Determining Triaxial Tensile Strength of UHPC with Varying Fiber Contents

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Abstract

The tensile strength of conventional concrete is often ignored in structural design due to its relatively low value when compared to compressive strength. However, when designing ultra-high performance concrete structures, ignoring tensile strength is overly conservative and could lead to inefficient designs. Uniaxial tensile data is available for UHPC mix designs, but very little data exists examining the multiaxial tensile strength of the material. To help fill this data gap, an apparatus was designed at the University of Oklahoma capable of applying multiaxial tensile stress states to a cube specimen. A UHPC mixture developed at the University of Oklahoma with fiber contents of 0%, 1%, 2%, 4%, 5%, and 6% by volume was characterized in this apparatus to assess the effect varying the fiber content had on its multiaxial tensile strength. The data collected was compiled and compared to previously published multiaxial compressive UHPC data. This dataset was then used to fit two previously published models with different meridian shapes (parabolic and cubic) to ascertain which shape best describes the failure criteria of UHPC in the tensile region. It was found that triaxial tensile strengths decreased as the fiber dose increased over 4%. Also, the combined dataset fit a cubic meridian shape more closely than parabolic.

Keywords: UHPC; Multiaxial Tension; Triaxial Tension; Tension-Tension-Compression; Failure Model; Failure Criteria.

1. Experimental Program

The UHPC mix design tested was developed by Looney et al. (2019) and consisted of a Type II cement, slag cement, silica fume, and masonry sand. The design fiber dosage for this mixture was 2% by volume. For this study, the mixture was altered to accommodate fiber dosages of 0%, 1%, 2%, 4%, 5%, and 6% by volume.

The multiaxial tensile tests were conducted using a novel, self-reacting apparatus designed at the University of Oklahoma (patent pending). The apparatus can subject a 2 in. (50 mm) cube specimen to tensile forces from three directions simultaneously. The three stress states tested in this study were triaxial tension (TTT), biaxial tension (TT), and tension-tension-compression (TTC). The TTT test was conducted by applying force to the threaded rod on the sides of the apparatus (side stresses) first to a prescribed stress state, then slowly applying load to the final direction until failure. The TTC test was similar, with the final step being the application of compressive load. Two loading methods were used for the TT test. The first was a non-proportional loading method, where load was applied to one face to a prescribed stress, then applied to the other face gradually to failure. The second was a proportional method, where load was applied to both faces simultaneously at near the same load rate to failure.

2. Results and Analysis

The results of a single test consisted of the three principal stresses at failure. For each prescribed set of side stresses, three replicate tests were conducted, and the final data was the average of at least two tests. Outliers were removed based on a statistical analysis. For each fiber content, the peak principal stress (σ_1) of TTT tests were similar in magnitude regardless of the side stress magnitudes. Those values are shown in Table 1. The σ_1 stress increased as fiber dose increased up to 5% fibers, where a drop in strength was observed. A clear trend between compressive strength and σ_1 was observed in the fiber reinforced specimens up to 4%.

Table 1 – σ_1 values for each TTT data points with average compressive strength

	0%	1%	2%	4%	5%	6%
σ_1, Each TTT Test (psi)	995	948	1272	1208	1070	1202
	908	1115	1088	1260	1106	1144
	765	1193	1141	1377	1080	1025
	861	1159	1277	1353	-	1192
	1251	1001	1267	1254	-	-
	980	1045	1169	1191	-	-
	1069	1270	1217	1080	-	-
	831	826	906	1333	-	-
	977	1139	1081	-	-	-
Avg. σ_1 (psi)	960	1077	1157	1257	1086	1141
Avg. f_c (psi)	16530	17300	18760	20230	20950	21220
Avg. σ_1/Avg. f_c	5.81%	6.23%	6.17%	6.21%	5.18%	5.38%

1 MPa = 145 psi

The final data points were then normalized by their respective compressive strengths and converted to the rotational Haigh-Westergaard coordinate system for comparison. The normalized data collected for the 0%, 1%, 2%, and 4% data is shown in Figure 1. The normalized data appeared to show that, up to 4% fibers, multiaxial tensile data more closely follows a concave parabolic shape. This differs from most failure shapes, which consist of a convex parabolic shape through each stress state.

The data was then combined with normalized UHPC multiaxial compressive data collected by Ritter and Curbach (2015) for fitting of the dataset to models developed by Ritter and Curbach (2016) used for UPHC and Menétry and Willam (1995), a generalized version of multiple established parabolic concrete failure models meant to be easily customizable to different datasets. The model fits are shown in Figure 2. The multiaxial tensile data fits more closely to a cubic function (displaying a clear change in curvature) than a parabolic function.

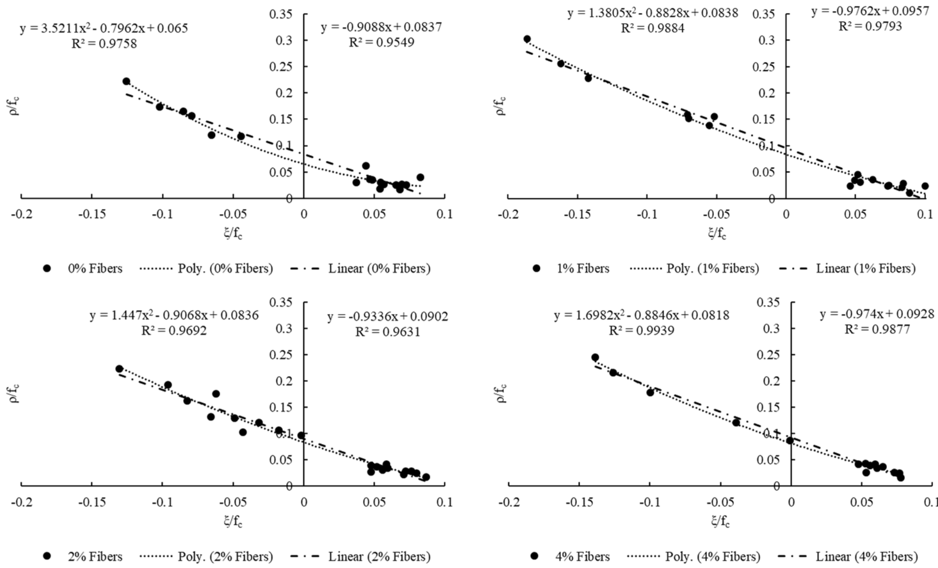

Figure 1 – All collected normalized data for 0% (upper left), 1% (upper right), 2% (lower left), and 4% fiber dosages (lower right)

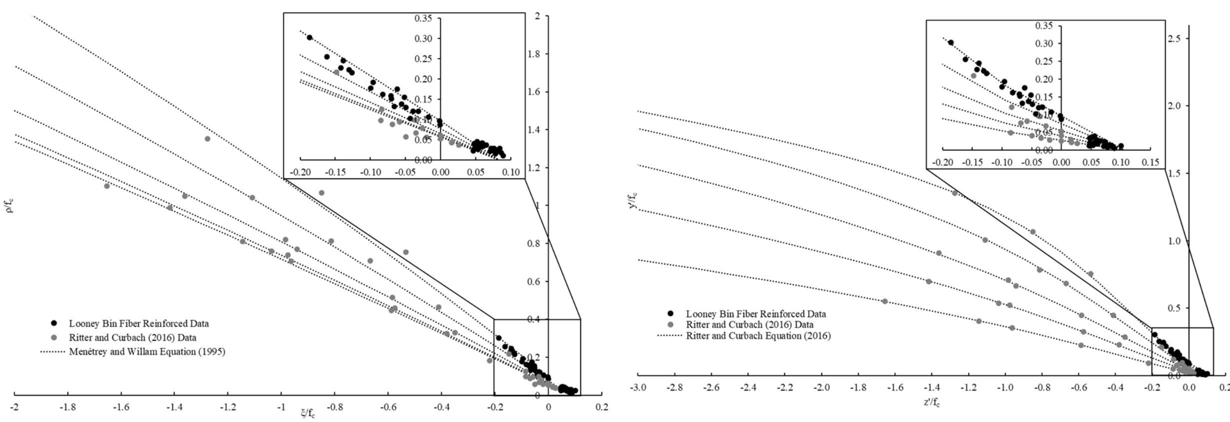

Figure 2 - Menétry and Willam fit (left) and Ritter and Curbach fit (right)

3. References

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