Development of Ultra-High-Performance Concrete (UHPC) for Bridge Deck Overlay

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Abstract

With superior mechanical strength and durability, ultra-high-performance concrete (UHPC) is becoming an emerging rehabilitation material for the bridge deck overlay. However, there still exists several challenges to prevent the wide applications of UHPC overlay: (1) the high shrinkage of UHPC leads to high cracking potentials, especially on early ages; (2) the highly flowable UHPC causes difficulties for the sloped casting on the bridge deck; (3) the high mixing difficulty restrains the large-scale production on job sites. To address the aforementioned problems, the Stevens team first optimized UHPC mixtures by properly combining the pre-saturated lightweight sand, expansive agent, and shrinkage-reducing agent, in which the shrinkage was significantly reduced, and mechanical strength was kept at the superior level. Compared to the control mixture, the peak and cumulative cracking potentials of optimized UHPC were reduced by 65% and 60%. Subsequently, the Steven team developed a thixotropic UHPC to facilitate the sloped overlay construction. A new type of well-dispersed nanoclay suspension was utilized to enhance the thixotropy. Results showed the nanoclay addition effectively enhanced the thixotropy of UHPC but slightly reduced the bond strength between the UHPC overlay and substrate. However, after applying the optimal vibration, the bond strength was improved without affecting its shape stability. In the end, the mixing kinetics of UHPC in the mixing process was investigated and a multi-batching method for large-volume production of UHPC was developed.

Keywords: ultra-high-performance concrete; expansive agent; prewet time; cracking potential.

1. Introduction

Concrete bridge decks are always exposed to a wide range of environmental and mechanical effects. It was reported that a large percentage of bridges in the United States are experiencing the rapid degradation. According to 2022 United States National Bridge Inventory (NBI) data (Du et al.). only 44.5% of US bridges are in “Good” conditions and more than 50% of US bridges exhibit some level of deck deterioration (i.e., evaluated as “Fair” or “Poor” conditions). Moreover, the bridge deck overlay is the main contributor to the service life of an entire bridge system because the deck serves not only as the riding surface comfortability but also the protective layer of the superstructure, substructure, and reinforcements (Meng, Valipour and Khayat). As an emerging bridge deck overlay material, this research aims to address the existing challenges for the existing UHPC mixtures, thus promoting the application of UHPC in more civil infrastructures.

2. Materials and Mixture Design

Type I Portland cement and slag were employed as cementitious materials. A CaO-type expansive agent (EA) and a shrinkage-reducing agent (SRA) were used to decrease the shrinkage. River sand (RS) and expanded shale lightweight sand (LWS) were used as fine aggregates. A PCE-based high range water reducer (HRWR) was used to enhance the workability. The water-based nanoclay suspension with a solid mass content of 19.5% and a specific gravity of 1.14 was used to adjust the thixotropic properties of UHPC. Straight steel fibers (SF) measuring 0.2 mm in diameter and 13 mm in length were incorporated to enhance the flexural performance.

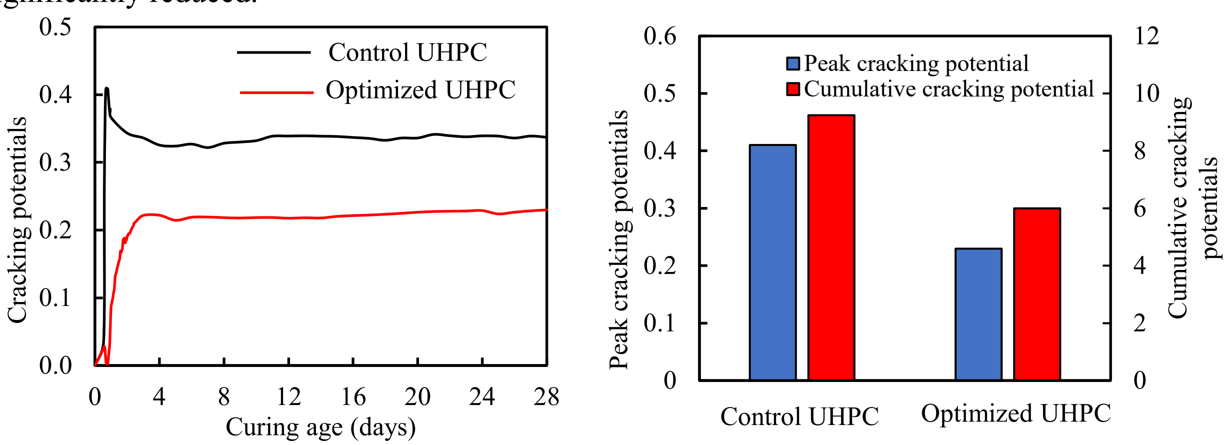
3. Results and Discussion

In order to quantify the cracking potentials of UHPC. The **Equation (1)** was proposed by dividing the restrained shrinkage stress (σ_c) by the axial tensile strength (f_t):

$$\Theta_{cp}(t) = \frac{\sigma_c(t)}{f_t(t)} \tag{1}$$

where $\Theta_{cp}(t)$ represents the cracking potential with curing age; $\sigma_c(t)$ represents the restrained shrinkage stress, in MPa; and $f_t(t)$ represents the axial tensile strength; in MPa.

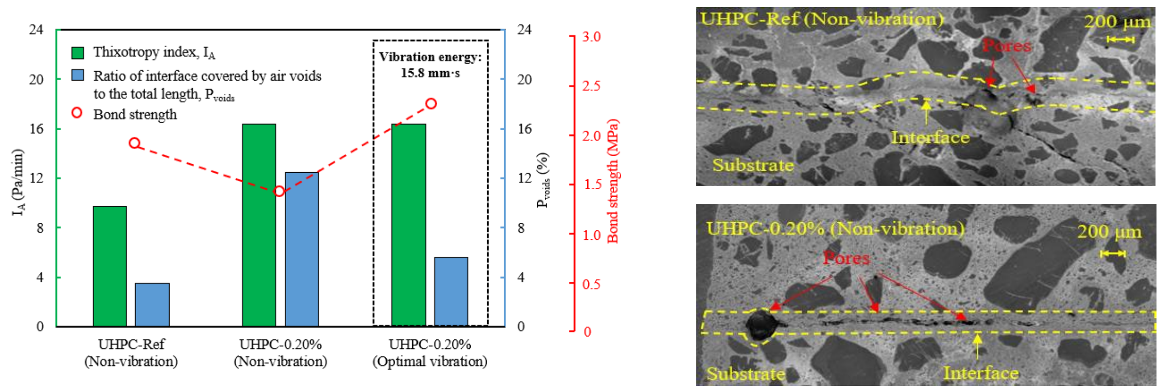
Figure 1 plots the cracking potentials of controlled UHPC and optimized UHPC. Results revealed that, by the proper combination of lightweight sand, expansive agent, and shrinkage-reducing agent, both peak and cumulative cracking potentials of the optimized UHPC are significantly reduced.



(a) (b)

Figure 1. Summarized cracking potentials of controlled UHPC and optimized UHPC.

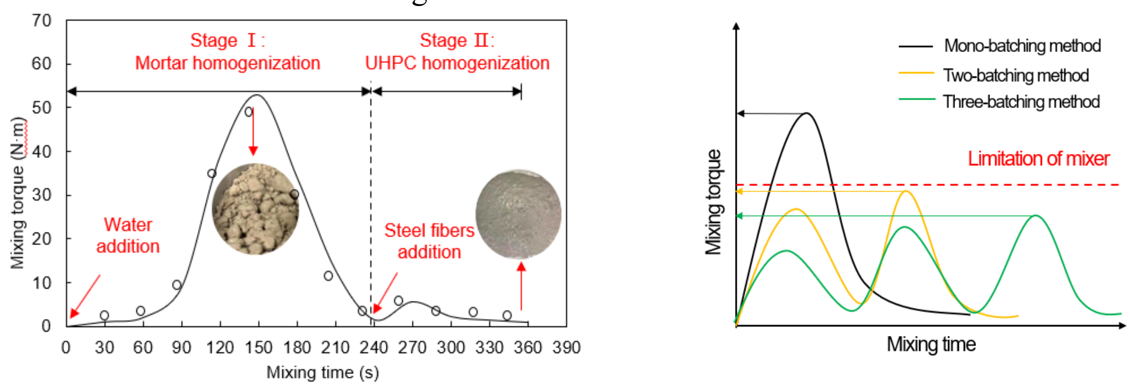
Figure 2 shows the effect of water-based nanoclay on thixotropy and bond behaviors of UHPC overlay. The nanoclay addition efficiently enhances the thixotropy of UHPC overlay. However, the bond strengths between thixotropic UHPC overlay and substrate are reduced by over 30%. To address this issue, the bond strength between thixotropic UHPC overlay and substrate was increased by 45% after the optimal vibration energy.



(a) (b)

Figure 2. Cracking potentials of investigated UHPC mixtures: (a) schematic diagram of calculation method; (b) summarized peak and cumulative cracking potentials.

Figure 3 shows mixing torque evolution of UHPC in the mixing process and develops a multi-batching method to reduce the mixing torque for large-volume production of UHPC. Moreover, the reliability and repeatability of the multi-batching method is verified through the validation tests with different UHPC mixture designs.



(a) (b)

Figure 3. Mixing torque evolution of mixing UHPC: (a) mono-batching method; (b) multi-batching method.

4. References

- "Bridge Condition by Highway System 2022." U.S. Department of Transportation Federal Highway Administration. Web.
- Du, Jiang, et al. "New Development of Ultra-High-Performance Concrete (Uhpc)." *Composites Part B: Engineering* (2021): 109220. Print.
- Meng, Weina, Mahdi Valipour, and Kamal Henri Khayat. "Optimization and Performance of Cost-Effective Ultra-High Performance Concrete." *Materials and Structures* 50.1 (2017): 29. Print.