Strength. Performance. Passion.

Update – Performance of C595 / M 240 Type IL Portland-Limestone Cement

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Update – Performance of C595 / M 240 Type IL PLC

- Last year, spring 2012 – Oklahoma City meeting
  - PLC Synergies that Enhance Concrete Performance
- This update:
  - Review, PLC background & performance trends
  - Concrete testing program in Georgia using PLC & OPC samples provided by 5 different companies
  - Evaluation of project data & performance trends
  - Research underway on PLC synergies at MSU

Portland-limestone cement (PLC): what is it?

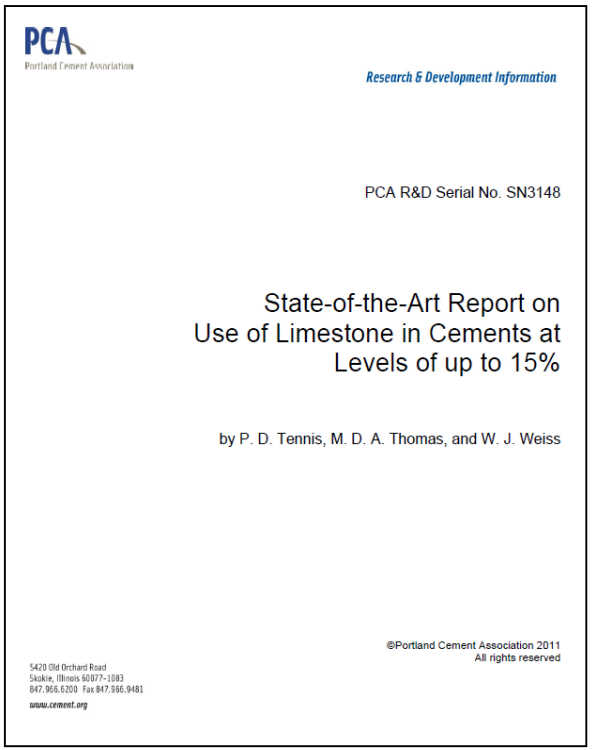
- Slightly modified version of portland cement
  - Contains up to 15% finely ground, raw limestone
  - Improves the environmental footprint of concrete without increasing cost or detracting from performance
  - Now available throughout the US
  - Can be made at any portland cement manufacturing plant
- Relatively new in the US but significant history elsewhere
- Supplied under ASTM C1157 in the US for several years
- Now included in blended cement specifications (ASTM C595-12 and AASHTO M 240-12, Type IL)
  - 5% to 15% limestone

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

- Crushed limestone is fed to the mill with the clinker and gypsum
- The limestone is more easily ground than the harder clinker and becomes concentrated in the finest particles
- Overall fineness must be higher (for equivalent performance)
  - Production rate is slowed
  - Additional grinding energy used is more than offset by energy savings associated with lower clinker content
- 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)

Reported performance of PLC – literature review

- Generally equivalent to OPC in identical concrete mixtures, when PLC Blaine is ± 100 m^2/kg higher
- Performance trends:
  - Favorable SCM interaction
  - Similar response to admixtures
  - No differences in management of air
  - Similar water demand, slump loss
  - Excellent finishing properties
  - Similar strength development
  - Similar setting performance
  - Similar shrinkage, heat of hydration, and durability attributes
  - Some beneficial synergies of both strength and setting are possible in combination with SCM's, heavily influenced by fineness and PSD


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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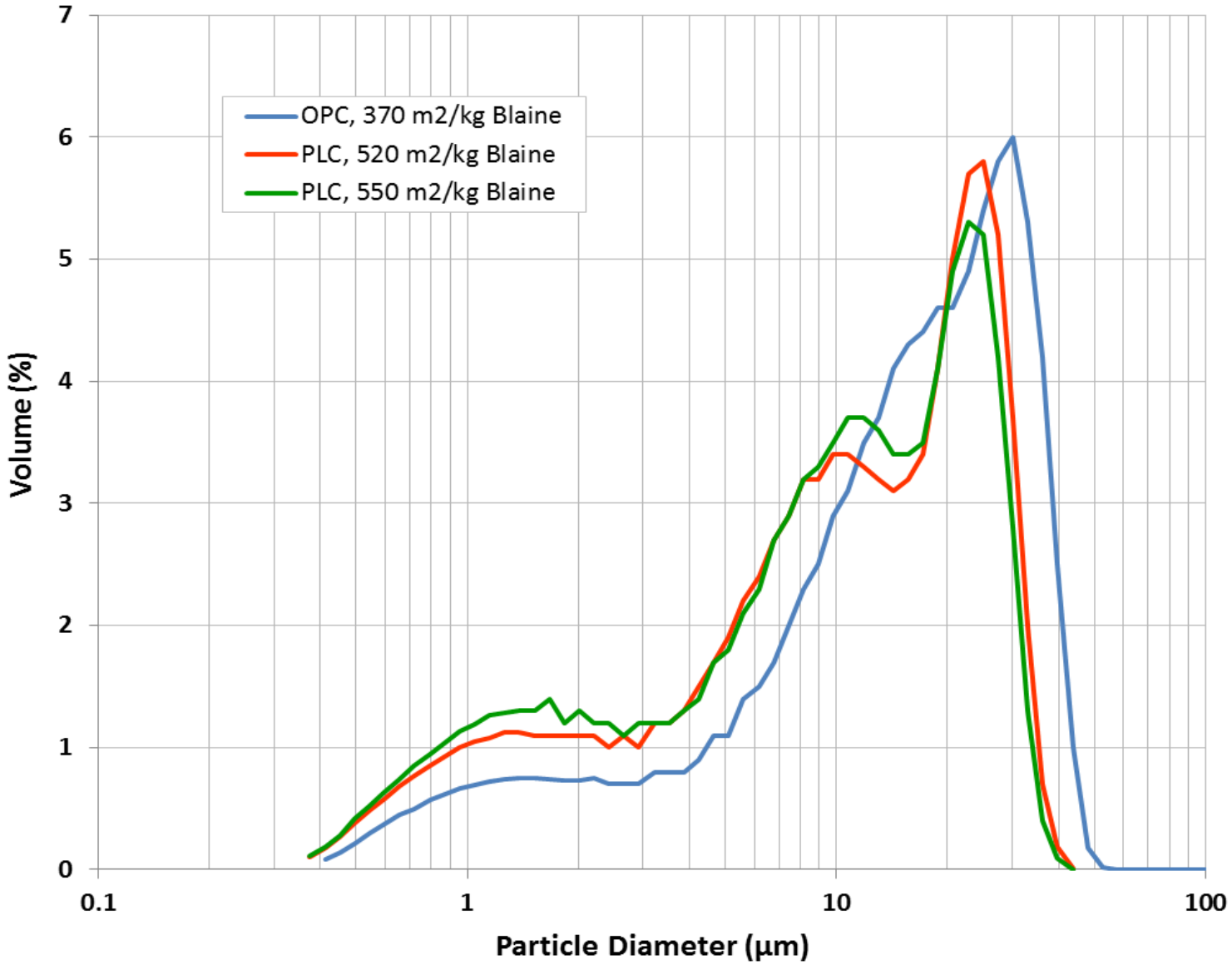
Conclusions, PLC "synergies" study presented last year

- Plant-produced PLC (ground in a ball mill) had more enhanced PSD and synergy with SCM's than any simulations using separate components
- This synergy potential clearly improved as fineness of PLC grinds increased, resulting in:
  - Increasing strength benefits with SCM's, especially Class C fly ash
  - Decreasing SCM set retardation effects

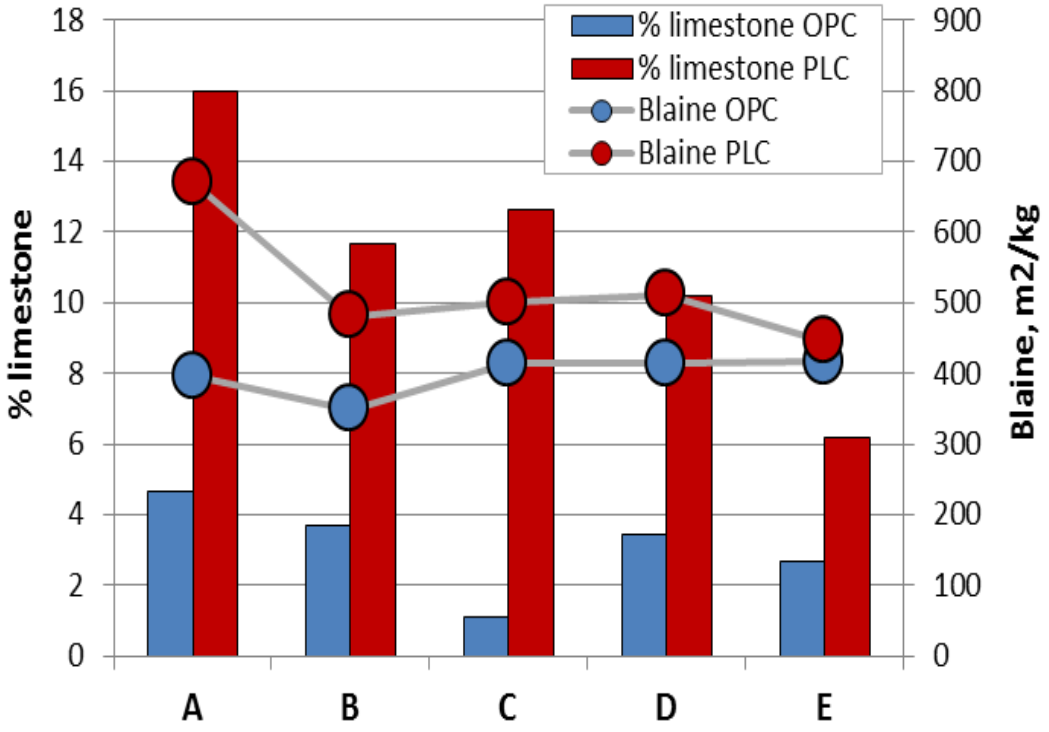
Typical PSD's and fineness differentials (PLC vs. OPC) that seem to influence enhanced PLC synergy with SCM's



PLC vs. OPC concrete testing program in Georgia

- 6 cement companies participating, samples provided by 5:
  - Argos, Buzzi Unicem, Cemex, Holcim, Lehigh, National
  - 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/cy 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

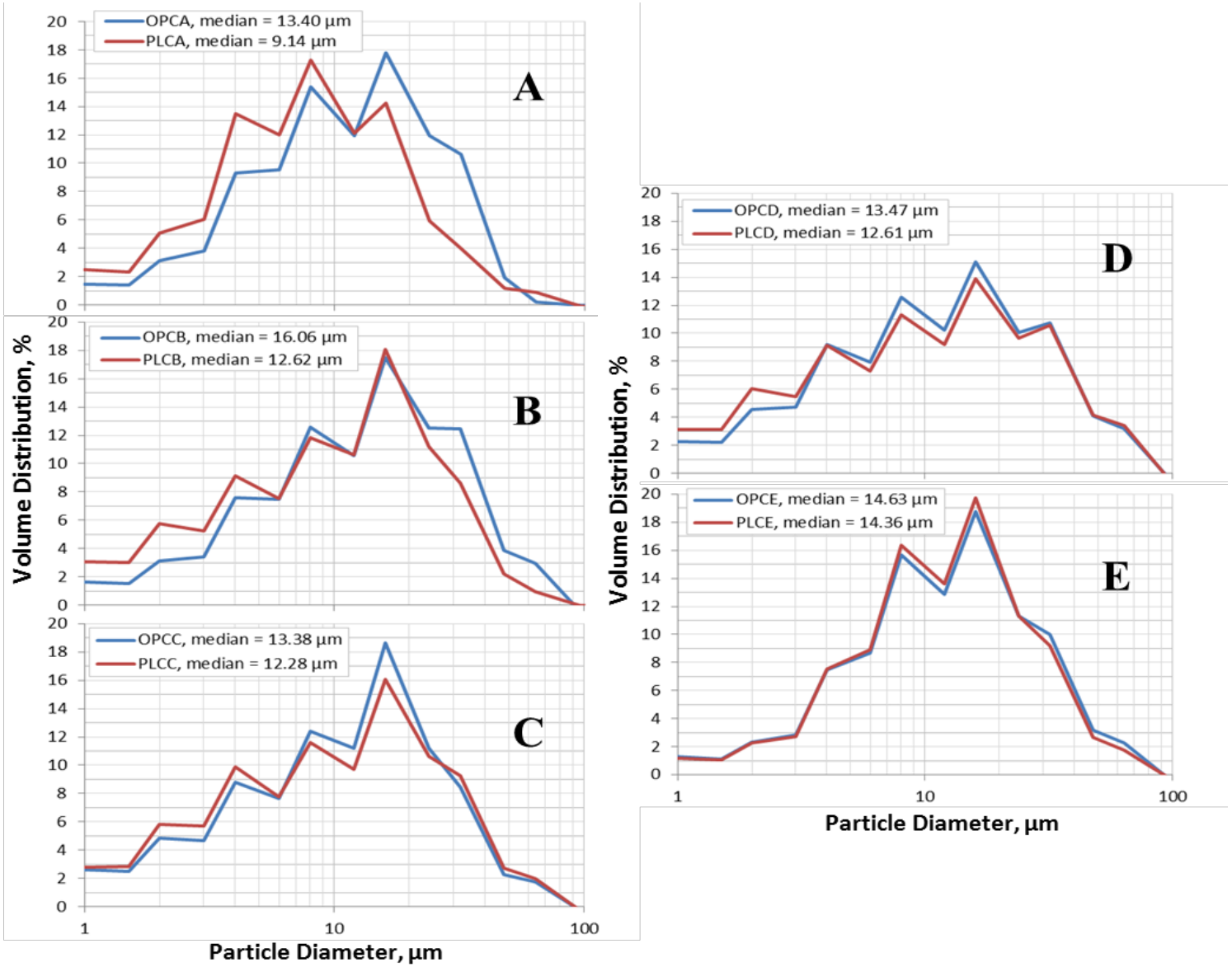
PLC vs. OPC sample characteristics



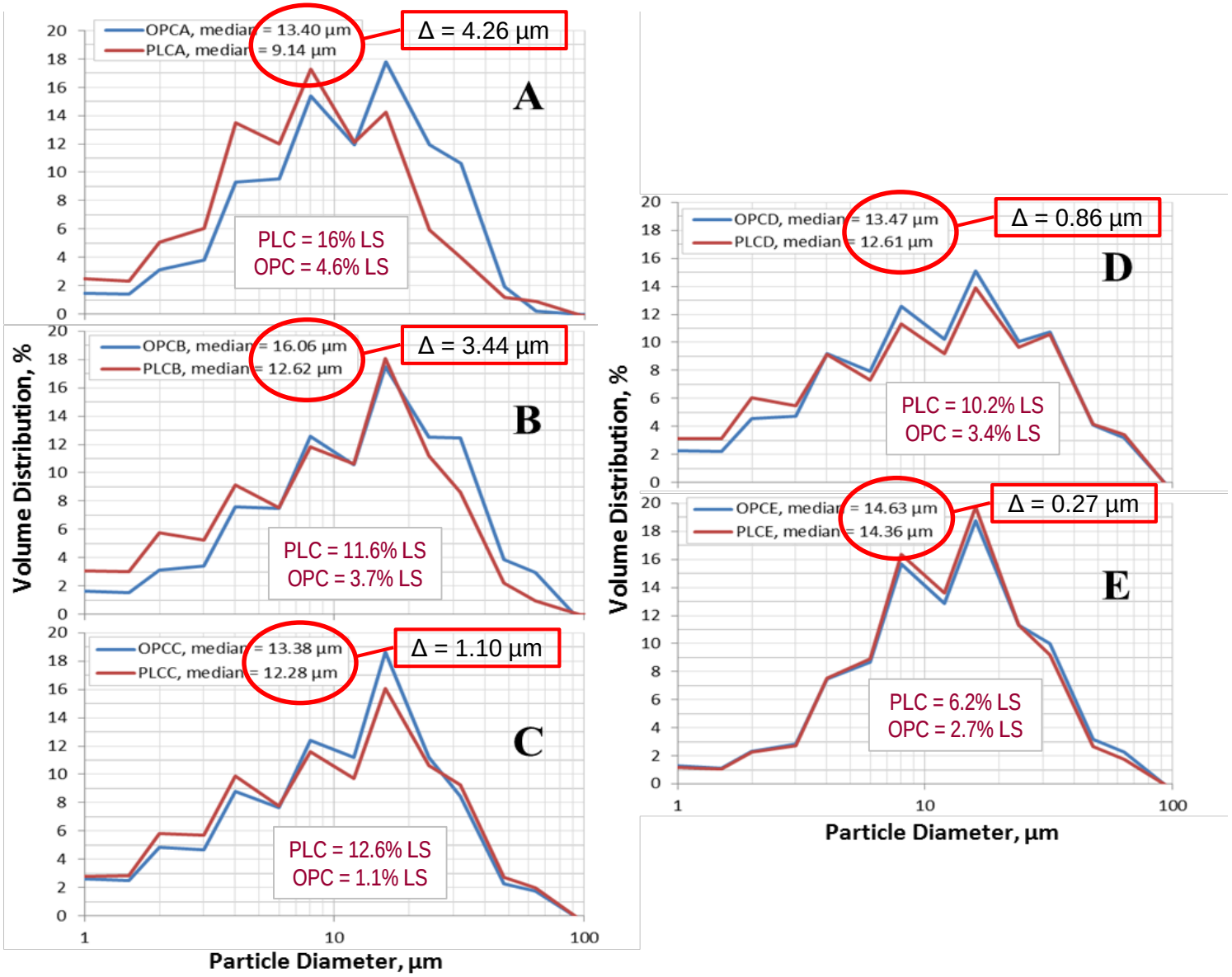
OPC and PLC % limestone and Blaine fineness by cement source

- 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

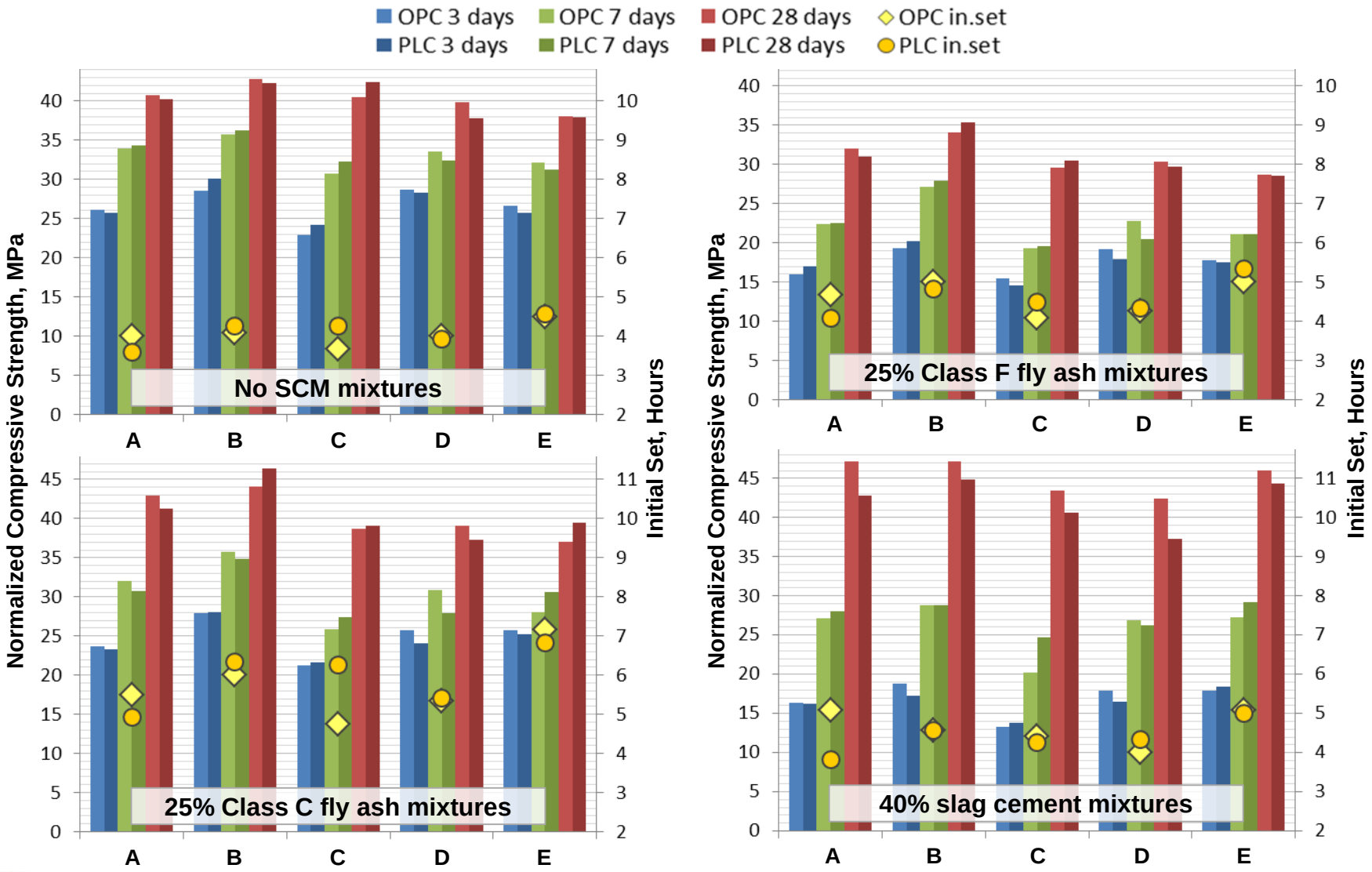
PSD's of cements from each source



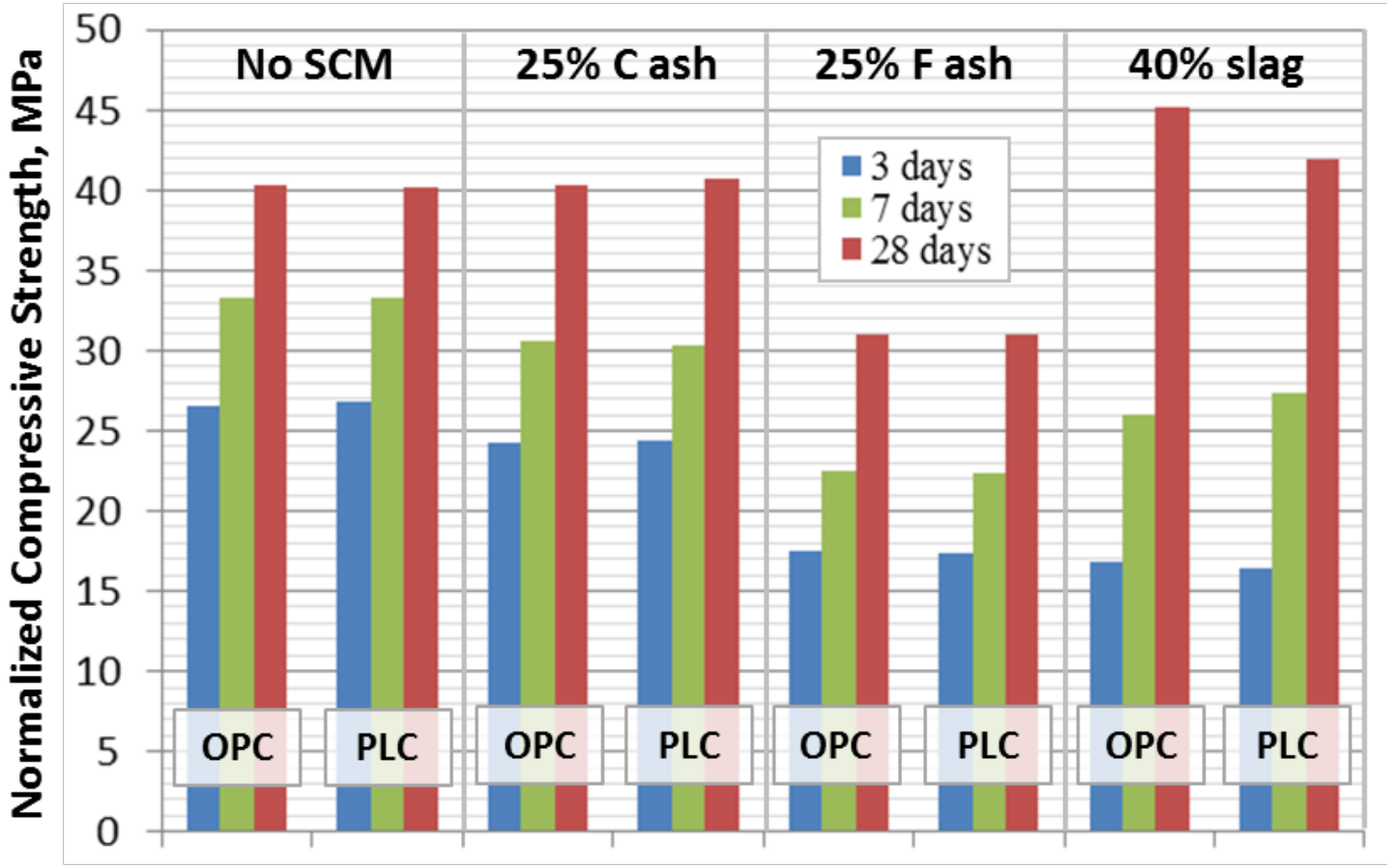
PSD's of cements from each source



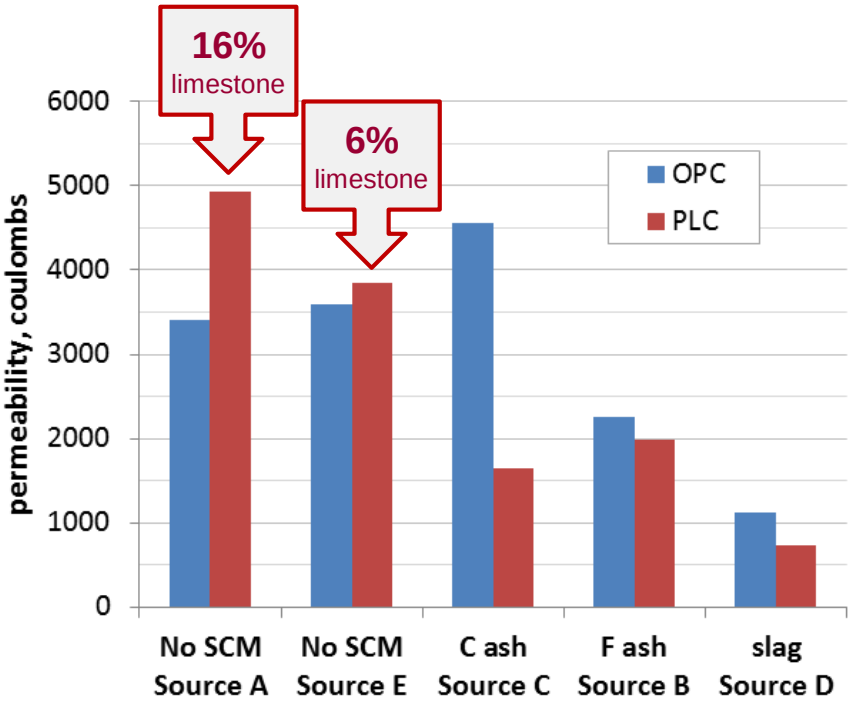
Concrete data – normalized strength and set, each mixture



Concrete data – normalized strength averages, each category

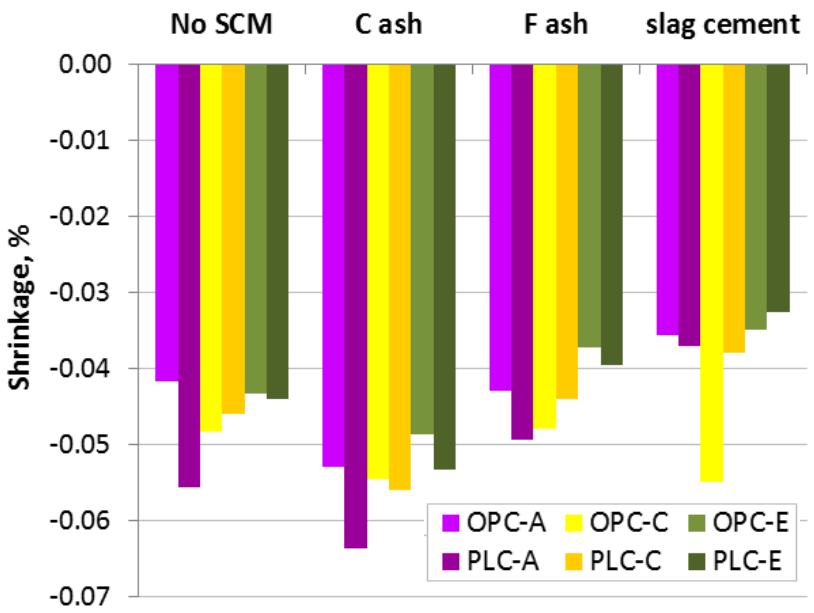


Permeability and shrinkage testing – selected mixtures



ASTM C1202 chloride ion penetration at 56 days

(one mix type from each source)



ASTM C157 (modified) length change at 28 days

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

Data observations

- PLC's performed almost identically to OPC's
  - Even though PLC limestone content ranged from 6.2% to 16% and other properties varied
  - Equivalent in each mixture category
- No performance trends suggest that usage distinctions (PLC vs. OPC) are needed
- Variability of performance was much greater as influenced by cement source or by mixture category than as influenced by cement type (PLC vs. OPC)

Acknowledgements

Testing participants:

Todd Moss - Argos USA
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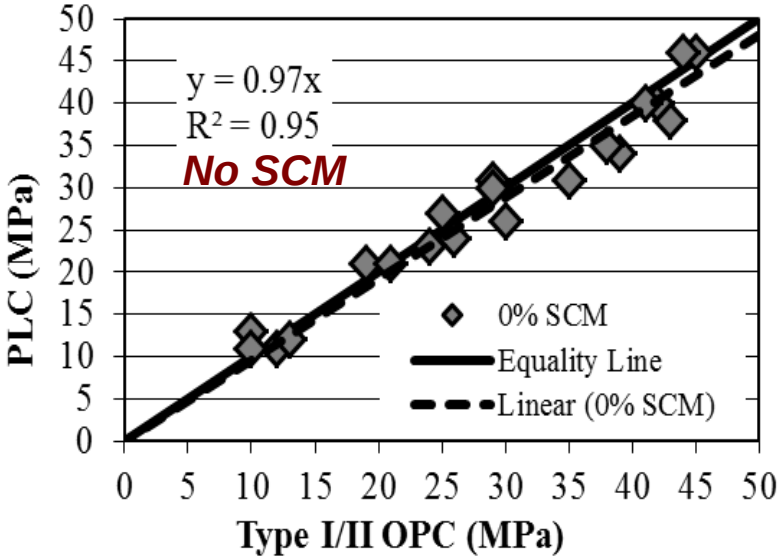
Wayne Wilson – Holcim (US) Inc.
Andy Chafin – Lehigh Cement Company / Heidelberg Technology Center
Gary Knight – Lehigh Cement Company / Heidelberg Cement Group
Derek Brown – Lehigh Cement Company
Dan Green – National Cement Company

Special thanks to the Heidelberg Cement Group for hosting all testing at their laboratory facilities in Doraville, GA, and for conducting chemical and physical testing of cement samples.

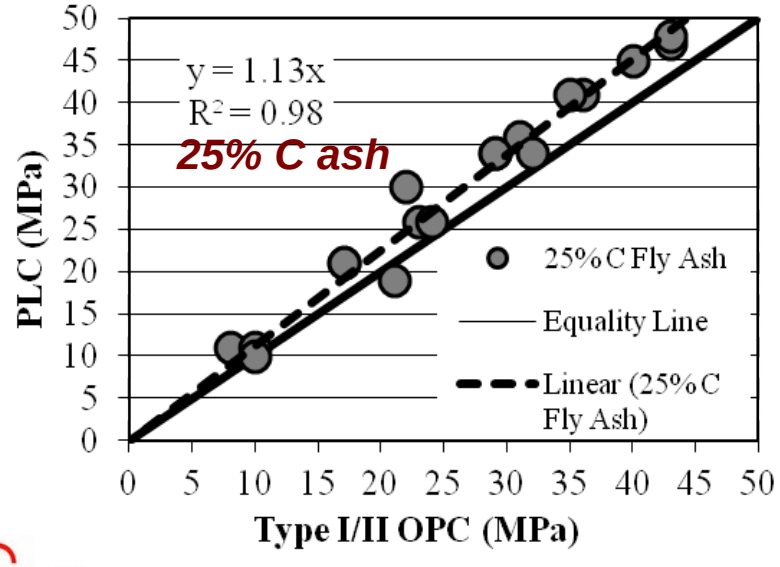
Research project: Mississippi State University

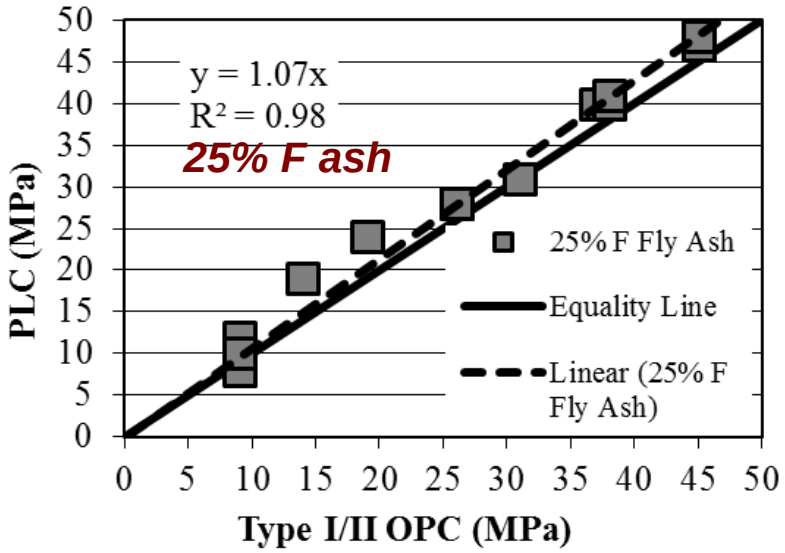
- Study of PLC synergies and how they can be optimized, including use / production guidance
- PhD dissertation
- Lab study with considerable bench testing and concrete
  - 5 cement companies furnishing cements and limestone
  - 3 SCM categories
- Full-scale construction project(s), mixture development support and performance monitoring

Concrete strength equality plots – early Holcim data



- Concrete mixtures made with multiple samples of OPC and PLC from two sources, over 4 years
- PLC: avg. ± 8% limestone, 520 Blaine
- OPC: avg. ± 1.5% limestone, 380 Blaine
- Strength synergies evident with SCM's, especially Class C fly ash





On-campus construction project with PLC: Davis-Wade Stadium

- $75 million expansion and renovation
- Increase capacity by 11.5% to 61,337
- Various improvements
- ± 35,000 cy concrete
- Considerable interest in sustainable attributes of materials
- Most structural concrete made with PLC and 50% replacement (~~ternary~~) mixtures using both slag and Class C fly ash
- CEE project support

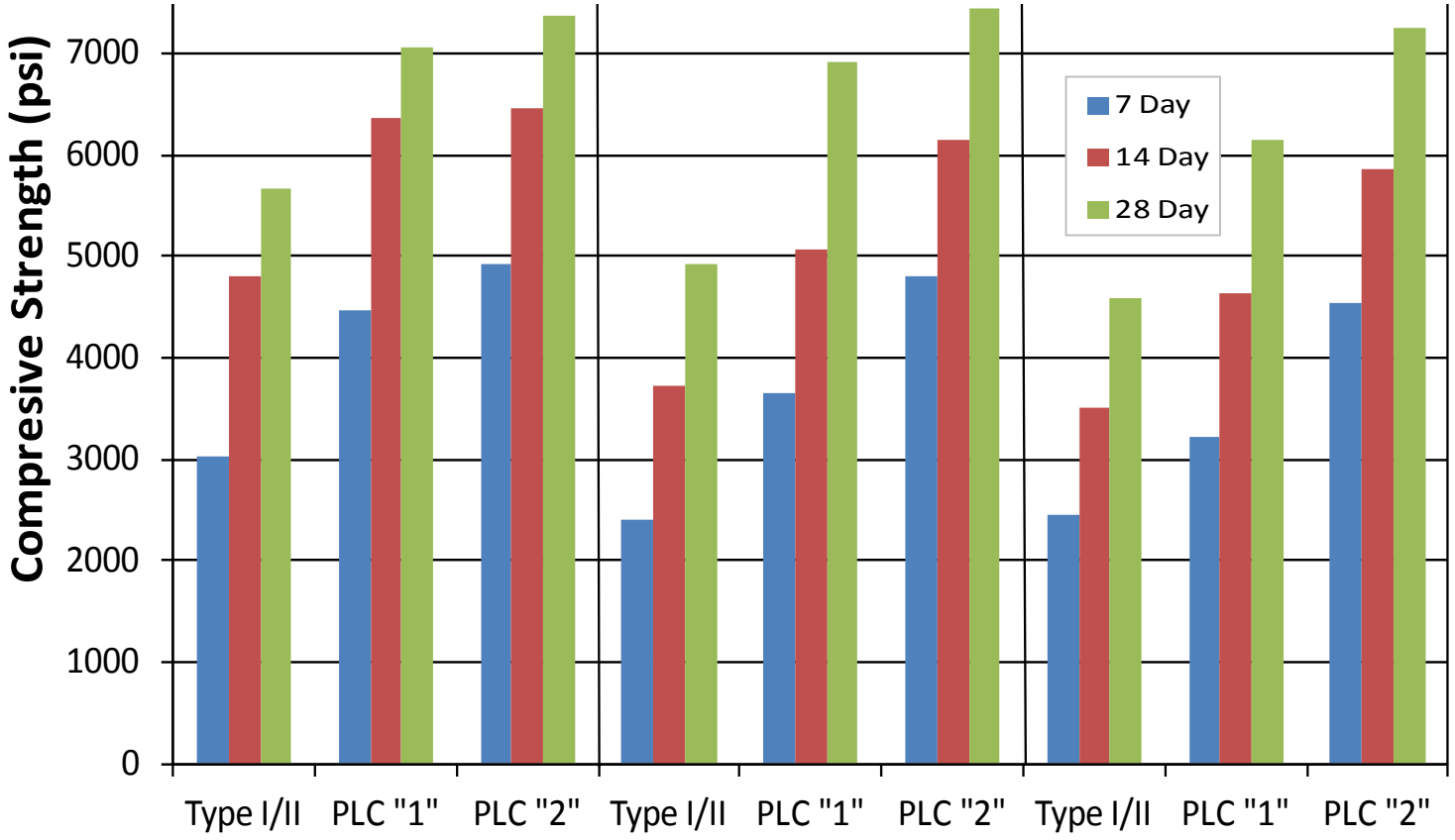
quaternary?

On-campus construction project with PLC: Davis-Wade Stadium

MSU Davis-Wade Stadium mixtures

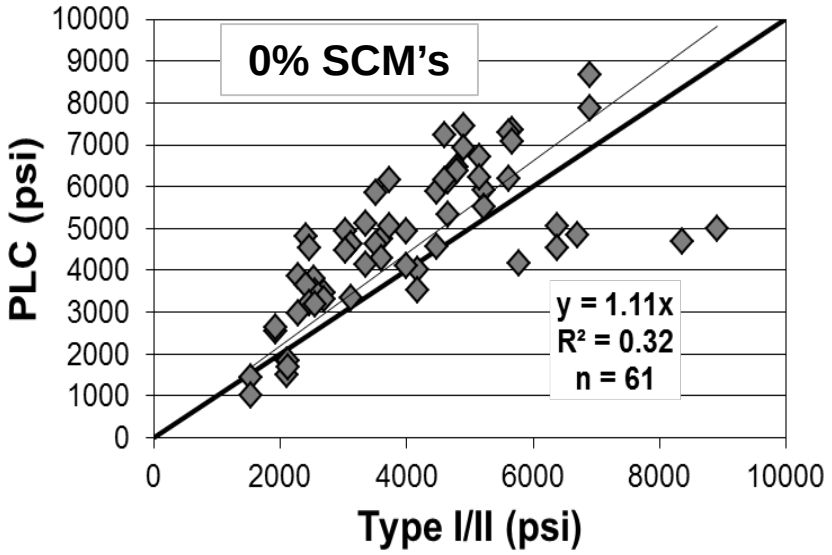
- Most structural concrete 50% replacement ~~ternary~~ mixtures using PLC (50/30/20)
- Data shown from 540 pcy mixtures, non-AE

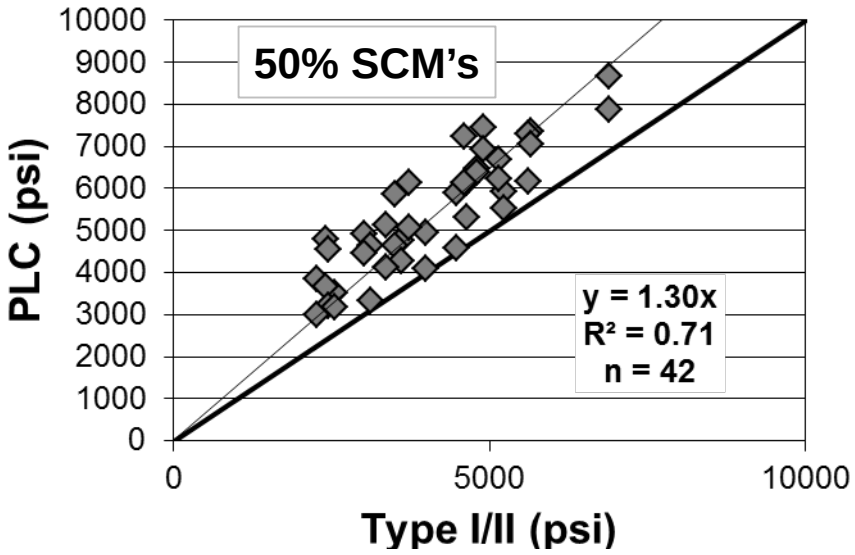
quaternary



Mixture equivalency: 0% vs. 50% SCM's comparison

- Equivalency plots for 540 pcy mixtures, no AE, 0% SCM's vs. 50/30/20
- Blaines:
  - OPC = 390
  - PLC1 = 500
  - PLC2 = 550
- Compressive strengths through 28 days





Summary / conclusions / recommendations

- PLC's can be used seamlessly as a substitution for OPC's in mix designs typical of those used for transportation structures and similar applications, without operational distinctions or differences in performance.
- Equivalent performance (PLC vs. OPC) is possible for a broad range of cement characteristics and limestone contents, within specification limits.
- The hydration synergies contributed by limestone help explain equivalent performance and it may be possible to extend related performance benefits with increased fineness, especially in combination with SCM's.
- These hydration synergies become more robust as fineness increases and can effect higher total cementitious efficiency in concrete, relative to OPC.
- Opportunities for research: increased understanding of PLC synergies and how they can best be optimized (PLC properties and use guidance).

Questions?

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