Can Portland-Limestone Cement Be Used in Bridge Construction?

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In the near future, portland-limestone cement (PLC) is expected to become the dominant cement available and in use in North America because of its many benefits for both concrete and the environment. PLC has a long history of successful use in concrete. It has been successfully used in Europe for at least three decades.[1] It has been sold in the United States as a Type IL cement with 5% to 15% interground limestone fines under *Standard Specification for Blended Hydraulic Cements* (ASTM C595[2]/AASHTO M240[3]) for use in transportation infrastructure since 2012. Cement containing up to 15% limestone fines has been allowed in Canada since 2008.[4] The Colorado Department of Transportation has been allowing PLC since 2007, and most other state departments of transportation now allow PLC use in at least some applications. However, some contractors, material suppliers, and specifying agencies in the United States are hesitant to use PLC because they have questions about its performance. In this article, I will address some of the most common questions and myths about PLC, discuss some of its advantages, and hopefully convince you to use it in the near future.

What Are the Driving Forces Behind PLC Adoption?

PLC has a lower environmental footprint than ordinary portland cement (OPC) meeting the *Standard Specification for Portland Cement* (ASTM C150).[5] Because limestone fines do not need to be heated or chemically changed during manufacture, Type IL cements can have up to 10% lower carbon dioxide (CO_2) emissions than equivalent OPC.[6] Government regulations in some areas have imposed limits or pricing on greenhouse gas emissions that apply to cement plants. Many cement manufacturers have adopted policies to reduce greenhouse gas emissions, even in areas where limits are not required by law. If a plant has sufficient grinding capacity, use of limestone fines in the cement can also increase cement plant production capacity at low additional cost. Some U.S. plants have converted or will soon convert to 100% PLC production.[7,8] In the near future, OPC may not be available in your area, leaving PLC as the only option. Thankfully, PLC can make concrete that is as good as or, in some cases, even better than concrete made with OPC.

Does Use of Limestone in the Cement Hurt the Strength?

There is a misconception that limestone fines are not reactive, do not contribute to strength, and only dilute the binding capability of portland cement. Most cement producers grind Type IL cements to have about 100 m^2/kg higher Blaine fineness than a Type I cement made with the same clinker to give similar setting time, strength gain rates, and heat of hydration.[4] When used at up to 15% by mass of cement, the limestone fines are not inert and can actually react chemically with the alumina-bearing compounds in the cement.[9] The small limestone particles also enhance the reactions from the other cementitious materials by creating better particle size distribution and better filling in empty space in a phenomenon called the filler effect. Additionally, they provide nucleation locations to enhance the

Figure 1. Ultra-high-performance concrete made with Type IL cement during flow testing. Figure: Megan Voss.

clinker reaction and are beneficial to the concrete properties overall.

Transitioning from an OPC to a PLC does not typically require any more testing or mixture adjustment than is required when switching cement sources for the same type of cement. Type IL cements can be easily proportioned to meet the high-early strengths needed at precast concrete plants. For example, Type IL cements from multiple suppliers were able to meet 4500-psi strength requirements at 18 hours at room temperature, and greater than 6000-psi strength at 18 hours when cured at simulated precast concrete temperatures.[10] High-early-strength PLC can be specified as a Type IL (HE) cement to give similar strength gain rates as Type III cement; this allows precast concrete producers to switch to a PLC with only the same testing required when switching Type III cement sources.

In our laboratory at the University of Florida, we have been using a Type IL cement to consistently produce an ultra-high-performance concrete (UHPC) with compressive strength in excess of 10 ksi at 2 days and 18 ksi at 28 days when cured in the fog room, direct tensile strength at 28 days above 1200 psi with strain-hardening properties, and with great flowability (**Fig. 1**), demonstrating the possibilities of PLC. The smaller particle size of the limestone fines in the cement may actually help with particle packing and achieving good flows when used in UHPC. We are also finding that UHPC with Type IL cement has excellent durability against chloride intrusion, resistance to freezing and thawing, and low creep.

PLC Used with Supplementary Cementitious Materials

PLC used with supplementary cementitious materials (SCMs) that contain high alumina content, such as fly ash per the *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete* (ASTM C618),[11] slag cement per the *Standard Specification for Slag Cement for Use in Concrete and Mortars* (ASTM C989),[12] or metakaolin also per ASTM C618, reacts to provide an increase in strength and durability. The CO_2 in the limestone and alumina in the SCMs react to form carboaluminates that reduce porosity, boost strength, and improve durability. Ternary blends with limestone fines and SCMs are being introduced around the world to take advantage of this synergy, with equivalent performance to OPC with as little as 50% clinker.[13–17]

How Durable Is PLC?

Concrete made with ASTM C595 Type IL cement has similar or better durability compared with concrete that uses an ASTM C150 cement made with the same clinker. The following summarizes the durability of PLC concretes against different forms of deterioration compared with OPC concretes:

- Chloride penetration resistance, chloride binding, and time to corrosion initiation are similar for limestone fines addition up to at least 15%.
- Sulfate-attack durability is mostly a function of the tricalcium aluminate content, water–cementitious materials ratio (*w/cm*), and type and amount of SCMs used, not of the limestone fines content.[18] There was a concern when PLC was first considered for adoption in North America that use of limestone fines in cement in environments with low-temperature sulfate exposure would lead to a particularly damaging form of sulfate attack called thaumasite formation. However, studies have found no significant difference in durability in sulfate exposure based on limestone additions in the ranges used in commercially available Type IL cements.[19,20] Sulfate durability of PLC can be significantly enhanced with use of SCMs such as metakaolin (**Fig. 2**).
- PLC systems have equivalent or better alkali-silica reaction performance compared with OPC systems.[18]
- PLC and OPC systems also have equivalent resistance to freezing and thawing, with both depending on the percentage of air entrainment. No significant difference in salt-scaling resistance is expected.[21]
- Shrinkage is similar (within 10%) in PLC and OPC sytems, as long as the PLC is not ground more than 30% finer than the OPC and typical *w/cm* limits applied to bridge members are followed. Overall, greater precautions are not needed to prevent shrinkage-related cracking in commercially available PLC systems.[10,18,22]

Conclusion

PLC is ground slightly finer than OPC to give equivalent strength and durability to the concrete. In most jurisdictions, the testing effort required to switch from the use of OPC to PLC in concrete mixtures should be the same as the effort needed to switch between OPCs made at different cement plants. Type IL (HE) cement can achieve concrete strengths at early

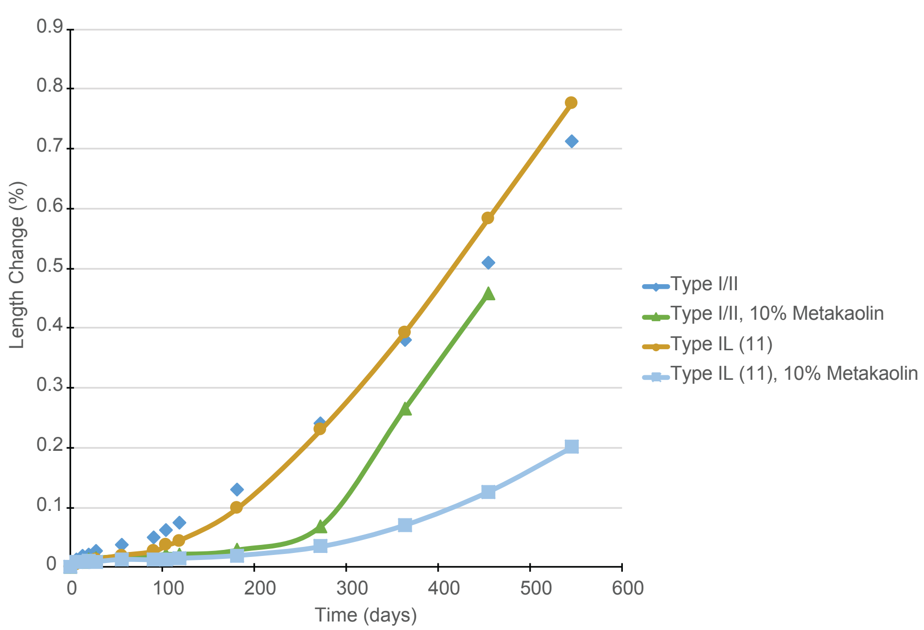

Figure 2. Sulfate attack durability of Type I/II and Type IL cement with and without 10% metakaolin. Note: Type IL (11) indicates Type IL cement with 11% limestone fines.
Figure: Alyami, M. H. M. 2019. "Sulfate Attack on Concrete: Potential for Accelerated Test Methods for Physical Salt Attack of Concrete." PhD diss., University of Florida.

ages equivalent to that achieved with a Type III cement for precast concrete applications. Type IL cement can be used to make concrete with compressive strengths greater than 18 ksi with excellent durability properties, allowing it to be used in nonproprietary UHPC. In the near future, concrete producers may not have other options as cement plants begin to produce only PLC.

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