Evaluation of AASHTO T 397, Standard Method of Test for Uniaxial Tensile Response of Ultra-High Performance Concrete

tech transfer summary

The direct tension test method for ultra-high performance concrete (UHPC) described in AASHTO T 397 is a promising option for assessing the tension characteristics of UHPC, which are independently evaluated for several different variables.

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RESEARCH PROJECT TITLE
Development of a Design Guide for Structural Design of Ultra-High Performance Concrete

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Objective

The main objective of this study was to independently evaluate the reliability and repeatability of a tension test method for ultra-high performance concrete (UHPC) developed by the Federal Highway Administration (FHWA) and adopted by the American Association of State Highway and Transportation Officials (AASHTO) as AASHTO T 397.

Background

UHPC is a cementitious material comprised of purposefully graded fine particles as well as fibers. This concrete composite can attain ultra-high strength and superior durability, ductility, and toughness. The addition of fibers provides tensile ductility in the post-elastic region and improved fracture energy. Previous studies have shown that UHPC exhibits significantly better mechanical characteristics and durability properties than conventional, high-performance, and fiber-reinforced concrete.

Accurately quantifying the mechanical properties of UHPC is fundamental for effectively designing and analyzing structural members made of this material. As is the case with any cementitious material, the tensile response of UHPC is an essential but challenging property to quantify in the laboratory.

A typical tensile response for UHPC can be divided into multiple phases: elastic, multi-cracking, crack straining, and crack localization, which is associated with softening. Simple tests such as bending and wedge splitting rely on assumptions and significant computational work to backcalculate the tensile response and identify these phases. In contrast, the various phases can easily be identified from direct tension test data without much computational effort.

However, direct tension tests are difficult to perform because the formation of cracks unevenly distributes load across the test sample's cross section, which can produce an unstable response. Several aspects of the direct tension test setup, including specimen shape and the boundary conditions of the specimen at the grips, may influence the test outcome.

Problem Statement

Despite the wide variety of tests, specimen geometries, and test approaches in use, no standard direct tension test method has been established that defines the specimen geometry, set of support conditions, and load protocol to characterize the tensile behavior of UHPC.

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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A promising approach is AASHTO T 397, Standard Method of Test for Uniaxial Tensile Response of Ultra-High Performance Concrete. However, the reliability and repeatability of this method and its ability to produce dependable results with different variables have not been independently evaluated.

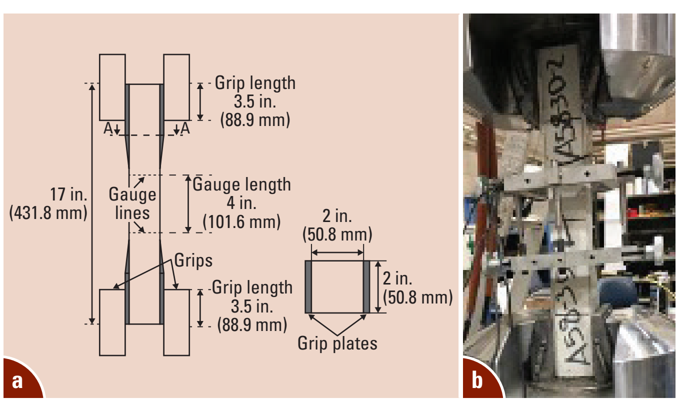
Research Methodology

To evaluate the AASHTO T 397 test method, UHPC types that are commercially available in the United States were used in a two-part study.

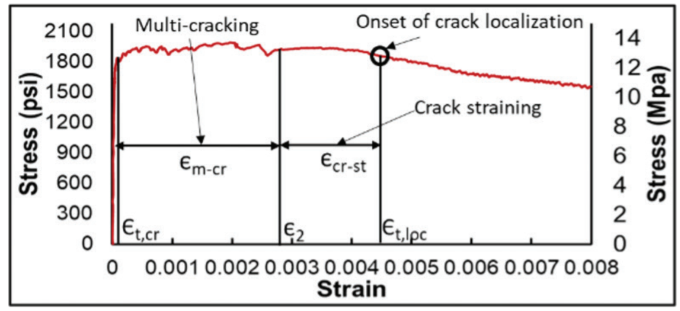
In the first part of the study, the UHPC type and fiber volume fraction were the main variables included in the evaluation. High-strength straight steel wire fibers 0.5 in. (12.7 mm) in length and 0.008 in. (0.203 mm) in diameter, as typically used, were the only type of fiber used in the first part of the study.

A total of 216 tension test samples, each with a length of 17 in. (431.8 mm) and a square cross section of 2 in. (50.8 mm) by 2 in. (50.8 mm), were cast from three different UHPCs with fiber volume fractions of 1% (UHPC B), 2% (UHPC C), and 3% (UHPC A). For each UHPC type, three batches of 24 tension test samples were cast, with each UHPC type producing a total of 72 tension test samples. In addition, 12 cubes (2 in. [50.8 mm]) and 12 cylinders (3 in. [76.2 mm] by 6 in. [152.4 mm]), were cast for each UHPC type to conduct compression tests.

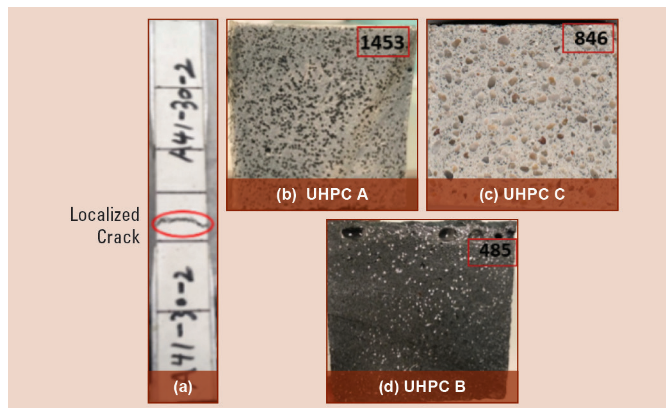
All tension test samples were prepared by affixing four aluminum plates to the gripping ends at Iowa State University (ISU) to ensure consistency in the preparation of the test specimens. However, the samples were tested in batches at six different laboratories to evaluate the repeatability and reliability of the test method. Each laboratory was asked to test three sets of ten specimens from UHPC A (3% fibers), UHPC B (1% fibers), and UHPC C (2% fibers).



(a) Schematic representation of AASHTO T 397 tension test and (b) experimental test setup



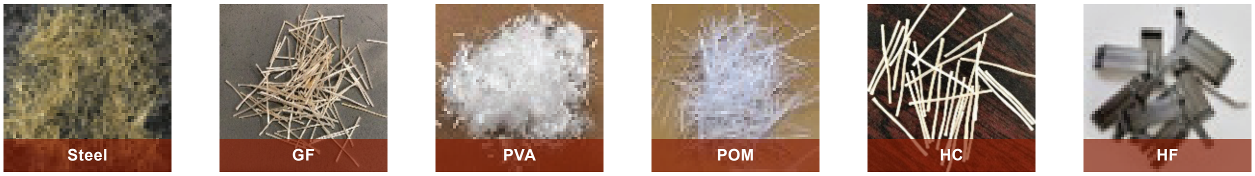
Results of a successful direct tension test depicting various phases of UHPC tensile behavior



(a) Failed specimen from a successful test and (b, c, d) number of fibers and their distribution near a failed section

The second part of the study evaluated the applicability of AASHTO T 397 for different sets of variables, including fiber type and volume and specimen shape and cross section. Accordingly, the tensile response was characterized for UHPC specimens with standard steel fibers partially or fully replaced with alkali-resistant glass (GF), poly-vinyl alcohol (PVA), poly-oxy-methylene (POM), hybrid-composite (HC), or hooked-end steel (HF) fibers. The specimen cross section was also considered as a variable because it has been hypothesized to affect the tensile behavior of UHPC.

Finally, comparisons were made between the UHPC tensile response obtained from dog bone-shaped specimens and that obtained from square prism specimens (AASHTO T 397) to evaluate the effects of specimen shape and the influence of testing machine capacity on the test outcomes. All specimens for this task were cast and tested at ISU.



Fiber types investigated for their effects on test method and UHPC tension characteristics

Key Findings and Conclusions

- With carefully prepared test specimens, the AASHTO T 397 test method can be used to establish the direct tension response of UHPC containing a sufficient quantity of fibers with a success rate of 60% to 70%.
- The boundaries of the different phases of the UHPC tension response were satisfactorily identified through visual observations of the measured responses. It was found that localized cracking begins to develop at the onset of the crack straining phase.
- When the number of successful tests exceeded 30 for a given UHPC, all tensile responses fell within 1.5 times the standard deviation.
- The tensile strength of UHPC was found to be directly proportional to the fiber volume. As the fiber volume increased, the multi-cracking phase was also extended regardless of the UHPC used.
- The length of the crack straining phase was found to depend on the UHPC type and not on the fiber volume.
- The average and characteristic responses of UHPC tensile behavior can be established for design and analysis purposes with a minimum of 15 successful tests, as demonstrated in the study.
- Comparable tensile responses were obtained from dog bone specimens and square prism specimens (AASHTO T 397) when the same gauge length was maintained for both specimen shapes.

Recommendations

Based on the experimental investigation, recommendations to increase the chances of conducting successful direct tension tests as described in AASHTO T 397 are as follows:

- Higher capacity uniaxial machines may produce a lower success rate. The use of a test machine with a capacity not exceeding 100 kips (~500 kN) is recommended.
- Securing aluminum plates to the ends of the specimens is a critical step for producing successful tests. Roughening and uniformly applying epoxy on the surfaces of both the plate and the specimen will adequately secure the plates to the test specimens.
- The originally proposed gripping pressure of 5.8 ksi (40 MPa) was found to be unnecessarily high, resulting in crack development at the ends of the grips. A reduced gripping pressure of 2.17 to 3.62 ksi (15 to 24.9 MPa), depending on machine capability, is recommended. An even lower gripping pressure is appropriate as long as the test can be conducted without slippage of the specimens.
- The use of C-clamps across the bottom ends of the tapered portions of the aluminum plates helps minimize crack development outside the gauged region, increasing the test success rate.
- With the above recommendations, a test success rate of 50% may be assumed in deciding the number of samples to be tested.

Implementation Readiness and Benefits

Direct tension tests have the potential to provide the tensile response of UHPC and identify the various phases in this response with much less computational effort than tests such as bending or wedge splitting.

The direct tensile test procedure developed by the FHWA has been adopted by AASHTO as AASHTO T 397 and is available for immediate use with the recommendations outlined above.