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Study on fiber hybridization effect of engineered cementitious composites with low- and high-modulus polymeric fibers

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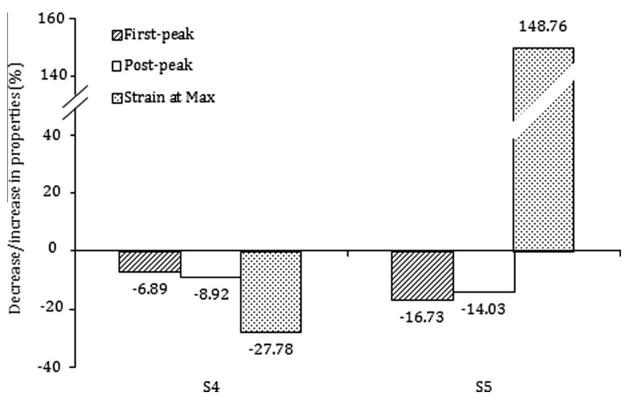
HIGHLIGHTS

- Improving the ductility of ECC composite with hybrid fibers.
- Study of low and high modulus polymeric fibers in hybrid composite.
- Study of the effect of fiber cross-sectional shape on the flexural behavior of hybrid ECC composite.
- Hybridization of PP fibers with different cross-sectional shape and PVA fiber in ECC composite.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study the flexural and compressive properties of hybrid engineered cementitious composite (ECC) was investigated. The hybridization with low- and high-modulus fibers was employed to increase deformability and flexural strain capacity of the ECC composite. It was found that the hybridization with non-round polypropylene (PP) fiber and low modulus polyvinyl alcohol (PVA) fiber have remarkable effect on the improving strain-capacity of resultant composite. The strain-capacity of hybrid ECC was increased by replacement of 20 vol.% of triangular PP fiber and low modulus PVA fiber up to 33% and 148%, respectively. This hybridization also increased the toughness ratio and meets the requirements for the strain-hardening with multiple cracking behaviors of cementitious composites.

1. Introduction

In the past two decades, engineered cementitious composites has been developed which exhibits strain-hardening behavior accompanied by multiple cracking resulting in higher strength and tensile ductility [1].

ECCs are known as cement based composites that have an ultimate strength higher than the first cracking strength. The tensile strain capacity of ECCs is 2 to 5% and shows the averaged tight crack width development about 60 µm even when strained to beyond 1% [2]. These properties can be achieved by using high modulus fibers such as PVA with moderate fiber volume fraction (e.g. typically 2%) [3]. They have industrial usage for a broad range of applications which needs load carrying capacity, deformability, and energy absorption capacity under monotonic and revers cyclic loading [4]. These high performances with a moderate fiber content combination are attained by micromechanics-based composite optimization.

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Table 1
Physical/mechanical characteristics of fibers.

Fiber		Cross-sectional shape	Diameter [μm]	Length [mm]	l/d ratio	Tensile strength [MPa]	Elongation at break [%]	Modulus of elasticity [GPa]
High Modulus	PVA-C	Circular	7.5	4	533	1600	7	35
	PVA-K	Kidney	14	6	428	1400	6–7	20
	PVA-N	Circular	38	8	210	1100	6	40
Low Modulus	PP-C	Circular	25	6	240	320	80–90	2
	PP-T	Triangular	28	6	214	300	80–90	1.5

Table 2
Chemical and physical properties of cement.

SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	Others (%)
21.6	4.61	3.49	64.07	1.94	2.59	1.7

Table 3
The mix design of engineered cementitious composite (weight ratio).

Cement	Sand	Fly ash	Water [%][*]	HRWR[**] [%]	Fiber [vol.%]
1	0.8	1.2	25.2	2.4	2

[*] Weight to cementitious materials ratio.
[**] High range water reducer, weight to cement ratio.

Table 4
The produced mixes with volume percentage of fibers.

Experimental program	Notation	PVA-N	PVA-C	PVA-K	PP-C	PP-T
First Part	S01	0	1.5%	0	0	0
	S02	0	0	1.5%	0	0
	S03	1.5%	0	0	0	0
Second Part	S1 (control)	2%	0	0	0	0
	S2	1.6%	0	0	0.4%	0
	S3	1.6%	0	0	0	0.4%
	S4	1.6%	0.4%	0	0	0
	S5	1.6%	0	0.4%	0	0

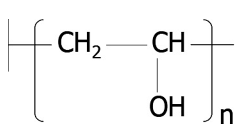

Fig. 1. Chemical structure of PVA.

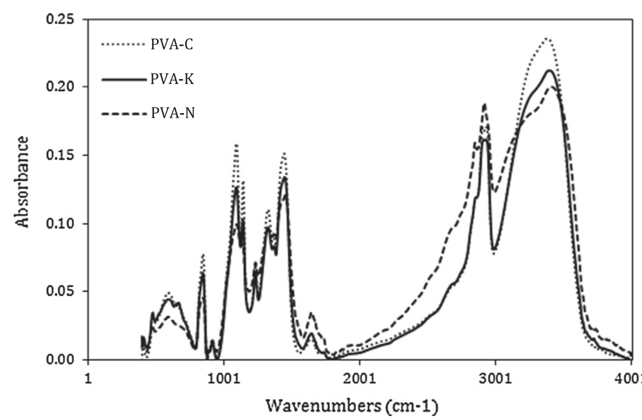

Fig. 2. FTIR spectra of different PVA fiber.

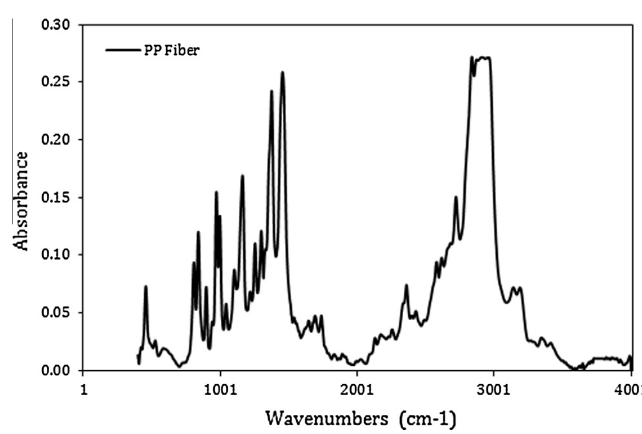

Fig. 3. FTIR spectra of PP fibers.

To achieve higher deformation and ductility performances are of great interest from the point of material design. The design criterion for ECC that relates fiber, matrix and interface parameters has first proposed by Li and Leung [5]. The strain-hardening behavior can be attained by tailoring the synergistic interaction between fiber, matrix and interface.

A major challenge of using PVA fibers in ECCs is the fact that these fibers have high hydrophilic nature which capable them to develop strong chemical bonding to cementitious matrix. The development of chemical bonding between the PVA fibers and cementitious materials is due to the presence of hydroxyl groups in their chemical structure. This strong chemical bonding can cause PVA fiber rupture instead of fiber pull-out during load bearing that tends to limit the multiple cracking effect and strain capacity of ECC in the post-cracking zone [6]. Many attempts have been made to develop a ductile fine aggregate concrete using tailoring fiber, matrix, and interface. It has been reported that the deformability of ECC can be modified by matrix tailoring using fine sand [7]. It was also reported that applying oil coating reduced chemical bonding strength of the PVA fiber to the cementitious matrix and significantly increased the ductility of PVA-ECC composite [8]. The chemical bonding of PVA fiber to ECC matrix drops with an increase in fly ash content due to the result of lower hydration degree in fiber/matrix interface [9]. Increase in fly ash content is also appropriate for reduction in crack width and increase in the frictional bond. It was exhibited that the ECC mix designed with slag particles shows higher toughness ratio which is helpful for

Table 5
Details of flexural behavior of ECC samples containing 1.5 vol.% of different PVA fiber.

	First-peak strength (MPa)	Post-peak strength (MPa)	Def. at Max load (mm)	Area under curve to def. = 1.5 mm
S01	8.59 + 1.23	11.22 + 0.38	2.85 + 0.07	1735.61 + 24.45
S02	9.22 + 0.16	9.73 + 0.55	3.41 + 0.33	2062.00 + 65.30
S03	8.06 + 0.00	9.24 + 0.48	4.11 + 0.10	2556.40 + 22.53