GEOTECHNICAL PARAMETERS OF IRON ORE TAILINGS FROM THE QUADRILÂTERO FERRÍFERO AFTER DIFFERENT TREATMENTS AND ORE PROCESSING

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The “Quadrilátero Ferrífero”

Legend:
- Grupo Itacolomi
- Supergrupo Minas (black - BIF)
- Supergrupo Rio das Velhas
- Metamorphic Complex
- City
- Capital of State

Vale has 19 iron ore mines and 10 industrial beneficiation plants in the QF region. These produce almost 200 million tons per year of iron ore, which represents approximately 70% of the total production in the region (DNPM, 2012; Vale S.A., 2012). Production is forecast to increase approximately 10% between 2013 and 2017, and 50% by 2030.
The QF region is one of the highest regions in the Brazilian plateau, covering an area of approximately 7,000 km², where the altitudes vary between 800 and 900 m. It is surrounded by mountain peaks that usually exceed 1,200 m and can reach over 2,000 m in altitude.
Neighbourhood
Context of Vale’s Mines

**Mines’ production**

**CRONOLOGIC SCALE**

1940  1960  1980  2000  2020

Period 1 - 1942...

Crushing
Screening

**Lump / Sinter Feed**

Period 2 - 1973...

Crushing
Screening
Flotation
Magnetic Concentration

**Lump / Sinter Feed / Pellet Feed**

Period 3 - 2013...

Crushing
Screening
Grinding
Flotation

**Ore Periods**

**Hematite**

**Hard rock**
Avg. Iron content: 68%
Period 1

**Soft rock**
Avg. Iron content: 62%
Periods 1 e 2

**Itabirite**

**Hard / Soft rock**
Avg. Iron content: 40% a 58%
Periods 2 e 3

68 %Fe

40 %Fe

Organized by InfoMine

PIMENTA DE AVILA
CONSULTORIA LTDA

17-20 June 2013 • Belo Horizonte, Brazil
www.paste2013.com
Challenge

The first industrial iron ore extraction in Brazil occurred in the Quadrilátero Ferrífero. Those areas most conducive to tailings disposal have been occupied over many years of operation; in the remaining areas there are many constraints that greatly hamper conventional tailings disposal. The need to reconcile tailings disposal and mining activities with lower environmental and social impacts has led to the increased national importance of new methods of disposal.

In the context of this search for alternatives for the disposal of tailings generated in the iron ore beneficiation process, the company Vale S.A. has conducted pilot studies and bench testing, and has evaluated the conditions for dewatering of tailings. All of this work was focused on tailings generated in the ore beneficiation plants in the Quadrilátero Ferrífero region with the greatest environmental, spatial, and topographical restrictions.
Vale’s Dams

Relationship between volume and impacted area

\[ V \left(10^6 m^3\right) = IA \left(ha\right)/3 \]
Vale’s Dams

The physicochemical and geotechnical characteristics of tailings generated in the processing of iron ore are affected by the changes or substitutions of iron ore treatment plants. This allows the exploitation of itabirite with low iron content. Geotechnical tests results presented here show the current feed plant conditions and the conditions after the transitions to low fractions of hematite with itabirite and to soft itabirite in the near future. Compact itabirites were not assessed in this study. Pilot tests and bench tests were performed with the tailings from Alegria, Timbopeba, Brucutu, Cauê, Conceição, Pico, Vargem Grande, and Fabrica.
Vale’s Dams - Coarse tailings
Vale’s Dams - Coarse tailings
Vale’s Dams - Coarse tailings
Vale’s Dams - Coarse tailings
Vale’s Dams - Fine tailings

The slimes from various flotation processes are characterized and summarized in the Table. Ten per cent of all the finer particle size slimes have particle diameters of less than 2.0 microns, and all slimes, except those from the Alegria plant, have over 94% passing the 200 mesh (0.075 mm) sieve.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Gs</th>
<th>%&lt;#200 (&lt;74μ)</th>
<th>Clay (&lt;2μ)</th>
<th>Silt (2&gt;μ&lt;60)</th>
<th>Fine sand (60&gt;μ&lt;200)</th>
<th>Medium sand (200&gt;μ&lt;600)</th>
<th>L.L. (%)</th>
<th>P.L. (%)</th>
<th>P.I. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alegria</td>
<td>3.86</td>
<td>66</td>
<td>22</td>
<td>44</td>
<td>4</td>
<td>30</td>
<td>48</td>
<td>23</td>
<td>25</td>
</tr>
<tr>
<td>Timbopeba</td>
<td>3.70</td>
<td>98</td>
<td>18</td>
<td>36</td>
<td>46</td>
<td>–</td>
<td>26</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>Brucutu</td>
<td>3.27</td>
<td>95</td>
<td>33</td>
<td>58</td>
<td>9</td>
<td>–</td>
<td>40</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Pico</td>
<td>3.73</td>
<td>99</td>
<td>23</td>
<td>53</td>
<td>24</td>
<td>–</td>
<td>29</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Vargem Grande</td>
<td>4.06</td>
<td>99</td>
<td>13</td>
<td>81</td>
<td>6</td>
<td>–</td>
<td>23</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Conceição</td>
<td>3.87</td>
<td>94</td>
<td>13</td>
<td>67</td>
<td>21</td>
<td>–</td>
<td>23</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>Cauê</td>
<td>3.55</td>
<td>94</td>
<td>15</td>
<td>69</td>
<td>16</td>
<td>–</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>

These results suggest that the greatest challenges facing any endeavor to dispose of the slimes are the permeability of the slimes, the consolidation time, and the dissipation of excess pore pressures developed during deposition.
Stacking of tailings (An alternative)

The availability of valleys for tailing disposal has decreased, and sites for new dam constructions are becoming scarce. In this context, the stacking of tailings is an alternative to be considered.

There are numerous benefits of disposal in piles, including the following:

- It allows disposal in slopes, which reduces impacts on thalwegs.
- It operates with little or no free water stored, which reduces the potential energy and the probable damage in the structure.
- It allows the optimized occupation of harassed open pit mines.
- It facilitates decommissioning.

Vale has used this method with good results in several locations, including Xingu (Mariana complex), Monjolo (Minas Centrais complex), and the Germano open pit mine (Samarco).
Stacking of tailings (An alternative)
Paste (thickened tailings)

Although the stacking of tailings has been identified as a possible alternative to traditional dams, the methodology, even though very promising for coarse tailings, is not viable for the disposition of fine tailings with low permeability. In order to address this problem, many researchers have been considering the disposal of thickened tailings or paste as a solution. There are currently numerous studying this theme, but a common understanding remains distant.

Vale S.A., with technical support from Westech, performed paste tests on a pilot scale with the slimes generated by the Cauê plant. The test stages comprised sedimentation and rheology tests in the laboratory, to define the parameters of the pilot equipment operation, and pilot tests to generate samples.
Paste thickener pilot tests at Cauê mine
Paste thickener pilot tests at Cauê mine

SECTION A – 14° - 25%
SECTION B – 8° - 16%
SECTION C – 8° - 16%
Paste thickener pilot tests at Cauê mine

The paste obtained in the tests showed an average solids concentration of 64% and a yield stress of around 375 Pa. The concentration peak was 67% of solids with a yield stress around 980 Pa. (This sample was collected without action of the recirculation pump.) The deposition angle of the material ranged from 16 to 26%, representing a significant profit in the fine tailings storing capacity.

Shelby tube samples were collected in the disposal bay at 6, 14, 35, and 56 days after the disposition, beginning on March 31, 2011, and density tests and consolidated undrained triaxial tests were performed. The results are summarized in Table.

<table>
<thead>
<tr>
<th>Days after disposition</th>
<th>Moisture content w (%)</th>
<th>Dry density ρd (kN/m³)</th>
<th>Cohesion intercept based on effective stress c' (kPa)</th>
<th>Friction angle based on effective stress φ' (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>33.6</td>
<td>15</td>
<td>17.0</td>
<td>32.4</td>
</tr>
<tr>
<td>14</td>
<td>36.3</td>
<td>15</td>
<td>28.0</td>
<td>30.0</td>
</tr>
<tr>
<td>35</td>
<td>31.7</td>
<td>16</td>
<td>17.7</td>
<td>34.6</td>
</tr>
<tr>
<td>56</td>
<td>23.9</td>
<td>18</td>
<td>15.8</td>
<td>34.9</td>
</tr>
</tbody>
</table>
Paste thickener pilot tests at Cauê mine

Results from in situ tests show a reduction in moisture over time – a natural consequence of drainage and evaporation in the stack. The phenomenon causes consolidation of tailings and shrinkage cracks.
Paste thickener pilot tests at Cauê mine

In order to evaluate the real increase in resistance with these phenomenon, the triaxial test data was reinterpreted observing the non-drained shear strength.

Some significant conclusions can be drawn from Figure. Under low stresses, there was a relevant increase in the shear strength during the exposition period.

- In the samples consolidated at 400 kPa, the non-drained shear strength ratio was practically the same for all days; it did not respond to the exposition period.
- All the samples submitted to confining pressures higher than 100 kPa presented contractile behavior.
- The normalized undrained shear strength ($S_u/\sigma'c$) tends to converge at greater confining pressures to a value between 0.2 and 0.3, with great susceptibility to liquefaction.
Conclusions for the Iron Ore (QF)

The data and information presented in this study allow us to wonder about many aspects. The intent of posing some points below is to provide guidance in further developing the design, by drawing attention to what we believe are some of the key issues.

- Iron ore tailings do not have the same geotechnical behavior even showing similar grading – Parameters cannot be generalized for other mines (≠ mineralogy) or beneficiation process

- Disposal areas must be considered as imperative constraints on the feasibility studies;

- Large volumes of tailings require large areas for disposal (there’s no magic!);

- Costs for tailings treatment are still high for Brazilian operations and most of cases become the project unfeasible;
Conclusions for the Iron Ore (QF)

-Lab tests showed that high velocities of raise in thickened tailings or paste deposition associated to high Tailings Storage Facility (TSF) may collapse by liquefaction;

-Seepage will always occur in thickened tailings and paste when subject to different total head (permeability ~ 10-6 cm/s);

- Dust and erosion are inherent to some tailings disposal and it’s very hard to solve and costly;

- Thickened tailings and paste show limitations to increasing gains in safety.

No doubt, there are other such questions that we have not identified, and others still that the answers to these questions will suggest. We do not expect that the designers will necessarily answer all of these questions to their own satisfaction. But those that remain unanswered will represent risks associated with this design that owner will then have to accept.
THANK YOU!

MUITO OBRIGADO!