Foundry Sand: Characteristics, Specifications, Environmental Considerations, Availability

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What is Foundry Sand?

• Foundry sand is a high-quality uniform silica sand that is used to make molds and cores for ferrous and nonferrous metal castings.

• Foundry sands typically comprise of >80% high-quality silica sand, 5-10% bentonite clay, 2 to 5% water and less than 5% sea coal.
Engineering Properties

- Physical properties of foundry sand and natural sand

Foundry Sand, 45X Mag

Natural Ohio Fine Grained Sand, 45X Mag
Foundry Sand Composition

- Base Sand: 85%
- Bentonite: 7%
- Organic: 3%
- Water: 5%

Foundry sands are sand-bentonite mixtures.
How is Foundry Sand Used?

• Foundry sand is reused within the foundry several times until the sand becomes unsuitable for mold construction.

• Approximately 9 to 10 million tons of foundry sand is discarded yearly.

• An estimated 28% of discarded foundry sand is reused in primarily construction-related applications.
Why Use Foundry Sand in Infrastructure Construction?

- Recycled foundry sand is generally considered a higher quality material than virgin construction sands.

- Reduce energy and financial expenses associated with obtaining virgin construction sands.

- Project managers can promote green construction and gain sustainability points for their projects.
State of the Industry and Future Goals

• The EPA (2008) estimates that current foundry sand recycling rates prevents 20,000 tons of CO₂ emissions and 200 billion BTUs of energy consumption.

• U.S. EPA, the Federal Highway Administration, the U. S. Department of Agriculture, the Recycled Materials Resource Center (RMRC), state environmental agencies, the foundry industry and end users have partnered together to increase foundry sand recycling to 50% by 2015.
Foundry Sand Being Used as Fill

Spent cores
Foundry sand grades and shapes easily.

Fines facilitate compaction with modest amount of moisture.
Foundry sand being spread as highway sub-base.

Foundry sand sub-base being compacted.
Design Considerations

Highway Subbase

• California Bearing Ratio
• Resilient Modulus
• Uncompressive Strength

• Design charts and methodology for constructing working platforms with FS found in Tanyu et al 2004 and 2005

• FS found to resist degradation due to winter conditions better than typical reference materials
Full-Scale Field Test: Wisconsin State Highway 60

Pavement Structure

- 0.125 m Asphalt Layer
- 0.115 m Grade 2 Gravel Base Course
- 0.14 m Salvaged Asphalt Base Layer
- 0.84 m Breaker Run
- 0.60 m B. Ash
- 0.84 m F. Sand
- 0.84 m F. Slag

Subbase

Soft Subgrade (ML or CL)

- $1 < \text{CBR} < 4$
- $100 \text{ kPa} < q_u < 150 \text{ kPa}$
Field Performance: Five Years After Construction
Design Considerations - Embankment

• Draft AASHTO and ASTM standards for the incorporation of FS in embankment/structural fill designs is being balloted

• Typical embankment design parameters include:

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Foundry Sand Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.39 – 2.70</td>
</tr>
<tr>
<td>Bulk Relative Density, lb/ft³</td>
<td>160</td>
</tr>
<tr>
<td>Standard Proctor Max Dry Density, lb/ft³³</td>
<td>109</td>
</tr>
<tr>
<td>Optimum Moisture Content, %</td>
<td>~ 12%</td>
</tr>
<tr>
<td>Hydraulic Conductivity (cm/sec)</td>
<td>$10^{-3}$ - $10^{-9}$</td>
</tr>
<tr>
<td>Plastic Index</td>
<td>NP to 12</td>
</tr>
<tr>
<td>Internal friction angle (drained)</td>
<td>33° - 43°</td>
</tr>
<tr>
<td>Cohesion intercept (drained), lb/ft²</td>
<td>145-585</td>
</tr>
</tbody>
</table>
Retaining Wall and Structural Fill Design Recommendations for Foundry Sands

- $\phi' = 40^\circ$, $c' = 0$
- $E = 55\%$ for geogrids
- $E = 65\%$ for geotextiles
- Compact dry of optimum water content

Frictional Efficiency $E(\%) = \tan \delta' / \tan \phi' \times 100$

$\delta' =$ interface friction angle  $\phi'$ = internal friction angle
Drainage & Foundry Sands

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Me an of Field Ks

S DRI

Foundry sands are poorly draining unless bentonite content is low.
Design Considerations

Hot Mix Asphalt

• FS replaces fine aggregate in standard asphalt mixes and conventional AASHTO pavement design and field testing methods can be employed

• The fines content of the FS determines the amount used to replace aggregate (usually replaces 8-25% fine aggregate)

• HMA-FS mixes demonstrate better resistance to weathering
Foundry Sands in Flowable Fill

- Flowable slurry mixed & delivered like concrete.
- Modest strength, but excavatable
- Trench backfill, underground void backfill, pipeline grouting.
- Use water-cement ratio of 9 to 12 to ensure strength in correct range (0.3 – 1.0 MPa)
Design Considerations

Flowable Fill

- FS replaces fine aggregate in flowable fill mixtures
- Bentonite content of FS >10% can impede flow causing an increase in water requirements
- For bentonite contents greater than 6 percent, no fly ash is necessary because the bentonite will be sufficient to prevent segregation
- FS may not satisfy gradation requirements but the uniform, spherical nature of the particles creates a free flowing mixture
- The same methods and equipment used for conventional flowable fill mixes can be used for FS mixes
Design Considerations

Portland Cement Concrete

• FS replaces some fine aggregate in Portland cement concrete

• FS should be screened and crushed to obtain the desired gradation, and magnetic particles should be separated. These processes will prevent technical problems when mixing the cement components.

• FS may cause a gray/black tint to finished concrete. Color change is minimized with <15% fine aggregate replacement.

• FS should have less than 5% fines to maintain durability of concrete
Is Foundry Sand safe to use in Infrastructure Construction?

• Discarded foundry sand can contain trace amounts of leachable metals and organic constituents.

• Ferrous and aluminum foundry sands have been approved for use as a construction material. 
  - Brass and Bronze foundry sands may contain high concentrations of heavy metals.

• Leaching studies of ferrous and aluminum foundry sands generally show metals and organic constituents are below designated environmental threshold levels.
Environmental Assessment: Issues to Consider

- Does a standard method exist to evaluate environmental impacts associated with foundry byproducts?
- Do leachates from foundry byproducts have more contaminants or greater concentrations than conventional construction materials?
Wisconsin NR 538 Code

- Evaluate byproducts based on total elemental analysis and water leach tests.

- Define byproduct categories based on test data.

- Define suitable application based on category.
Applications Based on Category

Lower category number provides more stringent limits on leaching characteristics.

<table>
<thead>
<tr>
<th>Beneficial Use Methods</th>
<th>Industrial Byproduct Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
</tr>
<tr>
<td>(1) Raw Material for Manufacturing a Product</td>
<td>X</td>
</tr>
<tr>
<td>(2) Waste Stabilization / Solidification</td>
<td>X</td>
</tr>
<tr>
<td>(3) Supplemental Fuel Source / Energy Recovery</td>
<td>X</td>
</tr>
<tr>
<td>(4) Landfill Daily Cover / Internal Structures</td>
<td>X</td>
</tr>
<tr>
<td>(5) Confined Geotechnical Fill</td>
<td>X</td>
</tr>
<tr>
<td>(a) commercial, industrial or institutional building subbase</td>
<td></td>
</tr>
<tr>
<td>(b) paved lot base, subbase &amp; subgrade fill</td>
<td></td>
</tr>
<tr>
<td>(c) paved roadway base, subbase &amp; subgrade fill</td>
<td></td>
</tr>
<tr>
<td>(d) utility trench backfill</td>
<td></td>
</tr>
<tr>
<td>(e) bridge abutment backfill</td>
<td></td>
</tr>
<tr>
<td>(f) tank, vault or tunnel abandonment</td>
<td></td>
</tr>
<tr>
<td>(g) slabjacking material</td>
<td></td>
</tr>
<tr>
<td>(6) Encapsulated Transportation Facility Embankment</td>
<td>X</td>
</tr>
<tr>
<td>(7) Capped Transportation Facility Embankment</td>
<td>X</td>
</tr>
<tr>
<td>(8) Unconfined Geotechnical Fill</td>
<td>X</td>
</tr>
<tr>
<td>(9) Unbonded Surface Course</td>
<td>X</td>
</tr>
<tr>
<td>(10) Bonded Surface Course</td>
<td>X</td>
</tr>
<tr>
<td>(11) Decorative Stone</td>
<td>X</td>
</tr>
<tr>
<td>(12) Cold Weather Road Abrasive</td>
<td>X</td>
</tr>
</tbody>
</table>

Note: Refer to NR 538.10 for description of each beneficial use.
Water Leach Test Criteria – NR 538

- Contaminants of concern depend on byproduct being considered.
- Category 1 has the most test requirements.

<table>
<thead>
<tr>
<th>Standard (mg/L)</th>
<th>Parameter</th>
<th>Ferrous Foundry Excess System Sand</th>
<th>Ferrous Foundry Slag</th>
<th>Coal Ash</th>
<th>Other¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03</td>
<td>Antimony (Sb)</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>Arsenic (As)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.02</td>
<td>Barium (Ba)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.025</td>
<td>Beryllium (Be)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>Cadmium (Cd)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Chloride (Cl)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>Chromium, Total (Cr)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Copper (Cu)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Total Cyanide</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Iron (Fe)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.075</td>
<td>Lead (Pb)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Manganese (Mn)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>Mercury (Hg)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>Nickel (Ni)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Nitrate &amp; Nitrite (NO₃⁻+NO₂⁻+N₂)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Phenol</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>Selenium (Se)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>Silver (Ag)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2500</td>
<td>Sulfate</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>Thallium (Tl)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Zinc (Zn)</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

¹ As provided under s. NR 538.06 (1), the testing program for materials other than ferrous foundry system sand, ferrous foundry slag and coal ash must be approved by the department prior to characterization. For other materials the department may modify the list of parameters required to be analyzed for test results based on a material specific basis for additional parameters.

Note: All testing is to be conducted on a representative sample of a single industrial byproduct prior to commingling with other materials, unless otherwise approved by the department.
Methods to Assess Leaching

• **Batch tests:**
  - solid and liquid in a vial
  - tumbled to ensure local well-stirred
  - supernatant analyzed for contaminants of concern

• **Column tests:**
  - flow through experiment simulating field scenario
  - effluent analyzed for contaminants of concern.
Batch Tests

• TCLP – toxicity characteristic leaching procedure (EPA Method 1311)
  - purpose: to determine if a waste is hazardous waste under RCRA (40 CFR Part 261)

• SPLP – synthetic precipitation leaching procedure (EPA Method 1312)
  purpose: to evaluate leaching of waste in response to precipitation

• ASTM Water Leach Test (D 3987)
  purpose: to evaluate leaching of waste
Column Test Schematic

Effluent Concentration ($\mu$g/L)

Theresa silt loam + King fly ash

ADU with instantaneous sorption

(a)
Leaching Patterns

Chromium
Theresa + King Fly Ash

First flush following ADRE

Delay response (user defined)
Environmental Impact Modeling Tools:

- IMPACT
- WiscLEACH
- IWEM (Industrial Waste management Evaluation Model)
- STUWMPP (Screening Tool for Using Waste Materials in Paving Projects)

Detailed information on assessing risk and protecting groundwater is available in EPA "Guide for Industrial Waste Management" which can be found at http://www.epa.gov/epaoswer/non-hw/industd/guide/index.asp
Environmental Profile

• Summarized on AFS-FIRST website http://www.foundryrecycling.org

• DOE funded a joint Penn State/Univ. of Wisconsin study completed in 2004. An extensive analysis of foundry sand data concluded that “the concentrations of most regulated metallic elements are less than or in the same level as those of soil. This illustrates that excess foundry sands do not pose greater threats to the environment than soil.”
Environmental Profile

- A second major national study undertaken by U.S. Dept. of Agriculture resulted in 11 peer-reviewed journal articles.
- In May 2009, U.S. EPA circulated a peer review draft of “Risk Assessment of Spent Foundry Sand in Soil-Related Applications” developed jointly with USDA. This exhaustive study of all risk pathways concluded that “there is overwhelming evidence that the metal constituents found in SFS are not only present at levels protective of human health and the environment, but present at levels that are very similar to those found in native soils.”
Summary Environmental Comments

• Look for regulations in your state. If none exist, propose using Wisconsin’s NR 538.

• Column tests provide a more realistic depiction of leaching, but batch tests are more common.

• Peak concentrations in effluent from column tests and from the field typically are larger than those measured in batch tests.

• Conduct tests with eluent that resembles field condition if possible. Do not use acidic eluents unless justified by site conditions.
Summary Environmental Comments

• Do not use TCLP for assessing suitability of foundry byproducts (or other industrial resources) for use in construction applications. ASTM D 3987 preferred.

• Determination of “non-hazardous” by TCLP does not mean OK. Only inference is that solid would not need to be disposed in a hazardous waste landfill.

• Compare leaching from byproducts against leaching from conventional materials. Leaching is expected from nearly all materials used for unbound applications in highway construction.
Models exist to evaluate groundwater impacts from reuse applications when a code providing predefined reuse options (e.g., Wisc. NR 538) does not exist. Comparison should be made considering byproducts as well as conventional materials.
Availability

http://www.afsinc.org/component/option,com_wrapper/Itemid,254
Acknowledgements

Federal Highway Administration
United States Environmental Protection Agency
Wisconsin Recycling Market Development Board
Wisconsin Solid Waste Research Program
Wisconsin Department of Natural Resources
Wisconsin Cast Metals Association
Wisconsin Department of Transportation
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