Synergizing Red (Mud) & Grey (Ash) for Greener Geopolymers

A Presentation for
Bauxite Residue Valorization & Best Practices Conference
Leuven, 5-7 October 2015

Sanjay Kumar & Rakesh Kumar
CSIR-National Metallurgical Laboratory
Jamshedpur 831007, India
Red Mud Research at CSIR-NML

Metallurgical Applications
- Chemical beneficiation of red mud (including mechanical activation)
- Reduction smelting and ceramic product
- Use in iron ore sinter

Cement & Building Applications
- Red mud in geopolymers

SMILE
- Mechanical activation of bauxite to Improve the Performance of the Bayer and Minimise Environmental Impact of Red Mud

Pollution Prevention Act of 1990, US EPA
Presentation Content

- Philosophy
  - Why Red Mud + Fly Ash
- Proof of Concept
- Pilot Scale Trials
- Technology
Synergy of Red Mud & Fly Ash
Power Consumption in Aluminium Smelting

World Reported for 2009 to 2014: 3,513,872 Gigawatt hours (GWh) (power mix)

Resulting into generation of Fly ash

Source: http://www.world-aluminium.org/statistics/primary-aluminium-smelting-power-consumption/#histogram
Why Add Fly Ash in Red Mud Geopolymer

Aluminum Production

Bayer's Process
- Red Mud
- Sodium Aluminate

Captive Power Plant
- Fly Ash

Geopolymer
## Chemical Analysis of Red Mud & Fly Ash

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Red Mud</th>
<th>Fly Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>29.2</td>
<td>60.4</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>31.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>15.2</td>
<td>28.1</td>
</tr>
<tr>
<td>CaO</td>
<td>4.5</td>
<td>1.7</td>
</tr>
<tr>
<td>MgO</td>
<td>0.2</td>
<td>0.4</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>3.1</td>
<td>0.1</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>--</td>
<td>1.4</td>
</tr>
<tr>
<td>LOI</td>
<td>10.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Phase Analysis of Red Mud & Fly Ash

Quartz

Mullite\(^3\) \((\text{Al}_2\text{O}_3)\) \((2\text{SiO}_2)\)

Glass

Gibbsite \(\text{Al}_2\text{O}_3\text{H}_2\text{O}\)

Al-goethite \((\text{Fe,Al})\text{O} \text{OH}\)

Hematite \(\text{Fe}_2\text{O}_3\)

Quartz \(\text{SiO}_2\)

Kaolinite  \(\text{Al}_2\text{Si}_2\text{O}_5\text{(OH)}_4\) \(2\text{Na} \text{X}\) \(\text{H}_2\text{O}\)

Sodalite \(\text{(Na,Al)SiO}_4\text{O}_6\)

Ilmenite \(\text{FeTiO}_3\)

Rutile \(\text{TiO}_2\)
Synergistic Use for Geopolymer

Figure 1: Ternary diagram showing geopolymer formation zone
Lab Scale Studies
Batch Composition

- 100% Fly ash
- 10% Red mud
- 20% Red mud
- 30% Red mud
- 40% Red mud
Process Flow Sheet

- Red mud
- Fly ash
- Alkali Soln
- Aggregate

Mixing

Mixing

Casting

Curing

Product
Reactivity of Red Mud & Fly Ash Mixture

At 27°C, reaction due to red mud is more prominent but at 60°C, reaction due to fly ash is more prominent.
Cancrenite is due to parent red mud but two types of sodalite, one derived from parent red mud and second formed due to reaction was observed.
Association of Fe with Si, Al and Na suggest ferro-sialate formation
## Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>IS 15658: 2006 Spec</th>
<th>FARM0</th>
<th>FARM1</th>
<th>FARM2</th>
<th>FARM3</th>
<th>FARM4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Inspection</td>
<td>95% free of defect</td>
<td>Meets spec</td>
<td>Meets spec</td>
<td>Meets spec</td>
<td>Meets spec</td>
<td>Blisters</td>
</tr>
<tr>
<td>Size tolerance, mm (L+W)</td>
<td>± 2</td>
<td>± 1</td>
<td>± 1</td>
<td>± 1</td>
<td>± 1</td>
<td>± 1</td>
</tr>
<tr>
<td>Water absorption, %</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Compressive strength, N/mm²</td>
<td>30</td>
<td>32</td>
<td>36</td>
<td>32</td>
<td>26</td>
<td>21</td>
</tr>
<tr>
<td>Tensile split strength, MPa</td>
<td>No Spec</td>
<td>&gt; 2.5</td>
<td>&gt; 2.5</td>
<td>&gt; 2.1</td>
<td>&gt; 2.0</td>
<td>&gt; 1.5</td>
</tr>
<tr>
<td>Flexural strength, MPa</td>
<td>3</td>
<td>4</td>
<td>4.5</td>
<td>3.2</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Abrasion resistance, mm</td>
<td>2</td>
<td>0.68</td>
<td>0.62</td>
<td>0.78</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>Electrical conductivity, Ϭ(s/cm)</td>
<td>No Spec</td>
<td>132</td>
<td>177</td>
<td>212</td>
<td>250</td>
<td>277</td>
</tr>
</tbody>
</table>
Red mud containing samples show marginally lower durability than only fly ash based sample.
Pilot Scale Trials
Pilot Plant
Production of Paving Tiles
## Properties & Performance of Paving Tiles

<table>
<thead>
<tr>
<th>Paving Blocks (80 mm thick)</th>
<th>Cement based</th>
<th>FARM20</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compressive strength, MPa</strong></td>
<td>Min 30</td>
<td>32</td>
</tr>
<tr>
<td><strong>Tensile split strength, MPa</strong></td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>Abrasion resistance, mm</strong></td>
<td>0.6</td>
<td>0.78</td>
</tr>
<tr>
<td><strong>Total CO₂ generation / ton</strong></td>
<td>180 -200 kg (from firing of cement)</td>
<td>16 - 20kg (conversion of alkali carbonate into oxide)</td>
</tr>
<tr>
<td><strong>Water requirement/ ton</strong></td>
<td>300 liters</td>
<td>250 liters</td>
</tr>
<tr>
<td><strong>Waste &amp; by-products reuse/ ton</strong></td>
<td>&lt;75 kg</td>
<td>&gt;400 kg</td>
</tr>
<tr>
<td><strong>Embodied energy/ kg</strong></td>
<td>1.2 MJ</td>
<td>0.8 MJ</td>
</tr>
</tbody>
</table>
Field Trials

Laid on 11 Nov 2010

Condition on 24 Sept 2015
## Technology

**100 tons/day capacity fully automatic plant**

Data generated based on Indian Condition & considering plant is within 50 km from Aluminum plant

<table>
<thead>
<tr>
<th>Area</th>
<th>Total 150 m X 100 m with shade in 20X15 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>Red mud, fly ash, alkali, sand, admixture, plasticizer</td>
</tr>
<tr>
<td>Capital Investment</td>
<td>100,000 USD</td>
</tr>
<tr>
<td>Cost of 80 mm thick tile / square meter</td>
<td>~5 USD</td>
</tr>
<tr>
<td>Specification</td>
<td>Meets IS 15658</td>
</tr>
<tr>
<td>Leaching/ toxicity</td>
<td>Meets USEPA 1311</td>
</tr>
<tr>
<td>Manpower</td>
<td>10 (2 skilled, 8 semiskilled)</td>
</tr>
</tbody>
</table>
Conclusions

- Red mud at the extent of 20% can be used for making paving blocks using geopolymerisation.
- Combining red mud and fly ash helps in formation of Sialate and ferro-sialate structure resulting into good mechanical properties & durability.
- The process can be scaled up.
- The paving blocks meet Indian standards and are commercially at par with conventional product.