Portland-Limestone Cement: An Option to Make Concrete Even Greener

Jeff Hook, Lehigh Cement
Shawn Kalyn, St. Marys Cement
Paul Tennis, Portland Cement Association
PLC – The Concrete Difference

Concrete Information for the Owner, Designer, Contractor and Producer

Portland-Limestone Cement: An Option to Make Concrete Even GREENER
Today’s Objectives

• What is a portland-limestone blended cement
• Why use it
• How is it made
• How does it perform in concrete
• Some examples
• Questions
Portland-Limestone Cement

• What is a PLC?
  – Type IL blended cement in ASTM C595/AASHTO M 240
  – 5% to 15% limestone by mass
  – Option to implement proven technology to obtain desired performance and improve sustainability of concrete

Typical US Cement Composition:

<table>
<thead>
<tr>
<th>Material</th>
<th>Portland Cement</th>
<th>PLC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinker</td>
<td>91 %</td>
<td>83%</td>
</tr>
<tr>
<td>Gypsum</td>
<td>6 %</td>
<td>6 %</td>
</tr>
<tr>
<td>Limestone</td>
<td>3 %</td>
<td>11 %</td>
</tr>
</tbody>
</table>

Up to 5% Limestone in Portland Cement – Up to 15% Limestone in PLC
Cement Manufacture
How is PLC Different?

- **PLC** is made by intergrinding regular clinker with up to 15% limestone while regular portland cement contains up to 5% limestone.
- **PLC** is a finer ground product than regular portland cement.

**PORTLAND CEMENT**

| 95% Ground Clinker | 5% limestone |

**PLC**

| 85% Ground Clinker | 15% limestone |
Energy to Produce Cement

![Graph showing energy usage to produce cement from 1965 to 2015. The energy usage decreases over time, from approximately 8 million BTU/ton in 1965 to 4 million BTU/ton in 2015.]
Some CO$_2$ Facts

- Each Tonne of clinker results in an unavoidable release of $\sim$525 kg of CO$_2$ due to calcination.

- This is about 60% of the total CO$_2$ emissions associated with cement manufacturing and occur regardless of the fuels used to support the kiln process.
Environmental Benefits

<table>
<thead>
<tr>
<th>Plant</th>
<th>Portland cement</th>
<th>Portland-limestone cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>0.80</td>
<td>0.70</td>
</tr>
<tr>
<td>Plant 2</td>
<td>0.82</td>
<td>0.75</td>
</tr>
<tr>
<td>Plant 3</td>
<td>0.84</td>
<td>0.78</td>
</tr>
</tbody>
</table>
History of Limestone in Cements

• 1965 Cement with 20% limestone in Germany for specialty applications
• 1979 French cement standards allows limestone
• 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% in limestone cement
• 2000 EN 197-1 allows 5% MAC (typ. limestone) in all 27 common cements
• 2000 EN 197-1 creates CEM II/A-L (6-20%) and CEM II/B-L (21-35%)
• 2004 ASTM C 150 allows 5% in Types I-V
• 2006 CSA A3001 allows 5% in other Types than GU
• 2007 AASHTO M85 allows 5% in Types I-V
• 2008 CSA A3001 includes PLC with 5%-15% limestone
• 2012 ASTM C595/AASHTO M 240 include PLC with 5% to 15% limestone
Why 15%?

- **Compressive strength measured**
- **Total porosity calculated**
- **Amount of CaCO₃ added [wt.-%]**

Legend:
- **Increase**
- **Decrease**

Data points indicate the relationship between the amount of CaCO₃ added and the relative change in porosity and compressive strength.
How Limestone Works

• Particle packing
  – Improved particle size distribution

• Nucleation
  – Surfaces for precipitation

• Chemical reactions
  – Only a small amount, but...
How Limestone Works

- **Particle packing**
  - Improved particle size distribution

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  - Surfaces for precipitation

- **Chemical reactions**
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How Limestone Works

• Particle packing
  – Improved particle size distribution

• Nucleation
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• Chemical reactions
  – Only a small amount, but...
Strength

Strength at 1 day:

- PC
- PLC - 12%

Strength at 7 days:

- PC
- PLC - 12%
Strength

Strength at 28 days

Strength at 56 days

Compressive Strength (MPa)

Compressive Strength (psi)

No SCM  35% Slag  20% Fly Ash

No SCM  35% Slag  20% Fly Ash

www.pacaweb.org  www.specifyconcrete.org  www.cement.org
Permeability T 277/C1202

- No SCM
- 35% Slag
- 20% Fly Ash

Charge Passed (Coulombs)

- PC
- PLC

28 days

- W/CM = 0.40
- W/CM = 0.45

56 days

- W/CM = 0.40
- W/CM = 0.45
Sulfate Resistance C1012

Fly Ash Mixes
Standard C1012
23C

Expansion, %

Exposure, weeks

GU
GUL
GU + 15% FA
GUL + 15% FA
GU + 20% FA
GUL + 20% FA
GU + 25% FA
GUL + 25% FA
GU + 35% FA
GUL + 35% FA
ASR - Accelerated Mortar Bar Test

Exposure, days

Expansion, %

Control
30% Slag
40% Slag
50% Slag

--- GU
----- GUL

14d limit

Exposure, days

Expansion, %

Control
20% Fly Ash
25% Fly Ash
30% Fly Ash

--- GU
----- GUL

14d limit
PLC Application in Pavement

➢ A ready-mixed concrete plant yard was paved in 4 sections with 4 different cementitious mixes in 2009
  ➢ 100% Type I
  ➢ 100% Type IL
  ➢ Type I with 25% slag
  ➢ Type IL with 25% slag
PLC Application in Pavement
Placed November 3\textsuperscript{rd} 2009, pavement is 9” thick
PLC APPLICATION IN PAVEMENT

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www.specifyconcrete.org
www.cement.org
Then and now

November 3rd, 2009

October 30th, 2018
ODOT Approved concrete mix

QC 1 4000psi <2000 rcp

- Type IL /I 450 lb
- Slag cem 150 lb
- W/C 0.45
- Slump 5.75/8
- Air 7.2%/6.8%
- RCP 1147/1171
IL MTO Field Trial – Sarnia (October 2011)

- The application was slip formed barrier walls (MTO Contract) located on the north side of HW 402 Westbound in Sarnia, Ontario
- Type I with 25% Slag
- Type IL with 25% slag
- Low slump concrete 13/64\(^{th}\) to 1 inch
- Air Content (5-8%)
- The barrier walls are exposed to harsh weather conditions
- Strength and durability testing was completed by University of Toronto, along with other third party laboratories showing similar results when comparing Type I and IL

Highway 402 Westbound – East of Front Street (Sarnia, Ontario)
IL MTO Field Trial – Sarnia (October 2011)

**Compressive Strength Results**
Cylinders Cast at Plant

- **Type I**:
  - 7 Day: 4790 psi
  - 28 Day: 6310 psi
- **Type II**:
  - 7 Day: 4640 psi
  - 28 Day: 6670 psi

**Flexural Strength Results**

- **Type I**:
  - 28 Day: 880 psi
- **Type II**:
  - 28 Day: 830 psi
**Concrete’s Ability to Resist Chloride Ion Penetrability**

**ASTM C1202**

<table>
<thead>
<tr>
<th>Mix Identification</th>
<th>28 Day Rapid Chloride Permeability (Coulombs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cast Cylinders</td>
</tr>
<tr>
<td>Type I</td>
<td>1391</td>
</tr>
<tr>
<td>Type IL</td>
<td>1470</td>
</tr>
</tbody>
</table>

**Hardened Air Void Analysis**

**ASTM C457**

<table>
<thead>
<tr>
<th>Mix Identification</th>
<th>Cast Cylinders</th>
<th>In Situ Cores</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Air Content (%)</td>
<td>Specific Surface (mm⁻¹)</td>
</tr>
<tr>
<td>Type I</td>
<td>4.5</td>
<td>30.72</td>
</tr>
<tr>
<td>Type IL</td>
<td>4.1</td>
<td>41.12</td>
</tr>
<tr>
<td><strong>Specifications</strong></td>
<td><strong>3.0 minimum</strong></td>
<td>-</td>
</tr>
</tbody>
</table>
IL MTO Field Trial – Sarnia (October 2011)

Freeze Thaw Durability
Cast (75 x 75 x 285mm) Prisms
ASTM C666

<table>
<thead>
<tr>
<th>Mix Identification</th>
<th>Freeze Thaw Durability</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Mass Loss (%)</td>
<td>Average Length Change (%)</td>
<td>Average Durability Factor (%)</td>
</tr>
<tr>
<td>Load 3 - GU</td>
<td>-1.678</td>
<td>0.022</td>
<td>93.92</td>
</tr>
<tr>
<td>Load 6 - GUL</td>
<td>-1.624</td>
<td>0.020</td>
<td>90.19</td>
</tr>
</tbody>
</table>

Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
300 x 250 x 75mm LS-412 Slabs

<table>
<thead>
<tr>
<th>Mix Identification</th>
<th>Average Salt Scaling Loss (kg/m²)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cast Slabs @ 50 Cycles</td>
<td>In Situ Cut Slabs @ 50 Cycles</td>
<td></td>
</tr>
<tr>
<td>Load 3 - GU</td>
<td>0.27</td>
<td>3.33</td>
<td></td>
</tr>
<tr>
<td>Load 6 - GUL</td>
<td>0.32</td>
<td>1.30</td>
<td></td>
</tr>
</tbody>
</table>

MTO Specification
0.80 kg/m² max @ 50 cycles
IL MTO Field Trial – Sarnia (October 2011)

Linear Shrinkage
MTO LS-435

<table>
<thead>
<tr>
<th>Mix Identification</th>
<th>Shrinkage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Load 3 – GU – Prism 1</td>
<td>-0.006</td>
</tr>
<tr>
<td>Load 3 – GU – Prism 2</td>
<td>-0.007</td>
</tr>
<tr>
<td>Load 3 – GU – Prism 3</td>
<td>-0.007</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>-0.007</strong></td>
</tr>
<tr>
<td>Load 6 – GUL – Prism 1</td>
<td>-0.007</td>
</tr>
<tr>
<td>Load 6 – GUL – Prism 2</td>
<td>-0.007</td>
</tr>
<tr>
<td>Load 6 – GUL – Prism 3</td>
<td>-0.007</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>-0.007</strong></td>
</tr>
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</table>
Tim Horton’s Field, Hamilton, ON

- 2013-2014
- 14,000 yd$^3$ concrete, 30 mixes
- PLC
- Mostly exterior concrete
- Design challenges
  - Cold weather construction
  - SCC
  - LEED Silver
- Design strengths to 5000 psi
Mattamy National Cycling Center

- 2013 to 2014
- 17,000+ yd³ concrete
- 34 mixes

- Strengths to 5000 psi for structural walls, slabs
- Leed Silver
Acceptance by State DOTs

Acceptance of Portland Limestone Cement
Tentative data: January 2014

Map of the United States showing acceptance status of Portland Limestone Cement by state.
Acceptance by State DOTs

Acceptance of Portland-Limestone Cement
Tentative data: January 2018

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www.specifyconcrete.org
www.cement.org

Accepting
Planning to accept
Considering
Type II market
Not considering or no information
Acceptance by State DOTs

Acceptance of Portland-Limestone Cement
Tentative data: October 2018

Note: FAA P-501 permits use of Type II L
US Type IL Cement  2012 to 2016

Thousand metric tons

<table>
<thead>
<tr>
<th>Year</th>
<th>Metric Tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>467</td>
</tr>
<tr>
<td>2013</td>
<td>348</td>
</tr>
<tr>
<td>2014</td>
<td>505</td>
</tr>
<tr>
<td>2015</td>
<td>526</td>
</tr>
<tr>
<td>2016</td>
<td>890</td>
</tr>
</tbody>
</table>
from Ashby (2009)
Summary

Portland-Limestone Cement

➢ Has a proven track record
  ➢ More than 75 countries around the world
  ➢ In Europe since 1960s
  ➢ In Canada many condos, industrial slabs and Pam-Am Games sporting facilities since 2010 successfully
➢ Reduces GHG emissions up to 10%
➢ Produces concrete with a comparable level of strength and durability as that produced with regular portland cement

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Shawn Kalyn, shawn.kalyn@vcimentos.com
Jeff Hook, jhook@lehighcement.com
Paul Tennis, ptennis@cement.org