Application of X-ray microtomography to investigate the effect of raw material properties on the kinetics of iron ores granulation
Introduction: steelmaking routes

Primary steel production

Raw material preparation
- lump ore
- fine ore
- lump ore
- fine ore

Iron making
- BF
  - natural gas, oil or coal
  - blast
  - O₂
- DR
  - natural gas, oil
  - shaft furnace
  - rotary kiln furnace
  - fluidized bed

Steel making
- OHF
  - air
  - oxygen
  - recycled steel
- BOF
- recycled steel
- EAF
  - recycled steel
- EAF
  - recycled steel

Crude steel (CS)

Energy Intensity (GJ/t):
- BF: 26.4 – 41.6
- DR: 19.8 – 31.2
- EAF: 28.3 – 30.9
- EAF: 9.1 – 12.5

Introduction: sinter plant flowsheet

Bedding

Iron ores

Return fines

Burnt lime

Limestone

Solid fuel

Drum granulator

Off-gas

Sinter strand

Sinter cooler

Blast furnace

Sintering fan

Cold screening
Introduction: drum granulator

- Mixing region
- Water injection
- Granulation region
- Revolution speed (w)
- Iron ore mixture
- Diameter
- Slope

Length
**Introduction: Iron ore granulation**

Process of transforming finely divided particles to granular materials with controlled physical properties by the introduction of outside forces.

Industrial granulation processes are run with:

- **Controlled parameters**
  - Drum speed
  - Water addition Wt%
  - Binders

- **Fluctuating parameters**
  - Iron ore quality
  - Particle shape
  - Particle size distribution

**MAIN OBJECTIVE**

- Understand the impact of **raw material properties** on granulation
## 1 Characterization of primary particles

2 types of iron ore concentrates:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Collection pieces</th>
<th>1 – 2 mm</th>
<th>&lt; 0.25 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematite</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
</tr>
<tr>
<td>Goethite</td>
<td><img src="image4" alt="Image" /></td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>
Qualitative analysis

Goethitic iron ore concentrate

Hematitic iron ore concentrate
1 Characterization of primary particles

SEM images

Goethite

Hematite

<250μm size fraction

1-2mm size fraction
1 Characterization of primary particles

Chemical composition of the iron ore concentrates

<table>
<thead>
<tr>
<th></th>
<th>%Fe</th>
<th>%Fe ++</th>
<th>% CaO</th>
<th>% SiO₂</th>
<th>% MgO</th>
<th>% Al₂O₃</th>
<th>% LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goethitic Iron ore</td>
<td>56,13</td>
<td>0,05</td>
<td>0,16</td>
<td>5,55</td>
<td>0,119</td>
<td>2,699</td>
<td>10,68</td>
</tr>
<tr>
<td>Hematitic Iron ore</td>
<td>65,34</td>
<td>0,54</td>
<td>0,01</td>
<td>4,55</td>
<td>0,087</td>
<td>0,604</td>
<td>1,4</td>
</tr>
</tbody>
</table>

Mineralogical quantitative analysis of the iron ore concentrates

<table>
<thead>
<tr>
<th></th>
<th>goethite (wt %)</th>
<th>hematite (wt %)</th>
<th>magnetite (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goethitic Iron ore</td>
<td>99,5</td>
<td>0,5</td>
<td>/</td>
</tr>
<tr>
<td>Hematitic Iron ore</td>
<td>1,3</td>
<td>98,6</td>
<td>0,1</td>
</tr>
</tbody>
</table>
1 Characterization of primary particles

Shape of primary particles

- Non-elongated particle
- Elongated particle

Ratio 1:4

- Zone with interlocking by surface asperities

Inner diameter (μm) vs. Length (μm)

Roughness (%) vs. Bluntness (%)
1 Characterization of primary particles

% elongated particles

% of particles in the zone with interlocking by surface asperities
2. Experimental methodology

The residence time in 3 steps:
1: Rolling mode
2: Water addition
3: Granulation time
2. Experimental methodology

![Graph showing Binder/solids vs Time and % nuclei/% fines]
2. Experimental methodology
2. Experimental methodology
3. Characterization of the granules

*Bruker Skyscan 1172 X-ray scanner*

- 100kv-100 µA
- 2D detector 4000x2300 pixels
- 12 bit CCD camera
- Al-Cu filter
- Size of objects: 0,5x0,7 cm
- -> resolution of 4 µm-6 µm
3. Characterization of the granules

![Characterization of the granules diagram](image)
3. Characterization of the granules

3 min of granulation
75 wt.% nuclei-25 wt.% fines
Binder/solid ratio: 0.15
3. Characterization of the granules

Goethite « 5 »
3. Characterization of the granules
3. Characterization of the granules

1. raw image

2. threshold

3. porosity

4. number of nuclei

5.4% porosity

10 nuclei
3. Characterization of the granules

Porosity

RUN

Porosity %

Porosity (Goet)

Porosity (Hem)
3. Characterization of the granules

![Graph showing the number of nuclei over runs](image)

**Number of nuclei**

- **Nb of nuclei (Goet)**
- **Nb of nuclei (Hem)**
3. Characterization of the granules

Goethite  Hematite

1mm

Binder/solids  Time  nuclei/%fines
3. Characterization of the granules

Polished sections

X-ray tomography
4. Conclusion

Many parameters can be used to control the granulation process

- % water
- % nuclei
- % fines
- time of granulation
- ...

BUT

-> Influence of these parameters on the d50 is strongly dependant of the mineralogy
X-Ray tomography is very useful for better understanding of granulation behavior in relation with the structure of granules, by providing 3D information on:

- texture
- porosity
- number of nuclei
- spatial distribution of primary particles
Future work

Test on particles closer to industrial mixtures:

- wider range of iron ore types
- lime(stone)
- solid fuel
- sinter return fines...

Evaluation of granule strength:

- link with structure of granules
- shock test with high speed camera
Shock test

Height at impact

Minimal height - compression

Rebound height

Fines generation
Thank you for your attention