

Mineralogical Characterization of Selected South African Mine Tailings for the Purpose of Mineral Carbonation

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Abstract This study looks to explore a combined solution to atmospheric CO₂ gas build-up and acid mine drainage (AMD), with Nkomati and O'okiep arguably being the main contributors to AMD due to their high sulphide content. Mineral tailings produced by a number of South Africa's mines are composed of silicates, oxides and sulphides that have the potential to be recycled into innovative schemes designed to reduce their footprint. There is a possibility of mineral recovery from historic dams in the platinum and nickel industry. South Africa's reputation as one of the leading producers of PGE worldwide consequently makes it one of the largest producers of mine waste compared to other mining industries. Coincidentally, this has resulted in the creation of a large number of platinum sampling points across the country. Incorporation into building materials, road aggregates, agricultural applications, landfills, manufactured fillers and many other schemes have been proposed, all of which raise issues of technical viability and cost of effectiveness, and also addresses issues relating to the fate of tailings.

Keywords mineral carbonation, carbon dioxide sequestration, ultramafic tailings

Introduction

Mine tailings produced by low grade, high tonnage operations are progressively increasing their environmental footprint across South Africa (as well as world-wide). They are often sources of a wide variety of environmental problems such as fine dust dispersal, slope instability, mud slides, and acid mine drainage (AMD), the last a well-known source of pollution of South Africa's increasingly fragile water supply. Traditionally, the approach has been to minimize the generation of acid waters, but it has also been recognized that acid reactions with Ca-Mg-Fe silicate minerals in tailings could render them more conducive to carbonation, since their surfaces become more reactive due to desilication (Blencoe and others, 2004).

Anthropogenic carbon dioxide (CO₂) is principally emitted from the burning of fossil fuels, such as those used for electric power generation where large point sources emit a continuous increasing amount per year. South Africa, a country dependent on coal energy for 93% of its electricity, is an energy-intensive state which generates approximately 400 million tonnes of CO₂ and significant volumes of industrial wastes yearly (SurrIDGE and Cloete, 2009). This study will focus on the suitability of ultramafic - mafic tailings as a mineral storage reservoir where sequestration of CO₂ is based on the reactions between Ca-Mg-Fe silicates such as olivine, pyroxene and plagioclase, to form carbonate analogues that are relatively inert and benign in surface reservoirs.

Carbon dioxide Capture and Storage (CCS) is considered one of the options for reducing atmospheric emission of CO₂ from human activities as this is seen to be a significant option for climate change mitigation. CCS involves the use of technology, firstly to collect and concentrate the CO₂ produced in energy-related sources, transport it to a suitable storage location, and then store it away from the atmosphere for long periods of time. Two opportunities for CO₂ storage exist for CCS. The first is mineral carbonation and geological storage, which requires converting CO₂ to solid inorganic carbonates, while the second option is the industrial use of CO₂, either directly or as feedstock for production of various carbon-containing chemicals (Jacobs 2011).

Important enabling factors in the reaction viability include mineral species, mineral composition, mineral structure, mineral proportions, grain size distribution, morphology and surface texture. Elucidation of these and other factors can provide an initial guide to the reactivity of mineral tailings.

Research approach

Sampling

Three categories of samples were taken from sites under this study. These comprised of mine feed, plant tails and actual samples collected from the dam. The samples were each collected into ordinary 20-litre paint buckets and weighed approximately 30kg. The motive for collecting 30kg material was to obtain sufficient sample representative of mine tailings, as these were suitable to evaluate the potential for mineral carbonation. A total of seven operations were samples of which five were big PGE producers. These comprised Impala, Union, Mogalakwena, Rustenburg Section and Amandelbult. The remaining two, an active Nkomati Nickel Mine and a dormant O'okiep Copper Mine are both sulphide-rich and as a result, highly prone to acid mine drainage.

Analyses

Splitting was carried out to homogenize each sample to reduce biases. Individual samples were effectively split down from 30 kg to 100 kg. Both dry and wet screening were the first techniques employed to determine the particle size distributions and mineral proportions on each size fraction with the aid of additional analytical procedures.

Further determination of the particle size distribution of tailing samples was carried out using a Malvern Mastersizer 2000. The refractive index used in the analysis was 1.620, which was calculated by factoring the modal mineralogy and the average density of each mineral phase. The specific surface area of each sample was analysed with the aid of a BET surface area analysis software and a Tristar.

Quantitative X-ray Powder Diffraction (QXRD) was used to determine the relative proportion of the crystalline phases present in the tailings. A 3.5 g representative sample from each of the mine tailings was micronized prior to analysis. A Bruker D8 diffractometer with a Vantec detector and Bruker Topas Rietveld refinement software was used for mineral phase quantification.

X-ray Fluorescence Spectroscopy (XRF) was used to determine the bulk chemical composition of the tailings. Fusion discs and pellets were manufactured on a Phillips PW 1480 X-Unique X-ray fluorescence Spectrometer.

QEMSCAN was used to measure the bulk mineralogy of the samples at the University of Cape Town. This technique is based on a LEO platform and equipped with two Bruker SDD detectors. Ore mounts for the tailings samples within this study were prepared for QEMSCAN analysis. Samples were analysed with pixel spacing of between 2 and 5 μ m. Results obtained from the QEMSCAN analysis were validated with those from XRF and QXRD.

Results and discussion

Particle size distribution and specific surface area

The particle size distributions of the samples are illustrated in Fig.1, which shows the vast variation in sizes. As depicted in Fig.1, samples from Mogalakwena, Nkomati, O'okiep and Amandelbult are fine grained in nature. The coarsest sample is the tailings from Impala.

According to results obtained from BET surface area analysis, the sample from Mogalakwena Platinum Mine has the largest surface area, recording 5.208 m²/g. This is followed by Nkomati Nickel Mine and the O’okiep Copper Company recording a specific surface area of 3.670 m²/g and 3.104 m²/g respectively. Tailings from Impala have proven to be the sample with the lowest surface area reporting at 0.0454 m²/g.

The particle size distribution and surface area play vital roles in the reactivity kinetics of the mineral and carbon dioxide. Fine tailings material should have a larger surface area and a coarser material should possess a lower surface area. Samples with finer particles and high surface area should react quicker than those with coarser particles with low surface area. In mineral carbonation, the reaction kinetics of a mineral and the carbon dioxide is carefully considered. A slow reaction would require the use of more reagents and catalysts.

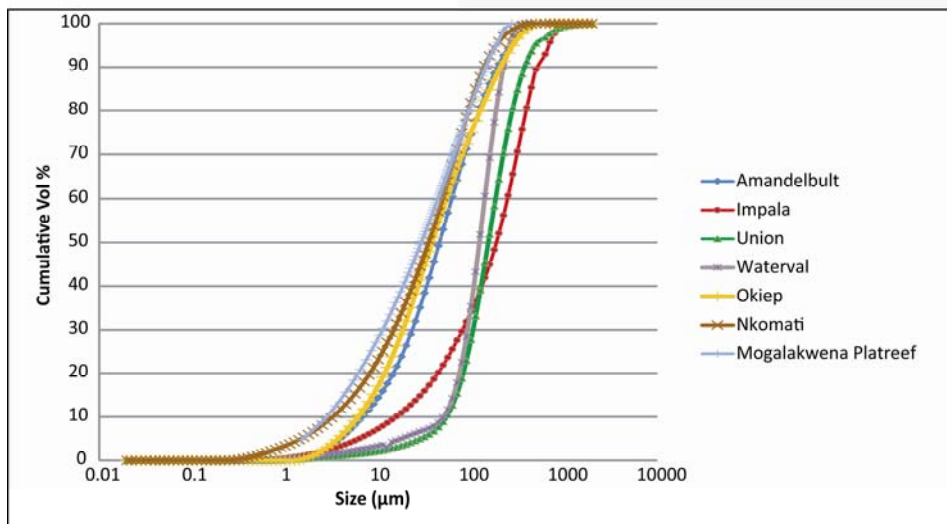


Fig. 1 A logarithmic graphic showing the particle size distribution of the samples in the study

Tailings mineralogy and chemistry

Major oxides and their various proportions required for mineral carbonation were estimated using X-ray Fluorescence spectroscopy (XRF) are shown in Table 1. It is evident that magnesium oxides (MgO), have reported high values during XRF analysis determined for all samples in this study. As seen in Table 1, calcium oxide (CaO) and iron oxide (FeO) recorded high values as well, giving a high indication to potential mineral carbonation of all tailings materials in the study.

Magnesium (*Mg*), calcium (*Ca*) and iron (*Fe*) silicates in the samples makes it favourable for mineral carbonation. *Mg* silicates popularly include amphibole, pyroxene, talc and serpentine. *Ca* silicates comprise of minerals such as wollastonite and plagioclase feldspars while iron silicates *Fe* silicates include olivine and garnet.

Samples with high chrome values as in the case of Union section and Impala Platinum, having a weight percentage of 24.35wt% and 12.17wt% cannot be entirely favourable for mineral carbonation. This is because chrome slows down the reaction kinetics, it is also not a sequestrable mineral.

Table 1 Bulk chemistry of the tailings samples as determined by XRF. The asterisk indicates oxides required for mineral carbonation.

Oxide (wt%)	Mining Operation						
	Mogalakwena	Amandelbult	Impala	Union	Waterval	Okiep	Nkomati
SiO ₂	48.13	38.24	35.05	25.99	47.16	56.36	44.18
TiO ₂	0.23	0.39	0.65	0.54	0.24	0.62	0.43
Al ₂ O ₃	9.12	12.24	13.00	12.23	16.90	16.22	4.96
FeO*	9.72	14.19	17.47	18.44	8.23	10.26	13.44
MnO	0.21	0.19	0.19	0.20	0.13	0.09	0.21
MgO*	19.28	17.09	16.23	15.74	13.31	2.29	19.50
CaO*	7.53	4.94	4.32	2.38	7.81	5.21	10.84
Na ₂ O	1.17	0.93	0.86	0.47	1.33	3.43	0.53
K ₂ O	0.35	0.16	0.09	0.10	0.20	1.43	0.45
P ₂ O ₅	0.05	0.04	0.04	0.04	0.04	0.19	0.07
SO ₃	0.52	0.12	0.09	0.01	0.03	0.25	0.99
Cr ₂ O ₃	0.43	10.93	12.17	24.35	3.69	0.23	0.78
NiO	0.27	0.13	0.13	0.13	0.09	0.03	0.14
H ₂ O-	0.28	0.08	0.02	0.26	0.37	0.20	0.15
LOI	2.73	0.33	-0.31	-0.87	0.48	3.20	3.32
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*oxides preferred for mineral carbonation

Conclusions

The aim of this paper was to mineralogically characterize selected South African mine tailings facilities for the purpose of mineral carbonation. The use of silicate waste material from proposed mining operations have the potential to introduce mineral carbonation technology due to the abundance of material and existing infrastructure. The potential for mineral carbonation would be variable throughout the waste material, depending on the mineralogy.

Apart from attending to the challenges associated with the availability of feedstock, mineral carbonation may have a stabilizing effect on tailings reservoirs, thereby reducing environmental risks associated with their disposal

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