RECYCLING OF SPENT REFRACTORY

Melvyn Bradley, Technical Director, LKAB Minerals
THE LKAB GROUP
THE LKAB GROUP

• Headquartered in Luleå, Sweden, and owned by the Swedish state.
• World leading producer of upgraded iron ore and growing supplier of mineral solutions.
• 30 companies in 15 countries
  – E.g. Minerals, Drilling, Concrete, Explosives, Railway, Harbour, Construction.

Produced 26M MT iron ore 2014
Total sales 2.27B EUR (20.61 BSEK) 2014
On average 4,539 employees 2014
Mineral Solutions for Our World

- **30+ MINERALS**
- **360 EMPLOYEES**
- **12 COUNTRIES**

- **Heat Insulation**
- **Ceramics**
- **Recycled Refractories**
- **High Quality Coatings**
- **Water Treatment**
- **Ballasting Wind Farms and Spar Platforms**

- **Protective Coatings**
- **Radiation Shielding**
- **Flame Retardancy**
- **Automotive Industry**
- **Steel Protection**
- **High Quality Casting**

**PIPE COATING**
LKAB MINERALS: THE NUMBERS

12 countries
Processing plants in the UK, Sweden, The Netherlands, Finland, Turkey and China
Deposits in Sweden, Turkey and Finland

Sales of 165 MEUR in 2015
On average 325 employees 2015
A portfolio of > 30 minerals
FOCUS FOR TODAY’S PRESENTATION

The new challenges in refractory recycling
OVERVIEW

- Significant increase in usage over last 10 years
- Initial drivers:
  - Environmental considerations
  - Escalating cost of virgin refractory raw materials
- Locally sourced material & price stability have fuelled growth
OVERVIEW

Current & future drivers:

— A simple recycling process has developed into a complex system
— Improve the quality and consistency of the recycled materials
— Investment in advanced processing equipment
— Development work on the use of reclaim material in finished product
## MARKET – REFRACTORY RAW MATERIALS

<table>
<thead>
<tr>
<th>MAGNESITE REFRACTORY GRADE</th>
<th>REFRACTORY GRADE BAUXITE &amp; ALUMINA</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% CHINA</td>
<td>77% CHINA</td>
</tr>
<tr>
<td>6% RUSSIA</td>
<td>9% RUSSIA</td>
</tr>
<tr>
<td>5% TURKEY</td>
<td>7% INDIA</td>
</tr>
<tr>
<td>4% AUSTRIA</td>
<td>6% GUYANA</td>
</tr>
<tr>
<td>3% SLOVAKIA</td>
<td>1% BRAZIL</td>
</tr>
</tbody>
</table>

*Source: Industrial Minerals*

- Recycled refractory materials offer locally sourced, long term supply
- Established as key component of supply chain
MARKET – RECYCLED REFRACTORIES

- Wider acceptance of recycled materials
- Several organisations have departments dedicated to the sourcing & use of secondary raw materials
- Other organisations reluctant to adopt recycled materials
- Europe leading in the utilisation of spent refractories
- Americas & Asia more fragmented

European Recycled Market Overview of 000’s tonnes per country
The Strategy (The Dream)

- Under the Europe 2020 strategy for growth, resource efficiency is one of flagship initiatives;
  - “Reduce the pressure on demand for primary raw materials”
  - “Make the EU a ‘circular economy’ based on a recycling society with the aim of reducing waste generation and using waste as a resource”

The Regulations (The Reality)

- EU Waste Shipment Regulations
  - Annex VII (green list)
    - Logistics!
- EU Waste Framework Directive
  - End of waste criteria (non-waste)
    - Definition!
- REACh
  - Substances recovered from waste
    - Definition!
LKAB MINERALS RECYCLING INVESTMENT

Flixborough, UK
• Processing recycled refractories +25 years
• Significant equipment upgrade 2014/15
• ISO 9001, 14001 & OHSAS18001 accredited

Moerdijk, BV
• Newest refractory recycling facility servicing Europe
• 12,000M² space dedicated to Recycling
• ISO 9001, 14001 & OHSAS18001 accredited

Richmond, UK
• Acquired successful UK recycling company May 2013
• Specialises in reclamation and recycling of spent refractories
• Experience spanning over 30 years
CYCLE OF LIFE CONCEPT

• **Purpose** - Avoid “spot lots” of secondary raw materials

• **Concept** - Establish a sustainable operation & develop strategic partnerships

• Key features:
  
  — *Reclamation* - Direct contact with industries seeking outlets for spent refractories & comply with legal considerations i.e. waste disposal licence
  
  — *Processing* – Ability to provide customers with products to meet their requirements
  
  — *Technical Knowledge* - Understand how recycled raw materials can be incorporated into refractory products
SORTING OF SPENT REFRACTORIES

• Spent material contains:
  — Mixed refractories
  — Contaminants (Cement, wood, fine aggregate)

• Licence reclamation site carries out cleaning and hand sorting

• Once clean pile created:
  — Sampled to determine chemical composition
  — Determine classification
  — Assign batch code

• Transport to processing plant
MOBILE SORTING UNIT

- Offers more flexible operation
- Minimal set up time
- Screening of fines saves cost of transporting waste
- Initial sorting on site reduces material movements
CLASSIFICATION OF SPENT REFRACTORIES

<table>
<thead>
<tr>
<th>Material</th>
<th>Product Group</th>
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</thead>
<tbody>
<tr>
<td>Cordierite</td>
<td>Alumina</td>
</tr>
<tr>
<td>Alumina 60 AND</td>
<td>Alumina</td>
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<tr>
<td>Alumina SC</td>
<td>Alumina</td>
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<td>MgO SC</td>
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<tr>
<td>Magnesia Spinel 85</td>
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<td>Mag Chrome</td>
<td>Magnesia</td>
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<tr>
<td>Mag Carbon OXI</td>
<td>Magnesia Carbon</td>
</tr>
<tr>
<td>Mag Carbon AF</td>
<td>Magnesia Carbon</td>
</tr>
</tbody>
</table>

Two primary categories:

— Magnesia based:
  • Magnesia (carbon-free)
  • Magnesia-carbon
    — Anti-Oxidant level
  • Magnesia-spinel

— Alumina based:
  • Classification by Al₂O₃ content
  • Carbon bearing
PROCESSING SPENT REFRACTORIES

Processing route:
- Primary crushing (100-50mm)
- Secondary crushing (0-20mm)
- Drying
- Screening (including Hammer Mill)
- Milling (powders)

*Recycled materials are subject to additional processing requirements*
PROCESSING SPENT REFRACTORIES

Light weight contaminants:
- Wood
- Plastic
- Paper
- Glass

Consequences
- <0.1% by weight
- Potential issues
  - Affect installation
  - Premature failure

*Investment in additional processing equipment can reduce this issue*
PROCESSING SPENT REFRACTORIES

Z-Classification:

• upward vacuum extracts light weight contaminants
• Dense aggregate tumbles down to bottom
PROCESSING SPENT REFRACTORIES

Advances in reducing metallic contamination:

Band magnets
- Sorting & primary crushing
  - Ideal for removing tramp metal etc.
  - Potential to remove “good” product
    - E.g. precast containing steel fibres

Drum magnets
- Post screening
  - Removes magnetic particles liberated after crushing & screening
  - Individual size fractions treated separately
PROCESSING SPENT REFRACTORIES

Comparison of data before and after installation of drum magnets:
• Significant reduction in $\text{Fe}_2\text{O}_3$
• Removal of steel fibres

<table>
<thead>
<tr>
<th></th>
<th>$\text{Al}_2\text{O}_3$</th>
<th>$\text{SiO}_2$</th>
<th>$\text{TiO}_2$</th>
<th>$\text{Fe}_2\text{O}_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Old Magnets</strong></td>
<td>62.65%</td>
<td>27.83%</td>
<td>1.78%</td>
<td>2.34%</td>
</tr>
<tr>
<td><strong>New Magnets</strong></td>
<td>62.63%</td>
<td>27.28%</td>
<td>1.49%</td>
<td>1.28%</td>
</tr>
</tbody>
</table>
APPLICATIONS FOR SPENT REFRACTORIES

Addition into bricks:
• Controls stability during firing
• Classification critical
  – Mag-carbon
    • Anti-oxidant level
    • Carbon content
  – Alumina bricks
    • Aggregate type
    • Binders
      – Phosphate content

Alumina monolithics:
– < 40% Al$_2$O$_3$ castable
  • 100% addition
– > 40% Al$_2$O$_3$ castable
  • 20 - 30% addition

Magnesia monolithics:
– Tundish spray/dry vibe
– Gunning repair
  • EAF, Convertor, Ladle slag line
APPLICATIONS FOR SPENT REFRACTORIES

Metallurgical Additives

• Magnesia based
  — EAF slag conditioner

• Alumina based
  — Ladle slag conditioner

• Key Requirements:
  — Chemistry
    o e.g. $Al_2O_3$ 65-75%
  — Particle Size
    o Zero or minimal fines
  — Pricing
    o Low!!!
FUTURE DEVELOPMENTS

Automated sorting systems
• In-line analytical technology
• Reduce manual handling

Recycled materials in monolithics
• Industry wide concern with material quality (e.g. Bauxite, microsilica)
  — New generation of dispersants
  — Engineered calcium aluminate cements

Pelletizing
• Processing has tendency to yield high % of fine grade (0-1mm)
• Feasible to pelletize fine grades
• Slag conditioning a good application for pellets
CONCLUSION

- Market for recycled materials will continue to grow
- Strategic partnerships are critical to maintain supply chain
- Steps continue to be taken to improve the quality of the finished product
- Close collaboration is necessary with refractory companies to expand use of recycled
- Clarification of EU waste regulations & directives
- Strong focus is needed to improve sorting techniques
THANK YOU FOR LISTENING

Visit our stand or go to www.lkabminerals.com