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RESEARCH PROJECT TITLE
Performance Evaluation of Very Early Strength Latex-Modified Concrete (LMC-VE) Overlay

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Performance Evaluation of Very Early Strength Latex-Modified Concrete (LMC-VE) Overlay

tech transfer summary

Bridge deck overlays made with high early strength latex-modified concrete have the potential to significantly reduce the time for opening to traffic while providing good long-term performance.

Goal and Objectives

The goal of this research was to explore the potential use of high early strength latex-modified concrete (LMC-VE) in Iowa bridge deck overlays by studying an LMC-VE overlay placed on the IA 15 bridge over Black Cat Creek in Emmet County.

Objectives included documenting the overlay construction processes, evaluating key engineering properties of the overlay material in the laboratory, monitoring the field performance of the overlay for five years, conducting a life-cycle cost analysis (LCCA) of the overlay, and providing recommendations for the use of LMC-VE overlays on Iowa bridge decks.

Background

The most commonly used bridge deck overlay materials in Iowa are high-performance concrete (HPC) and portland cement concrete (PCC). According to Iowa's standard specifications, these materials require 72 hours of wet curing. Given the high cost of traffic control for heavily traveled highways, it is desired to reduce the duration of traffic disruptions as much as possible.

LMC-VE overlays are designed to open to traffic within 3 to 6 hours of placement. Research has indicated that LMC-VE overlays are less prone to shrinkage-related problems and chloride ion penetration than other early strength overlays. The high initial cost of an LMC-VE overlay can be offset by the reduced need for traffic control and the overlay's ability to extend bridge deck service life to over 75 years.

Several states (e.g., Virginia, Ohio, Missouri, Kentucky) have explored the use of LMC-VE overlays in their bridge construction projects. In September 2019, the Iowa Department of Transportation (DOT) conducted the first trial placement of an LMC-VE bridge deck overlay in the state. The overlay was placed on the IA 15 bridge over Black Cat Creek in Emmet County.

LMC-VE overlay on the IA 15 bridge over Black Cat Creek (May 20, 2023)

Problem Statement

The LMC-VE bridge deck overlay on the IA 15 bridge over Black Cat Creek is the first of its kind in Iowa. An evaluation of the overlay's construction, performance, and economic feasibility can inform future bridge deck overlay decision-making and provide design and construction guidance for future practice.

Research Description

To assess the overlay's performance, the following program of field and laboratory testing was carried out:

1. The LMC-VE overlay placement processes were documented, including LMC-VE materials and mix proportions, substrate surface preparation, concrete placement, and post-construction activities.

2. During overlay placement, on-site field tests were conducted, and specimens were prepared in the field for laboratory testing. Field tests measured concrete setting time and the surface resistivity (SR) of the overlay three hours after construction. Laboratory tests measured compressive and flexural strength development, chloride penetration resistance through SR testing and salt ponding, water sorptivity, and freeze-thaw durability.

3. After placement, the short-term (beginning at four days) and long-term (up to five years) performance of the overlay was monitored in the field through 10 field visits. During each visit, the overlay surface was examined for cracking and deterioration, core pull-out tests were conducted, friction index was measured via British Pendulum Number (BPN), and SR was measured.

Additionally, a comprehensive LCCA was performed to evaluate the total economic value of the construction (considering the direct costs) and maintenance (considering the user costs) of the LMC-VE overlay in comparison to four overlay alternatives: HPC, PCC, polyester concrete, and latex-modified concrete (LMC).

Placement of LMC-VE overlay material

SR measurement performed on field overlay three hours after casting

Key Findings

Laboratory Performance of Field-Cast Specimens

- LMC-VE is highly flowable and easy to use during construction.

- LMC-VE developed a satisfactory compressive strength of 2,827 psi at 3 hours, which is favorable for quickly opening a pavement to vehicular traffic.

- The LMC-VE binder was mainly made of calcium sulfoaluminate (CSA) cement, latex, and citric acid. In contrast to portland cement, the LMC-VE binder rapidly generated a significant amount of heat during hours 5 to 10 hours of cement hydration.

- The 28-day pull-out strength testing on beams comprised of an HPC substrate overlaid with LMC-VE indicated a bond strength of 283 psi (greater than the 250 psi recommended for thin epoxy overlays).

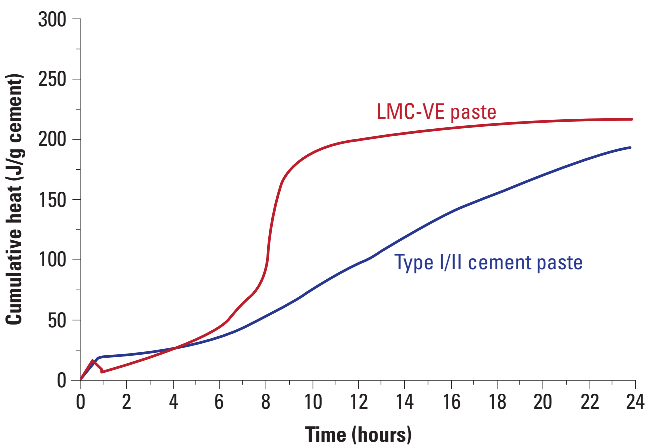
- SR values of 61.4 kΩ-cm at 170 days and 110.3 kΩ-cm at 440 days were found, indicating enhanced impermeability with time.

- The chloride content determined from 90-day salt ponding tests indicated that an LMC-VE overlay has better chloride penetration resistance than a low-slump dense concrete (LSDC) overlay.

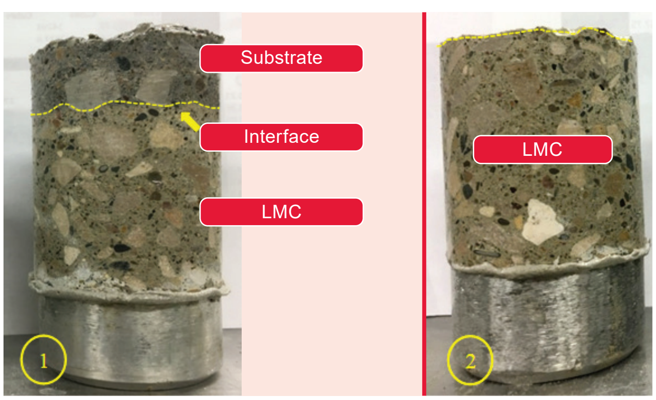
- The initial sorptivity of the field-cast and field-cored LMC-VE specimens was lower than that of the HPC field substrate concrete, but the secondary sorptivity of the 28-day LMC-VE specimens was higher. Both the initial and secondary sorptivity values decreased with time, indicating a potential reduction in material permeability over time.

- After 400 days, LMC-VE beam specimens showed autogenous and drying shrinkage values of 115 and 440 microstrain, respectively, well within the typical values for PCC.

- Beams containing only LMC-VE showed relatively poor freeze-thaw resistance, contrary to previous studies, with significant mass loss at 72 freeze-thaw cycles. In contrast, beams comprised of LMC-VE overlaid on an HPC substrate showed better freeze-thaw resistance, with no considerable mass loss at 144 freeze-thaw cycles.



Cumulative heat over time for LMC-VE paste versus Type I/II cement paste



Pull-out test cores showing failure in the substrate (left) and at the substrate-overlay interface (right)

Field Overlay Performance

- The overlay tended to develop hairline cracks over time, though the frequency of cracking slowed after three years. Possible causes include LMC-VE's high heat of hydration, the skew angle of the bridge, and early loading from construction vehicles.

- Slight material spalling and abrasion/erosion was observed in a few areas on the overlay.

- The average BPN (friction) values decreased over time but remained above 55, the value deemed necessary for traffic safety.

- Up to 26 months, SR values generally increased as the overlay age increased, indicating an improving microstructure and pore network. SR values decreased slightly at later ages, possibly indicating a small decrease in permeability resistance due to spalling and cracking.

- Pull-out tests indicated a strong LMC-VE-substrate bond. Even the few failures observed at the substrate-overlay interface had a bond strength at failure above 250 psi.

Life-Cycle Cost Analysis

- Though the LMC-VE overlay requires less maintenance during its service life, both deterministic and probabilistic analysis indicated that the LMC-VE overlay had the highest agency cost among the overlay alternatives, primarily due to its very high initial construction cost, but the lowest user cost due to its rapid opening to traffic.

- The annual average daily traffic (AADT) threshold for the LMC-VE overlay was determined to be 3,300. Above this AADT, the total cost of the LMC-VE overlay is expected to be less than that of the other overlay alternatives.

Typical spalled (left) and abraded (right) areas on the overlay concrete

Recommendations

- LMC-VE overlays should be constructed only when early traffic opening to traffic, a high bond strength with the substrate, and/or abrasion resistance are critical.
- Because LMC-VE tends to generate a large amount of heat rapidly during hours 5 to 10 of cement hydration, which leads to a high potential for thermal cracking, the concrete temperature should be carefully monitored and controlled prior to, during, and after construction. A sprinkling system may be considered for curing.
- The mix design of LMC-VE can be further optimized, for example, through the use of supplementary cementitious materials like fly ash and slag, to reduce the rate of heat generation and the secondary sorptivity of the concrete. A small amount (≤2% by volume) of fibers may be used to control cracking.
- A detailed microstructural investigation may help determine the causes of the spalling observed on the overlay. Causes may include chemical reactions between the cement and latex components in the overlay and the deicer chemicals applied to the deck surface.
- Because the overlay was cast just before the onset of the winter season, early exposure to extreme conditions (e.g., freeze-thaw cycles and deicer salts) may have exacerbated the deterioration observed. Construction during warmer seasons or delayed exposure to harsh conditions should be considered.
- Though the construction cost of an LMC-VE overlay is much higher than that of other overlay types, an LMC-VE overlay may be cost-effective above an AADT threshold of 3,300.

Implementation Readiness and Benefits

The results of this research can inform decision-making related to the selection of overlay alternatives and LMC-VE overlay construction for future bridge deck applications in Iowa.

Bridge deck overlays made with LMC-VE have the potential to significantly reduce the time for opening to traffic while providing good long-term performance.

However, the high life-cycle cost of an LMC-VE overlay, largely due to the very high initial construction cost, outweighs the potential benefits when AADT values are below 3,300. Above this AADT threshold, an LMC-VE overlay could be a cost-effective alternative.