Tailings2013

28 - 30 August 2013, Santiago, Chile
www.tailings2013.com • tailings@gecamin.com • Tel.: +56 2 2652 1514

ABSTRACT 61

DISCUSSION ON THE INFLUENCE OF MINERALOGY ON THE RHEOLOGY OF TAILINGS SLURRIES

Gordon McPhail
SLR Consulting Australia Pty Ltd

Marco Becerra
ASMIN Chile

Sergio Barrera
IVAN Chile

ABSTRACT

The influence of mineralogy and chemistry on the yield stress of tailings slurries is fundamental to solids liquids separation and forms the heart of the design of flocculating and coagulating agents used to promote thickening of the slurry. The chemistry determines the nature of positive and negative charges in the slurry suspension the effects of which are, in turn, affected by the van der Waals forces. What is not generally appreciated is the extent to which a slurry, once dosed with flocculant, thickened, and sheared, will still exhibit significant degrees of variability in the yield stress of the slurry. The authors have conducted extensive rheology testwork on a number of slurries that have shown unexpectedly high variation in rheological parameters. Such variability complicates the design and specification of thickeners as well as pumping and piping systems for the delivery of the tailings to the tailings storage facility. This paper revisits the definition and measurement of yield stress and provides an indication of the range of yield stresses that could be expected in slurries of problematic mineralogy.

INTRODUCTION

As mineral processing and tailings engineers we are fully aware that mineralogy is the key determinant of the extraction processes and tailings management methods appropriate to any given ore body. What is not generally appreciated by tailings engineers, however, is the importance of the proportion of clay minerals in the host rock containing the ore to be extracted. Process engineers will be all too aware that clay minerals have the ability to interfere with chemical reactions by using up reagents, clogging up leach tanks and thickeners, and in causing flocculation control problems. For most tailings engineers, however, it is just about getting the slurry at the required water content – once that is achieved the tailings beaching behavior is set. However, clay minerals, and in particular, active clay minerals, show this to be fallacious - they have the potential to seriously derail even the most careful and comprehensive of process plant, as well as tailings management system, designs.

This paper sets out the authors' experience from laboratory, pilot scale and full scale tailings assessments and observations over a range of projects and ore bodies with specific reference to the influence of active clay minerals. The paper begins with a brief summary of the groups of clay minerals and then explores the observed influence of these minerals on flocculation, yield stress, and thickener and tailings management. The paper is, by design, observation and experience-based and contains a minimum of hard data due to restrictions placed by the mining companies who own the data. However, the reader is assured that the observations and experience are grounded in an extensive suite of laboratory tests and measurements over some 15 projects in Chile, Australia and Southern Africa.

CLAY IN MINERALS

As geotechnical engineers we usually associate clay with highly weathered materials. The clay minerals are usually finer than 2 microns and show varying degrees of plasticity and swell depending on the exact nature of the clay mineral [Mitchell and Soga]. We would recognize four groups of clay minerals, namely:

- Kaolinites:
- Montmorillonites/smectites:
- Illites
- Chlorites

The clay minerals are all characterised by silicate sheets which would be bonded to aluminium oxide/hydroxide layers in varying numbers of layers sometimes with bonded water between the layers. Because the clay minerals are small in size they have a large surface area so even relatively small proportions of active clay can have a significant effect on the behaviour of a mass. The clay minerals absorb or lose water and can become plastic when mixed with water. The water bonds between the silicate layers causing active clays to swell on wetting or shrink on drying. Kaolinites, Illites and Chlorites would usually exhibit low activity whereas montmorillonites/smectites would be of high activity and prone to extensive swelling and shrinkage on wetting or drying respectively.

However, clay minerals may also be present in hard rock as hydrous layers of silicates and, on grinding, these minerals may be released and become active. In an ore body, the host rock mineralogy will determine the proportions of the various clay minerals and types of clay, for example, basalts are more likely to contain or lead to the development of a higher proportion of montmorillonite/smectites while granites are more likely to generate higher proportions of kaolinites. But it is common to have more than one group of clay minerals present.

The presence of clay minerals in rocks is usually determined using:

- X-ray diffraction
- Electron microscopy
- Infrared Spectrometry
- neutron diffraction analysis
- Differential .Thermal Analysis
- Chemical methods including potash determination, glycol absorption, and caution exchange analyses.

As geotechnical engineers we routinely specify Atterberg Limit testing on the tailings to determine if the tailings solids show plasticity and therefore may contain clay minerals.

The authors' experience is that there are high degrees of uncertainty when applying the above methods specifically to clay mineralogy. It is advisable to use a number of the methods and consider applying these methods over a number of laboratories in order to gauge the variability of the relative proportions of the clay mineralogy.

In a variably weathered ore body there is a higher probability of the host rock containing clay minerals. In addition, some host rocks may contain pockets or zones of different mineralisation so that from a mineral processing perspective "plugs" of higher clay content minerals may move through the processing plant as mining progresses.

INFLUENCE OF CLAY ON FLOCCULATION

When the clay minerals are released during milling and leaching these minerals will have a strong influence on flocculated behavior. Flocculation relies on the management of positive and negative van der Waals forces that dominate in the finer fractions of a slurry and these charges are determined by mineralogical components and molecular structure [Australian Centre for Geomechanics]. Since clays are fine and have a plate-bonded structure they will be particularly dominant. A wide range of flocculants exist and determination of which flocculants work most effectively for a given slurry is a complex mixture of art, science and empirical correlation. Moreover, flocculants that may work well when the clay content is low may not necessary be as effective if the clay content is high or the relative proportions of the various clay minerals varies.

It is common to make use of ore blending to try and dilute the effects of zones of rock with high proportions of clay minerals but there are limits to the practicality and reliability of blending. In designing mineral processing systems, and specifically flocculation systems, it is vital to develop an understanding of the influence of clay minerals and clay mineral variability on the behavior of the slurry and the reliability of achieving a specified percent solids in the slurry which, in turn, will influence the beaching characteristics of the slurry.

YIELD STRESS

Slurries flowing down a beach on a tailings storage facility will do so at a low shear rate, commonly between 2 and 20 reciprocal seconds (s^{-1}). This is in stark contrast to the shear rates that slurry transport engineers aim for in their pipelines – usually of the order of 400 reciprocal seconds. Either way the yield stress, defined as the intercept of the flow diagram on the shear stress axis, plays a vital role. Figure 1 shows a typical flow diagram or rheogram. The flow line indicated would normally be determined from a rotary viscometer and, in this case, represents a pseudo plastic shear thinning material typical of mill tailings.

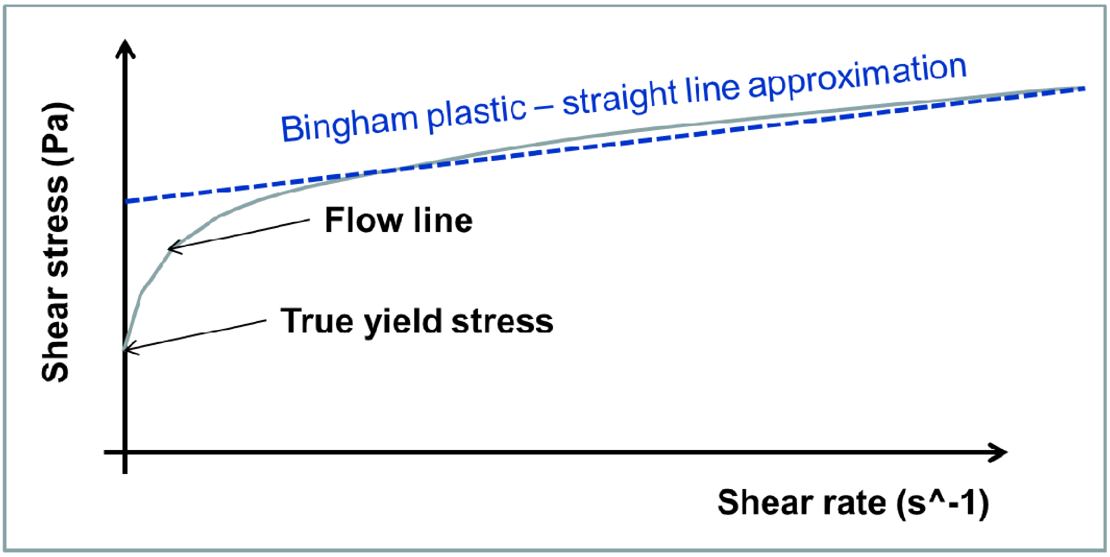

Figure 1: Typical flow diagram or rheogram

Also indicated on Figure 1 is the straight line that would often be used as an approximation for the flow line. This line would represent a Bingham Plastic with the slope of the line referred to as the Bingham viscosity and the intercept of this line on the shear stress axis referred to as the Bingham yield stress. This approximation is entirely acceptable for slurry transport design where the shear rates are within the approximately straight section of the true flow line. However, at low shear rates, such as occur when a slurry is beaching, the Bingham approximation is not sufficiently accurate.

While on the subject of yield stress it is worth noting that the common practice in the mining industry of determining the yield stress with single measurements using a vane rheometer is invalid. Certainly a vane rheometer will measure a peak stress as illustrated in Figure 2 but this peak stress is dependent on the rate of rotation of the vane. Moreover, because the vane test is unbounded ie the locus of the position of zero strain is unknown during the test, it is not possible to determine the shear rate. All vane rheometers have a default setting on the rotation speed and those rheometers that provide a shear rate usually base this shear rate on a default assumption that the locus of zero strain is one vane diameter from the edge of the vane. Since testing is usually done at the default settings the results are usually interpreted as yield stresses and the shear rates are taken at face value without understanding the implications of the default settings.

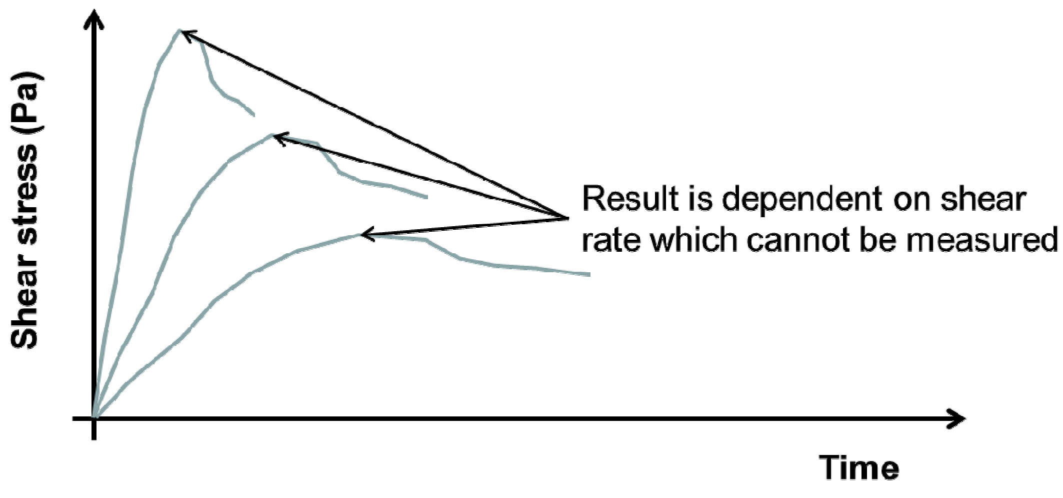

Figure 2: Typical results from a vane rheometer

There are methods for determining the flow diagram using a vane [Sofra et al] but these involve multiple tests at a range of rotational speeds as well as plotting the peak torque against the revolutions per minute (RPM) on log-log paper to determine the slope. Using this slope value the shear rate for a given shear stress can be estimated. This approach works well provided there is no settling out of the slurry during the test, a common issue with mill tailings.

The approach commonly used in industry, where one vane test is carried out with the rheometer on default settings is fine when evaluating the relative consistencies of slurries provided all comparisons are based on the same model rheometer and the same vane dimensions. However, the result is not a true yield stress, only a peak stress. In fact, back analysis of vane test data on one model of rheometer shows that on default settings the applied shear rate is approximately 250 reciprocal seconds.

The fact is that the true yield stress cannot be measured using any apparatus as, by definition, it is the shear stress at zero shear rate and there is no test that can be carried out at zero shear rate. The yield stress can, however be extrapolated from a rotary viscometer test or a flume test.

INFLUENCE OF CLAY ON YIELD STRESS

Regardless of how the yield stress or peak stress is estimated, whether on the basis of single vane shear measurements or using a rotary viscometer and deriving Bingham rheological parameters, the authors have found that the presence of certain clay minerals has a very significant effect on the estimate of true yield stress, a parameter that is vital for beach prediction. The authors have extensive pump loop and rheological test data on slurries containing a range of proportions of the four clay minerals and find that those slurries that have even a small proportion of smectites can show yield stress estimates that vary by a factor of 10 ie 1000% (for example from 30Pa to 300Pa), whereas slurries with low clay mineral contents, or a combination of the less reactive clay minerals, show variations of less than 10%. During the pump loop tests the percent solids on the slurries varied by less than 1% and temperature and particle size distribution testing verified that the effects of particle attrition as a result of re-circulation of the slurries in the pump loops were minimal. The variability in yield stress estimates is therefore entirely dependent on test accuracy and the influence of mineralogy.

IMPLICATIONS OF ACTIVE CLAY IN MINERALS FOR HIGH DENSITY TAILINGS

Given the above background, the implications of the presence of active clay minerals in mill tailings are very significant when it comes to the application of high density tailings management, a practice that is becoming increasingly necessary in the interests of saving water and embankment construction costs.

The first implication is that thickening the tailings slurry to a specified, high density, consistency will likely be difficult to control or unachievable. There are, unfortunately, a number of cases in the industry where the required slurry densities have not been achieved notwithstanding extensive pilot testing and careful process plant design. It is suggested that the presence of active clay minerals in these slurries may be a significant factor in the failure of the thickeners to perform. Given that it is almost certain that pilot scale thickener trials would have been conducted prior to full scale installation of the thickeners we can only deduce that, if the pilot scale thickeners were unable to pick up on the influence of the clay minerals, the sample used in pilot scale thickening was unrepresentative of the full scale operation. The implication of a loss of thickener performance is that if the required slurry consistency is not achieved the beach profiles in the field will be significantly flatter than predicted from pilot testing. This means that not only will the anticipated savings in water losses will not be achieved at the thickener but also that embankment construction costs to contain the tailings will increase dramatically compared with planned costs.

The second implication is that the yield stress of the tailings slurry with active clay minerals will be significantly more variable than slurries without the active clay minerals - even assuming the operators are able to bring the slurry consistency produced by the thickeners under control. Not only will the presence of the active clays induce variability but this will be further exacerbated by fluctuations in the proportion of clay minerals through the ore body. Low yield stress tailings streams tend to beach at a flatter angle so that there will be a tendency for the stream to trench down into tailings beached at higher yield stresses and for the stream to flow directly to the lowest part of the beach with minimal deposition along the way and build up at the confining embankment. Therefore, while water savings may be under control as a result of a controlled slurry consistency, embankment construction costs will be significantly increased.

CONCLUSIONS

Clay minerals are known by geotechnical engineers to be potentially problematic particularly active minerals such as montmorillonite/smectite. However these issues are commonly only anticipated by the engineers in weathered materials. But the fact is that these minerals may also be present in hard rock ores and they may become active on milling when they are released from the bonds that make up the host rock. Once released, they have the potential to cause significant problems in process control as well as in tailings management particularly where high density tailings management is being evaluated in order to reduce water losses as well as embankment construction costs. High density tailings management and specifically beach profile management is strongly dependent on the yield stress of the slurry, a parameter that is not only difficult to measure but which fluctuates widely in slurries that have even small proportions of active clay minerals.

The authors' experience is that it is vital, when evaluating the efficacy of high density tailings management, to understand the percentage of clay in the ore and, more specifically, to understand the relative proportions of the four groups of clay minerals in the ore body. This data will provide insight as to the proportion of active clay minerals such as montmorillonite/smectite and therefore the potential for thickening and tailings management problems. With this knowledge it will be feasible to explore with the mine planners and process engineers the extent to which it will be feasible to either:

- Blend the active clay content minerals so as to minimise the impact of the clays, or,
- Batch process ores with a higher proportion of active clay minerals and make appropriate provision for this batch processing on the TSF.

Both of these approaches will improve extraction efficiency as well as tailings management efficiency leading to higher revenues and lower costs.

Moreover, since all design is, inevitably, based on limited sample testing it will be vital to ensure that laboratory, pilot or full scale testing is based on samples that are representative of the extremes as well as the expected average conditions. The data gained from testing may then be interpreted against the mining plan and anticipated mineralogical variations as the ore body is mined.

As the saying goes, "forewarned is forearmed".

REFERENCES

Mitchell, J. K. and Soga, K. (2005) *Fundamentals of Soil Behaviour*, Publ John Wiley and Sons (3rd edition) pp 35 – 106.

Australian Centre for Geomechanics (2012) *Polymer Workshop*, Paste 2012, 15th International Seminar on Paste and Thickened Tailings, 16-20 April 2012, Sun City, Pilansberg, South Africa.

Sofra, F., Fisher, D.T. and Boger, D.V. (2007) *The bucket rheometer for thickened tailings and paste flow curve determination,* in Proceedings Tenth International Seminar on Paste and Thickened Tailings (Paste07), A.B. Fourie and R.J. Jewell (eds), 13–15 March 2007, Perth, Australia, Australian Centre for Geomechanics, Perth, pp. 249–258.