Blast-furnace and steelmaking slags: Which future valorisation in the next 20 years?

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ὄνους σύρματ᾽ ἂν ἐλέσθαι μᾶλλον ἢ χρυσὸν.

(only) Asses would rather have straw than gold.

Heraclite of Ephesus,
Fragments, circa 500 BC
Summary and Methodological approach

Prospective Outlook 2030

Current situation

Markets applications

Economic trends

Regulatory trends

Physico-chemical potential

Recent developments

Current situation

Markets applications

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Recent developments
Where we are today
Blast Furnace Slags
One single dominant valorisation: GBFS in cement

Valorisation ratio close to 100%

20% air-cooled

80% granulated

25% to aggregates

75% to cement

BF Slag common issues

- One technical drawback in cement: low early strength
- Insufficient local cement market volume:
  - The local market for cement within a competitive distance is often not big enough, due to the size of steel integrated plants.
  - Output of one plant $\rightarrow$ yearly consumption for 18 M inhabitants
  - Cheap local addition materials: Fly ash, limestone, pozzolans
  - Declining or shrinking cement consumption in some areas since 2008: Europe on the whole (-20%), Spain (-75%)
- Environment: CO2 footprint (allocation)
  $\rightarrow$ market diversification needed
Steel Slags in Europe
79% valorized, 62% in roads

Only 8% to metallurgical recycling!

Use of Steel Slag in 2008: 17,2 mio tonnes\(^1\)

- road construction 62%
- internal use for metallurgical purposes 8%
- fertilizer 4%
- hydraulic engineering 1%
- cement production 1%
- final deposit 6%
- interim storage 15%
- others 3%

\(^1\) Data from: A, B, D, DK, E, F, FIN, GR, L, NL, PL, RO, UK, S, SK, Slo

Source: Euroslag

(16 countries)
BOF Slag common issues

■ **Variability**: from heat to heat!

■ **Local Market**:
  - demand may be too small, or competition too strong (quarries of natural stone, recycled materials such as demolition wastes)

■ **Free lime**:
  - by far the most highlighted issue, as it is the first cause of expansion, which limitates the utilisation as aggregates, today the main destination. But, it is a problem only for this destination.

■ **Phosphorus**:
  - only 1% in average. Phosphorus is a limitation to internal recycling to sinter plant or BF, depending on operating parameters of the BOF shop.

■ **Fluor, Vanadium, pH, may be environmental problems**
Long Term economic trends
Raw materials: a new era

Average price of iron ore imported in the UE (15 countries), in €/T

Fourfold increase

8 years
Energy: higher prices and development of renewables

Fourfold increase

WTI Oil Price History (US $ per barrel)
Regulatory trends
Opportunities overweight constraints

- Landfilling rules
- Water quality
- Chemistry (F, heavy metals, pH)
- Leaching

- Wastewater treatment
- Polluted soils and sediments treatment

- Life-Cycle Assessment
- Circular economy
- End of Life recycling
- CO2 emissions quotas
- Sustainable construction
- Sustainable agriculture
Sustainable construction

- Positive energy buildings
- Environmental footprint (incl. CO2)
- End of life recycling of materials
- Use of secondary materials

**Issues:**
- Legal status of slags
- CO2 footprint
Other examples:

- **Agriculture**: less chemicals (fertilizers, pesticides)
- **Wastewater quality**: less phosphorus
- **Management of dredging sediments and contaminated soils**
A more rigorous regulatory framework for slags, ...but clearer and more stable (hopefully) to move forward

Example: new French guidelines on Acceptability of Alternative Materials in Road Construction.
Recent Developments in the last 5 years
EUROSLAG conference
Madrid Oct 2010: topics

Leaching of EAF slags
- Micro-structure and release of pollutants
- Stability of spinels in high basicity slag
- Long term leaching behaviour

High Alloyed and Stainless slags
- Cement & concrete
  - EAF slag as aggregates in concrete
  - (3 presentations)

Innovative uses
- Raw material for sinter plant
- P sorbent for waste water
- Water pollution control
- Seaweeds beds (Japan)
- Fe-Mn alloy production (Japan)

Road construction
- Soil Stabilization
- EAF slag (Egnatia Highway)
- EAF slag (Spain)
Overview of major developments at pilot or industrial stage

Industrial

- BOF slag as Hydraulic binder or concrete component (China, France)
- BOF slag stabilisation by hot slag treatment (Germany, Belgium)
- BOF slag short flow process

Pilot

- GBFS for geopolymers
- BOF slag as P sorbent from wastewater
- GBFS dry granulation
- BOF slag for life support in sea waters

Small « niches » or big volume markets?
Physico-chemical potential
### Chemical potential of BF Slag

<table>
<thead>
<tr>
<th>Element</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>S</th>
<th>Alcali</th>
<th>TiO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>35-45</td>
<td>35-40</td>
<td>10-15</td>
<td>6-8</td>
<td>0.5-1</td>
<td>0.5-1</td>
<td>0.5-1</td>
</tr>
</tbody>
</table>

Total potential value of circled components: 40 to 70 €/T slag

The CaO-MgO-SiO₂-Al₂O₃ combination not only allows the slag to be perfectly liquid and fluid, easily to control, but also to produce by quenching a vitreous material having good cementitious properties.
Chemical potential of BOF slag: Primarily, a good raw material for the ironmaking process

**Table: BOF Slag (after usual metal recovery)**

<table>
<thead>
<tr>
<th>Element</th>
<th>CaO (total)</th>
<th>CaO (free)</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>P₂O₅</th>
<th>Fe (total) *</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>40-60</td>
<td>5-15</td>
<td>10-20</td>
<td>1-3</td>
<td>6-8</td>
<td>0.5-2</td>
<td>10-25</td>
</tr>
</tbody>
</table>

**Total potential value of circled components:** 80 €/T slag

Steel slag also contains minor elements, which may have a huge value. Some slags contain 1% Vanadium, worth 20 € per kg, which means 200 € / T slag.
Physical potential: still much to be explored, looking for differentiating properties.
Future directions

From straw to gold?
BF Slag: Towards more diversified market-driven valorisations

Heat recovery

- Air-cooled
- Expanded
- Granulated

Aggregates
- Clinker
- Rock wool
- Lightweight aggregates

Cement & Concrete
- Dry granulation

Heat storage?
Steel Slags:
Better Value from mineral components

Type 3 destinations account today for 25% of all recycling destinations and are likely to grow strongly, driven by rising economical value, and ecological benefits (such as CO2).

Value as Volume (m³)

Value as Stable Volume + aggregate properties (mechanical)

Value as Chemical or Mineralogical components

- Earthworks e.g. ports, dykes, Landscaping Civil works Fill
- Roads Aggregates Asphalt Pavement Railroad Ballast Blasting material Concrete
- Iron & Steel process Cement Rockwool Fertilizer Loamy Soil treatment De-pollution
BOF slags: recovery in the steel process should be the priority

- The first limit to recycle BOF slag is its phosphorus content: can we extract P?

Phosphorus is concentrated in this phase
50% of the minerals composing BOF slag are valuable ores
50% are valuable for other applications looking for lime silicates and phosphates

- slag should be processed like ores: fine crushing, selective separation and enrichment.
Conclusion: slags, a future gold mine?

- The **100% recycling target is already achieved** by many leading performers.

- The next challenge is to **MAXIMISE THE VALUE** in terms of **SUSTAINABILITY**, economically, and ecologically.

- This means **making the best out of the minerals**, moving to new diverse destinations, particularly for Steel slags.

- **It will take years**, but there is the way forward.
How to achieve it?

- associate in **partnership projects** the competencies:
  - of all the players of the industrial value chain, from the steel maker to the end user.
  - of research institutes and universities

- Challenges and roadblocks will have to be overcome, technical, regulatory ones, for sure, but the hardest ones might be the difficulty of access to the market, including standards.
« ...τὸ μέλλον οὔτε πάντως ἡμέτερον, οὔτε πάντως οὔχ ἡμέτερον... »

« the future is neither wholly ours nor wholly not ours,... »

**Epicurus**, *Letter to Menoeceus*, circa 300 BC