“MINERAL4/RECOGNITION4: A UNIVERSAL OPTICAL IMAGE ANALYSIS PACKAGE FOR IRON ORE, SINTER AND COKE CHARACTERIZATION”

Dr Eugene Donskoi - Project Leader, Process Modelling - Downstream Processing Performance

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WHY?

- Increased productivity (up to 10 times higher than manual point counting)
- Higher level of characterisation (quality and amount of information, consistency)
- Textural Characterisation
  1. Ore texture is important for prediction of downstream processing
  2. Particles within the same textural group have analogous properties
- Reflected Light Microscopy
  1. Capability to reliably identify different iron oxides and hydroxides
  2. Higher resolution, faster and cheaper than QEM SCAN and Raman spectrography

Textural composition

Mineral composition

Chemical assay

Texture – microstructure which relates both the spatial distribution of different minerals and porosity, and the spatial distribution of different grains and crystals

H = hematite (martite), HH = hydrohematite, vG = vitreous goethite, oG = ochreous goethite, K = kaolinite, P = pore, E = epoxy resin
Examples of four hematitic particles exhibiting different textural types ranging from dense to highly porous

These different textures have different characteristics in terms of hardness, attrition resistance, moisture absorption, and will behave differently during comminution and beneficiation processes as well as granulation and sintering.
Comparison of modelled and experimental TI values for runs included in the modelling

(a) modelling without textural information (SD = 1.53, R-Sq = 75.6%)

(b) modelling with textural information (SD = 1.13, R-Sq = 86.9%)

Not a single outlier has been removed (either from the modelling set or the verification set) !!!
CSIRO OPTICAL IMAGE ANALYSIS (OIA) PACKAGE (‘MINERAL4’ and ‘RECOGNITION4’)

- Initially created for iron ore and now successfully used for other minerals
- Allows automatic, semi-automatic and manual acquisition and comprehensive processing of sets of images
- Works for any particle size including lumps
- Allows users to build their own iron ore classification scheme and to perform automated iron ore and gangue texture classification

- Imports images in all major formats including output from QEMSCAN and MLA
- performs calculation of mineral composition, chemical assay, density, dimensional or textural characteristics for every particle section, liberation class and ore texture class or any particle group based on specific mineral, dimensional, textural or chemical criteria
- performs calculation of mineral liberation, iron liberation and mineral association characteristics for any group of particles
### Ore texture group characterisation (example of output to Microsoft Word)

This tables includes the following parameters grouped by iron ore texture type: the number of particles, frequency %, area % and weight % of this ore texture group, total iron and specific gravity with coefficients of variation (standard deviation/mean), mean area with coefficient of variation, mean shape factor and elongation, percentages of each mineral within each class by area or by weight, and the percentage of pores by area.

<table>
<thead>
<tr>
<th>Parameters // Part Type</th>
<th>Hardness</th>
<th>No. of Part</th>
<th>Freq %</th>
<th>Area %</th>
<th>Wt %</th>
<th>Mean Fe Tot</th>
<th>Mean SG</th>
<th>Mean Mineral Area (µm²)</th>
<th>Mean Shape Fact</th>
<th>Mean Elong</th>
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<table>
<thead>
<tr>
<th>Part Type / Mineral</th>
<th>Keno-Magnetite (Wt)</th>
<th>Hematite (Wt)</th>
<th>Hydro-Hematite (Wt)</th>
<th>Vitreous Goethite (Wt)</th>
<th>Ochreous Goethite (Wt)</th>
<th>Kaolinite (Wt)</th>
<th>Quartz (Wt)</th>
<th>Pores % (Area)</th>
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<td>53.08</td>
<td>5.97</td>
<td>0.13</td>
<td>0.0493</td>
<td>10.9</td>
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</tbody>
</table>
Sample of Brockman ore with some addition of martite/kenomagnetite ore

Optical photomicrograph

Corresponding mineral map
Sample of Marra Mamba ore

Optical photomicrograph  corresponding mineral map
Identification of martite and microplaty hematite using textural identification

Original reflected light photomicrograph

Mineral map (martite - yellow, microplaty hematite - magenta)
Automated identification of primary and secondary hematite

Problem – the same mineral, so similar reflectivity
Solution – segmentation by textural identification

Automated identification of Fibrous, Columnar SFCA and Dense SFCA (silicoferite of calcium and aluminium)

Problem – the same mineral, so similar reflectivity
Solution – segmentation by textural identification

- primary hematite – light blue
- secondary hematite – dark blue
- magnetite – magenta
- fibrous SFCA – light green
- Columnar SFCA – cyan (relatively large elongated grains, prismatic structure)
- glass – dark green
- porosity and epoxy – yellow

200 µm
Comparison of sinter phase quantification by manual point counting (PC) and automated optical image analysis (OI) techniques
Automatic Identification of Inert Maceral Derived Components (IMDC) from Reactive Maceral Derived Components (RMDC) in Coke

Currently there are three methods used for IMDC identification:

1) bulk identification of IMDC
2) small size porosity IMDC identification
3) Identification of “washed out” areas

Magenta – IMDC, blue – RMDC, yellow - porosity
Textural identification of IMDC based on identification of small size porosity

Photomicrograph of coke

Porosity map

Map of fine porosity

IMDC areas obtained based on map of fine porosity

Final IMDC map from fine porosity method
Segmentation of IMDC boundary layers

The wall abundance (RMDC) in the IMDC boundary area is 7.4%, while the overall abundance of RMDC in the sample is 23.6%
The change of RMDC abundance and thickness in IMDC boundary area depending on IMDC area.
Correlations between parameters characterising parent coal composition, coke structure and measured coke properties.

MCS - arithmetic mean coke size in mm. determined by hand sizing over 125.0, 106.0, 75.0, 50.0, 25.0 and 13.2 mm square mesh screens AREA_1 – average pore area, ModWT- modified wall thickness, ECD-equivalent circle diameter
Dependence between coke strength indices and cumulative amount of IMDC

Dependence of correlation coefficient of M40(AS1038) and I40 on cumulative amount of IMDC down to a specific size of IMDC expressed in equivalent circle diameter (ECD).
Large Object Characterization: Pellets, Lumps, Pebbles - Magnetite pellet heated to 620°C

Ø 12.7 mm, compound image made of 18 x 18 2 x 2 MosaiX images
Clear hematite presence in outer layers

Individual image:
2 x 2 MosaiX at magnification x100
Magnetite – pink
Hematite – white
Porosity – dark
Large Object Characterization: Pellets, Lumps, Pebbles - Magnetite pellet heated to 620°C

compound mineral map

clear hematite presence in outer layers

magnetite
hematite
flux
porosity
Magnetite pellet heated to 620°C

Mineral/porosity distributions

magnetite
hematite
porosity
Graph of average hematite, magnetite, and porosity abundances as a function of distance from pellet centre.
Conclusions

• Iron ore textural information is important for prediction of downstream processes.

• Textural identification in Mineral4 allows identification of different morphologies of the same mineral in iron ore and sinter.

• Textural identification allows differentiation of IMDC and RMDC in cokes and comprehensive characterisation of coke structure.

• Unique features and capabilities created in CSIRO’s Mineral4/Recognition4 software allow comprehensive and, in some cases, unique characterisation of important features relevant to ironmaking researchers and industry plant operators.
Thank you

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Carbon Steel Futures group/Resources, Community and Environment Program/CSIRO Mineral Resources
Optical Image Analysis Advantages and Drawbacks (compared with SEM methods)

**ADVANTAGES**

- Fast and cheap
- High resolution
- Reliable identification of minerals with close chemical compositions (like hematite, hydrohematite, magnetite)
- Porosity identification

**DRAWBACKS**

- No simultaneous chemical composition
- Possible misidentifications
- Problems with identification of non-opaque minerals within epoxy blocks

**COMMON PROBLEMS**

- Representability of the studied sample
- Stereological error
- Touching particles or particle sections separated by cracks or pores.

Average presence of iron ore minerals in different layers of thin 1mm settled sample in epoxy polished block.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Top</th>
<th>Middle</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematite</td>
<td>50</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Hydro-Hematite</td>
<td>10</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Vitreous Goethite</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Ochreous Goethite</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>20</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Quartz</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Pores</td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Diagram: Layers Top to Bottom -150+106 µm fraction

**Layers Top to Bottom**
- Top
- Middle
- Bottom
Possible sectioning of non-liberated particles during block polishing

- Dependence from texture.
- Iron ore much more complex

a) sectioning of three similar two-mineral particles - side view; b) corresponding particle sections: – two particles appear as fully liberated and only the one in the middle is not liberated

Unique feature - Automatic identification of non-opaque minerals based on relief

(a) Ore photomicrograph, (b) Image enhanced for quartz identification, (c) Coloured mineral map (Q = Quartz)
Applications of “Mineral4/Recognition4”

- OIA of iron ore sinter
- OIA of manganese sinter

Determination of coal maceral composition

Manganese ore analysis