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The effect of composite additives on the rheology of concentrated iron ore tailings and their components

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Abstract

The major components of iron ore tailings produced in the Pilbara region are hematite, goethite and kaolinite. At times, these tailings have developed a viscosity or yield stress too high for the pump to handle. This rheological problem urgently requires a cost-effective and simple solution. To address this issue, this study evaluates the yield stress-solids concentration relationship of iron ore tailings, ochreous goethite sourced from a Pilbara mine, and kaolin suspensions with and without the composite additive NaOH-Na_2SiO_3-Na polyphosphate. Our results reveal that the yield stress-concentration curve shifts to a higher concentration for all three materials when the additive is above a critical level. At 0.5 dwb% (g/100g solids) of the composite additive, the yield stress was close to zero at 65 wt% solids for all three suspensions. This indicates that iron ore tailings can be transported at a concentration in excess of 65 wt% solids by using the composite additive. The cost required to process tailings of 55 to 65% solids was between USD 2 to USD 4 per ton of solids, although the additive dosage's optimisation was outside this study's purview. The tailing viscosity and yield stress can be converted back to paste consistency with a neutralising additive for safer storage in the dam or as a feedstock for dry stacking, i.e., drying, harvesting and stacking.

Keywords: *Rheology control; composite additives, goethite, kaolin, hematite*

1 Introduction

Mining companies are concerned with the "*processibility*" of their ores in beneficiation, mixing and pumping processes. The viscous properties of the ore suspensions affect the behaviour of the fine waste tailings during thickening and pumping. Some tailings develop a high yield stress and viscosity that, once thickened, cannot be pumped efficiently to the tailings storage facilities, acting as a bottleneck affecting the plant's throughput. In turn, tailings are produced at lower solids concentrations, resulting in reduced water recovery and potentially increasing the cost and risk of the tailings dam associated with storing increased volumes of water at the facility. Whilst the mining engineers seek to ensure that ores that can be processed are mined, for example, via appropriate blending of easy-to-process ore with the more difficult ones, pit constraints, grade, and primary plant throughput are usually the first consideration for blend optimisations. Therefore, a solution to processing difficult ores without the need for blending should enhance the optimal extraction of the deposit. However, this has yet to be easily achieved.

In this study, we evaluate the yield stress-concentration relationships of the mineral impurities of iron ore from the Pilbara region of Western Australia that can potentially affect processing. The main components in the tailings are slimes comprised of kaolinite clay and goethite, with a small amount of quartz also present. The effects of rheology-modifying additives on these single and mixed mineral components are also evaluated.

2 Materials and methods

The Rio Tinto Group provided ochreous goethite (OG) sourced from one of their iron ore deposits. Prestige kaolin was used. Chemicals such as sodium hydroxide and sodium polyphosphate were sourced from Sigma Aldrich™. The Na_2SiO_3 was sourced from Alfa Aesar™. The Rio Tinto Group provided the flocculated iron ore tailings.

Table 1 provides the chemical content of the OG.

Table 1 Chemical composition of OG

	Fe	SiO_2	Al_2O_3	TiO_2	Mn	P	MgO	CaO	LOI 425	LOI 650	LOI
OG	55.1	3.9	2.4	0.1	0.7	0.4	0.9	0.03	11	0.6	11.9

In terms of mineral composition, this corresponds to ~4% kaolinite, ~94% goethite, ~1% quartz and trace anatase/rutile. In addition, Quantitative X-ray Diffractometry (QXRD) analysis indicated a significant amount (24%) of amorphous materials.

The suspensions were prepared using a sonic probe, and the OG and kaolin suspensions were prepared from dried powders. A Sigma Aldrich centrifuge was then used to concentrate the suspensions further. The received iron ore tailings at 26.3 wt% solids contained a small amount of flocculant, but shear had already broken down the flocs. These tailings settled, and the top supernatant layer was decanted to produce tailings of ~ 40wt% solids. The yield stress was measured with a range of Brookfield vane viscometers of different spring constants. The zeta potential was measured with a ZetaProbe. An Orion pH and conductivity meter was also used.

3 Results and discussion

Figure 1 shows the yield stress-solids concentration relationships of the kaolin suspensions with different concentrations of composite additive (CA) or $NaOH:Na_2SiO_3:Na_n(PO_3)_n$. The CA was evaluated earlier as an additive for controlling tailings rheology and mining iron ore from tailings (Leong 2020a, 2020b). The concentration of additives was reported in dwb% or per cent on a dry mass basis (g additive per 100 g solids). The yield stress was as high as 1500 Pa at 60 wt.% solids for the untreated suspension. The sharp increase in the yield stress commenced at about 55 wt.% solids. The effect of CA is small at 0.025 and 0.05 dwb% (g /100g kaolin). The reduction in yield stress only became significant at 0.1 dwb% and higher content of CA. The dramatic decrease in yield stress to values close to zero for kaolin suspensions with concentrations of more than 60 wt.% solids is clearly illustrated in Figure 1.

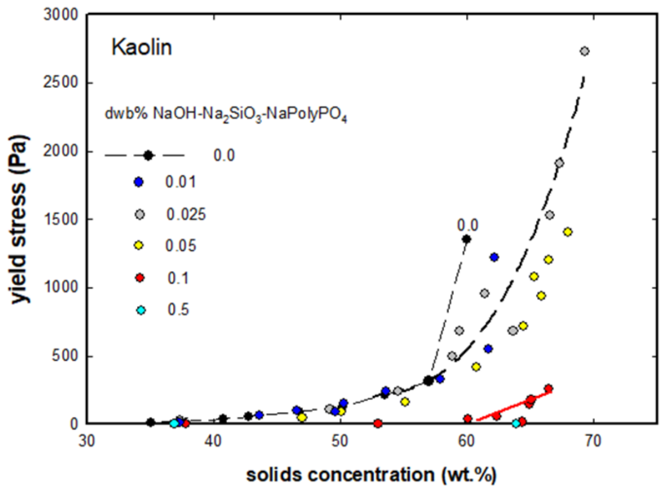

Figure 1 The yield stress-concentration relationships of kaolin suspension at various CA concentrations.

The concentration limit of a handleable or processible suspension under extreme processing conditions should be just before the onset of the sharp yield stress increase. Most pumps in the mine can only handle a maximum yield stress of 100 Pa. Therefore, the 60wt.% kaolin suspension with 1500 Pa of yield stress will not be practically pumpable. However, after treatment with 0.1 dwb% CA (g/100g solids), this suspension is easily processible as the yield stress was reduced to nearly zero; this suspension can then be pumped using standard pumping equipment. Increasing the CA concentration to 0.5 dwb% shifted the zero yield stress suspension to a higher concentration of 64 wt% solids.

The researchers observed a similar result with ochreous goethite (OG) suspensions, as shown in Figure 2. The untreated OG suspension attained a yield stress of ~ 2000 Pa at ~ 60 wt.% solids. Addition of 0.025 dwb% CA produced a marginal effect on the yield stress. Like the kaolin suspension, the reduction in the yield stress only became significant at 0.1 dwb% CA. The yield stress at 60% solids was reduced to ~100 Pa.

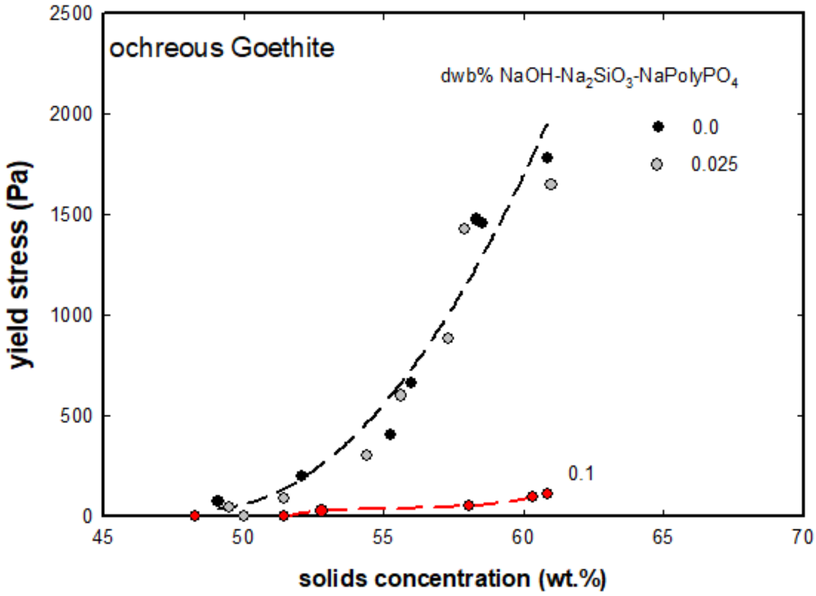

Figure 2 The yield stress-concentration relationships of ochreous goethite (OG) suspensions at various composite additive (CA) concentrations.

Figure 3 illustrates the yield stress-concentration relationship of the iron ore tailings. The yield stress is much lower than those obtained for the kaolin and OG suspensions. This sample contained a significant amount of hematite particles which are generally coarser in size and required higher dosage rates of CA additives to achieve the same relative reduction in yield stress. The yield stress-concentration relationship of the untreated suspension and the sample treated with 0.1 dwb% is similar, but the additive data are scattered. Only when the additive concentration was greater than 0.25 dwb% did the yield stress decrease significantly at any solids concentration, i.e. the yield stress-concentration curve was shifted to the higher concentration region.

The yield stress-concentration measurements for the untreated and the sample treated with 0.25 dwb% CA (Figure 3) were repeated, and there was satisfactory agreement between the tests. The sample treated with 0.25 dwb% CA showed significantly lower yield stress than the untreated sample at the same solids concentration. At 0.5 dwb% CA, the yield stress is zero at 64 wt.% solids.

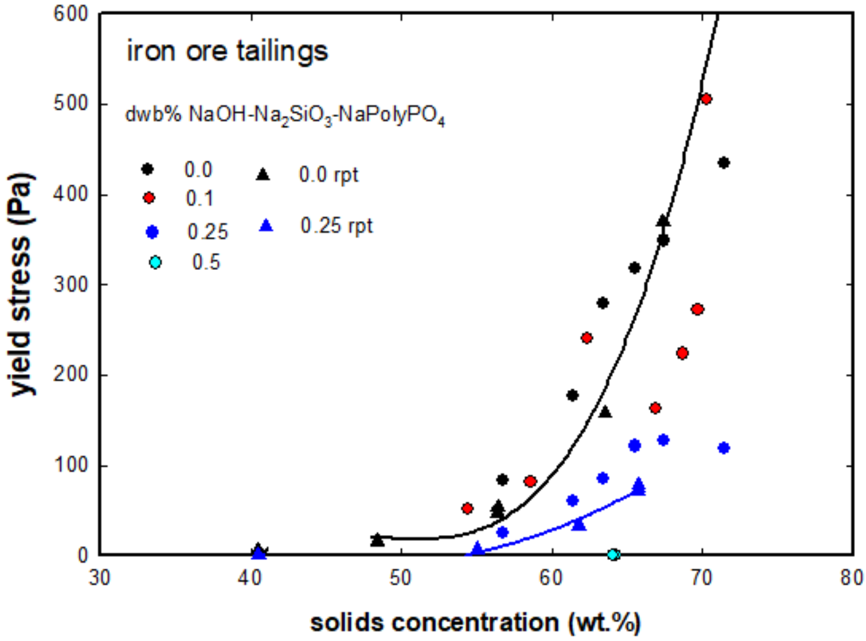

Figure 3 **The yield stress-concentration relationships of iron ore tailings suspensions at various composite additive (CA) concentrations.**

Figure 4 shows the effect of pH on the zeta potential of OG suspension. The pH of zero charge is ~ 6 when prepared in deionised (DI) water with 0.01M KCl or when prepared in tap water (EC ~ 0.9 mS/cm). The particles are positively charged at pH values less than six and negatively charged at pH values above six. The van der Waals attractive force should dominate the particle-particle interactions in the pH region where the point of zero charge or zeta potential is located. The electric double layer repulsive force should become more important at low and high pH.

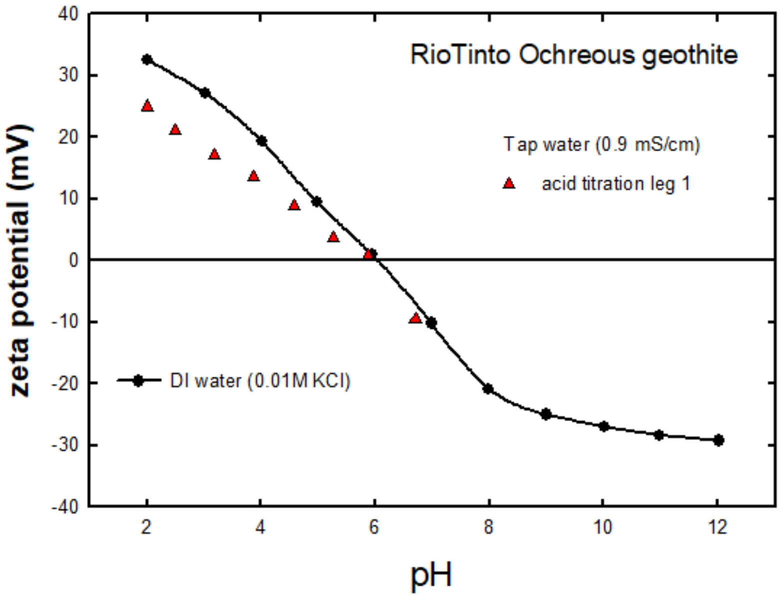

Figure 4 **The effect of pH on the zeta potential of OG suspensions.**

Figure 5 illustrates the yield stress-pH behaviour of OG suspensions under the influence of composite $NaOH:Na_n(PO_3)_n$ additive, $CaCl_2$ and NaOH. Adding these $NaOH:Na_n(PO_3)_n$ and $CaCl_2$ changed the pH for the

55.4 and 54.7 wt.% OG suspensions. With the 48.6 wt.% OG suspension, only NaOH was used to change the pH. The maximum yield stress of OG suspension (48.6% wt.%) occurred at pH 5.5-6.0, where the point of zero net charge or pH of zero zeta potential is located. At this point, only the van der Waals attractive force is operating between the OG particles. The yield stress decreased to zero at pH 8.5 since the particles have a strong negative charge. The composite additives decreased the yield stress of 55.4 wt.% OG suspension from 180 Pa at pH 4.5 to ~ 0 Pa at pH 6.6. Subsequent $CaCl_2$ addition caused the yield stress to increase sharply and the pH to decrease slightly. The effect of composite additives and the subsequent Ca(II) addition on OG suspension in mine water caused the yield stress curves to shift to a higher pH. The zero yield stress is now located at a higher pH of 7.4.

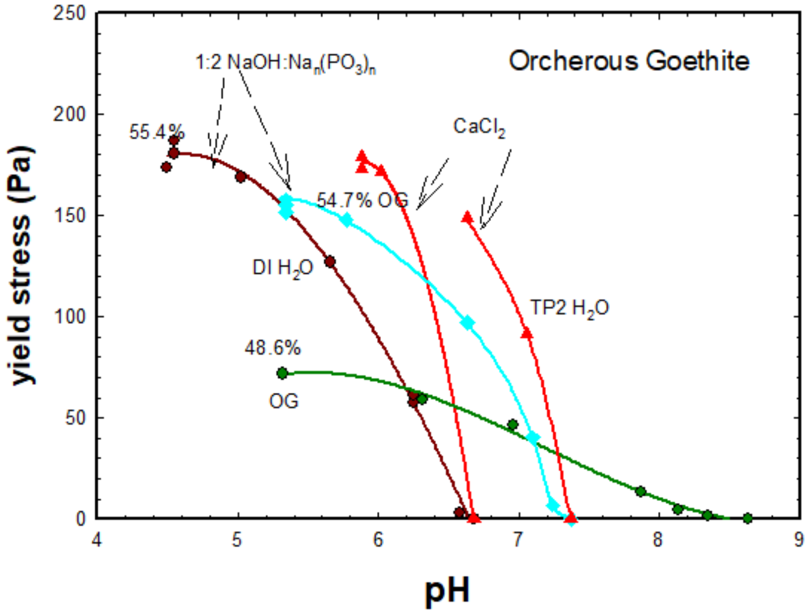

Figure 5 The effect of pH and additives on the yield stress of OG suspensions.

Figure 6 shows the yield stress-pH behaviour of 50 wt% 80%kaolin:20%OG suspensions under the influence of composite NaOH:$Na_n(PO_3)_n$ additive, $CaCl_2$ and NaOH. The yield stress of the suspension treated with NaOH alone remained constant at high pH. This yield stress-pH behaviour is similar to tailings shown in the figure where the yield stress remained relatively large and finite with a pH > 12. The effect of composite additives on the yield stress-pH of OG-kaolin composite suspensions is also shown. This additive gradually increased the pH of the suspension. The yield stress, however, showed a sharp decrease to zero at a pH ~ 9. The subsequent addition of $CaCl_2$ caused the yield stress to increase sharply. The pH was decreased slightly by the Ca(II) solution. A similar result was obtained with 55% OG suspension except occurring at a much lower pH. The effects of the composite additives and $CaCl_2$ treatment are similar to that reported for iron ore tailings treated with the same composite additives and lime (Leong 2018, 2021; Leong et al. 2019). The processibility of the tailings can be improved markedly by using these relatively cheap composite additives, particularly in long-distance pipeline transportation. At the dam, soluble Ca(II) compounds such as $CaCl_2$ or CaO can be added to increase the yield stress for the safe storage of tailings.

The use of CaO produced a delayed effect due to its sparing solubility. This effect may be an advantage or a desirable property giving more time to work with tailings before its yield stress becomes too high. This paste tailings product can also be used for drying and stacking (Gomes et al. 2016), filtration and potential as a feedstock for tile and brown porcelain manufacture (Das et al. 2000; Fontes et al. 2019).

The amount of kaolinite present in the iron ore tailings was much lower. The goethite content was as high as ~ 40-50%. The quartz content was only ~ 1%. However, a high amount of unknown amorphous materials of ~ 15% of the total was also present based on that in OG. While the OG-kaolin composite suspension displayed rheological behaviour in response to pH, similar to the tailings, the amorphous materials may also play an important role.

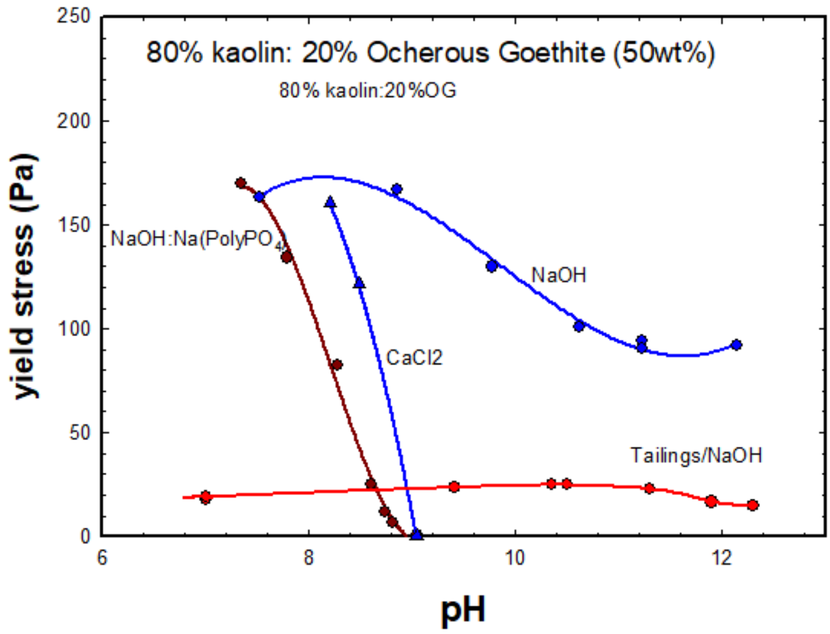

Figure 6 The effect of pH and additives on the yield stress of 20% OG-80% kaolin suspensions.

4 Conclusion

The yield stress showed a sharp increase at 55 wt% solids for both kaolin and ochreous goethite suspensions and at 60% for the iron ore tailings. Composite additives above a critical concentration cause the yield stress to decrease sharply, shifting the yield stress-concentration curve to the right or a high-solids loading for all three suspensions. Composite additives based on phosphate and NaOH cause a sharp decrease in the yield stress at a much lower pH than NaOH alone for both 80%kaolin:20%Ochreous goethite and pure OG suspensions. Ca(II) neutralised the composite additives' effect and increased the yield stress. The 80%kaolin:20%Ochreous Goethite suspension displayed a similar response to NaOH as tailings in that the yield stress remained significant and constant at a pH above 12.

References

Das, SK, Kumar, S & Ramachandrarao, P 2000, 'Exploitation of iron ore tailing for the development of ceramic tiles', *Waste Management*, vol. 20, pp. 725-729, https://doi.org/10.1016/S0956-053X(00)00034-9

Fontes, WC, Franco de Carvalho, JM, Andrade, LCR, Segadaes, AM & Peixoto, RAF 2019, 'Assessment of the use potential of iron ore tailings in the manufacture of ceramic tiles: From tailings-dams to "brown porcelain"', *Construction and Building Materials*, vol. 206, pp. 111-121, https://doi.org/10.1016/j.conbuildmat.2019.02.052

Gomes, RB, De Tomi, G & Assis, PS 2016, 'Iron ore tailings dry stacking in Pau Branco mine, Brazil', Journal of Materials Research and Technology, vol. 5, no. 4, pp. 339-344, https://doi.org/10.1016/j.jmrt.2016.03.008

Leong, YK 2018, *Method of Rheology Control*, Australia, Innovation Patent No: 2018100304, Australia Government, IP Australia

Leong, YK 2020a, *Controlling Rheology of Iron Ore Tailings Slurries*, Australia, Innovation Patent No: 2020103937, Australia Government, IP Australia.

Leong, YK 2020b, *Improved Mineral Separation of Tailings*, Australia, Innovation Patent No: 2020900408, Australia Government, IP Australia.

Leong, YK 2021, 'Controlling the rheology of iron ore slurries and tailings with surface chemistry for enhanced beneficiation performance and output, reduced pumping cost and safer tailings storage in dam', *Minerals Engineering*, vol. 166, article no. 106874, https://doi.org/10.1016/j.mineng.2021.106874

Leong, YK, Drewitt, J & Bensley, S 2019, 'Reducing the viscosity of concentrated iron ore slurries with composite additives for quality upgrade, reduced power, safer tailings storage and smaller environmental footprint', in *Iron Ore 2019: Optimising Value*, The Australasian Institute of Mining and Metallurgy, Perth, pp. 738-743, https://doi.org/10.1016/j.mineng.2021.106874