Performance of Typical Concrete Mixtures for Transportation Structures as Influenced by Portland-Limestone Cements from Five Sources

Alabama Standard Specifications

On August 27, 2019 the Department issued Special Provision 18-0600 that allowed the use of:

Type IL Portland Limestone Cement

The provision added a cement type to Section 815 on Cements in the 2018 edition:

SECTION 815 CEMENT

813.05 Type IL Portland Limestone Cement. Type IL Portland limestone cement shall meet the requirements of ASTM C150, Blended Hydraulic Cement.

History of Portland-Limestone Cements

- 1965 Cement with 20% limestone in Germany for specialty applications.
- 1979 French cement standards allow limestone addition.
- 1983 CSA A5 allows up to 5% limestone in portland cement.
- 1990 15±5% limestone blended cements routinely used in Germany.
- 1992 UK specs allows up to 20% limestone cement.
- 2000 EN 197-1 allows 5% limestone in all 27 common cements and creates CEM I/IV (16-20%) and CEM II/B-L (21-35%).
- 2004 ASTM C150 allows 5% in Types I-V.
- 2004 US Cement producers start marketing a 10% PLC under performance specification ASTM C1157.
- 2006 CSA A23.1 allows 5% in more Types other than GU.
- 2007 AASHTO M95 allows 5% in Types I-V.
- 2008 CSA A3001 includes PLC containing 5%-15% limestone.
- 2012 ASTM C959 & AASHTO M240 adopt a IL PLC (15% Max. Limestone Content)
It’s all about the Environment…

Energy & Emission Savings; When producing PLC instead of OPC

<table>
<thead>
<tr>
<th>Percent Limestone</th>
<th>10%</th>
<th>15%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Reduction*</td>
<td>Fuel (million BTU)</td>
<td>443,000</td>
</tr>
<tr>
<td></td>
<td>Electricity (kWh)</td>
<td>6,970,000</td>
</tr>
<tr>
<td>Emissions Reduction*</td>
<td>SO₂ (lb)</td>
<td>581,000</td>
</tr>
<tr>
<td></td>
<td>NO₅ (lb)</td>
<td>580,000</td>
</tr>
<tr>
<td></td>
<td>CO (lb)</td>
<td>104,000</td>
</tr>
<tr>
<td></td>
<td>CO₂ (ton)</td>
<td>189,000</td>
</tr>
<tr>
<td></td>
<td>Total hydrocarbon, THC (lb)</td>
<td>14,300</td>
</tr>
</tbody>
</table>

* Per million tons cement

Production Energy per ton powder

<table>
<thead>
<tr>
<th>Energy (MBtu/Ton)</th>
</tr>
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<tbody>
<tr>
<td>OPC</td>
</tr>
<tr>
<td>PLC-10%</td>
</tr>
<tr>
<td>PLC-15% Slug Cement</td>
</tr>
<tr>
<td>Fly Ash</td>
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</tbody>
</table>

Energy Consumption per yd³ of Concrete

<table>
<thead>
<tr>
<th>Energy Requirements (btu/cy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPC</td>
</tr>
<tr>
<td>PLC-10%</td>
</tr>
<tr>
<td>PLC-15%</td>
</tr>
<tr>
<td>PLC-15% &amp; PLC-15% &amp; 30% Ash</td>
</tr>
<tr>
<td>PLC-15% &amp; 50% Slag</td>
</tr>
</tbody>
</table>

Initial indications of “synergies” with SCM’s

Example concrete data comparing OPC vs. PLC w/ C and F ash

<table>
<thead>
<tr>
<th>Synergies w/ C ash – gravel aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each bar group shows the average of 4 mixes – 1 with each cement source</td>
</tr>
<tr>
<td>OPC</td>
</tr>
<tr>
<td>5% No SCM</td>
</tr>
<tr>
<td>5% 15% C ash</td>
</tr>
<tr>
<td>5% 25% F ash</td>
</tr>
<tr>
<td>5% PCM</td>
</tr>
<tr>
<td>100% Slump</td>
</tr>
<tr>
<td>143% Blaine</td>
</tr>
</tbody>
</table>

Synergies w/ C ash – gravel aggregates

<table>
<thead>
<tr>
<th>Type I/II vs. 10% LS Type GU; mixes w/ gravel CA, 517 pcy total cementitious, 5&quot; slump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representative of trends from 100’s of mixes between 2005 and 2009, PLC produced to Blaine typically 120 to 140 m²/kg higher than OPC</td>
</tr>
</tbody>
</table>
Example fineness trends:
PLC vs. clinker and limestone component fractions

Why Limestone Works?
• Particle packing
• Improved particle size distribution

Why Limestone Works?
• Nucleation
  • Surfaces for precipitation of CSH
  • Unusually high cementitious efficiency, especially with Class C fly ash, for some PLC samples
  • Mix: 517 pcy total cementitious, 5” slump, Type A WR, gravel CA
  • 28-day strength of C ash mix was 124% of control (No SCM)

Why Limestone Works?
• Chemical Reactions
  • Only a minor contributor, but small amounts of carboaluminate phases in the CSH paste have been found
  • Key point: synergistic strength benefits are, in large part, the result of documented chemical interaction & crystal formation

Analytical evaluation of limestone-aluminate interaction
XRD Diffractograms: evolving mineralogy differences, OPC and PLC mixtures with 40% Class C fly ash

Holcim experience in the US
• Over 2,000,000 tons supplied from 5 different US plants
  • Extensive experience in UT and CO (ASTM C1157 approved by DOT’s)
  • 600+ lane miles of concrete pavements
  • Limited experience in AASHTO states
  • No AASHTO specification until 2012
  • State transportation agency concerns
  • Is limestone just a filler, diluting clinker?
  • Is performance really going to be at least equivalent to OPC in traditional concrete?
  • Low familiarity, southeastern states
Industry & Academia Research

Local Industry Trial with a GDOT Class A Mixture

Rapid Chloride Permeability

Shrinkage, Cement C

Expansion of Davis-Wade Stadium, Mississippi State University

MSU Davis-Wade Stadium project concrete data, 50/30/20 mixtures

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Expansion of Davis-Wade Stadium, Mississippi State University

- $75M expansion, renovation
- Design focus on sustainable attributes of materials
- Most concrete using 50% replacement (30% slag + 20% Class C fly ash), some with OPC, some with PLC
- Study part of research project underway at MSU CEE

Local Industry Trial with a GDOT Class A Mixture

- 4 cement types

Rapid Chloride Permeability

- High: > 4000
- Moderate: 2000-4000
- Low: 1000-2000

Shrinkage, Cement C

- Over 500 bars of data

MSU Davis-Wade Stadium project concrete data, 50/30/20 mixtures

- Strengths at ages up to 28 days, averages of project data to date
- PLC vs. OPC equivalency, each data point = a PLC mixture strength vs. a corresponding OPC mixture strength
- 3 cylinders averaged for each
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New Slipform Silo for Lehigh Cement, Leeds, AL

13% PLC & 40% Slag

Mobile River Bridge Trial Concrete Research

Thank You!
Questions?

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