U.S. Department of Transportation
Federal Highway Administration
Turner-Fairbank Highway Research Center

Portland Limestone Cement Variability and Use in High-Early-Strength (HES) Concrete Mixtures

American Concrete Institute (ACI)
Spring 2024 Meeting
New Orleans, LA

Michelle Cooper
Concrete Materials Research Engineer,
Federal Highway Administration (FHWA), Office of Infrastructure Research and Development, Infrastructure Materials Team

March 26, 2024

Source: FHWA.

Who Am I?

- B.S. in Civil Engineering from Virginia Tech
- Worked at NIST
- M.S. in Civil Engineering from UIUC
- Worked as a forensic structural engineer
- Concrete Materials Research Engineer for FHWA TFHRC
- Concrete Sustainability Ph.D. student at Michigan Tech

Source: FHWA.

Team

Luca Montanari
lucopr@gmail.com
Graduate Student
The University of Texas at Austin

Payam Hosseini
Payam.Hosseini.CTR@dot.gov
Materials Research Engineer
Genex Systems

Dr. Maria Juenger
mjuenger@mail.utexas.edu
Professor
The University of Texas at Austin

Robert Marinello
Robert.Marinello.CTR@dot.gov
Technician
Genex Systems

Michelle Cooper
Michelle.Cooper@dot.gov
Concrete Materials Research Engineer
Federal Highway Administration

Scott Muzenski
Scott.Muzenski.CTR@dot.gov
Concrete Research Engineer
Concrete Contract Laboratory Manager
Genex Systems

Acronyms and Abbreviations

Acc	**accelerator**
ADOT	Arizona Department of Transportation
AE	**air entrained**
AFt	aluminate ferrite trisubstituted
Al	alumina
Al_2O_3	alumina oxide
FHWA	Federal Highway Administration
GG	ground glass
HES	**high-early-strength**
HRWR	high-range water reducer
MK	metakaolin
NAE	**non-air entrained**
OPC	ordinary portland cement
PennDOT	Pennsylvania Department of Transportation
PLC	portland limestone cement
SCM	supplementary cementitious material
TxDOT	Texas Department of Transportation
w/c	water-to-cement ratio
Wt	weight

Why Is FHWA Performing PLC Research?

PLC TechNote is available![1]
It discusses implementation challenges and best practices.

TECHNOTE

U.S. Department of Transportation
Federal Highway Administration

Turner-Fairbank
Highway Research Center

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

https://highways.dot.gov/research

Portland Limestone Cement

FHWA Publication No.: FHWA-HRT-23-104

FHWA Contact:

Michelle Cooper
(ORCID: 0000-0001-8112-693X), HRDI-10,
202–493–3691, michelle.cooper@dot.gov

Robert Spragg
(ORCID: 0000-0001-9205-1486), HICP-40,
202–366–0120, robert.spragg@dot.gov

INTRODUCTION

Portland limestone cement (PLC) is a binary blended cement manufactured according to ASTM International (ASTM) C595[1] or American Association of State Highway and Transportation Officials (AASHTO) M 240.[2] PLC contains 5- to 15-percent blended or interground limestone and is alternatively identified with the term "IL," which indicates portland cement-limestone blended cement in ASTM C595 and AASHTO M 240.[1,2] PLC is engineered to provide 28-d performance equivalent to that of ordinary portland cement (OPC) (ASTM C150[3] or AASHTO M 85[4]) for 1:1 replacement while reducing global-warming potential (GWP) 8.3 percent on average, thanks to its lower clinker content.[5] Cement suppliers are typically producing PLC with 10- to 12-percent limestone powder because such a blend results in a more optimal, 1:1 performance.

Though PLC has now become widely available throughout the United States, several agencies and contractors have reported challenges with its implementation due to limited field experience using the material in the United States.[6] This TechNote is designed to help State highway agencies (SHAs) and contractors become more acquainted with technical and background information regarding PLC and to promote its successful application nationwide. The document provides information regarding the history, specifications, sustainability, manufacture, engineering principles, and performance of PLC. In addition, the document presents successful case studies and best practices for implementing PLC.

History of PLC in the United States

ASTM C150 began allowing the use of up to 5-percent interground limestone in OPC types I–V in 2004.[3] Before then, in North American specifications, limestone had not been permitted as an addition to cement. AASHTO M 85 was harmonized with ASTM C150 in 2007, when the 5 percent allowable limestone content for OPC was balloted and accepted.[4] PLC was introduced in the United States in 2005 through ASTM C1157 as a performance cement.[7] While cements with high ground limestone contents have been successfully used in Europe for 15–20 yr, North American PLC differs in that it was designed to have mechanical properties similar to those of OPC at 28 d, and the concrete producers often add supplementary cementitious materials (SCMs) to PLC.[8] Beginning in 2012, ASTM C595 and AASHTO M 240 standard specifications for blended hydraulic cements started allowing up to 15-percent blended or interground limestone to be used in binary blended cements, and the specifications defined the product as IL or PLC.[1,2] While PLC has been allowed in many States since 2012,

Source: FHWA.[1]

https://highways.dot.gov/research/publications/infrastructure/FHWA-HRT-23-104.pdf [1]

Use tools such as calorimetry to investigate the early-age reaction behavior of the PLC or the PLC in combination with the anticipated admixtures and SCMs.

Differing sulfate content requirements for PLC concretes— especially with SCMs, compared to OPC concretes.

Evaluate production variation (e.g., strength or air content) prior to transitioning from OPC to PLC to provide an understanding of within-plant product variations.

FHWA PLC Research

PLC Variability

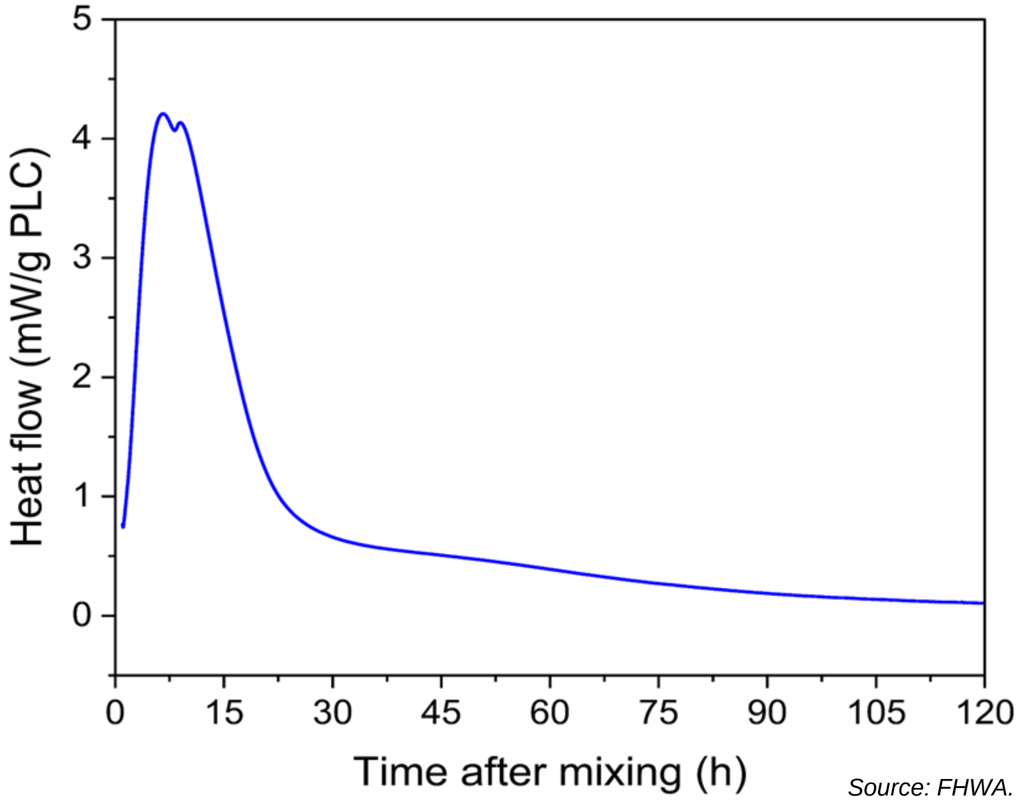
Provide the industry with information regarding how different PLC characteristics can affect performance.

PLC for HES Concretes

Evaluate how PLCs can be used in HES concretes.

Hydration Kinetics

Typical Hydration Kinetics Curve From Isothermal Calorimetry



Source: FHWA.

Hydration kinetics relate to:

- Performance.
- Reactivity:
  - Rate of reaction.
  - Magnitude of reaction.

PLC Variability

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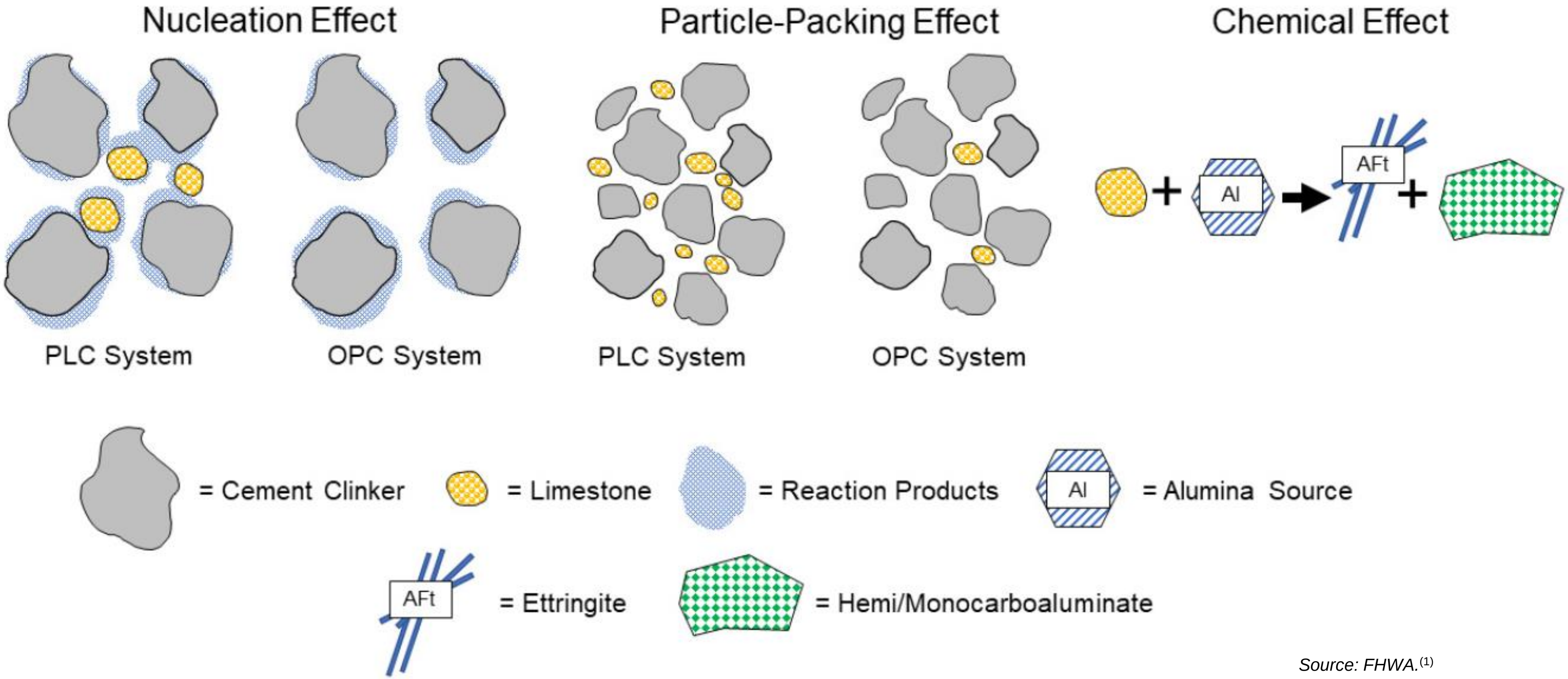
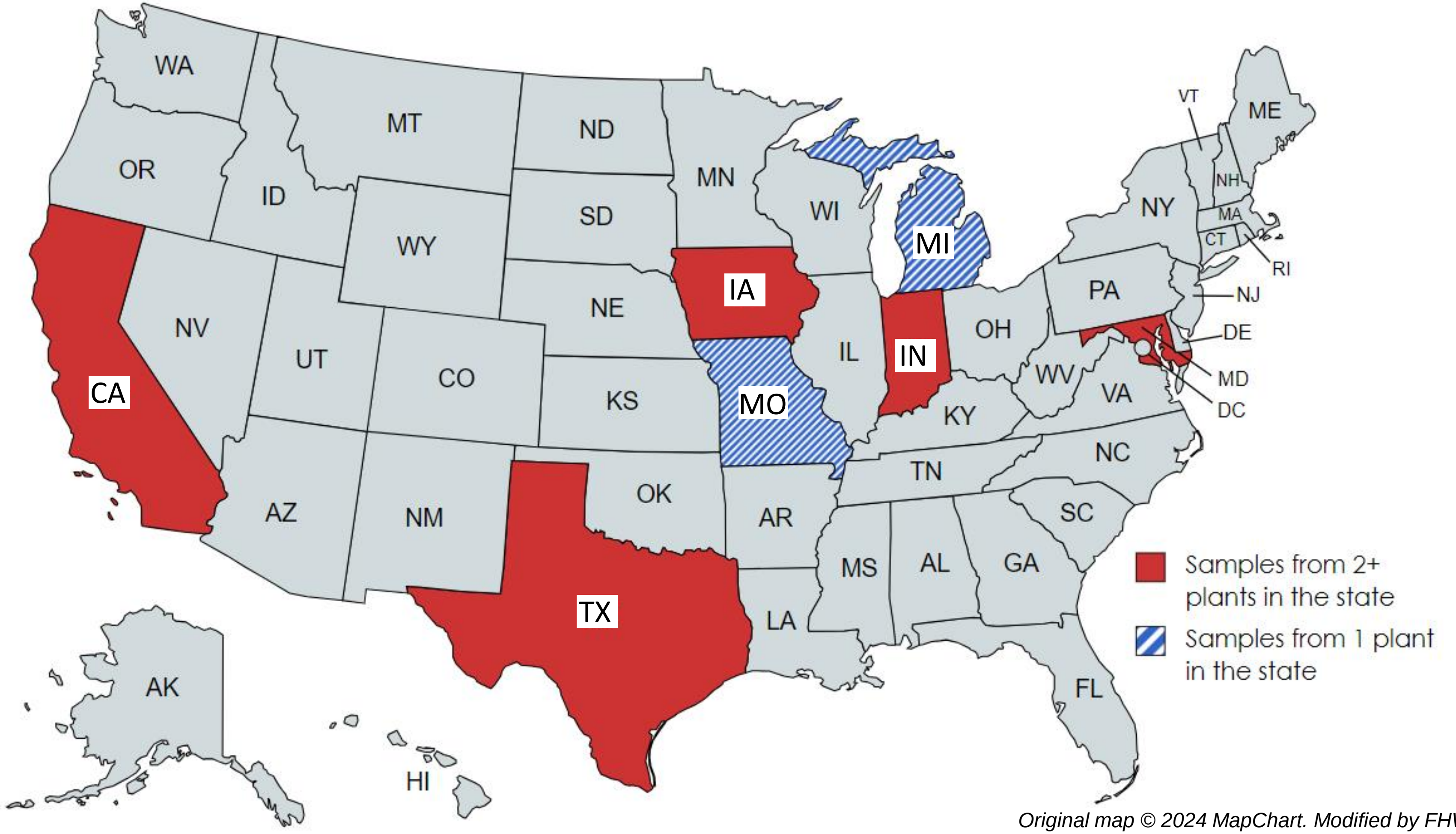
Limestone Effects in Cement



Source: FHWA.(1)

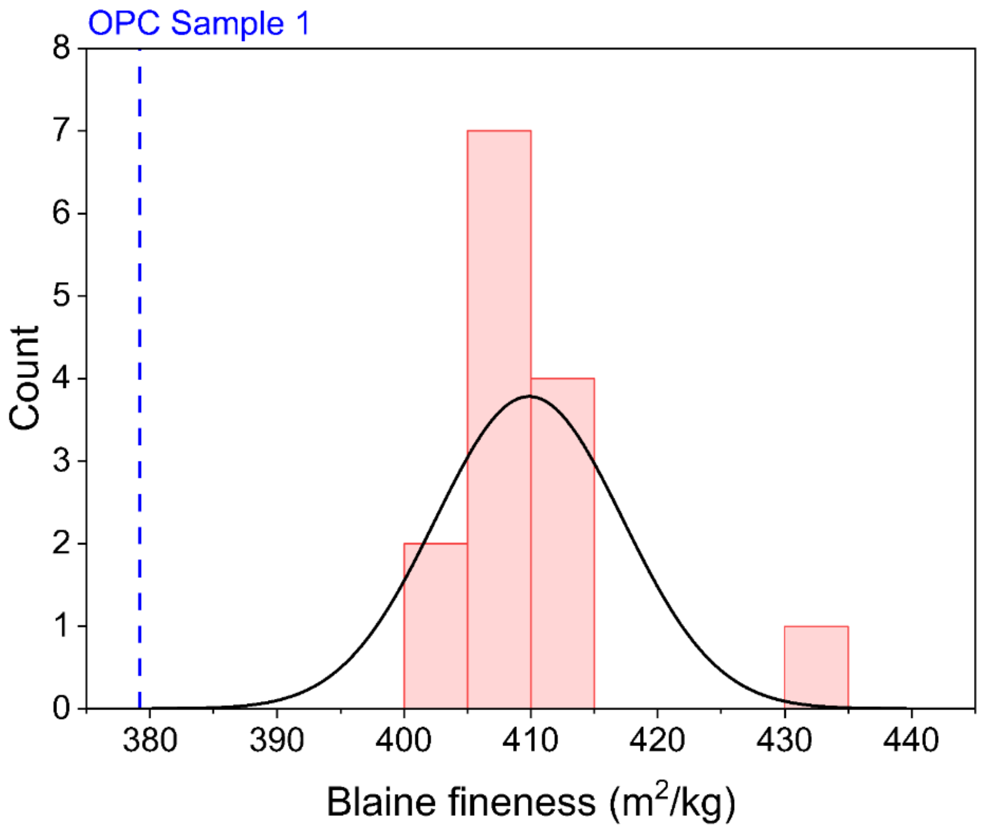
Map of PLCs Tested From Around the United States



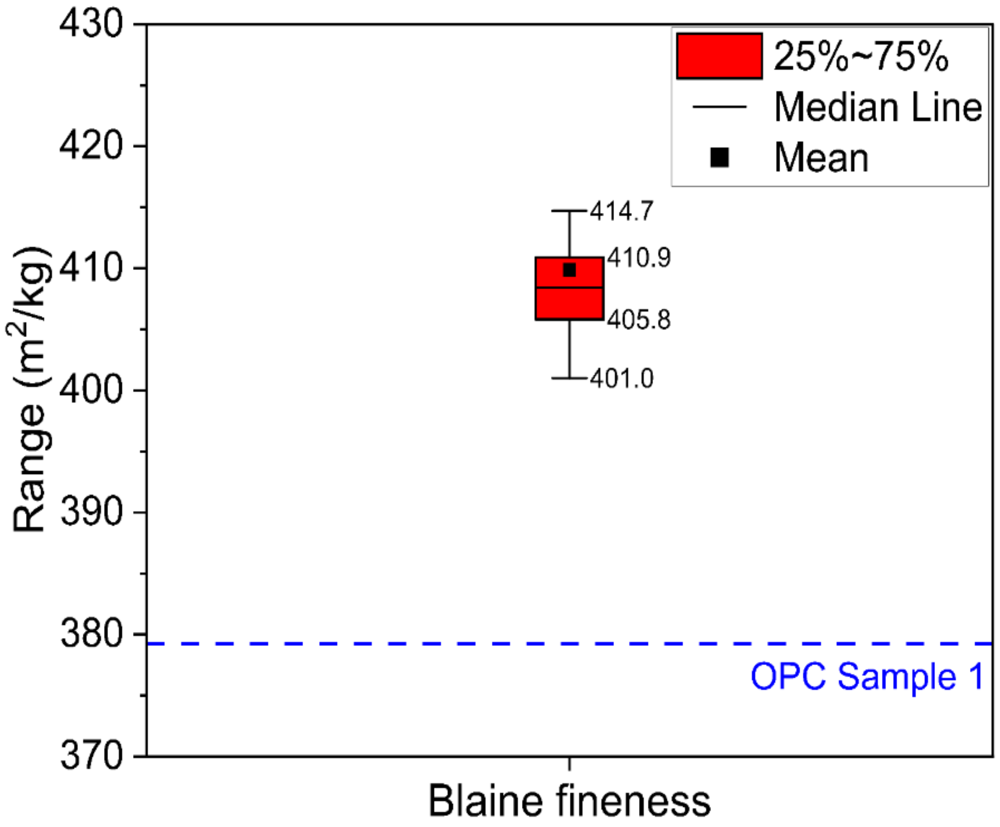
Original map © 2024 MapChart. Modified by FHWA.[(2)]

Blaine Fineness(3)

Distribution of Measurements



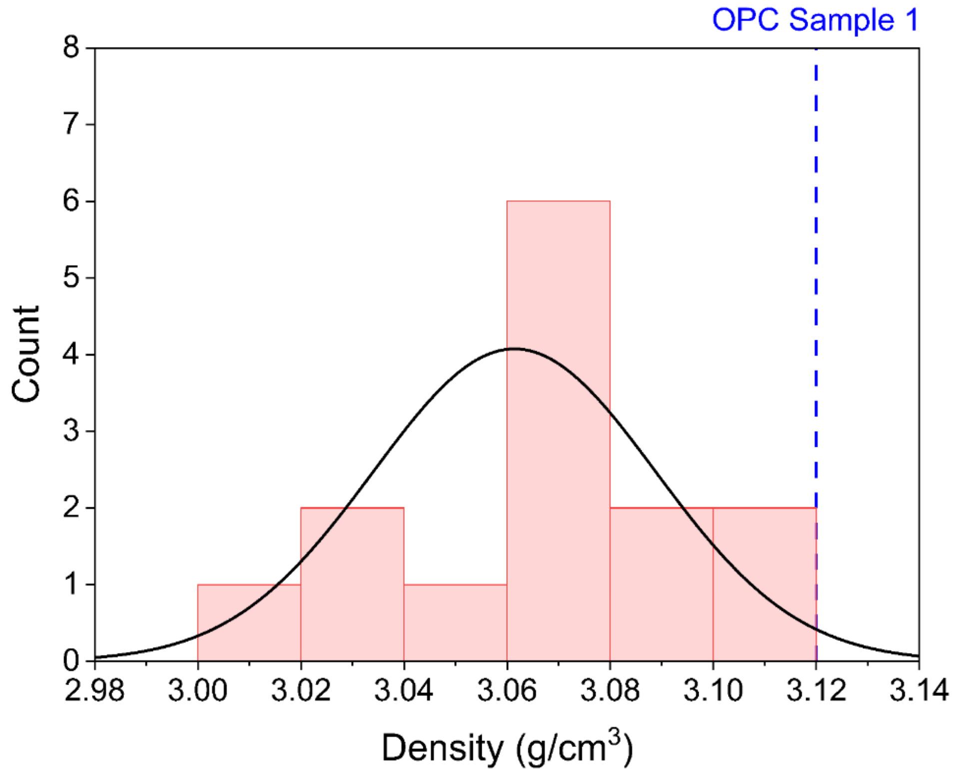
Minimum and Maximum of Fineness Measured for PLCs Versus OPC



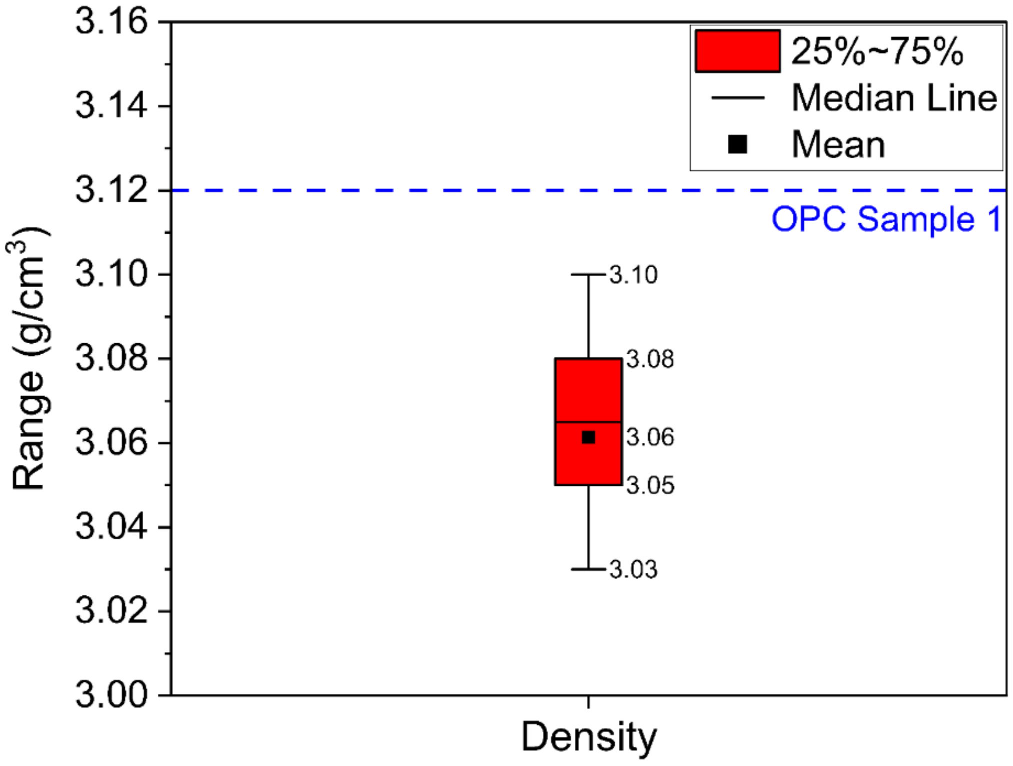
All images source: FHWA.

Density

Distribution of Measurements



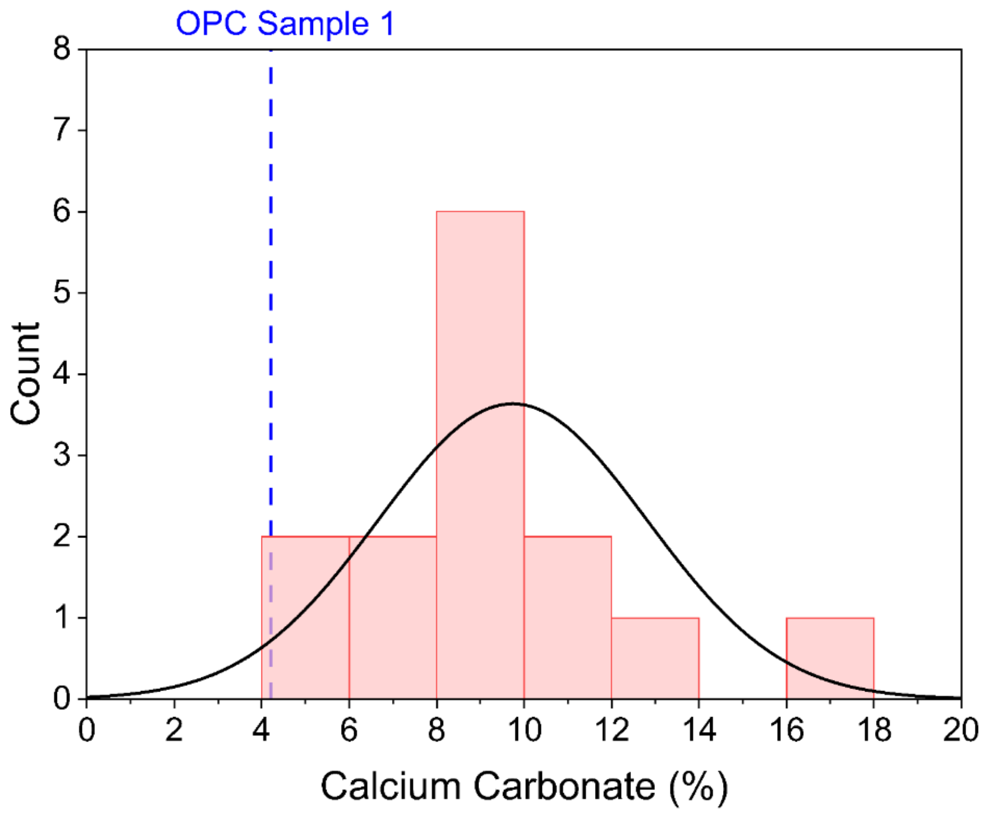
Minimum and Maximum of Density Measured for PLCs Versus OPC



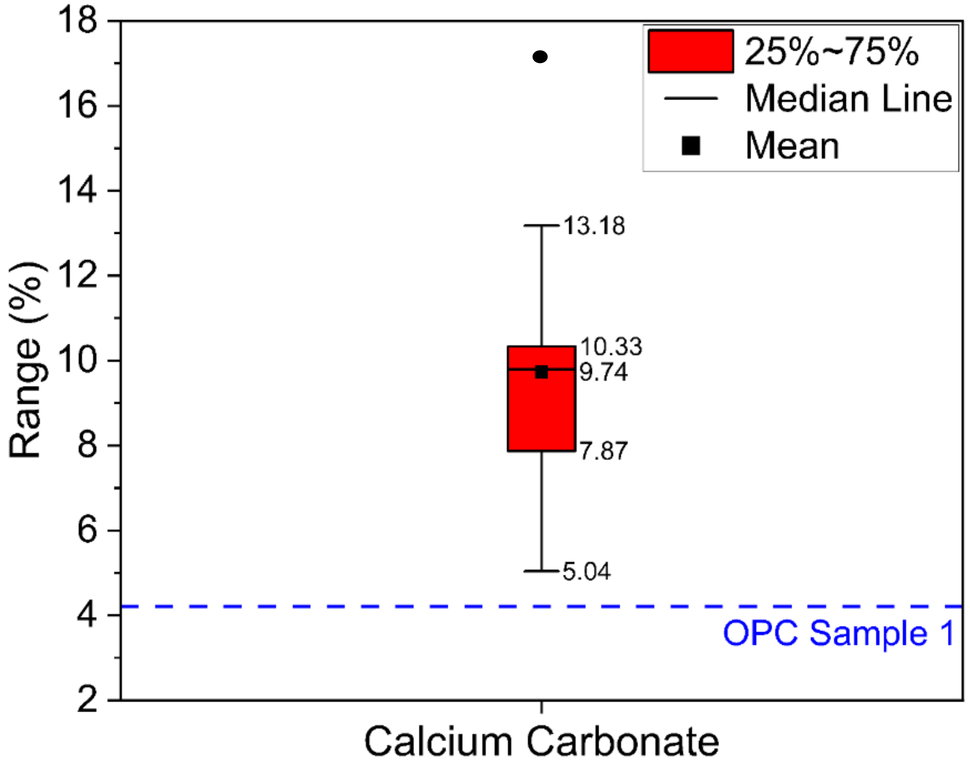
All images source: FHWA.

Calcium Carbonate Content

Distribution of Measurements



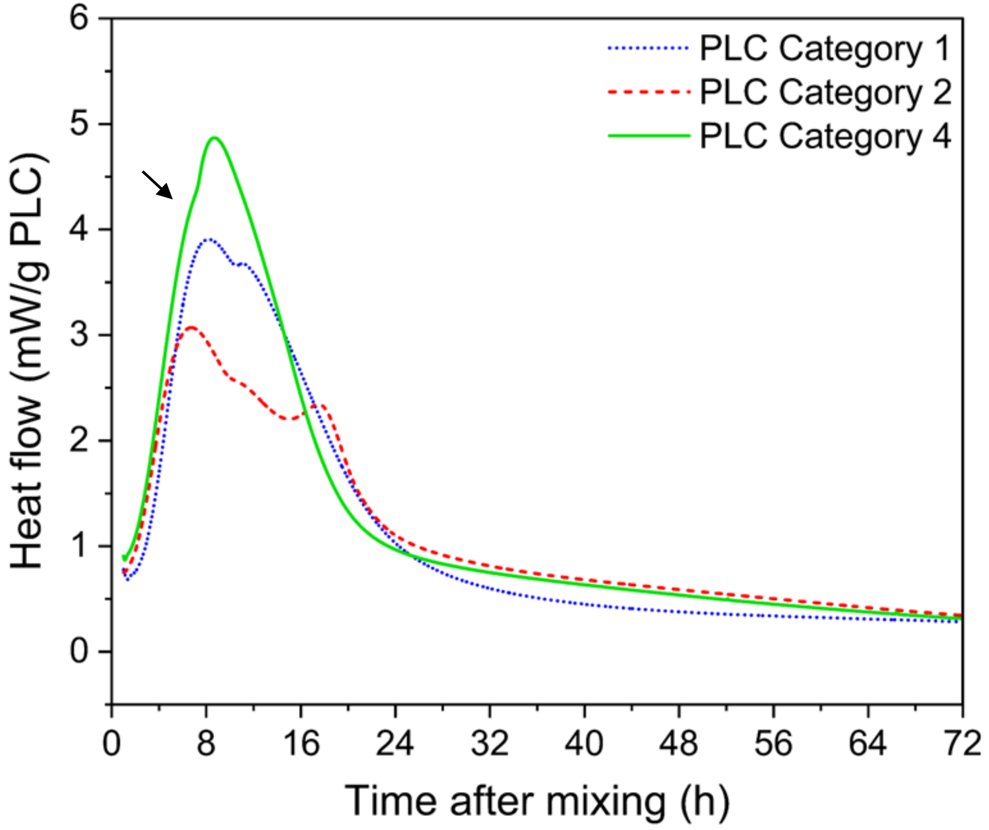
Minimum and Maximum of Calcium Carbonate Content Measured for PLCs Versus OPC

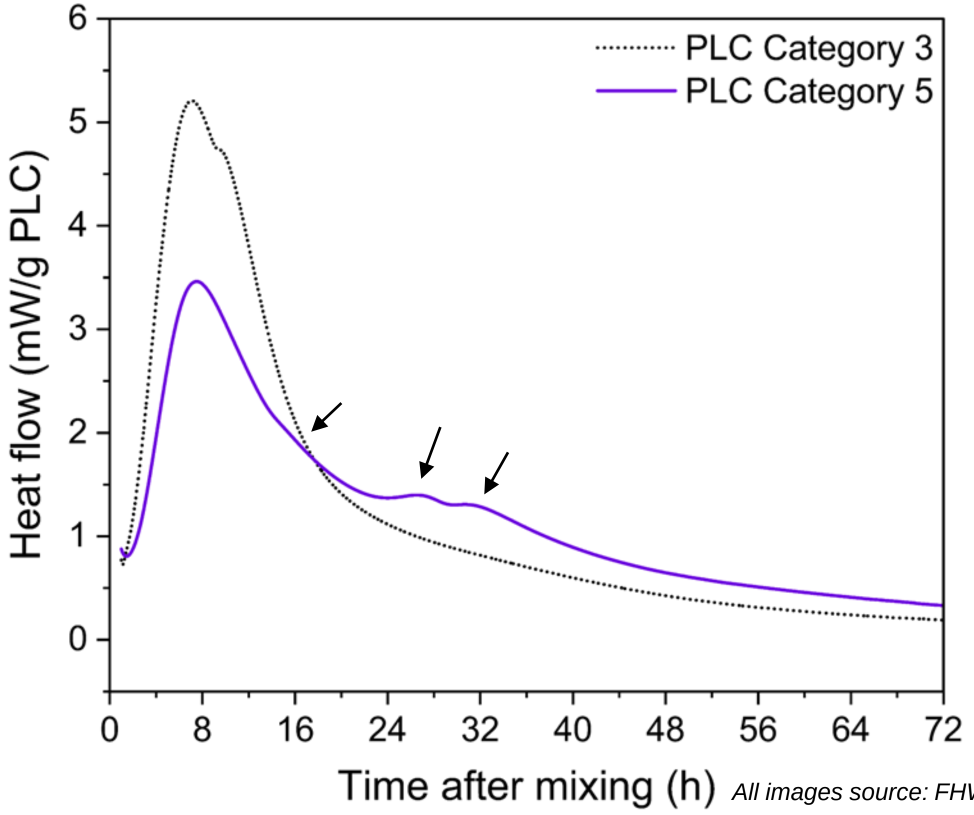


All images source: FHWA.

Sulfation

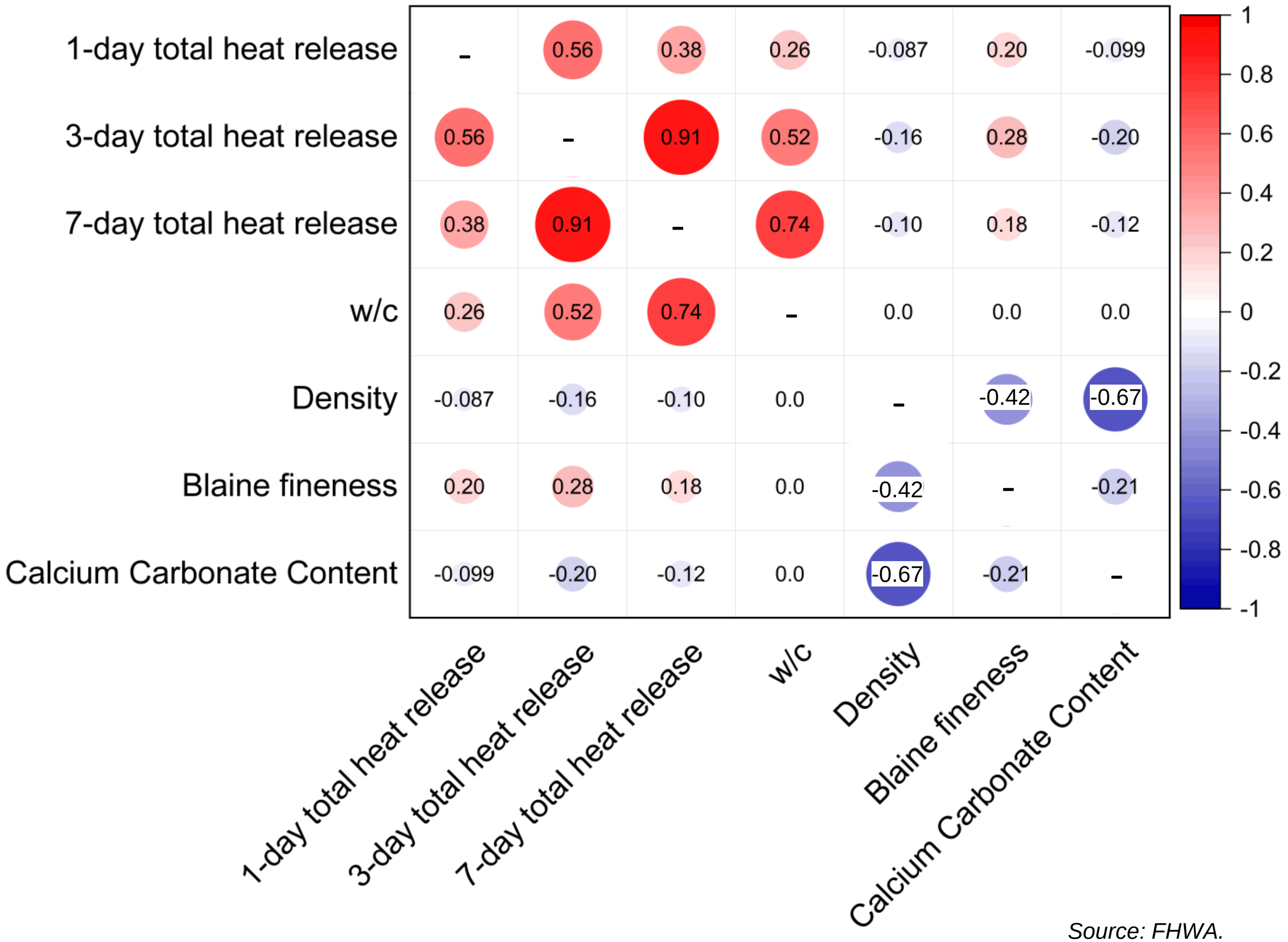
Category	Description	Number of PLCs Tested
1	Properly sulfated	4
2	Three close peaks	7
3	Overlapping alite and aluminate peaks	2
4	Higher aluminate peak than the alite peak	2
5	Four peaks	1





All images source: FHWA.

Correlations



Source: FHWA.

How Can PLC Characteristics Affect Performance? (1/3)

PLC characteristic:

- Fineness.
- Density.
- Sulfate level.
- Calcium carbonate content.

Potential influence on performance:

- Air content.
- Slump.
- Setting time.
- Strength development.
- Water demand.
- Shrinkage.

How Can PLC Characteristics Affect Performance? (2/3)

PLC characteristic:

- Fineness.
- Density.
- Sulfate level.
- Calcium carbonate content.

Potential influence on performance:

- Air content.
- Slump.
- Setting time.
- Strength development.
- Water demand.
- Shrinkage.

How Can PLC Characteristics Affect Performance? (3/3)

PLC characteristic:

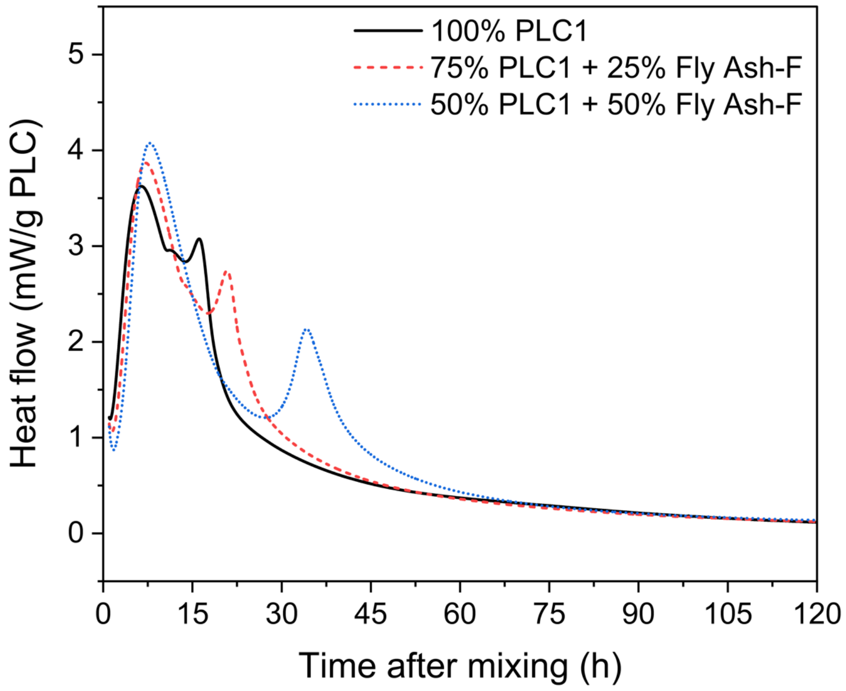
- Fineness.
- Density.
- Sulfate level.
- Calcium carbonate content.

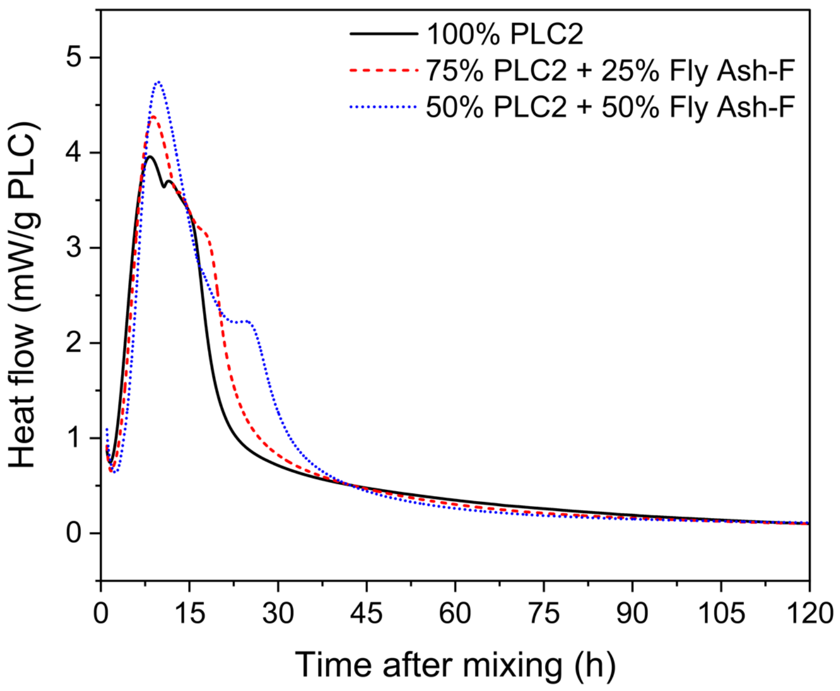
Potential influence on performance:

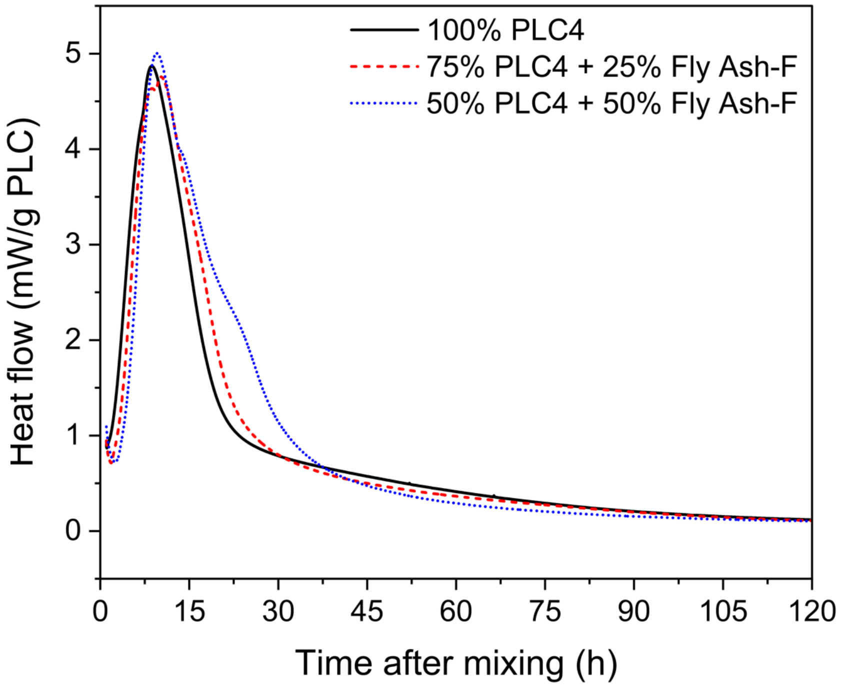
- Air content.
- Slump.
- Setting time.
- Strength development.
- Water demand.
- Shrinkage.

Durability

Varying effects when combined with SCMs







Summary

- Higher fineness typically results in higher water demand.
- Densities ranged from 3.03 to 3.10 g/cm^3.
- Calcium carbonate contents:
  - Ranged from 5 to 17 percent.
  - Correlated with lower densities.
- Varying sulfation levels lead to varying hydration kinetics and performance.
- Greater variability in hydration kinetics expected when used with SCMs.

PLC-Related Publications

Background and best practices TechNote is available![(1)]


TECHNOTE

Portland Limestone Cement

FHWA Publication No.: FHWA-HRT-23-104

FHWA Contact:

Michelle Cooper
(ORCID: 0000-0001-8112-693X), HRDI-10,
202–493–3691, michelle.cooper@dot.gov

Robert Spragg
(ORCID: 0000-0001-9205-1486), HICP-40,
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https://highways.dot.gov/research

https://highways.dot.gov/research/publications/infrastructure/FHWA-HRT-23-104[(1)]

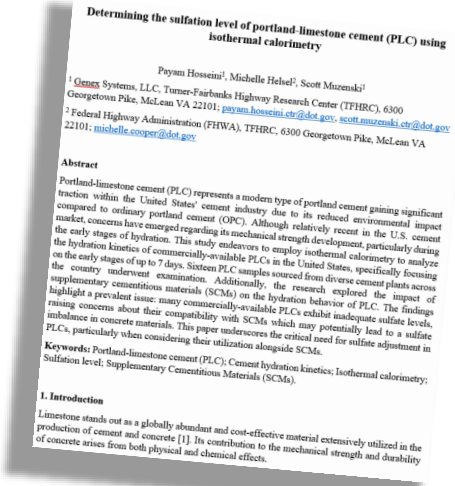
Upcoming Publications

TechNote: *PLC Variability**


TECHNOTE

Portland Limestone Cement Variability

Journal paper: "Determining the sulfation level of PLC using isothermal calorimetry"†


Determining the sulfation level of portland-limestone cement (PLC) using isothermal calorimetry

Payam Hosseini[1], Michelle Helsel[2], Scott Muzenski[1]

[1] Genex Systems, LLC, Turner-Fairbanks Highway Research Center (TFHRC), 6300 Georgetown Pike, McLean VA 22101; payam.hosseini.ctr@dot.gov, scott.muzenski.ctr@dot.gov

[2] Federal Highway Administration (FHWA), TFHRC, 6300 Georgetown Pike, McLean VA 22101; michelle.cooper@dot.gov

Abstract

1. Introduction

All images source: FHWA.

*Hosseini, P., M. Helsel, and S. Muzenski. *Portland Limestone Cement Variability*. Washington, DC: FHWA. In progress.

†Hosseini, P., M. Helsel, and S. Muzenski. Forthcoming. "Determining the sulfation level of portland-limestone cement (PLC) using isothermal calorimetry." In progress.

Use of PLCs in HES Mixtures

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Objective

Highlight the potential differences when switching OPC with PLC in HES mixtures.

Set accelerators and corrosion inhibitors ASTM C494:[(4)] type C calcium nitrite and calcium nitrate based	Polycarboxylate HRWR to ensure workability ASTM C494:[(4)] types A and F	High-reactivity SCM: high purity metakaolin (MK)	Low-reactivity SCM: Ground glass (GG)

Mixture Designs Tested*

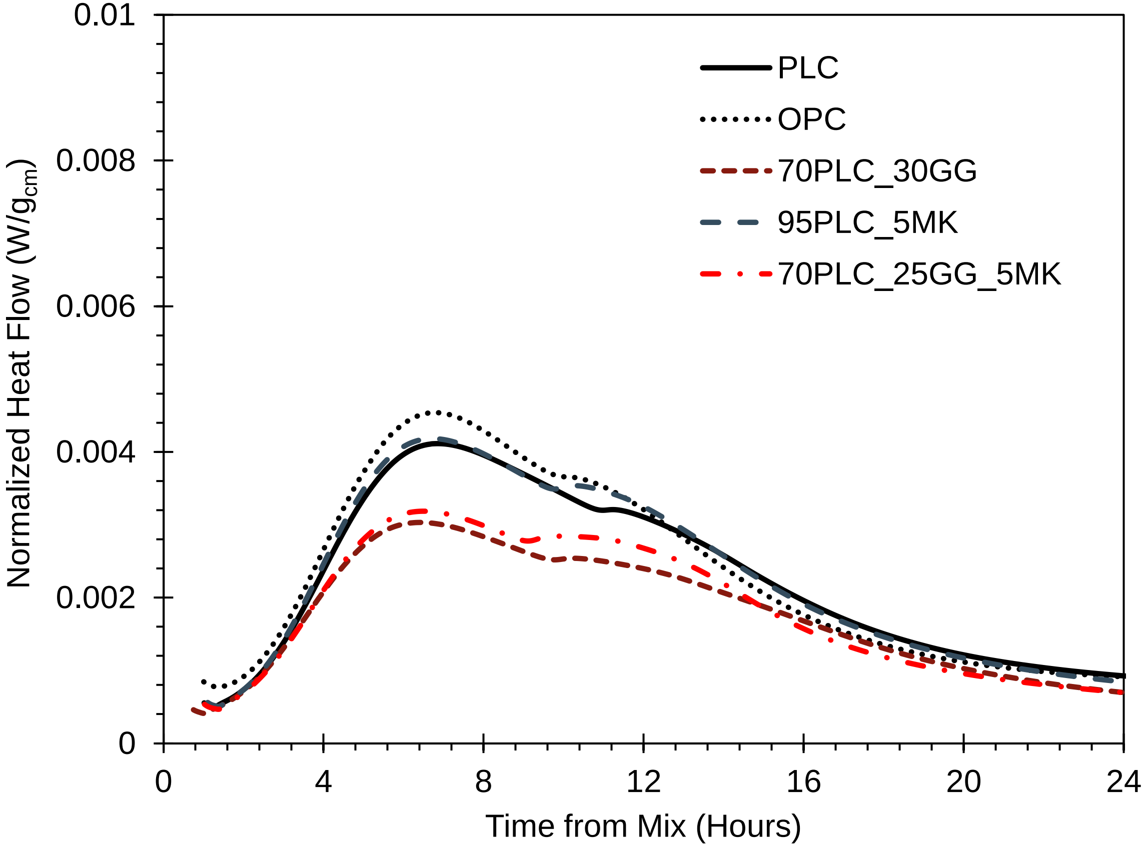
Mix ID	Cementitious Material Mass (percent)				Set Accelerating Admixture (Y/N)
	PLC	OPC	GG	MK	
PLC	100	0	0	0	N
OPC	0	100	0	0	N
70PLC_30GG	70	0	30	0	N
95PLC_5MK	95	0	0	5	N
70PLC_25GG_5MK	70	0	25	5	N
PLC_Acc	100	0	0	0	Y
OPC_Acc	0	100	0	0	Y
70PLC_30GG_Acc	70	0	30	0	Y
95PLC_5MK_Acc	95	0	0	5	Y
70PLC_25GG_5MK_Acc	70	0	25	5	Y

*Montanari, L., M.A. Helsel, P. Hosseini, and M. Juenger. “Evaluation of early age strength and porosity of binary and ternary mixtures incorporating portland limestone cement and a set accelerator.” In progress.

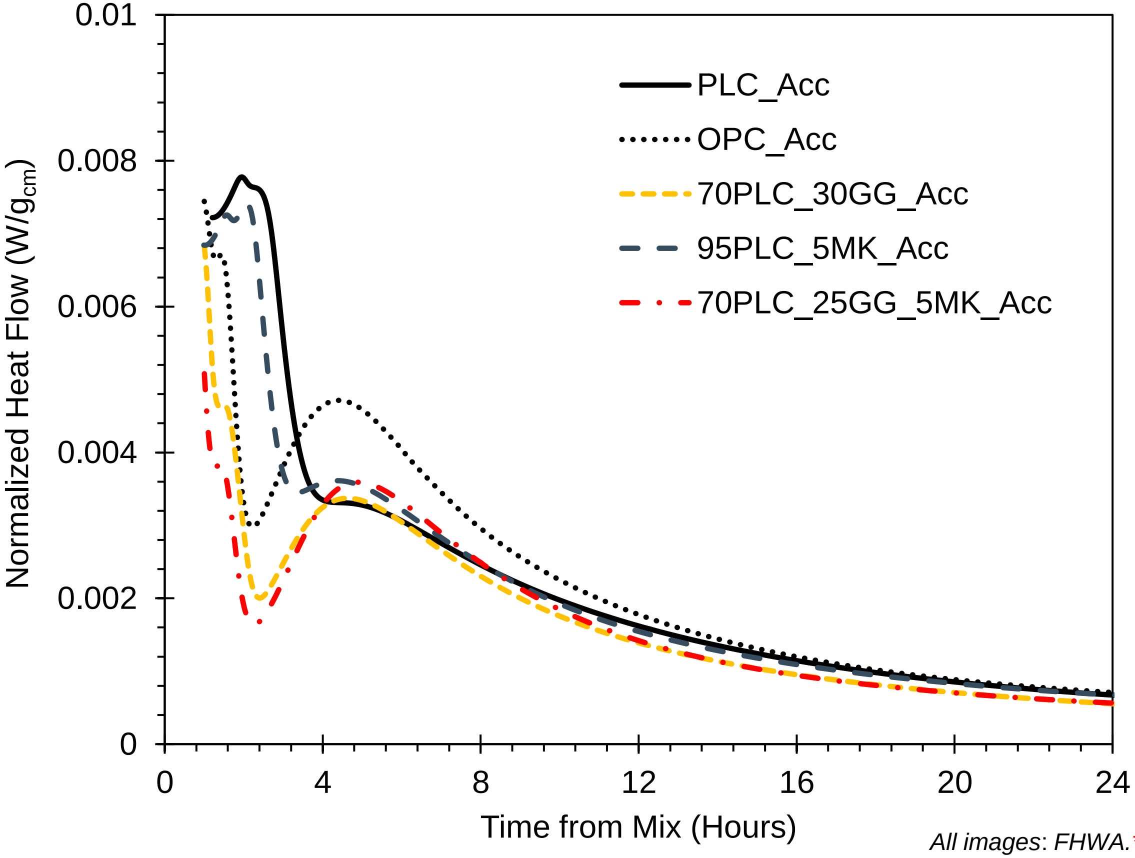
Y = yes; N = no.

Normalized Heat Flow

Without Accelerators



With Accelerators

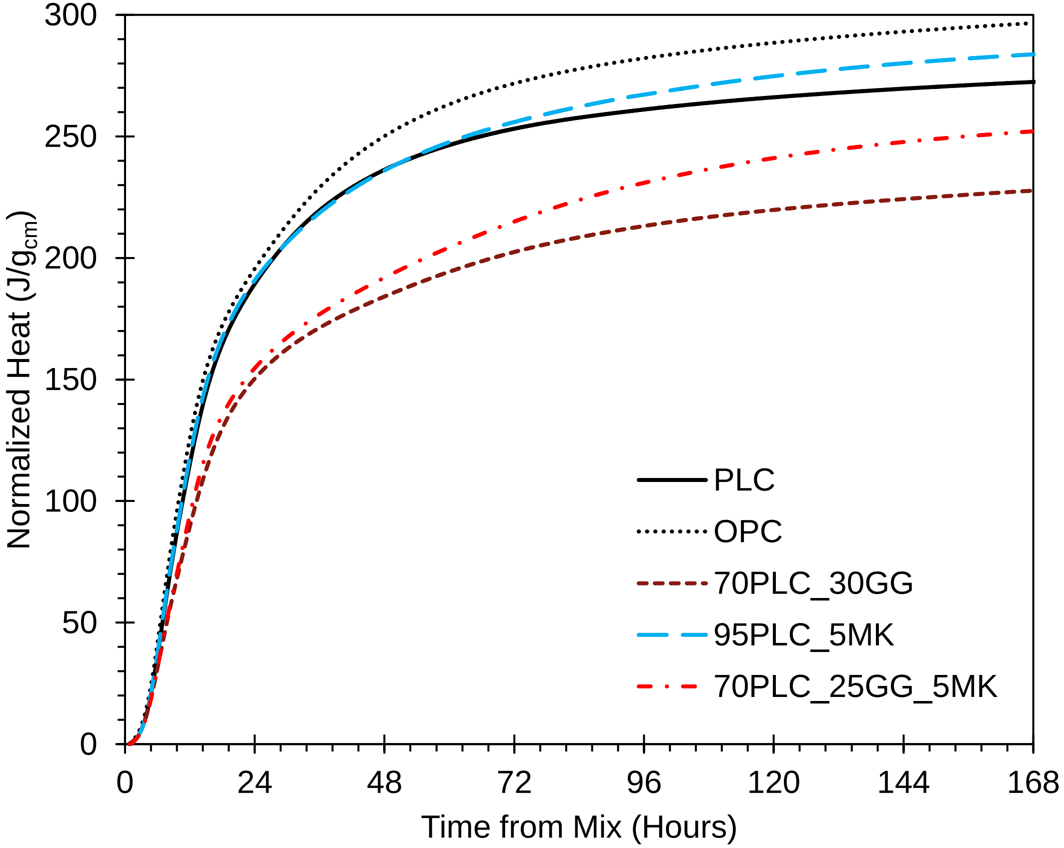


All images: *FHWA.**

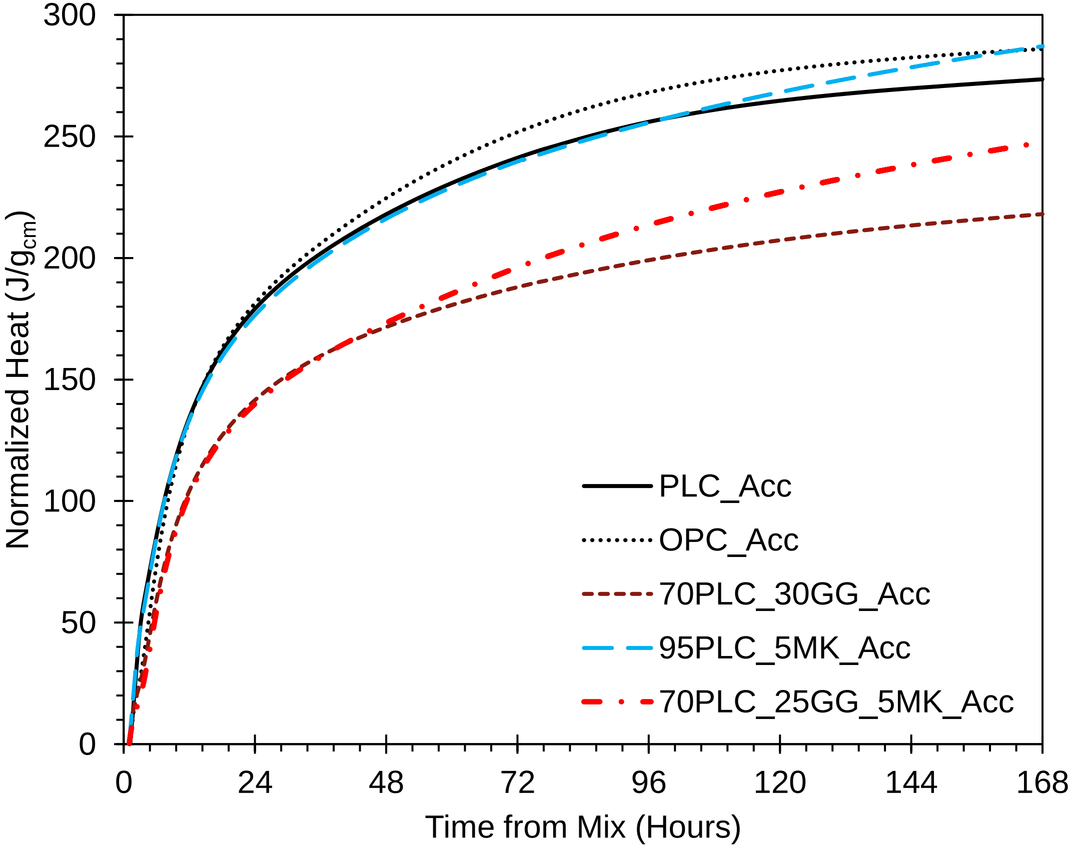
*Montanari, L., M.A. Helsel, P. Hosseini, and M. Juenger. “Evaluation of early age strength and porosity of binary and ternary mixtures incorporating portland limestone cement and a set accelerator.” In progress.

Cumulative Heat Released

Without Accelerators



With Accelerators



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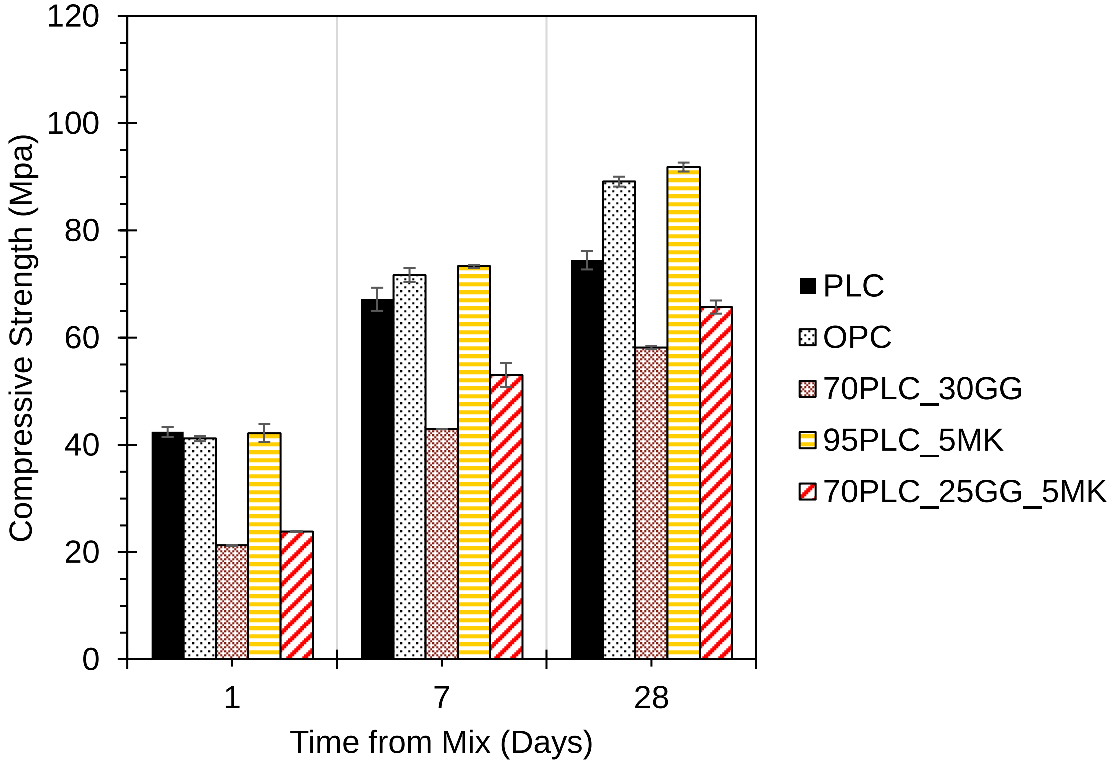
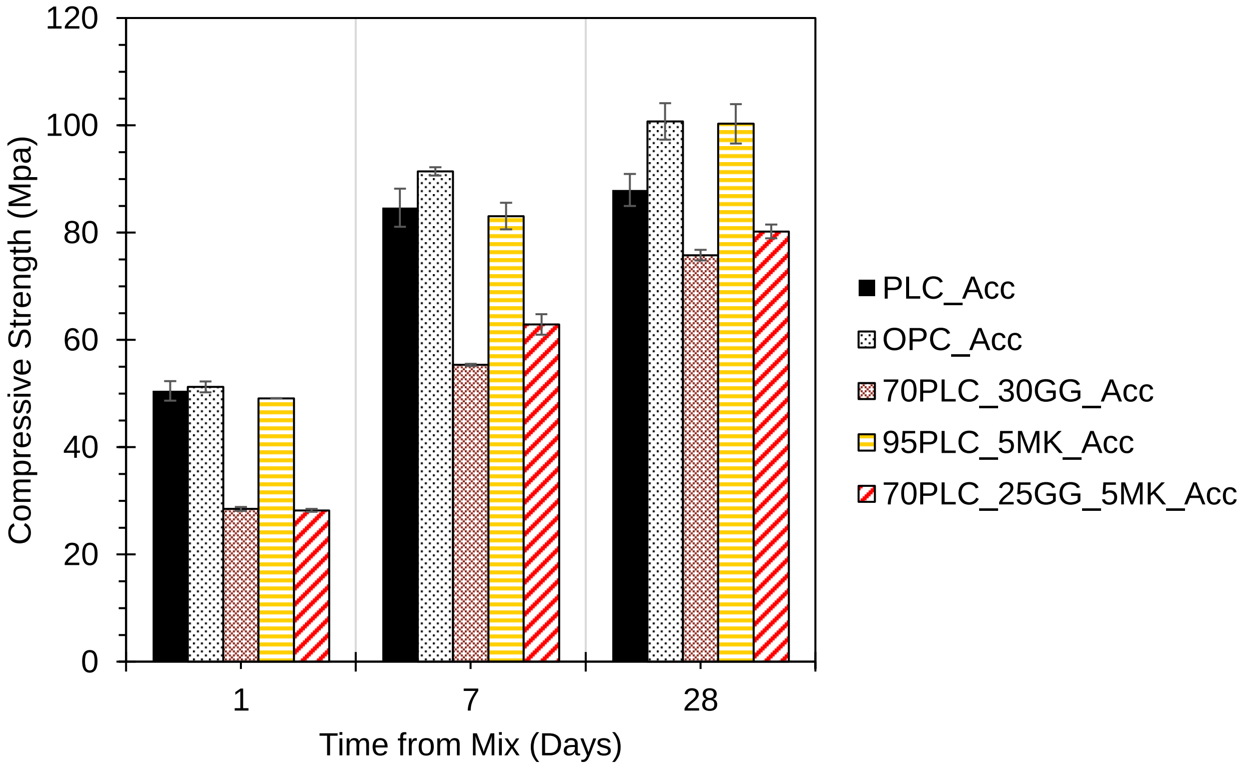
*All images source: FHWA.**

Mortar Cube Strength

Without Accelerators



With Accelerators



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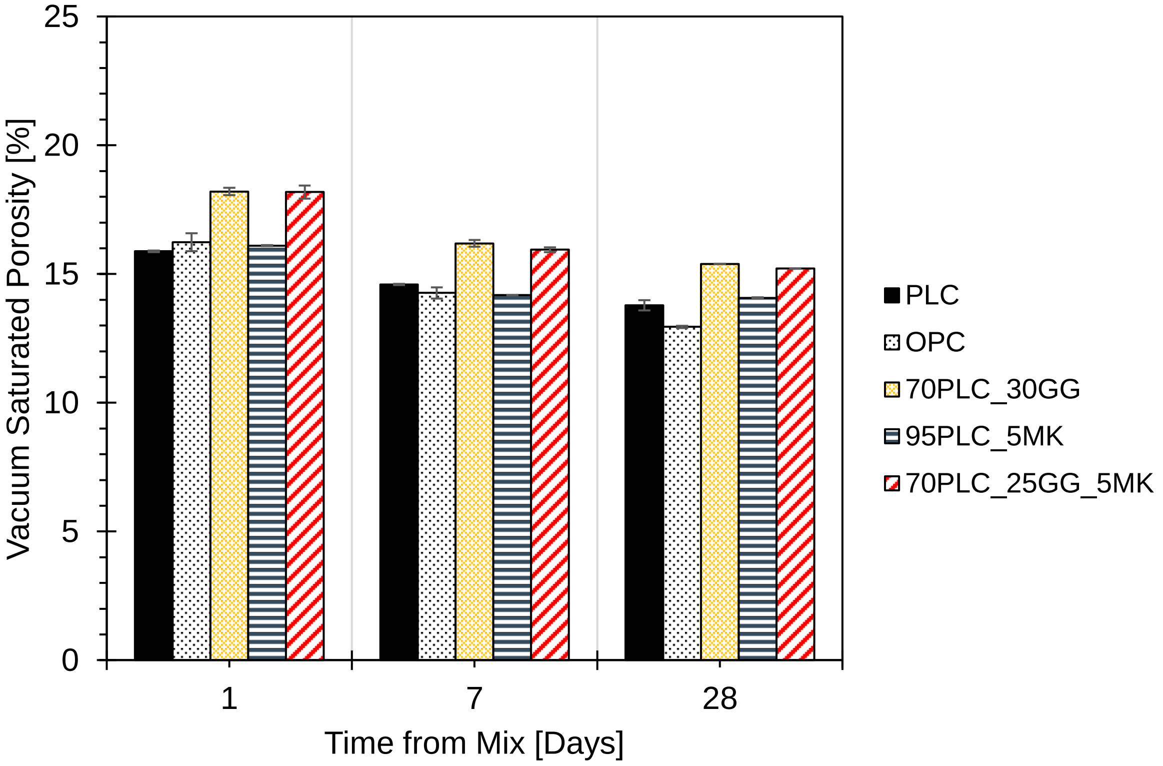
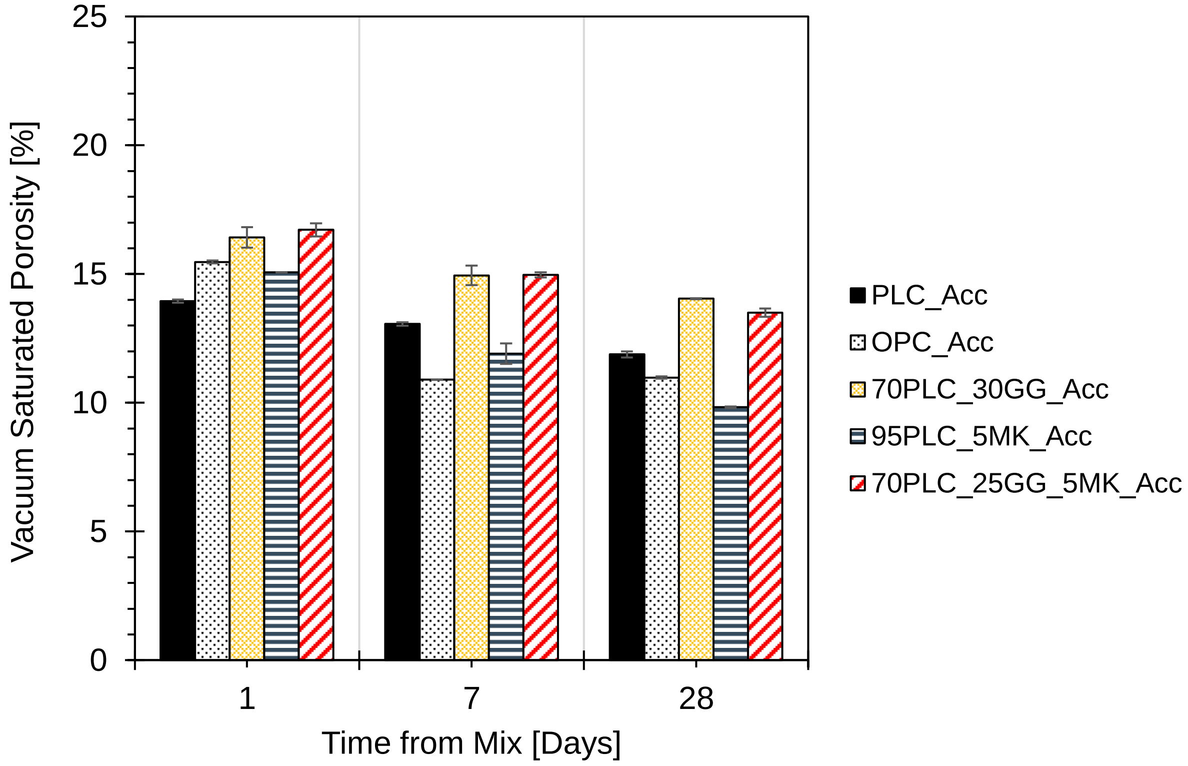
*All images source: FHWA.**

Porosity

Without Accelerators



With Accelerators



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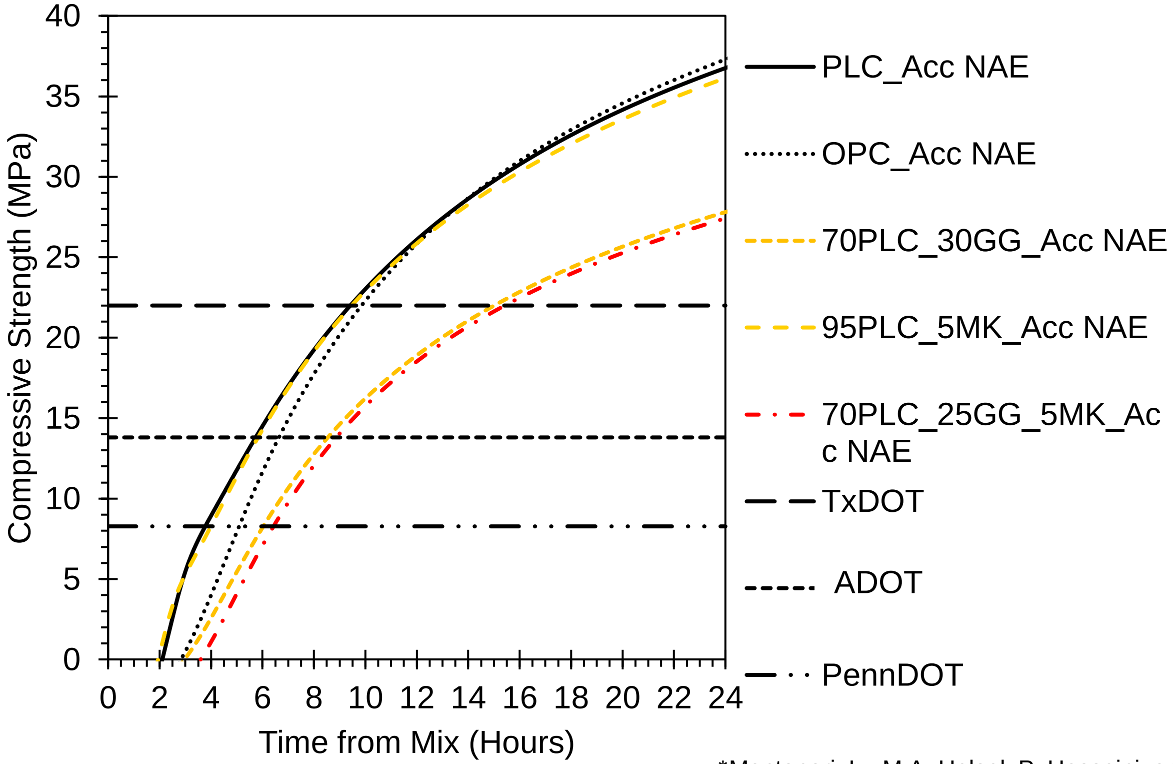
*Montanari, L., M.A. Helsel, P. Hosseini, and M. Juenger. “Evaluation of early age strength and porosity of binary and ternary mixtures incorporating portland limestone cement and a set accelerator.” In progress.

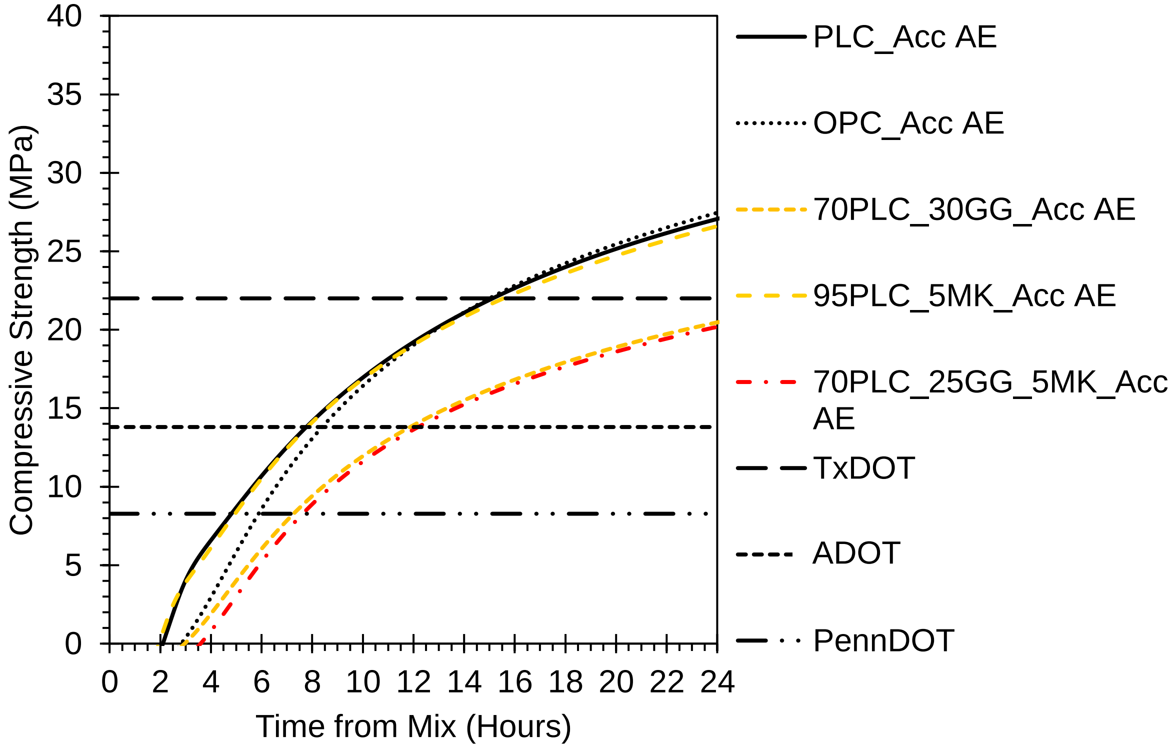
Concrete Strength Development

Extrapolated using isothermal calorimetry, mortar cube strengths, and Bentz et al.[5] methodology.

Non-Air Entrained



Air Entrained



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*All images source: FHWA.**

PLC Use in HES Mixtures Related Publications

Upcoming Publication*

Evaluation of Early Age Strength and Porosity of Binary and Ternary Mixtures Incorporating Portland Limestone Cement and a Set Accelerator

Authors

Luca Montanari (Corresponding Author)[1]
Michelle Helsel[2]
Payam Hosseini[3]
Maria Juenger[4]

[1]Graduate Student
Cockrell School of Engineering
University of Texas at Austin
Austin, TX 78712 (lucopr@gmail.com)

[2]Concrete Laboratory Federal Lab Manager
Turner-Fairbank Highway Research Center
Federal Highway Administration
McLean, VA 22101 (michelle.cooper@dot.gov)

[3]Concrete Materials Research Engineer
Genex Systems, LLC
Turner-Fairbank Highway Research Center
McLean, VA 22101 (payam.hosseini@dot.gov)

[4]Professor
Cockrell School of Engineering
University of Texas at Austin
Austin, TX 78712 (mjuenger@mail.utexas.edu)

Abstract

With the goal of reaching carbon neutrality by 2050, the cement and concrete industries in the US have accelerated the implementation and adoption of technologies that promote the reduction of embodied carbon emissions in new concrete mixtures. One of the available strategies to reduce the embodied emissions of concrete is the use of cements with a lower clinker content than the typical ordinary portland cement (OPC). Portland limestone cement (PLC) is one example of lower clinker cement, thanks to the limestone content ranging between 5 and 15%. PLC is designed to provide similar 28-day compressive strength to an OPC produced from the same clinker. However, little information and data are currently available regarding PLC's ability to satisfy very early age mechanical performance (i.e., within 24 hours from initial mixing) for high-early-strength (HES) concrete applications. Due to the partial replacement of clinker with limestone in PLC, it is not immediately clear whether early age reactions can

*Source: FHWA.**

*Montanari, L., M.A. Helsel, P. Hosseini, and M. Juenger. "Evaluation of early age strength and porosity of binary and ternary mixtures incorporating portland limestone cement and a set accelerator." In progress.

Summary

Can we use PLC in HES mixtures? **YES!**

- PLC can replace OPC in HES mixtures with and without SCMs and accelerating admixtures while meeting State HES requirements, depending on:
  - SCM replacement level.
  - SCM reactivity and type.
  - Exposure class.
  - Reopening strength and time requirements.
- The inclusion of accelerators improved early-age degree of reaction and compressive strength for all systems.

Questions?

Contact

Michelle Cooper

michelle.cooper@dot.gov

U.S. Department of Transportation
Federal Highway Administration

Turner-Fairbank Highway Research Center

References

1. Montanari, L., M. A. Helsel, R. Spragg, O. B. Isgor, and W. J. Weiss. 2023. *Portland Limestone Cement*. Publication No. FHWA-HRT-23-104. Washington, DC: FHWA. https://doi.org/10.21949/1521434, last accessed March 7, 2024.
2. MapChart. 2024. *MapChart* (software). https://www.mapchart.net/usa.html, last accessed March 12, 2024.
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Extra Slides

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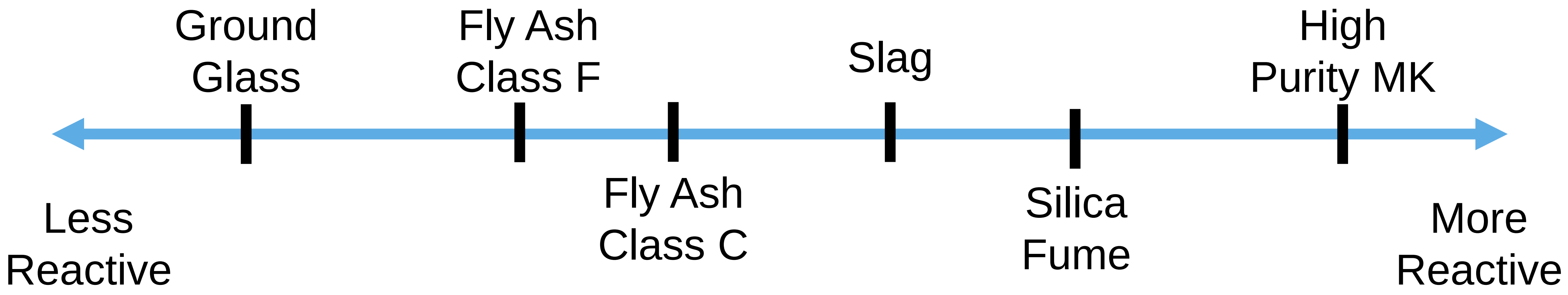
SCM Reactivity



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