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Comparative flexural behavior of Hybrid Ultra High Performance Fiber Reinforced Concrete with different macro fibers

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ABSTRACT

The flexural performance of four Hybrid (H-) Ultra High Performance Fiber Reinforced Concretes (UHPFRCs) with different macro fibers was investigated according to ASTM standards C1018-97 and C 1609/C 1609M-05. Four macro fibers were long smooth (LS-) steel fiber, two types of hooked (HA- and HB-) steel fibers, and twisted (T-) steel fibers while one type of micro fiber, short smooth (SS-) steel fiber, was blended. The enhancements in modulus of rupture, deflection capacity and energy absorption capacity were different according to the types of macro fiber as the amount of micro fiber blended increased. The order of flexural performance of H-UHPFRC according to the types of macro fiber was as follows: HB- > T- > LS- > HA-fiber. The influence of strain capacity in tension on the flexural performance of H-UHPFRC was also examined. The deflection capacity and the ratio between flexural strength and tensile strength were dependent upon the strain capacity of H-UHPFRC.

1. Introduction

Much research has been conducted to enhance the tensile strength and ductility of Ultra High Performance Fiber Reinforced Concrete (UHPFRC) [24,8,16,7,23,10,11,32]. The advantages of UHPFRC include higher durability, ductility and strength in comparison with normal concrete and Fiber Reinforced Concrete (FRC) due to its extremely low porosity; dense matrix; high tensile/compressive strength; and, ductile tensile behavior. In comparison with normal steel reinforced concrete, the application of UHPFRC is expected to improve the resistance of buildings and infrastructure under extreme mechanical and environmental loads. However, the cost of 1% volume content of fiber applied in UHPFRC is generally higher than that of matrix. Thus, it is important to minimize the amounts of fiber without scarifying the superior performance of UHPFRC. Much interest is now focused on both minimizing the amounts of fiber and maximizing the performance of UHPFRC.

The tensile or flexural performance of UHPFRC is influenced by many material parameters. The parameters include strength, stiffness, shape, aspect ratio, and Poisson's ratio of fibers; the strength, stiffness, and shrinkage of matrix; and, the physio-chemical and frictional bond properties at the interface between fiber and matrix. Under the assumption that an identical Ultra High Performance Concrete (UHPC) matrix is used, the type of fiber is the most governing factor among the several parameters mentioned above. Thus, the material, geometry, and volume contents of fiber should be very carefully determined to improve the flexural performance of UHPFRC.

To improve the flexural performance of UHPFRC, one of the promising methods is to blend two or three different fibers together in a matrix, because the macro and micro fibers play a role at two different levels, material and structural, according to the length and diameter of fibers [24,23]. There has been much research on the development of Hybrid Fiber Reinforced Concrete (H-FRC) with normal compressive strength and consequently, it was found that the fiber blending in normal strength matrices produced favorable blending effect on the mechanical performance including tensile strength and ductility in comparison with FRC with one type of fiber [22,33,14,5,4,1,27]. In general, H-FRC employs a long and thick fiber as macro fiber and a short and thin fiber as micro fiber. Fibers blended together in a brittle matrix can be classified into macro and micro fibers according the role of fibers in a brittle matrix [24,23].

However, most research on H-UHPFRC has been focused on finding the optimum volume contents of micro fiber blended with one type of macro fiber to improve tensile/flexural strength and ductility [30,6,9,17,26]. Thus, it is difficult to find any information about the influence of macro fibers on the flexural performance of H-UHPFRC.

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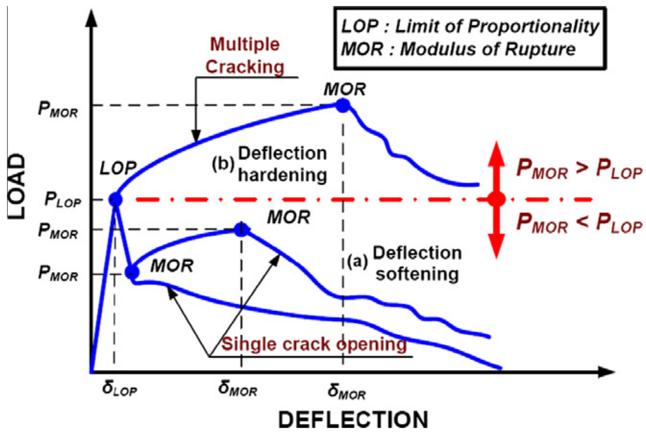

Fig. 1. Typical load–deflection response curves of FRCC.

Table 1
Composition of matrix mixtures by weight ratio and compressive strength in Park et al. [20] and Ryu et al. [25].

Cement (type I)	Silica fume	Silica sand	Silica powder	Super-plasticizer	Water	f'_c, ksi (MPa)
1.00	0.25	1.10	0.30	0.05	0.20	29.0 (200)

Table 2
Properties of fibers.

Fiber type	Name (notation)	Diameter in (mm)	Length in (mm)	Density (g/cc)	Tensile strength ksi (MPa)	Elastic modulus ksi (GPa)
Macro	Smooth (SL-)	0.012 (0.3)	1.181 (30)	7.9	373.9 (2580)	29,000 (200)
	Hooked A (HA-)	0.015 (0.375)	1.181 (30)	7.9	334.9 (2311)	29,000 (200)
	Hooked B (HB-)	0.031 (0.775)	2.441 (62)	7.9	274.1 (1891)	29,000 (200)
	Twisted (T-)	0.015 (0.3)*	1.181 (30)	7.9	351.8 (2428)**	29,000 (200)
Micro	Smooth (SS-)	0.008 (0.2)	0.512 (13)	7.9	404.0 (2788)	29,000 (200)

* Equivalent diameter.
** Tensile strength of the fiber after twisting.

Recently, the influence of macro fibers on the tensile behavior of H-UHPFRC has been investigated by authors [21]. As the amount of micro fiber blended increases, the improvement of the post cracking strength, strain capacity and multiple cracking behaviors is very different according to the types of macro fiber.

Since the flexural behavior of Fiber Reinforced Cementitious Composites [FRCC] is dependent on the tensile stress–strain response of FRCC, the maximum equivalent bending strength, deflection capacity and energy absorption capacity of H-UHPFRC would be highly influenced by both strain capacity (material ductility) and post cracking strength (material strength) of H-UHPFRC [19,13].

The objective of this research is to investigate the flexural performance of H-UHPFRC according to different types of macro fiber. The detailed objectives are: (1) to investigate the influence of different macro fibers on the flexural behavior of H-UHPFRC, (2) to investigate the influence of the micro fiber volume contents on the flexural behavior of Hybrid UHPFRC, and (3) to correlate the tensile response (material ductility) and flexural response (structural performance) of H-UHPFRC.

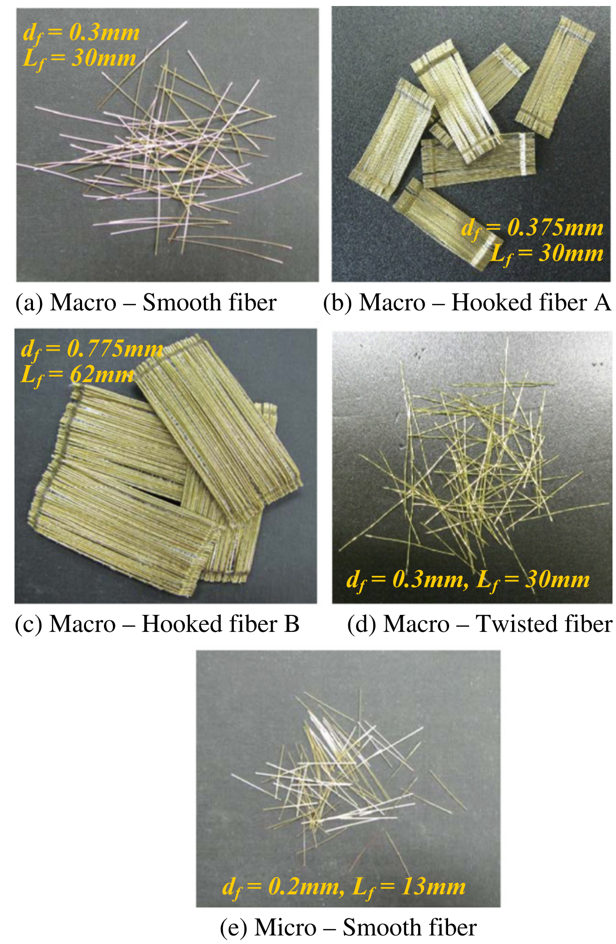

Fig. 2. Pictures of fibers: (a) macro-long smooth fiber, (b) macro-Hooked fiber A, (c) macro-Hooked fiber B, (d) macro-twisted fiber, and, (e) micro-short smooth fiber.

Table 3
Test matrix.

Type of macro fiber (V_f = 1.0%)	Micro fiber volume content (%)	Notation
Long Smooth (LS-)	0.0	LS10SS00
	0.5	LS10SS05
	1.0	LS10SS10
	1.5	LS10SS15
Hooked A (HA-)	0.0	HA10SS00
	0.5	HA10SS05
	1.0	HA10SS10
	1.5	HA10SS15
Hooked B (HB-)	0.0	HB10SS00
	0.5	HB10SS05
	1.0	HB10SS10
	1.5	HB10SS15
Twisted (T-)	0.0	T10SS00
	0.5	T10SS05
	1.0	T10SS10
	1.5	T10SS15
No macro fiber	2.0	SS20

2. Research significance

Very little information is available about the influence of the types of macro fiber on the flexural behavior of hybrid UHPFRC (H-UHPFRC). This research provides useful experimental data on the influence of different macro fibers blended with micro fibers on the flexural performance of H-UHPFRC to optimize fiber blending in hybrid systems. Furthermore, this research highlights the