SPR RESEARCH PROGRAM
SECOND-STAGE PROPOSAL SUMMARY

PROBLEM NUMBER AND TITLE

24-52 Low Carbon Concrete for ODOT

PROBLEM SUMMARY

The concrete industry is pushing toward lower carbon footprint systems. One significant way to accomplish this goal is to employ locally-available materials to minimize transportation impacts in terms of cost and carbon emissions. However, research is needed to identify the local materials in Oregon (and surrounding areas) that can be used to produce low carbon concrete while still achieving the desired mechanical and durability properties necessary for implementation.

ODOT OBJECTIVES

This research will develop low-carbon blended cement using local Oregon material. This way, up to 20% of Portland cement could be replaced with finely ground limestone other supplementary cementitious material such as calcined clay, nature pozzolans, slag, etc. Accelerated curing approaches will also be investigated.

BENEFITS

Primary benefit resulting from this research is to improve long-term performance and reduce CO_{2eq} emissions by as much as 50% compared to ordinary Portland cement for ODOT concrete assets. Additional benefit from this research is to meet ODOT's mission by addressing ODOT's current strategic action plan to further enable a modern transportation system with lower maintenance costs and lower carbon footprint.

SCHEDULE, BUDGET, AND AGENCY SUPPORT

Estimated Project Length: 30 months.
Estimated Project Budget: $300,000
ODOT Support:
Justin Moderie, State Construction and Materials Engineer, Justin.G.MODERIE@odot.oregon.gov

FOR MORE INFORMATION
For additional detail, please see the complete STAGE 2 RESEARCH PROBLEM STATEMENT online at:
https://www.oregon.gov/odot/Programs/ResearchDocuments/24-52.pdf

SPR RESEARCH PROGRAM
SECOND-STAGE PROBLEM STATEMENT
FY 2024

PROBLEM NUMBER AND TITLE
24-52 Low Carbon Concrete for ODOT

RESEARCH PROBLEM STATEMENT
The concrete industry is pushing toward lower carbon footprint systems. However, research is needed to elucidate the local materials in Oregon (and surrounding areas) that can be used to produce low carbon concrete while still achieving the desired mechanical and durability properties necessary for implementation. CO_{2eq} emissions from cement production account for approximately 8% of the world's CO_{2eq} contribution. In mid-2022 most U.S. cement suppliers made a significant change by increasing the substitution of finely ground limestone from less than 5% to 10-15%. In combination with replacements by supplementary cementitious materials (SCMs), CO_{2eq} emissions can be lowered by as much as 50% or more. A recent approach that is gaining significant traction in the U.S. are LC^3 systems (limestone calcined clay cement). These cementitious blends have been proven to reduce CO_2 emissions without compromising design strength and durability. Several challenges exist for full-scale implementation. First, the availability and the quality of kaolinite calcined clay can play a significant role in the performance of LC^3. Second, locally available SCMs may be able to be used in place of the calcined clay portion of LC^3 where kaolinitic clays are not available. Finally, while later age strength is retained, or even exceeded compared to 100% OPC systems, the early-age strength (e.g., prior to 7 days) can be reduced in systems with high cement replacements. Such blended cements must be carefully designed to maximize the synergistic benefits while obtaining desired mechanical and durability properties. Several different acceleration techniques to overcome the early-age strength impacts are possible, and merit investigation in this proposed project.

RESEARCH OBJECTIVES
Overall, the objective of this research project is to identify in-state materials and concrete mixture designs that result in concrete with similar strengths, workability, and durability characteristics as traditional mixes which do not employ low carbon, in-state materials. In addition to changing the cementitious materials, SPR-823 reported that the cementitious materials content can be reduced by almost 20% if the aggregate is first characterized. However, the research noted the need for better dimensional stability (e.g., shrinkage) and abrasion testing. The goal of this research is to develop low-carbon blended cements using local Oregon materials that are durable and can be readily produced in Oregon per ODOT requirements. This will involve replacing up to 20% of the Portland cement with finely ground limestone and another 20-40% with a supplementary cementitious material such as calcined clay, natural pozzolan, slag, or others to be identified, all after minimizing the cementitious materials content following the method proposed in SPR-823. The performance of the locally available kaolin clays, nature pozzolans, slag, etc., will be evaluated to target a clinker factor of 50% (or lower) and optimized for producing long-lasting concrete for ODOT applications. Since low cement content concrete can have reduced early age (e.g., prior to 7 day) strength, accelerating approaches to offset this lower initial strength gain will be investigated.

WORK TASKS, COST ESTIMATE AND DURATION
The proposed scope of work for this project includes:

Task 1 - Literature Review and Materials Availability Review
A detailed literature review focusing on low-carbon blended cement (with clinker factor of 50% or lower) will be done, and the available local materials will be identified for inclusion on subsequent tasks. Locally available clays, natural pozzolans and traditional SCMs are the focus.

Task 2 – Materials Characterization
Detailed materials characterization for physical and chemical properties (including fineness, bulk chemical composition, mineralogical composition, reactivity, etc.) will be done for the materials identified in Task 1.

Task 3 - Impact of PLC Type
The synergy between PLC with SCMs will be investigated in detail by following the hydration characteristics of blended cement. One OPC blended with various levels of commercially available limestone will also be considered as a reference to study the effect of limestone purity and replacement levels. The experimental study will include the hydration behavior, strength development and the evolution of microstructure and mechanical properties over time.

Task 4 – Laboratory Investigations: Fresh Properties, Strength Gain, Transport Properties, Shrinkage and Abrasion Resistance
Concrete mixtures will be developed in the lab to meet the targeted mechanical, thermal, and environmental loading conditions based on the Technical Advisory Panel and ODOT input. The workability characteristics, rate of strength gain and change in electrical properties (highlighting the chance in transport properties) will be studied in detail. The volumetric change (shrinkage and/or expansion) and abrasion resistance, two key properties critical for ODOT concrete, will be quantified according to the best methodologies identified in Task 1.

Task 5 – Recommendations to Specifications and Procedures for ODOT
Based on the performance of different SCMs combinations, cost and desired properties, the recommendations for developing high-performance concrete with low-carbon blended cement having 50% clinker (or lower) will be provided in detail.

Key Deliverables:

1. Literature Review and Materials Availability Review – Interim Report
2. Materials Characterization – Interim Report
3. Impact of PLC Type – Interim Report
4. Laboratory Investigations: Fresh Properties, Strength Gain, Transport Properties, Shrinkage and Abrasion Resistance – Interim Report
5. Final Report: Includes all previous interim reports and also, final recommendations to Specifications and Procedures for ODOT

Estimated Project Length: 30 months
Estimated Project Budget: $300,000

IMPLEMENTATION
Overall, the objective of this research project is to identify in-state materials and cement mixture designs that result in concretes with similar strengths, workability, and durability characteristics as traditional concrete mixes that do not employ in-state materials. Once the in-state materials are identified, an adequate mixture design is developed, and laboratory testing indicates that these concrete mixtures perform similarly or better than traditional concrete mixes, ODOT will test these in concrete pavement pilot construction projects.

POTENTIAL BENEFITS

Developing low-carbon blended cement (with 50% clinker or lower) can improve long-term performance and reduce CO_{2eq} emissions by as much as 50% compared to OPC for ODOT concrete assets. In addition, developing new low-carbon blended cement will meet ODOT's mission by addressing ODOT's current strategic action plan to further enable a modern transportation system with lower maintenance costs and ***carbon emissions***. The implementable actions covered in this research problem statement will be to identify alternative lower-carbon materials for developing blended cements for use in ODOT construction practices.

Low-carbon blended concrete optimized using locally available materials and new mixture design methods will help ODOT meet one goal of the ODOT Strategic plan to reduce carbon emissions. Any updates to current materials specifications will need to be made based on the outcome of this research project. The eventual result is anticipated to be the commoditization of low-carbon concrete using local Oregon materials.

The major advantages of developing low-carbon blended cement are that: (1) the performance of the concrete members under the mechanical, thermal, and environmental loading (e.g., alkali-aggregate reactivity, shrinkage, chloride exposure, etc.) can be specifically designed based on their design requirements, and ; (2) highway structures built with low-carbon blended cement will have lower carbon footprint, maintenance and repair costs compared with conventional concrete.

PEOPLE

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REFERENCES

Trejo, D., Vaddey, P., Vasudevan, G.D., Isgor, O.B., and Amirkhanian, A., Constructability and Durability of Concrete Pavements: SPR-823, Final Report, Oregon Department of Transportation, September 2021, 186 pp.

STAFF REVIEW PAGE

Literature Check

TRID&RIP

☒ A review of TRID & RIP databases found no existing research that answers the research question

Technology & Data assessment

☒ No Identified T&D output

☐ At the end of this project, the implementing unit(s) within ODOT will need to coordinate the adoption of new technology or data in order to realize the full potential of this research.

Cross-agency stakeholders

- List stakeholders or impacted units
  - Pavement Construction
  - Pavement Services

- Identify any issues of concern raised by an ODOT stakeholder. Note expected mitigation
  - None