

# Evaluation of the rheology of pipehead flocculated tailings

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## Abstract

*Pipehead flocculation is now a realistic option for mining tailings dewatering and disposal. However, for beach slope prediction, it is of fundamental importance to gauge the impact that pipehead flocculation could have on the rheology of the agglomerated tailings material, and how this might change after extended periods of shear as the agglomerated material flows down the beach. To this end, the laboratory of ATC Williams was requested to conduct a programme of laboratory testing of mine tailings samples. The objective was to provide information on the rheological properties of pipehead flocculated tailings samples. For this exercise, two different tailings samples were used, and two different types of flocculants were used. The overall aim of the study was to obtain rheology for the purpose of predicting beach slopes. In order to achieve this, rheograms were obtained after varying time periods of sample pre-shear, so that any change in flow characteristics as the tailings flowed down the beach could be ascertained. For the first tailings material, for both flocculants, the rheological behaviour was essentially very similar for each test. Furthermore, there was no evidence of structural rebuild of the polymeric agglomerates. The second tailings sample material was sensitive to both flocculant type and shear history. This material showed evidence of structural rebuild of the polymeric agglomerates. Possible reasons for the fundamentally different behaviour are discussed. It is concluded that pipehead flocculation is a viable option, but needs to be evaluated for each material and flocculant type.*

## 1 Introduction

The subject of this paper is tailings rheology from a proposed iron ore mining project. In the design for the new tailings storage facility for this project, it is proposed that a pipehead flocculation system will be implemented. In order to confirm the beach profile it is critically important to have a good understanding of the full rheology of the tailings material, as well as any possible time-dependent effects of the rheology of the tailings material as the tailings flows the full length of the beach deposit area. Mizami et al. (2014) investigated polymer-amended tailings and have emphasised the importance of the full rheology for predicting deposition geometry. They (ibid) have also reported that significant recovery of structure can occur as material flows away from the deposition point. Guang et al. (2014) conducted several testing programmes for the application in-line polymer addition for tailings disposal and reported that polymer selection is both site-specific and operation-specific. They also reported yield stress reduction as the tailings flowed across the tailings beach.

Preliminary laboratory testing was conducted in order to identify the optimum flocculants (four were initially screened), and assess the required dose rates. This work was aimed primarily at yield stress determination. This is useful, but for an accurate beach slope evaluation a full rheogram is a required input. This initial laboratory testing showed that the yield stress is sensitive to shear. This suggests that the rheology has time/flow-dependent properties and is likely to change as the tailings flow down the beach, and the design assumption of a (close to) uniform beach slope may not be correct.

It was therefore proposed to build on this initial test set to provide full rheograms and additional data on the time-dependent shear rate degradation of the flocculated slurry. These results will then provide input data for a full analysis of beach slope.

This paper covers the execution and analysis of rheology test work for this project.

The scope of the test work programme for this investigation was as follows.

- Two flocculant types were used.
- Testing was carried out at just one solids concentration (68%).
- One flocculant dose rate was used for all the tests.
- Full rheogram rheology testing was conducted, not just yield stress, at each test point using a Haake rheometer.
- Samples were tested after low-shear (to represent beach flow) mixing time periods of 0 s, 20 s, 40 s, 60 s, 120 s, 300 s, 600 s, in order to detect and measure any rheological effects induced by the flow down the beach.

The results are presented in this paper.

## 2 Sample preparation

Several samples were received from the initial exploration at the proposed mine site. After the initial testing results were known, Sample A and Sample B were selected for rheological testing, as they were coarsest and finest samples, but otherwise very similar.

### 2.1 Particle size distribution and density

A particle size determination was carried out on a sub-sample of all four initial samples in accordance with AS 1289.3.6.1 (Standards Australia 2009d). The results of this analyses are plotted in Figure 1. Sample A and Sample B are the coarsest and finest samples respectively, although it is apparent that all samples were very close. Sample A had 31.3% passing 38 microns, while Sample B had 36.9% passing 38 microns.

A sub-sample was taken and was tested in accordance with AS 1289.3.5.1 (Standards Australia 2006). The particle density measured was 3.37 t/m<sup>3</sup> for both samples.

### 2.2 Atterberg limits

This test is a semi-empirical test to measure the plasticity of the fines component of a sample. ATC Williams carry out this test routinely to allow cross correlation with other test results.

Sub-samples were taken from all four samples and tested in accordance with the following Australian standard test methods:

- AS 1289.3.1.2 (Standards Australia 2009a) – liquid limit (one point Casagrande method).
- AS 1289.3.2.1 (Standards Australia 2009b) – plastic limit.
- AS 1289.3.3.1 (Standards Australia 2009c) – calculation of the plasticity index.

The results of the testing are shown in Table 1.

**Table 1 Atterberg limits**

Sample description	Liquid limit	Plastic limit	Plasticity index (%)
Tailings Sample A	18	16	2
Tailings Sample B	23	21	2

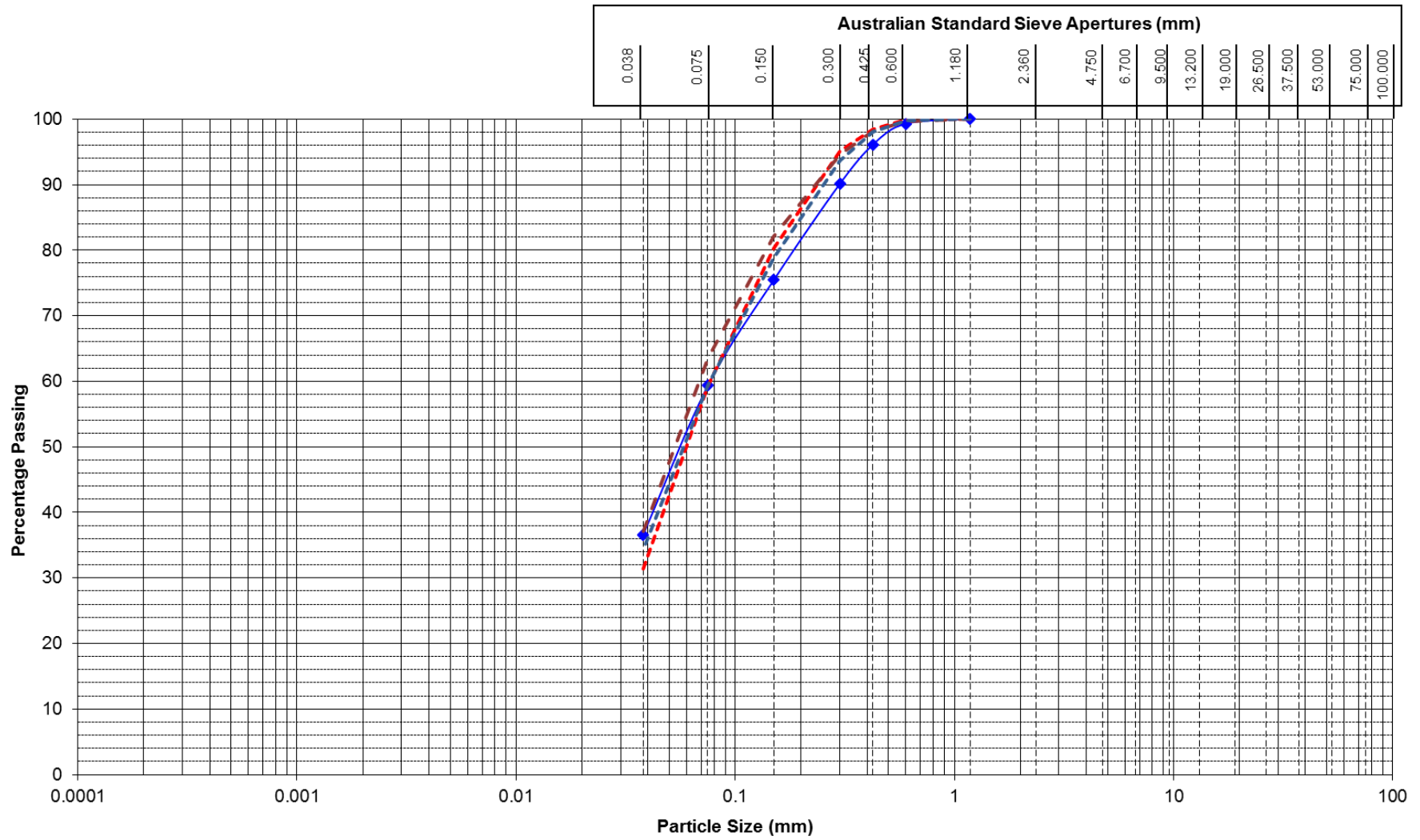


Figure 1 The particle size distribution results

### 3 Rheological sample preparation

#### 3.1 Sample pre-flocculation

As no decant water was available, sufficient water which was chemically equivalent to that expected as decant was prepared for sample pre-flocculation and solids concentration adjustment. Apart from the usual aspects of pH, etc., a relatively high salt content was required with salt at a dose rate of 5,500 mg/L.

Both tailings samples were diluted to a solids concentration of 10% in a large tub. The sample was mixed to a uniform slurry and flocculated using the plant flocculant at a dose rate of 15 g/t. The samples were allowed to settle overnight before decant was removed, so that no fines were lost. Each sample was adjusted to a solids concentration of 68%.

#### 3.2 Sample pipehead flocculation

Two types of flocculant were tested on both the tailings samples for pipehead flocculation. The flocculants tested will be nominated as Flocc1 and Flocc2 which were obtained from the manufacturers just prior to testing. Both flocculants were prepared at a concentration of 0.5% in glass jars and mixed using a bottle roller until there were no observable 'fish eyes'.

The sample at 68% solids concentration was mixed to a uniform state and 383.7 g of slurry was sub-sampled into a 250 ml beaker. This sub-sample was poured into a second beaker while a pre-measured amount of flocculant (1.83 ml) was injected into the stream using a syringe. This dose rate is equivalent to 35 g/t. The sample was then poured back and forth between beakers a total of nine times and immediately tested in the rheometer. As stated earlier, this dose rate had been determined and optimised in the preliminary studies to attain the best water release.

### 4 Rheology

The rheology flow curve testing was carried out using a Thermo Haake VT550 Viscotester. An FL100 shear vane measurement system in a 250 ml beaker of pipehead flocculated sample was used for vane in cup measurements, as per the methodology and data reduction approach in Sofra et al. (2007).

Where required, the samples were pre-sheared at a shear rate of  $50 \text{ s}^{-1}$  for the required time and immediately following on from this the tests were run from a shear rate of  $10 \text{ s}^{-1}$  ramping up to a shear rate of  $100 \text{ s}^{-1}$  over 140 seconds using a linear distribution and then ramped back down to a shear rate of  $0.1 \text{ s}^{-1}$  over 140 seconds also using a linear distribution. The up ramp on some of the first tests performed were started at a shear rate of  $30 \text{ s}^{-1}$  to try to limit the amount of shear occurring in the sample before data was gathered in the shear rate range expected on the tailings beach, however, after these initial tests it was decided to start the up ramp at a shear rate of  $10 \text{ s}^{-1}$ .

Many of the rheograms are characterised by sharp initial shear stress peaks. Since the overall objective of the rheological characterisation was to provide rheological input for the beach slope modelling exercise, the region of the rheogram which excludes the sharp initial peaks was considered. The reason for this is that the material on the beach has already overcome the shear rates and shear stresses required to flow far enough to become part of the flowing beach material.

The Bingham Plastic Rheological Model was used to characterise the tested materials. This approach will provide values for the yield stress and plastic viscosity in each case. These rheological parameters can then be used as inputs for beach slope prediction.

#### 4.1 Rheological characterisation for Tailings Sample B

For Tailings Sample B material, for both flocculants, the rheological behaviour was essentially very similar for each test. Furthermore, there was no evidence of structural rebuild of the polymeric agglomerates. In

this context, structural rebuild refers to the process of re-agglomeration as the material flows, leading to increased viscous stress.

The results of the rheological characterisation for the Tailings Sample B with both flocculants are shown in Table 2.

**Table 2 Rheological characterisations for the Tailings Sample B with both flocculants**

Yield stress (Pa)	Plastic viscosity (Pa.s)
10	0.548

#### 4.2 Rheological characterisation for Tailings Sample A

Tailings Sample A was sensitive to both flocculant type and shear history. This material showed evidence of structural rebuild of the polymeric agglomerates.

The results of the rheological characterisations for the Tailings Sample A with Flocc1 are shown in Table 3.

**Table 3 Rheological characterisations for the Tailings Sample A with Flocc1**

Pre-shear time (s)	Yield stress (Pa)	Plastic viscosity (Pa.s)
0	33.2	0.278
20	14.3	0.439
40	25.1	0.574
120	35	0.699
300	30.5	0.870
600	30.5	0.995

It is important to restate here that many of the rheograms are characterised by sharp initial shear stress peaks. However, these sharp initial peaks have not been considered in the rheological characterisations, since the overall objective of the rheological characterisation was to provide rheological input for the beach slope modelling exercise, and the fact that the material on the beach has already overcome the shear rates and shear stresses required to flow far enough to become part of the flowing beach material.

The results of the rheological characterisations for the Tailings Sample A with Flocc2 after different periods of pre-shear are shown in Table 4. Figure 2 shows the rheogram for Tailings Sample A with Flocc2 after 20 s of pre-shear.

**Table 4 Rheological characterisations for the Tailings Sample A with Flocc2**

Pre-shear time (s)	Yield stress (Pa)	Plastic viscosity (Pa.s)
0	24.2	0.511
20	22.4	0.412
40	41.2	0.394
120	41.2	0.457
300	37.7	0.879
600	33.2	0.798

The rheological characterisations presented in Tables 2, 3 and 4 can now be used as inputs for the beach slope prediction exercise.

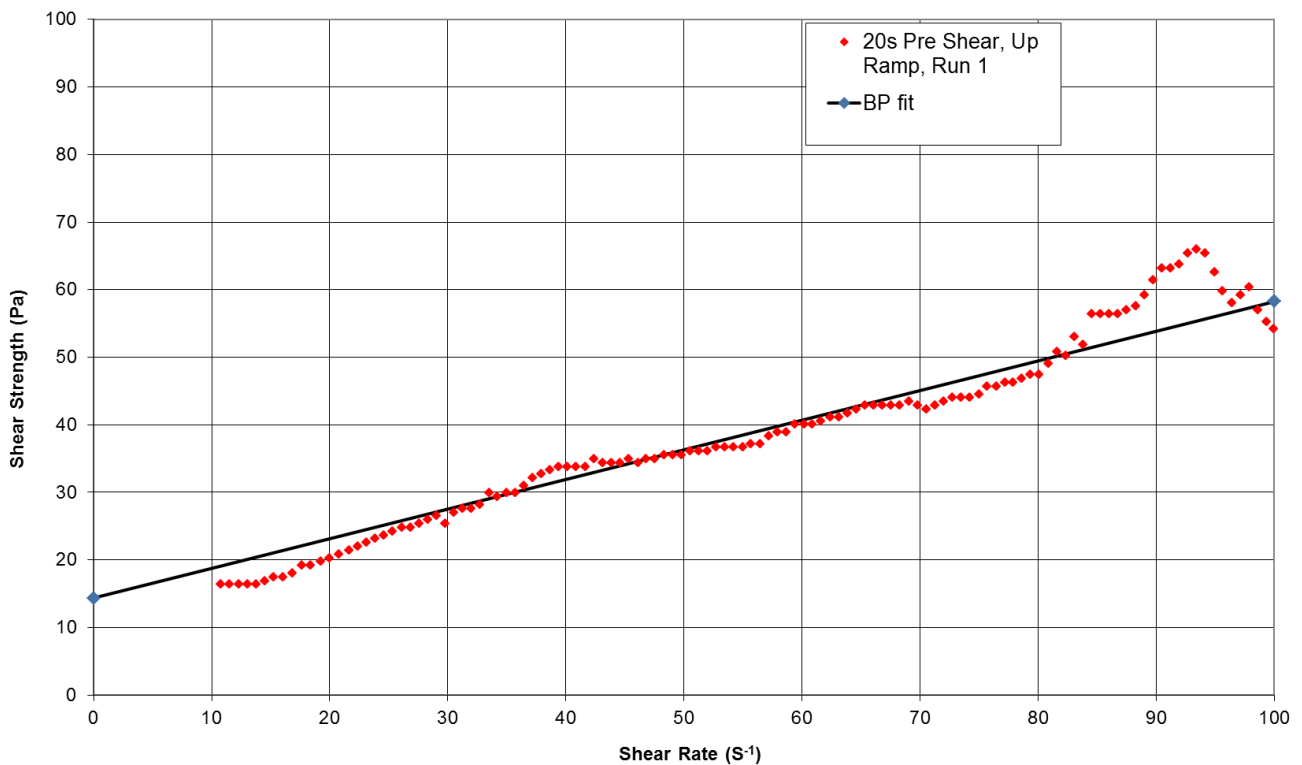


Figure 2 Rheogram for the Tailings Sample A with Flocc2 after 20 s pre-shear

## 5 Discussion

The rheological test work performed for this investigation has shown that both samples exhibited marked initial loss of shear strength during the pre-shear phase.

In the post pre-shear phase Sample A was sensitive to both flocculant type and shear history, whilst Sample B showed neither of these. It is important to restate that both samples were treated identically during all stages of this investigation.

From the other measurements performed for this investigation, the main differences in the properties of the two samples is that Sample A contained more marginally coarser material and had lower liquid and plastic limits than Sample B.

Arguably, the principal issue is that Sample A showed evidence of structural rebuild of the polymeric agglomerates during shear flow. Issues such as excess polymer usage and/or ineffective polymer conditioning can effectively be ruled out, as both samples were treated identically during all stages of the process. Opposed to this, Sample B showed evidence of a more stable agglomerate structure which did not change under shear flow. This would imply that the presence of more fine material, and some degree of intrinsic plasticity will promote the formation of more stable agglomerate structures which can lead to higher shear stresses over time of shear.

It is important to quantify these issues, as they will impact directly on both tailings beach slope and beach shape. Furthermore, very little information in this area is available in the literature on this topic, and much further investigation to improve our knowledge in this area is required.

## 6 Conclusions

Two different tailings samples, and two different types of flocculants were used to obtain rheology for the purpose of predicting beach slopes. Rheograms were obtained after varying time periods of sample pre-shear, so that any change in flow characteristics as the tailings flowed down the beach could be ascertained. For the Sample B material, for both flocculants, the rheological behaviour was essentially very similar for each test. Furthermore, there was no evidence of structural rebuild of the polymeric agglomerates. The Sample A was sensitive to both flocculant type and shear history. This material showed evidence of structural rebuild of the polymeric agglomerates. It is concluded that pipehead flocculation is a viable option, but needs to be evaluated for each material and flocculant type.

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