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Mineral Paste Comparison Between Copper and Iron Tails

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Abstract

Low-water content mineral tailings disposal has been the focus of study of many scientists, academicians, and engineers in the mining industry. In countries like Canada and Australia, several mineral paste tails disposal pilot and industrial scale test have been successfully carried out, both surface and underground. Chile is the world's largest copper producer and the main deposits are located in the country's driest region, therefore, the Chilean companies with concentration operations have focused on the use of sea water, such as Minera Esperanza project (given its favourable geographic location compared to other operations), or extra water recovery through tails thickening, that makes mineral paste technology attractive. Some companies have already undertaken preliminary studies and pilot tests, but in Chile, it is still a new technology. Brazil, South America's largest steel producer, has also worked on this idea. Some iron deposits have begun to dispose of their tails as mineral paste. These tailings contain a high iron concentration, as it could be expected in some Chilean copper deposits, located between regions 3 and 4. This work aims at comparing the properties of mineral pastes, such as consistency, fluidity and viscosity, from the samples studied in the UFMG, Brazil (high iron content), to recent studies conducted by UNAP, Chile, using Chilean tailings (high magnetite content).

1 Introduction

Currently, most tailings produced by the mining industry in South America, such as iron ore and copper plants in Brazil and Chile, are normally disposed of sub-aquatically in tailing basins. In some countries such as Australia, Canada, United States, and South Africa, tailings from mineral processing are disposed of in mineral paste form, for either subsequent surface disposal or the generation of "pastefill," used to fill up cavities of underground operations. This disposal alternative offers several technical, economic, social, and environmental advantages; namely, greater recovery of process water and thus a smaller environmental impact, especially if the footprint of the surface area required for disposal is taken into account.

It is very important to define the mineral paste concept. A mineral paste can be conceptually defined as a colloidal or almost colloidal system, that resembles a homogeneous fluid, in which size segregation does not take place, and if the material is disposed of smoothly on stable surfaces, it does not show significant water drainage. According to Araujo et al. (2004) aspects related to fluidity and consistency during the disposal of pastes can be determined by means of techniques such as flume and slump test. The cone slump test, that was originally used to determine the consistency of a mixture of concrete, is very much used at present time by the mineral industry. It can be employed to characterize that property in the case of pastes of underground filling and surface tailings. A conical geometry may also be used. The cylindrical shape, for its enhanced simplicity, and because it presents some advantages, according to some authors, as in Clayton et al. (2003) and Jung and Biswas (2002), is preferred however.

In the case of rheological characteristics, such as yield stress and apparent viscosity of pastes, it is very important to indicate the existence of a critical solid value concentration, above which, the increase of viscosity or yield stress becomes very significant. Obviously, depending on the material that constitutes the paste, this critical value of solids concentration may change significantly, as shown in the work of Sofrá and Boger (2002).

The visual aspect of a mineral paste used in mineral industry disposed of on an impermeable surface can be observed in Figure 1a according to Vietti and Dunn (2002). Figure 1b shows a laboratory cylinder of PVC and slump test applied to mineral paste, according to Hernandez et al. (2005).

The use of aggregates, as polymeric flocculants and coagulants, helps the solid-liquid separation process, generating a beneficial effect in the mineral paste production, for example improving the characteristics of fluidity or rheology of the system. The addition of flocculants, for instance, can affect the properties of mineral paste in different ways.

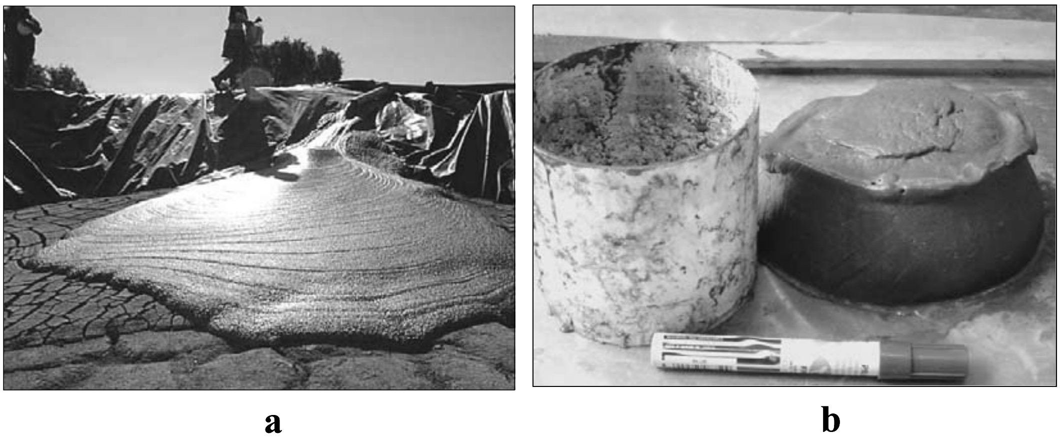


Figure 1 a) Surface disposal of industrial mineral paste, Vietti and Dunn (2002); b) Slump laboratory cylinder, Hernández et al. (2005)

In Figure 2, Boger (2003) shows, for example, the effect of adding different flocculants on yield stress, as a function of solids concentration.

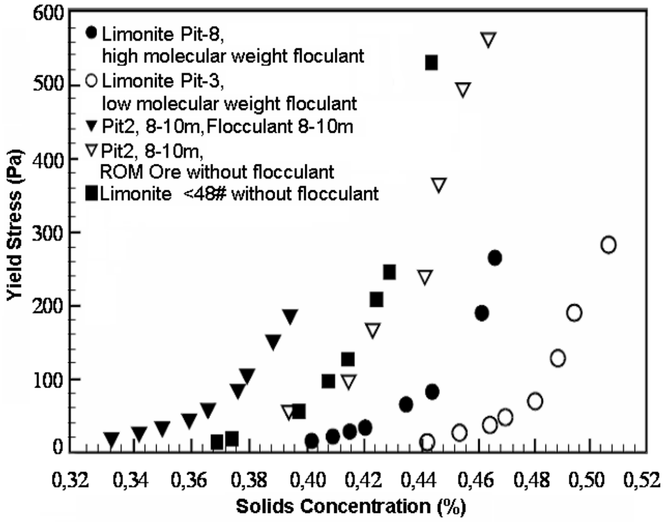


Figure 2 Flocculation effect on yield stress behaviour versus solids concentration (Boger, 2003)

From Figure 2 it can be observed that a greater addition of flocculant implies a greater water content (lower solids concentration) to produce a significant increase in the rheological response expressed as yield stress. This indicates an increase between 4–5% approximately of water requirement, because a greater presence of floccules results in greater water retention.

2 Methodology

Mineral samples from S.C.M. Collahuasi (Chile) collected before the tailings thickener and samples from an Urucum RDM-CVRD (Brazil) iron-ore beneficiation plant, collected at same location on the flowsheet were used. Equipment and methods applied in the current research are summarised in Table 1.

Table 1 Characterisation of solids and pastes tests

Property	Technique	Equipment
Specific gravity	Pycnometry	Liquid pycnometer
Size distribution	Sieving	Standard vibratory sieving apparatus
Chemical composition	Spectrophotometry	Flame spectrophotometry and FRX
Paste consistency	Slump test	100 mm height by 100 mm diameter slump cylinder
Paste fluidity	Flume test	Plexiglass flume apparatus
Paste viscosity	Viscosity	Rotational viscometer (Brookfield)

2.1 Slump test

As shown in Table 1, a 100 mm high, and 100 mm diameter cylinder, made of PVC, was used for all tests in the laboratory. The paste was initially prepared at high solids concentration (between 74–80% solids), and with the addition of tap water to a previously dried and weighed tailings sample. The procedure was used as recommended by the Brazilian Standard NBR NM 76, (1998). Determination of slump percentage (% ABT) is given by equation (1), as follows:

$$\%ABT = s / H \times 100 \tag{1}$$

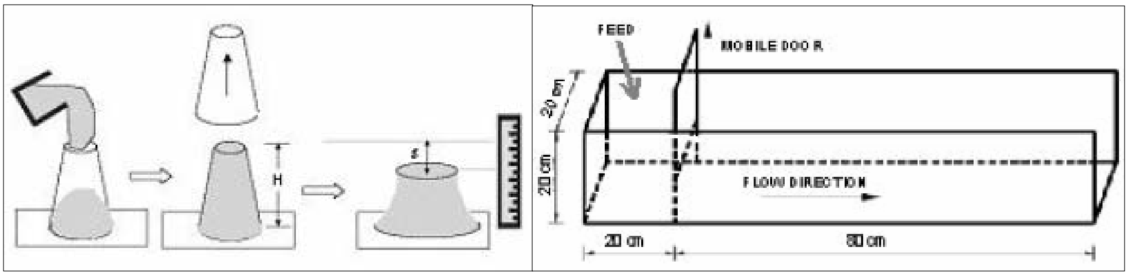
where: s is the interval between the height of the cylinder and the height of the slump for the test paste and H is the total height of the cylinder. This procedure is shown in Figure 3a, according to Clayton et al. (2003).

2.2 Flume testing

A plexiglass flume laboratory-scale apparatus, 1000 mm long, 200 mm wide and 200 mm high was used for testing of the repose angle. Solid-liquid mixtures were prepared at specific solids concentration (w/w). Figure 3b shows a depiction of the apparatus. Equation 2 shows the way the repose angle of the paste (θ_R) can be calculated, according to Kwak et al. (2005):

$$\theta_R = arctg\ [(h_1 - h_2) / L] \tag{2}$$

where: h_1 is the height of the flume initial point; h_2 is the height of the flume final point and L corresponds to the length of paste deposited on the flume after the paste sliding movement ends.



a b

Figure 3 a) Slump test procedure; b) Flume test procedure

2.3 Rheology and settling

A Brookfield model DV-II pro (Chile) and DV-III (Brazil) viscometer was used to evaluate the apparent viscosity of the pastes and high-density slurries. Spindle rotation was varied and viscosity measurements were taken considering a rheological cycle of 20–100–20 rpm (Chile) and 1–20–1 rpm (Brazil) in order to determine the rheological behaviour of these solid mixtures obtained with and without the use of aggregates. The experiment was performed using apparent viscosity and rheological behaviour as response settling rate.

3 Results

The results obtained for both samples are presented in this section.

3.1 Specific gravity

The mineral sample showed an average specific gravity of 3.62 g/cm^3 for iron ore tailings and 2.87 g/cm^3 for copper ore tailings.

3.2 Chemical and mineralogical composition

For the copper sample, only a qualitative analysis was performed. The most important components found, were Fe_3O_4 and SiO_2.

Table 2 shows the chemical composition of the iron ore tailings used in this research.

Table 2 Chemical analyses

Component	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	MnO	Na_2O	P_2O_5	SiO_2	TiO_2	LOI
Grade (%)	8.3	0.08	60.7	0.14	0.25	0.14	< 0.1	0.38	28.2	0.36	3.46

LOI = loss on ignition

For the iron-ore tailings sample, X-ray diffraction showed only quartz and hematite as clearly defined phases. SEM/EDS of particles of the sample also showed the presence of an aluminium bearing phase, likely gibbsite.

3.3 Particle size distribution

Figures 4 and 5 show the particle-size distribution for iron and copper tailings.

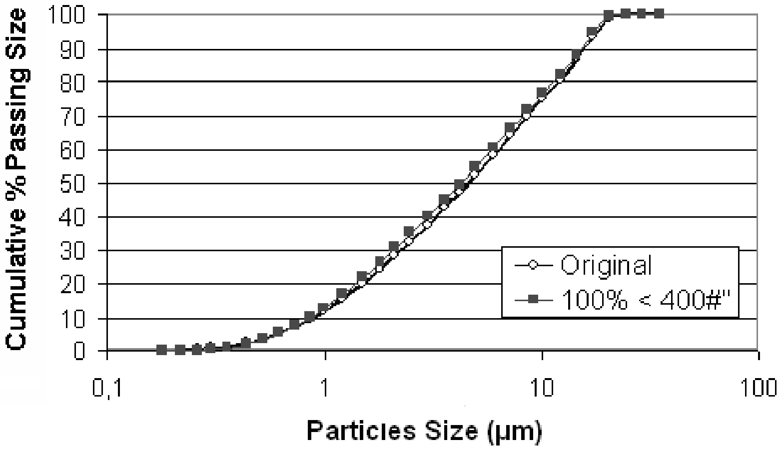


Figure 4 Particle size distributions for iron sample

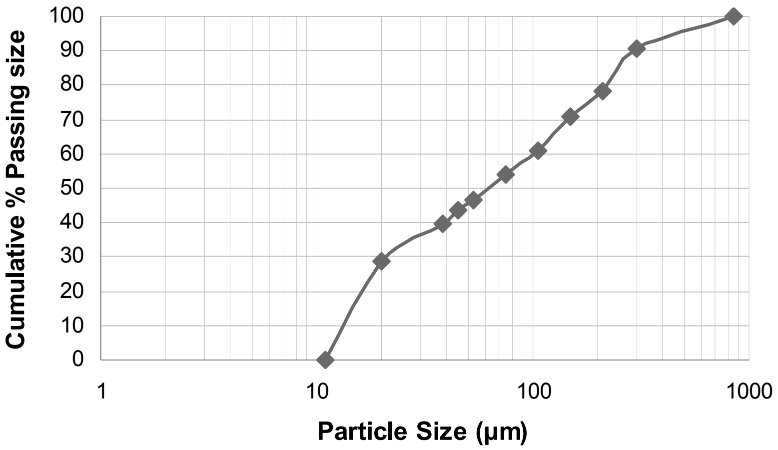


Figure 5 **Particle size distributions for copper sample**

3.4 Slump test for paste consistency

A slump test was used to study paste consistency.

Figures 6 and 7 show the results for iron and copper tailings using slump test.

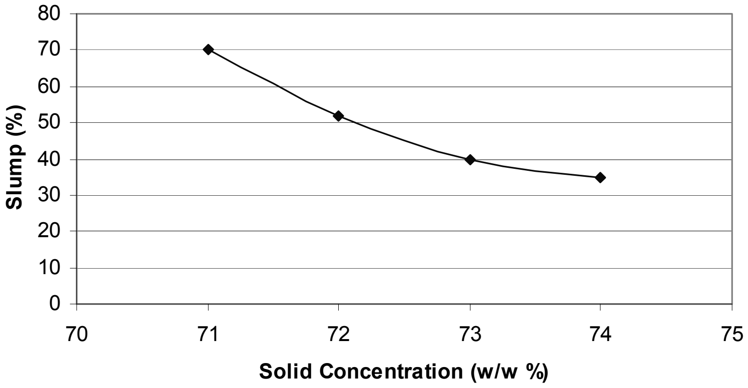


Figure 6 **Slump test results for iron sample**

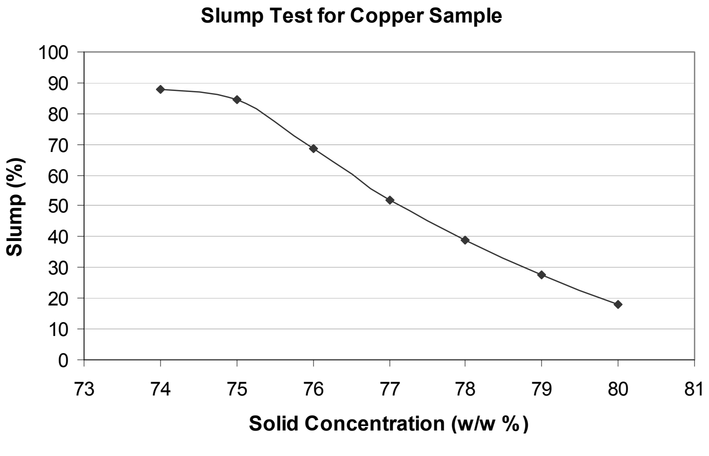


Figure 7 **Slump test for copper sample**

When comparing Figures 6 and 7, 70% consistency for iron paste and 76% consistency for copper paste, may be observed at 71% solids concentration. This may be explained by the different chemical composition and particle size distribution, which is bigger in the case of the copper sample ($d_{50} = 45\mu m$) compared to the iron sample ($d_{50} = 6.5\mu m$). A copper system retains less water compared to an iron system.

3.5 Paste fluidity

Paste fluidity is characterised by the repose angle percent, estimated using flume test.

The results of flume tests for iron and copper tailings samples are shown in Figures 8 and 9:

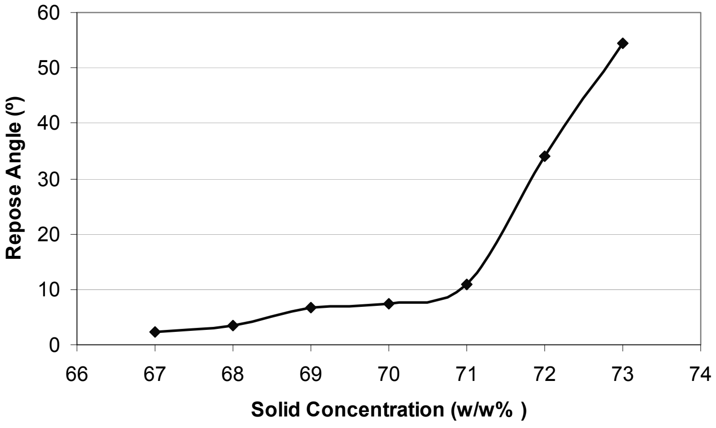


Figure 8 **Flume test for iron sample**

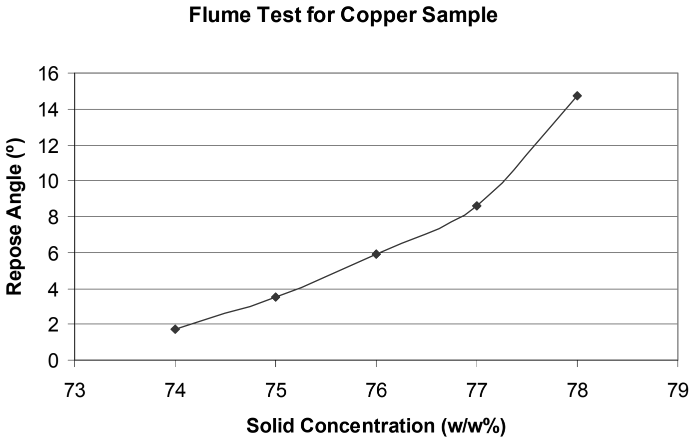


Figure 9 **Flume test for copper sample**

When comparing the results of Figures 8 and 9, it may be seen that for iron tailings, the paste reaches an angle in the order of 10°, when solids concentration is close to 71%. On the other hand, for copper, the same 10° angle may be obtained at 77% solids concentration. This fluidity difference may be explained by the different chemical composition and bigger particle size distribution in the case of copper.

3.6 Rheological and settling tests

Table 3 shows the aggregation effect on settling rate and rheological behaviour for iron ore pastes. Figure 10 shows the results of rheological cycles for copper ore tailings pastes.

Table 3 Effect of aggregates on the settling rate and rheological behaviour of paste mineral (70% w/w) prepared with iron sample (Brazil)

Test	Aggregation Condition	Settling Rate (cm/min)	Rheological Behaviour on an 1–20–1 rpm Cycle
1	Blank Test	4.6×10^{-3}	Double (mostly rheotropic)
2	Addition of 20 g/t of coagulant (C)	13.3×10^{-3}	Double (mostly thixotropic and with smaller viscosities)
3	Addition of 20 g/t of flocculant (F)	5.6×10^{-3}	Double (mostly thixotropic and with smaller viscosities)
4	Addition of 20 g/t of (C) and 20 g/t of (F)	5.5×10^{-3}	Almost Newtonian (viscosities very close)
5	Addition of 10 g/t of (C) and 10 g/t of (F)	4.7×10^{-3}	Double (mostly rheotropic with increased viscosity)
6	Addition of 10 g/t of (C) and 10 g/t of (F)	4.9×10^{-3}	Double (mostly rheotropic with increased viscosity)

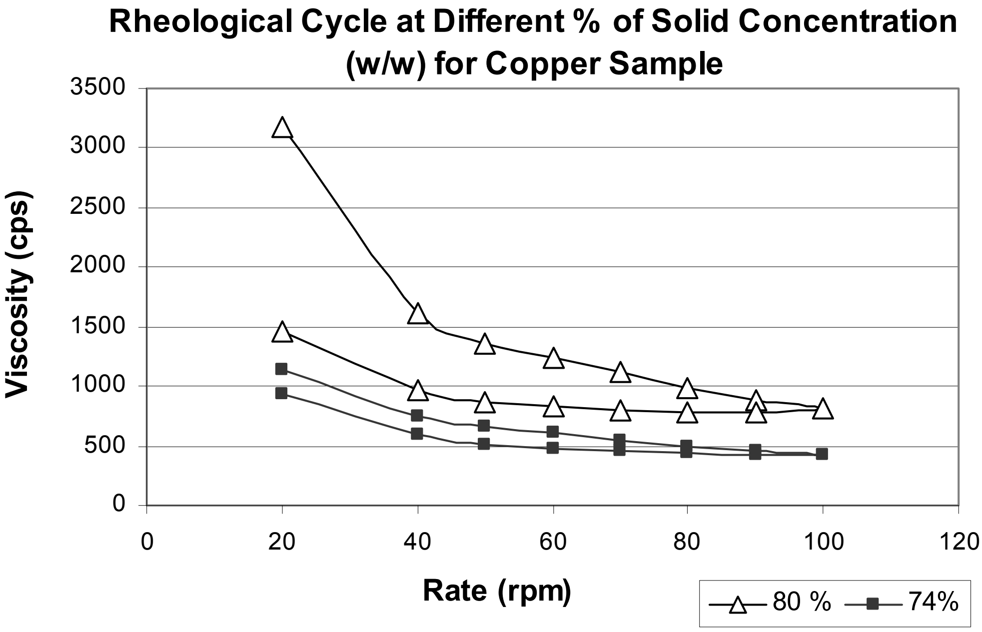


Figure 10 Rheological cycle at different solids concentration (w/w)

When comparing the results for iron and copper tailings pastes, the latter always shows a thixotropic behaviour for all solids concentrations studied (from 74–80% of solids), while in the case of iron, the rheological cycle showed a rather rheotropic mixed behaviour. It should be noted that the rheological cycle was different; therefore, this comparative analysis may not be the most appropriate.

Table 4 shows settling rates for copper ore tailings samples.

Table 4 Effect of aggregates on the settling rate at 20% solid weight concentration, prepared with copper sample (Chile)

Test	Aggregation Condition	Settling Rate (cm/min)
1	Blank test	0.26
2	Addition of 10 g/t of flocculant	1.99

The sedimentation rates are not comparable, because the tests with copper tailings were conducted at 20% solids concentration, and 70% solids concentration for the iron samples in Table 4.

4 Discussion

4.1 Iron samples

From Table 4 it may be observed that the best aggregation condition corresponds to the addition of 20 g/t of coagulant $Al_2(SO_4)_3$ whenever settling rate and rheological behaviour (smaller viscosities and a trend to thixotropic behaviour) are taken into account. The combined addition of 10 g/t of each aggregate would represent the worst condition as the settling rate increased only by 10% and the trend in rheological behaviour was found to be towards rheotropic fluid. Transport of a rheotropic fluid is a much more complicated issue in comparison to a thixotropic one.

4.2 Copper samples

From Figure 7, paste behaviours between 75–80% (w-w) of solids may be observed. From Figure 9, it may be observed that greater water additions imply greater differences between repose angles. The highest repose angle was 15º, for 78% (w-w) of solids. By rheological test measurements (20–100–20 rpm), the same may be determined for 74, 77 and 80% of solids. For the case of 80%, the rheological behaviour was more thixotropic. Furthermore, in all the cases, the rheological behaviour was thixotropic.

5 Conclusions

- Paste behaviour, for iron tailings, was observed between 71–75% of solids (w-w). For copper tailings, paste behaviour was observed between 75–80 % (w-w) of solids.
- For iron tailings, the highest repose angle was 11° at 71% of solids. For copper tailings was 15° at 78% of solids.
- The settling rate, for iron tailings, increased almost three times when adding 20 (g/t) of coagulant, and the rheological behaviour was highly thixotropic in a rotational cycle 1–20–1 rpm, which represents a most favourable rheological condition.
- The settling rate, for copper tailings, increased almost three times when adding 10 (g/t) of flocculant, and the rheological behaviour was highly thixotropic in a rotational cycle 20–100–20 rpm, which represents a most favourable rheological condition.

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