Portland Limestone Cement (PLC)

Reducing Embodied Carbon (REC)

REC #1 v1 - April 2022

Use of Portland Limestone Cement (PLC) in Concrete Mixes

Abstract

SE 2050 and AIA 2030 have set aggressive targets for low carbon mix designs. Likewise, the California Cement Industry (CNCA) is committed to carbon neutrality by 2045.

The goal of this series of papers is to highlight and make accessible a variety of carbon emission reduction techniques in concrete production, with a focus on the Southern California region.

This paper contains information and resources to help the industry with the design and implementation of mixes using Portland Limestone Cement (PLC) to help achieve these carbon neutrality goals. Using PLC can achieve an up to 10% embodied carbon reduction of concrete and significantly contribute to our carbon reduction goals!

SEAOSC Concrete and Sustainability Committee Collaboration

Date: April 19, 2022

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Committee Mission Statement

Our mission is to provide structural engineers, specifiers, owners, regulators, ready mix suppliers, architects and contractors in the Southern California region with resources and strategies for reducing embodied carbon in concrete mix designs, as well as to bring awareness to the roles which the design and construction community plays in achieving net zero embodied carbon buildings by 2050.

Introduction/Background

As C40 cities, Los Angeles and San Francisco have made a historic commitment to take ambitious, collaborative, and urgent climate action to build a more sustainable, resilient and equitable future. The mayors' steering committees have made a Clean Construction Declaration to achieve the following goals:

- Reduce embodied emissions by at least 50% for all new buildings and major retrofits by 2030, striving for at least 30% by 2025.
- Reduce embodied emissions by at least 50% of all infrastructure projects by 2030, striving for at least 30% by 2025.
- Require zero emission construction machinery in municipal projects from 2025 and zero emission construction sites city-wide by 2030, where available.

This paper was created to help design professionals, ready mix suppliers, architects, owners, and contractors to understand the use of PLC (Portland Limestone Cement) to help reach these targets. Widespread adoption of PLC has the potential to provide a significant reduction in global carbon emissions, with cement production having been demonstrated to account for up to 8% of the global total[9].

Typically, concrete uses Ordinary Portland Cement (OPC), which has up to 5% limestone. Portland Limestone Cement (PLC) uses between 5 - 15% limestone. This increase in limestone produces up to 10% less clinker, which is the main contributor of cement production emissions, and reduces the amount of carbon in the manufacturing process, as compared to OPC.

PLC has been widely used in Europe for decades, widely used in Canada since the early 2010s, has a wide assortment of published research conducted by CalTrans, Portland Cement Association, and universities throughout North America, and has seen success in the US transportation industry. As of October 15, 2022, PLC has also been approved for use by CalTrans. As the California cement industry increases the production of Portland limestone cement, this paper hopes to aid the structural engineering community in accelerating the adoption of PLC.

Applicability

PLC is replaceable at a 1:1 replacement level with OPC[1], allowing for easy design and minimal disruption for ready mix producers. PLC can be mixed with SCMs without negative impact to strength or performance, and has in some cases been shown to improve SCM performance[1]. PLC concrete exhibits comparable compressive strength (f'c), and shrinkage performance as OPC mixes[1]. PLC mixes also display comparable durability properties, in freeze-thaw cycling, salt-scaling resistance, and rapid chloride permeability testing.[8] Project participants in the Example Projects listed below have indicated that setting times and workability of PLC concrete mixes used in the project were comparable to OPC.

Availability

At the publication of this paper (2022), the availability of PLC in Southern California is growing. As CalTrans and other entities are moving towards PLC, many local suppliers are making it available. Additionally, local suppliers are beginning to have EPDs for mixes with PLC available. As of May 14, 2022, the CalPortland Mojave cement plant will be producing only PLC. This represents approximately 20% of the available cement in Southern California.

Note: To quantify the environmental impact, suppliers are commonly using third-party companies, like Climate Earth, to develop EPDs. More information and resources are available on the EC3 website.

Cost

As of the publication of this paper (March 2022), PLC mixes can be comparable in cost to traditional mixes. Contact your local cement supplier for project specific pricing.

Aesthetics

The lighter color of some PLC materials can make the selection of PLC both a sustainable and aesthetically preferred option over OPC (see *Example Project UCSD Theatre District)*. Where the aesthetics of a mix are important, it is recommended to obtain aggregate, cement and fly ash (or other SCM's) from a single source to reduce the variability. This helps ensure consistent coloration out of the mix.

Suggested Specification for Design Professionals

There are minor changes a mix design may need, including adjusting admixture dosages or aggregate content to fit the performance criteria of the specific project application. For example, a post tensioned slab mix where a high early strength is required for stressing purposes will likely include admixtures that enhance the performance of the PLC. Obtaining the trial batch test performance metrics for that specific mix number is necessary prior to implementing the mix on a project.

For the PLC specification, you can copy your existing OPC specification and change ASTM C150 Type I Portland Cement to ASTM C595 Type 1L, as shown below. Where PLC is exposed to sulfate in soil or water, Type IL MS or Type IL HS should be specified.

Sample Specification

Ordinary Portland Cement (OPC)

#. PORTLAND CEMENT SHALL BE TYPE II/V CONFORMING TO ASTM SPECIFICATION C150, UNLESS NOTED OTHERWISE.

Portland Limestone Cement (PLC)

#. PORTLAND LIMESTONE CEMENT (PLC) SHALL BE TYPE IL CONFORMING TO ASTM SPECIFICATION C595, UNLESS NOTED OTHERWISE.

Portland Limestone Cement (PLC) - Sulfate Conditions

#. PORTLAND LIMESTONE CEMENT (PLC) SHALL BE TYPE IL MS/HS CONFORMING TO ASTM SPECIFICATION C595, UNLESS NOTED OTHERWISE.

Recommendations and guidelines

Actions for EOR

- The concrete specification sections need to include PLC (see “sample specification” section above).
- Coordinate with the mix supplier to ensure trial batching is performed to confirm expected fresh and hardened performance. Trial batching should be in accordance with typical jurisdictional standards for cement plant certification and batch acceptance, as with any new OPC mix.
- The "References and Resources" available below include research conducted on PLC describing more specifics about mix designs, such the impact of limestone fineness and intergrinding on strength properties.

Recommendations for Owners

- Owners can have a significant influence on the use of PLC in the mix designs for their project by communicating embodied carbon reductions as a goal of the project.
- Embodied carbon reduction offers the opportunity for clients to achieve their environmental, social, governance (ESG) goals.

Exceptions and Conditions

- Modification to PLC composition should be considered where the concrete will be exposed to sulfates.[10] The Canadian Standards Association provides compositional and testing requirements for portland-limestone cement to be used under various degrees of sulfate exposure.[15]

Example Projects

UCSD Theatre District Living & Learning Center

Image by: EYRC

EOR: Walter P. Moore

Architect: HKS & EYRC

GC: Kitchell

Concrete Sub-Contractor: Largo

Ready Mix Supplier: Robertson's

Estimated Project Completion: Fall 2023

Applications of PLC Mixes:
All visible Shear Walls, Columns, and PT Slabs.

PLC Performance: The PLC mix utilized for the UCSD Theatre District Living & Learning center exhibited strength gain curves comparable or greater than those achieved using a similar OPC mix. In areas where high early strength was required, SCMs were excluded and 4000 psi strength was consistently achieved within 24 hours. Contractor's representatives indicated that the shrinkage, temperature control, and workability properties of the PLC mix were similar to those of OPC. The carbon footprint reduction afforded by the use of PLC is intended to support the project team's pursuit of LEED Silver certification for the development.

Utilization of Technology: Maturity meters were utilized at the beginning of the project to help project strength of pt slabs with high degree of accuracy in an effort to reduce the amount of cylinders and early age breaks and eliminate the need for off hour use of the testing labs.

North Torrey Pines Living & Learning Center

Image by: HKS

EOR: MKA

Architect: HKS

GC: Clark

Concrete Sub-Contractor: Morley

Ready Mix Supplier: Robertson's

Project Completion: Fall 2020

Applications of PLC Mixes:
Foundations, columns, shear walls, elevated two way slabs

PLC Performance: PLC was primarily selected for the vibrant, near-white, color of Cal Portland's *Advancement LT PLC* and led to its use on the Theatre District project as well due to the aesthetically pleasing finish of the concrete.

Intuit Dome (Clippers Performance Venue)

EOR: Walter P Moore

Architect: AECOM

GC: AECOM Hunt Turner Joint Venture

Concrete Sub-Contractor: Largo

Ready Mix Supplier: Catalina Pacific

Estimated Project Completion: September 2024

Applications of PLC Mixes:
All visible shear walls, columns, and PT slabs.

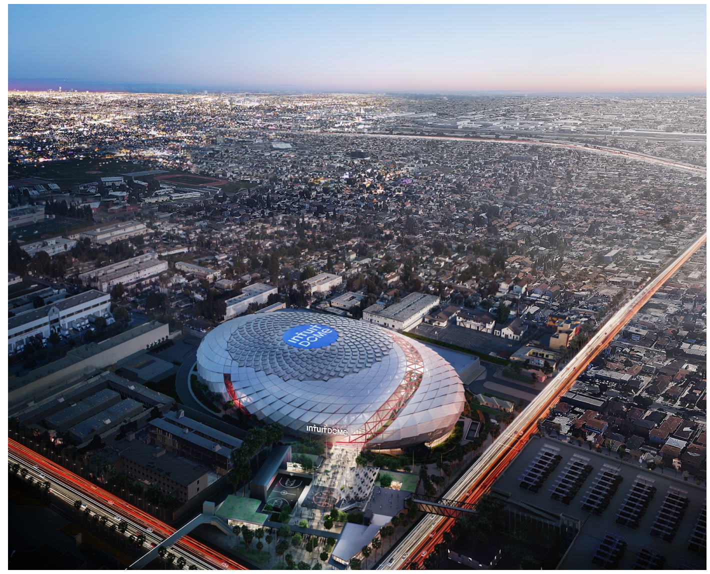

Image by: AECOM

PLC Performance: Owner driven sustainability goals are the driving force behind the use of PLC. With the goal of being the most sustainably conscious venue in the country, many different sustainable design measures were implemented

Utilization of Technology: Carbon Cure was also used starting with the foundation mixes throughout the project.

Other Projects Using PLC

Telus Garden

Photo by: Robert Stefanowicz

EOR: Glotman Simpson

Architect: Henriquez Partners Architects (HPA)

GC: ICON Construction

Ready Mix Supplier: Ocean Concrete

Project Completion: 2015

Applications of PLC Mixes:
Shear walls, columns, slabs, and footings.

PLC Performance: Strength gain curves comparable or greater than those achieved using a similar OPC mix. Shrinkage, temperature control, and workability properties of the PLC mix were similar to those of OPC.

Other Projects:

- Teck Acute Center - **Manusson Klemencic, ZGF & HDR/CEI**
- Metro Tower III - **Stantec**
- Exchange Building - **RJC, Harry Grugger & Iredale**
- Quartz, Elko, Willow and Sackum Bridge Projects - **Stantec**

Applicable Standards and Specifications

ASTM C150
Standard Performance Specification for Ordinary Portland Cement
ASTM C1157
Standard Performance Specification for Hydraulic Cement
ASTM C595
Standard Specification for Blended Hydraulic Cements
ASTM C1797
Standard Specification for Ground Calcium Carbonate and Aggregate Mineral Fillers for use in Hydraulic Cement Concrete
ACI 211.7R
Guide for Proportioning Concrete Mixtures with Ground Limestone and Other Mineral Fillers

References and Resources

Quick Guides

- "Primer on Portland Limestone Cement." Youtube, uploaded by California Nevada Cement Association (CNCA), 25 March 2021, https://www.youtube.com/watch?v=5NlTZJjbx54
- "Portland Limestone Cement and Sustainability." *American's Cement Manufacturers PCA*, https://www.cement.org/sustainability/portland-limestone-cement
- "Portland-Limestone Cement U.S. Fact Sheet." *Portland Limestone Cement*, https://b910efcb-b4f5-4088-990d-b624f092391e.filesusr.com/ugd/f3d485_bf593dd744f049d98cbd293109fc42ce.pdf
- "How to Specify PLC." *Portland Limestone Cement*, https://b910efcb-b4f5-4088-990d-b624f092391e.filesusr.com/ugd/f3d485_5bd63ac767ed4e35b2676bb97e34f653.pdf
- "We’re Encouraging The Use Of Low-Carbon Cement." *CNCA*, https://cncement.org/ser1-low-carbon-cement

Related Research

1. Weiss, Bharadwaj, Keshav, et al. "Caltrans: Impact of the Use of Portland-limestone Cement On Concrete Performance As Plain Or Reinforced Material - Final Report." : Oregon State University, 2021. https://ir.library.oregonstate.edu/concern/articles/7h149x67f
2. Berke, Inceefe, Kramer, and Antommattei., "Durability of Portland Limestone Cement Concrete: Testing mixtures for an infrastructure project," *Concrete International*, January 2022, pp. 34-39. https://www.tccmaterials.com/wp-content/uploads/2022/01/ACI-February-2022-Durability-of-PLCs.pdf
3. Diab, et al. "Long Term Study of Mechanical Properties, Durability, and Environmental Impact of Limestone Cement Concrete." *Alexandria Engineering Journal*, Vol. 55, Iss. 2. 2016. pg. 1465-1482. https://www.sciencedirect.com/science/article/pii/S1110016816000375
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5. Irassar, Bonavetti, Menendez, Donza, Cabrera., "Mechanical Properties and Durability of Concrete Made with Portland Limestone Cement," *Symposium Papers*, V.202, August 2001, pp. 431-450 https://www.researchgate.net/publication/290488355_Mechanical_properties_and_durability_of_concrete_made_with_Portland_limestone_cement
6. Tennis, et al. "State-of-the-Art Report on Use of Limestone in Cements at Levels of up to 15%." *Portland Cement Association,* 2014. https://fcpa.org/wp-content/uploads/Use_of_Limestone_in_Cements_up_to_15_percent.pdf
7. Thomas, et al. “Lowering the Carbon Footprint of Concrete by Reducing the Clinker Content of Cement.” *University of New Brunswick*, 2010. http://conf.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2010/docs/k3/thomas.pdf
8. Thomas, Michael, and Doug Hooten. "The Durability of Concrete Produced with Portland-Limestone Cement: Canadian Studies." *Portland Cement Association*. 2010. https://www.fcpa.org/wp-content/uploads/The_Durability_of_Concrete_Produced_with_PLC-Canada.pdf
9. "Making Concrete Change: Innovation in Low-carbon Cement and Concrete" Chatham House Report. *Chatham House. 2018.* https://www.chathamhouse.org/2018/06/making-concrete-change-innovation-low-carbon-cement-and-concrete

Digging Deeper

The papers listed above offer a comprehensive examination of the effects on a concrete mix with the use of PLC. It should be noted, some studies list compressive strengths lower than OPC for mixes beyond 8-10% limestone. This can be overcome for mixes up to 15% when the Blaine fineness of the cement is increased, as shown in (Tennis pg. 28)[6] , (Hooten pg. 20-22)[4], (Bharadwaj pg. 71)[1] . These three papers, (Tennis)[6], (Hooten)[4], (Bharadwaj)[1] also review many different properties observed in PLC, including workability, bleed rates, heat of hydration, and durability.

Acknowledgements

This paper would not have been possible without the generous contributions of time and expertise provided by our reviewers. Special thanks to Nathan Forrest, Chris Garcia, Ann Harrer, Mahmoud Fargihi, Juan Gonzalez, Shubhada Gadkar, Behnaz Zaribaf, John Philp, Oon-Soo Ooi, Lourette Swanepoel, Harrison Glotman, Rachelle Habchi, Dirk Kestner, John Halverson, Behnaz Zaribaf, Melanie O'Regan, Alana Guzzetta and Kelly Roberts.

GLOSSARY

C40 CITIES – a coalition of 97 cities around the world committed to the research and implementation of strategies fighting climate change, with a specific goal to halve emissions of its member cities within a decade.

CARBON – symbol C, abundant chemical element, used in almost every industry. Purest carbon form are diamonds and graphite.

CARBON DIOXIDE – symbol CO2 odorless colorless tasteless gas, mainly formed by burning fuels or (a byproduct of cellular metabolism)

CARBON LEADERSHIP FORUM (CLF) - is an organization composed of architects, engineers, contractors, material suppliers, building owners, and policymakers who are taking bold steps to decarbonize the built environment, with a keen focus on eliminating embodied carbon from buildings and infrastructure.

CLIMATE CHANGE – long-term alteration of temperature and typical weather patterns affecting directly humans, communities and wild life through draught, storms, heat waves, rising sea levels, wildfires, warming oceans and much more.

EC3 - Embodied Carbon in Construction Calculator (EC3) tool, is a free, cloud-based, easy to use tool that allows benchmarking, assessment and reductions in embodied carbon, focused on the upfront supply chain emissions of construction materials.

EMBODIED CARBON – the entire carbon footprint of a building or infrastructure project until it becomes operational. It includes: extraction, manufacturing, transportation of raw materials, installation, disposal of all materials, etc. It accounts for 11% of global GHG. The biggest source of embodied carbon in a building is Concrete. Cement is about 95% of carbon emissions in Concrete. It is measured in kg, CO2/kg of product material.

EMBODIED CARBON BENCHMARK STUDY – provides data to building industry professionals integrating embodied carbon into life cycle decision making. It compiled the largest known database of building embodied carbon and created an interactive database.

EPD – Environmental Product Declaration is independently verified and registered document who communicates verifiable, accurate, non-misleading environmental information for products and their information.

ESG – Environmental, Social and Corporate Governance are a set of standards for a company's operations that considers social and environment factors.

GREENHOUSE GASES (GHG) – gases in atmosphere (CO2 accounts for 76%) that creates a cover which traps sun's heat energy. The biggest contributors are Electricity and Heat production by burning of coal, natural gas and oil. Buildings and Construction sector generate nearly 40% (Embodied Carbon + Operational Carbon) of annual global CO2 emissions.

LIFE CYCLE ASSESMENT (LCA) – is the method used to quantify embodied and operational carbon.

NET ZERO CARBON BUILDING – highly efficient and powered building powered by on/off site renewable energy sources.

OPC – Ordinary Portland Cement is the most widely and commonly used cement in the world as traditional binder materials in the construction industry. Taking into account that in the manufacture of one ton of OPC up to one ton of carbon dioxide is emitted, the cement industry leads with 6% of the overall carbon dioxide emissions.

OPERATIONAL CARBON - the amount of carbon emitted during the operational or in-use phase of a building. This includes the use, management, and maintenance of the structure such as: keeping building warm, ventilated, lighted, powered. It accounts for 28% of global GHG.

PLC – Portland Limestone Cement is blended cement with higher limestone content (5%-15% vs 5% in OPC), which results in a product that works the same, measures the same and performs the same but with a reduction in carbon footprint of 10% on average.

SE 2050 – is a vision/mission started in December of 2019 and developed by Sustainability Committee of SEI (Structural Engineering Institute), to achieve the globally stated goal of net zero carbon embodied carbon by 2050