Fracture Behavior of Interfaces Between Ultra-High-Performance Concrete and High-Performance Concrete

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Abstract

This research introduces a fracture-mechanics-based test method to evaluate the fracture behavior of interfaces between Ultra-High-Performance Concrete (UHPC) and High-Performance Concrete (HPC). By means of the developed test method, it is aimed to characterize the cracking propensity of HPC/UHC interfaces accurately. Three-point bending tests on notched bi-material beams (consisting of UHPC and HPC) were conducted in a closed-loop test setup controlling crack mouth opening displacement (CMOD). Substrate hygric states (dry and saturated surface dry or SSD) and substrate surface tortuosity (as-cast and exposed aggregate finish) conditions were used as the test variables to evaluate the interfacial properties (fracture energy, tension softening) of HPC/UHPC interfaces. The results indicate that both tensile strength and fracture energy are lower in HPC-UHPC interfaces as compared to neat HPC. Exposed aggregate surface finish was beneficial for the fracture energy, but did not have an effect on the tensile strength. Finally, hygric state of the HPC substrate did not have a statistically significant effect on the bond properties.

Keywords: concrete, precast, bridge, HPC, UHPC, bond, interfaces, fracture mechanics

1. Introduction

The connection of precast (HPC) bridge deck panels with UHPC enhances the constructability and ultimate strength limit state performance of such connections. However, interfacial cracks that were observed in UHPC connections under service loads raise concerns about potential implications on serviceability and long-term durability of UHPC connections. Prior research utilized strength-based test methods to assess bonding between UHPC and neat concrete substrates. While offering helpful insights, data obtained from these strength-based tests cannot be used to model or predict cracking in HPC-UHPC interface. This study offers additional insights into the fracturing of HPC-UHPC interfaces by conducting fracture tests on HPC-UHPC interfaces.

Roughening and wetting of the substrate are thought to enhance the bond performance of bi-material connections. In HPC-UHPC connection specifically, it is recommended to ensure saturated surface dry (SSD) substrate with exposed aggregate surface finish at UHPC placement (FHWA). However, conflicting findings exist in the literature regarding the effects of pre-wetting the substrate on the bond performance. Therefore, in this study, substrate hygric states (dry and

SSD) and substrate surface tortuosity (as-cast and exposed aggregate finish) were varied to evaluate their effect on the fracture behavior of HPC-UHPC interfaces.

2. Materials and Methods

Neat HPC, supplied by a local contractor, and a proprietary UHPC with 2% brass-coated steel fibers by volume were used. Average compressive and splitting tensile strengths of HPC were measured as 8.4 ksi (58 MPa) and 0.67 ksi (4.64 MPa). The average tensile and compression strength of UHPC were 20.9 ksi (144 MPa), and 1.1 ksi (7.8 MPa), respectively.

Fracture experiments on neat HPC and HPC/UHPC bonded specimens were conducted using the test setup illustrated in Figure 1a. The loading was applied at the midspan in the plane of the HPC/UHPC interface, above the 50 mm notch. The specimens were loaded under the constant CMOD rate of 0.0006 in/s (0.015 mm/min), ensuring that the peak load was reached at 150 to 210 seconds of initial load application. Prior to crack mouth opening control loading, an initial load of 50 lbf (0.2 kN) was applied on the specimens to increase the stability of the test. Self-weight compensation was attached to both ends of the frame to eliminate the instable crack growth. The fracture tests were run until a minimum of 0.08 in. (2 mm) CMOD was achieved.

The tensile strength of HPC specimens and HPC/UHPC interfaces was measured via splitting tensile strengths (Figure 1b) on a 200-kip (890kN) Tinius Olsen hydraulic testing machine, per BS 1881-117 (BS 1881-117). For splitting tensile strength testing 6x6x6 in. (150x150x150 mm) size cube specimens were used, and loaded at a rate of 0.94 lbf/s (4.2 N/s) along a steel load-bearing strip with a width of (0.5 in.) (12.5 mm).

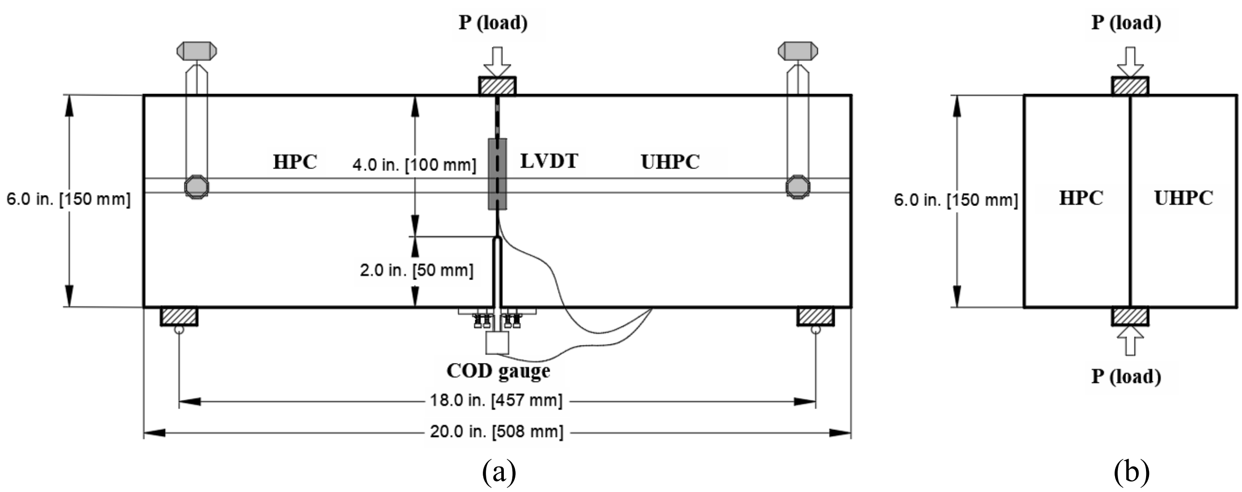

Figure 1. Test setups: a) Three-Point Bending Fracture Test Setup b) Splitting Tensile Test Setup.

3. Results and Discussion

The splitting tensile tests indicated a notable decrease in HPC-UHPC interface strength as compared to the near HPC, ranging from 50 to 66% on average (Figure 2a). Interestingly, there was no statistically significant difference between the interface groups indicating that neither surface tortuosity nor the substrate hygric state have a significant influence on the bond strength.

The decrease in fracture energy of HPC/UHPC interfaces was more pronounced than the decrease in splitting tensile strength (Figure 2b). Compared to neat HPC specimens, a reduction in fracture energy between 63% to 86% was observed. The substrate tortuosity was found to have a significant effect on the fracture energy than the tensile strength. The UHPC placed against as-cast (AC) substrate exhibited either no bonding or brittle failure without softening. Contrary to substrate tortuosity, the substrate hygric state had no statistically significant effect on the fracture energy in the exposed aggregate (EA) group.

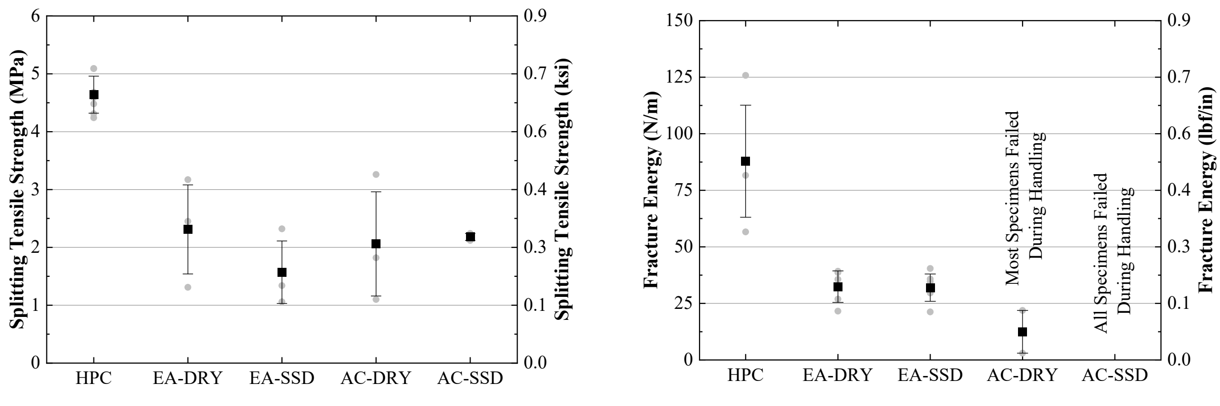

Figure 2. Test results: a) splitting tensile test data at 28 days; and b) average fracture energies.

4. Conclusion

This study investigated the Mode I fracture behavior of HPC/UHPC interfaces, varying the substrate tortuosity and hygric state. Overall, a decrease in HPC/UHPC interfaces in strength and fracture energy was observed compared to neat HPC specimens. The substrate hygric state effect was found insignificant in terms of both strength and fracture measurements, while the as-cast substrate surfaces indicated a brittle failure with no pronounced tension softening behavior.

5. Acknowledgements

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6. References

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