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Shear resistance of ultra-high-performance fiber-reinforced concrete

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HIGHLIGHTS

- A newly shear testing system to investigate shear resistance of UHPFRC was proposed.
- The shear related hardening behavior, accompanied by multiple crack formation was obtained.
- The shear resistances of UHPFRCs significantly depended on both the fiber volume and *a/d*.
- The shear strengths of UHPFRCs containing 0.5 and 1.5 vol.% smooth fibers were shown to exceed the direct tensile strengths about 1.6 times.
- A theoretical model predicting the shear strength of UHPFRC based on the direct tensile strength and *a/d* was proposed.

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ABSTRACT

The shear resistance of ultra-high-performance fiber-reinforced concrete (UHPFRC) was investigated by using a newly proposed shear testing system. UHPFRCs displayed strain-hardening responses, in both shear and tensile testing, accompanied with multiple microcracks. The shear resistance of UHPFRCs was clearly influenced by their tensile resistance in addition to shear span to depth ratio (*a/d*). The shear strengths of UHPFRCs generally exceed the direct tensile strengths about 1.6 times. A theoretical model predicting the shear strength of UHPFRCs was proposed based on the tensile strength and *a/d* ratio.

1. Introduction

Ultra-high-performance fiber-reinforced concretes (UHPFRCs) have demonstrated superior mechanical properties, including very high compressive strengths (>150 MPa), tensile strengths (>13 MPa), tensile strain capacities (>0.3%), and energy absorption capacities (>30 kJ/m^2) even when containing only 1.5 vol% deformed steel fibers [1,2]. These properties favor the enhancement of the resistances of civil infrastructure and buildings to extreme loads, such as seismic, impact, and blast loads [3–5]. Among these extreme load conditions, impacts typically generate shear failure, rather than flexural failure, in infrastructure and buildings; shear failure is usually both brittle and catastrophic in concrete structures. However, very limited information is available regarding the shear resistance of UHPFRCs, because no standard test method exists for such concretes.

Several methods have been applied to investigate the shear resistances of UHPFRCs, as well as those of fiber-reinforced concretes (FRCs). One popular shear test method uses push-off specimens [6–11]. Two notches are made on the surface of the push-off specimen to guide shear failure between the two notch tips under tensile [6] or compressive loading [9]. Another popular method uses punch-through specimens (PTS) [12–16]. The test method to investigate shear strength of steel FRC was guided in JSCE-SF6 [12] and was modified in technique by other researchers [13–16]. In the modified PTS, two notches are made surrounding the specimen, two adjustable yokes are installed, and support plates are extended to prevent the specimen from moving. In 1967, Iosipescu proposed a shear test method using the Iosipescu specimen. This test method has been developed by several researcher to investigate shear resistance of concrete and FRC [17–19].

However, current shear test methods cannot be directly applied to investigate the shear resistance of UHPFRCs because they do not

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reflect the unique strain-hardening response, accompanied by the formation of multiple microcracks, of UHPFRCs under tension.

In this research, a new test method was proposed to investigate the shear resistance of UHPFRCs. The proposed setup was designed to provide favorable conditions for multi-shear cracking. A prism specimen without notches or reinforced steel bars was used for this setup, easing the manufacture, installation, and operation of the specimens during the test. Besides, the correlation between tensile and shear resistance, i.e., the linkage between the material levels to the structural level resistance of UHPFRCs was investigated.

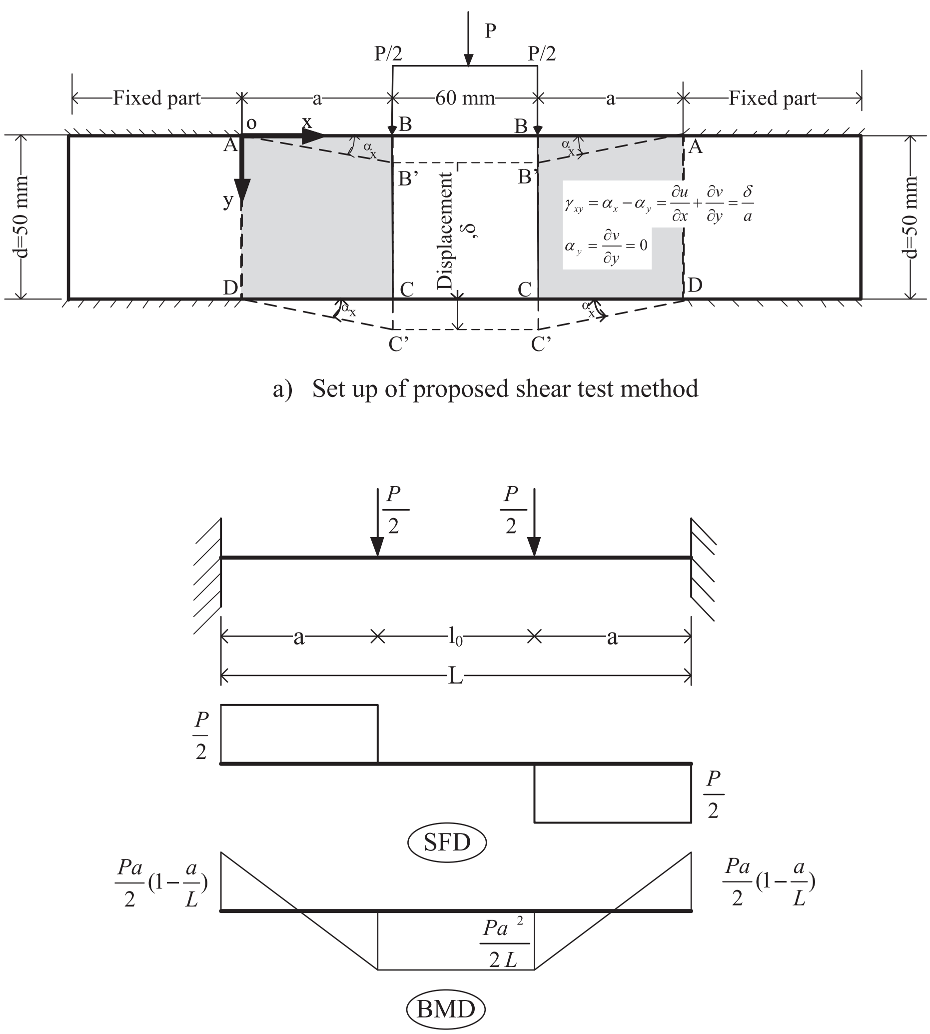
This study aims to develop a fundamental understanding of the shear resistances of UHPFRCs. The specific objectives are (1) to develop a new and valid test method for the shear resistance of strain-hardening UHPFRCs with multiple microcracks, (2) to investigate the shear resistances of UHPFRCs, and (3) to discover correlations between the shear and tensile resistances of UHPFRCs.

2. Proposed shear test method for UHPFRCs

The proposed shear test system was designed to satisfy the following conditions: (1) the specimen should experience shear rather than flexural failure; (2) the results from the proposed system should reflect the unique strain-hardening characteristics, accompanied by the formation of multiple microcracks, of UHPFRCs; and, (3) the proposed system should be simple to operate.

Fig. 1 illustrates the expected shear deformation as well as the shear force diagram (SFD) and bending moment diagram (BMD) of UHPFRC specimens in the proposed test system. Both ends of the specimen are fixed while the load (P) is applied through two separate points at a distance of 60 mm, as shown in Fig. 1a. The geometry of the specimen and the load/boundary conditions are designed to generate shear failure in the UHPFRCs, rather than flexural failure, as shown in Fig. 1b. Consequently, the shear span (a), which is the distance between the loading and supporting points, is varied to generate the shear-related hardening response accompanied by the formation of multiple microcracks. As the load is applied to the specimen, the region ABCD experiences shear deformation, as shown in Fig. 1a. The engineering shear strain is defined as the change in angle between the lines $\overline{AB}$ and $\overline{AD}$, that is the vertical displacement of the middle part of the specimen (δ) per shear span (a), as shown in Eq. (1):

$$\gamma_{xy} = \alpha_x - \alpha_y = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{\delta}{a} \tag{1}$$



a) Set up of proposed shear test method

(b) Shear force and bending moment diagram

Fig. 1. Proposed shear test setup.