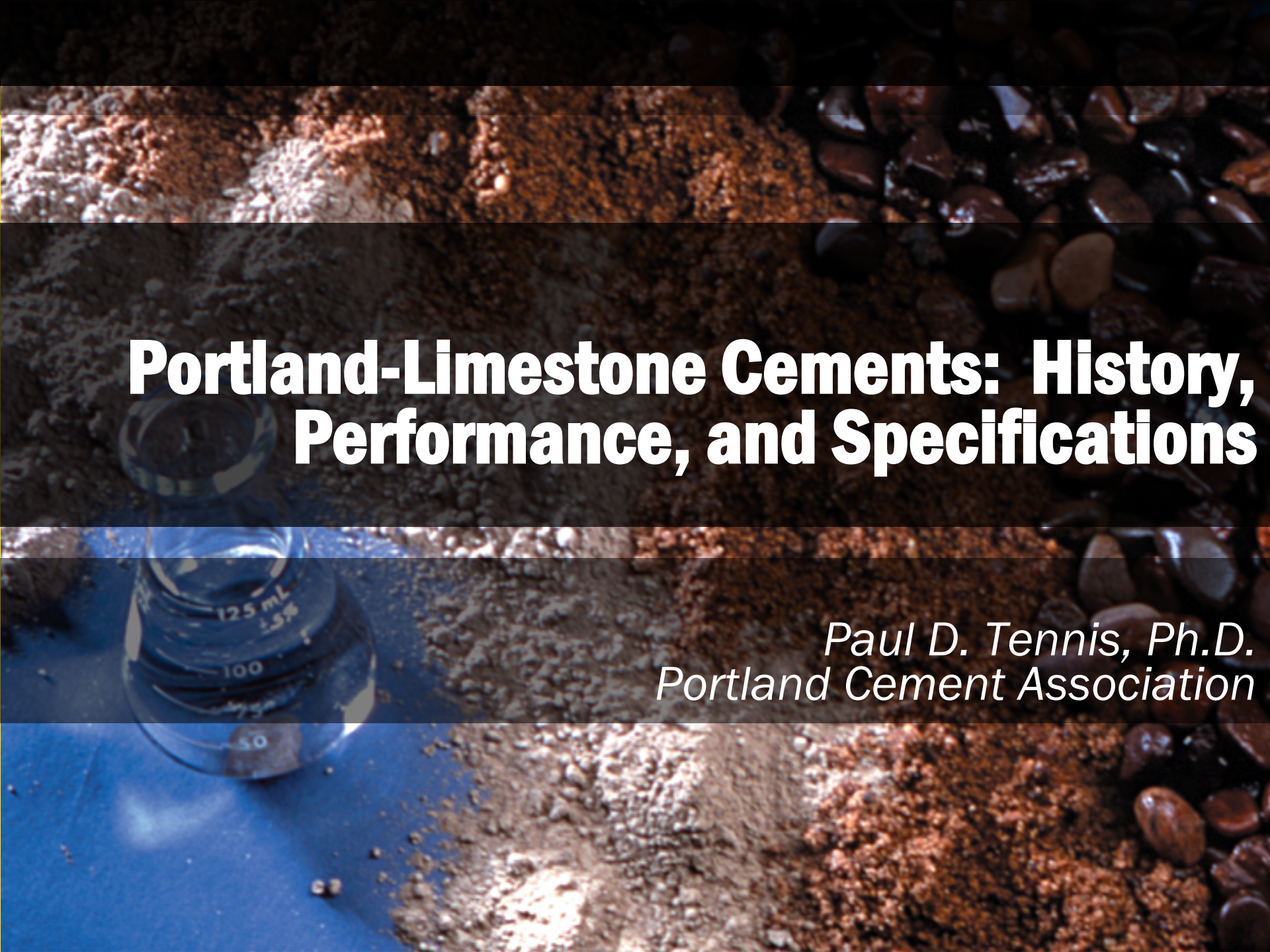


Portland-Limestone Cements: History, Performance, and Specifications

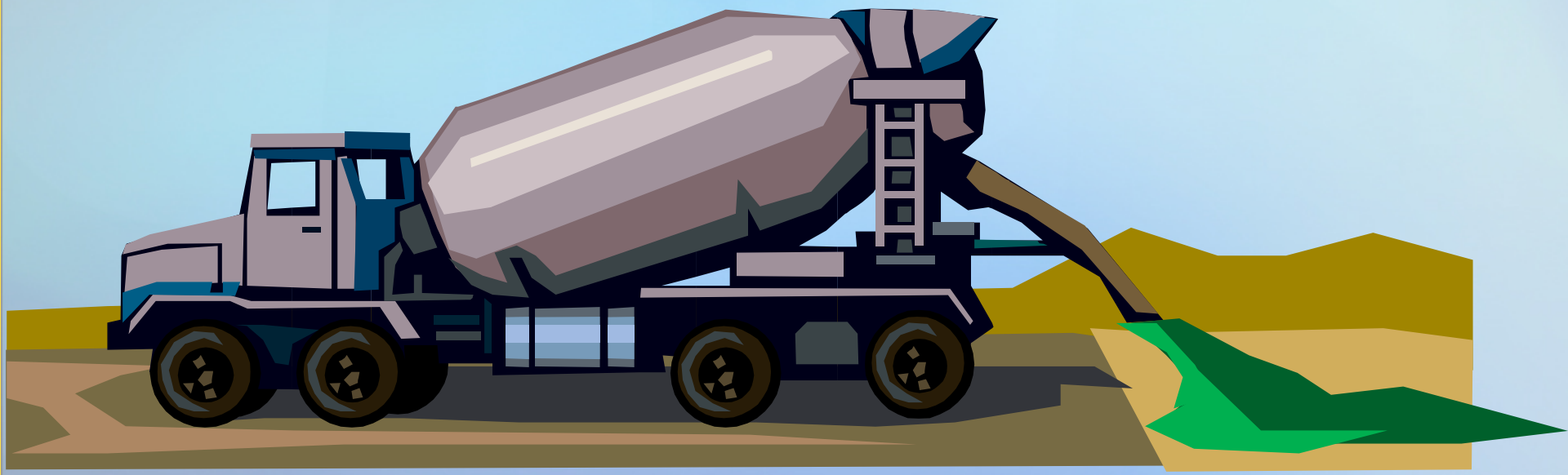
Paul D. Tennis, Ph.D.
Portland Cement Association

Today's Objectives

- What is a portland-limestone blended cement
- History
- Environmental performance
- *Concrete performance*
- Changes to the specifications

Portland-Limestone Cement

- Why? Provides an option to implement proven technology to obtain desired performance and improve sustainability of concrete



What is Portland-Limestone Cement?

- ASTM C595 and AASHTO M 240 Blended Cement
- Type IL or Type IT with limestone
- 5% to 15% limestone

HISTORY

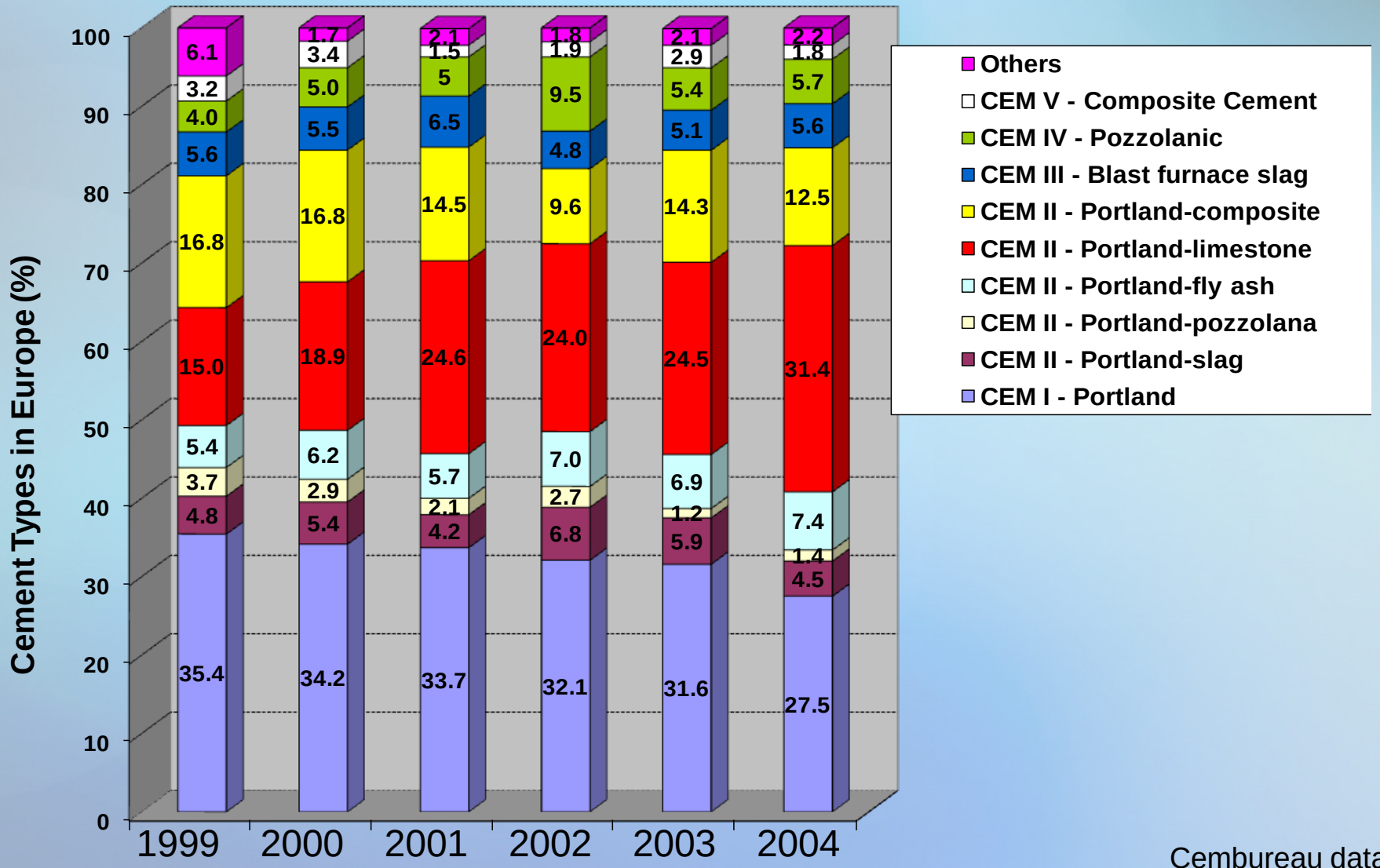
History of Limestone in Cements

- 1965 Cement with 20% limestone in Germany for specialty applications
- 1979 French cement standards allows limestone additions.
- 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,

History of Limestone in Cements

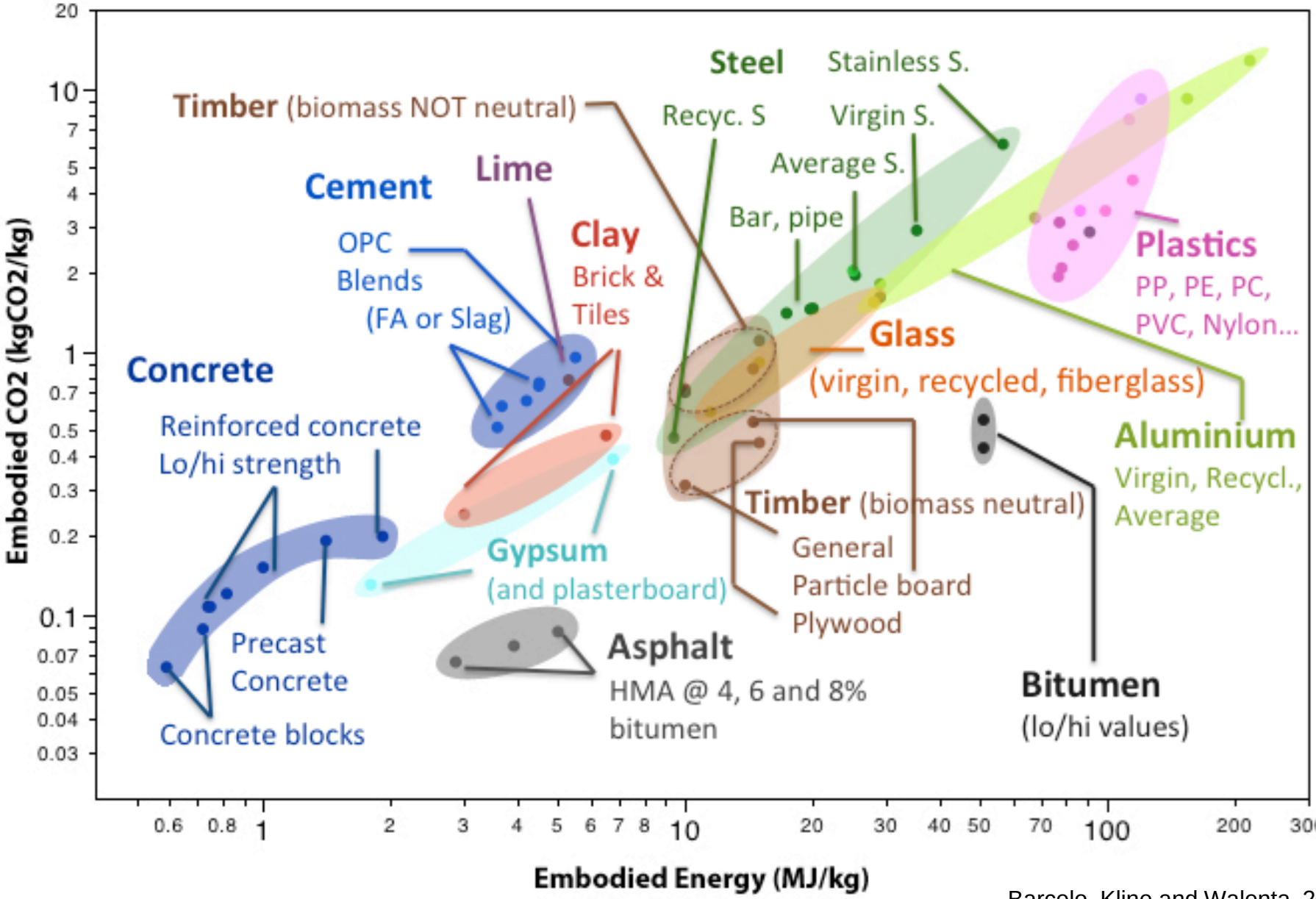
- 2000 EN 197-1 creates CEM II/A-L (6-20%) and CEM II/B-L (21-35%)
- 2004 ASTM C150 allows 5% in Types I-V
- 2006 CSA A3001 allows 5% in other Types than GU
- 2007 AASHTO M85 allows 5% in Types I-V
- 2008 CSA A3001 includes PLC containing 5%-15% limestone

European Cement Use

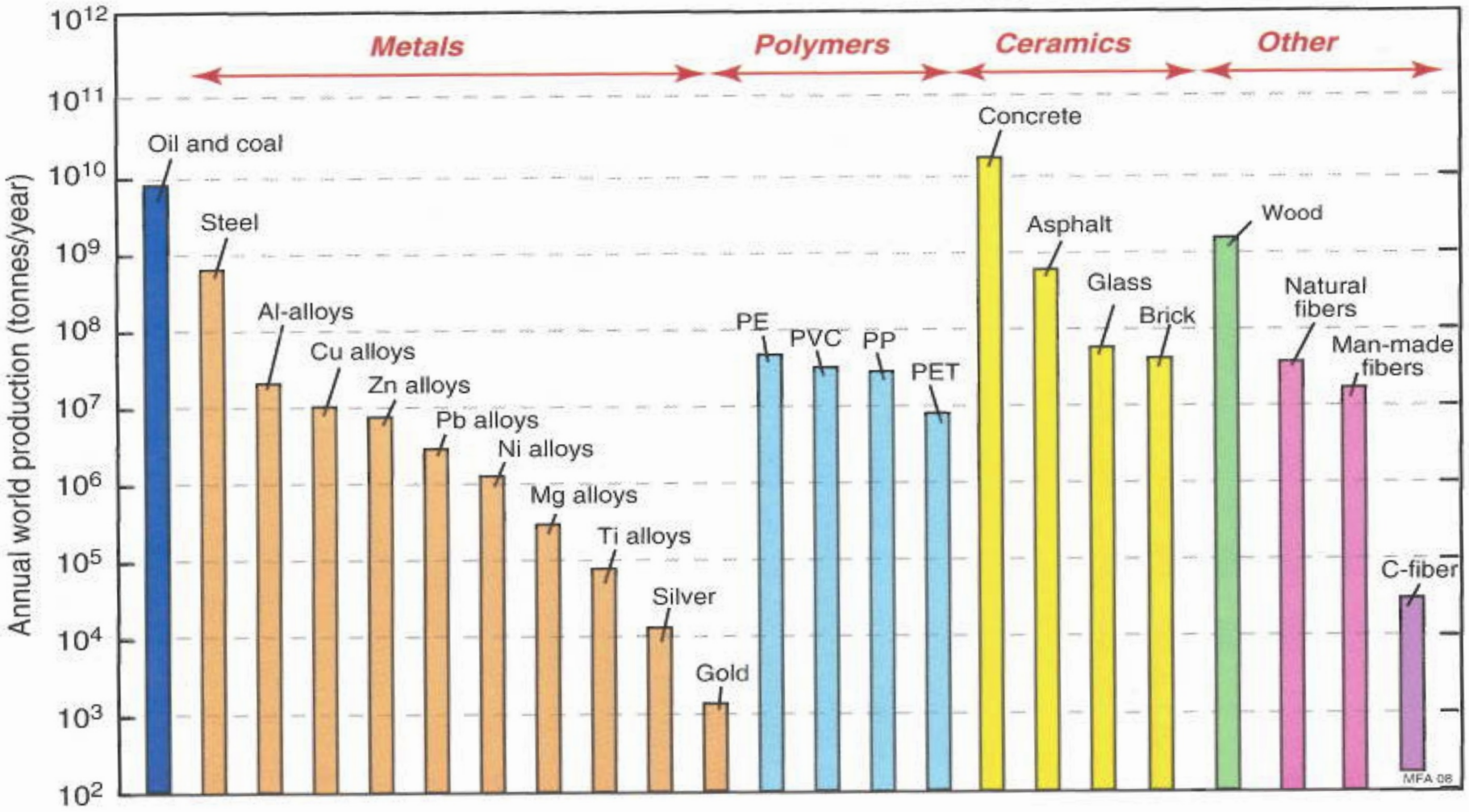


Cembureau data

ENVIRONMENTAL BENEFITS

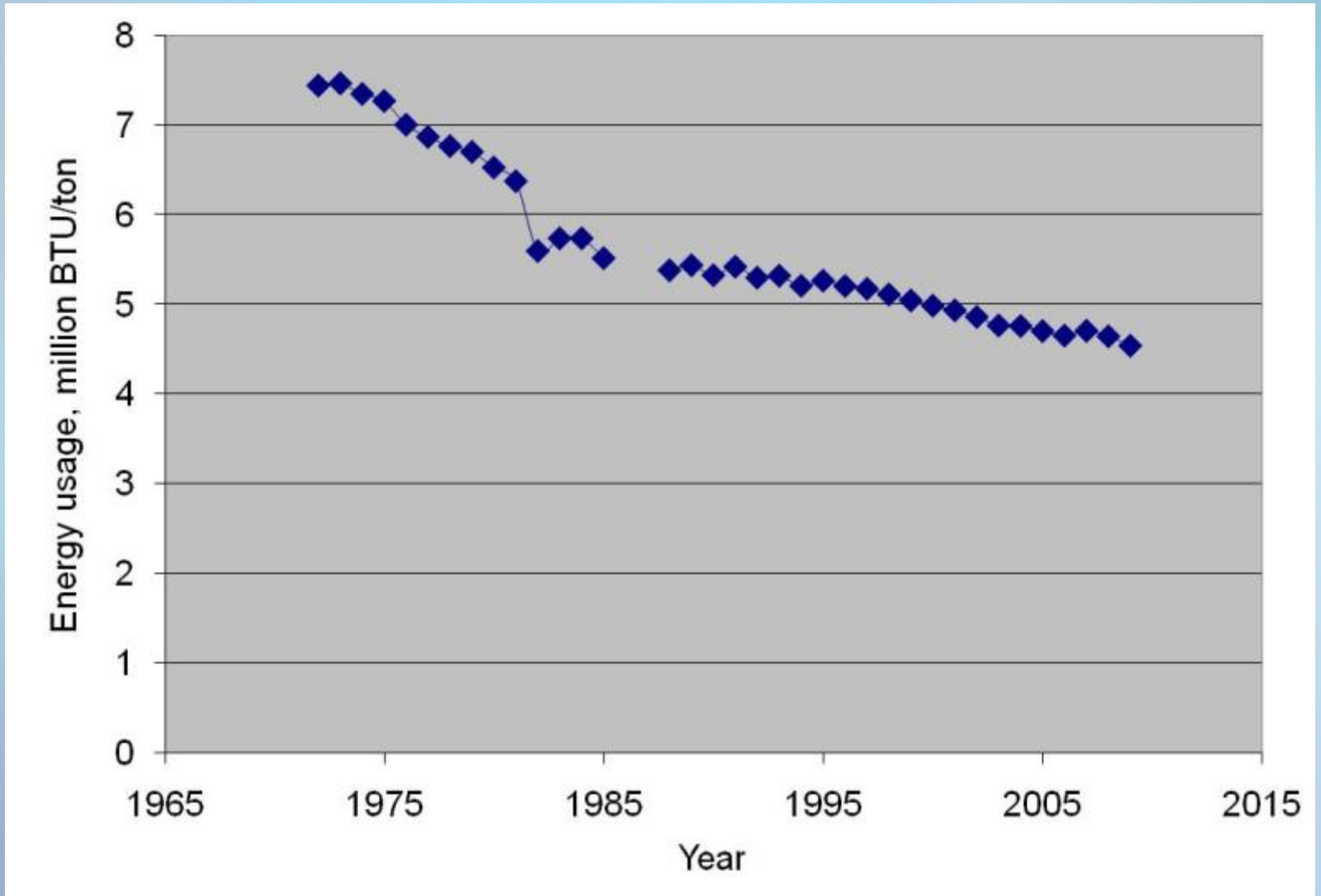


Barcelo, Kline and Walenta, 2012



from Ashby (2009)

Energy to Produce Cement

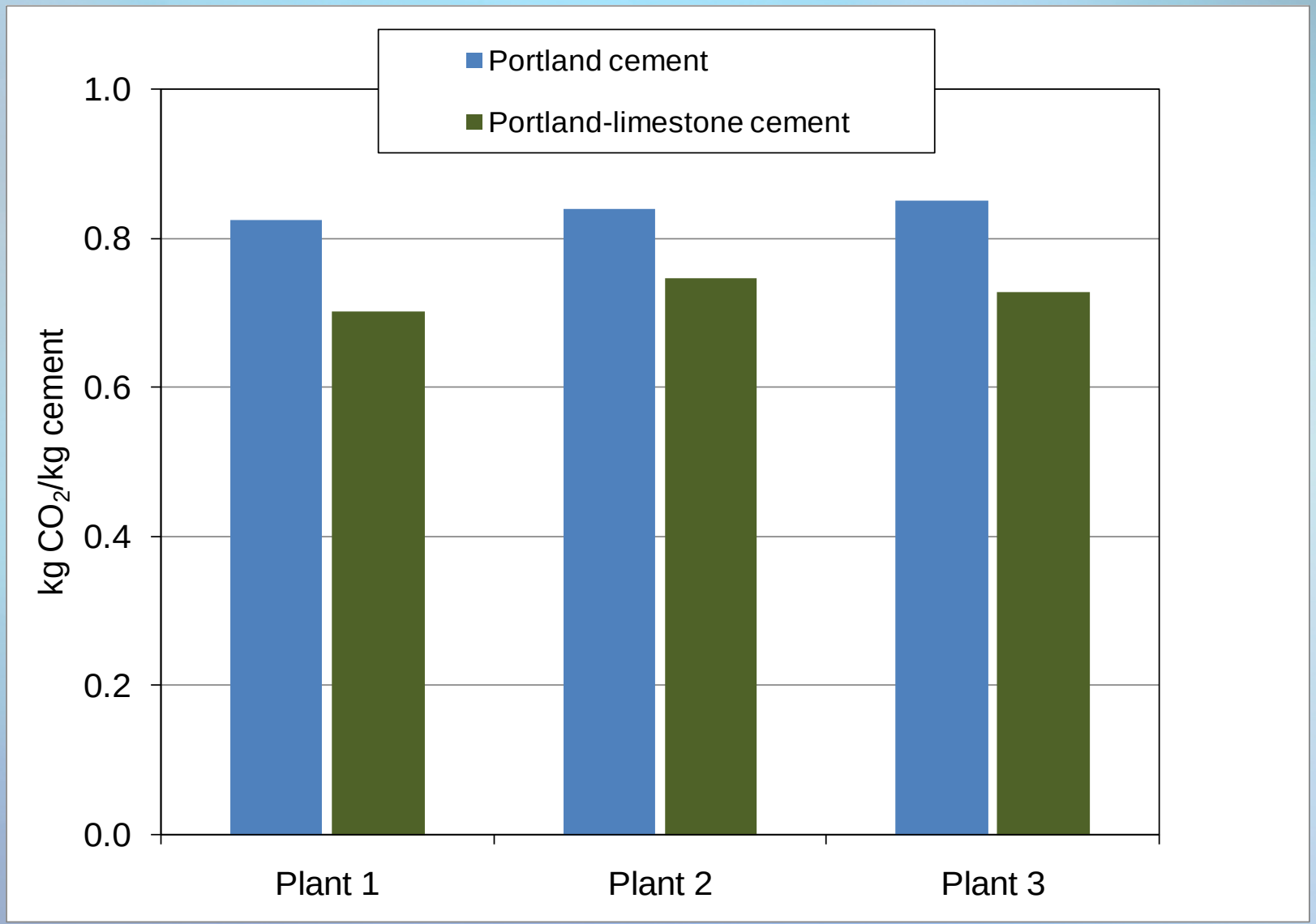


Environmental Benefits

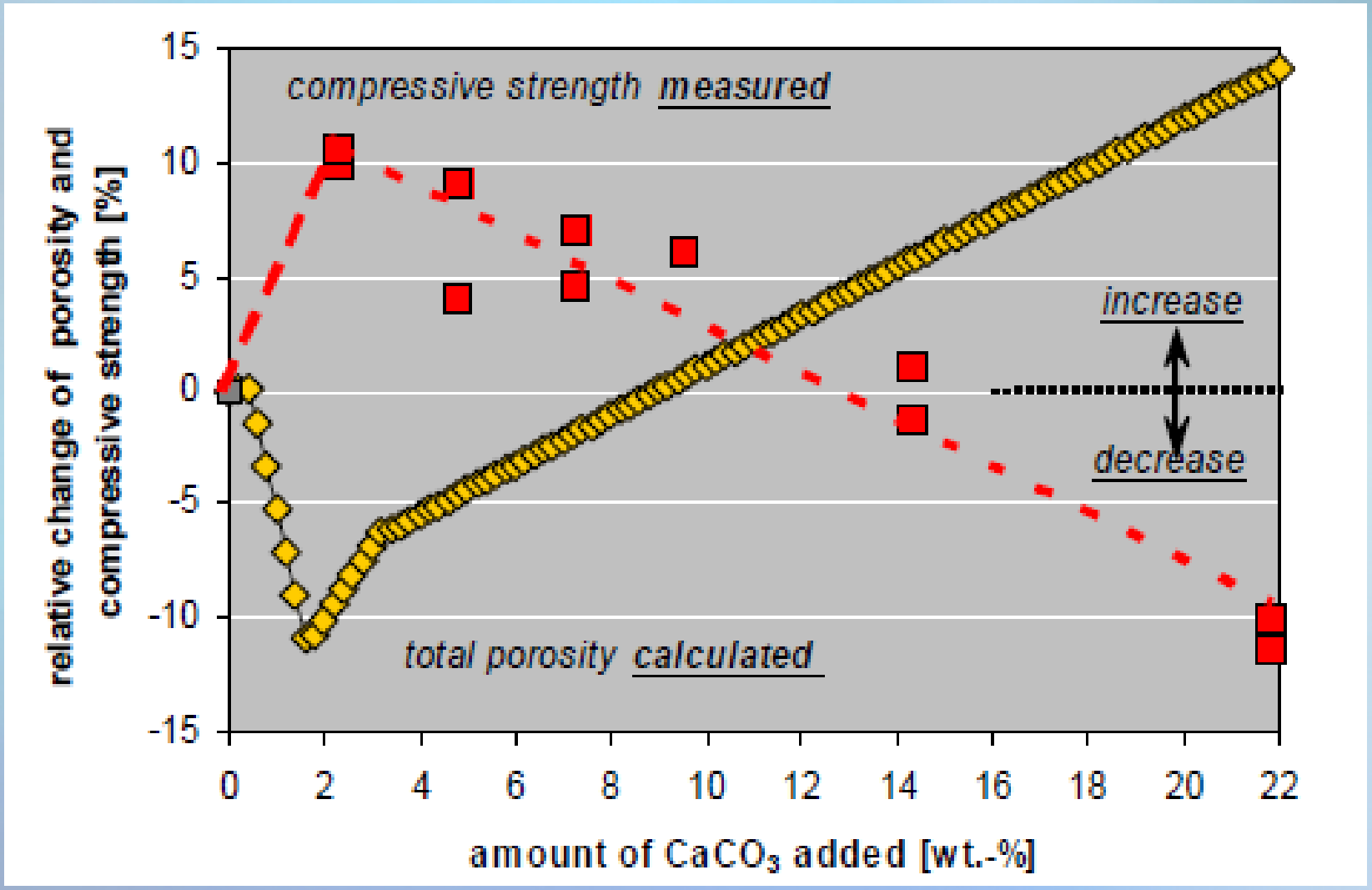
	10%	15%
Energy Reduction*		
Fuel (million BTU)	443,000	664,000
Electricity (kWh)	6,970,000	10,440,000
Emissions Reduction*		
SO_2 (lb)	581,000	870,000
NO_X (lb)	580,000	870,000
CO (lb)	104,000	155,000
CO_2 (ton)	189,000	283,000
Total hydrocarbon, THC (lb)	14,300	21,400

* Per million tons cement

Environmental Benefits

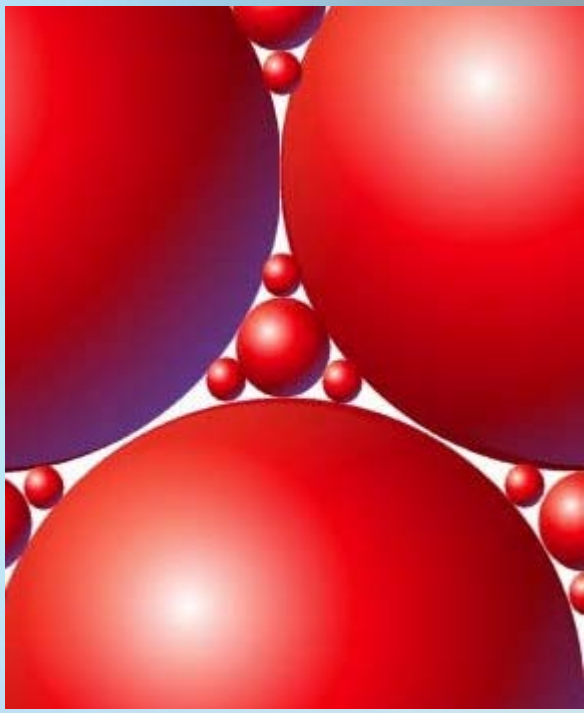


Why 15%?


compressive strength measured
total porosity calculated
increase
decrease
relative change of porosity and compressive strength [%]
amount of CaCO3 added [wt.-%]
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
22

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 distr
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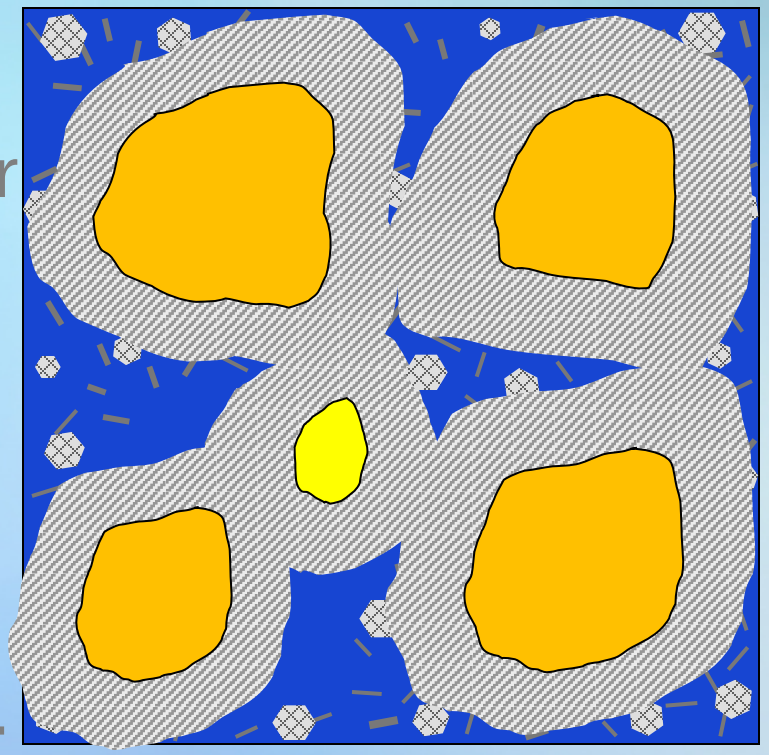
  - Surfaces for precipitation
- Chemical reactions
  - Only a small amount, but…



How Limestone Works

- Particle packing
  - Improved particle size distribution
- Nucleation
  - Surfaces for precipitation
- Chemical reactions
  - Only a small amount, but…

Ca^{2+} $CaOH^{+}$

$HSiO_3^{-}$ SO_4^{2-}

CO_3^{2-}

ASTM AND AASHTO UPDATES

Process

- JAAHTG reviewed concept January 2010
  - Technical information from Europe and Canada considered
- Presented concept to AASHTO TS3a and ASTM C01.10 summer 2010
- TS3a ballot in 2011; SOM ballot December 2011.
- C01.10 ballot April 2011; C01 ballot October 2011
- Ballot items passed; 2012 AASHTO M240 and ASTM C595 published

AASHTO M240 & ASTM C595 Requirements

- **Type IL**—Portland-limestone blended cement
  - Example: Type IL(10) = 10% limestone
- **Type IT**—Ternary blended cement with limestone
  - Example 1: Type IT(L12)(P10) = 12% limestone and 10% pozzolan
  - Example 2: Type IT(S15)(L10) = 15% slag and 10% limestone
- Limestone content 5% to 15%

AASHTO M240 & ASTM C595 Requirements

- Same physical requirement as existing C595/M240 cement types
- Chemical requirements – sulfate content, LOI
- Sulfate resistance – no MS or HS in initial specifications
- Limestone characteristics– $CaCO_3$, MBI, TOC

	IP IS (<70) **IL** IT(P≥S) **IT(P>L)** **IT(L≥S)** **IT(L≥P)** **IT(L<S<70)** IT(P<S<70)	IS (< 70) (MS), IT(P<S<70)(MS) IP(MS), IT(P≥S)(MS)	IS (< 70) (HS), IT(P<S<70)(HS) IP (HS), IT(P≥S)(HS)	IS(≥70), IT(S≥70)	IP(LH), **IL(LH),** IT(P≥S)(LH) **IT(L<S<70)(LH)** **IT(P>L)(LH)** **IT(L≥S)(LH)** **IT(L≥P)(LH)**
Fineness	C	C	C	C	C
Autoclave exp, max, %	0.80	0.80	0.80	0.80	0.80
Autoclave contr, max %	0.20	0.20	0.20	0.20	0.20
Vicat test: minutes, not less than hours, not more than	45 7	45 7	45 7	45 7	45 7
Air content of mortar, volume %	12	12	12	12	12

	IP IS (<70) **IL** IT(P≥S) **IT(P>L)** **IT(L≥S)** **IT(L≥P)** **IT(L<S<70)** IT(P<S<70)	IS (< 70) (MS), IT(P<S<70)(MS) IP(MS), IT(P≥S)(MS)	IS (< 70) (HS), IT(P<S<70)(HS) IP (HS), IT(P≥S)(HS)	IS(≥70), IT(S≥70)	IP(LH), **IL(LH),** IT(P≥S)(LH) **IT(L<S<70)(LH),** **IT(P>L)(LH)** **IT(L≥S)(LH)** **IT(L≥P)(LH)**
Compressive strength, min., MPa (psi):					
3 days	13.0	11.0	11.0	...	...
	(1890)	(1600)	(1600)	...	...
7 days	20.0	18.0	18.0	5.0	11.0
	(2900)	(2610)	(2610)	(720)	(1600)
28 days	25.0	25.0	25.0	11.0	21.0
	(3620)	(3620)	(3620)	(1600)	(3050)
Heat of Hydration, max., kJ/kg (cal/g):					
7 days	290	290	290	...	250
	(70)	(70)	(70)	...	(60)
28 days	330	330	330	...	290
	(80)	(80)	(80)	...	(70)

	IP IS (<70) **IL** IT(P≥S) **IT(P>L)** **IT(L≥S)** **IT(L≥P)** **IT(L<S<70)** IT(P<S<70)	IS (< 70) (MS), IT(P<S<70)(MS) IP(MS), IT(P≥S)(MS)	IS (< 70) (HS), IT(P<S<70)(HS) IP (HS), IT(P≥S)(HS)	IS(≥70), IT(S≥70)	IP(LH), **IL(LH),** IT(P≥S)(LH) **IT(L<S<70)(LH),** **IT(P>L)(LH)** **IT(L≥S)(LH)** **IT(L≥P)(LH)**
Water req. max %	...	...	...	...	64
Drying shrinkage, max, %	...	...	...	...	0.15
Mortar expansion, max, %:					
14 days	0.020	0.020	0.020	0.020	0.020
8 weeks	0.060	0.060	0.060	0.060	0.060
Sulfate resistance, expansion, max, %:					
at 180 d		0.10	0.05		
at 1 year			0.10		

Chemical Requirements for Blended Cements

Cement Type	IS(< 70), IT(P<S<70), IT(L<S<70)	IS(≥70), IT(S≥70)	IP, IT(P≥S), IT(P>L)	IL IT(L≥S), IT(L≥P)
MgO, max, %	. . .	. . .	6.0	. . .
SO_3, max, %	3.0	4.0	4.0	**3.0**
S^{2-}, max, %	2.0	2.0	...	. . .
Insol. res. max, %[C]	1.0	1.0	...	. . .
LOI, max, %	3.0[D]	4.0[D]	5.0[D]	**10.0**

[C] Insol res max does not apply to ternary blended cements.

[D] For ternary blended cements with limestone LOI max = 10%.

Requirements for *Limestone* for Use in Blended Cements

	Test Method	Limit
$CaCO_3$ content	C114/T105	Min. 70%
Methylene blue index	See Annex A2	Max. 1.2 g/100g
Total organic carbon	See Annex A3	Max. 0.5%

Limestone Testing

A2. METHYLENE BLUE INDEX TEST FOR LIMESTONE

A2.1 Scope

A2.1.1 This annex describes the laboratory procedures for the quantitative determination of methylene blue dye adsorption index of limestone for use as an ingredient in blended cement.

A2.1.2 The text of this annex references notes and footnotes which provide (excluding those in tables and figures) shall not be considered as requirements of

A2.1.3 *Units*—The values stated in SI units are to be regarded as standard. this annex.

A2.1.4 *This annex does not purport to address all of the safety concer responsibility of the user of this standard to establish appropriate safety and he regulatory limitations prior to use.*

A2.2 Summary of test

A2.2.1 The sample is reduced to a fine powder prior to testing. Increme successively to a suspension of the prepared test portion in water. The adsorptic after each addition of solution by carrying out a stain test on filter paper to dete of free dye is confirmed, the methylene blue index value (*MBI*) is calculated and of the sample tested.

A2.3 Significance and Use

A2.3.1 This annex provides a means to determine the amount of methylene l limestone. Methylene blue dye is preferentially adsorbed by clay minerals that m adsorbed is related to the clay type and content. Certain clays may increase t cements if present in sufficient quantity in the limestone when used an ingredien the methylene blue index of limestone permitted as an ingredient in blended ceme

A2.4 Apparatus

A2.4.1 The equipment and materials, including the temperature and humidity water, shall meet the requirements of C511, unless otherwise specified.

A2.4.2 The following equipment shall be included to perform this test:

(a) burette, with capacity of either 100 mL or 50 mL and graduation of either micro-pipette;

A3. TOTAL ORGANIC CARBON CONTENT OF LIMESTONE

A3.1 Scope

A3.1.1This annex specifies the laboratory procedures for the quantitative determination of the total organic carbon content of limestone for use as an ingredient in blended cement.

A3.1.2 The text of this annex references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the annex.

A3.1.3 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this annex.

A3.1.4 *This annex does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

A3.2 Summary of test

A3.2.1 Total organic carbon is determined either on a sample from which the inorganic carbon has been removed through hydrochloric acid extraction or by difference of inorganic carbon from total carbon.

A3.3 Significance and Use

A3.3.1 This annex provides a means to determine the total organic carbon content of a sample of finely ground limestone. The organic carbon content of a limestone used as an ingredient in cement may increase the air-entraining agent dosage required to achieve a specific air content in concrete. The specification places a limit on the total organic carbon content of limestone permitted as an ingredient in blended cement.

A3.4 Apparatus

A3.3.1 The equipment shall meet the requirements of Specification C 511, unless otherwise specified.

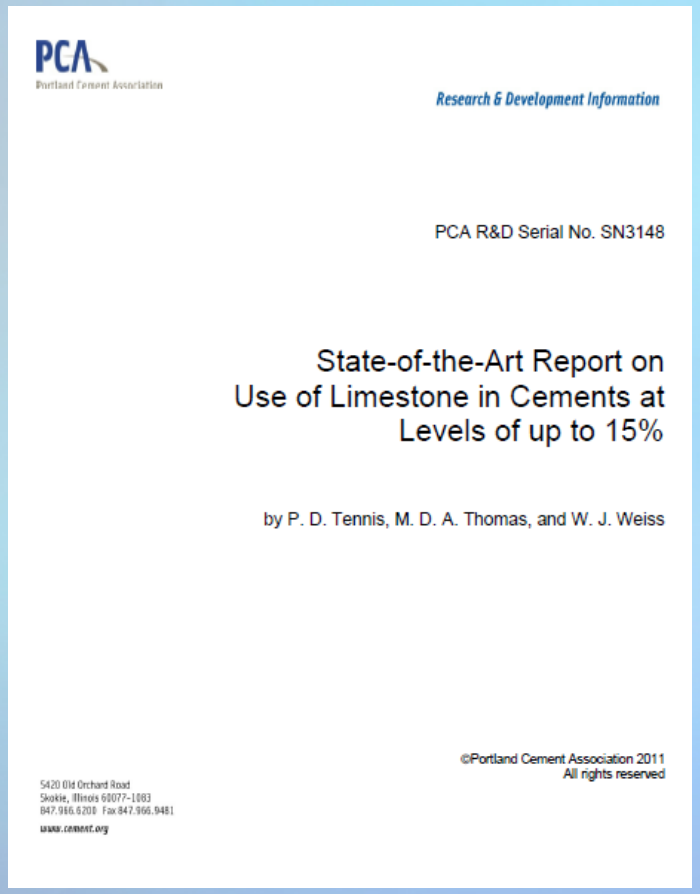
A3.3.2 The following equipment shall be included to perform this test:

(a) analytical balance, precision = 0.1 mg;
(b) beaker, 800 mL;
(c) vacuum flask, 1000 mL;
(d) glass frit, 40 mm diameter, and porosity = G4;
(e) magnetic stirrer;
(f) magnetic stir bar;
(g) oven, able to maintain a temperature of 45°C ± 5 °C;
(h) mortar and pestle made of agate

Summary

- Portland-limestone blended cements
  - 5% to 15% limestone
  - History of use: Europe, Canada, US
  - Mechanisms
  - An option to make greener concrete

Additional information



PCA
Portland Cement Association

Research & Development Information

PCA R&D Serial No. SN3148

State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%

by P. D. Tennis, M. D. A. Thomas, and W. J. Weiss

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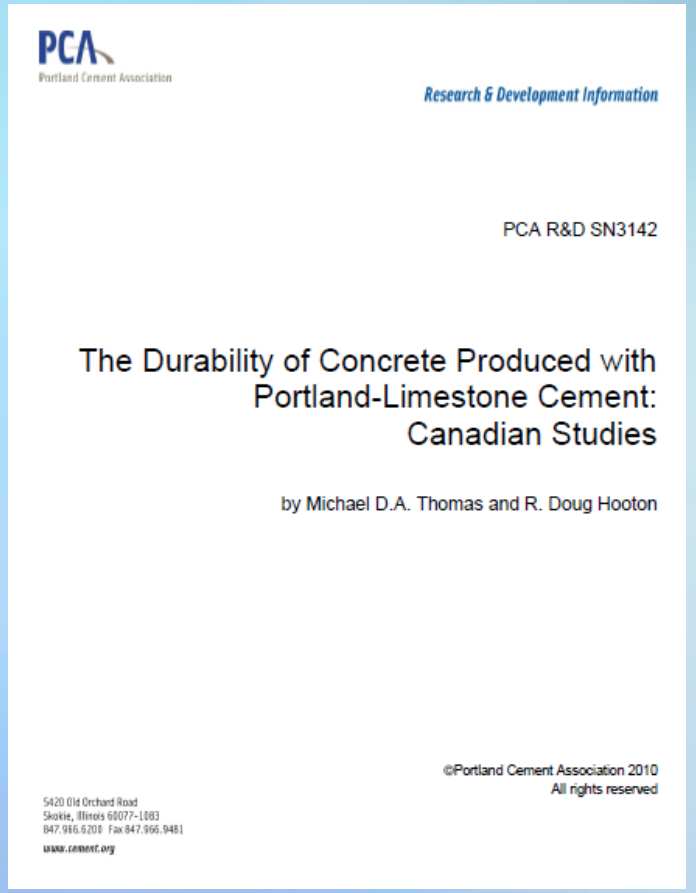
5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9481
www.cement.org



PCA
Portland Cement Association

Research & Development Information

PCA R&D SN3142

The Durability of Concrete Produced with Portland-Limestone Cement: Canadian Studies

by Michael D.A. Thomas and R. Doug Hooton

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5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9481
www.cement.org

PTennis@cement.org

Thank you!

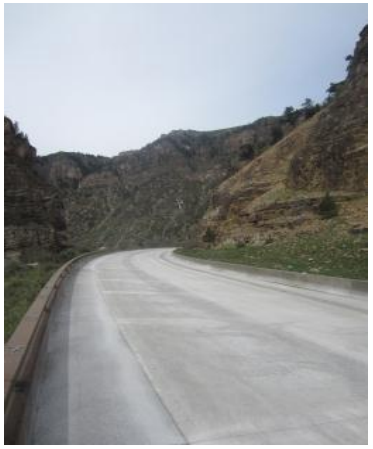
North American PLC Pavements
Field Applications in Canada, Utah and Colorado

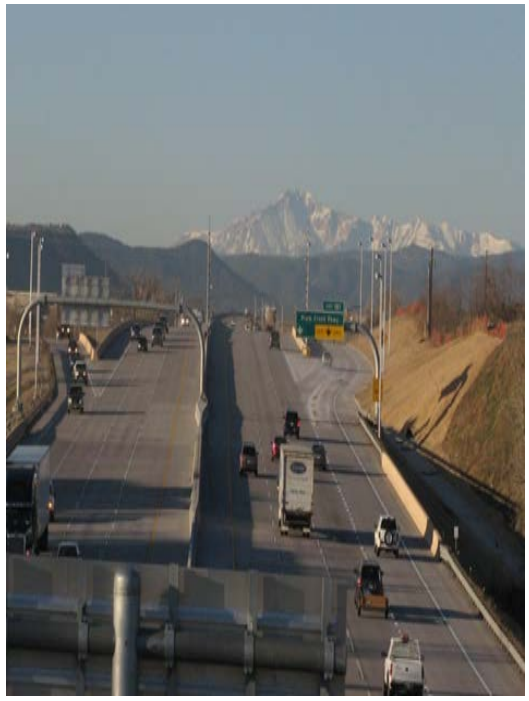
Todd Laker, Holcim (US) Inc.

Brooke Smartz, Holcim (US) Inc.

Portland-Limestone Cement Paving Projects

- +125 miles of concrete paving in Colorado and Utah





Performance and Environmental Benefit

CDOT and UDOT Specifications

- Allow portland-limestone cements that meet ASTM C1157 performance specification for GU (General Use), MS (Moderate Sulfate Resistance) and HS (High Sulfate Resistance)
- Supplementary cementitious materials required for applications that require resistance for sulfate attack and/or alkali silica reactivity for both ASTM C150 and ASTM C1157 cements

Verifying Portland Limestone Cement Durability

- Holcim ASTM C595 (Type IL) or ASTM C1157 cements are tested for durability performance. Tests generally include:
  - Fresh & Hardened concrete properties
    - Requirements are met through concrete mix design – ASTM
  - Sulfate Resistance - ASTM C1012
  - Alkali-Silica Reactivity - ASTM C1260/1567
  - Freeze Thaw & Deicer Scaling Resistance - ASTM C666 & C672
  - Shrinkage – ASTM C157
  - Chloride Ion Penetration – ASTM C1202

How do Portland-Limestone Cements compare?

ASTM Designation	PLC vs C150	PLC vs C150	PLC vs C150	PLC vs C150	PLC vs C150
Strength 28D (C39)	Equal	Better	Better	Better	Equal
Sulfate (C1012)	Equal	Equal	Equal	Equal	Equal
ASR (C1260/C1567)	Better	Equal	Equal	Equal	Equal
Freeze-Thaw (C666)	Equal	Equal	Equal	Equal	Equal
Deicer Scaling (C672)	Equal	Equal	Equal	Equal	Equal
Shrinkage (C157)	Equal	Equal	Equal	Equal	Equal
Permeability (C1202)	Slightly Better	Equal	Equal	Equal	Equal

How do Portland-Limestone cements perform in the field?

- Equal or improved to C150 cements
  - Strength
  - Set time
  - Water demand
  - Compatibility with fly ash
  - Compatibility with admixtures
- Improved finishability
- Lower environmental impact

Devil's Slide, Utah Cements

- Type V clinker
  - C_3A <5%
- ASTM C150 Type II/V
  - High sulfate resistance
    - C_3A <5%
  - <5% limestone per ASTM C150
  - Naeq <0.60%
- ASTM C1157 Type GU/MS
  - General use/Moderate sulfate resistance
    - ASTM C1012, sulfate performance test
  - 10% limestone

Utah PLC Case Studies

Performance & Lower Environmental Impact

Lost Creek Road Morgan, Utah

- Rural County Road
  - Constructed 2009
  - Major Truck Traffic
  - Construction Limitations
  - Mountain weather issues
- Performance System
  - 10% Limestone Cement
  - 20% Class F fly ash
- Compressive strength
  - design 4000 psi, average 5120 psi
- Flexural strength
  - design 650 psi, average 720 psi

104th South, Salt Lake City, Utah

- Pooled Fund Ternary Study (2009)
  - University of Utah* (Tikalsky)
  - 10% Limestone Cement
  - 25% Class F Fly ash
- Single days production
- Control Section Strength*
  - Compressive 4454 psi
  - 28Day
- Actual Test Section Strength*
  - Compressive 5396 psi
  - 28Day

SR 201, Salt Lake City, Utah

- Eastbound lanes paved August 2009 with ASTM C150 Type II/V
- Westbound lanes paved October 2009 with ASTM C1157 10% portland-limestone cement
  - Both mixes contained 25% Class F fly ash
- Eastbound Strength
  - Compressive ~5000 psi
  - Average Concrete Temp ~70 F
- Westbound Strength
  - Compressive ~4500 psi
  - Average Concrete Temp ~50 F

UTA FrontRunner South

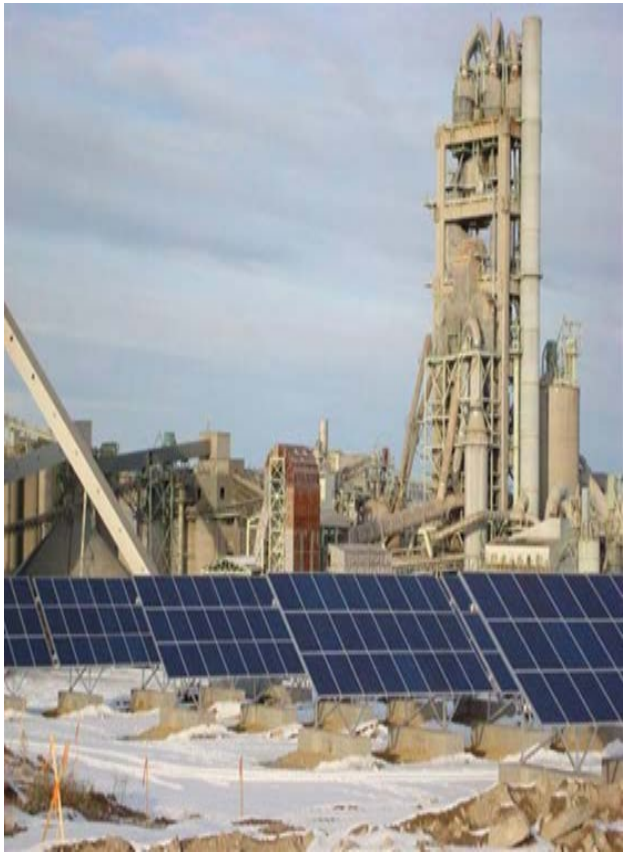
Salt Lake City to Provo, Utah

UTA FrontRunner South

Salt Lake City to Provo, Utah

- Keystone Concrete Masonry Units (CMU)
  - 10% Limestone Cement
  - 15% Class F Fly ash
- 350,000 square feet or retaining wall
- Block on the project Averages:
  - 28 day Compressive Strength 6,500 psi
  - Absorption of 5.3%
- 37 Foot Tall Retaining Wall
  - 55 block courses above grade
  - 10 block courses below grade

Portland, Colorado Cements



- Type II clinker
  - C_3A <8%
- ASTM C150 Type I/II
  - General use/Moderate sulfate resistance
    - C_3A <8%
  - <5% limestone per ASTM C150
  - Naeq >0.70%
- ASTM C595 Type IP(HS)
  - 25% Class F fly ash
- ASTM C1157 Type GU/MS
  - General use/Moderate sulfate resistance
    - ASTM C1012, sulfate performance test
  - 10% limestone

Colorado PLC Case Studies

Performance & Lower Environmental Impact

City of Denver Concrete Paving

40th & Havana and Holly Street

City of Denver Concrete Paving

- Aligns with Denver Greenprint Program
- 40th & Havana - side by side comparison of ASTM C150 I/II and ASTM C1157 GU cements (2007)
  - 20% Class C fly ash
  - No noticeable performance differences
  - Winter construction
- Holly Street - Ready-mix concrete supply (2008)
  - 25% Class C fly ash

City of Denver Concrete Paving

Central Park Boulevard

DIA Pena Boulevard

US HW 287 Near Lamar, CO

US HW 287 Near Lamar, CO

- 7 Miles PCCP (2008)
  - Hot dry summer construction
- Ports to Plains US Highway route
  - Heavy truck traffic
- 20% Class F fly ash
- 695 psi average 28-day flexural strength
- Contractor received quality incentive per CDOT specifications
- Used in concrete paving on a regular basis in Colorado

US HW I-25 Near Castle Rock, CO

US HW I-25 Near Castle Rock, CO

- 5 Miles PCCP (2008)
- Major Interstate Highway
- 20% Class F fly ash
- 720 psi average 28-day flexural strength
- Contractor received quality incentive per CDOT specifications
- Used in concrete paving on a regular basis in Colorado

Canada PLC Case Studies

- http://www.mto.gov.on.ca/english/engineering/new-cement.shtml

QEW Barrier Wall GUL Trial

- First GUL use for a public wall section in Canada in 2009
- Various durability tests will be carried out at UofT
- Initial strength test results show comparable performance of GU and GUL
- GU & GUL AVS results similar
- RCPT similar in cylinder but GUL higher in core samples (@ 62d 1600 vs. 1400 C)
- Similar scaling test results

Concrete performance

	GU	GUL
1 d [MPa]	9.5	10.3
3 d [MPa]	19.3	19.4
7 d [MPa]	25.6/25.8	26.8/24.9
28 d [MPa]	36.9/36.0	37.9/34.7
56 d [MPa]	38.9	38.0
Slump [mm]	95	100
Air (P) [%]	7.8	6.4
AVS	0.104	0.103
Air (H) [%]	6.6	6.1

Cement Association of Canada

contempra
Cement engineered for a better tomorrow

Keep in mind…

- No cement or scm's can offset low quality concrete
- Durable concrete depends on:
  - Appropriate mixture proportions
  - Lower w/cm
  - Air entrainment in F/T conditions
  - Proper placement
  - Curing
  - Maintenance
- When good practices are followed, concrete will attain its expected service life

Summary

- Projects demonstrate concrete made with portland-limestone cements are readily constructible and can easily achieve specified strength requirements.
- Durability testing shows similar or improved performance to ASTM C150 cements
- Portland-limestone cements can provide performance and lower environmental impact

Over 125 miles of paving in Colorado and Utah

Performance & Lower Environmental Impact

Thank You!

Todd Laker, LEED AP
Holcim (US) Inc.
todd.laker@holcim.com or 801-829-2178
Brooke Smartz, LEED AP
Holcim (US) Inc.
brooke.smartz@holcim.com or 303-716-5288

Performance of PLC Concrete:
Fresh, Hardened and Durability Properties

Michael Thomas

University of New Brunswick

TRB Webinar: Portland Limestone Cement (PLC) - A Technology to Improve the Sustainability of Concrete Pavements – November 13, 2012

Portland Cement (PC) Manufacture

$CaCO_3$ (**limestone**)

$2SiO_2 \cdot Al_2O_3$ (clay, shale)

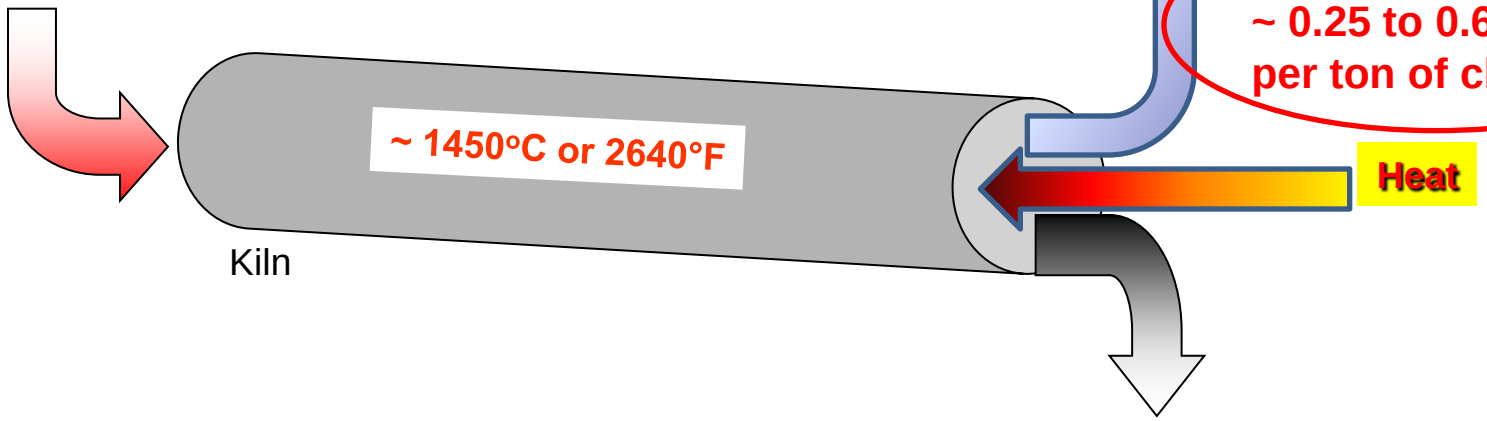
Fe_2O_3 (iron oxide)

SiO_2 (silica sand)

Calcination: $CaCO_3 \rightarrow CaO + CO_2$
~ 0.50 ton CO_2 per 1.0 ton of clinker

CO_2

Fuel:
~ 0.25 to 0.65 ton CO_2 per ton of clinker



$CaO \cdot SO_3 \cdot 2H_2O$

Gypsum + Clinker

- $3CaO \cdot SiO_2$
- $2CaO \cdot SiO_2$
- $3CaO \cdot Al_2O_3$
- $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$

interground

Finished cement

Cement production accounts for approximately 7% to 8% of CO_2 globally *(Mehta, 1998)* …

… and approximately 2.8% of CO_2 emissions in Canada *(Neitzert, 1997)*

Calcination: $CaCO_3 \rightarrow CaO + CO_2 \uparrow$ (gas)

60%

Energy: $C + O_2 \rightarrow CO_2 \uparrow$ (gas)

40%

www.cement.ca

Portland Limestone Cement (PLC) Manufacture

$CaCO_3$ (limestone)

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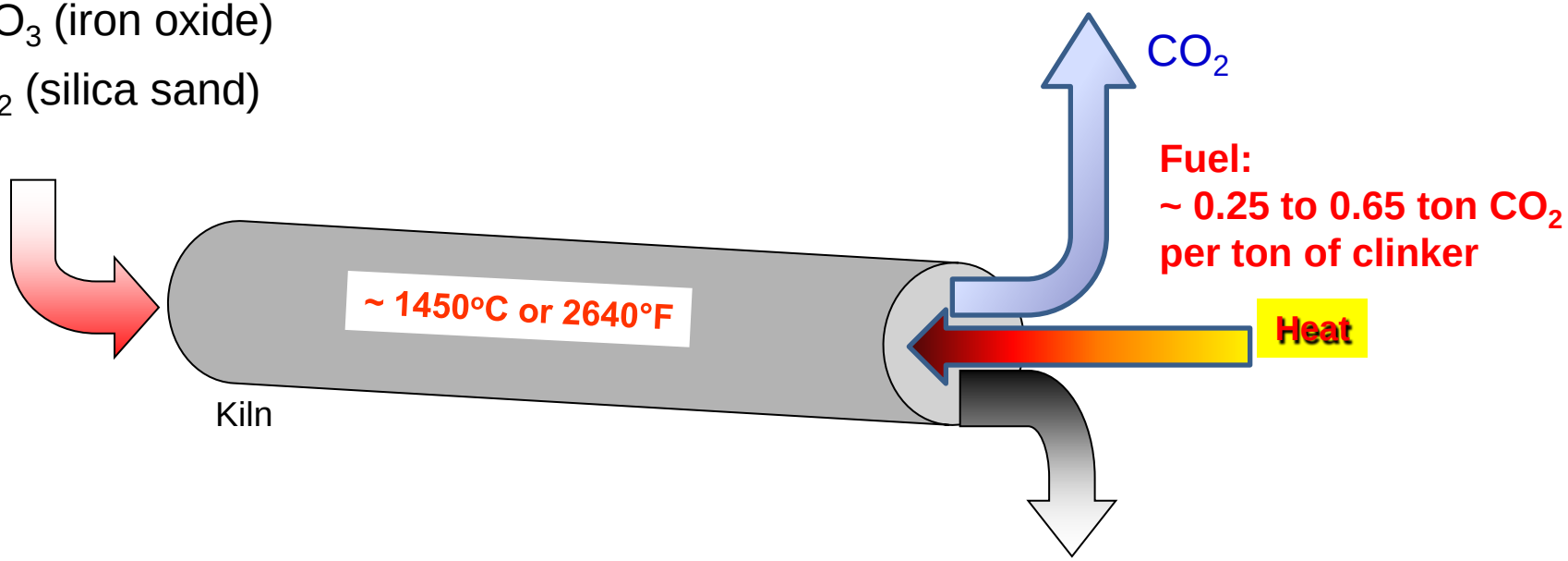


$CaCO_3$ Limestone + $CaSO_4 \cdot 2H_2O$ Gypsum + Clinker

- $3CaO \cdot SiO_2$
- $2CaO \cdot SiO_2$
- $3CaO \cdot Al_2O_3$
- $4CaO \cdot Al_2O_3 \cdot Fe_2O_3$

interground

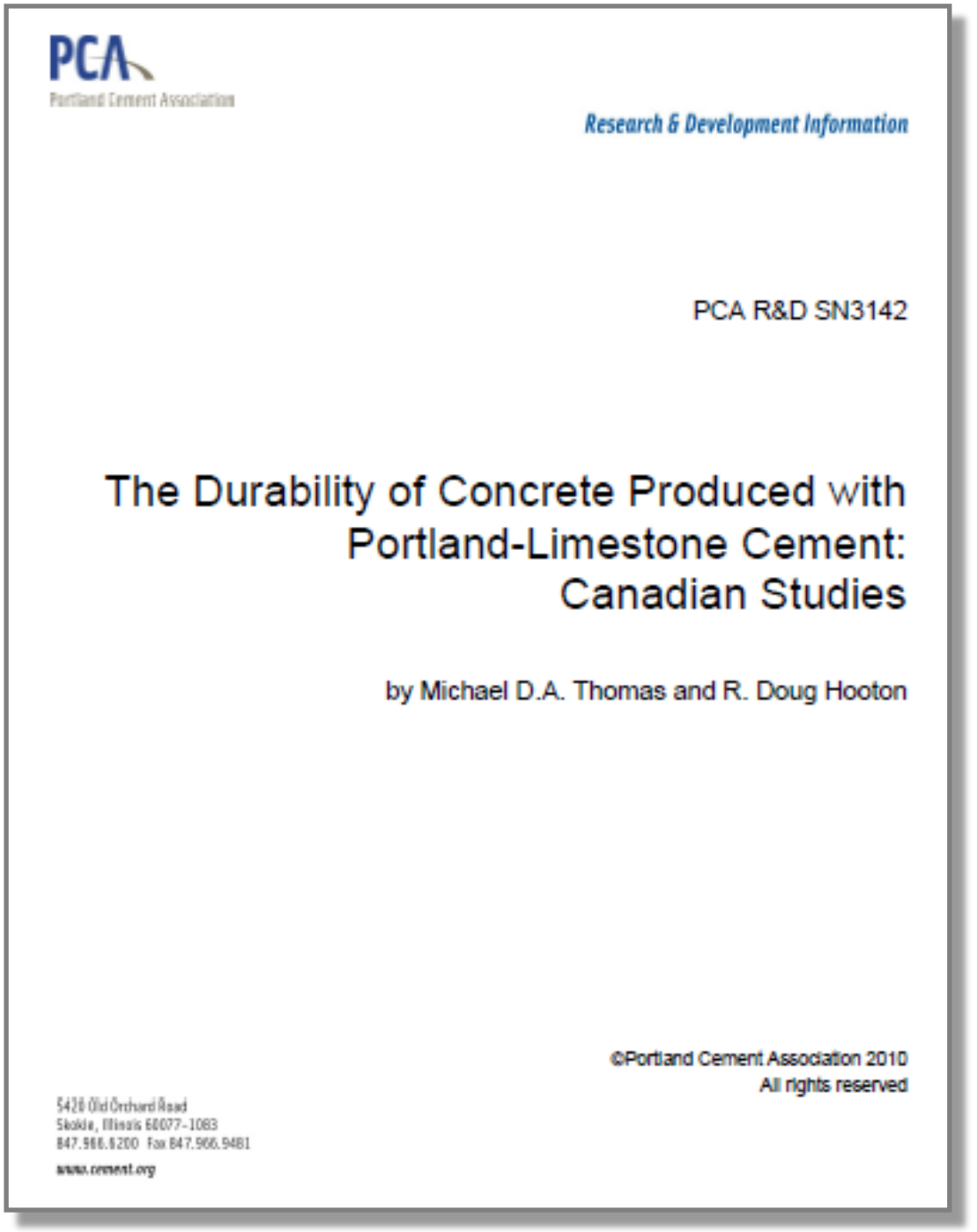
Finished cement

Tests carried out with Canadian materials: 2007-10

- Portland-limestone cements (PLC) were produced in different grinding circuits with various clinkers (C_3A from 4.5 to 12%) and limestones.
- Amount of limestone varied between 3 and 19% (to keep within limits, the real CSA PLC max. will be ~13%).
- Standard mortar tests and chemical analyses were performed on the different PLCs.
- Concrete with various w/cm ratio's 0.35 to 0.80 were produced. The cement contents in the mixed varied between 225 and 420 kg/m^3
- Concrete tests with different PLC's (10 to 22 %LS) and various amounts of slag (15, 25, 30%) and fly ash (20%) were performed
- Slump, slump retention and air were measured
- Durability tests were performed, e.g. RCP, freeze/thaw, salt scaling, shrinkage, sulfate resistance, and ASR
- Testing conducted by cement companies and universities
- **<u>Field trials</u>**

Durability of PLC Concrete: Canadian Studies

- PLC with up to 15% limestone - equivalent performance as portland cement from the same clinker
- Equivalent performance achieved by increasing Blaine by 100 to 120 m^2/kg
- Performance in this study was evaluated based on:
  - Strength
  - Resistance to freeze-thaw and de-icer salt scaling
  - “Chloride permeability” and chloride diffusion.
  - Alkali-silica reaction


PCA
Portland Cement Association

Research & Development Information

PCA R&D SN3142

The Durability of Concrete Produced with Portland-Limestone Cement: Canadian Studies

by Michael D.A. Thomas and R. Doug Hooton

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5420 Old Orchard Road
Skokie, Illinois 60077-1083
847.966.6200 Fax 847.966.9481
www.cement.org

CSA A3001-08 Types of Hydraulic Cement

Blended PLC – 2010 Amendment

Portland cement type	Blended hydraulic cement type*	Portland-limestone cement type†‡		Name§
GU	GUb	GUL	GULb	General use cement
MS	MSb	–	MSLb	Moderate sulphate-resistant cement
MH	MHb	MHL	MHLb	Moderate heat of hydration cement
HE	HEb	HEL	HELb	High early-strength cement
LH	LHb	LHL	LHLb	Low heat of hydration cement
HS	HSb	–	HSLb	High sulphate-resistant cement

New in 2008 →

*The suffix "b" indicates that the product is a blended hydraulic cement.
†The suffix "L" indicates that the product is portland-limestone cement.
‡Portland-limestone cements should not be used in an environment subjected to sulphate exposure as defined in Table 3 of CAN/CSA-A23.1.

PLC is produced to provide equivalent performance to PC in Canada

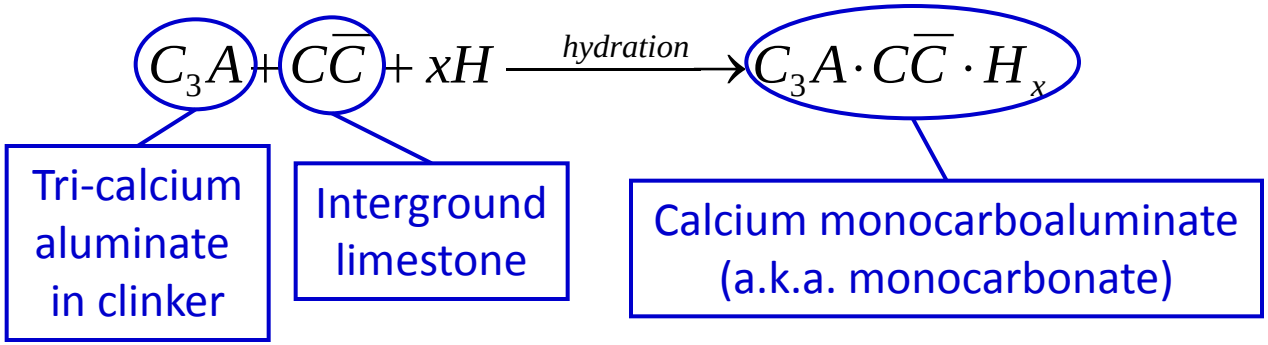
So requirements for Type GUL (up to 15% limestone) same as Type GU (< 5%)

CSA A23-09 Use of Portland Cement in Concrete

- Portland limestone cement is permitted for use in all classes of concrete except for sulfate exposure classes (S-1, S-2, S-3)

Beneficial Effects of Limestone Addition

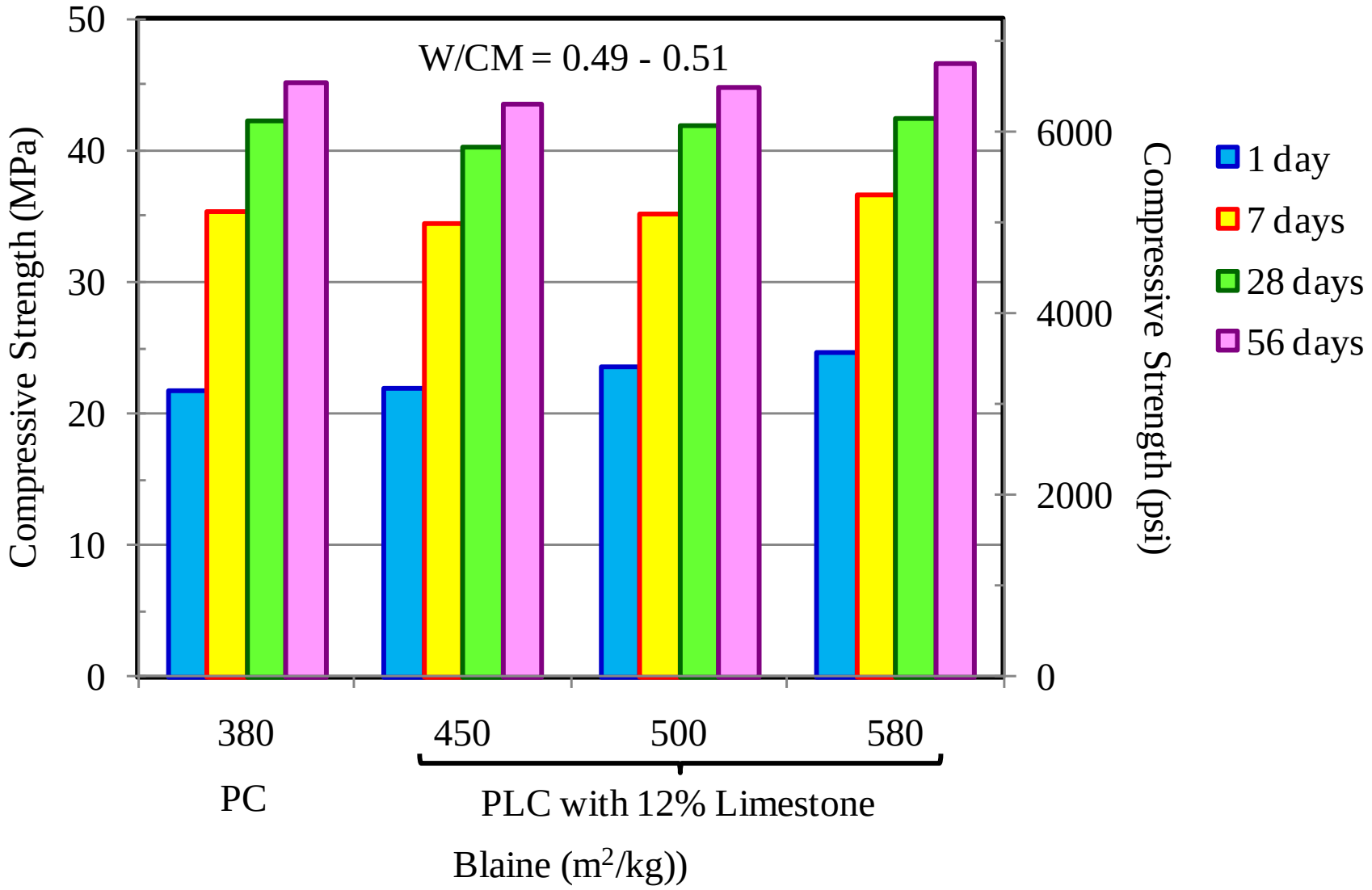
- Limestone (primarily $CaCO_3$) chemically reacts with C_3A to form carboaluminates—at least at replacements of 5-10%



Limestone is not totally inert !

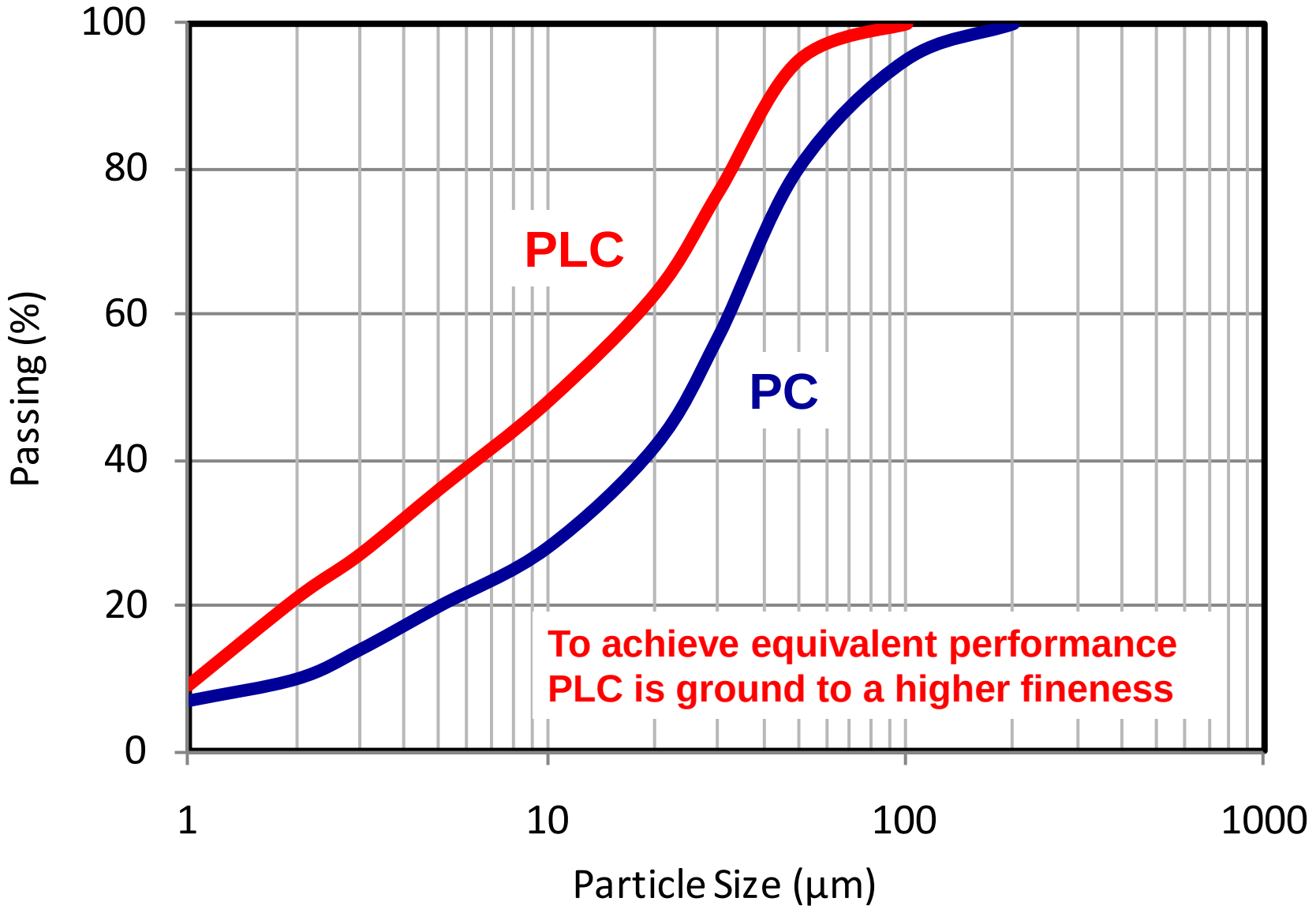
- Finer limestone particles fill the voids between clinker particles improving the grain packing of cement
- Fine limestone particles as nucleation sites for hydration products at early hydration ages accelerating the hydration and consequently improving the early strength

Effect of Fineness on Performance

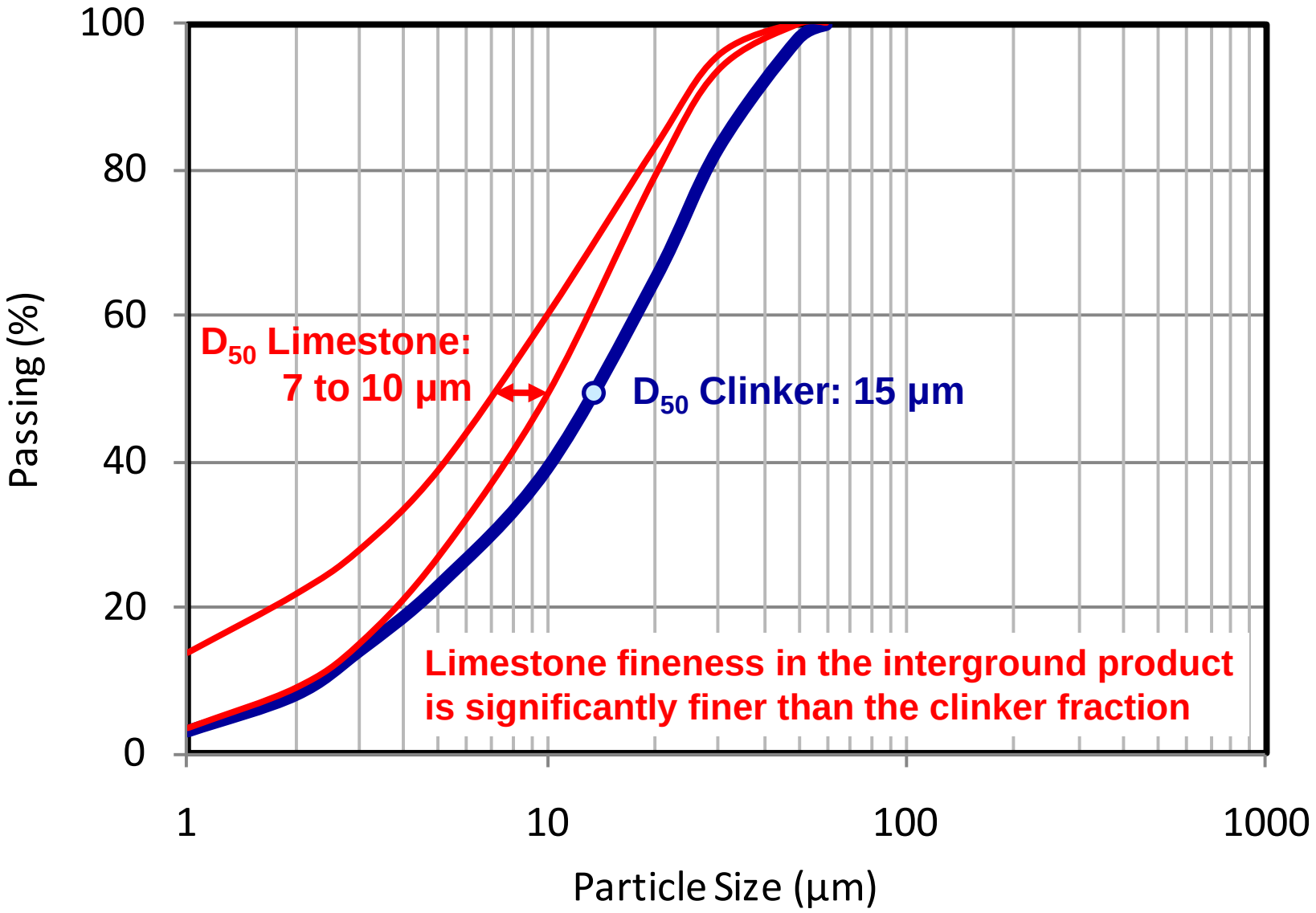


Testing in Canada indicates that the Blaine of PLC needs to be increased by approx 100 – 120 m^2/kg compared with PC to obtain equivalent performance

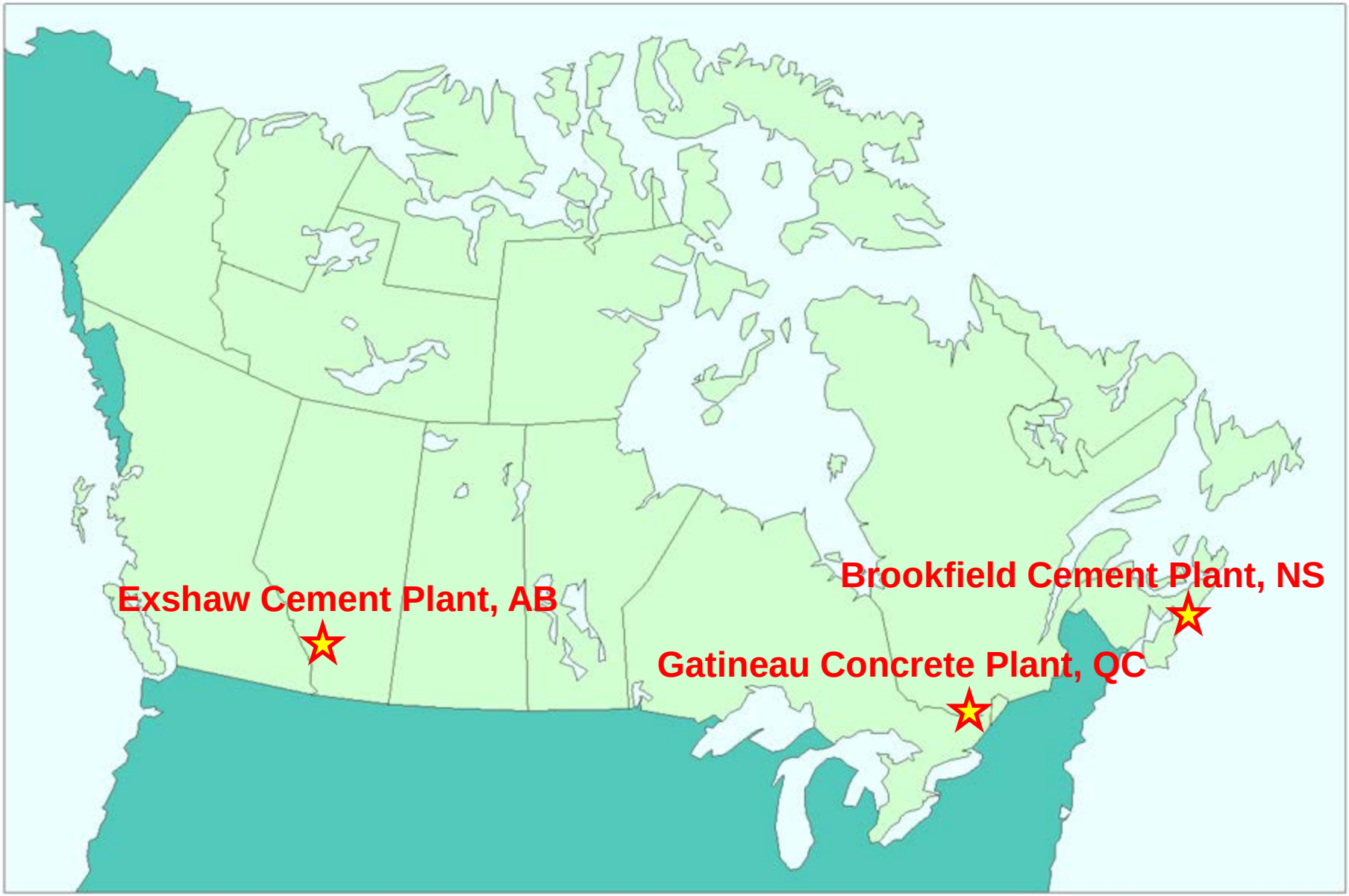
Fineness PLC vs. PC



Fineness in PLC: Clinker vs. Limestone

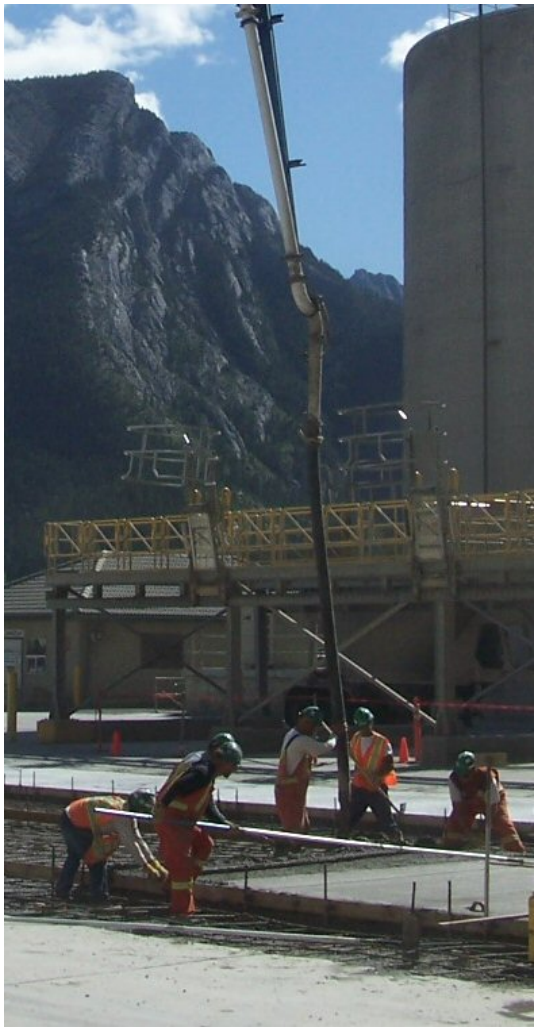


Field Trials



Gatineau, Quebec
October 2008

Exshaw, Alberta
September 2009



Brookfield, Nova Scotia
October 2009

Cementitious Materials used in Field Trials

CSA Type	Description	ASTM Equivalent
GU	“General Use” portland cement, **PC**	C 150 Type I
GUL	“General Use” portland limestone cement, **PLC**	C 1157 Type GU
GUb-15S	“General Use” blended hydraulic cement	C 595 Type IS
GULb-15S	“General Use” blended limestone cement	C 1157 Type GU
F	Fly ash < 8% CaO	C 618 Class F
CI	Fly ash 8-20% CaO	C 618 Class F
S	Ground granulated blastfurnace slag	C 989

PLC Trial Pour at Gatineau Ready-Mixed Concrete Plant – October 6, 2008

Objective:

- Field test performance of PLC concrete with various levels of SCM in an exterior flatwork application.
- Control sections with Type GU + SCM

Eight Concrete Mixes:

Cement	SCM Replacement Level (%)			
	0	25	40	50
Type GU (PC)	X	X	X	X
Type GUL (PLC)	X	X	X	X

Cementing Materials:

- Type GU with 3.5% limestone (PC)
- Type GUL with 12% Limestone (PLC)
- Blended SCM = 2/3 Slag + 1/3 Fly Ash

Exshaw Cement Plant, Alberta

- Sept 2009
- Paving, Curbs & pumped concrete
- PC & PLC cements
- 15, 25 & 30% fly ash

Brookfield Cement Plant, Nova Scotia

•Oct 2009

•Paving

•Blended PC & PLC cements containing 15% slag

•15 & 20% fly ash

CSA Type	Abbrev.	Gypsum (%)	Limestone (%)	Slag (%)	Clinker (%)	Target Blaine (m^2/kg)
Type GU	PC	5	4	0	91	380
Type GUb	PC-Slag	5	0	15	80	450
Type GULb	PLC-Slag	5	12	15	68	500

PC, PC-Slag & PLC-Slag compared in laboratory mixes

Only PC-Slag & PLC-Slag compared in field mixes

Testing of Concrete Produced for Laboratory Trials

Test	**Method**
Slump	C 143
Air (plastic concrete)	C 231
Set time	C 403
Hardened air voids	C 457
Compressive strength	C 39
“Rapid chloride permeability”	C 1202
Freeze-thaw resistance	C 666 (Proc. A)
Salt-scaling resistance	C 672
Diffusion coefficient	C 1556

PLC Trial Pour at Gatineau Ready-Mixed Concrete Plant – October 6, 2008

Fresh concrete properties:

- Slump
- Air
- Temperature
- Density

Hardened concrete properties on site-cast specimens:

- Strength
- RCPT
- Hardened Air-Void Parameters
- Freeze-thaw (ASTM C 666: Proc. A)
- Salt Scaling (ASTM C 672 & BNQ Method)

Properties of 35-Day-Old Cores:

- Strength
- RCPT
- Chloride diffusion coefficient

Brookfield Trial: Type PC-Slag versus Type PLC-Slag

Mix Proportions (lb/yd^3)

	No Fly Ash		15% Fly Ash		20% Fly Ash	
	PC-Slag	PLC-Slag	PC-Slag	PLC-Slag	PC-Slag	PLC-Slag
PC-Slag	653	-	545	-	513	-
PLC-Slag	-	384	-	545	-	515
Fly Ash	0	0	95	97	128	128
Water	272	283	277	275	280	275
W/CM	0.42	0.44	0.43	0.43	0.44	0.43

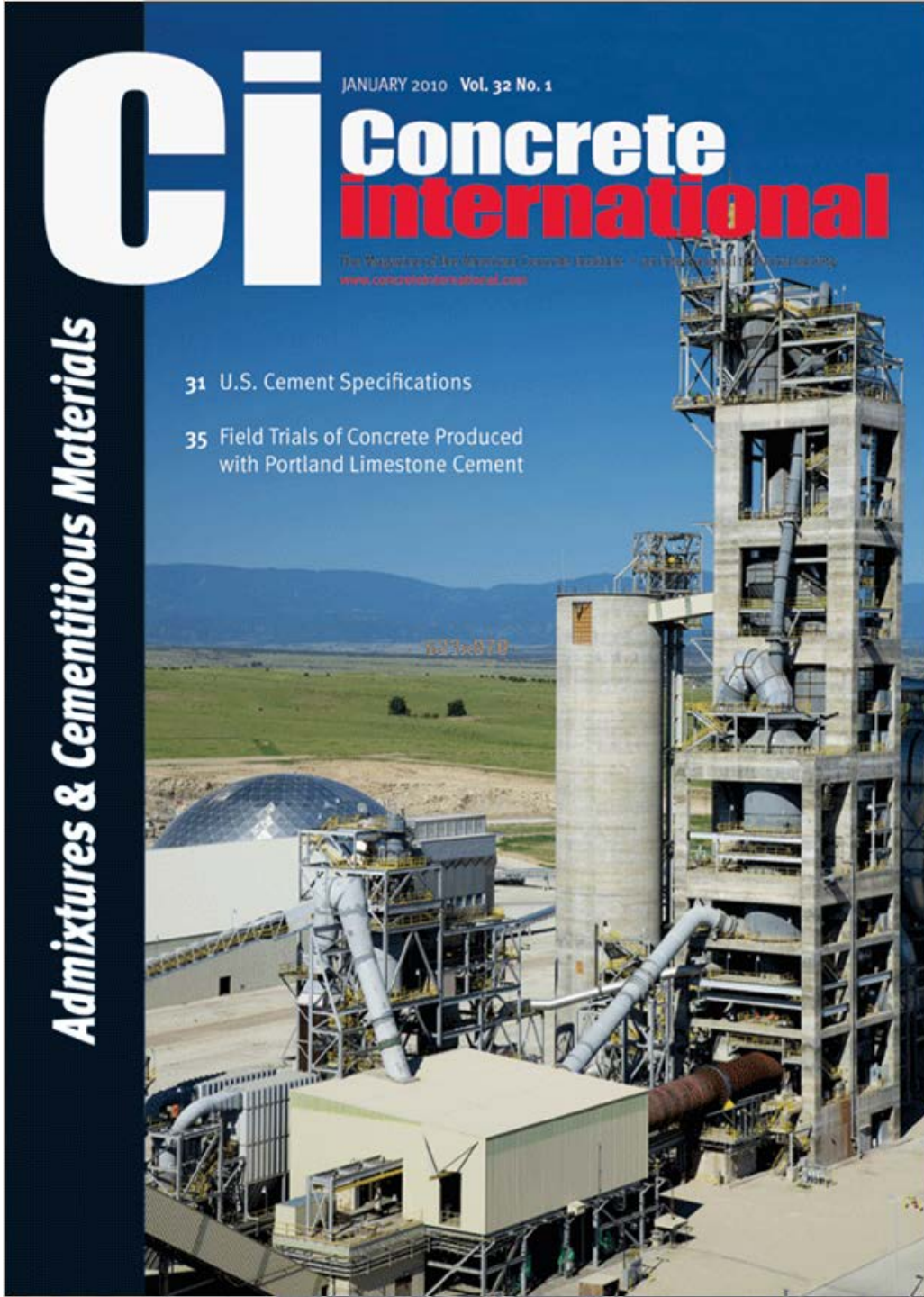
Brookfield Trial: Type PC-Slag versus Type PLC-Slag

Fresh Concrete Properties

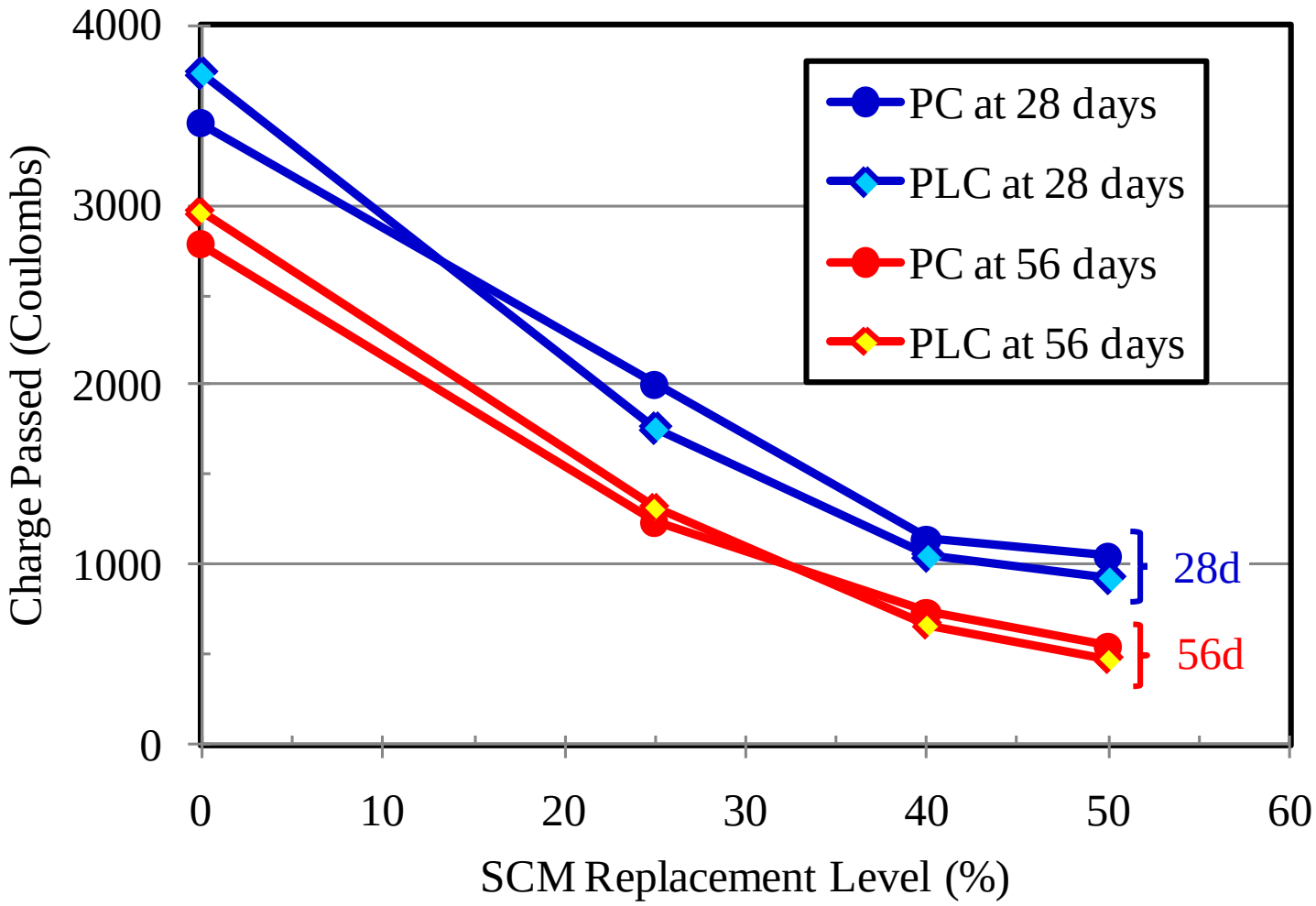
	No Fly Ash		15% Fly Ash		20% Fly Ash	
	PC-Slag	PLC-Slag	PC-Slag	PLC-Slag	PC-Slag	PLC-Slag
Air (%)	5.8	6.6	6.1	6.2	6.6	6.5
Slump (mm)	3	2¼	3¼	2½	2½	3

PLC Trial Pour at Gatineau Ready-Mixed Concrete Plant – October 6, 2008

- Results published in Concrete International (Jan 2010)
- SCM had significant impact on properties
- No consistent difference between the durability results for PLC versus PC at the same level of SCM
- Mix with PLC-50% SCM contained just 42% clinker by mass of cementing material. Compare with mix with PC only – 92% clinker
- CO_2 reduced by 1 ton per 8-yd^3 truck through combined use of limestone and SCM



PLC Trial Pour at Gatineau – RCPT Results



PLC Trial Pour at Gatineau – Results of Tests on Cores taken at 35 Days

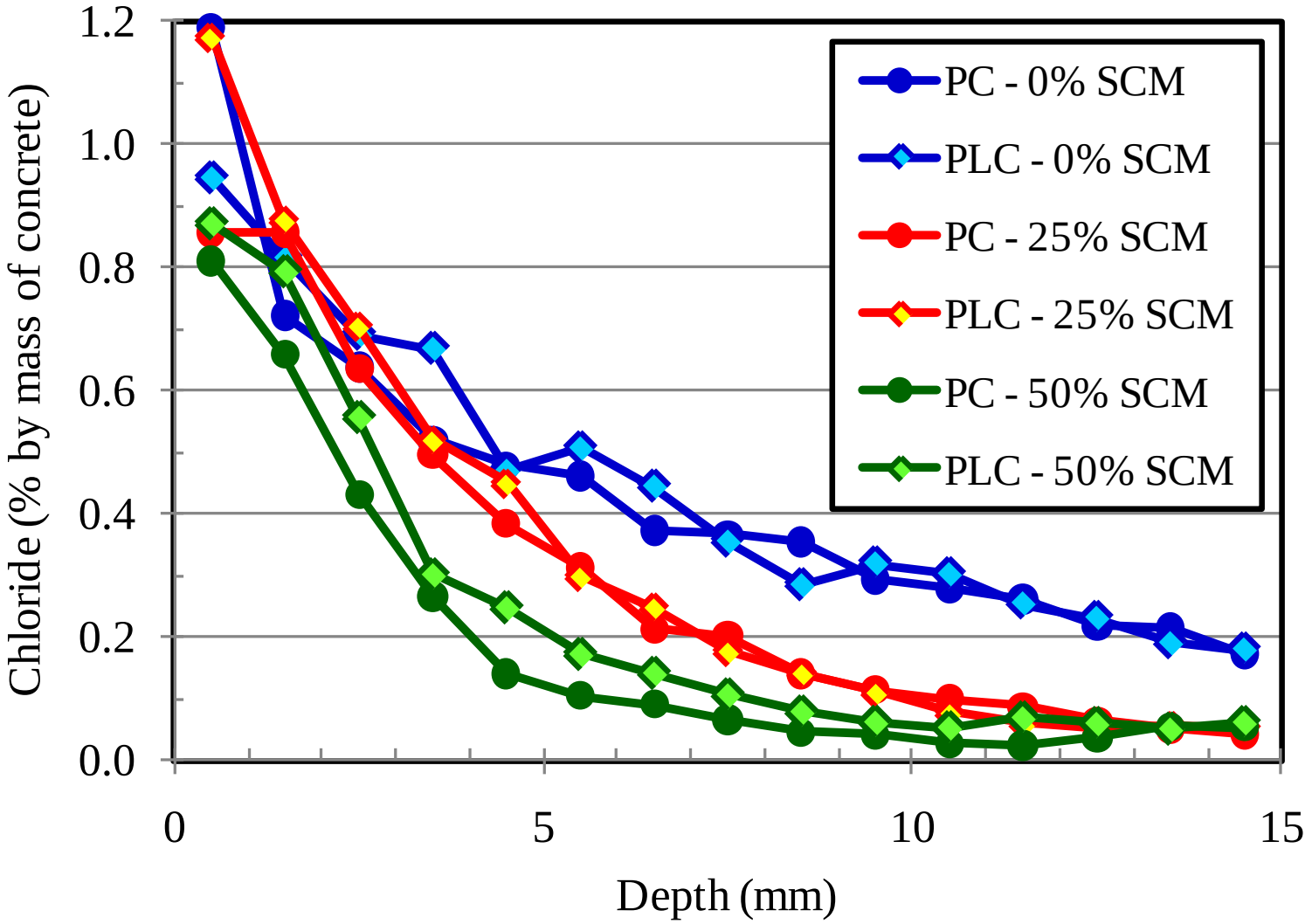
RCPT Results

Cement	Charge Passed in 6 Hours (Coulombs			
	0% SCM	25% SCM	40% SCM	50% SCM
PC	2395	1410	570	491
PLC	2345	1308	617	520

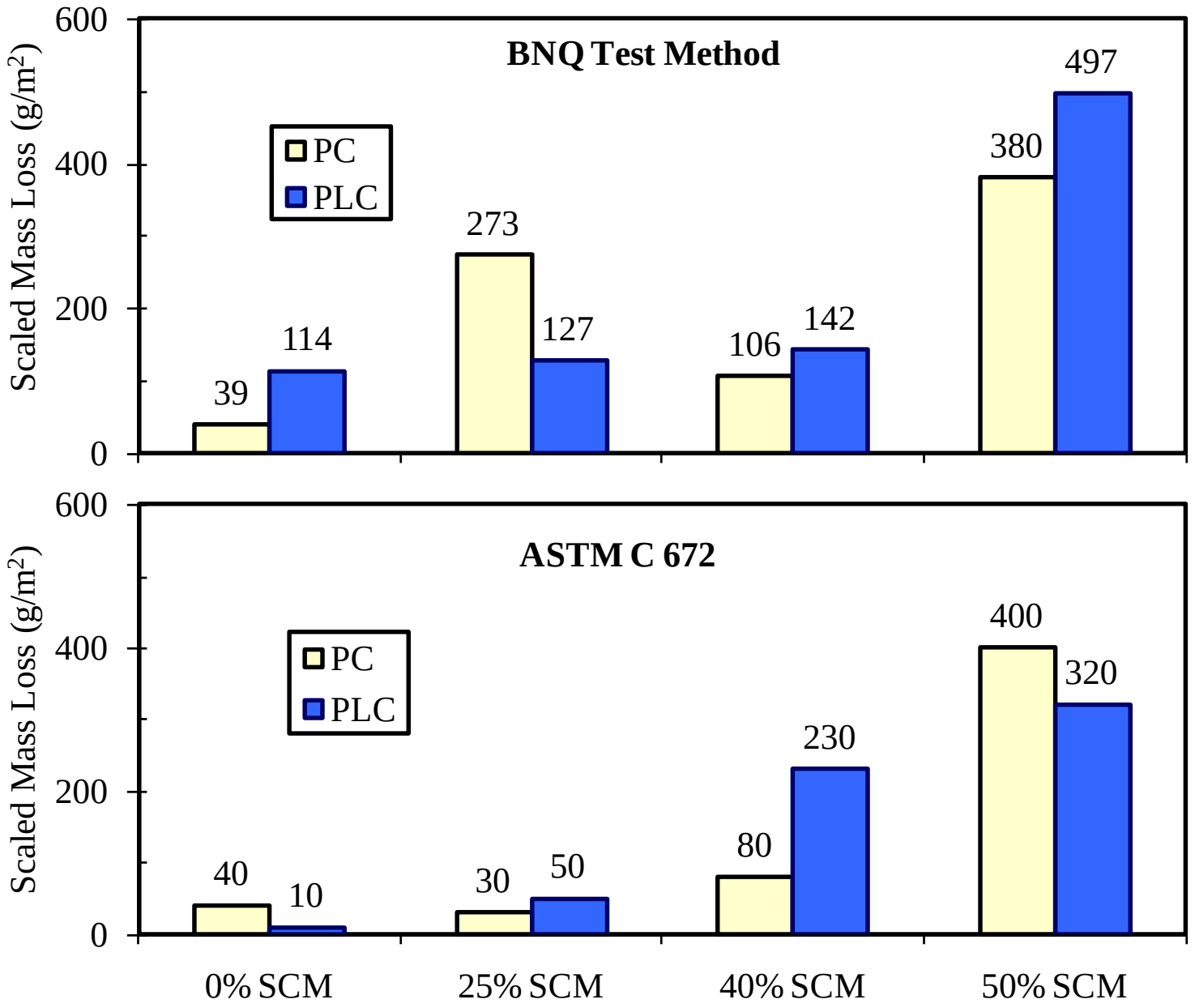
Chloride Diffusion Coefficients

Cement	Charge Passed in 6 Hours (Coulombs			
	0% SCM	25% SCM	40% SCM	50% SCM
PC	15.0	3.77	1.51	1.25
PLC	11.9	2.91	1.22	1.81

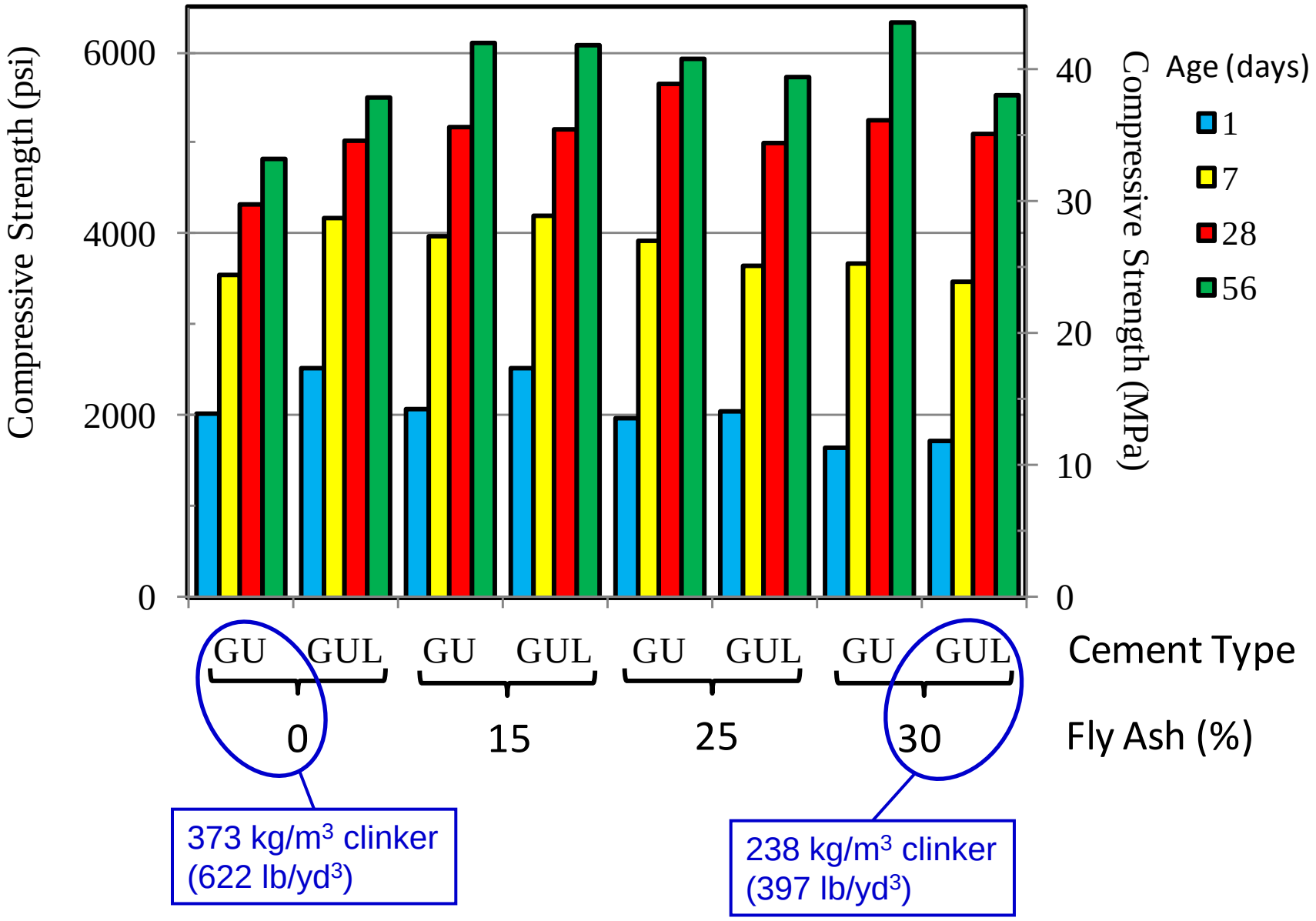
PLC Trial Pour at Gatineau - Chloride Profiles for Cores taken at 35 Days and Immersed in NaCl for 42 Days



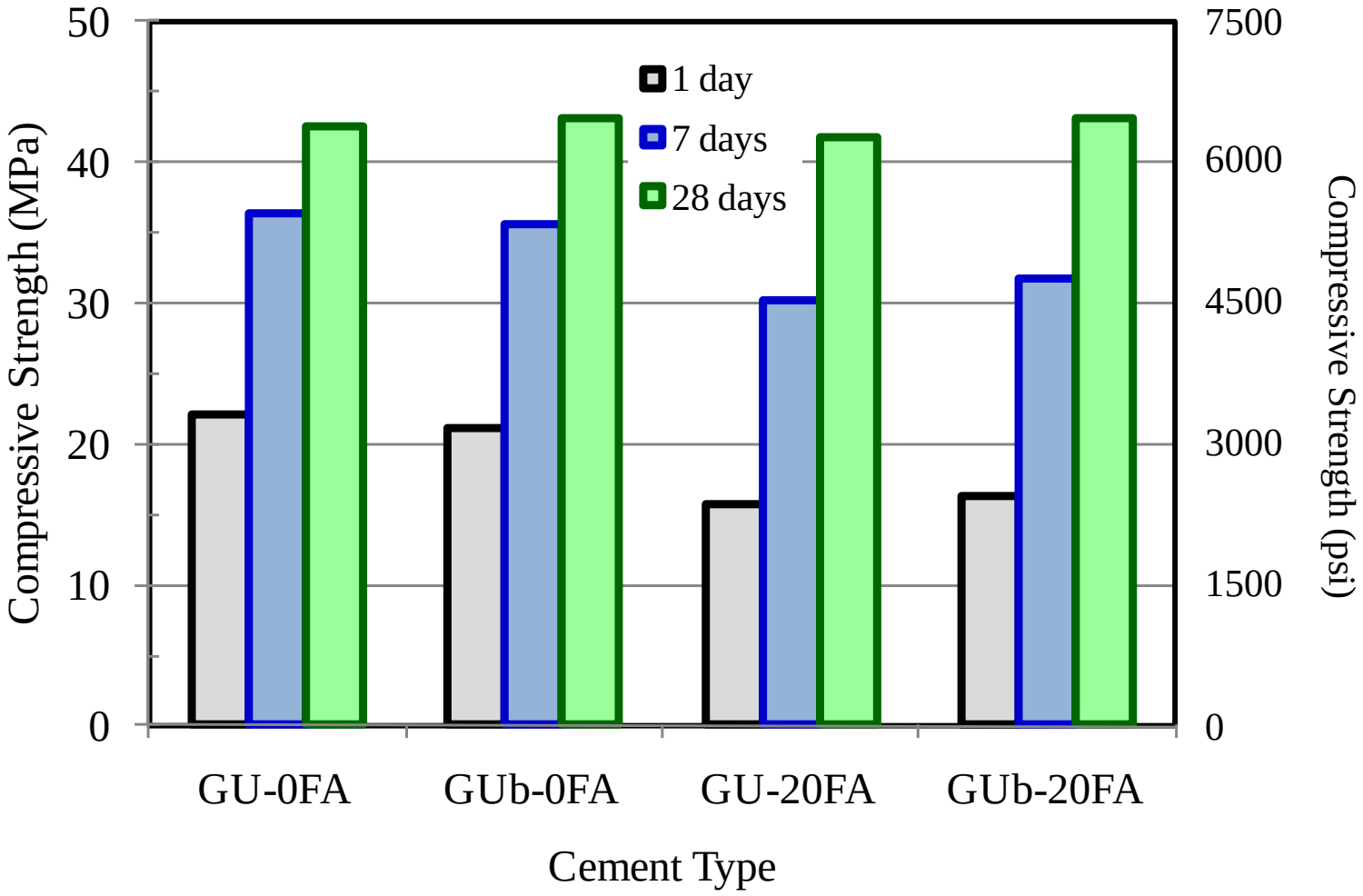
PLC Trial Pour at Gatineau – Scaling Test Results



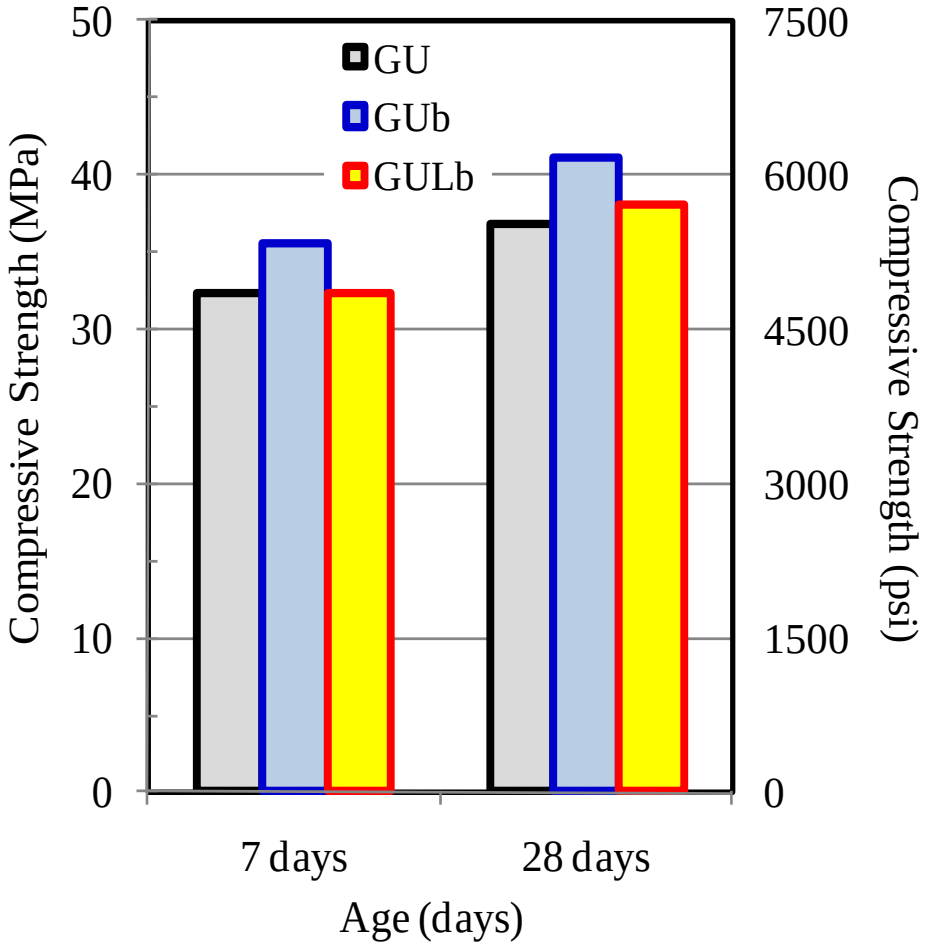
PLC Trial Pour at Exshaw – Cylinder Strengths

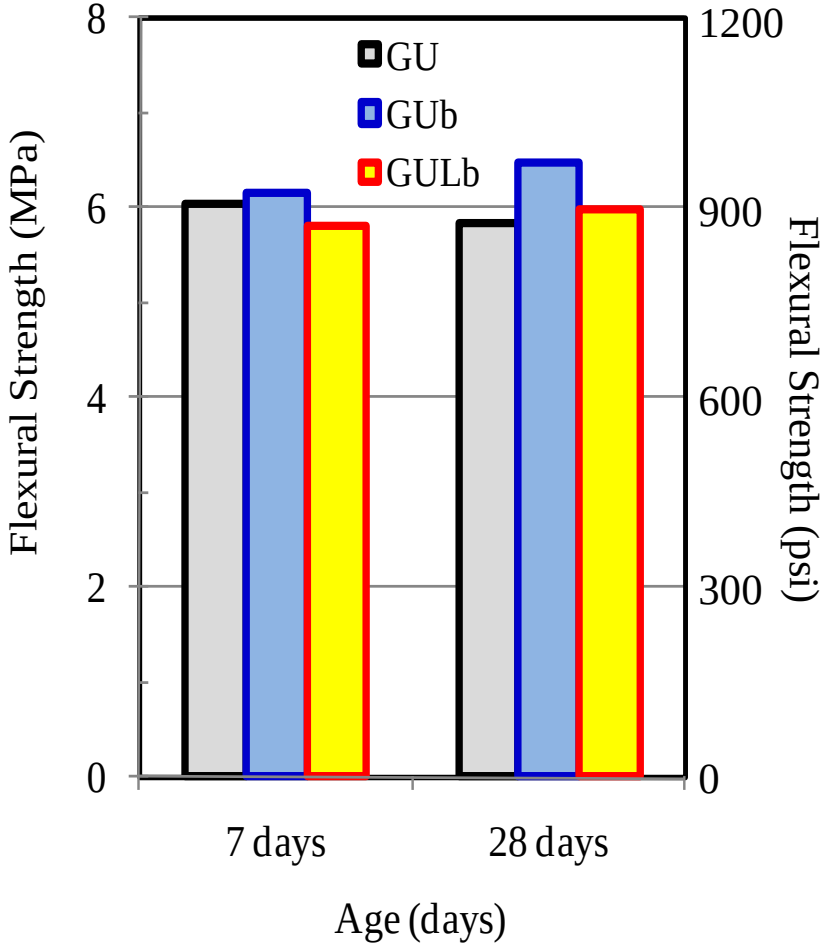


Initial Trials at Brookfield – Type GU versus Type GUb – with & without Fly Ash



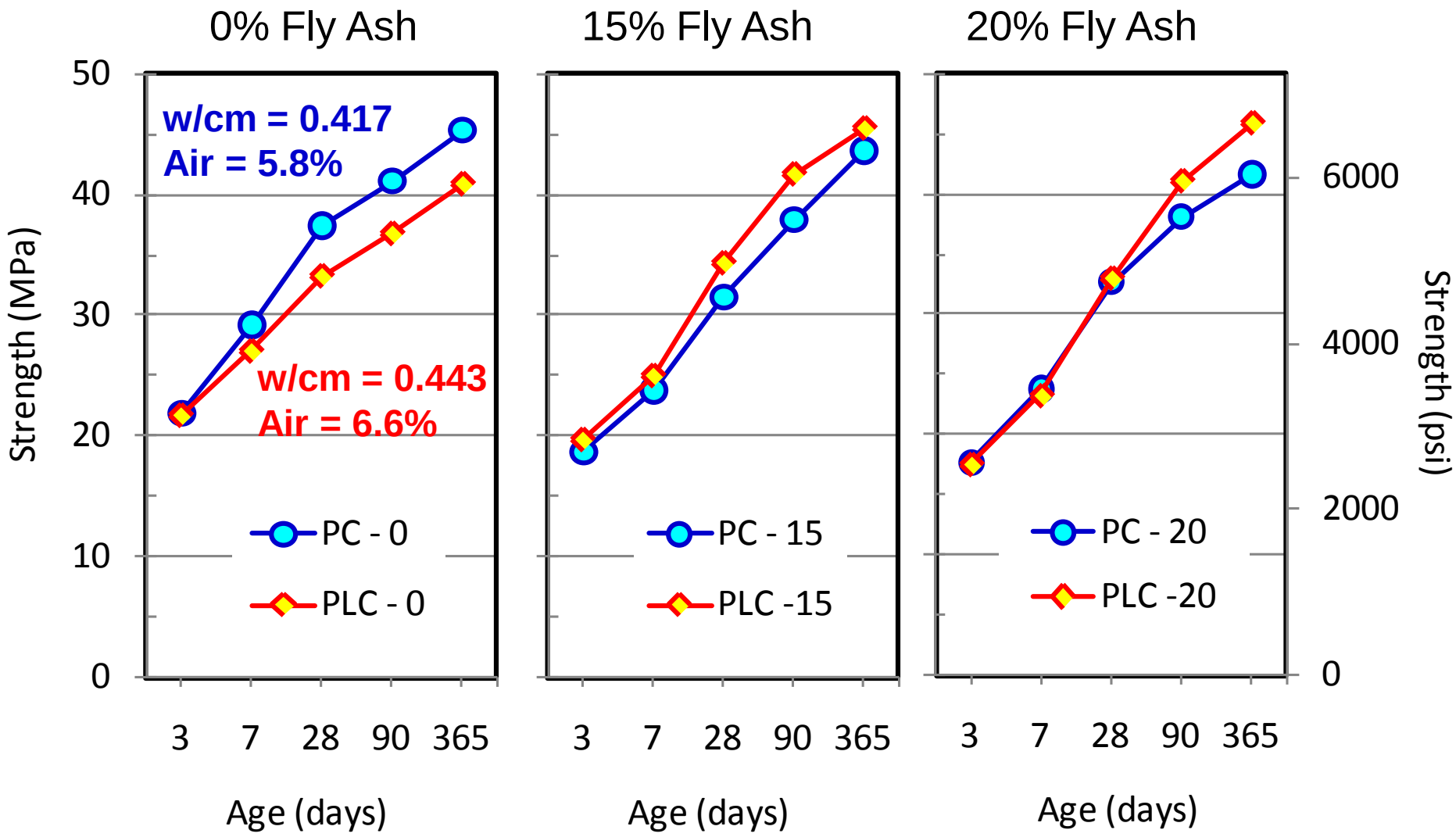
Laboratory Mixes at Brookfield – Type GU, Type GUb & Type GULb



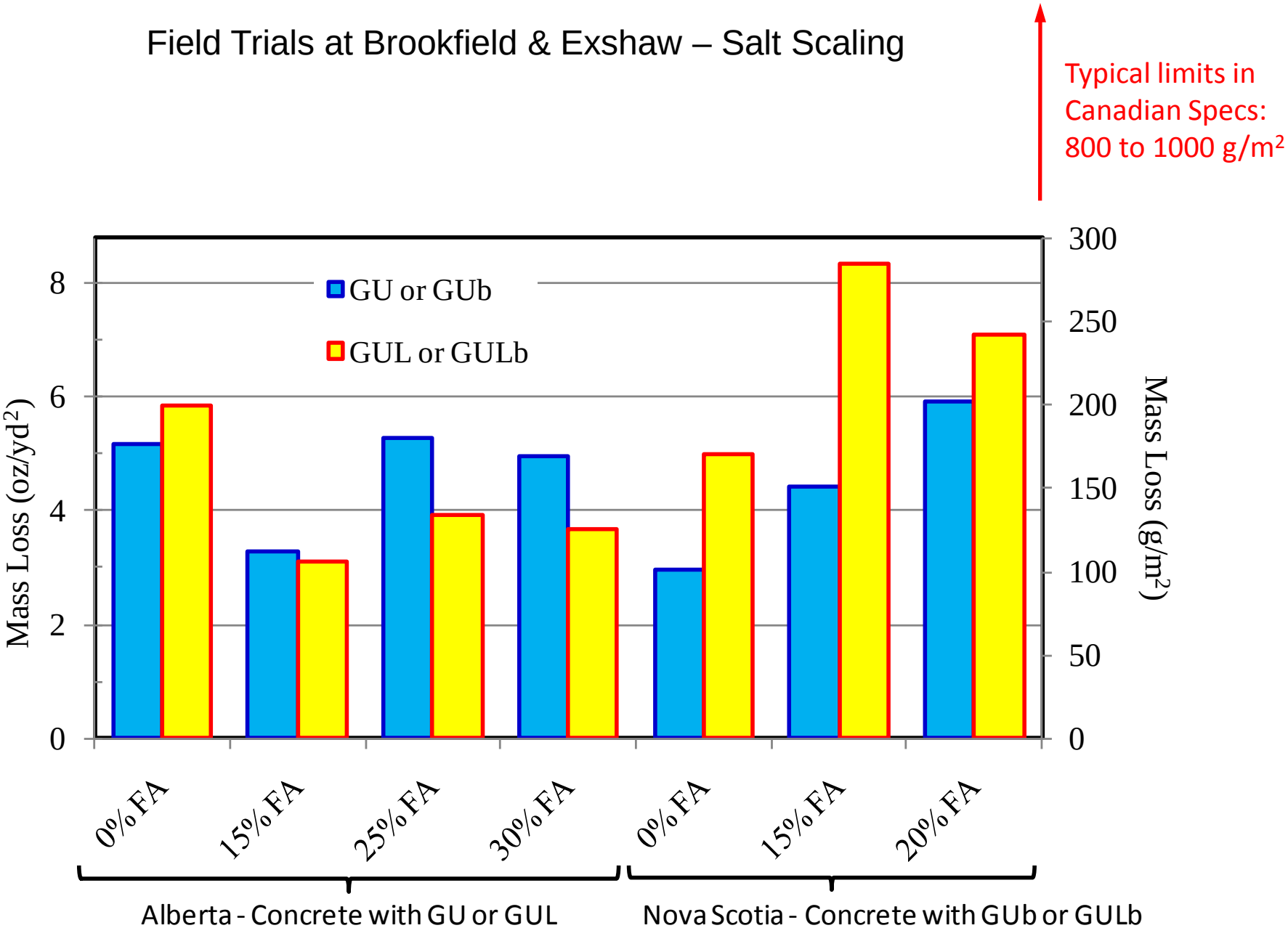


	Gypsum (%)	Limestone (%)	Slag (%)	**Clinker (%)**	Target Blaine (m^2/kg)
Type GU	5	4	0	**91**	380
Type GUb	5	0	15	**80**	450
Type GULb	5	12	15	**68**	500

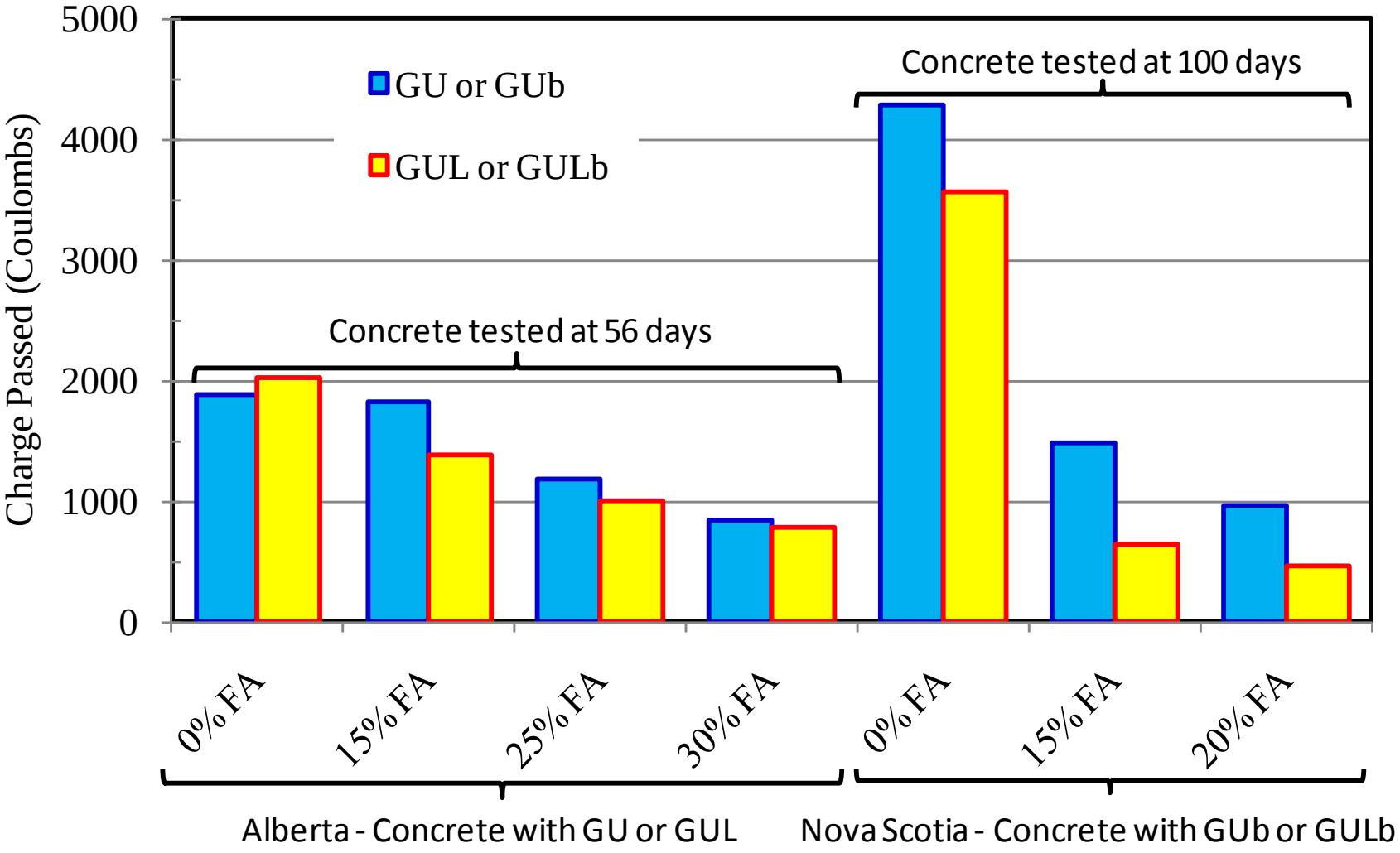
Field Trials at Brookfield – Compressive Strength



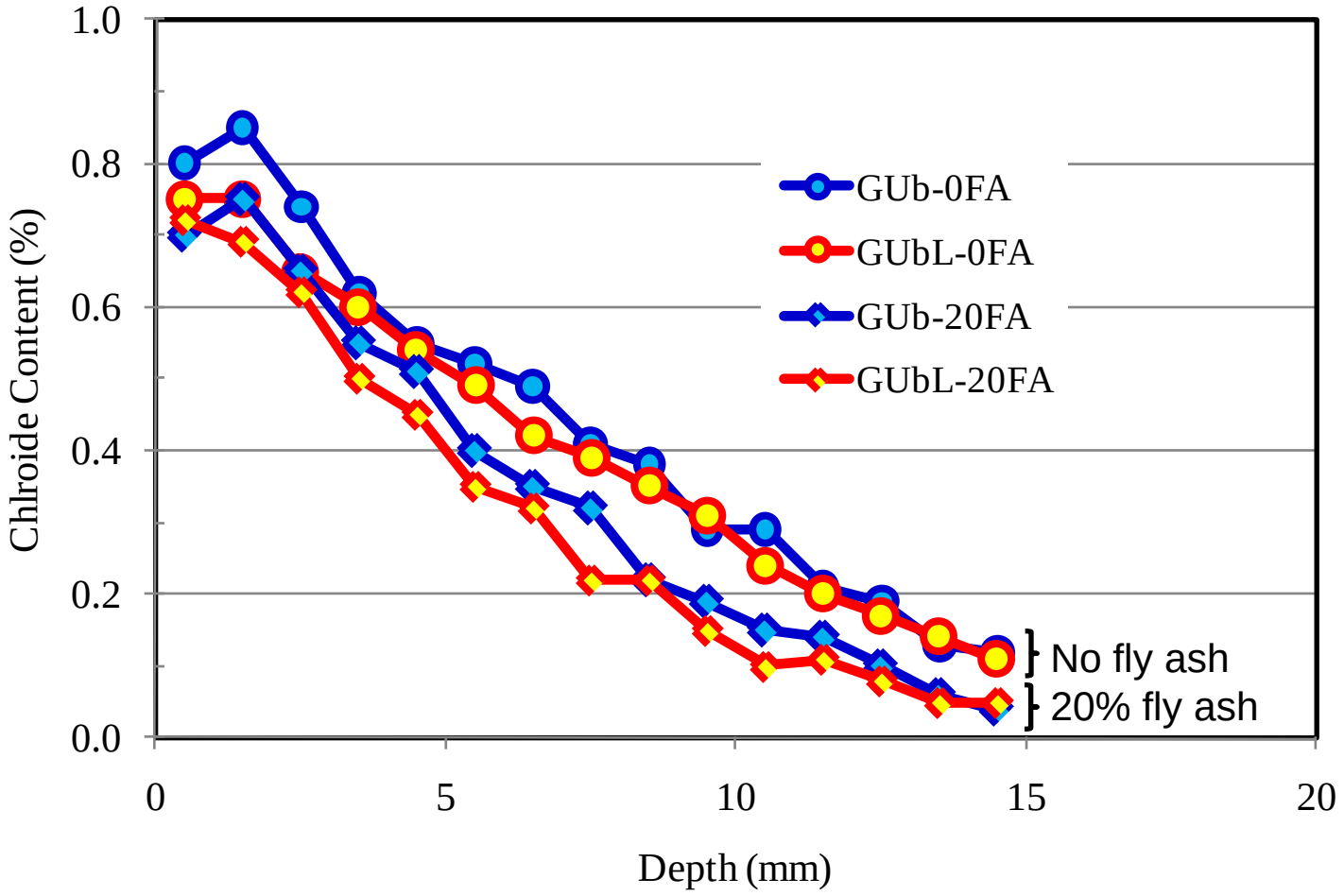
Field Trials at Brookfield & Exshaw – Salt Scaling



Field Trials at Brookfield & Exshaw – RCPT



Field Trials at Brookfield – Chloride Diffusion Coefficients



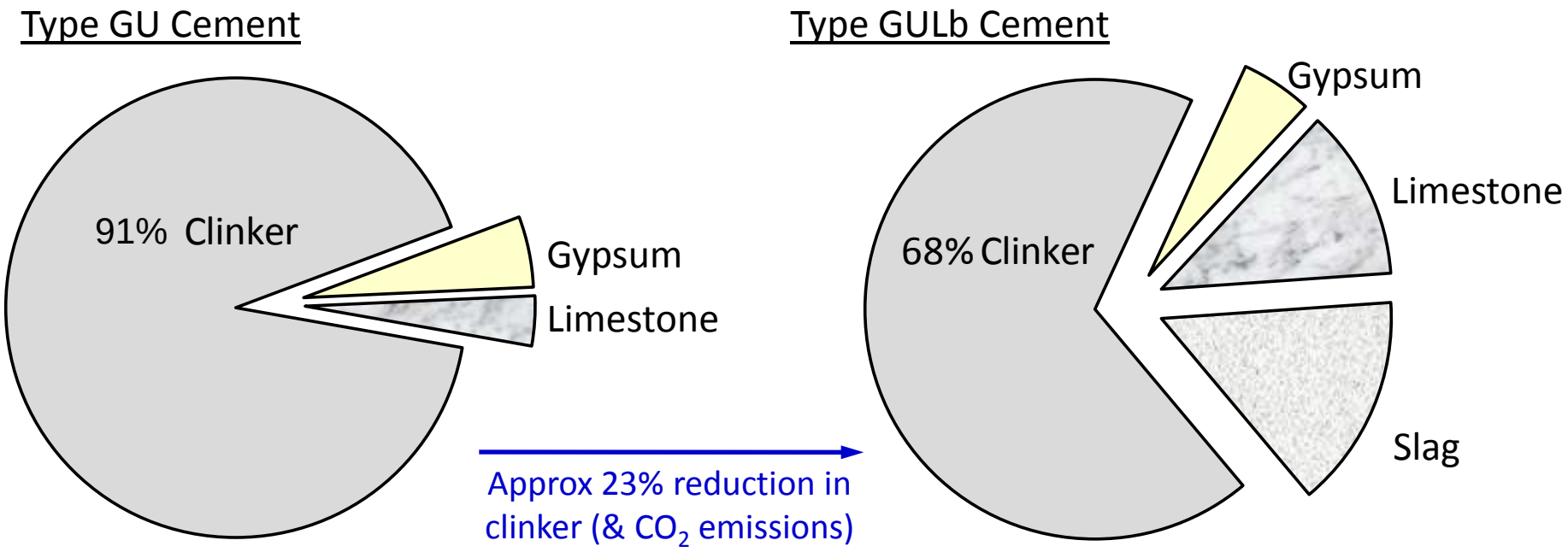
$$C_x = C_0\left(\frac{x}{\sqrt{4D_a \cdot t}}\right)$$

	No Fly Ash		20% Fly Ash	
	GUb	GULb	GUb	GULb
D_a (x 10^{-12} m^2/s)	6.1	6.4	3.9	3.4

Brookfield Cement Plant, Nova Scotia

	Gypsum (%)	Limestone (%)	Slag (%)	Clinker (%)	Target Blaine (m^2/kg)
Type GU	5	4	0	91	380
Type GUb	5	0	15	80	450
Type GULb	5	12	15	68	500

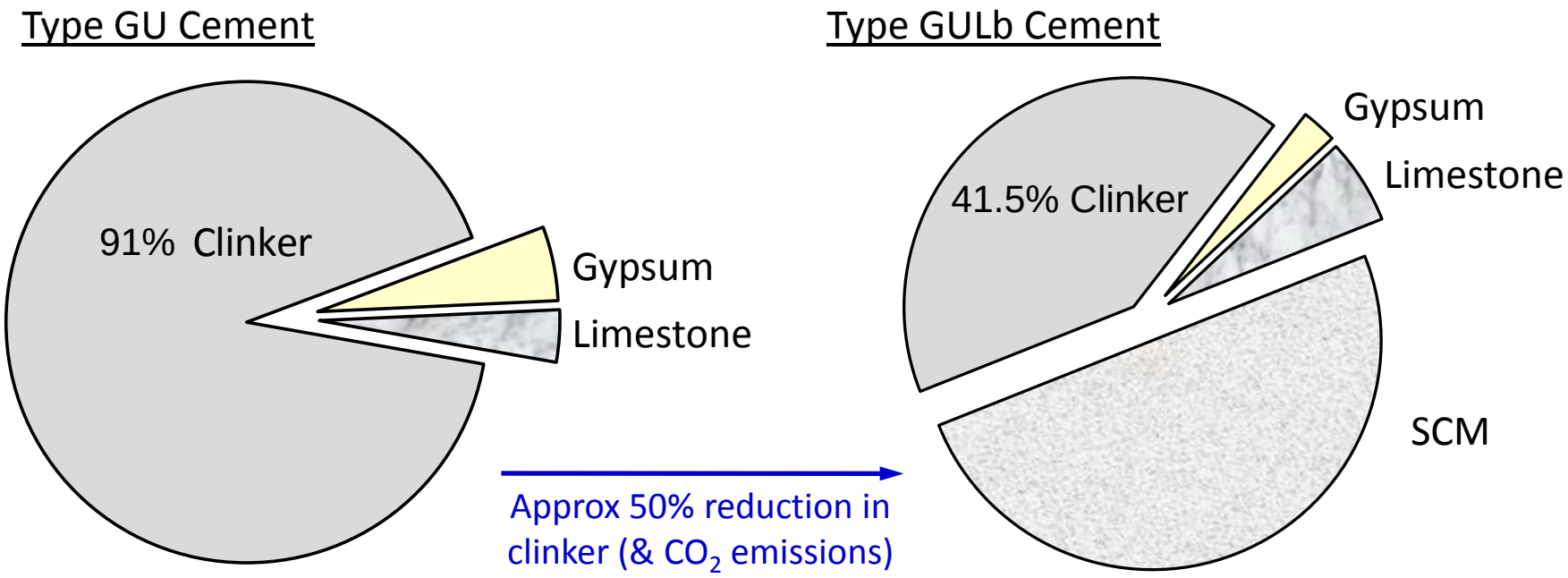
- Type GULb contains 23% less clinker than Type GU



Mixes used in Gatineau Field Trial

Concrete Mix	Composition of Binder (%)			
	Gypsum	Limestone	SCM	Clinker
GU + 0% SCM	5	4	0	91
GUL + 50% SCM	2.5	6	50	41.5

- Mix with GUL + 50% SCM contains approximately 50% less clinker in the binder than mix with straight Type GU cement



Gatineau Field Trial

Clinker Contents of Mixes used for Paving Trials (355 kg/m^3 cementitious material)

Concrete Mix	Clinker in Cement (%)	Clinker in concrete without SCM (kg/m^3)	Clinker in concrete with 50% SCM(kg/m^3)
GU + 0% SCM	91	**323**	162
GUL + 50% SCM	83	295	**147**

- 176 kg/m^3 reduction in cement clinker (= 176 kg/m^3 reduction in CO_2) by combined use of Type GUL cement plus SCM compared with Type GU
- **CO_2 reduced by almost 1½ tonne per 8-m^3 truck**

- 293 lb/yd^3 reduction in cement clinker (= 293 lb/yd^3 reduction in CO_2) by combined use of Type GUL cement plus SCM compared with Type GU
- **CO_2 reduced by almost 1½ ton per 10-yd^3 truck**

Overall Summary

- Portland-limestone cement (PLC) with 12% limestone, when optimized for equal strength, can provide equivalent performance to Portland cement (Type PC)
- Blended portland-limestone cement with 12% limestone and 15% slag also provided equivalent performance to PC with 23% less clinker
- PLC performs well with (further) additions of SCM at the ready-mixed concrete plant (providing further opportunities to reduce CO_2 emissions).
- Using a combination of PLC or blended PLC together with (further) SCM additions at the concrete plant provides the opportunity to reduce the clinker content of paving mixes by up to 50%. Such reductions can translate to CO_2 reductions of the order of 1 to 1½ tons per concrete truck!