CURRENT DEVELOPMENT OF SLAG VALORISATION IN CHINA

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Introduction to Wuhan University of Sci. and Tech.

Wuhan Univ. of Sci. and Tech.:
A key public higher learning institution in Hubei Province

Traditional strengths: metallurgy-related engineering and technology
Contents

- Introduction
- Current State of Ironmaking and Steelmaking Slags Valorisation in China
- Current development and fundamental research activities in China
- Conclusions
Crude steel production of China and its ration in world total
Introduction

- in 2010, the steel slags and blast furnace slags have reached 81.47 and 200.67 million tonnes, respectively.
- The ratios of utilisation or valorisation are 21% for steel slags and 76% for blast furnace slags.
- Realizing “zero” dumping of iron and steelmaking slag has been an urgent task to save energy, to reduce the emission, to protect the environment and to develop a recycling economy in the steel industry.
- A series of technical routes, management modes, valorisation standards and environmental regulations for the utilisation of iron and steelmaking slags were established in China.
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Changes in the quantity of iron and steelmaking slags during 2005 to 2010 in China
Changes in the ratio of the utilised slag to total slag during 2005 to 2010 in China
### Table 1: Slag valorisation routes and their ratio

<table>
<thead>
<tr>
<th>Type of slags</th>
<th>Main valorisation routes</th>
<th>Ratio(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BF slag</td>
<td>Ground granulated BF slag powder as cement and concrete material</td>
<td>48.5</td>
</tr>
<tr>
<td></td>
<td>Cement mortar material</td>
<td>46.5</td>
</tr>
<tr>
<td></td>
<td>Air cooled Blinding</td>
<td>5.0</td>
</tr>
<tr>
<td>Steel slags</td>
<td>Ground granulated steel slag powder as cement and concrete material</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>A series of Portland cements grades</td>
<td>30.1</td>
</tr>
<tr>
<td></td>
<td>Bricks</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Road construction and backfilling</td>
<td>63.4</td>
</tr>
</tbody>
</table>
Main hot stage slag valorisation processes for Ironmaking and Steelmaking Slags in China

The hot stage processing for BF slags mainly include INBA, TYNA, SG-MTC, and HK processes.
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Main hot stage slag valorisation processes for Ironmaking and Steelmaking Slags in China
Current State of Ironmaking and Steelmaking Slags Valorisation in China

- **WISDRI** Engineering & Research Incorporation Limited Company developed a modified INBA process called **IDE** (Impact, Drum improved and Environmental friendly)

- Granulated BF slag contains more than 95% vitreous phases and less than 15% water.

- Up till June 2012, 9 sets of IDE units were employed in practice, thereby operating in 6 blast furnaces ranging from 1800 m³ to 5800 m³, and 6 sets are under construction.
Current State of Ironmaking and Steelmaking Slags Valorisation in China

IDE drum filter for water granulated BF slag
Main hot stage slag valorisation processes for Ironmaking and Steelmaking Slags in China

The current hot stage processing of BOF slags

- Pyrolytic Self-slaking process
- Baosteel’s Slag Short Flow (BSSF)
- Instantaneous slag chill process (ISC)
- Water-granulation process
- Wheel-granulation process (HK)
- ....
The pyrolytic Self-slaking process was designed by China Jingye Eng. Corporation Ltd.

The hot molten slag is poured into a tank with a cover, while water is sprayed into the tank, resulting in steam generation. This water steam reacts with the free lime and magnesia in the slag to obtain a stabilised BOF slag. This stabilised slag is subjected to size reduction for different utilisations.

Due to the good stability, the wide suitability of the treated slag and the high recovery yield of steel grains from the residual slag, the pyrolytic self-slaking process is generally used in China.
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Pyrolytic Self-slaking process
Current State of Ironmaking and Steelmaking Slags Valorisation in China

rod mill

Screener

Steel block: Fe>85%
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Magnetic Powder

Tailing, Size <10 mm
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Bayuquan Plant, An Steel
800,000t/year

Jingtang Plant, Capital Steel Group (Corp.)
1600,000t/year

Rizhao Steel
1700,000t/year

Xinyu Iron and Steel
1160,000t/year
From 2007 to 2010, this process has been adopted by more than 30 steel companies.

The treatment ability of these installations ranges from 0.25 to 1.7 million tonnes slag/year.

During 2008 to 2010, 31 million tonnes steel slags were treated and recovered iron increased 496 thousand tonnes by the newly installed Pyrolytic Self-slaking processing units which increased the valorisation ratio of steel slags from 10% to 21%.
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Demonstration of Wheel-granulation process (HK)
Current State of Ironmaking and Steelmaking Slags Valorisation in China

Layout of Wheel-granulation installation (HK)
Current State of Ironmaking and Steelmaking Slags Valorisation in China
Current State of Ironmaking and Steelmaking Slags Valorisation in China
Current State of Ironmaking and Steelmaking Slags Valorisation in China

**Table:** Operation parameters of the HK steel slag granulation process

<table>
<thead>
<tr>
<th>An example of slag composition (%)</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>FeO</th>
<th>T. Fe</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40.6</td>
<td>11.1</td>
<td>3.0</td>
<td>21.0</td>
<td>23.8</td>
<td>3.2~3.5</td>
</tr>
<tr>
<td>Temperature of taping slag (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1550~1650</td>
</tr>
<tr>
<td>Water supply (in circulation, t/h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>430~485</td>
</tr>
<tr>
<td>Water pressure (MPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.32~0.38</td>
</tr>
<tr>
<td>Rate of granulation for total slag (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80~85%</td>
</tr>
<tr>
<td>Water consumption (t/t slag)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.657</td>
</tr>
<tr>
<td>Granulation speed (t slag/min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5~3</td>
</tr>
<tr>
<td>Size (mm) distribution of granulated slag</td>
<td>&lt;1</td>
<td>1~3</td>
<td>3~7</td>
<td>7~12.5</td>
<td>&gt;12.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>41%</td>
<td>36%</td>
<td>13%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Water ratio in granulated slag (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;10</td>
</tr>
</tbody>
</table>
HK process was first applied in Benxi Steel in 2004 for $3 \times 120t$ and $3 \times 150t$ BOF. In total 4 units were built. In 2006, Liuzhou Steel built 2 units for their $3 \times 100t$ BOF.
A temporary standard system has been constructed, which includes 18 product standards, 7 analysis and test method standards, and 4 technical specifications related with slag valorisation.
## Current State of Ironmaking and Steelmaking Slags Valorisation in China

**Table : Standards for ironmaking and steelmaking slag valorisation**

<table>
<thead>
<tr>
<th>Category</th>
<th>No.</th>
<th>Title</th>
<th>Serial No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Portland steel slag cement</td>
<td>GB 13590-2006</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Steel slag powder used for cement and concrete</td>
<td>GB/T20491-2006</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Low heat Portland steel slag cement</td>
<td>JC/T1082-2008</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Steel slag cement for road</td>
<td>JC/T1087-2008</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Steel slag masonry cement</td>
<td>JC/T1090-2008</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Steel slag cement for road</td>
<td>GB 25029-2010</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Low heat BF slag and steel slag cement</td>
<td>report for approval</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>BF slag and steel slag powder</td>
<td>report for approval</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Steel slag sand for road</td>
<td>YB/T 4187-2009</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Ground granulated blast furnace slag powder used for cement and concrete</td>
<td>GB/T 18046-2008</td>
<td></td>
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<tr>
<td>11</td>
<td>Crushed air-cooled blast furnace slag for concrete</td>
<td>YB/T 4178-2008</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Ground Silicon-manganese slag used for cement and concrete</td>
<td>YB/T 4229-2010</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Ground lithium slag used for cement and concrete</td>
<td>YB/T 4230-2010</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Steel slag used for cement</td>
<td>YB/T 022-2008</td>
<td></td>
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</tbody>
</table>
## Current State of Ironmaking and Steelmaking Slags Valorisation in China

**Table**: Standards for ironmaking and steelmaking slag valorisation (continued)

<table>
<thead>
<tr>
<th>Category</th>
<th>No.</th>
<th>Title</th>
<th>Serial No.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product standard</strong></td>
<td>15</td>
<td>Steel slag for engineering backfill</td>
<td>YB/T 801-2008</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>Steel slag for metallurgical burden</td>
<td>YB/T 802-2009</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Steel slag for roads</td>
<td>GB/T 25824-2010</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Steel slag for concrete perforated brick and concrete pavior brick</td>
<td>YB/T 4228-2010</td>
</tr>
<tr>
<td><strong>Basic standard</strong></td>
<td>19</td>
<td>Terminology for iron and steel slag &amp; treatment and utilisation</td>
<td>YB/T 804-2009</td>
</tr>
<tr>
<td><strong>Methodology standard</strong></td>
<td>20</td>
<td>Test method for stability of steel slag</td>
<td>GB/T 24175-2009</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Methods for chemical analysis of steel slag</td>
<td>YB/T 140-2009</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Method for the determination of content of magnetic metallic iron in steel slag</td>
<td>YB/T 4188-2009</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>Methods for the determination of total iron content in steel slag</td>
<td>YB/T 148-2009</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>Test method for grindability of smelting slag</td>
<td>YB/T 4186-2009</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>Method for the determination of particle size of smelting slag by using powder laser diffraction</td>
<td>YB/T 4183-2009</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Method for estimation of the metal content in stainless steel slag</td>
<td>YB/T 4227-2010</td>
</tr>
<tr>
<td><strong>Technical specification</strong></td>
<td>27</td>
<td>Technical specification for iron and steel slag concrete application</td>
<td>Under working</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>Code for construction of the mass concrete</td>
<td>GB 50496-2009</td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>Technical specification for the construction of steel slag mixture used as base course</td>
<td>YB/T 4184-2009</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>Technical specification of the tailings mortar</td>
<td>YB/T 4185-2009</td>
</tr>
</tbody>
</table>
Even though a certain part of ironmaking and steelmaking slags could be valorised as resources, the sensible heat in all kinds of molten slags was not recovered.

The waste sensible heat of the molten BF slag at 1500 °C and that of the molten steel slag at 1550 °C reached respectively 18.5 and 5.1 kgCE per tonne of steel production.

Based on the industrial Data, the total waste heat energy of Chinese steel industry to be 243.8 kgCE (kilogram of coal equivalent) per tonne of steel production. The recovery ratio was less than 15.1%.
Furthermore, the recovery ratio of sensible heat for the molten BF slags was only 2.16% and that for steel slag was zero. 

A simple estimation shows $2.7 \times 10^8$ GJ heat energy, i.e. 9.2 million tonne CE (coal equivalent) was wasted in 2010 by BF slag in China. 

The energy consumption ratio of steel industry is about 10 to 15% of the total energy consumption in China. Therefore, the heat recovery of the BF slag is of significant importance for energy saving and emission reduction of Chinese steel industry.
Current development and fundamental research activities

- The current widely used process for BF slag treatment is the water granulation method, such as INBA which can obtain vitreous slag product as cement chamotte. This method shows high added value and environmental benefit.

- However, the water granulation transforms the high temperature sensible heat in the molten BF slag into the low temperature heat of the granulating water. The high quality heat in molten BF slag cannot be well utilised.
Current development and fundamental research activities

- The problem of heat recovery from molten slag is the lower exergy (Availability or Work Potential) recovery efficiency.
- Most of the heat recovery efficiency in various industrial scale tests was higher than 60%, even to 80%, but the exergy recovery efficiency was only about 40%.
- To realise the commercial operation of heat recovery from molten slag, the exergy recovery efficiency must be improved.
- The key issue is to recover heat in a closed system with simultaneously the valorisation of the slag products.
Recently, Chinese researchers are interested in using the Rotary Cup atomisation process to recover heat from BF slag.

Several projects have been conducted respectively by the Central Iron and Steel Research Institute (CISRI), Shougang Group, Ansteel, Northeastern University, Qingdao University, Chongqing University and Wuhan University of Science and Technology.
Current development and fundamental research activities

Fundamental woks in Wuhan University of Sci. and Tech.
Current development and fundamental research activities

5 kg Rotary Cup atomisation unit for molten BF slag dry granulation experiments
Current development and fundamental research activities

Discs

- Stainless Steel
- Heat Resistant Steel
- Graphite
- SiC-SiN
Current development and fundamental research activities

- Layout of experimental equipments
Current development and fundamental research activities

(a) 0~2mm

(b) 2~5mm

(c) 5~8mm

Vitreous ratio: 92%
Current development and fundamental research activities
Current development and fundamental research activities

Mathematical Simulation with FLUENT
The experimental results show that the best disc material was graphite and the most suitable rotation speed was in the range of 1500 to 2300 rpm;

the vitreous content of granulated slag was more than 88%, which was comparable to that of water granulated BF slag.

The higher the molten slag temperature and the rougher the surface of the rotation disc, the better the results in the slag wool formation. The slag composition has also influence on the slag wool formation.
Current development and fundamental research activities

- Based on model simulations and laboratory experiments, the SKLP (State Key Laboratory of Advanced Steel Process and Products of the CISRI in China) developed a Dry Slag Granulation Technology.
Current development and fundamental research activities

Vitreous Ratio 84.8%

Vitreous Ratio 93.9%

Vitreous Ratio 96.2%

Vitreous Ratio 97.8%

Process flowsheet of BF slag dry granulation and heat recovery developed by the Central Iron and Steel Research Institute (CISRI), China
Current development and fundamental research activities

- The size of the slag tank was 1 meter in diameter and 1.3 meter in height with a volume of 1 m³. The slag tundish size was 0.56 meter in diameter and 1.5 meter in height with a volume of 0.05 m³. The inner diameter of the slag outlet nozzle (in the bottom of the slag tundish) was 30 mm.

- During the test, the slag tank and tundish were heated to a constant temperature. The diameter of the steel rotary cup was 250 mm and the rotating power of the rotary cup was 1.5 kW. The diameter of steel rollers was 150 mm, and the rotating power of roller was 2.2 kW. Rotary cup and rollers were inner cooled by water.
Current development and fundamental research activities
Current development and fundamental research activities

- The BF slag quantity treated was 1.2 tonne;
- The line speed of slag flow was 0.2m/s; slag flowed 1 hour in the experiment.
- 2020 m³ hot air with temperature of 594° C was recovered from 1.2 tonne molten slag theoretically containing 2.1 GJ heat. The recovered heat was 1.6 GJ and the electricity consumed in this process was 38.5 MJ, accounting for 2.4% of the recovered heat. The heat recovery efficiency by the heat exchange between molten slag and cooling air was 77%.
Current development and fundamental research activities

Figure: The recovered hot air temperature and vitreous ratio of the granulated BF slag as a function of the air flow rate in the experiment.
About 96% vitreous components in the dry granulated BF slag could be obtained when the cooling air flow rate was higher than 2200 m³ per hour. This is similar to the level of water granulated BF slag.

The maximum particle size of the dry granulated BF slag was 3.1 mm.

Further studies, however, are needed concerning to the issues of slag crusting and heterogeneous size distribution, and to the phenomenon of glass wool formation in the process.
Conclusions

- The slag valorisation in China improved gradually during the recent past years. This was not only in quantity but also in quality, thereby increasing the economical and environmental benefits.

- The hot stage processing processes with respect to BF slag granulation and steel slag pyrolytic self-slaking have made progress and are applied in a number of large steelmaking companies in China.

- The fundamental researches and process developments are mainly focusing on the dry granulation of molten BF slag with both heat recovery and improvement of the slag product quality.
Thank you for your attention!