You're invited!

Please join us for an informal workshop on:

Portland-Limestone Cement (PLC)

10:00 AM to 2:00 PM, January 23, 2013
Mississippi State University Campus, Starkville, MS

PLC is a slightly modified version of portland cement that improves both the environmental footprint and the basic performance of concrete. It is now described in ASTM and AASHTO specifications, is available in Mississippi, and is used just like traditional portland cement in mix designs. This workshop will acquaint participants with background and technical data on this new product with respect to its manufacture and related sustainability benefits, performance attributes, specifications, and applications.

Scheduled Agenda:

10:00 AM	Welcome and introduction, Harry Lee James, PE – MCIA
10:15 AM	PLC production, specs, use, and performance, Tim Cost, PE, FACI – Holcim
11:00 AM	PLC research, Davis-Wade Stadium expansion, Isaac L. Howard, MSU CEE
11:45 AM	Lunch, provided at meeting room location
12:30 PM	PLC benefits for project owners
1:00 PM	Discussion and questions
2:00 PM	Adjourn, and optional tour of MSU CEE laboratories

-- This workshop is intended for a broad audience and will have content of interest for anyone who works with cement and concrete.
-- There is no fee to attend, and lunch is included.
-- A certificate for professional development hours (PDHs) will be provided for those attending the workshop in its entirety.
-- Please RSVP to MCIA by January 14th at 601-957-5274. Seating is limited.
-- Parking and meeting room details will be provided to those who register.

Sponsors:

Mississippi Concrete Industries Association

Mississippi State University CMRC Construction Materials Research Center — An Industry, Agency & University Partnership

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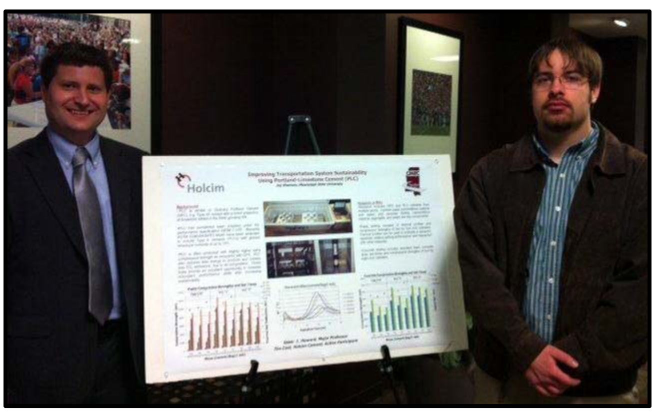
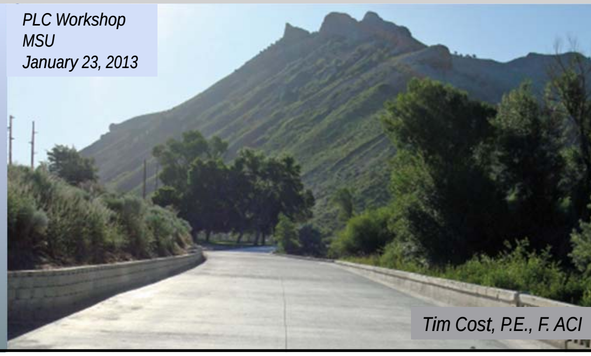
Portland-Limestone Cement (PLC) Workshop Summary

There were fifty-three participants on campus for the PLC workshop on January 23, 2013. Twenty-two of the attendees were from the Mississippi Department of Transportation, sixteen represented construction and materials supply companies, ten were from architecture and/or engineering firms, and five were from academia or trade associations. The flexible agenda was adjusted to accommodate the excellent group discussion throughout. Tim Cost presented the morning session, Isaac L. Howard presented after lunch, and additional discussion and feedback related to presentations and other topics of interest followed. The workshop concluded with an optional tour of the CEE-CMRC laboratory facilities for participants, which was well attended. Participant responses to the workshop have been quite favorable, indicating new awareness and understanding of PLC and its benefits in concrete. Anticipated market acceptance of the product should be favorable, based on feedback. Photos from the workshop are below, and the presentation slides used by Tim Cost and Isaac L. Howard are included thereafter.

Workshop Number CMRC WS 13-1



PLC Production, Specifications, Use, and Performance



PLC Workshop
MSU
January 23, 2013

Tim Cost, P.E., F. ACI

Overview

PLC Production, Specifications, Use, and Performance

- What, why, and how of PLC
- PLC experiences, documented performance
- Investigating PLC “synergies” that benefit concrete strength and setting performance

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What, why & how of PLC

So, what is portland-limestone cement (PLC), anyway?

- PLC is a slightly modified version of portland cement that improves both the environmental footprint and the basic performance of concrete. It is now described in ASTM and AASHTO specifications, is available in Mississippi, and is used just like traditional portland cement in mix designs. It can be made at any portland cement manufacturing plant.
- While ordinary portland cement (OPC) may contain up to 5% limestone, PLC as described in current US specifications contains between 5% and 15% limestone.

What, why & how of PLC

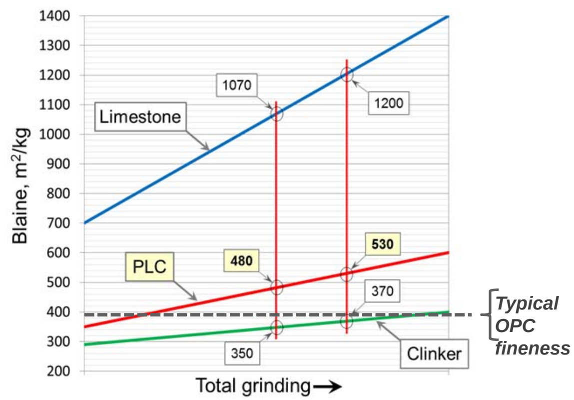
How is it made, and what’s different about it?

- A metered proportion of crushed, dried limestone is fed to the finish grinding mill along with clinker and gypsum
- The limestone is more easily ground than the clinker (which is harder) and becomes concentrated in the finest particles
- Overall fineness must be higher (for equivalent performance) in order for fineness of the clinker fraction to be similar to OPC
  - Production rate is slowed
  - Some additional grinding energy is required but is more than offset by lower clinker content and related kiln fuel savings
- Particle size distribution is enhanced
- Hydration is enhanced by both physical and chemical interaction; greater overall cementitious efficiency is possible
- Sustainability benefits are significant via reduced associated carbon emissions and embodied energy (less clinker)

What, why & how of PLC

How is it made, and what's different about it?

Example fineness trends, PLC vs. clinker and limestone component fractions



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What, why & how of PLC

How is increased hydration efficiency possible?

Limestone is not inert, but contributes to hydration both physically and chemically.

- Physical mechanisms:
  - Enhanced particle packing and paste density due to enhanced overall cement particle size distribution
  - "Nucleation site" phenomenon – small limestone particles are suspended in paste between clinker grains and become intermediate sites for CSH crystal growth, improving efficiency
- Chemical mechanisms:
  - Limestone contributes calcium compounds that go into solution and become available for hydration interaction
  - Calcium carbonate reacts with aluminate compounds to produce durable mono- and hemi-carboaluminate hydrate crystals
    - Some aluminates are available as byproducts of normal cement hydration but additional aluminates may be contributed by SCM's
    - Other side-effects include stabilization of ettringite and increased total volume of hydration products, thus lower porosity and higher strength

– De Weerdt , Kjellsen, Sellevold, and Justnes, "Synergy Between Fly Ash and Limestone Powder in Ternary Cements," *Cement and Concrete Composites*, Vol. 33, Issue 1, January 2011, pp 30-38.

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What, why & how of PLC

How does PLC affect concrete properties?

- Fresh concrete effects are all favorable (though slight)
- No difference in water demand, slump loss
- Excellent finishing properties
  - Limestone has a lower SG than clinker
- Setting: generally no change for straight cement systems
  - Retardation effects of SCM's can be reduced (!)
- Similar response to admixtures
- Strength development: at least equivalent, though both rate of strength gain and ultimate strength may be enhanced, especially in combination with SCM's
- Shrinkage, heat of hydration, and durability performance attributes all similar or even slightly improved

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What, why & how of PLC

What specifications cover PLC?

- Some US cement makers have supplied PLC containing up to 15% limestone under ASTM C1157 for several years
  - Performance specification for hydraulic cement
  - Recognized by building codes & ACI 318
  - No equivalent AASHTO specification
- PLC containing from 5% to 15% limestone is now included in current blended cement specifications (2012)
  - ASTM C595-12 and AASHTO M 240-12, Type IL
  - Both specs also include a Type IT designation for PLC blends that include fly ash or slag cement

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PLC Production, Specifications, Use, and Performance

What, why & how of PLC

Can PLC be used in the same mix designs as OPC?

- Yes
- Efficiency of fly ash and slag may even be improved
- No special admixtures or dosage changes needed
- No differences in entrained air management
- No operational distinctions

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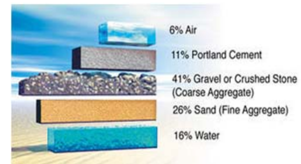
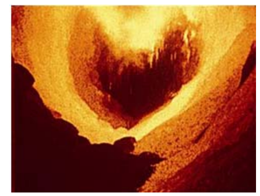
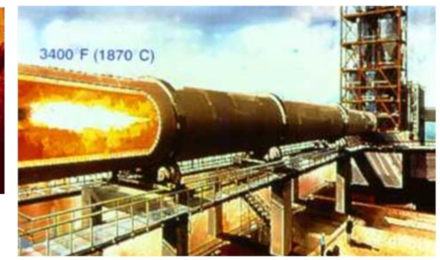
What, why & how of PLC

How does PLC improve the sustainability of concrete?



- Cement is the source of most of concrete's CO_2 footprint & embodied energy, from burning of fossil fuels and the combustion gases emitted in the production of clinker
- Reductions of clinker content reduce related CO_2 emissions and associated production energy of concrete





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What, why & how of PLC

How does PLC improve the sustainability of concrete?

- PLC substitution for OPC = most significant improvement to concrete sustainability within current technology
- When OPC's w/ up to 5% limestone are replaced with PLC's containing 10% to 15% limestone, the resulting impact per million tons of cement produced equates to:
  - 443,000 to 664,000 million BTU less clinkering energy used
  - millions of pounds less SO_2, NO_x, and CO emissions
  - 189,000 to 283,000 tons reduction of CO_2 emissions
  - Potential for beneficial use of SCM byproducts increases
  - Total concrete cementitious requirements may decrease
  - Improvements in HoH, permeability, and other concrete durability parameters are possible

from Tennis, P. D., Thomas, M. D. A., and Weiss, W. J., "State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%", PCA SN3148, 2011

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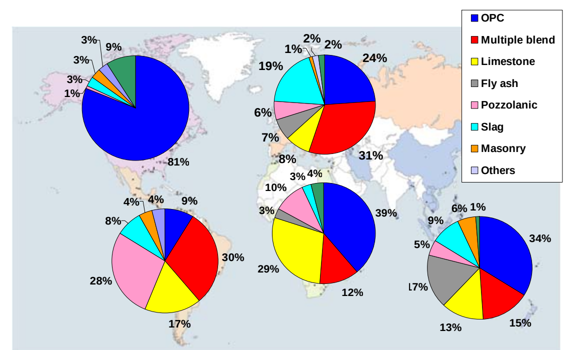
PLC experiences, documented performance

Limestone in cement around the world (snapshot: 2005)



- Experiences span several decades in many countries
  - Especially in Europe, South America, Africa, Australia
  - Since 1970's in Europe, now predominant with specification categories for up to 35% limestone

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PLC Production, Specifications, Use, and Performance

PLC experiences, documented performance

Literature review – PLC performance

- Significant sustainability impacts
- Performance in concrete equivalent to or better than OPC
  - Strength
  - Freeze-thaw resistance
  - Resistance to deicer salt scaling
  - Chloride permeability & diffusion
  - Heat of hydration
  - AAR potential
  - Shrinkage & creep
  - Reduced carbonation depth
  - Sulfate resistance
  - Interaction with SCM's

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PLC experiences, documented performance

PLC performance trends and fineness

- Fineness is known to heavily influence performance
- Concrete with PLC is generally found to have performance equivalent to or slightly better (relative to with OPC), both with and without SCM's at traditional rates, when Blaine fineness of PLC is controlled to <u>about 100 m^2/kg higher</u> than for OPC**
- Literature reviews report few investigations of effects of higher finenesses
- Interesting new trends have become evident in US concrete – US cements are finer, some SCM's unique

**Tennis, P. D., Thomas, M. D. A., and Weiss, W. J., "State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%", PCA SN3148, 2011

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PLC experiences, documented performance

Holcim has supplied over 1,000,000 tons of PLC in the US

- 5 different US plants
  - Extensive experience in UT and CO (ASTM C1157 approved by DOT's)
  - Over 400 lane miles of concrete pavements
- General performance
  - Higher early strengths
  - Comparable or better later strengths
  - Similar or slightly longer set times
  - Excellent concrete finishing properties
  - Lower bleeding and slump loss
  - Highly successful in products plants
  - No differences in water demand
  - Excellent response with SCM's and chemical admixtures

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PLC experiences, documented performance

Durability testing (±10% LS) – favorable data

- Production samples, 2005 – 2007
  - No issues indicated
  - Essentially equivalent performance to that of non-limestone cements from the same plants, some slight enhancements:
    - ASTM C 1012 Length Change
    - ASTM C 1260 and C1567 ASR Testing
    - ASTM C 666 Freeze-Thaw
    - ASTM C 672 Salt Scaling
    - ASTM C 157 Drying Shrinkage
    - ASTM C 39 Compressive Strength (500 lb. Mix)
    - ASTM C 39 Compressive Strength (564 lb. Mix)
    - ASTM C 1202 Permeability (500 lb. Mix)
    - ASTM C 1202 Permeability (564 lb. Mix)
- Similar to data from published references

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PLC Production, Specifications, Use, and Performance

PLC experiences, documented performance

PLC vs. OPC concrete testing program in Georgia

- 5 cement companies participating, one plant each from:
  - Argos, Buzzi Unicem, Cemex, Holcim, Lehigh
  - 2 cement samples, each plant: Type I or II OPC and Type IL PLC
  - No special requirements; PLC as per C595/M240 Type IL
    - No direction suggested for PLC production targets
  - All testing done at Heidelberg Technology Center, Atlanta
- Four concrete mixtures made with each cement sample:
  - 100% cement, 25% C ash, 25% F ash, 40% slag cement
  - All mixes: 611 lb/cf total cementitious, water content adjusted for constant slump (4" to 5"), 4 fl oz/cwt Type A WR, 2.5 fl oz/yd AEA
  - Actual slumps 3.75" to 5.25" (avg ± 4.5"), w/cm ≈ 0.46 – 0.51
  - Air contents were variable, 1.5% to 5.5% (2 outliers higher), fly ash mixes generally 2% to 3% lower, slag mixes slightly lower than straight cement
  - Presented strength data normalized for 4% air content, using factor of 5.5% Δ psi / 1% Δ air content; no slump normalization
  - ASTM C1202 (RCP) and C157 (shrinkage) on some mixes

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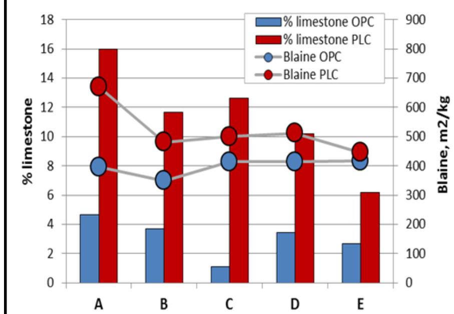
PLC experiences, documented performance

PLC vs. OPC concrete testing program in Georgia



OPC and PLC % limestone and Blaine fineness by cement source

Sample characteristics:

- OPC's all normal production samples
- Similar clinker used for PLC's
- Broad range of PLC limestone contents (6% to 16%)
- Range of PLC fineness
- Range of limestone purity (% $CaCO_3$), 76% to 98%
- Range of PLC-OPC fineness differential

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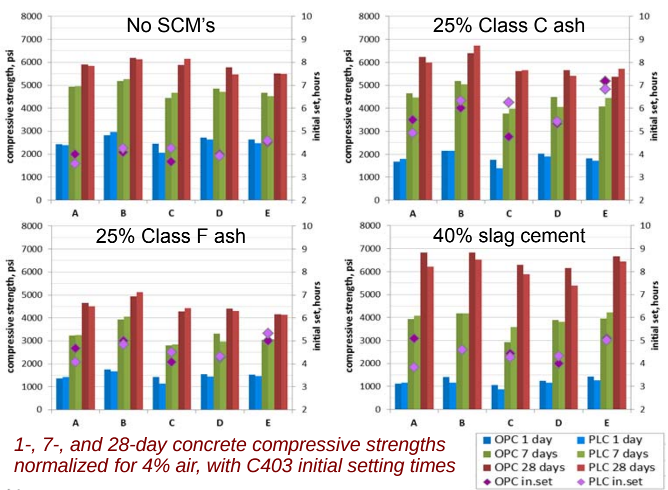
PLC experiences, documented performance

PLC vs. OPC concrete testing program in Georgia



1-, 7-, and 28-day concrete compressive strengths normalized for 4% air, with C403 initial setting times

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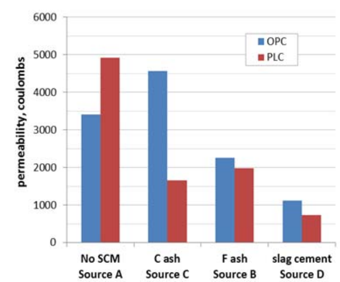
PLC experiences, documented performance

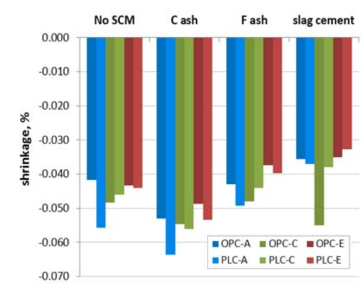
PLC vs. OPC concrete testing program in Georgia

Permeability and shrinkage testing – selected mixes



ASTM C1202 chloride ion penetration at 56 days

(one mix type from each of sources A-D)



ASTM C157 length change (shrinkage) at 28 days

(all mixes from each of sources A, C, E)

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Investigating PLC synergies

What are PLC "synergies"?

- Synergy \ˈsin·ər·jē\ *n* – working together of two things to produce a result greater than the sum of their individual effects
- When limestone particles are sufficiently fine (high enough surface area), enhanced hydration may result in concrete performance levels higher than those for similar OPC mixtures (strength, setting, some durability attributes)
  - Necessary PLC fineness may vary with different mill systems
  - Generally higher PLC fineness differentials (vs. OPC) than 100 m^2/kg
- Most evident in combination with SCM's
- The net effect is a higher overall performance level for the same total amount of cementitious material
- Particularly interesting in US cements due to inherently high fineness levels (vs. cements in other countries) and chemistry attributes of US SCM's

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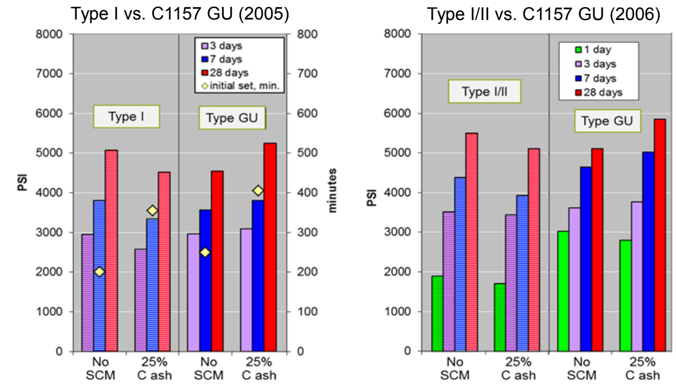
Investigating PLC synergies

PLC strength synergy with Class C fly ash

Example concrete data, 10% LS C1157 GU vs. C150 cements from two plants



517 pcy concrete mixtures, gravel aggregates, 5" slump

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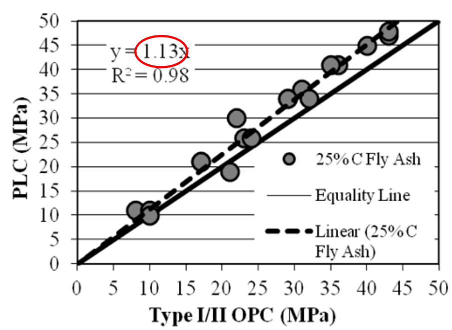
Investigating PLC synergies

Concrete strength equality, multiple samples, 2005-2009



Concrete strength, PLC vs. OPC, equality equation constants:

0% fly ash replacement 0.97
25% F ash replacement 1.07
25% C ash replacement 1.13

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Investigating PLC synergies

Literature review – PLC synergies

References

Bentz, D. P.; Ferraris, C. F.; De la Varga, I.; Peltz, M. A.; and Winpigler, J. A., "Mixture Proportioning Options for Improving High Volume Fly Ash Concretes," *International Journal of Pavement Research and Technology*, V. 3, No. 5, 2010, 234-240.

Bentz, D. P., "Powder Additions to Mitigate Retardation in High-Volume Fly Ash Mixtures," *ACI Materials Journal*, V. 107, No. 5, September-October 2010, 506-514.

Bentz, D. P.; De la Varga, I.; Sato, T.; and Weiss, W. J., "Fine Limestone Additions to Regulate Setting in High Volume Fly Ash Mixtures," submitted to *Cement and Concrete Composites*, 2011.

De Weerdt, K.; Kjellsen, K. O.; Sellevold, E.; and Justnes, H. "Synergy Between Fly Ash and Limestone Powder in Ternary Cements," *Cement and Concrete Composites*, V. 33, No. 1, January 2011, 30-38.

Gurney, L.; Bentz, D.P.; Sato, T.; and Weiss, W.J., "Using Limestone to Reduce Set Retardation in High Volume Fly Ash Mixtures: Improving Constructability for Sustainability," submitted for presentation to the Transportation Research Board annual conference, January, 2012.

Mehta, P. K., "High-Performance, High-Volume Fly Ash Concrete for Sustainable Development," Proceedings of the International Workshop on Sustainable Development and Concrete Technology, Beijing, China, 2004, 3–14.

Mounanga, P.; Khokhar, M.I.A.; Hachem, R. E.; and Loukili, A., "Improvement of the Early-Age Reactivity of Fly Ash and Blast Furnace Slag Cementitious Systems Using Limestone Filler. Materials and Structures, Vol. 44, 2011, 437-453.

Sato, T., and Beaudoin, J. J., "The Effect of Nano-Sized $CaCO_3$ Addition on the Hydration of Cement Paste Containing High Volumes of Fly Ash," Proceedings of the 12th International Congress on the Chemistry of Cement, July 2007.

- A number of papers (esp. since 2010) report LS synergy with SCM's
- Many papers document synergies of setting useful in HVFA concrete
- Most data sets also indicate parallel synergies of strength development
- All related benefits improve as LS surface area (fineness) increases

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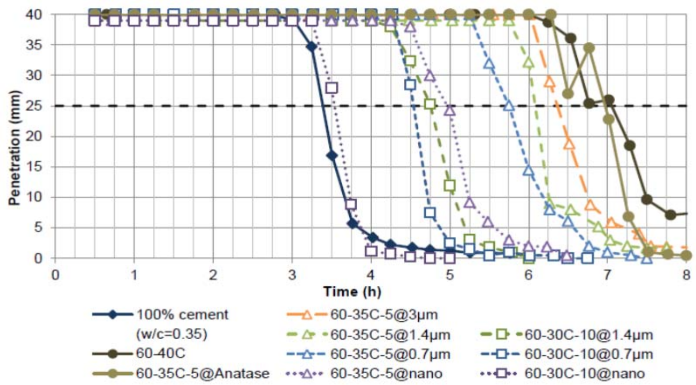
Investigating PLC synergies

Gurney, et al. – vicat data, C ash mixes



from: Gurney, L.; Bentz, D.P.; Sato, T.; and Weiss, W.J., "Using Limestone to Reduce Set Retardation in High Volume Fly Ash Mixtures: Improving Constructability for Sustainability," 91st Annual Meeting of the Transportation Research Board, Washington, D. C., January, 2012.

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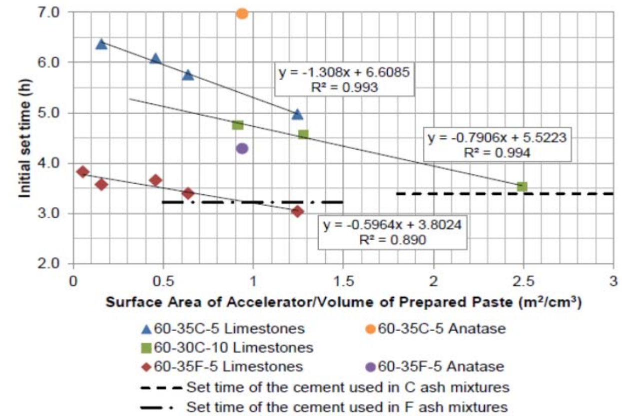
Investigating PLC synergies

Gurney, et al. – LS surface area related to set acceleration



from: Gurney, L.; Bentz, D.P.; Sato, T.; and Weiss, W.J., "Using Limestone to Reduce Set Retardation in High Volume Fly Ash Mixtures: Improving Constructability for Sustainability," 91st Annual Meeting of the Transportation Research Board, Washington, D. C., January, 2012.

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Investigating PLC synergies

Multi-variable experimental program w/ laboratory paste

- Objective: to help explore PLC synergy trends and fineness influences
- Some PLC simulated with OPC+ separately added LS
  - Ground LS of 327 to 1090 m^2/kg Blaine @ 10%
  - Comparisons with 10% LS mill-ground samples
- SCM's at generally higher-than-normal proportions (C and F ash) to exaggerate trends:
  - 40% replacement of cement
    - Class C fly ash w/ aggressive properties
    - Class F fly ash, low Ca, almost a pure pozzolan
    - Some slag cement, C989 Grade 100 (common, mild replacement rate, but consistent for comparison value)
    - 14 oz/cwt HRWR, w/cm = 0.32

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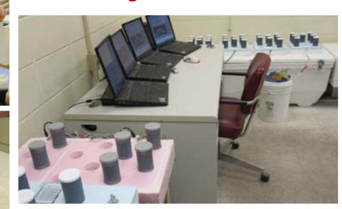
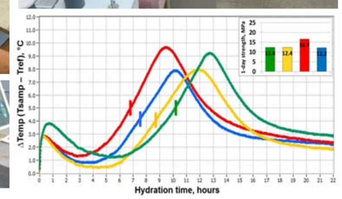
Investigating PLC synergies

Thermal profile and strength testing of lab paste mixtures

Simple method for rapid evaluation of mixture setting and strength trends





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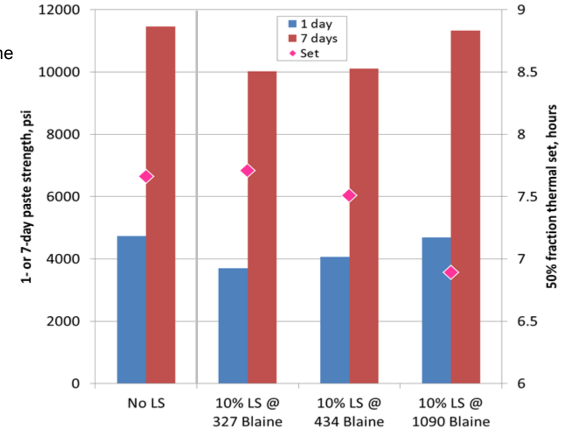
Investigating PLC synergies

No SCM's, 10% LS @ 327 to 1090 Blaine

Type I/II cement, 360 Blaine



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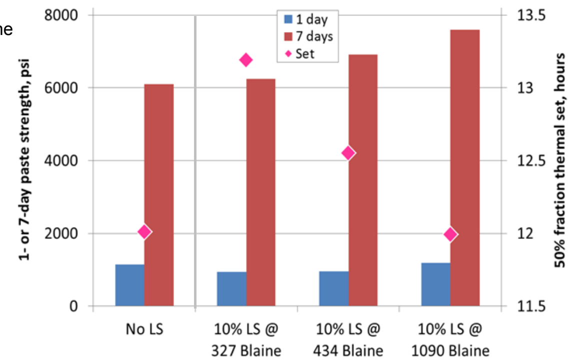
Investigating PLC synergies

40% C ash, 10% LS @ 327 to 1090 Blaine

Type I/II cement, 360 Blaine



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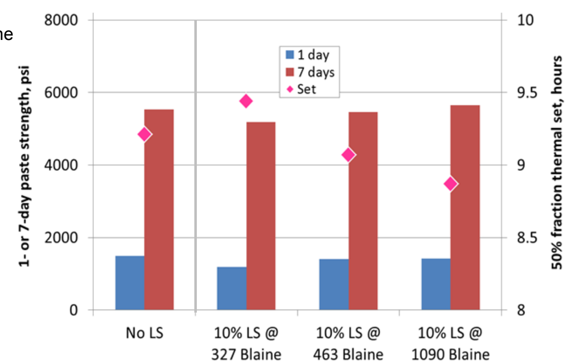
Investigating PLC synergies

40% F ash, 10% LS @ 327 to 1090 Blaine

Type I/II cement, 360 Blaine



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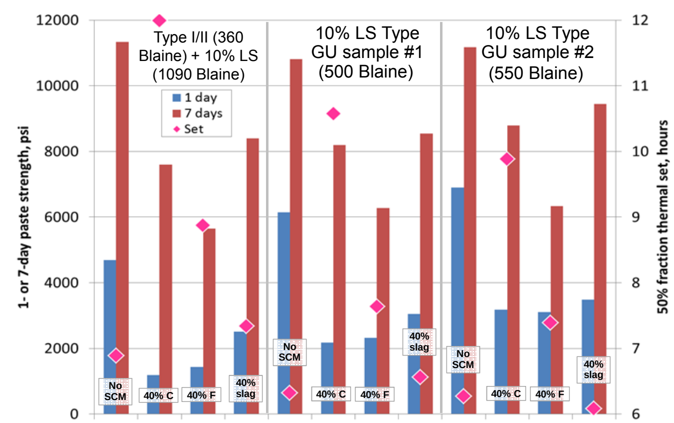
Investigating PLC synergies

10% added LS vs. 2 samples of mill-ground 10% LS PLC



Fly ash "synergy" with mill-ground 10% LS cement samples slightly exceeds that with Type I/II + 10% separately-added LS of 1090 Blaine

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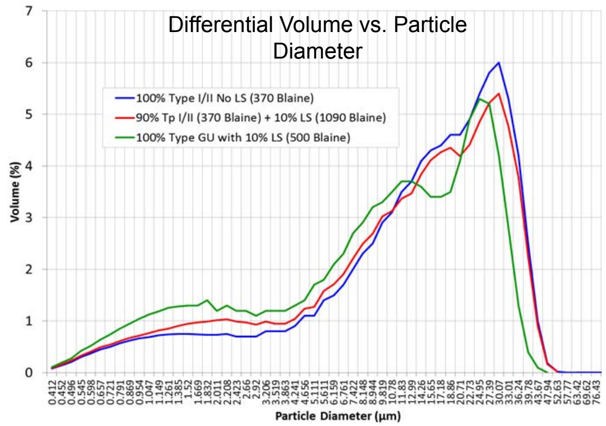
Investigating PLC synergies

PSD, Type I/II OPC vs. simulated and mill-ground 10% LS PLC



Particle size analyses of individual materials performed using a Beckman Coulter LS 13 320 laser diffraction PSA

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Summary / conclusions / recommendations

- PLC's have the potential to significantly improve concrete sustainability with performance equal to or better than C150 / M85 cements, similarly used.
- PLC's can be used seamlessly as a substitution for OPC's in mix designs.
- PLC's hydrate with synergies contributed by limestone that enable enhanced setting and strength performance, especially in combination with SCM's.
- Limestone fineness is a key influence on the extent of synergy benefits.
- The particle size distribution of PLC produced to optimum overall fineness in finish grinding ball mills appears well suited for synergy-driven performance enhancement.
- More research is needed to refine understanding of PLC synergies, how they can best be optimized in concrete (use guidance), and what properties of both component materials and mill-ground PLC's will be most important in order to derive maximum value from PLC use.

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PLC Production, Specifications, Use, and Performance

PLC Workshop
MSU
January 23, 2013

Questions?

Tim Cost, P.E., F. ACI
tim.cost@holcim.com

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PLC Research, Davis-Wade Stadium Expansion

Workshop on Portland-Limestone Cement (PLC)

January 23, 2013, MSU Campus, Starkville, MS

Presenter: Isaac L. Howard, PhD, PE
Associate Professor
Materials and Construction Industries Chair

Assisted With Presentation Development:
Jay Shannon
Graduate Research Assistant

Lets Talk Football Before PLC

- Presenter picks MSU games before season and puts on office door; good student talking point
- Never successfully predicted all 12 games
- 2012 season
  - Games 1 to 10: predicted 10 for 10 ✓
  - Game 11: predicted win vs. U of A ✓✓
  - Game 12: predicted win in Egg Bowl ✗✗✗
- Disclaimer: Presenter may be subconsciously trying to be 12 for 12 w/ football picks and that may be driving project involvement

Maybe This Will Help Football Picks

- Davis Wade Stadium Expansion Features
  - 7,076 grandstand seats
  - 1,155 club seats
  - 22 Suites
  - 75 million dollar projected cost
- Thousands of cubic yards of concrete
  - Supplied from MMC Starkville plant
  - 7.5 acre facility
  - 3 Silos @ 110 tons and 1 Silo @ 60 tons
  - Can pull from a 42 truck fleet

Key Project Participants-Concrete

(There are likely others)

- MMC Materials [Mark Stovall, Rodney Grogan]
- Holcim (US) Inc. [Tim Cost]
- Harrell Contracting Group [Casey B. Rogers, Ches Fedric, Talty Shannon]
- LPK Architects pa [Robert E. Luke, Mitchell Marshall]
- 360 Architecture [Paul J. Leskovac]
- Walter P. Moore [Thomas W. Langlitz]

Stadium Project Timeline

- May 2012: Plans revealed
- August 2012: First MMC concrete order placed
- November 2012: 1st concrete placement-shafts
- Feb 2013: 1st slab on deck (SOD) placement
- October 2013: Concrete completion

That Said, What is MSU-CEE-CMRC's Main Interest in All This?

- Show benefits of collaborations between: agency/academic/industry/other private groups
- Highlight our role in sustainability of construction materials
- Study a project more carefully than often is feasible for other types of projects

CMRC's Main Interests Continued

- Use data from this project in conjunction with larger effort ultimately leading to J. Shannon's PhD dissertation
  - Five cement companies, three SCM companies, and five ready mix suppliers have agreed to support this effort. Project will focus on southeast US cement market.
  - Journal article on stadium project is in early stages of development, but for us, this project is the beginning of more detailed characterization to further improve PLC performance (look to optimize fineness, limestone content…plant by plant)

Davis Wade Stadium

- The rest of the presentation focuses on testing performed, at least indirectly, for this project
- Some of the testing performed was for research purposes more so than direct application to the project
- The data in this presentation provides the findings to date; full cement characterization is pending and additional testing is planned

Mix Designs

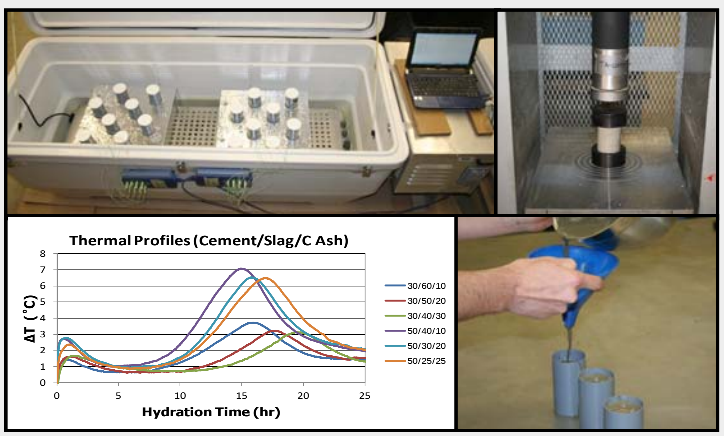
- 28 different concrete features
- Design specifications
  - Compressive strengths 4,000 – 6,000 psi
  - Air contents 0% – 5%
  - Allowable cement replacement 0% – 70%
- Large allowable replacements rates and an interest in sustainable concrete led to the discussions that ultimately got CMRC involved

Test Methods

- Test program focused on two test types

1. Cement paste testing. Test only cementitious material, water, and admixtures. More efficient than testing concrete mixes. Evaluated compressive strength and thermal set time indications.
2. Concrete testing. Traditional testing where compressive strength and ASTM C 403 set time testing was performed.

Cement Paste Testing



Paste Mixes Tested

- 2 OPC's and 2 PLC's (Holcim Theodore)
  - OPC Blaine ~ 391 (Mill Cert)
  - PLC Blaine ~ 519 (Mill Cert)
- 2 SCM's
- 2 replacement rates
- 2 w/cm ratios
  - 0.4 and 0.5
- 3 admixtures

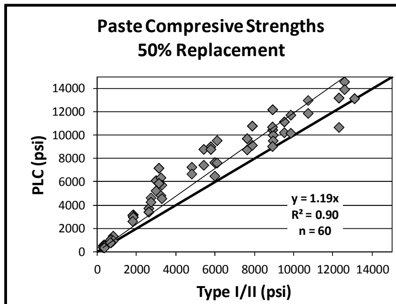
Blend #	Cementitious Content		
	Cement	**Slag**	**C Ash**
1	30	60	10
2	30	50	20
3	30	40	30
4	50	40	10
5	50	30	20
6	50	25	25

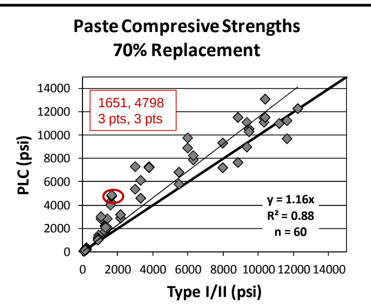
Concrete Mix Designs Tested

- Same 6 cementitious material blends as paste
- w/cm ratio between lower and upper bounds of paste w/cm ratio
- 2 aggregates
  - 57 Gravel with 3/8" gravel
  - 57 Limestone with 3/8" gravel
- 2 sack contents
  - 5.75 and 6.75

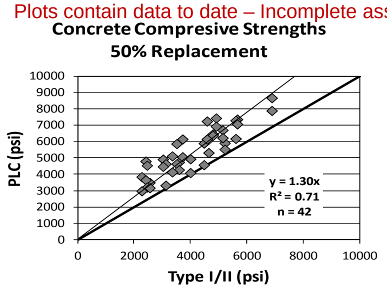
Current Testing with Progress

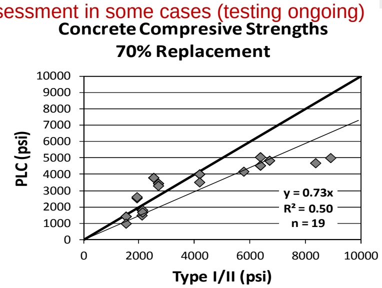
- 40 concrete mixes with 12 specimens each
  - 480 concrete specimens
  - 468 made, 381 tested
- 48 paste mixes with 18 specimens each
  - 864 paste specimens
  - 774 made, 645 tested
- Note that most of the data on the following slides compares the highest strength OPC with two PLC's that bracket the production range





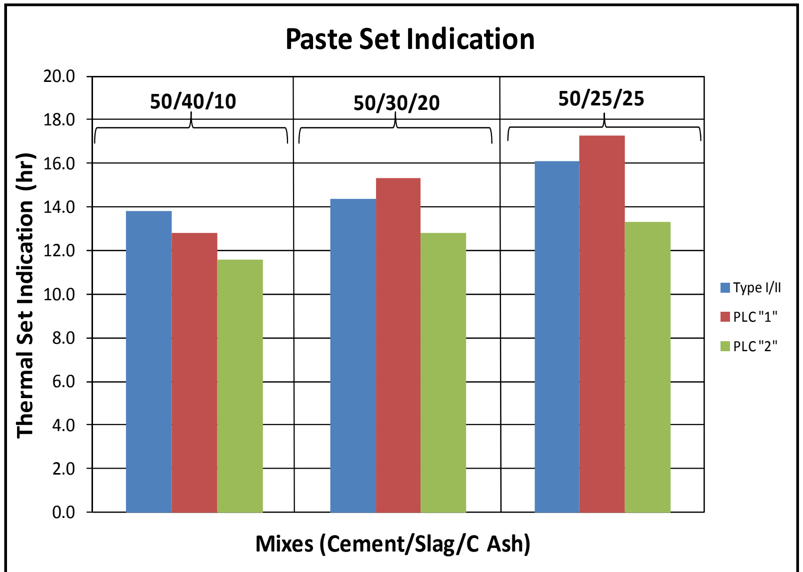
Plots contain data to date – Incomplete assessment in some cases (testing ongoing)



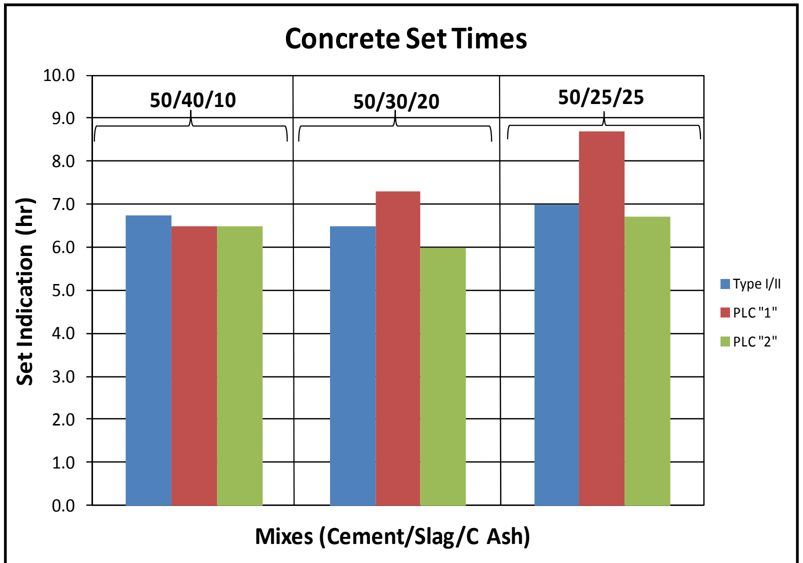


Moving Forward

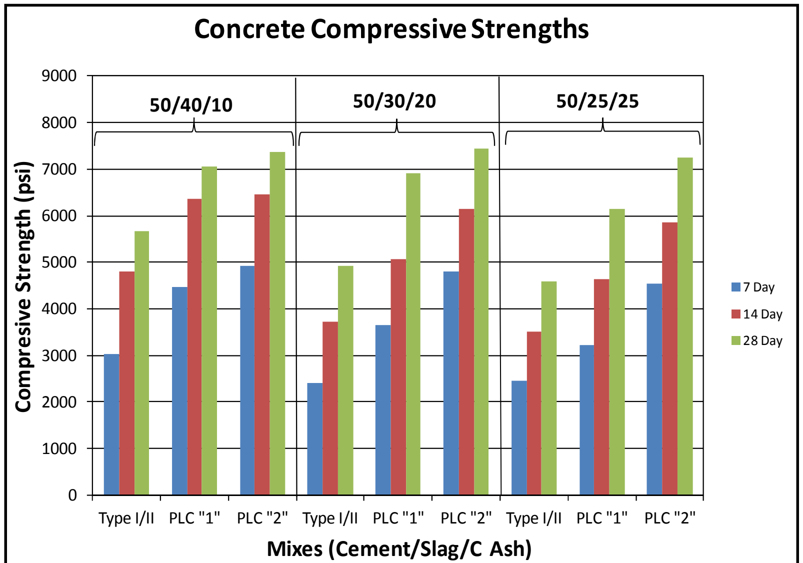
- Stadium schedule and performance of 70% replacement mixes to date make focusing on 50% replacement suitable for this project
- Additional research is planned to look into the 70% replacement mixes in more detail (e.g. paste to concrete trends), but they are not discussed further in this presentation.



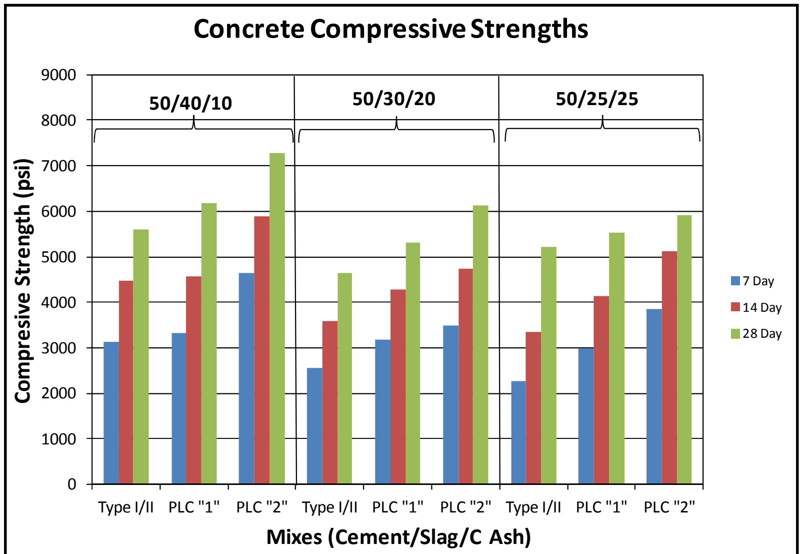
Paste thermal set indication is not indicative of actual set times



Type I/II shown had highest comp. str. of the two materials



Mixes shown with lowest tested sack content (5.75)



Mixes shown at higher sack content (6.75), but same w/cm ratio

So What?

- Data suggests Davis Wade Stadium mixes with 50% replacement could be improved noticeably by using PLC as opposed to OPC.
- 70% replacement mixes with PLC did not fare as well relative to OPC. This area needs further investigation as there could be other factors leading to the results obtained.
- PLC provides significant opportunities to improve concrete sustainability. The overall findings are very encouraging and everyone should consider PLC use on their projects.

Questions?

CMRC
Construction Materials Research Center

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Civil and Environmental Engineering