Utilization of Iron Tailings as Aggregates in Paving Asphalt Mixture: A Sustainable and Eco-Friendly Solution for Mining Waste

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Introduction

- **Background**
  A tremendous amount of iron tailings has led serious environmental pollution with the rapid development of mining industry. Meanwhile, the demand for natural mineral aggregates is increasing in highway industry. Therefore, it is very promising to use iron tailings to replace natural aggregates for asphalt pavement construction in terms of resources conservation and sustainable development.

- **Research gap**
  Existing researches on the application of iron tailings in pavement is mainly in the field of cement-based materials and related studies about asphalt-based materials is not sufficient.

- **Research purpose**
  The purpose of study is to comprehensively evaluate the feasibility of iron tailings as aggregate in paving asphalt mixture in terms of aggregate properties and pavement performances as well as investigate the performance enhancement methods for asphalt mixture with iron tailings.

Materials and Methods

- **Raw materials**
  - Asphalt: 70# base asphalt (B), SBS/crumb rubber composite modified asphalt (M).
  - Coarse aggregates: iron tailings from Liaoning (TA), Jilin (TB), China, basalt (Ba).
  - Fine aggregates: iron tailings sand (TS), basalt, limestone (Li).
  - Filler: limestone, hydrated lime (H).
  - Additive: silane coupling agent (S).

- **Asphalt mixture design**
  - AC-20 was adopted as target gradation which is a dense gradation widely applied in pavement.
  - Marshall method was used to determine optimum asphalt content for every type of asphalt mixtures.

- **Laboratory tests**
  - Aggregate properties: composition characteristics, microstructure, physical and mechanical properties, weather resistance, adhesion to asphalt.
  - Pavement performances: rutting resistance, thermal cracking resistance, moisture damage resistance.

Aggregate Properties

- **Composition characteristics**
<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>SO₃ (%)</th>
<th>Al₂O₃ (%)</th>
<th>Fe₂O₃ (%)</th>
<th>CaO (%)</th>
<th>MgO (%)</th>
<th>SiO₂ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td>66.68</td>
<td>12.25</td>
<td>14.16</td>
<td>4.23</td>
<td>3.05</td>
<td>2.32</td>
</tr>
<tr>
<td>Basalt</td>
<td>44.17</td>
<td>18.45</td>
<td>13.53</td>
<td>8.78</td>
<td>5.58</td>
<td>1.61</td>
</tr>
<tr>
<td>Limestone</td>
<td>12.17</td>
<td>2.62</td>
<td>2.54</td>
<td>29.09</td>
<td>0.89</td>
<td>0.41</td>
</tr>
</tbody>
</table>

- **Microstructure**
<table>
<thead>
<tr>
<th>Aggregate type</th>
<th></th>
<th></th>
<th>0.1-0.0625 mm</th>
<th>0.0625-0.01 mm</th>
<th>Average size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB</td>
<td>65.09</td>
<td>26.54</td>
<td>8.38</td>
<td>0.80</td>
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<tr>
<td>Basalt</td>
<td>65.53</td>
<td>26.87</td>
<td>7.31</td>
<td>6.39</td>
<td></td>
</tr>
<tr>
<td>Limestone</td>
<td>63.80</td>
<td>26.03</td>
<td>10.56</td>
<td>6.63</td>
<td></td>
</tr>
</tbody>
</table>

- **XRF** shows that iron tailings possess a lot of acidic components.
- **XRD** shows that iron tailings contain the minerals with perfect cleavage and lower hardness.

- **BET** shows that iron tailings have a similar pore distribution with conventional aggregates.
- **SEM** shows that the surface texture of iron tailings is smooth relatively.

- **Physical and mechanical properties**
<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>Apparent density (g/cm³)</th>
<th>Water absorption (%)</th>
<th>Blended aggregate particle size (%)</th>
<th>Shrink content (%)</th>
<th>Crushability value (%)</th>
<th>Abrasion loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA</td>
<td>2.604</td>
<td>0.733</td>
<td>72.2</td>
<td>6.90</td>
<td>16.2</td>
<td>19.3</td>
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<tr>
<td>TB</td>
<td>2.706</td>
<td>0.737</td>
<td>12.9</td>
<td>0.44</td>
<td>14.5</td>
<td>15.7</td>
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<tr>
<td>Basalt</td>
<td>2.687</td>
<td>0.736</td>
<td>11.7</td>
<td>0.78</td>
<td>5.28</td>
<td>0.36</td>
</tr>
</tbody>
</table>

- **Performance enhancement**
  - All properties of iron tailings can meet specification requirements.
  - Adhesion to asphalt
    - Adhesion between iron tailings and asphalt is weaker in comparison of basalt.

Pavement Performances

- **High-temperature performance**: asphalt mixtures with iron tailings have a satisfactory rutting resistance.
- **Low-temperature performance**: thermal cracking resistance of Ba-TS(B) is weaker obviously.
- **Water stability**: moisture damage resistance of TA-Ba(B) and Ba-TS(B) cannot reach the critical value in specification.

Performances Enhancement

- **Using limestone as fine aggregate instead of basalt**: pavement performances can meet specification requirement.
- **Applying composite modified asphalt as binder**: various performances are further improved, especially water stability.
- **Adding silane coupling agent to asphalt**: pavement performances are significantly enhanced, especially thermal cracking resistance.
- **Replacing limestone filler partially by hydrated lime**: pavement performances are also obviously enhanced, especially rutting resistance.

Findings and Conclusions

- Physical and mechanical properties of iron tailings meet the specification requirements, and it also has a good weather resistance.
- Asphalt mixtures with iron tailings possess a satisfactory high-temperature performance, but its low-temperature performance and water stability are needed to be improved.
- Using limestone as fine aggregate or applying asphalt with superior properties can make the key performances reach technical requirements for use in pavement.
- By adding silane coupling agent or hydrated lime, comprehensive level of pavement performances can surpass conventional mixture applied maturely at present.