Improvement of Concrete Sustainability and Performance using Portland-Limestone Cements
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• What, why, and how of PLC
• PLC performance, history of use
• Investigating PLC “synergies” that benefit concrete strength and setting performance
So, what is portland-limestone cement (PLC), anyway?

- 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 in Louisiana
  - 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 it 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)
How is increased hydration efficiency possible?

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

- **Physical mechanisms:**
  - Enhanced particle packing / particle size distribution
  - “Nucleation site” phenomenon

- **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

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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
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
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 about 100 m²/kg higher than for OPC**
• Interesting new trends have become evident in US concrete – US cements are finer, some SCM’s unique
• Indications of enhanced synergies when fineness is further increased

PLC experiences, documented performance

Fineness vs. grinding time

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

Performance-enhancing
Research shows ways of reducing concrete’s footprint

One of the most extraordinary things about ASTM C 1157/GU performance cements is how ordinary they are. Compared to ASTM C-273/GU Portland cements, they have similar strength gain characteristics, can be used under identical environmental conditions, and have similar durability characteristics.

The only major difference between the two cements is what is missing. The energy and carbon-dioxide footprint may be decreased 10% or more for ASTM C1157/GU performance cement compared to ordinary Portland cement — and that is something extraordinary.

This is enormously important, because sustainability and sustainable design cannot grow in significance unless governments, the cost of energy, and environmental awareness is integrated into all elements of transportation design and construction. As a result of technology’s low cost, local availability, amenability and ballast longevity, Portland cement concrete is the most widely used building material on the planet.

This article, however, this data is being used by an independent laboratory to test two ASTM C1157/GU Portland concrete cements produced by Holcim (US) Inc. in Colorado and Utah and several projects conceptualizing the use of these cements: the new Indawo, where sustainability is a priority and the ordinary concrete is not.

Clue to clinker
So why is the manufacture of Portland cement (or CO2, in fact)? There are two primary sources of CO2 inherent in the manufacturing process.
What are PLC “synergies”?

- Synergy \( \text{ˈsin-ər-je} \ n \) – 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 is possible
  - Strength, setting, some durability attributes may benefit
  - 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
- Net effect = 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
Investigating PLC synergies

Concrete strength equality, multiple samples, 2005-2009

- 25% C ash
  - $y = 1.13x$
  - $R^2 = 0.98$
  - No SCM

- 25% F ash
  - $y = 0.97x$
  - $R^2 = 0.95$
  - 0% SCM

[Graphs showing the relationships between PLC and Type I/II OPC for different ash percentages.]
Investigating PLC synergies

Literature review – PLC synergies

- 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

References


Multi-variable experimental program w/ laboratory paste

- Objective: to help explore PLC synergy trends and fineness influences
- Lab simulations of PLC with OPC+ separately added, finely ground limestone
  - Ground LS of 327 to 1090 m²/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
Investigating PLC synergies

Thermal profile and strength testing of lab paste mixtures

Simple method for rapid evaluation of mixture setting and strength trends
No SCM’s, 10% LS @ 327 to 1090 Blaine

Type I/II cement, 360 Blaine
Investigating PLC synergies

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

Type I/II cement, 360 Blaine
Investigating PLC synergies

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

Type I/II cement, 360 Blaine

![Graph showing 1- or 7-day paste strength and 50% fraction thermal set](image)
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
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
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.
- Opportunities for research: additional benefits of PLC use seem possible with increased understanding of PLC synergies and how they can best be optimized (PLC properties and use guidance).
Questions?