Reuse of Linz-Donawitz (LD) Slag in Asphalt Mixtures for Pavement Application

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What is LD-Slag?

- byproduct of steel production (LD process in particular) as pig iron is processed into crude steel
- slag is separated from the crude steel and separately processed
- main components: iron oxide, calcium oxide and silicon dioxide

Europe: ~ 12 mio. tons of steel slag is produced per year
Objective & Research Approach

How does use of LD slag in asphalt mixtures affects the functional performance of pavement construction compared to asphalt mixtures with natural aggregate Gabbro?

Structure layers of asphalt pavements

- Surface layer
- Binder layer
- Base layer
- Sub base (unbounded, e.g. Stone)
- Asphalt = mixture of bitumen ("glue") + aggregates

natural ground
Objective & Research Approach

Production of asphalt mixture variants with LD slag and natural aggregate Gabbro in the lab:

- MA 11 S (surface layer, mastics asphalt)
- SMA 11 S (surface layer, stone-mastic-asphalt)
- AC 16 B S (binder layer with a maximum aggregate size of 16 mm)
- AC 22 T S (base layer with a maximum aggregate size of 22 mm)
Objective & Research Approach

Asphalt properties evaluated in the lab:

- Resistance to permanent deformation
- Stiffness
- Fatigue resistance
- Resistance to low temperature cracking
- Skid resistance of surface layer
Test Methods - Resistance to permanent deformation

Penetration Test
[EN 12697-25, Pt. A1]

T = +50 °C

loading time rest period

Strain @ turning point [%]

penetration depth ET_{dyn} after 2500 load cycles [mm]

No. of load cycles @ turning point [-]

Cyclic Compression Test
[EN 12697-25, Pt. B1]

T = +50 °C

Belastungszeit        Belastungspause

Lastwechsel

permanent deformation

deformation rate
Test Methods - Stiffness and fatigue resistance

Cyclic Indirect Tensile Test [EN 12697-24]

Stiffness

$$E = f(T)$$

Fatigue

$$N_{Makro} = C_1 \cdot \varepsilon_{el, anf}^{C_2}$$

- **Modulus** [MPa]
- **Temperature T [°C]**
- **Number of load cycles until macro crack [x]**

### Graphs

- **E - Modulus [MPa]** vs. **Temperature T [°C]**
- **Number of load cycles until macro crack [x]** vs. **strains [%]**
Test Methods – Resistance to low temperature cracking

Thermal Stress Restrained Specimen Test [EN 12697-46]

1. Start @ T = 20 °C
2. Cooling Rate $\Delta T = -10 \, ^\circ C/h$
3. Specimen at constant length

Due to prohibited thermal shrinkage

Failure stress $\sigma_F$ [MPa]

Failure temp. $T_F$ [°C]
Test Methods – Skid Resistance

Skid resistance of surface layer [German Standard TP Gestein-StB, Pt 5.4.2]

- Simulation of traffic exposure
  - 1 hour / 500 rpm
  - Injection water-quartz powder mix

- Rotating rubber bodies (100 km/h) lowered onto specimen surface thereby braked → friction coefficient

- Polishing
- Friction measurement
**Results** - Resistance to permanent deformation

Surface layer: mastic asphalt (MA)

- Slag much lower penetration depth compared to MA with natural Gabbro aggregate

> use of LD slag in mastic asphalt (MA) leads to an advantageous deformation resistance compared to mastic asphalt with natural Gabbro aggregate
Results - Resistance to permanent deformation

Surface layer: stone mastic asphalt (SMA)

- Slag lead to higher number of load cycles compared to SMA with natural Gabbro

use of LD slag in stone mastic asphalt (SMA) leads to an advantageous deformation resistance compared to stone mastic asphalt with natural Gabbro aggregate (same tendency as for MA)
Results - Resistance to permanent deformation
Binder- & base layer: AC 16 BS & AC 22 TS

- number of load cycles @ turning point much lower for LD slag
- Strains comparable in magnitude

Deformation behavior of the asphalt binder and asphalt base mixtures with LD Slag

**but:**
LD slag mixtures showed higher air voids contents (up to 3.0 vol.-%)
→ affects negatively resistance to permanent deformation

*figure showing load cycles and strains for different mixtures*
Results - Stiffness

Surface layer: mastic asphalt (MA) & Stone mastic asphalt (SMA)

Resulting stiffness is for all asphalt surface mixtures at a comparable level, regardless of whether LD slag or natural Gabbro aggregate was used.
Results – Fatigue resistance
Surface layer: mastic asphalt (MA) & Stone mastic asphalt (SMA)

Similar fatigue resistance for mixtures with natural aggregate Gabbro and LD slag
Use of LD slag in asphalt binder and asphalt base course mixtures leads to a higher fatigue resistance in comparison to mixture with natural Gabbro.
Results - Resistance to low temperature cracking
Surface layer: mastic asphalt (MA) & Stone mastic asphalt (SMA)

- Comparable resistance to low temperature cracking
- Failure stresses at a high (good) level
- Typical for commonly used asphalt pavement surface layers in Europe
Results – Skid Resistance of surface layer

- friction coefficients of the mixtures with LD about 15 to 20% lower compared to Gabbro

→ Nevertheless high level of friction (satisfactory for safety purposes)
Summary and conclusions

How does use of LD slag in asphalt mixtures affects the functional performance of pavement construction compared to asphalt mixtures with natural aggregate Gabbro?

<table>
<thead>
<tr>
<th>Resistance to permanent deformation</th>
<th>Stiffness</th>
<th>Fatigue resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>advantageous</td>
<td>comparable (good!) level</td>
<td>disadvantageous</td>
</tr>
</tbody>
</table>

Surface: 
- Advantageous

Binder, base: 
- Voids!
Summary and conclusions

- disadvantageous
- comparable (good) level
- advantageous

Resistance to low temperature cracking

Skid resistance of surface layer

1. asphalt mixtures with LD slag are suitable for asphalt pavement construction
2. performance as good as or even better than conventional asphalt mixtures prepared with natural aggregate Gabbro
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Thank you!

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