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Iron ore textural information is the key for prediction of downstream process performance

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ABSTRACT

Textural information or information about the presence of porosity, different material or mineral types and their structural arrangement in iron ore is crucial for understanding, predicting and optimising downstream processing performance. Ores with the same chemical and mineral composition may behave very differently during downstream processing due to differences in textural components.

To produce a textural description of iron ore, it is preferable to use an automated system to avoid subjectivity and to collect additional information about mineral abundance, liberation and association. CSIRO created a unique dedicated optical image analysis software package for automated textural classification and characterisation of different minerals, sinters and coke. This software, called Mineral4/Recognition4, has been used extensively to collect data for this article.

Four case studies of CSIRO research are presented to demonstrate the importance of textural information.

- The first example shows that iron ore samples with different texture but similar mineralogy undergo different degrees of assimilation in compact sintering.
- The second example shows that empirical modelling of sinter properties was improved considerably after introducing textural information.
- The third example demonstrates the application of classification by ore texture to model and optimise hydrocyclone performance.
- The last example is an experimental study of ultrasonic treatment of hematitic–goethitic iron ore fines. It demonstrates how the resulting breakdown or deagglomeration of different particles, and the mineral deportment, can be better understood when textural information is also considered.

In all cases, the availability of textural information was critical, providing a better prediction of process performance or a deeper understanding of the unit process.

1. Introduction

Three levels of ore characterisation detail are applicable to understanding, modelling and predicting the downstream processing performance of iron ore. At the first (the simplest) level, only the chemical composition of the bulk ore or specific size fractions is considered. Such an approach is very basic and does not explain many phenomena about a given process. At the second level of ore characterisation, mineral composition is taken into account. This approach can give a much better understanding of processing behaviour, especially if mineral liberation and association information is available. However, ores that have analogous mineralogy can behave differently during the same processing. For example, consider two types of pure hematite with the same percentage of porosity, where in one case, the porosity presents as microporosity distributed throughout the whole particle, while in the other case, the porosity presents as macroporosity – i.e. large separate pores. The physical hardness and breakage characteristics of these two types of hematite will be significantly different, as well as their

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moisture absorption characteristics, behaviour during granulation and reactivity during sintering.

Therefore, to understand the peculiarities of specific processes and to predict the results of particular processes adequately for a large range of ores and conditions, a third level of characterisation is needed which considers textural ore information (Box et al., 2002; Clout, 1998, 2002; Donskoi et al., 2008a). Here "texture" is understood as a synonym of "fabric" referring to the spatial distribution of different minerals and porosity in ore particles (Iglesias et al., 2011). Researchers from industry and academia have considered this textural concept and applied it in their research (Bonnici et al., 2008, 2009; Lamberg and Lund, 2012; Lund et al., 2013, 2015); however, there are some problems in conducting textural characterisation of iron ore, because many researchers obtain textural information by manual point counting.

The only well-known software package which performs automated textural characterisation of iron ore is the Mineral4/Recognition4 automated optical image analysis (OIA) package created by CSIRO (Donskoi et al., 2010, 2013, 2015b). The automation of multi-set imaging, image processing and reporting by this software made it possible for industry and researchers to reduce the cost and subjectivity of iron ore characterisation significantly, while simultaneously increasing the accuracy of mineral identification and textural characterisation. Mineral4/Recognition4 was developed specifically for iron ore characterisation, but it should be noted that it is now used successfully for characterisation of other ores, sinters and coke. It imports images in all major formats, and importantly, it allows users to build their own ore classification schemes, which can be modified or switched by the operator. Data from previously processed image sets can easily be reprocessed using different classifications, which is not possible with manual point counting (the point counting would have to be repeated).

Manual point counting has several deficiencies compared to an automated textural characterisation system such as Mineral4/Recognition4. The main problems are as follows:

- Even experienced mineralogists are subjective, so the results of point counting for textural classification may depend on external and internal factors. The results can differ significantly between different mineralogists or by the same mineralogist at different times. On the other hand, automated classification will always reproduce the same result for a given set of particles if the classification scheme and setup are consistent.
- Manual point counting is limited by human capability to identify different minerals with close (but different) reflectivity while modern automated optical image analysis can recognise more than 16,000 different shades of the same colour.
- The number of particles that can be characterised manually in a given amount of time is very limited – maximum 1000–2000. This means that particle statistics for minor textural classes will be statistically insignificant. Automated image analysis is faster and more efficient in this respect. In some studies, up to 200,000 particles have been characterised by Mineral4/Recognition4, providing robust statistics for minor textural components.
- The data obtained by manual point counting contains only information on the particle abundance of different texture classes, while automated OIA gives comprehensive sample characterisation information including mineral abundances, liberation and association data, calculated chemical composition and densities for all the measured particle sections in a polished block or for any selected subgroup of particles.

There are two major automated imaging techniques used for characterisation of iron ores and capable of providing mineral abundances, mineral associations, mineral liberation and grain size distributions: Scanning Electron Microscopy (SEM) (Gottlieb et al., 2000; Gu and Guerney, 2000; Maddren et al., 2007) and OIA (Pirard et al., 2007; Donskoi et al., 2007a, 2015a; Gomes and Paciornik, 2008a, 2008b). Both systems have their advantages and drawbacks (for detailed comparisons see Donskoi et al., 2013, 2014). Among the major advantages of optical systems over SEM systems, such as QEMSCAN and MLA, lower capital and maintenance costs can be counted.

Another important advantage of optical systems is their better identification of different iron oxides and oxyhydroxides. SEM systems struggle to distinguish between minerals with close chemical composition, or oxides and oxyhydroxides of the same major elements, which in the case of iron ores are hematite, kenomagnetite, maghemite, hydrohematite and different types of goethite. OIA systems can even identify zones with different oxidation and hydration for the same non-stoichiometric phase, due to the differences in reflectivity.

Also, optical systems generally provide much higher resolution than SEM methods. The theoretical limit of resolution for OIA systems is 0.20 μm (Slayter, 2015), although it is usually around 0.35 μm for systems that don't use oil immersion and which are therefore more suitable for automation. The actual resolution of QEMSCAN is limited by the size of the excitation volume and the point-by-point raster technique used to scan samples, even though the maximum spatial resolution of electron microscopes is in the nanometre range. Using smaller spacing between consecutive measurement points can result in much longer overall imaging times and thus in significantly smaller imaged areas compared to OIA. For routine QEMSCAN mineral characterisation, the spacing used between measurement points is about 5–10 μm. However for non-massive screening, or when characterisation of a small area is needed, the spacing can go down to 0.5 μm or even smaller, depending on the size of the excitation volume in certain material.

Finally, OIA provides better porosity identification. It reliably identifies pores larger than 0.5 μm, while SEM methods can only identify much larger pores. Accurate identification of porosity is important for the reliable determination of mineral abundances (Donskoi et al., 2010, 2013). Different minerals can have different porosity; for example, quartz usually has very low porosity, while ochreous goethite is usually highly porous (Donskoi et al., 2008a). If porosity is not taken into account or is significantly underestimated, the relative mineral abundances will not be measured correctly. Proper calculation of porosity is also necessary for the calculation of particle density, which, together with size distribution, is the major input parameter required for modelling of beneficiation processes (Donskoi et al., 2006a, 2008b, 2010). It has also been shown (Donskoi et al., 2014) that SEM systems like QEMSCAN can significantly misidentify minerals with microporosity. For previously tested samples (Donskoi et al., 2014), large areas of microporous hematite were misidentified by QEMSCAN as vitreous or ochreous goethite, while microporous vitreous goethite was misidentified as ochreous goethite. Abundant misidentifications on the edges of particles were also present in the QEMSCAN characterisation.

The major drawback of OIA compared with SEM methods is the distinguishing between different minerals that have similar reflectivities. It should be noted that the latest Mineral4/Recogntion4 OIA package by CSIRO provides significantly improved mineral identification and can discriminate minerals with significantly overlapping reflectivities (Donskoi et al., 2015a,b). The textural identification in Mineral4/Recogntion4 can also discriminate areas of the same mineral or different minerals that have similar reflectivities but different textures or morphologies.

Another drawback of OIA is identification of non-opaque minerals, especially those with reflectivities close to that of epoxy resin (e.g. quartz). It should be noted that some non-opaque minerals