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Emerging Technologies

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

ACI WEB SESSIONS

Tim Cost has over 35 years of professional experience relating to cementitious materials, concrete, and related applications, including work for USAE WES (now ERDC), PCA, the Mississippi Concrete Industries Association, and Holcim. He is a Fellow of the American Concrete Institute (ACI) and is active in various other professional organizations. He is past chair of ACI committee 330, Concrete Parking Lots and Site Paving, and is an active member of several other committees. He was a recipient of the ACI's Delmar L. Bloem Distinguished Service Award in 2010. He is active on ASTM Committees C01 and C09, a member of the C01 Executive Subcommittee, and chairs a Task Force of Subcommittee C01/09.48 which is developing a Standard Practice document for thermal measurement testing. He has served as a seminar instructor for ACI International, the CONEXPO/Conn-Agg trade show, the National Ready-Mixed Concrete Association, and the World of Concrete.

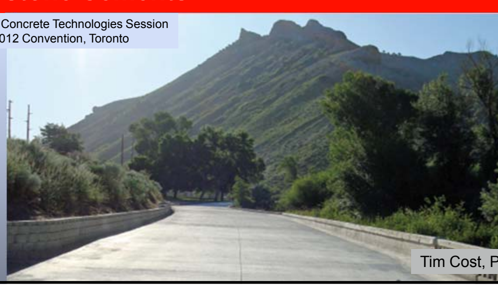
ACI WEB SESSIONS

Holcim

Strength. Performance. Passion.

Beneficial Hydration Synergies of Portland – Limestone Cements

Emerging Concrete Technologies Session
ACI Fall 2012 Convention, Toronto



Tim Cost, P.E., F. ACI

Recap, use of limestone in cement

- Experiences span several decades in many countries
  - Since 1970's in Europe, now predominant with spec categories for up to 35% LS
  - Up to 5% LS allowed in Canada since early 1980's
  - New CSA A3001 classification created for up to 15% LS in 2008 and was adopted by Canadian building code in 2010
- US experiences: up to 5% LS in portland cement
  - ASTM C150 in 2004
  - AASHTO M 85 in 2007
  - ASTM & AASHTO cement specs became "harmonized" in 2009
  - Practical limitations mean common LS% usually ≈ 3.5% or less
- New 2012 specs for blended cements containing 5% to 15% LS, ASTM C595 and AASHTO M240 (Type IL portland-limestone cement)
  - Specs now include Types IS, IP, IL, and IT (combinations of S, P, L)
- Only US spec option for LS > 5% up to now has been ASTM C1157 (performance spec), no AASHTO equivalent
  - Several US producers have made supplied with 10% or more LS since around 2004 to 2005; limited market in many AASHTO states

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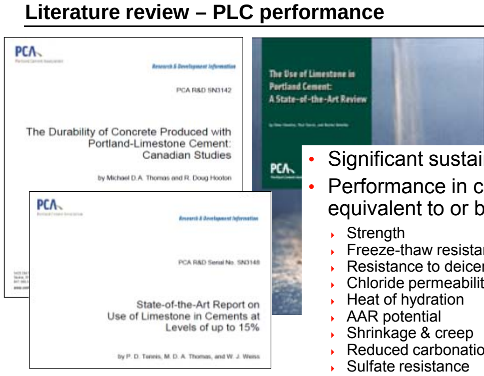
Literature review – PLC performance



- 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

PLC production, basic performance trends

- PLC is made by metering LS to the finish mill with clinker and gyp
- Blaine of PLC must be somewhat higher for equivalent performance
  - LS fraction is finer
  - Blaine must be increased as LS% is increased
- Grinding production is slowed somewhat
- Performance in concrete equivalent to or slightly better than cements without LS, both with and without SCM's at traditional rates, when Blaine fineness is controlled to about 100 m^2/kg higher than for traditional cements**
- Limestone contributes to hydration both physically *and chemically*

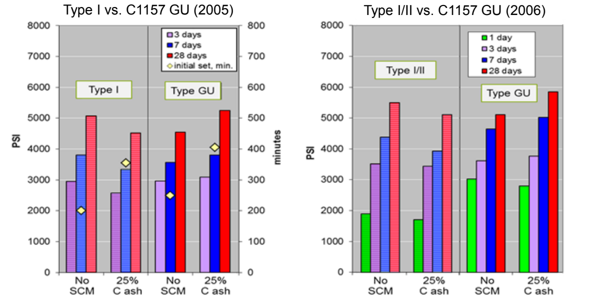
**Tennis, P. D., Thomas, M. D. A., and Weiss, W. J., "State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%", PCA SN3148, 2011

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 100 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

First indications of unexpected PLC "synergy" with fly ash

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



517 pcy concrete mixtures, gravel aggregates, 5" slump

Literature review on limestone 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.

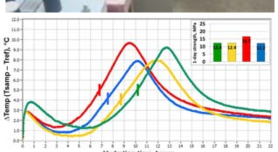
- A number of papers (esp. since 2010) report LS synergy with SCM's, in addition to known OPC interactions
- Reported beneficial LS interaction & synergy mechanisms include:
  - **A) Enhanced particle packing via improved overall PSD**
  - **B) Nucleation site phenomenon**
  - **C) Formation of carboaluminates from calcium carbonate reactions with aluminates (some from OPC but more from SCM's), increasing hydration products, decreasing porosity, and enhancing strength**.
- Synergies are reported to accelerate set as well as increase strength
- All related benefits improve as LS surface area (fineness) increases

Experimental program: evaluation of set and strength trends in laboratory paste, multiple PLC & SCM variables

- Objective: to help evaluate the fineness of limestone (& clinker) fractions, related performance impacts
- Some PLC simulated with OPC+ separately added LS
  - Ground LS of 327 to 1090 m^2/kg Blaine
  - Typically 10% of OPC total, some 15%
  - 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, 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

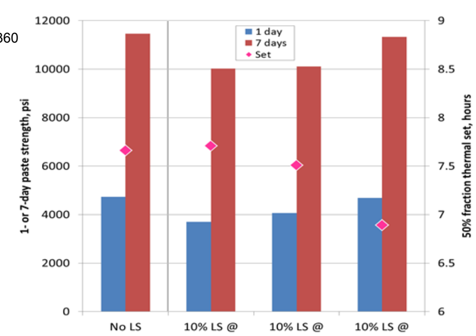
Thermal profile and strength testing of lab paste mixtures

Simple method for rapid evaluation of mixture setting and strength trends



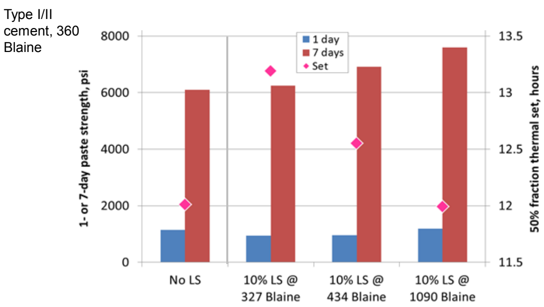
Paste thermal profile "set" and strength comparisons

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



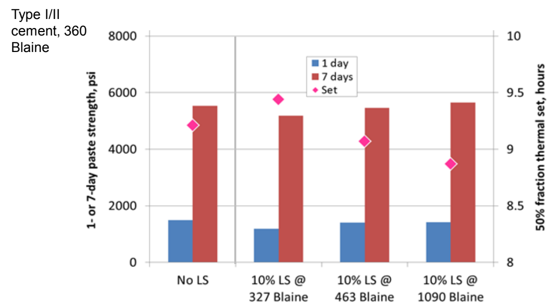
Paste thermal profile "set" and strength comparisons

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



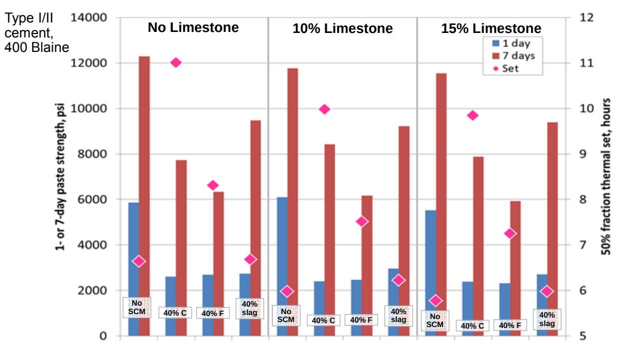
Paste thermal profile "set" and strength comparisons

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



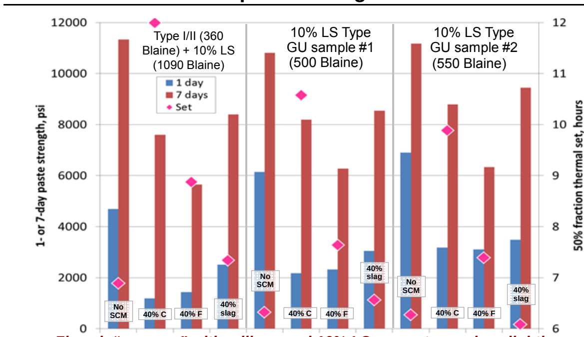
Paste thermal profile "set" and strength comparisons

0% & 40% SCM mixtures with 0%, 10% & 15% LS (1090 Blaine)



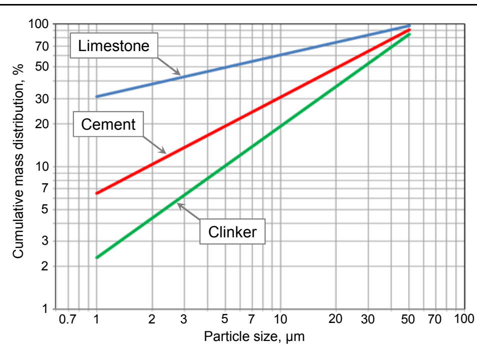
Paste thermal profile "set" and strength comparisons

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



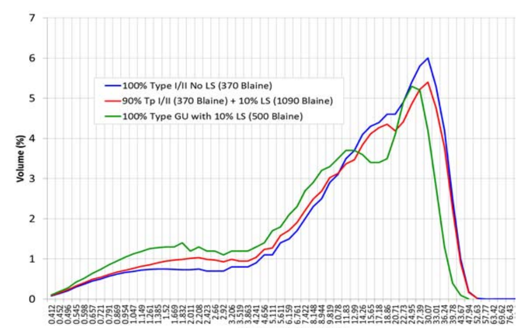
Fly ash "synergy" with mill-ground 10% LS cement samples slightly exceeds that with Type I/II + 10% separately-added LS of 1090 Blaine

Mill-ground PLC: fineness relationships of composite cement, LS and clinker fractions



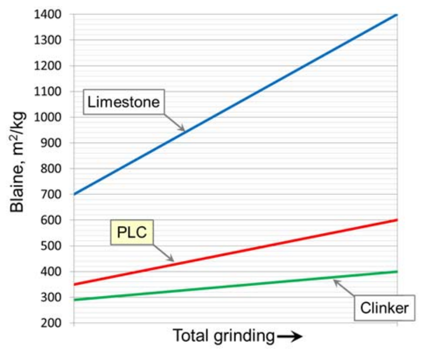
data from: Schiller, B., and Ellerbrock, H.-G., "The Grinding and Properties of Cement with Several Main Constituents, "*Zement-Kalk-Gips*, vol. 45, no. 7, July 1992, as discussed in *The Use of Limestone in Portland Cement: A State-of-the-Art Review*, PCA EB227, 2003.

PSD (differential volume) compared, Type I/II with and without 10% added LS vs. mill-ground 10% LS Type GU

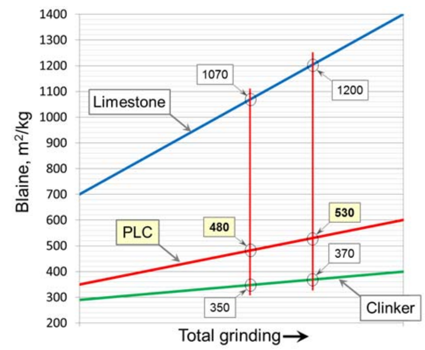


Particle size analyses of individual materials performed using a Beckman Coulter LS 13 320 laser diffraction PSA

Hypothetical Blaine relationships, LS / PLS / clinker, for a given mill system and set of materials



Example: suggested Blaine trends of component fractions for 2 Blaine levels of composite PLC



Summary / conclusions

- Portland-limestone cements produced at up to 15% LS have the potential to significantly improve concrete sustainability with performance equal to or better than C150 / M85 cements.
- Portland-limestone cements clearly hydrate with synergies contributed by limestone that enable enhanced setting and strength performance, especially in combination with SCM's.
- The extent of synergy benefits relates to LS fineness; clinker fineness similar to reference OPC's must be maintained in the composite PLC.
- The particle size distribution of PLC produced to optimum overall fineness in finish grinding ball mills appears well suited for synergy-driven performance enhancement.
- SCM replacement of cement as with traditionally-used C150 / M85 cements must be allowed and encouraged in order to achieve the maximum possible sustainability and performance benefits of PLC.
- Higher-than-traditional replacement rates with some SCM's appear possible without loss of performance, extending sustainability benefits.

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Questions?

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