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Iron Ore Coarse Particle Characterisation: Towards Prediction of Particle Distribution in Gravity Separation Processing

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Abstract **–** The Limpopo and Northern Cape provinces of South Africa host hematitic iron ore deposits that, geologically, form part of the Transvaal Supergroup. Due to various geological processes that took place during the formation of the ore, textures are variable, and may be qualitatively described as massive, laminated, conglomeratic, brecciated, etc. These textures affect the separation efficiency during processing to upgrade low-grade ore by gravity separation. Mineralogy plays a crucial role during beneficiation; the obtained particle mineralogy can be linked to density classes to predict particle distribution during processing. Measures can thus be taken to improve the separation efficiency. Commonly used mineralogical techniques like automated scanning electron microscopy (AutoSEM) and optical microscopy, however, are not well-suited for coarse particle characterisation. For this study, therefore, the emerging technique, micro-X-ray fluorescence (micro-XRF) imaging, was investigated to produce elemental maps for texture characterisation on coarse particles (>6mm) of an Fe ore sample from Limpopo, together with X-ray diffraction (XRD) to characterise the coarse particle samples. The results show that the ore contains massive hematite as well as laminated hematite-quartz particles. These preliminary results predict that, for sink-float separation tests, massive hematite particles will be recovered at high density, but laminated hematite-gangue particles will be lost to the floats at different density classes, dependent on the ratio of hematite:gangue in the particles. Quantification of these effects is the next step in the study, towards establishing a predictive method for coarse particle distribution in gravity separation of Fe ore.

Keywords**:** Micro-XRF, iron ore, beneficiation, ore texture, coarse particles, sink-float test-work

1. Introduction

Iron ore is primarily used to produce pig iron for steel manufacturing. In South Africa, hematitic iron ore deposits are geographically located in the Limpopo and Northern Cape provinces. The ore is hosted by sedimentary rocks of the Transvaal Supergroup. The iron ore is usually mined as lumpy (>6mm) and fines (<6mm) [1]. The high-grade lumpy ore is used as-is locally or exported internationally. In contrast, the high-grade fines undergo sintering prior to their utilization. The low-grade ore requires beneficiation to improve Fe grade to meet specification for steel production. Iron ore beneficiation is commonly undertaken by means of gravity separation methods, which separate ore from gangue based on density differences. However, separation of particles containing ore and gangue minerals is controlled by properties such as mineral proportions, particle size, ore texture, degree of mineral liberation and mineral association [2]. Hence, it is important to quantify these mineral-particle properties so as to relate them to density classes. The relationship of particle-properties to density allows prediction of plant performance for upgrading and recovery.

Characterisation methods like automated scanning electron microscopy (AutoSEM) and other mineralogical microscopy instruments are normally used to acquire particle-mineral data. However, these instruments are not well-suited for coarse particle (>6mm) characterisation, primarily because of small sample chambers/stages. In this respect, the emerging technique of micro-X-ray fluorescence (micro-XRF) imaging [3] may be considered for coarse particle assessment, from which the mineral-particle data can be directly correlated to the density class in sink-float tests. This paper outlines preliminary mineralogical results from work conducted using micro-XRF, together with X-ray diffraction (XRD) for characterisation of an iron ore from Limpopo province, South Africa, subsequently subjected to sink-float tests.

2. Methodology

The ore has a top size of 25 mm, and was screened into various size fractions, three of which are further explored here: -25+19 mm, -19+8 mm and -8+3.35 mm. A representative sub-sample of the head was pulverised and micronized for 10 minutes for bulk mineralogical examination using XRD, via a Bruker D8 Advance powder diffractometer, fitted with a cobalt X-ray tube and Lynxeye detector. The ore was analysed over a range of 3 to 80° 2Θ. Minerals were identified using the Bruker EVA software package, which depends on crystal structure to identify minerals. Only minerals present in amounts >2-3 mass% are detected. Quantification of the identified minerals was achieved through the use of the DIFFRAC SUITE TOPAS software package, which is based on Rietveld Refinement and a fundamental parameters approach. In addition, sub-samples of sized fractions of the ore were mounted using epoxy resin to produce large sections of particles. The sections were imaged using a Bruker M4 Tornado micro-XRF instrument to acquire compositional information and consequently provide an overall element map of the sample. Elements <Na in atomic number cannot be detected using the M4 micro-XRF system. The micro-XRF instrument is fitted with a Rh tube source of X-rays and two silicon drift detectors.

Two kilogram aliquots of each size fraction were subsequently subjected to lab-scale sink-float test-work using 6 density cut-points (4.9, 4.7, 4.5, 4.0, 3.5, and 3.0 g/cm^3) via a mixture of tetra-bromo-ethane (TBE) and ferrosilicon (>2.96 g/cm^3) for density cut-points below 3.8 g/cm^3. Tungsten carbide (15.63 g/cm^3) and a ferrosilicon mixture were employed for density classes above 3.8 g/cm^3. Sub-samples from each density class were pulverized, micronized and analysed using XRD for determination of bulk mineralogy.

3. Results and discussion

The XRD results indicate the head sample of the ore primarily consists of hematite (Figure 1). The main gangue is quartz, with traces of goethite. Figure 2 shows an example of particle distribution in the coarsest size fraction of the ore, -25+19 mm, acquired from the microXRF imaging. Based on the elemental maps, Fe-rich portions may be correlated with hematite, and Si-rich portions may be correlated with quartz. It is clear that massive and laminated textures are evident in the particles. The particles contain laminations of hematite and quartz in different proportions. The elemental maps can be correlated with bulk mineralogy obtained via XRD analysis. The observed textural variability can be used to predict the performance of this ore during downstream processing as particles of different texture are anticipated to report to different density classes, depending on the proportion of quartz to hematite in the particle. Massive hematite particles are anticipated to report to the sinks fraction of highest density, whereas massive quartz particles should report to the lowest density class. Hematite-quartz intergrowths will result in different proportions of quartz and hematite in the particles, dependent on the nature of the laminations. Thus, more hematite-rich particles should report to higher middlings classes (4.9 and 4.5 g/cm^3 floats), whereas more quartz-rich particles should report to lower middlings classes (4.0 and 3.5 g/cm^3 floats).

The results in Figure 3 show that, for all three size fractions, the abundance of hematite decreases with the decrease of density class, with the opposite being true for the gangue abundance. In addition, it has been observed that in all fraction sizes for the ore, hematite of considerable amounts could not be recovered as it reported to the floats at different density classes, as predicted from the mineralogy results on the coarsest fraction. Massive hematite particles are easily recoverable during processing as they tend to report to the sinks. Laminated hematite particles are problematic as they either sink of float depending on the ratio between silica and iron and the density class. Therefore, hematite was lost to the floats because of variability in the laminated texture of most particles. The extent to which this occurs is to be determined through micro-XRF imaging of the sink-float test products, towards the development of a predictive model for particle distribution during gravity separation, based on particle textural quantification.

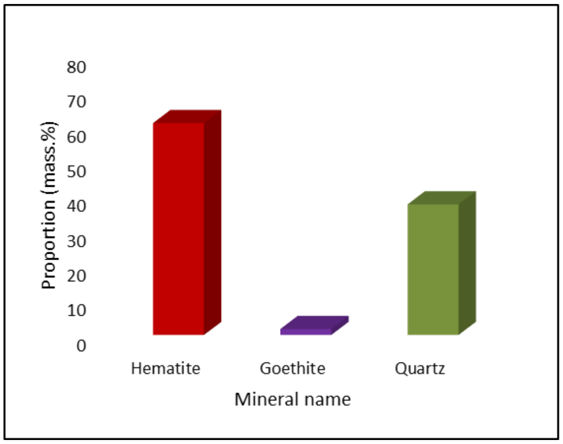


Figure 1. Bulk mineralogy of the head sample of Fe ore

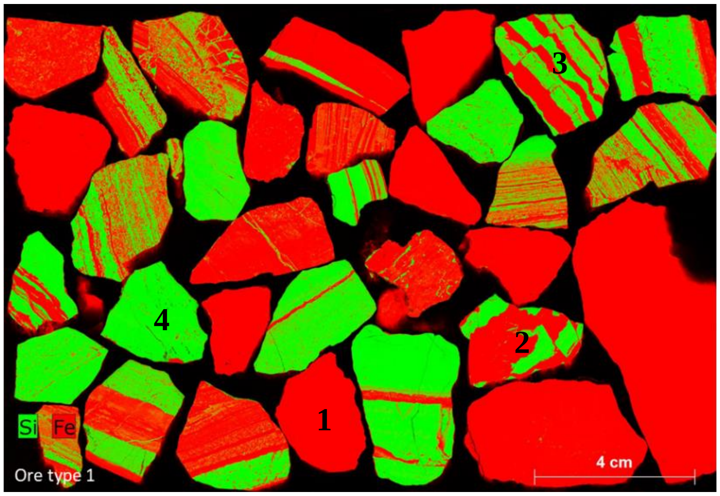
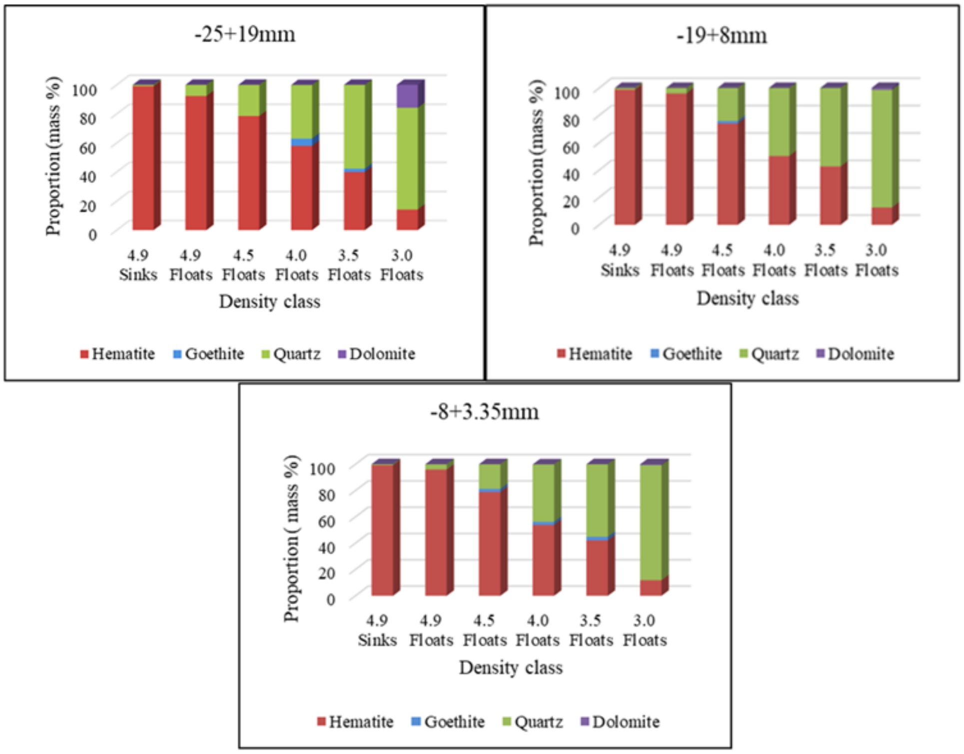


Figure 2. Elemental map produced via micro-XRF, for the ore at a size fraction of -25 +19 mm. Si is in green and Fe in red, corresponding with quartz and hematite, respectively. 1 = massive hematite; 2 = hematite-rich; 3 = quartz-hematite laminated; 4 = massive quartz

4. Conclusion

Beneficiation of low-grade iron ore requires upfront mineralogy so as to predict the separation efficiency. Micro-XRF has proven to be a potentially viable technique for coarse particle (>6mm) characterisation. To date, the study has shown that mineral-particle data obtained via the use of XRD and micro-XRF imaging are useful for prediction of particle behaviour during processing. However, it is important to be able to quantify mineral-particle properties such as ore texture to enable more accurate prediction of particle distribution during gravity separation. This work forms part of an ongoing MSc project in pursuit of developing a methodology suitable for ore texture quantification using micro-XRF imaging.


-25+19mm

-19+8mm

-8+3.35mm

Figure 3. Bulk mineralogy as function of fraction size and density class, for three size fractions of the ore

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References

[1] Ratshomo K. South African iron ore industry developments, 2004-2013. Department of Mineral Resources, Pretoria. 2104.
[2] Whiteman, E., Lotter, N.O. and Amos, S.R. Process mineralogy as a predictive tool for flowsheet design to advance the Kamoa project. Minerals Engineering, 96-97, pp.185-193, 2016.
[3] Menzies, A., Scheller, S., Tagle, R., Gloy, G.and Barazza, M. Advancements in Automated Mineralogy incorporating Micro-XRF technology. Proceedings of Process Mineralogy '17. Minerals Engineering International. 2017.