Lab Study of Optimized Concrete Pavement Mixtures

Research Objectives

- To support the development of concrete specifications inclusive of aggregate gradation and use of superplasticizers
- To improve the performance and environmental sustainability of concrete paving mixtures used in Wisconsin

Research Benefits

- Optimizing concrete mixture proportions can result in up to 18 percent reduction of cementitious materials content
- Supplementing portland cement with cementitious industrial by-products can potentially reduce the consumption of cement by up to 18 percent
- Optimized concrete has enhanced workability, strength and reduced permeability

Principal Investigator

Konstantin Sobolev
UW-Milwaukee
sobolev@uwm.edu

Project Manager

Andrea Breen
LafargeHolcim
andrea.breen@lafargeholcim.com

Background

The contribution of portland cement to the carbon footprint of concrete is a key factor that requires immediate improvement in order to reach the objective for a more sustainable paving material. One approach to combat concrete's environmental impact is to reduce cementitious materials in its mixture. Previous WisDOT research concluded that concrete mixtures with reduced cementitious material have adequate durability, but poor workability. Those findings prompted this research to identify a multi-faceted approach to optimizing mixture proportions for low-slump concrete.

Current proportioning standards have limited or no guidelines on the optimization or use of aggregate gradations, including ternary aggregate blends, supplementary cementitious materials (SCM), modern superplasticizers or air-entraining admixtures. The application of these alternative mixture strategies requires a deep knowledge of the materials' properties, behaviors and time-dependent interactions.

Methodology

The SCM and air-entraining admixtures were selected to comply with existing WisDOT performance requirements, and chemical (mid-range and high-range water reducing) admixtures were selected based on the optimization study. Concrete mixtures were batched and mixed, and the concrete specimens were cast, cured and tested according to the corresponding ASTM and AASHTO standards. The performance of different concrete mixtures was evaluated for workability (slump), air content, compressive and flexural strength ranging from one and up to 365 days, drying shrinkage, freeze-thaw resistance, and rapid chloride permeability**.**

Research results were obtained by testing three specimens for compressive strength, two for modulus of rupture, three for length change, two for rapid chloride permeability and three for freezing and thawing resistance.

Testing the workability of concrete mixture using a slump cone

"Using these research findings to optimize concrete mixtures will result in improved durability, economy and environmental sustainability of concrete pavements on WisDOT projects statewide."

– James Parry, WisDOT

Interested in finding out more?

Final report is available at: WisDOT Research website.

Results

It was demonstrated that concrete mixtures can be effectively designed by optimizing two essential phases comprising the material: aggregate blends and cement paste.

Improved aggregate packing can improve the compressive strength and enhance concrete performance, allowing for a reduction of up to 18 percent in the cementitious material content compared to current WisDOT specifications for concrete mixtures, while still satisfying all other performance requirements. The optimized, superplasticized concrete consisting of up to 30 percent fly ash (Class C) and up to 50 percent ground granulated blast furnace slag demonstrated exceptional mechanical and durability performance.

Air-entraining (AE) admixtures form the desired air-void structure of concrete and low spacing factors which, in turn, provide extra space for freezing water to expand, reducing the associated stresses and enhancing the concrete's freezing and thawing resistance. The use of polycarboxylate ether superplasticizing admixtures enabled up to a 10 percent reduction of the water-to-cement ratio and water content compared to commonly used water-reducing admixtures, resulting in better performance.

Recommendations for Implementation

The proposed concrete optimization strategy with optimal aggregate blends, superplasticizing admixtures and SCM reduces environmental impacts of pavement production while providing enhanced performance, durability, life-cycle and sustainability.

Although superplasticizers introduce remarkable advantages, there are some limitations. For example, the compatibility of superplasticizers with other admixtures such as air-entraining agents and SCM must be verified prior to application.

The developed concrete has better workability, flowability and durability than currently used portland cement concrete, while using 18 percent less cementitious material. Using concrete with SCM from industrial by-products such as slag or fly ash can reduce the overall cement consumption by up to 50 percent.

This brief summarizes Project 0092-13-04,
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