Slag – as Subbase

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What is ‘slag’

- ‘Slag’ is a by product of either iron or steel making processes.
  - Blast Furnace Slag – Produced as a by product from iron making. Typically air cooled, then crushed and graded.
  - Steel Slag – Produced from steel making processes such as electric arc furnace, basic oxygen furnace, etc.
What kind of slags do we have?

- Only two of our eleven approved sources are ‘pure slags’.
  - Lafarge buys exclusively from US Steel – fresh 100% blast furnace slag
  - Harsco is a 100% steel slag from a former steel mill outside of Harrisburg
- All remaining 9 sources are from waste sites commonly referred to as ‘brownfields’. These are areas where the mills landfilled slag waste since the 1930’s. Their composition varies from stockpile to stockpile (i.e., usually mixtures of steel and blast furnace slag) along with their material properties. All operate under either a ‘General Permit’ from DEP or a Co-Product determination supplied to DEP.
Slag - Usage

• Slag aggregates are approved for a number of uses although there are restrictions.
  • Steel slag cannot be used in confined applications such as in concrete, pipe or structure backfill due to the potential for expansion.
  • Blast furnace slag may be used in concrete.
    • Both types of slags may be used as subbase material
      • Concerns with past performance when used as subbase have been noted and studied leading to further restrictions by some Districts which will be discussed here.
Bulletin 14 Approved Slag Sources

PennDOT currently has eleven Slag sources approved to supply 2A

Most of the eleven sources are located in the Western part of the State.
In 1999, District 9 experienced substantial frost heaving on US-22, Cambria Co. Slag aggregate was used as subbase. The District attributed the frost heave to the high absorption and instituted a special provision restricting subbase aggregate absorptions to less than 3.5%.
Fallout

• Following this, several other Districts who had experienced problems with slag aggregates used as subbase adopted and implemented the DSP on their projects.

• Unhappy with this action, the National Slag Association requested that PennDOT prohibit use of the DSP and countered that the issues we were experiencing were not related to the subbase, ie attributable to other causes.
Subsequent Actions

• An NSA-PennDOT workgroup was formed to discuss PennDOT’s concerns.

• A study to assess material performance was initiated shortly thereafter. Ten 50 lb bags of 2A were sampled by District staff and sent to NSA’s selected private lab (Bowser Morner).
  • European Test methods were (also) used based on their extensive use and testing of slag aggregates for transportation. Over 27 countries utilize their DIN test standards.

• Test results: SLAG DURABILITY TESTING RESULTS 2011-2014 - For internal meeting 9-12-14.xlsx
Testing Analysis

- The European freeze thaw (ten cycles in water) was used and compared to the slag absorption value.
- A very good correlation was found between the two tests, i.e., low absorption slags produced low freeze thaw losses.

\[ R^2 = 0.7254 \]

\[ R^2 = 0.5079 \]
A very good correlation between sodium sulfate soundness and the European freeze-thaw durability test was also found.
European F/T loss limit and AASHTO F/T Comparison

- PennDOT utilized the European F/T loss limit of F2 or 2% loss for unbound bases (2.49% max due to rounding).

- This is roughly equivalent to a 5% loss when compared to the AASHTO F/T test (25 cycles) or twice the loss.
Subbase SSP

Based on the correlation testing, PennDOT implemented SSP B03501 for projects let after February 13, 2015:

**Special Provision Name:** b03501 SECTION 350 - SUBBASE

**Provision Body:**

In accordance with Section 350 and as follows:

- Revise Section 350.2(a) Aggregate to read as follows:

  **(a) Aggregate** - Provide Type C or better, No. 2A material with freeze thaw resistance according to European Standard DIN EN 13242 with a maximum freeze/thaw loss of 2% as determined by European Standard DIN EN 1367-1 for all slag aggregates and any natural aggregate whose absorption exceeds 2%. Test for thermal and weathering properties of aggregates, Part 1: Determination of resistance to freezing and thawing.
Admittedly, the SSP is somewhat difficult to interpret, especially without the referenced standards and without the (rounded) maximum values clearly specified.

- Natural Aggregates with absorptions less than 2% (F2 – 2.49% max) are considered freeze thaw resistant and DO NOT require freeze thaw testing.
  - Dept. testing on low absorption aggregates have verified this, ie very low f/t losses
- All slag aggregates must be tested. Six of the eleven slag sources produced f/t losses less than 2.49%. The ‘pure’ slags were the best performers during our split study testing with very low (less than 1%) f/t losses.
## Tested sources

<table>
<thead>
<tr>
<th>Supplier Code</th>
<th>Reference Number</th>
<th>Lot Number</th>
<th>Stockpile Number</th>
<th>Natural Aggregate Absorption, %</th>
<th>Freezer-Thaw Loss, %</th>
<th>Maximum permitted Freezer-Thaw Loss</th>
<th>Pass [Green] or Fail [Red]</th>
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<td>BVA04A14</td>
<td>A569698</td>
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</table>

- Six of the eleven slag sources originally met the 2.49% max loss. 4 currently available. All high absorption natural aggregates also met (8 – most gravels)
- Spreadsheet maintained on shared drive for District access.
- Verify during pre-construction meeting as source of supply!
Chemistry – limits needed

- Tests/limits for chemistry are needed:
  - Blast furnace slag: Leachate – sulfur which can contaminate streams
    - Adopting Indiana Test method
  - Steel slag: CaO (calcium oxide as free lime)
    - FHWA indicates that above 1%, the CaO can cause tufa precipitation that clogs pavement base drains
Tufa Precipitation
Other concerns: Cementation

- Some slag subbases that have been exhumed were found to have been cemented. LTS is working to identify how these types of slags can be identified and either prohibited for use as 2A where we need a free draining subbase or otherwise controlled—perhaps through revised grading, site restrictions (non ‘wet’ areas)
Material Breakdown

- The freeze-thaw loss limit is intended to address issues like this where the project experienced over 2” of longitudinal joint settlement
Next Steps

• PennDOT met recently with NSA. Slag may be appropriate for use as an alternate soil stabilization.
• PennDOT is reviewing information provided by NSA where Indiana DOT has utilized slag for soil stabilization
• Warranty’s
• NSA has argued that PennDOT should increase the freeze-thaw loss to 4% based on information from Germany that this is their limit (F4) for unbound bases
• PennDOT is considering allowing up to 4% loss if the contractor warranties the subbase (and pavement based on distress types) for ten years.
Questions