Reducing Concrete’s Carbon Footprint using Portland-Limestone Cements

Ohio Concrete - November 2, 2021
We can’t live without concrete...
Concrete is Environmentally Friendly

Barcelo, Kline, Walenta (2012)
PCA 2050 Roadmap to Carbon Neutrality

CO2 and Sustainability

Increased pressure to reduce our environmental impact from many groups: designers, regulators, even the public

Concrete is so essential to the way we live, that our industry must do its part to address climate issues

Blended cements can help position concrete as more sustainable

Roadmap executive summary
PLC is a Key Lever for the Roadmap

CO2 Footprint of Construction

CO2 problem?
CO2 opportunity!
PLC is proven technology
PLC can help position concrete as more sustainable
What is PLC?

A greener cement option

A blended cement with additional limestone content, optimized for performance

The easiest way to reduce your carbon footprint by up to 10%

Suitable for buildings, bridges, pavements, geotechnical applications

Readily available throughout the U.S. and Canada
Portland-Limestone Cement - How it’s Made

• What is 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
How is PLC Different?

- PLC is made by blending or inter-grinding 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

How Limestone Works

- Particle packing
  - Improved particle size distribution
- Nucleation
  - Surfaces for precipitation
- Chemical reactions
  - Only a minor contribution
U.S. Standards

Cementitious Material Standards

C150 portland cement – Types I and I/II, II, III, and V

C595 blended cement – Types IP, IS, IL, and IT. Allows for pozzolans, slag cement, limestone
Long Track Record

Portland-Limestone Cements

Europeans introduced in the late 1960s
Canada has used them since 2008
U.S. introduced them in 2012
Confidence in PLC is growing
U.S. is currently more 1 MMT/year
# Products on the Ohio DOT Certified List

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash Grove</td>
<td>Joliette QC, Mississauga ON</td>
</tr>
<tr>
<td>Fairborn Cement</td>
<td>Fairborn OH</td>
</tr>
<tr>
<td>Continental Cement</td>
<td>Davenport IA</td>
</tr>
<tr>
<td>Lehigh Cement Company</td>
<td>Logansport IN, Mason City IA, Mitchell IN, Picton ON, Speed IN</td>
</tr>
<tr>
<td>Roanoke Cement Co.</td>
<td>Trout Ville VA</td>
</tr>
<tr>
<td>St Marys Cement</td>
<td>Bowmanville ON, Detroit MI</td>
</tr>
<tr>
<td>(currently undergoing initial ODOT certification approval process)</td>
<td>Charlevoix MI, St Marys ON</td>
</tr>
</tbody>
</table>
Mix Designs with PLC

Proportioning, batching, and mixing

PLC replaces ordinary portland cement at 1:1 ratio

PLC allows for the same dosages of fly ash or other pozzolans, slag cement

As with any new material, some testing is warranted to confirm effect fresh and hardened properties

   Air content, slump, bleed potential, setting time, compressive strength

Some producers report no adjustments are needed, others tweak proportions or adjust admixture dosages
Mix Designs with PLC

Typical effects on fresh and hardened properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>Increase or decrease&lt;br&gt;No significant effect on admixtures</td>
</tr>
<tr>
<td>Bleeding</td>
<td>Decreases with increasing fineness&lt;br&gt;Generally of no concern</td>
</tr>
<tr>
<td>Setting time (initial, final)</td>
<td>Can be slight decrease w/increasing fineness&lt;br&gt;Not a concern even up to 15% limestone</td>
</tr>
<tr>
<td>Heat of hydration</td>
<td>Slight increase at early ages (up to 48 hours)&lt;br&gt;But less significant at later ages</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>Can increase slightly&lt;br&gt;Both early-age and long-term strengths</td>
</tr>
<tr>
<td>Scaling and freeze-thaw resistance</td>
<td>Use same techniques as with OPC concrete mixes:&lt;br&gt;Proper air-void systems, curing, higher strengths</td>
</tr>
<tr>
<td>Sulfate resistance</td>
<td>Use same techniques as with OPC concrete mixes:&lt;br&gt;Low w/cm, min. strength, and MS or HS designations</td>
</tr>
</tbody>
</table>
PLC for Special Properties

Cement modifiers

Sulfate resistance – MS, HS
  Sulfate-containing soils
  Sulfate-containing groundwaters

Heat of hydration – LH, MH
  For mass concrete placements
  No counterparts in CSA

High-early strength – HE
  For precast concrete
  New in August 2021

<table>
<thead>
<tr>
<th>Cement type</th>
<th>OPC C150 (M 85)</th>
<th>PLC C595 (M 240)</th>
<th>PLC CSA A3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>General use</td>
<td>I</td>
<td>IL</td>
<td>GUL, GULb</td>
</tr>
<tr>
<td>moderate sulfate resistance</td>
<td>II, II(MS)</td>
<td>IL(MS)</td>
<td>MSL</td>
</tr>
<tr>
<td>moderate heat of hydration</td>
<td>II(MH)</td>
<td>IL(MH)</td>
<td>-</td>
</tr>
<tr>
<td>high sulfate resistance</td>
<td>V</td>
<td>IL(HS)</td>
<td>HSL</td>
</tr>
<tr>
<td>low heat of hydration</td>
<td>IV</td>
<td>IL(LH)</td>
<td>-</td>
</tr>
<tr>
<td>high-early strength</td>
<td>III</td>
<td>IL(HE)</td>
<td>HEL, HELb</td>
</tr>
</tbody>
</table>
Working with PLC Mixes

Normal operations for:

Placing
Finishing
Curing

As fineness increases, may see:

- Slightly less bleed water
- Slightly shorter setting times
- Slightly higher water demand

Virtually the same handling and performance as OPC
Performance of PLC Concrete

A look at hardened properties

Strength
- OPC to PLC comparisons
- With and without SCMs

Durability
- Scaling
- Freeze-thaw resistance
- Chloride permeability
- ASR resistance
- Sulfate resistance
- Field trial results
Performance of PLC Concrete

Early age strength development with and without SCMs

Thomas and Hooton 2010
Performance of PLC Concrete

Later age strength development with and without SCMs

Thomas and Hooton 2010
Performance of PLC Concrete

“Permeability” T277/C1202

Charge Passed (Coulombs)

0 1000 2000 3000

28 days 56 days

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

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

PC PLC

Thomas and Hooton 2010
Performance of PLC Concrete

Scaling resistance (ASTM C672)

Thomas et al. 2010
Performance of PLC Concrete

Freeze-Thaw Resistance (ASTM C666)

![Bar chart showing durability factor for different supplementary cementing materials.](image)

- No SCM (0.40)
- No SCM (0.45)
- 35% Slag (0.45)
- 20% Fly Ash (0.45)

Thomas et al. 2010
Performance of PLC Concrete

Field Trials: Pavement slab after one winter

- PLC + 50% SCM
- PLC + 25% SCM
- PC + 25% SCM
- PC + 50% SCM
Performance of PLC Concrete

ASR resistance

Test (age when expansion reported)

Thomas et al. 2010
PLC and Sulfate Resistance

Same approach as for other blended cements

Use additional SCMs and low w/cm

Use moderate- or high-sulfate resistant types:

- Type IL(MS)
- Type IL(HS)
- Type IT(MS)
- Type IT(HS)

Performance confirmed by numerous research studies and decades of field exposures on real-world installations

Blair and Delagrave 2012
Hardened Properties

• Summary in PCA Report SN3148 at www.cement.org

• Strength

• Scaling

• Freeze-thaw resistance

• Chloride permeability

• ASR resistance

• Sulfate resistance
Durability Research

2010- University of Toronto “Vault”

Over 1000 specimens in various storage solutions
Caltrans Research Confirms PLC Performance

- Provide data to make informed decisions about PLCs
- Oregon State University comprehensive research program on PLC
- “Impact of Use of Portland-limestone Cement on Concrete Performance as Plain or Reinforced Material”
  - Similar set times, shrinkage, bound chloride contents, and time to corrosion initiation
  - Similar or improved ASR performance and sulfate resistance
  - Flexural strength similar to the parent system (-5% to +13%)
- Due to these positive results, Caltrans updated its specs in October 2021 (exclude FDR for now)
PCA Research into PLC Soil-Cement

• PCA conducting research on PLC for soil-cement materials
• Supports many of the markets shown
• Direct comparisons of PLC with OPC (Type I/II)
• Testing complete, report being prepared
  • Cohesive and cohesionless soils, and aggregate base materials
Procuring PLC Concrete

Basics of specifying and ordering

A simple revision to specifications: 1:1 replacement of OPC with PLC

Same suppliers for your ready mix

Same delivery and placing equipment
National, Model, and State Specs

Type IL cements permitted in:

- AIA MasterSpec 033000  Cast-in-Place Concrete
- FAA P-501 Portland Cement Concrete Pavement
- More than 34 State DOT specifications
- Multiple ASTM Specifications (incl.)
  - Ready-Mixed Concrete (C94)
  - Concrete pipe, culverts, tile (8 standards)
  - Grout for masonry (C476)
  - Plaster (C926)
- ACI 301, 318
- ICC codes
greenercement.com - Your PLC Resource

• Calculators for CO2 savings
  • Basic, advanced
• Benefits of PLC
• Spec language
• Case studies
• PLC availability map
• Industry partners
• FAQs
• Contact an expert
• Mobile friendly
Greener Roads for Right Now!

“Excellent durability and improved sustainability”

Proven technology

Easy to implement

Sustainable, resilient pavements

These states were some early adopters of PLC concrete pavements – more than a decade ago:

Colorado
Utah
Oklahoma
Partner Resources

- NRMCA CIP on PLC
- Build With Strength
- ACPA Position Paper on PLC
Portland Limestone Cements

Using [www.greenercement.com](http://www.greenercement.com) calculator to demonstrate CO2 savings

Then using the EPA “equivalent CO2” calculator...
[https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator](https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator)

<table>
<thead>
<tr>
<th>Year</th>
<th>CO2 Saved (kgs)</th>
<th>Total CO2 Saved (kgs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>6.9 Million</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>8.9 Million</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>19.7 Million</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>18.7 Million</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>54.2 Million</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td>54200 MTonnes</td>
</tr>
</tbody>
</table>

66,405 acres of U.S. forests in one year
Real-World Projects with PLC

Pan Am Games projects used PLC to support lower carbon initiative
Portland-Limestone Cements

York Region Annex used 10960 tonnes of PLC

Greenhouse gas emissions from

- 237 Passenger vehicles driven for one year
- 2,719,603 Miles driven by an average passenger vehicle

Source: Greenercement.com
Project – Wastewater Treatment Plant, Woodward WWTP, Hamilton, ON

Contractor – North America Const
Type IL and slag specified (30-40%)
23,000 m³ (30,000 yd³)

Woodward Upgrade Project Update - November 2020 - YouTube
Project – West Park Healthcare Centre, Toronto, ON

Contractor – EllisDon
Type IL and slag (10-50%)
35,000 m³ (45,000 yd³)

West Park Healthcare Centre New Hospital Flythrough - YouTube
Davis Wade Stadium
Mississippi State University

• $75M expansion & renovation
• Design focus on sustainability
• OPC and PLC mixes
• Most with 50% SCM replacement – 30% slag + 20% Class C fly ash
• Study part of MSU research
Ben Lomond High School – Ogden, Utah

- Seismic remodel, reconstruction in 2010
- CMU mixes
  - PLC
  - 0-10% Class F fly ash
- CMU unit styles
  - 70,000 smooth face
  - 12,000 split face
  - 110,000 honed face
University of Utah Meldrum Building

- Constructed 2009-2010
- Cementitious materials
  - 80% PLC
  - 20% Class F Fly ash
- SCC mixtures
- Architectural finishes
- Lightweight
- Winter placement
- Compressive strength
  - 4000 psi specified
  - 7 Day Field Range: 6100-6600 psi
IW EPDs for Cement

2016 and 2021 GWP results

L to R
Portland 2016: 1040 kg CO2eq
Portland 2021: 922 (11.3% drop from 2016)
PLC 2021: 846 (8.3% lower than 2021 Portland)

EPDs -> LCA
### 2021 PCA Industry Wide EPDs for OPC and PLC cements

<table>
<thead>
<tr>
<th>Impact category and inventory indicators</th>
<th>Unit</th>
<th>Portland Cements 1 metric ton</th>
<th>Unit</th>
<th>PLC Cement 1 metric ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming potential, GWP 100, IPCC 2013</td>
<td>kg CO₂ eq</td>
<td>922</td>
<td>kg CO₂ eq</td>
<td>846</td>
</tr>
<tr>
<td>Ozone depletion potential, ODP</td>
<td>kg CFC-11 eq</td>
<td>2.10E-05</td>
<td>kg CFC-11 eq</td>
<td>2.17E-05</td>
</tr>
<tr>
<td>Acidification potential, AP</td>
<td>kg SO₂ eq</td>
<td>1.75</td>
<td>kg SO₂ eq</td>
<td>1.64</td>
</tr>
<tr>
<td>Eutrophication potential, EP</td>
<td>kg N eq</td>
<td>1.02E</td>
<td>kg N eq</td>
<td>0.94</td>
</tr>
<tr>
<td>Smog formation potential, SFP</td>
<td>kg O₃ eq</td>
<td>32.9</td>
<td>kg O₃ eq</td>
<td>30.2</td>
</tr>
</tbody>
</table>
Lowering Carbon Footprints of Mixes

5000 psi concrete mixes comparing OPC and PLC with various SCM contents.
Green Rating Systems

Potential credits for PLC

LEED V4, beta V4.1

LEED MRc2

Option 1 Type III EPD

Option 2 Optimization less than 10% reduction in GWP vs. baseline

Maximum of 2 points

Applies to ready mix concrete and masonry grout

### Option 2. Embodied Carbon/LCA Optimization (1 point)

Use products that have a compliant embodied carbon optimization report or action plan separate from the LCA or EPD. Use at least 5 permanently installed products sourced from at least three different manufacturers. Products are valued according to the table below.

<table>
<thead>
<tr>
<th>Report Type</th>
<th>Reference Document(s) for the Optimization Report</th>
<th>Report Verification</th>
<th>Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied Carbon/LCA Action Plan</td>
<td>Product-specific LCA or product-specific Type III EPD</td>
<td>Prepared by the manufacturer and signed by company executive</td>
<td>$\frac{1}{2}$ product</td>
</tr>
<tr>
<td>Reductions in Embodied Carbon: less than 10% reduction in GWP relative to baseline</td>
<td>Baseline: Product-specific LCA, Product-specific Type III EPD, or Industry-wide Type III EPD Optimized: Product-specific LCA or product-specific Type III EPD</td>
<td>Comparative analysis is verified by an independent party</td>
<td>1 product</td>
</tr>
<tr>
<td>Reductions in Embodied Carbon: 10%+ reduction in GWP relative to baseline</td>
<td>Baseline: Product-specific LCA or product-specific Type III EPD Optimized: Product-specific LCA or product-specific Type III EPD</td>
<td>Comparator analysis is verified by an independent party</td>
<td>1.5 products</td>
</tr>
<tr>
<td>Reductions in Embodied Carbon: 20%+ reduction in GWP and 5%+ reduction in two additional impact categories, relative to baseline</td>
<td>Baseline: Product-specific LCA or Product-specific Type III EPD Optimized: Product-specific LCA or product-specific Type III EPD</td>
<td>Comparator analysis is verified by an independent party</td>
<td>2 products</td>
</tr>
</tbody>
</table>

Note: Reference documents for the optimization reports must be compliant with Option 1.
Reducing Concrete’s Carbon Footprint using PLCs

Ohio Concrete - November 2, 2021
Shawn Kalyn, St Marys Cement, a Votorantim Company
Jamie Farny, Portland Cement Association