Application of steel slag aggregate in road construction

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Damaged building at Hrušica, 1988
IMPORTANT TO KNOW!

Slag is a broad term for a particular waste product in the field of metallurgy.

Just its name DOES NOT TELL US ANYTHING about the properties of this material.

Black steel slag ≠ Siemens-Martin slag.
THE RESEARCH PROJECT

SPENS - Sustainable Pavements for European New Member States (2006-2009)

WP 3 - Improvement of pavement structure

Task 3.2 - Sustainable road construction processes that include recycling of materials and use of industrial by-products
Origin of steel slag in electric arc furnace and the production of aggregate
Test field on a regional road
Test field on a main road
Test field on the A1 motorway
ORIGIN OF SLAG

Steel scrap → Electric Arc Furnace → Steel products
Lime → Electric Arc Furnace → Liquid slag
Some facts about using steel slag in Europe

• About 150 - 200 kg of slag per 1 ton of steel occur.

• Nearly 12 million tons of steel slag are produced annually in the Europe.

• About 65% is used in different applications, mainly as aggregate in road construction.

• Some of this aggregate is used as a high-quality aggregate in wearing courses (replacing vulcanic aggregate).
### Average chemical composition of steel slag

<table>
<thead>
<tr>
<th>Oxide</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeO</td>
<td>30-40</td>
</tr>
<tr>
<td>CaO</td>
<td>20-35</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>5-12</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>6-9</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>5-7</td>
</tr>
<tr>
<td>MgO</td>
<td>4-12</td>
</tr>
</tbody>
</table>

+ small quantities of other oxides.
Mineral composition of steel slag

Wustite (FeO),
Calcium silicates (C$_3$S, C$_2$S),
Brownmillerite (C$_4$AF),
Mayenite (Ca$_{12}$Al$_{14}$O$_{33}$),
and
free CaO + free MgO

Both can cause expansion of aggregate!
Quenching and ageing of material is needed!
Quenching of slag

Quenching of fresh slag (artificial magma)  Quenching of cooled slag (15 days)
Ageing of slag (30 days)
Production of aggregate

Crushing, magnetic separation

Sieving
Products

4/8 mm

8/11 mm
# Characteristics of aggregates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Slag aggr.</th>
<th>Natural aggr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance to fragment. (LA)</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Resistance to abrasion (MD)</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Polish stone value (PSV)</td>
<td>61</td>
<td>57</td>
</tr>
<tr>
<td>Frost resistance (MS)</td>
<td>0.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Frost resistance (F)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Water absorption</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Bulk density</td>
<td>3.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Volume stability</td>
<td>1.6</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Eluates</td>
<td>Very low</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Radioactivity</td>
<td>Very low</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>
Comparison between microtextures

The microtexture of slag

The microtexture of volcanic aggregate
AGENDA

Origin of slag in EAF and production of aggregate

Test field on a regional road
Test field on a main road
Test field on the A1 motorway
Purpose of the test fields

• Determination of long term behaviour of the wearing course with slag in a continental climate.

• Getting experience about the use of slag in road construction with regard to engineering and environmental performance.
Test section on a regional road

Location: Idrijsko-Peršeti
Bird's-eye view of the test field
First test field with slag in Slovenia!

Annual average daily traffic: 4000

Date of reconstruction: 6.6.2007, replacing the wearing course

Type of asphalt: AC 11 (asphalt concrete)

Width: 6 m

Length: 300 m

Thickness of asphalt layer: 4 cm
Method of construction

One lane using conventional natural aggregate (silicate 4/8 and 8/11 mm + carbonate 0/2 mm)

One lane using slag aggregate from Ferriere Nord (0/4, 4/8, 8/11 mm + carbonate 0/2 mm).
Construction of the test field
The test field after completion
## Characterization of the asphalt layers

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>SAMPLE T (°C)</th>
<th>SOLUBLE BINDER CONTENT (mas %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt with slag aggregate</td>
<td>156</td>
<td>5.5</td>
</tr>
<tr>
<td>Asphalt with natural aggregate</td>
<td>163</td>
<td>5.4</td>
</tr>
</tbody>
</table>
### HOT MIX ASPHALT

<table>
<thead>
<tr>
<th></th>
<th>Density (Mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt with slag aggregate</td>
<td>3.124</td>
</tr>
<tr>
<td>Asphalt with natural aggregate</td>
<td>2.600</td>
</tr>
</tbody>
</table>
SURFACE CHARACTERISTICS

Equipment: SCRIMTEX measuring device
Date of measurement: November 7th 2007
Comparison of the skid resistance of both lanes

The levels of skid resistance are similar on both lanes!
Comparison of texture on both lanes

Slight difference in texture on the first half of the test field
AGENDA

Origin of slag in EAF and production of aggregate
Test field on a regional road
Test field on a main road
Test field on the A1 motorway
Test field with surface dressing

Location: the main road Ušnik - Plave
What is surface dressing?

- Bitumen in the form of an emulsion, is sprayed onto the road surface.

- Chippings of aggregate are immediately applied to the bitumen.

- The bitumen part of the surface dressing will seal the old road surface, thus preventing the ingress of water.

- The chippings will restore texture to road surfaces that have become smooth with traffic wear.
Construction of the test field
A close-up view
Test field with surface dressing

Annual average daily traffic (PLDP): 7000
Date of reconstruction: 14.8.2007
Width: 7 m
Length: 250 m
Thickness of asphalt layer: 0.5 cm
<table>
<thead>
<tr>
<th>Method of construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>One lane with surface dressing using conventional natural aggregate (silicate 4/8 mm)</td>
</tr>
<tr>
<td>One lane with surface dressing using slag aggregate from Ferriere Nord (4/8 mm)</td>
</tr>
</tbody>
</table>
AGENDA

Origin of slag in EAF and production of aggregate
Test field on a regional road
Test field on a main road
Test field on the A1 motorway
Test field on the A1 motorway

Location: Postojna - Razdrto
Bird's-eye view of the test field
Test field on the A1 motorway

Annual average daily traffic: 30,000
Date of construction: 28.4.2008, only replacing the wearing course
Width: 6 m
Length: 100 m
Thickness of asphalt layer: 4 cm
Test field on the A1 motorway

**Type of asphalt:** SMA 11 PmB 45/80-65 A2

**Aggregate:** slag aggregate from ACRONI (2/4, 4/8, 8/11 mm) + limestone aggregate from the Laže quarry (0/2 mm).
Construction of the test field
Construction of the test field
Construction of the test field
Asphalt - resistance to wheel tracking

<table>
<thead>
<tr>
<th>Rut depth PRD&lt;sub&gt;AIR&lt;/sub&gt;</th>
<th>Wheel-tracking slope WTS&lt;sub&gt;AIR&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIST EN 12697-22</td>
<td>SIST EN 12697-22</td>
</tr>
<tr>
<td>3.3 %</td>
<td>0.03 mm/1000</td>
</tr>
</tbody>
</table>

Excellent results!
Asphalt – low temperature test

<table>
<thead>
<tr>
<th>Tension test</th>
<th>Cooling test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T (°C)</strong></td>
<td><strong>Failure T (°C)</strong></td>
</tr>
<tr>
<td>+ 20</td>
<td>Tensile strength (MPa)</td>
</tr>
<tr>
<td>+ 5</td>
<td>Failure stress (MPa)</td>
</tr>
<tr>
<td>- 10</td>
<td>2.07</td>
</tr>
<tr>
<td>- 25</td>
<td>6.31</td>
</tr>
<tr>
<td></td>
<td>5.29</td>
</tr>
</tbody>
</table>

6,12 MPa at -13.9 °C

Tension strength reserve

Excellent results!
Skid resistance measurements
September 2008 versus March 2009

Test field on motorway A1 - Two measurements - Skid resistance at 80 km/h

SR (S,T)

Chainage (m)
Texture measurement
September 2008 versus March 2009

Test field on motorway A1 - Two measurements - Texture SMTD (mm)

SMTD (mm)

Chainage (m)
Conclusions

During the construction of the test fields, no problems occurred (design of the mix, transport to the site, placing of the asphalt).

The test fields are stable, and show no signs of degradation.

The surface properties appear to be better on the field with slag aggregate.
Conclusions

Further work

Monitoring of all the test fields.

Focus mainly on surface (safety) characteristics.

Performance of asphalt concrete during service life.
Conclusions (for Slovenia)

The use of steel slag in asphalt is everyday practice in the developed countries.

The successfully constructed test fields are proof that Slovenia can follow these trends.

Fear of the use of steel slag is unnecessary.

There are opportunities for designers, investors and producers of asphalt mixes.