Flexibility of Using Slag Cement in Concrete Paving

ACPA General Meeting
Austin - December 1, 2016

Gordon McLellan
Technical Manager
Lehigh Cement Company
Slag Cement – A New/Old material in Concrete Paving

- First used in North America in Paving in the late 70’s in Chicago IL – Eden’s Expressway as part of a blended cement system (25 – 45% slag cement).
- First Concrete Airport paving used as a separate cementitious material – Atlanta Airport in the early 80’s at 50% slag.
- Now routinely allowed or specified by most state DOT’s and FAA pavements across USA.
- Footprint of slag continues to grow with complimentary use of other cementitious materials such as fly ash/silica fume/metakaolin.
Flexibility: How much Slag should I use in paving?

Depends on many factors

- Location/Cost Analysis/Durability/Construction Timing

Highest recent doses for paving

- FDOT mainline concrete Paving at 60% Slag and minimum total cementitious

Typical mainline paving

- Ontario Canada 25%/Northern US 35%/Southern US 50%

Ternary mixes with either three silos or blended cement with third material becoming more common

- 50/30/20, 40/40/20

ASR or similar aggregate issues: Typical 50% use of Slag Cement to control expansive properties
What is slag cement?

- The granulated blast-furnace slag (GBFS) is finely ground
- Cementitious material
What is slag cement?

- Non-metallic product of an iron-making blast furnace
- The molten slag is granulated
Portland Cement Reaction

Portland Cement + Water → Calcium-Silicate Hydrate + Calcium Hydroxide
Slag Cement Reaction

Slag Cement + Water → Calcium-Silicate Hydrate

Slag Cement + Calcium Hydroxide → More Calcium-Silicate Hydrate

From Portland Cement
Durability - Chloride Permeability
ASTM C1202 (an electrical conductivity test)

Charge Passed (Coulombs)

<table>
<thead>
<tr>
<th>Slag Cement Replacement (%)</th>
<th>W/C = 0.45</th>
<th>W/C = 0.55</th>
<th>W/C = 0.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>8,000</td>
<td>4,000</td>
<td>0</td>
</tr>
<tr>
<td>25%</td>
<td>2,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>50%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Charge Passed (Coulombs)
Flexural Strength

Flexural Strength (psi)

- 100% Portland
- 50% Slag Cement

<table>
<thead>
<tr>
<th>7 Day</th>
<th>28 Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>583 lb/cy</td>
<td>635 lb/cy</td>
</tr>
<tr>
<td>635 lb/cy</td>
<td>583 lb/cy</td>
</tr>
</tbody>
</table>

LEHIGH HEIDELBERGCEMENT Group
Effect of Slag Cement on ASTM C403 time of setting

This is for the case when no chemical admixtures (e.g., WRA, HRWRA) are in the mix to add their effect(s).

If you want the time of setting to be in a specific window for a given temperature range, adjust the concrete mixture materials and proportions to achieve this.
Across the range of typical pavement proportions, slag-cement use increases strength.
Concrete Performance:
Binary System Compressive Strength

Compressive Strength (psi)

<table>
<thead>
<tr>
<th></th>
<th>7 Day</th>
<th>28 Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland 100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slag Cement 25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slag Cement 50%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compressive Strength (psi):
- Portland 100%
- Slag Cement 25%
- Slag Cement 50%
Vibration effect
Slag Cement and Total Concrete Alkali Loading

From Thomas and Innis, 1998

- Concrete Prisms ~ ASTM C1293
- Sudbury Aggregate

Concrete Alkali Content, kg/m³

% Expansion at 2 Years

- Control
- 25% Slag
- 35% Slag
- 50% Slag
- 65% Slag
All tests performed with Kalkberg aggregates and portland cement with an equivalent alkali content of 0.98.
Effect of Slag Cement on Sulfate Resistance

![Graph showing the effect of slag cement on sulfate resistance. The graph compares the expansion of OPC (Ordinary Portland Cement) with 25% and 50% slag cement Mixtures over time.](chart.png)

ASTM C1012

- **OPC**
- **25% Slag Cement**
- **50% Slag Cement**
- **180-day Limit**
- **1-year Limit**

**Legend:**
- OPC
- 25% Slag Cement
- 50% Slag Cement
- 180-day Limit
- 1-year Limit

**Axes:**
- **Y-axis:** Expansion, %
- **X-axis:** Age, days
Examples of Significant Paving

Examples of Roads & Bridges use of slag-cement concrete
Edens Expressway, Chicago, the construction of 1977-1978; between 25% and 45% slag supplied as ASTM C595 Type IS blended cements to various lengths of the pavement.

Good Showing for Edens Expressway after 17 years in service. ‘High degree of wear resistance.

  - 30% slag cement
  - Construction segment on west side of Columbus loop.

Chicago — I-290 / Hwy 53 (2006): The project segment was several miles along Schaumburg. 25% slag cement.

Fig above and below—Columbus: curing compound applied; saw-cut joints.

← % slag cement. Curing compound used. Mainline paving by Athens OH, 2006. 30
ODOT Project 10-0281 IR – 75/IR -475 Interchange

- Toledo, Ohio project included
  - New interchange, 6 bridge reconstructions, 4 new bridges, 3,700 ft cast-in-place retaining walls, 4 noise walls, and replacement of 2.1 miles of pavement

- Used ternary mixture for bridge decks and substructure
  - 25% slag cement and 25% fly ash
  - Exceeded 28-day 4,500 psi $f'$c with average 5650 7-day and 7910 28-day strengths
  - ASTM C1202 RCP of 752 coulombs

- Provided consistent and workable mix with strength, durability, and reduced environmental footprint
Ohio DOT since 1996
- Hundreds of bridge parapet walls and piers have included 30% slag cement
- Ternary mixes allowed in decks with slag cement

Fig.—1st ODOT use of slag cement concrete in a bridge deck. Notice wet-burlap curing (early 1990s).
Ternary bridge decks w/ ≤40% slag cement+fly ash placed routinely.

Missouri River MoDOT I-70 Blanchette Bridge rebuild, 2012-2013; 7800 cy of ternary 60:25:15 PC:SC:C-ash in 110 pcf lightweight concrete deck. MoDOT has allowed ternary concrete since 2004, which is commonly used in the St Louis area. No load rejections on job—and all results were acceptable.

Stan Musial Veterans Memorial Bridge. Most of 16,000 cy in pylons used 30:70 PC:SC concrete. All results were acceptable.
Delaware DOT State Route 1

- Built 1989-2004
- 1 Million cy concrete
- 35-50% slag cement
- Mitigated ASR
- Allowed use of local aggregates
- Approx. savings:
  - 221,000 tons mat’l
  - 490,000 mbtu
  - 109,000 tons CO₂
Florida – I-95

- Design build project with Kiewit Southern
- Widening I-95 from 4 to 6 lanes from Cape Canaveral to Rockledge
- 200,000 + cubic yards, 30,000 tons of Lehigh Slag Cement
- Featured 60% Slag Cement at 508 pounds total cementitious
- Average compressive break of 6800 psi
- Data supported FDOT 2010 specification change to Minimum 470 pounds
Success story I - 95

Trial Mix I-95, 508 lbs Cementitious With CAMCEM

- 50% CAMCEM
- 60% CAMCEM

Strength (PSI)

- 7 Day
- 28 Day
Airport Projects Using Slag Cement

Examples of slag-cement concrete in US Airport Projects
Port Columbus Airport, Columbus, Ohio (1993-1995)

- 1993 airport: new construction associated with a paving expansion
- 30% slag cement concrete using 540 pcy total cementitious materials. Limestone coarse aggregate.

1994: continuation of the expansion project. All told, over 20,000 cy of paving.

1995: continuation of the expansion project. All told, over another 20,000 cy of paving.
Indianapolis Airport, Indianapolis, IN (1995)

- Indianapolis Airport, 1995
- Contractor and concrete supplier: Reith Riley
- Airport expansion with a new runway of 17-in.-thick paving.
- The runway used a 50:50 282:282 pcy portland cement: slag cement concrete with a No. 57 limestone coarse aggregate.
- Note: From 30,000 ft. in the color of the slag runway is remarkably whiter.
- P501 specification changed to allow ternary, higher slag doses (55%) and Grade 100 or Grade 120
Johnstown Air-Force Facility, Johnstown, PA (1996)

- Construction of two large hangars, each for multiple helicopters, ending in 1996
- Concrete supplier: Fi-Hoff Concrete, of Johnstown, PA
- Apron construction associated with the hangars used 30% slag cement concrete.
- Caissons, grade beams, and other structural elements of the hangars used 50% slag cement. The minimum dimension size of these castings was three feet.
- The specification included aspects of both FAA and the Corps of Engineers Specifications.
- 563 pcy cementitious at $w/cm = 0.53$ for non-pavement elements. The paving used a PennDOT mix.
Other Airports . . . pre-1999

a) Hopkins Cleveland, Cleveland, OH. 15,000 cy slag-cement concrete paving. Concrete supplier: Cuyahoga Concrete. No. 57 limestone coarse aggregate

b) Langley AFB. At least three different projects.

c) Norfolk, VA.

d) Richmond, VA

e) Salisbury, MD.

f) Raleigh-Durham, NC.

g) Oceana Naval Air Station, VA.

h) Seymour-Johnson AFB.

i) Hartsfield-Atlanta, GA. A 4th runway and taxiway.

j) Savannah, GA. Taxiway and apron.

k) Little Creek Amphibious Base, VA. An air-cushioned vehicle facility.
Other Airports . . . pre- mostly 1999

n) Minnesota, MN (1998)
o) Dane County, WI. Runway cast on asphalt base (late 1990s)

Pavement construction with slag cement concrete at Minneapolis, MN Airport (1998)
Spirit of St Louis Airport, Chesterfield, MO
Southwest St Louis area (2000)

- Concrete cast late spring and summer of 2000
- Contractor and concrete producer: Milstone Bangert
- Slag supplied as an ASTM C595 Type IS(20) blended cement, milled (inter-ground) with GBFS from Gary IN.
- Concrete used a ternary mix of the Type IS(20) cement and Class C fly ash

- After an inspection several years after the project, MoDOT included Type IS cements in the specification.
- Spirit Airport Ground Run Up Enclosure
- 1700 cy of 35% slag-cement concrete paving
- Paving cast in August and September, 2010
- Concrete Supplier: American Ready Mix, Chesterfield, MO (part of the Kienstra group of companies)
The Wayne County Airport Authority needed to improve the central portion of Taxiway Zulu prior to the start of Runway 4R/22L reconstruction scheduled to begin in 2012. Portions of Taxiway Zulu required reconstruction due to deterioration of pavement and shoulders; other portions of the taxiway did not meet current minimum runway-taxiway separation distance required during poor weather conditions operations for Aircraft Design Group V and larger.
The project specifications included FAA P-501 requirements for the evaluation of each individual aggregate for ASR using the modified ASTM C 1260 test. The local sands exceeded the maximum 0.1% expansion at 28 days, therefore, Ajax chose slag cement replacement of 30% to mitigate the reactivity. The sand was evaluated using the modified ASTM C1567 test and expansion of below the FAA maximum of 0.1% at 28 days. The pavement also met the required 650 psi flexural requirement at 28 days and the surface smoothness requirements.
Columbia Airport, Columbia, MO (2012 – 2013)

- Columbia, MO airport—new runway construction. - 25,000 cy of paving, all told

- 40% slag cement used in the concrete. About 75% of the paving was in 2012, and about 25% was in the beginning of 2013

- ‘Purpose for slag cement use was ASR prevention

- Concrete made on-site by contractor—Emery Sapp & Sons Inc. (ESS), 2301 I-70 Drive N.W., Columbia MO 65202, phone: (573) 445-8331.

- Owner: State of Missouri. Followed Missouri DOT concrete tradition (eg., test concrete air after being cast)
### Slag Cement – A Recycled Material

Environmental - Life Cycle Inventory for Portland and Slag Cements

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>Portland Cement</th>
<th>Slag Cement</th>
<th>Percent Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Material</td>
<td>lb/ton</td>
<td>2,851</td>
<td>-</td>
<td>100%</td>
</tr>
<tr>
<td>Energy</td>
<td>MBTU/ton</td>
<td>4.57</td>
<td>0.62</td>
<td>86%</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>lb/ton</td>
<td>1,801</td>
<td>42</td>
<td>98%</td>
</tr>
</tbody>
</table>
Reduced Energy Consumption

<table>
<thead>
<tr>
<th>Energy Requirements (MBtu/cy)</th>
<th>Ready Mix</th>
<th>Precast</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland 100%</td>
<td>1.66</td>
<td>2.30</td>
<td></td>
</tr>
<tr>
<td>Slag 35%</td>
<td>1.10</td>
<td>1.46</td>
<td></td>
</tr>
<tr>
<td>Slag 50%</td>
<td>1.27</td>
<td></td>
<td>1.36</td>
</tr>
<tr>
<td>Slag 65%</td>
<td></td>
<td></td>
<td>0.98</td>
</tr>
<tr>
<td>Slag 80%</td>
<td></td>
<td></td>
<td>0.79</td>
</tr>
</tbody>
</table>
Reduced Greenhouse Gases

Carbon Dioxide Emissions (lb/cy)

- **Ready Mix**
  - Portland 100%: 555 lb/cy
  - Slag 35%: 382 lb/cy
  - Slag 50%: 307 lb/cy

- **Precast**
  - Portland 100%: 812 lb/cy
  - Slag 35%: 438 lb/cy
  - Slag 50%: 550 lb/cy

- **Mass**
  - Portland 100%: 422 lb/cy
  - Slag 35%: 254 lb/cy
  - Slag 50%: 171 lb/cy

Legend:
- Grey: Portland 100%
- Black: Slag 35%
- Green: Slag 65%
- Olive: Slag 50%
- Light Green: Slag 80%
Environmental Savings
Material, Energy and Greenhouse Gas

<table>
<thead>
<tr>
<th></th>
<th>Raw Material</th>
<th>Energy</th>
<th>Carbon Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw Mix (35% Slag)</td>
<td>7%</td>
<td>24%</td>
<td>31%</td>
</tr>
<tr>
<td>Ready Mix (50% Slag)</td>
<td>10%</td>
<td>34%</td>
<td>45%</td>
</tr>
<tr>
<td>Precast (50% Slag)</td>
<td>15%</td>
<td>37%</td>
<td>46%</td>
</tr>
<tr>
<td>Mass (80% Slag)</td>
<td>13%</td>
<td>42%</td>
<td>59%</td>
</tr>
</tbody>
</table>
Thank you