American Concrete Institute®
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Green Binders Technology

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ACI, ASTM, and American Ceramic Society Fellow, **Doug Hooton**, is a Professor and NSERC/CAC Industrial Research Chair in Concrete Durability and Sustainability in the Department of Civil Engineering at the University of Toronto. His research over the last 35 years has focused on the materials science of cementing materials for concrete, as well as concrete pore structure and fluid penetration resistance, and concrete durability and service life when exposed to aggressive environments including sulphate soils, freezing, and de-icer salts. Professor Hooton is an honorary member of both ASTM Committees C01 on Cements and ASTM C09 on Concrete. He received the Award of Merit from both the Canadian Standards Association and ASTM.

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Decreasing the Clinker Component in Cementing Materials: Performance of Portland-Limestone Cements in Concrete in Combination with Supplementary Cementing Materials

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ACI Green Binder Technology
Session Oct. 27 2010

Concrete Thinking for a sustainable world

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Why Portland-Limestone Cements (PLC)?

- Portland Cement manufacturing produces CO_2
  - Limestone decomposition
  - Fuel consumption
- Governments are preparing cap and trade limits on point source CO_2 emissions
- Not new since PLC (CEM IIA-L) has been in use in Europe for > 20 years and is now the most widely used cement type

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PLC in CSA Standards

- In 2008, a new class of Portland-Limestone cements was added to CSA A3001, with up to 15% blended or interground limestone replacing cement clinker.
- The CO_2 emissions from PLC are ~10% less relative to Type GU (~ASTM Type I) Portland cement.
- In addition, fewer raw materials and less energy are used to produce PLC.
- When properly optimized, the limestone is not inert and contributes to the properties of the cement.
- PLC have to meet the same set time and strength development performance as portland cement of the same type (eg. GU ---same as ASTM Type I)

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Portland-Limestone Cements in CSA Standards

- Changes to the A3000 Cementitious Materials standard in 2008 and to the A23.1 concrete standard in 2009 allow use of PLC
- NBCC Building Code was updated in 2010 to include these changes

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More Sustainable Cementing Materials

SCMs (and blended cements)

PLC

Portland cement type	Blended hydraulic cement type	Portland-limestone cement type
GU	GUb (GULb)	GUL

ASTM and PLC

- At least 2 producers in the USA are making 10% limestone cements under ASTM C1157.
- ASTM C595 may be amended in 2011 to allow for PLC blended cements.
- Thomas & Hooton wrote a PCA report summarizing the Canadian data in support of ASTM actions.

A3001 PLC Performance Requirements

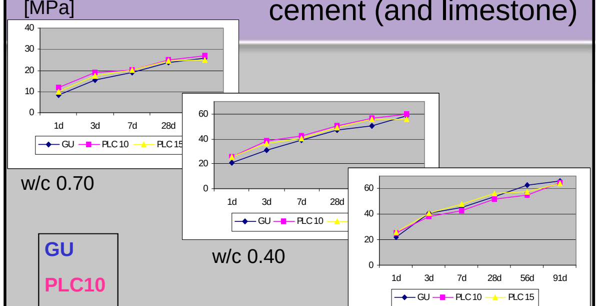
- In CSA A3000, the setting times and strength development limits are the same for PLC as for portland cements.
- Heat of hydration limits are also the same for MH and LH cements.
- In concrete, PLC also performs well with slag or fly ash at normal replacement levels.
- Mechanisms: Carboaluminate hydrates form and also fine carbonates provide nucleation sites that accelerate hydration

Lab Concrete Data

- Before balloted by CSA A23.1, all of the Cement companies and several universities performed extensive testing for fresh, hardened, and durability properties on PLC and together with SCMs normally used.
- A couple of examples follow.

Initial concrete test results – straight cement (and limestone)

[MPa]



w/c 0.70

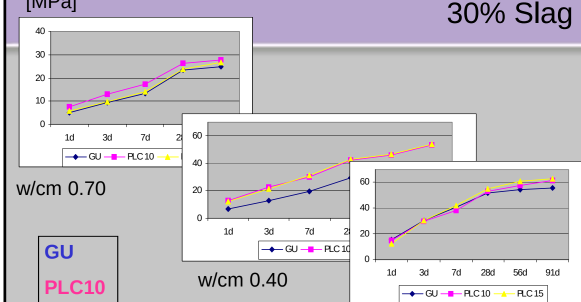
w/c 0.40

w/c 0.37

GU
PLC10
PLC15

Initial concrete test results – with 30% Slag

[MPa]



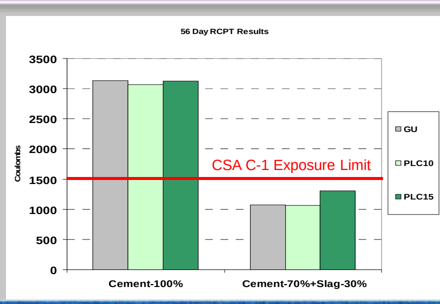
w/cm 0.70

w/cm 0.40

w/cm 0.37

GU
PLC10
PLC15

56-day RCP Results (w/cm = 0.40)



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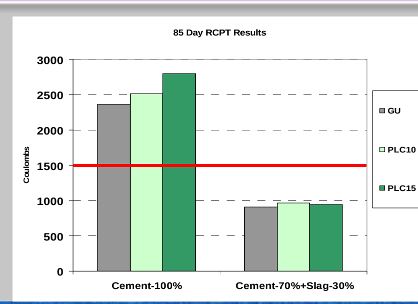
85-day RCP Results



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Lafarge PLC Trials from 2008 (Concrete International, Jan. 2010)

BY MICHAEL D.A. THOMAS, DOUG HOOTON, KEVIN CAIL, BRENTON A. SMITH, JOHN DE WAL, AND KENNETH G. KAZANIS

- 8 concrete slabs were cast in Oct 2008 at Lafarge, Gatineau QC
- 80-100mm (3-4 in.) slump, air-entrained, 30MPa, C-2 exposure(355kg/m3, 592 pcy)
- GU and PLC with 0, 25, 40 & 50% mixed SCM (2 slag: 1 fly ash)

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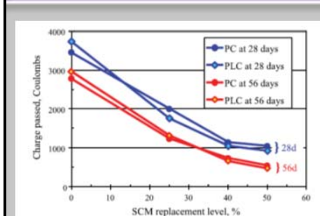
RCP Coulomb Values for Site Cast Cylinders & Cores



Equal performance of GU and PLC mixes at same age and SCM content

Rapid chloride permeability test (ASTM C1012) results for cores taken from slabs at 35 days (values in Coulombs)

Cement type	SCM replacement level, %			
	0	25	40	50
PC	2400	1410	570	490
PLC	2350	1310	620	520

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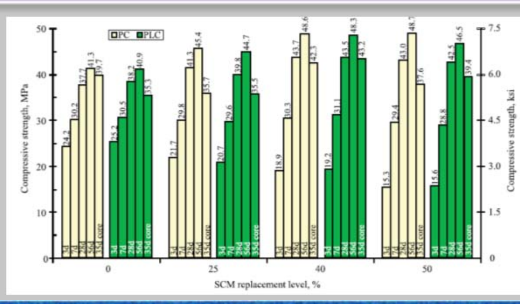
3, 7, 28, 35-day Cylinder & 35-day Core Strengths (12% limestone PLC mixes in Green)



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Air Void, Freeze/Thaw and Chloride Diffusion Data

Air void parameters per ASTM C457 and durability factor (resistance to freezing and thawing) per ASTM C666

SCM replacement level, %	Cement type	Air void parameters		Durability factor, %
		Air content, %	Spacing factor, µm	
0	PC	5.3	173	101
	PLC	5.6	187	100
25	PC	4.9	148	101
	PLC	5.4	149	104
40	PC	5.6	164	101
	PLC	5.3	165	103
50	PC	5.6	150	102
	PLC	6.6	147	100

TABLE 5:
Calculated values of diffusion coefficient D_A ($\times 10^{-12}$ m^2/s) from bulk diffusion tests per ASTM C1556

Cement type	SCM replacement level, %			
	0	25	40	50
PC	15.0	3.8	1.5	1.3
PLC	11.9	2.9	1.2	1.8

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Nov. 2009 Barrier Wall

- Dufferin Construction Barrier Wall Test sections 23m^3 of PLC+Slag vs GU+Slag
- Queen Elizabeth Expressway in Burlington
- First MTO trial of PLC
- Testing performed by Dufferin Concrete (Holcim) and University of Toronto

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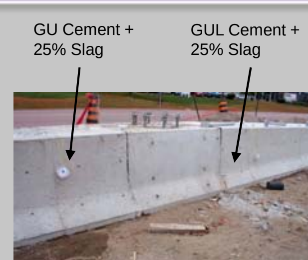
PLC Barrier Walls on QEW Nov. 4, 2009



23 m^3 of each mix placed, 30 MPa, 60-100 mm (2.5-4 in.) slump

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Nov. 2009 QEW Barrier Wall

QEW Barrier Wall	PC +25% SLAG	PLC + 25% SLAG
Shrinkage (28d)	0.038%	0.038%
Strength (MPa)		
1	9.5	10.3
3	19.3	19.4
7	25.6	26.8
28	36.9	37.9
56	38.9	38.0
91	40.7	40.2
Freeze/Thaw Durability	94%	94%
MTO LS-412 Scaling	0.24 kg/m^2	0.24 kg/m^2
RCP (Coulombs)		
28 days	2070	1490
56 days	1930	1340

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PLC Paving Trial Sept 27, 2010

Cooperation between MTO, Dufferin Construction, Holcim and University of Toronto

- New Highway 401 East bound exit to #10 from collector lanes.
- 100 m of paving was done with PLC+25% Slag as binder, otherwise identical to GU+25% Slag control mixture.
- Pavement was 4.25 m (13 ft) wide x 280 mm (11.5 in.) thick with pre-placed dowel baskets
- ~8 m (25 ft) was wet-cured and rest used normal curing compound

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Testing

- Fresh concrete tests and strength development
- Flexural and tensile strengths
- Shrinkage
- Freeze/Thaw and De-icer scaling tests
- Chloride Permeability and Bulk Diffusion
- Temperature monitoring

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Concrete Plant

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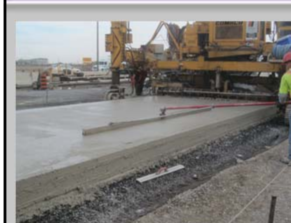
PLC (GUL) Test Section



Floating and Tyning

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GUL (Left) and GU (Right)
(after tyning but before curing compound)

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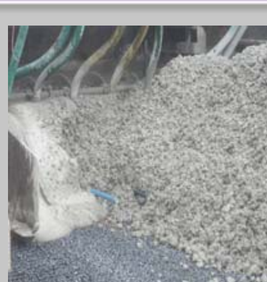
GUL Mix (Left) and GU Mix (Right) in Paver (note segregation in GU Mix)



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Burlap & Plastic vs. Curing Compound

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7-Day Data

	GU Control	PLC
Slump (mm)	35	20
Air (%)	5.4	4.6
Temp.	18	19
Strength (MPa)		
7 day	35.0	31.9
28 day		
Split Tensile MPa)		
7 day	3.3	3.0
28 day		
Flexural (MPa)		
7 day	5.8	5.2
28 day		

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Holcim US PLC Pavements

- Holcim makes ASTM C1157 cements with 10% limestone for use in Colorado and Utah.
- These have been used on at least 5 State paving contracts.
- In several cases the PLC was used together with Class F fly ash

Data courtesy of Al Innis, Brooke Williams, & Tom Van Dam

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Colorado 2008-2009
US HW 287 Near Lamar

- 6.5 Miles PCCP with 10% Limestone cement meeting ASTM C1157 and 20% Class F fly ash (CM = 540 pcy, 322 kg/m3) w/cm = 0.34
- 28-day flexural strength average = 695 psi (4.8 MPa)
- Contractor received quality incentive per CDOT specifications
- Concrete was placed in 100 F (38C) weather without problems

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Lehigh Cement Terminal
20,000 Ton Silo, 2010

- In Leeds, Alabama
- Slip-formed silo made with PLC (10%) and 40% slag
- Three concentric silos all slip-formed
- Mix used 10% limestone blended cement meeting ASTM C1157 HE (clinker was Type II low-alkali)

Data from Gary Knight and Colleagues

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80 foot (24 m) diameter x
240 feet (72 m) high

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Three concentric silos
Outer wall 33 in. (0.84 m) thick at bottom

Concrete Mixture for slip Form	PCY	kg/m3
C1157-HE PLC	420	250
Slag	280	167
Sand	1202	716
Stone	1856	1106
Water	275	164
w/cm	0.39	0.39

Water-reducer and HRWR used

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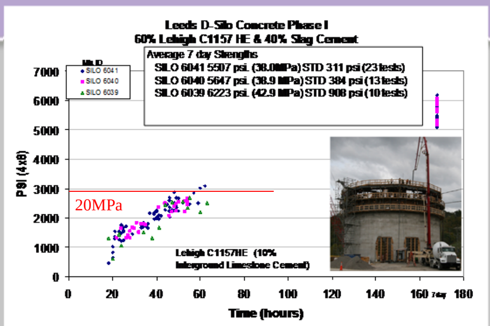
Early-age and 7-Day Strengths



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Summary

- Portland-Limestone cements have been used successfully in numerous pavements, in a barrier wall and in a large slip-formed silo.
- PLC works well with slag and fly ash at typical cement replacement levels.
- PLC provides a 10% reduction in CO_2 emissions from cement plants and reduce the carbon footprint of concrete by an additional 10% without affecting performance.
- Use of PLC should not affect concrete properties or construction practices.

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Portland-Limestone Cement Makes "Greener" Concrete

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