Enhancing the Durability of Performance-Based Concrete Overlays by the Optimization of Binder Content

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Abstract

Concrete overlays are essential for the rehabilitation of bridge decks, minimizing early-age cracking and improving durability. This study aims to optimize performance-based concrete overlay mix designs to reduce early-age cracking and increase durability. The research evaluates the impact of using new materials, such as Type IL (containing ground limestone powder) or calcium sulfoaluminate (CSA) cement, on the overall performance of the concrete overlays. Using a modified void ratio approach and aggregate gradation optimization, using the Tarantula Curve and 0.45 Power Curve, various formulations were tested, analyzing aggregate blends, water-to-cement ratios, cement content, and admixture additions. Results showed that optimized aggregate gradation and binder content significantly improve the mechanical properties of concrete mixtures. Type IL cement allowed higher cement content utilization compared to ordinary Portland cement (OPC), while CSA cement blends accelerated strength development and improved chloride resistance. Latex modifiers further enhance workability. Additionally, while the paste-to-void ratio strongly influenced workability, its correlation with compressive strength was weaker than expected. These preliminary findings indicate that incorporating novel materials can enhance the sustainability of concrete overlays while maintaining their overall performance.

Introduction

Goals

According to the American Society of Civil Engineers (ASCE), the United States (U.S.) has approximately 617,084 bridges [1]. Of these, 46,163 (7.5%) are classified as "poor" due to a significant decline in primary structural components. Based on research and engineering, an experienced concrete overlay could be the best option for road pavement renovation. However, traditional prescriptive mix designs frequently fail to achieve long-term performance under varying environmental conditions. Instead, a performance-based mix design enhances aggregate particles to minimize cementitious material content utilization while maintaining durability and mechanical performance. This study aims to optimize performance-based concrete overlay mix designs to reduce early-age cracking and increase durability. The goal is to achieve a sustainable concrete overlay, which can save money and also be eco-friendly.

Materials

Aggregates

Type	***Source Location***
River Sand	Garfield
1” MSA Crushed Limestone (TXDOT Grade 5)	Hunter
½” MSA Crushed Limestone (TXDOT Grade 6)	North Bridgeport
½” MSA River Gravel (TXDOT Grade 6)	Tin Top
3/8” MSA River Gravel (TXDOT Grade 7)	Tin Top

Cements

Cements	***Source***
Type I/II Portland cement	Texas Lehigh (Buda)
Type IL (10) MS	Capitol (San Antonio)
Calcium Sulfoaluminate Cement + Latex	CTS Cement
Calcium Sulfoaluminate Cement + Polymer	CTS Cement

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Methods

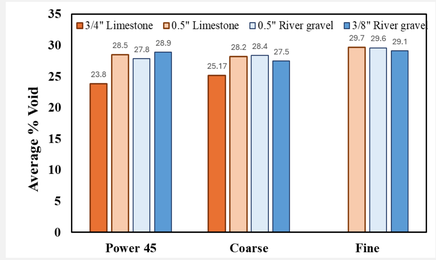
Category	Method/Approach	Objective
Aggregate Optimization	Finding optimal aggregate blends	Finding optimal aggregate blends.
	Power 45 Curve	Using the Power 45 curve for higher aggregate density.
	Conventional Aggregate Mixes	Comparison using different coarse-to-fine ratios.
Fresh Concrete Testing	Slump Test (ASTM C143)	Evaluating workability and consistency.
	Air Content Test (ASTM C231)	Essential for freeze-thaw resistance.
	Unit Weight Test (ASTM C138)	Calculates homogeneity and density.
Hardened Concrete Testing	7-Day Compressive Strength (ASTM C39)	Measures early-age strength .

Aggregate Type	MSA	Aggregate Combination		
		Power45	Coarse	Fine
Limestone	1"	62%LS, 38%RS	-	-
	1/2"	50%LS, 50%RS	60% LS, 40% RS	35%LS, 65%RS
Gravel	1/2"	52%RG, 48%RS	60% RG, 40% RS	35%RG, 65%RS
	3/8"	46%RG, 54%RS	-	-

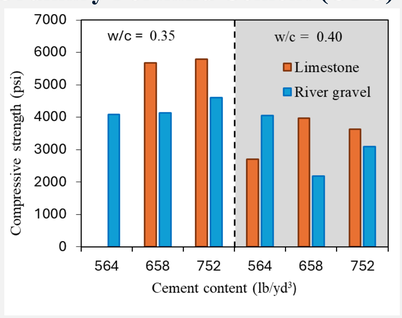
Results

Air Voids quantification

The power 45 curve helps to achieve an aggregate combination that has the lowest void content due to providing optimized tradition. This fact helps to reduce the demand for extra cement. Additionally, angular aggregates (limestone) have more voids in comparison to river gravel rounded aggregates, and dinner river gravel particles (3/8") provide less reduced voids.



Ordinary Portland Cement (OPC)



Mixes OPC-658-0.35 and OPC-752-0.4 exhibited almost no slump loss but had lower compressive strength compared to the other mixes, despite using the maximum allowable amount of high-range water reducer (HRWR) in them. This result indicates that low cement content (564 pounds per cubic yard) and a water-cement ratio (0.35) reduce workability, but the combination does not necessarily make the resulting concrete stronger, and finding the optimal proportions is crucial.

OPC-658-0.35-1/2" River Gravel

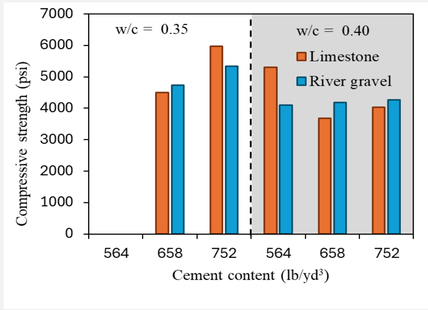
OPC-658-0.4-1/2" River Gravel

OPC-752-0.4-1/2" Limestone

OPC-752-0.35-1/2" Limestone

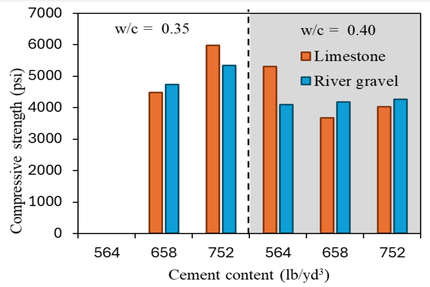
Results

Portland-limestone cements (PLC, or Type IL)



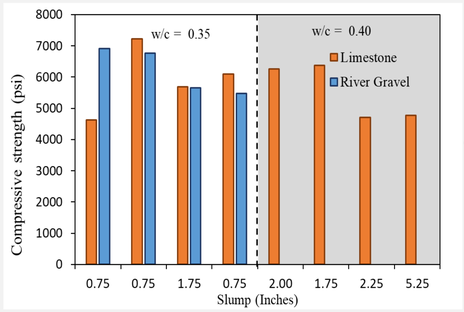
Smaller river gravel (3/8” river gravel) improved void content and packing but led to reduced strength. On the other hand, 1-inch limestone offered superior strength.

Calcium Sulfoaluminate Cement + Polymer



The lack of improvement in compressive strength at higher water-cement ratios, despite an increase in cement content, highlights the importance of determining the optimal cement content for each mix.

Calcium Sulfoaluminate Cement (CSA)+ Latex



- **CSA cement + latex enhances workability.**

Conclusions

This study works on finding optimal performance-based concrete overlay mix designs to enhance durability and resistance to early-age cracking. The Power 45 curve provided the most effective aggregate gradation. Results showed that optimized aggregate gradation and binder content significantly improve the mechanical properties of concrete mixtures. Type PLC cement allowed higher cement content utilization compared to ordinary Portland cement (OPC), while CSA cement blends accelerated strength development. Latex modifiers further enhance workability. Additionally, while the paste-to-void ratio strongly influenced workability, its correlation with compressive strength was weaker than expected. These preliminary findings indicate that incorporating novel materials can enhance the sustainability of concrete overlays while maintaining their overall performance

References

[1] American Society of Civil Engineers (ASCE), "2021 Infrastructure Report Card," 2018. [Online]. Available: https://www.infrastructurereportcard.org/cat-item/bridges/

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