figure 4 Schematic layout of rheology modifier trial at Pinjarra

Figure 5 Mixing plunge pool, liquor drainage, and decant

The total mass of residue deposited into the test area was approximately 4000 tonne. The dosage averaged 177 g/tonne dry solids over the duration of the trial. The dosage was slightly higher than the laboratory determined dosage of 150 g/tonne due to a lower than expected bypass feed solids from the refinery. The reported SG for fine residue was in the range of 1.14 to 1.19 providing an incoming residue stream of 22 to 27% solids w/w, which was lower than the nominal target of 30% solids w/w. Figure 6 shows the deposition bay in the final minutes before shutdown.

Figure 6 Deposition bay during trial and 2 days later

The solids settled rapidly from dilute slurry, creating a layer of residue of similar appearance to a layer of slurry discharged from the super thickener. The initial layer depth was not measured, but was estimated to be around 700 mm deep. The rate of increase in density and shear strength were determined from moisture content measurements made via core sampling and vane shear testing through the depth of the deposited material. Measurements were taken at four locations along the scaffolding, as depicted in Figure 7. The core sampling revealed rapid drainage to around 50% solids w/w after two days, increasing to over 60% solids w/w after two weeks. Drying was then slower, controlled by evaporative losses. Table 1 shows measurements of shear vane strength and percent solids.

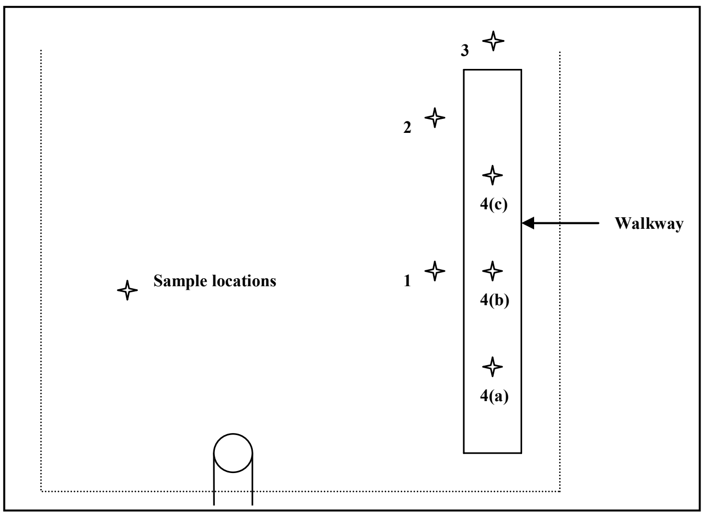

Figure 7 Sample locations along walkway

Table 1 Core sample data

		Test Site 1		Test Site 2		Test Site 3		Test Site 4	
Date	**Days**	**Strength** (kPa)	**Density** (% solids)	**Strength** (kPa)	**Density** (% solids)	**Strength** (kPa)	**Density** (% solids)	**Strength** (kPa)	**Density** (% solids)
10/08/2005	1	1	53	1.5	50	1	47		
11/08/2005	2	2	49	2	52	2	49		
12/08/2005	3	2	55	4	55	3	52		
15/08/2005	6	2	54	4	56	4	55		
18/08/2005	9	3	55	6	57	5	58		
19/08/2005	10	4	59	6	60	6	61		
23/08/2005	14	6	62	9	64	9	64		
24/08/2005	15	7	60	11	63	12	60		
09/09/2005	31							23	63
09/09/2005	31							20	62
09/09/2005	31							21	63

The layer was ploughed with a dozer after 15 days, after which testing of density and shear strength was made much more difficult. A fourth test location under the scaffolding was left undisturbed, and density and strength measurements at this site were made after 31 days. Figure 8 shows the ploughing of the drying layer by dozer.

Figure 8 Ploughing by Swamp Dozer

On each of the density and strength plots (Figures 9, 10 and 11), a typical density and strength gains is shown as a dotted line. This is the rate determined from previous testing at Kwinana on thickened residue deposited to a similar layer depth and at a similar time of year (Bodley et al, 2003). Although a direct comparison cannot be made, it indicates that the rate of density increase, and the strength of the residue as a function of density, is similar to that which might be expected from a thickener underflow slurry.

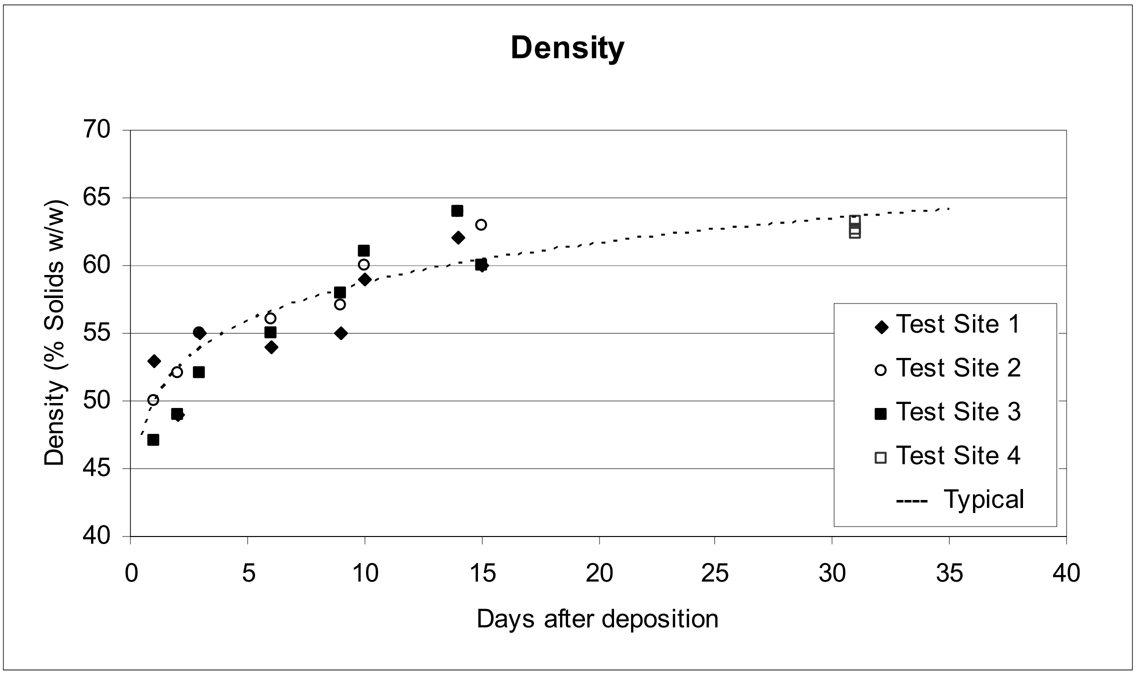

Figure 9 Density testing from core samples

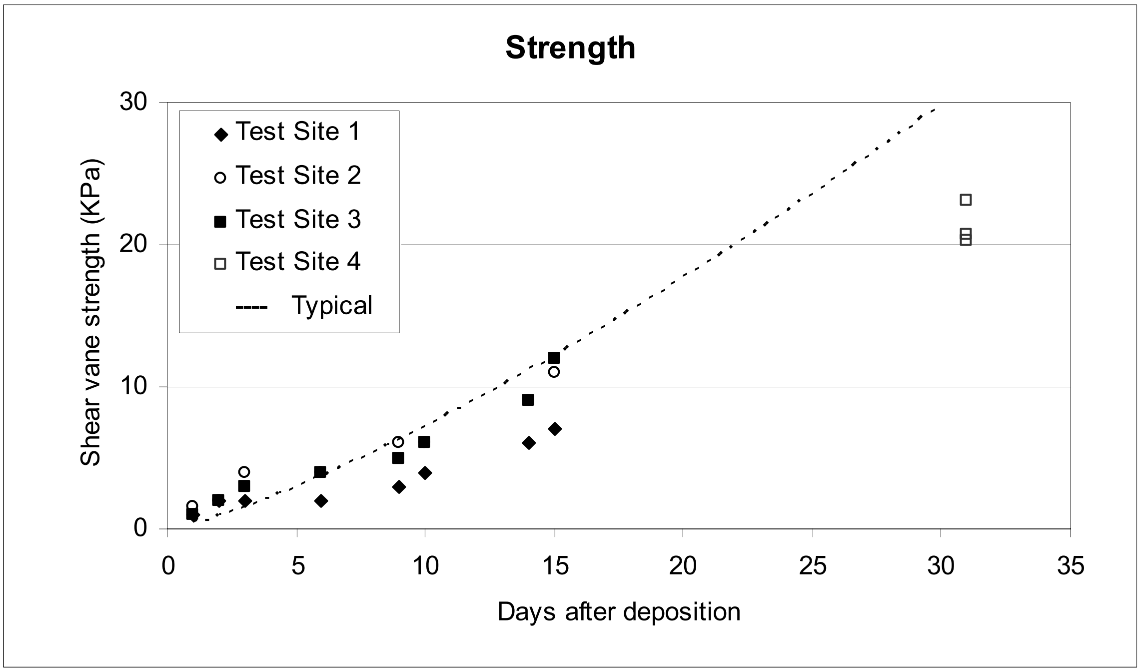

Figure 10 Shear vane strength measurements

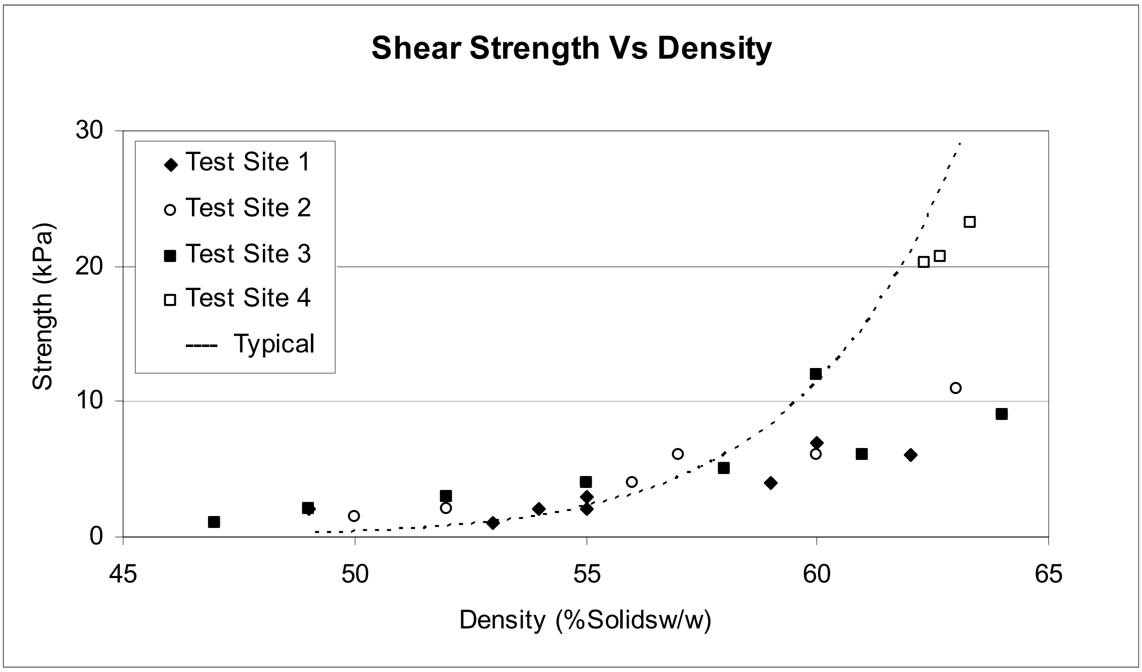

Figure 11 Density as a function of strength

3.2 Trial details - Pinjarra sand plant bypass

The total mass of residue deposited into the test area was approximately 1900 tonne discharged at 40% w/w solids from the refinery. The dosage averaged 140 g/tonne of dry solids over the duration of the trial. Access by foot near the head of the deposit during the last stages of deposition was an indication of the strength of the deposit. Samples along the face of the deposit were cored to a depth of 600 mm at locations as indicted in Figure 12. The deposit drained rapidly over the first three days, enabling foot access to much of the deposited material (Table 2). An excavator was used to open an inspection trench across the deposited material. While some of the coarse material was well mixed with the fine mud fraction, there were obvious lenses of coarse sand through the deposit.

After 3 days, the core results indicated a density of 75% solids w/w at the beach and 63% solids w/w along the sides and lower slopes of the test area. After 11 days, the majority of the test area had also reached 75% solids w/w. It should be noted that these density measurements cannot be compared directly to density measurements made on the fine mud fraction only. The presence of sand with the mud, and inclusion of discrete sand lenses in the core samples, will give a much higher density measurement. However, the presence of the sand lenses will certainly aid drainage and consolidation of the deposited material.

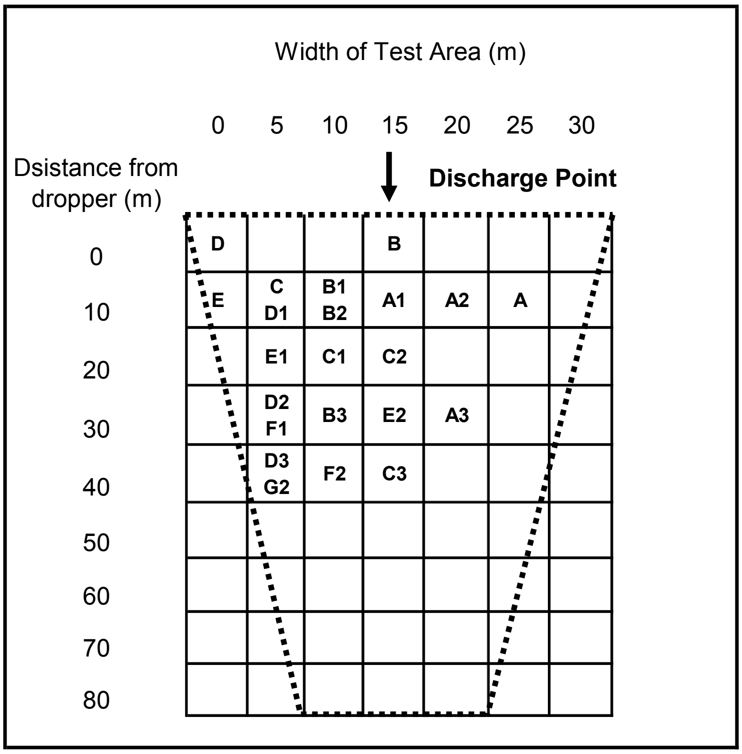

Figure 12 Core sampling locations

Table 2 Core sample data

	Core sample positions (%Solids w/w)						
3 days	***A*** 67	***B*** 80	***C*** 76	***D*** 64	***E*** 62	***F*** 67	
11 days	**A1** 74	**B1** 74	**C1** 75	**D1** 74	**E1** 74	**F1** 71	
17 days	**A2** 71	**B2** 73	**C2** 75	**D2** 65	**E2** 69	**F2** 70	**G2** 68
24 days	**A3** 74	**B3** 71	**C3** 75	**D3** 71			

The sand lenses were obvious through the full extent of the deposited material, although they were thinner and less pronounced at the down slope ends of the test area. It is not known how extensive this layering effect would be on a full scale deposition area. There could be a beaching effect close to the drop point where layering occurs, but only fine mud with no layering further down a full scale slope area. Larger scale testing would need to be undertaken to determine the extent to which the sand and mud are retained as a homogeneous mix and the extent to which sand layering occurs.

4 CONCLUSIONS

Testing with Ciba® RHEOMAX™ ETD has been carried out on two different dilute slurries. In the first set of trials, the rheology modifier was added to a 30 % w/w dilute slurry of fine mud. The rheology modifier was shown to be very effective in producing large aggregates which settle rapidly, forming a sloped beach from which drainage water would readily escape. The drainage water was clear, free of suspended solids. The resulting layer of settled solids was monitored for strength and density gain, and was found to exhibit similar drying characteristics as a layer of slurry thickened via a conventional super thickener. This offers significant opportunities within the current operation. When the thickening facilities are off line for any extended period, the dilute feed slurry to the thickener can be bypassed, and can continue to be deposited into the drying beds without interfering with the overall dry stacking processes. In the longer term, it may be possible to utilise the rheology modifier to develop processes for dry stacking of a dilute slurry feed without the need for a thickener. However, significant work is still required to confirm deposition behaviour, density increase and strength development on a full scale operation. Consideration will also need to be given to the management of the significant quantities of drainage water to be recovered from the deposited slurry, and the effect of this drainage water on the overall deposit stability.

In the second set of trials, the rheology modifier was added to a 40% w/w dilute slurry of the combined sand and mud fractions. Some co-settling of the mud and sand was observed, but more significantly, there were discrete layers of the coarse sand fraction left through the deposited material, providing horizontal drainage paths for rapid dewatering of the deposited material. It is not known to what extent the co-settling of fine and coarse materials or formation of sand lenses will occur on a full scale operation. However, the testing does suggest that there may be opportunities for alternative deposition strategies to the current approach which requires initial separation of the coarse fraction from the total slurry, and then thickening of the fine fraction to a consistency suitable for deposition onto drying beds.

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