Lowering the CO_2 Footprint of Concrete with Portland-Limestone Cement (Type IL)

June 8, 2022

Eric P. Koehler, Ph.D., P.E., FACI
Director of Quality | Titan America | ekoehler@titanamerica.com

TITAN AMERICA

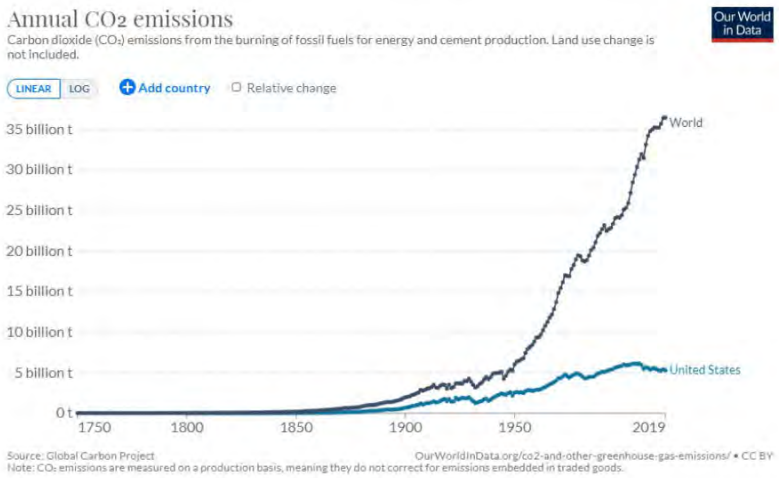
Outline

TITAN AMERICA

- CO_2 Emissions and Outlook
  - All Sources
  - Cement and Concrete
- Cement and Concrete Roadmaps for Carbon Neutrality
- Portland-Limestone Cement
  - Definitions
  - Performance
  - Specifications
  - Sustainability
  - Case Studies

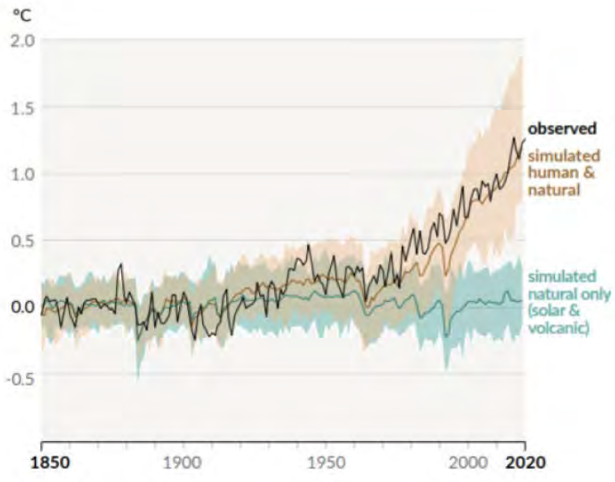
© National Ready Mixed Concrete Association

CO_2 Emissions



Source OurWorldInData.org

Global Temperatures



Source UN IPCC Climate Assessment Report 2021

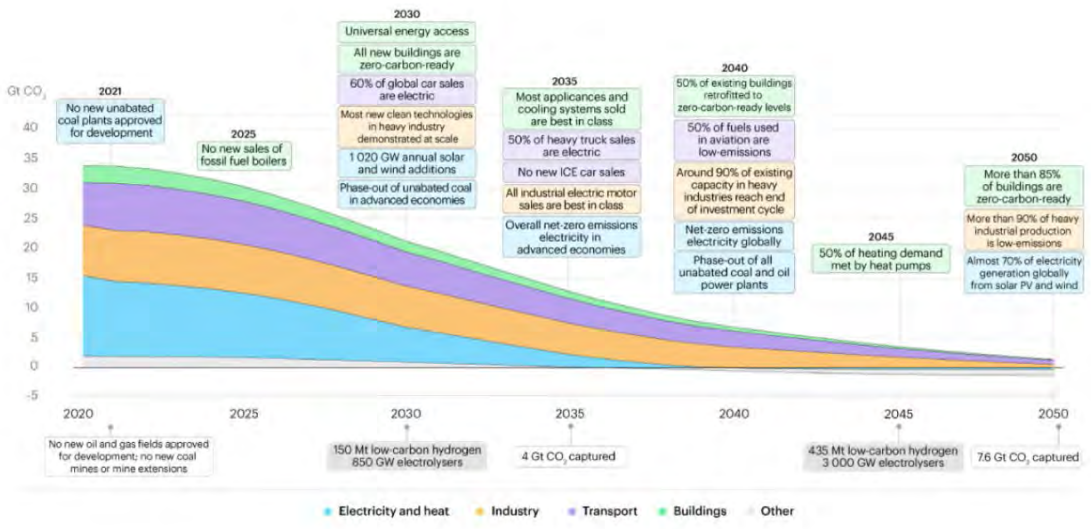
Global Commitment to Decarbonize

2015 Paris Climate Agreement set a max 1.5°C temperature rise from pre-industrial levels.

Requires global carbon neutrality by mid-century.

Businesses, governments, investors, and NGO's committing to and developing plans for a decarbonized world.

Achieving Carbon Neutrality Globally

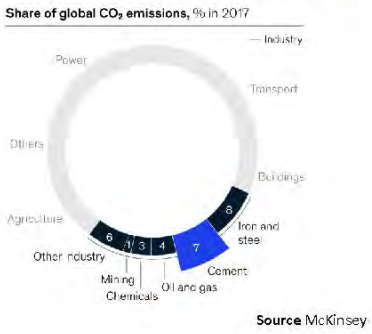


Source IEA

© National Ready Mixed Concrete Association

Cement and Concrete

Cement represents 7% of global CO_2 emissions (1.25% in US)

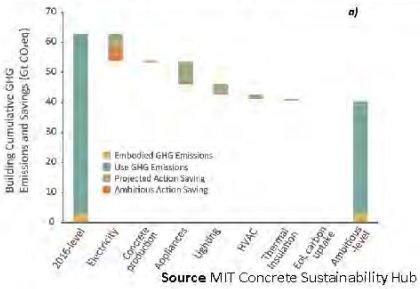


Source McKinsey

The world will continue to demand more concrete

- 1 NYC per year in the US
- 1 NYC per month globally

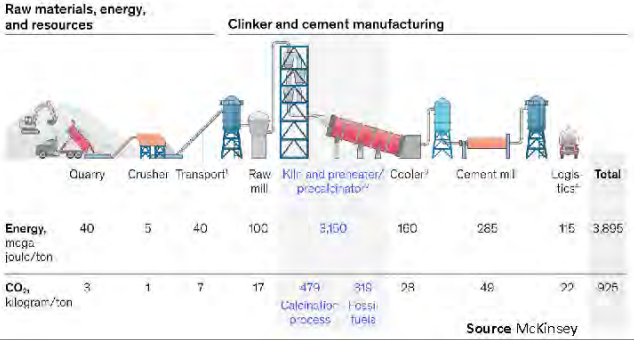
Cement and Concrete



Source MIT Concrete Sustainability Hub

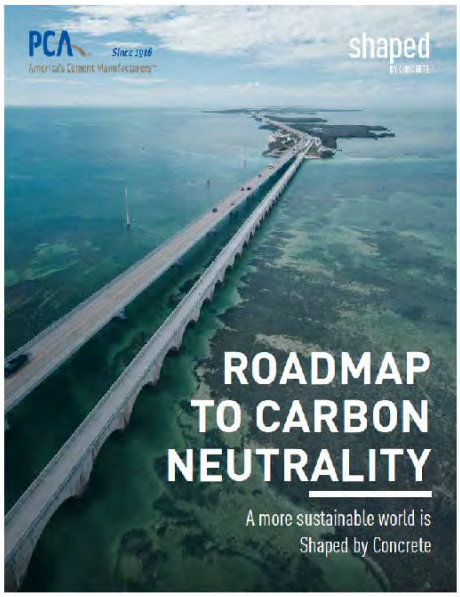
Cement plays an essential role in resiliency and energy efficiency, which will become increasingly important.

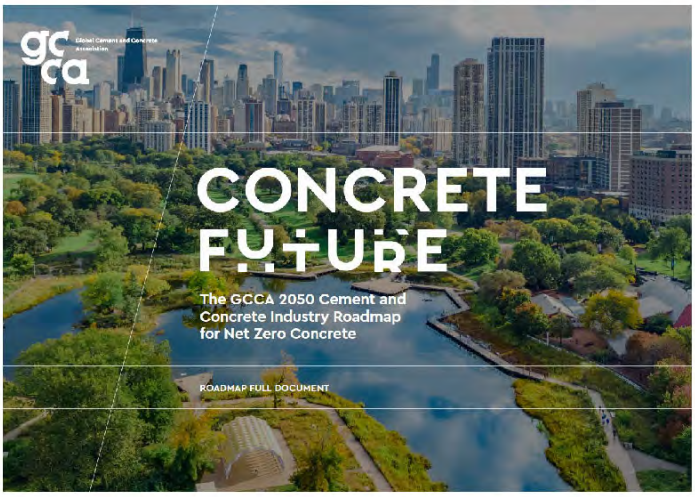
Cement is considered "difficult to abate" because a large portion of emission are process (~525 kg/tonne)



Source McKinsey

Cement and Concrete Industry Roadmaps to Net Zero

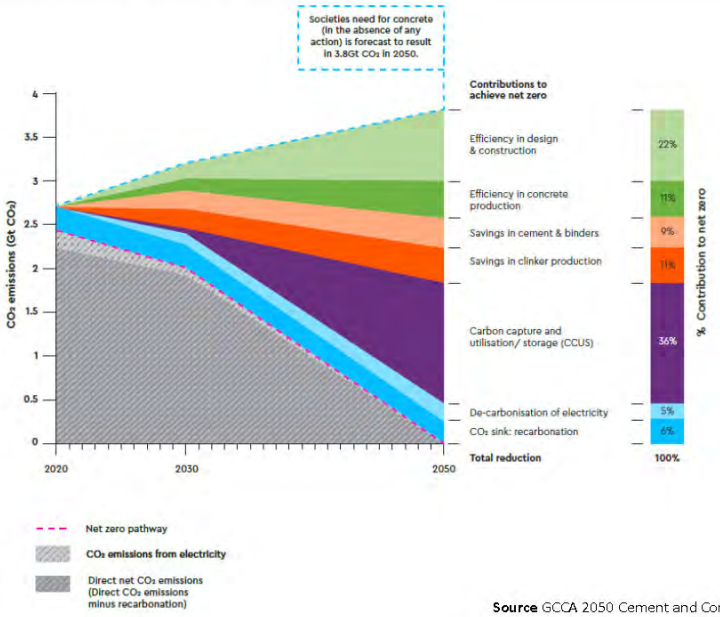




Achieving Net Zero CO_2 Across The Concrete Value Chain

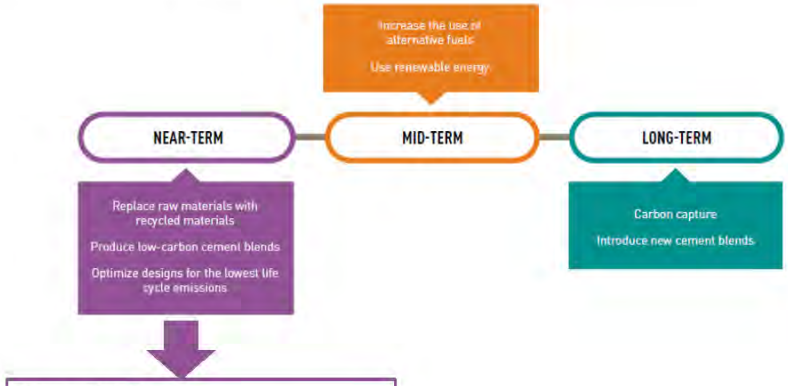
Source PCA Roadmap to Carbon Neutrality

Levers for Achieving Net Zero CO_2



Source GCCA 2050 Cement and Concrete Industry Roadmap to Climate Neutrality

How to Get from Here to There



Proven Solutions
"All Concrete Like Our Best Concrete"

- Portland-Limestone Cement
- Optimized Mix Designs
- Increase SCM Utilization
- Improved Testing and Acceptance
- Performance Specifications

Source PCA Roadmap to Carbon Neutrality

What is Portland-Limestone Cement (PLC)?

TITAN AMERICA

Portland-Limestone Cement is a blended cement meeting Type IL in ASTM C595/AASHTO M240

	Portland Cement ASTM C150 AASHTO M85	Portland-Limestone Cement ASTM C595 AASHTO M240
Clinker (typical)	90-95%	80-90%
Gypsum (typical)	4-6%	4-6%
Limestone (allowed)	0-5%	5-15%

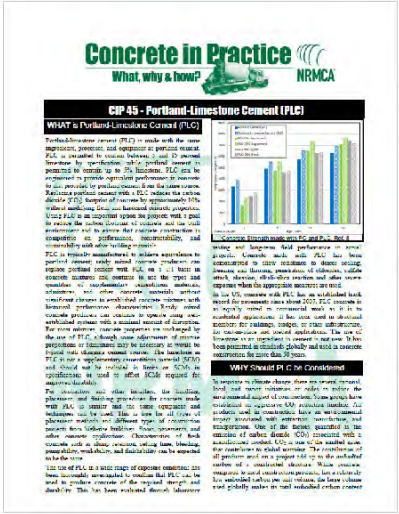
- Designated as Type IL(X) where X is the amount of limestone
  - Type IL(13) includes 13% limestone by mass
- Same raw materials, manufacturing methods, and quality control as portland cement
- Optional requirements can also apply
  - Type IL(MS) Moderate sulfate resistant (comparable to Type II)
  - Type IL(HS) Highly sulfate resistant (comparable to Type V)
  - Type IL(MH) Moderate heat of hydration
  - Type IL(LH) Low heat of hydration
- Approximately 10% lower CO_2 emissions (Global Warming Potential - GWP)
- Typically a 1-to-1 substitute for Type I/II cement

What is Portland-Limestone Cement (PLC)?

TITAN AMERICA

Learn More:
greenercement.com

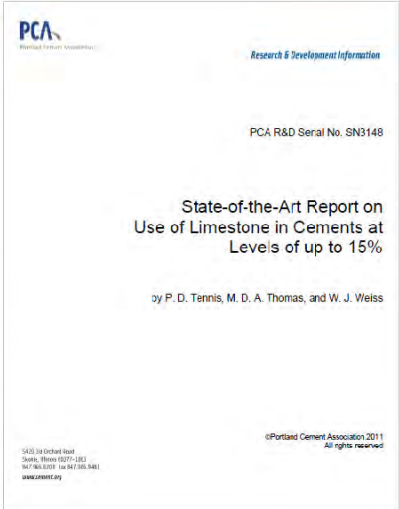
plc
portland-limestone cement


Concrete in Practice
What, why & how?
NRMCA

CIP 45 - Portland-Limestone Cement (PLC)

WHAT is Portland-Limestone Cement (PLC)?

WHY Should PLC be Considered


PCA

Research & Development Information

PCA R&D Serial No. SN3148

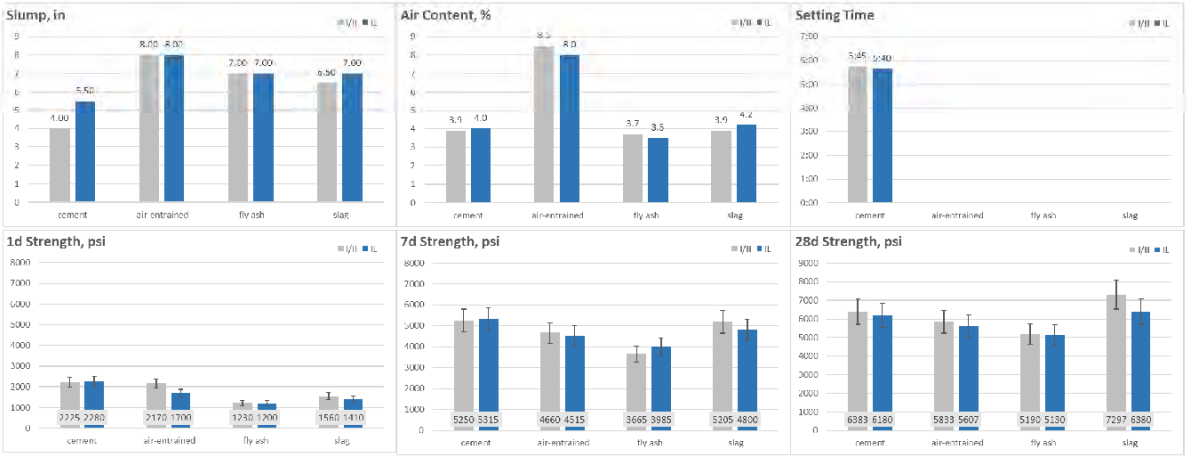
State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%

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

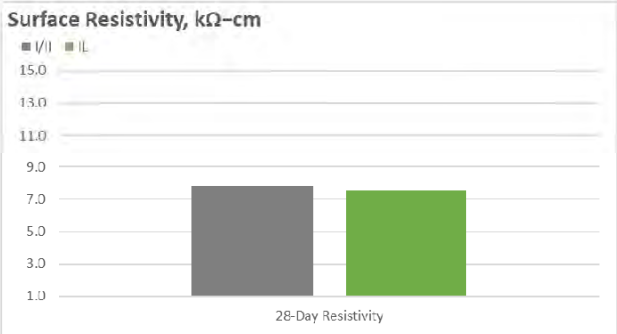
©Portland Cement Association 2011
All rights reserved

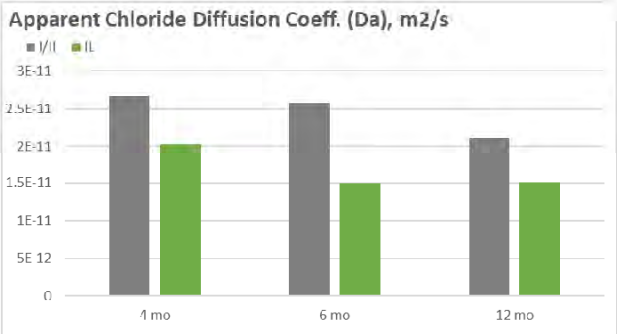
Performance: Fresh Properties and Strength

Mix	Cement, pcy	Fly Ash, pcy	Slag, pcy	Coarse, pcy	Fine, pcy	Water, pcy	AEA, oz/cwt	HRWR, oz/cwt
Cement	550			1725	1500	270		6
Air Entrained	550			1725	1350	259	0.2	6
Fly Ash (25%)	412	138		1725	1477	259		6
Slag (30%)	412		165	1725	1535	281		6

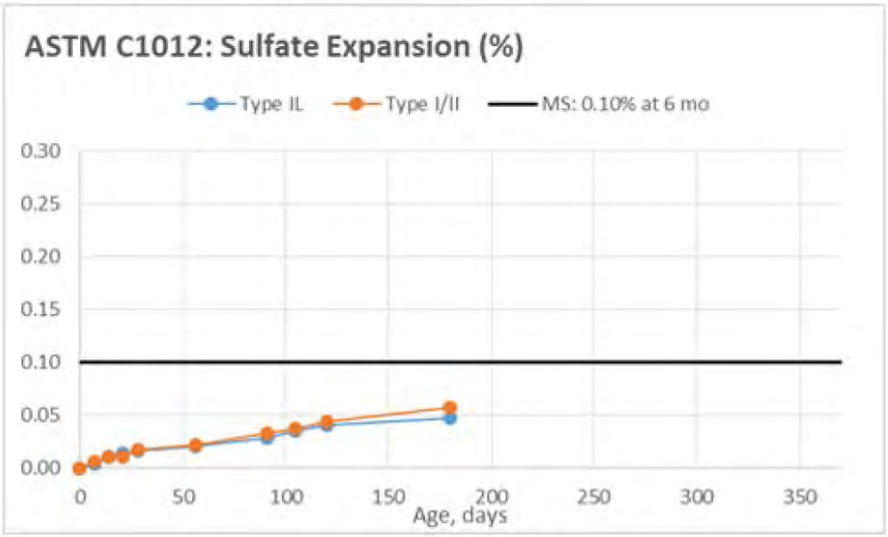


Permeability and Resistance to Chloride

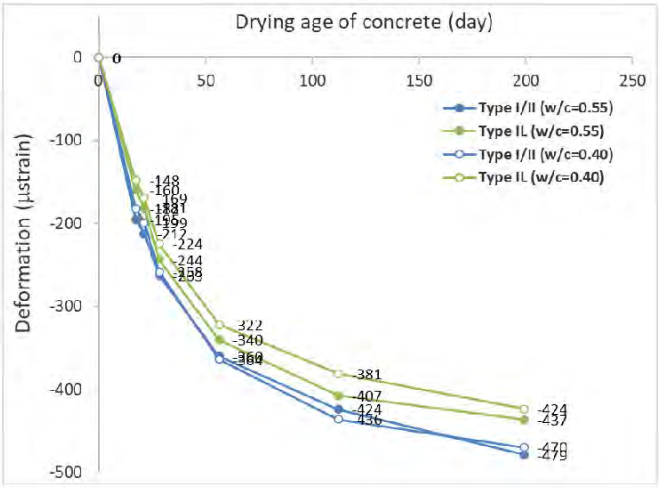




Performance: Sulfate Durability (ASTM C1012)

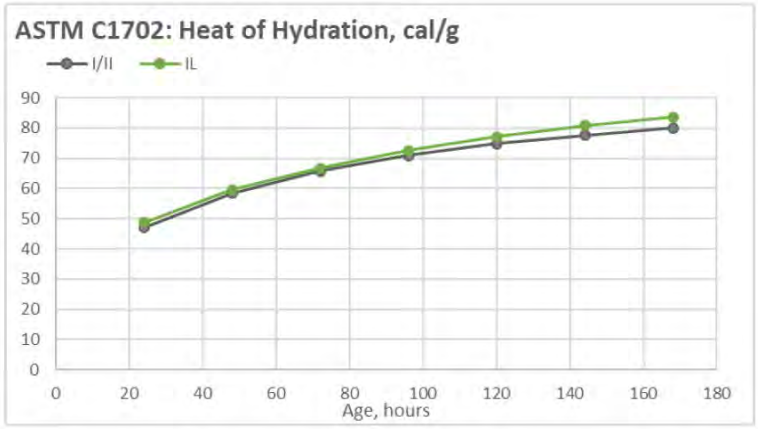


Performance: Shrinkage (ASTM C157)



© National Ready Mixed Concrete Association

Heat of Hydration



Testing Results – RIME Group

Mix Design

Mixtures (lbs/cy)	Cement	FA	Water	Sand	Coarse Aggregate		HRWR	Slump
					#57	#8	Oz/cy	
Type IL Mix	420	105	230	1160	1661	382	4.67	3.63
Type II Mix	420	105	231	1162	1664	383	-	4

FA: fly-ash, HRWR: High-ranger-water-reducer

Free shrinkage

- With Type IL cement, the shrinkage after wet-curing for 14 days is **-330 us** which is similar to the mix with Type I cement **(-310 us)**

Free shrinkage ASTM C 157
(modified for wet-curing period)

Compressive and Tensile Strength

Age (days)	Type II Mix		Type IL Mix	
C = compressive strength; T = tensile strength (psi)				
Test	C	T	C	T
1	2049	332	2905	387
			+42%	+17%
7	3860	456	3939	466
			+2%	+2%
14	4178	488	4854	610
			+16%	+25%
28	5232	584	5968	650
			+14%	+11%

Compressive Strength	ASTM C 39
Tensile Strength	ASTM C 496

Data Courtesy:
Hani Nassif and
Adi Abu-Obeidah

Testing Results – RIME Group

RUTGERS Infrastructure Monitoring and Evaluation (RIME)

TITAN AMERICA

Modulus and Flexural Strength

Age (days)	Type II Mix		Type IL Mix	
F = Flexural strength; M = Elastic Modulus (psi)				
Test	F	M	F	M
1	399	3874	437	4311
			+10%	+11%
7	571	4400	585	4895
			+2%	+11%
14	509	4386	527	4956
			+4%	+13%
28	532	4800	626	4336
			+18%	-11%

Modulus of Elasticity	ASTM C 469
Flexural Strength	ASTM C 78

Surface Resistivity and Permeability

Age (days)	Type II Mix		Type IL Mix	
D= Dry Curing; W = 14 days wet curing				
Test	SR	RCPT	SR	RCPT
7	4.2	NA	11.3	NA
			+169%	
14	5.2	NA	10.5	NA
			+102%	
28	16.0	3589	27.5	2984
			+72%	-20%

Surface Resistivity	AASHTO T358
Rapid Chloride Permeability	AASHTO T277

Data Courtesy:
Hani Nassif and
Adi Abu-Obeidah

Mill Certificate Data – Cement Lab

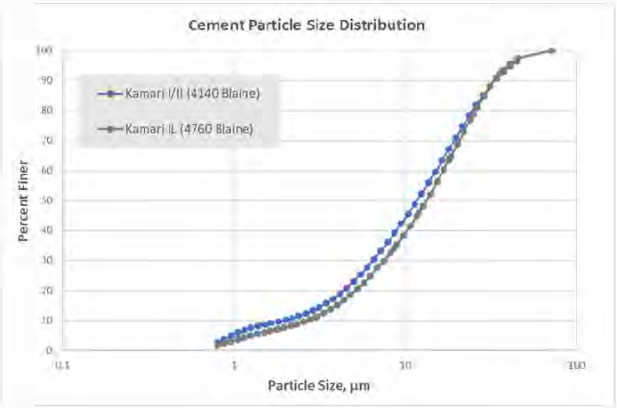
TITAN AMERICA

	Target	Type I/II	Type IL	
SiO2, %		19.1	17.93	Bogue values (C3S, C2S, C3A, C4AFI are not reported with Type IL cement
Al2O3, %		4.74	4.56	
Fe2O3, %		3.51	3.74	
CaO, %		63.77	62.38	
MgO, %		3.14	2.97	
SO3, %		2.74	2.71	
Na2O, %		0.18	0.18	
K2O, %		0.56	0.49	
Na2O_eq, %	<0.60	0.56	0.50	Slightly lower alkali cement
LOI, %	I/II <3.5, IL <10	2.11	5.17	
Limestone, %	I/II <5, IL <15	3.8	10.2	Target limestone +/- 2.5%
Mortar air, %		7.8	7.4	
Blaine, m2/kg		411	499	Limestone results in higher blaine for a similar particle size distribution
Vicat, min	110-150	127	125	
1-Day strength, psi	2000-2600	2510	2470	
3-Day strength, psi		4031	4160	Similar strength and setting
7-Day strength, psi	4500-5300	5167	5510	
28-Day strength, psi	6200-6700	6641	6900	
Heat of hydration, kJ/kg	<335	310	300	Same criteria for MH designation

Type IL Fineness and Blaine

- Blaine is an indirect, relative measurement of fineness. It actually measures air permeability, which is affected by the presence of limestone.
- The ASTM standard for blaine warns about using for other cement types, such as Type IL

  This test method is known to work well for portland cements. However, the user should exercise judgement in determining its suitability with regard to fineness measurements of cements with densities, or porosities that differ from those assigned to Standard Reference Material No. 114.
- Type IL is typically similar fineness to Type I/II even with higher blaine



Specifications

Commercial Specifications

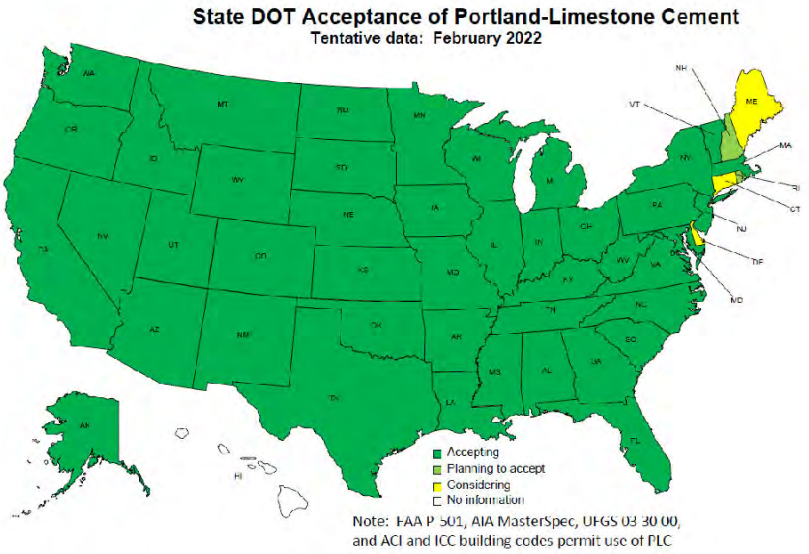
- ✓ **ASTM**
  - ASTM C595 – Blended cement
  - ASTM C94 – Ready Mix Concrete
  - Pipe, culverts, tile, block, plaster, masonry grout
- ✓ **American Concrete Institute**
  - ACI 318 – Building Code
  - ACI 301 – Specification for Structural Concrete
  - ACI 332 – Residential Code
  - ACI 350 – Environmental Concrete Structures
- ✓ **International Building Code**
- ✓ **AIA** MasterSpec 033000 Cast-in-Place Concrete
- ✓ **Military** UFGS Spec (USACE, Air Force, Navy, NASA)
- ✓ **FAA** P-501 Portland Cement Concrete Pavement

Suggested to include Type IL as an option on all submittals even if not allowed in the specification.

- Type IL is relatively new in the US (2012) and has not been widely available until recently, so it is not yet in all commercial specifications.
- Suppliers can propose alternatives for acceptance.
- Most engineers do not oppose Type IL cement even if they do not explicitly allow in their specification.

© National Ready Mixed Concrete Association

Specifications

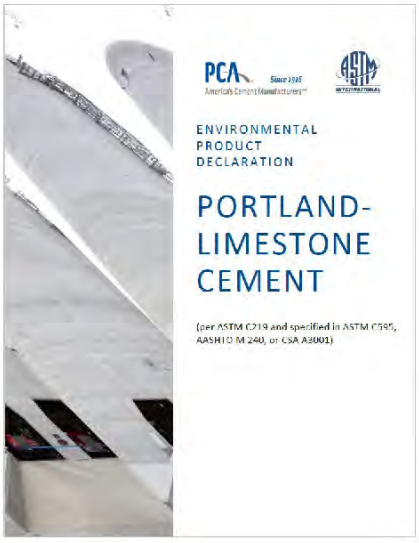


Note: FAA P-501, AIA MasterSpec, UFGS 03 30 00, and ACI and ICC building codes permit use of PLC

Sustainability

Savings of up to 10% CO_2 equivalent with Portland Limestone Cement, mainly due to lower clinker factor.

NEW in 2021 – Industry-Wide EPD for PLC

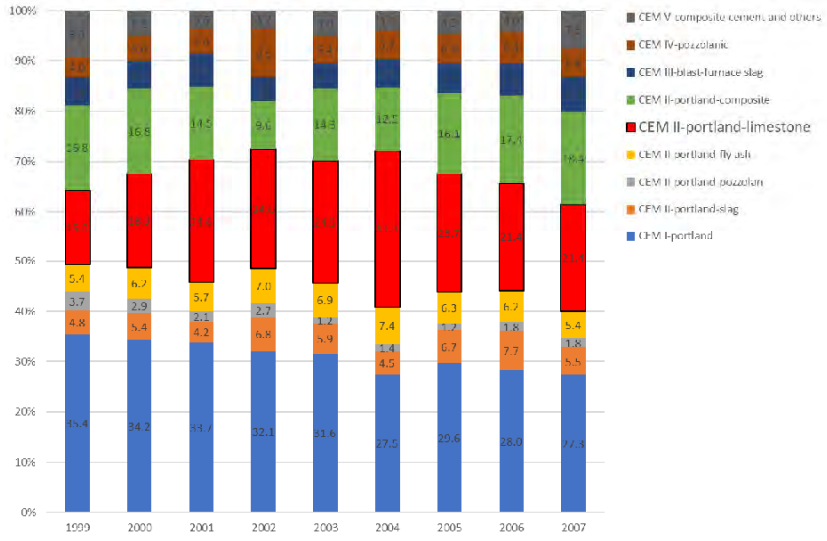


© National Ready Mixed Concrete Association

History of Portland-Limestone Cement

- 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, as was commonly practiced in various European cement standards prior to that.
- 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 containing 5%-15% limestone
- **2012 ASTM C595/AASHTO M 240 include PLC**

European Cement Use



Case Studies

- 4,400 cy mass concrete foundation
- Type IL and class F fly ash
- Temperature consistent with expectations and comparable to Type I/II

- Multiple e-commerce tilt-up warehouses
- F_f/F_l criteria met
- Early strength achieved to tilt panels
- Low shrinkage to prevent curling and joint openings
- Durable surface finish

Case Studies

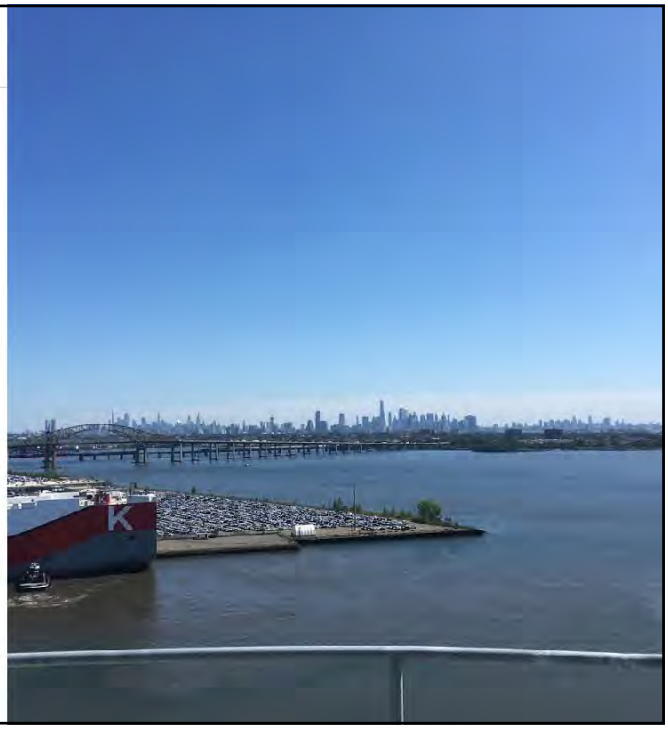
- Multiple high-rise buildings
- 16,000 psi compressive strength and higher
- Modulus of elasticity – no difference versus Type I/II

- Multiple precast applications
- Excellent early strength
- Slightly lighter color reduces pigment use

© National Ready Mixed Concrete Association

Summary

- Cement and concrete industry committed to achieve carbon neutrality by 2050.
- Carbon neutral concrete will require many solutions.
- Portland Limestone Cement (Type IL) is a proven solution available now
  - 10% reduction in CO_2
  - Equivalent performance
  - Accepted by DOTs, building codes, commercial specifications



Thank You!

Eric P. Koehler, Ph.D., P.E., FACI
Director of Quality | Titan America | ekoehler@titanamerica.com