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Mechanical response and shrinkage performance of cementitious composites with a new fiber hybridization

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HIGHLIGHTS

- A new kind of fiber hybridization was designed.
- Mechanical response and shrinkage performance were presented.
- Good mechanical response and satisfactory shrinkage performance were achieved.
- Using $CaCO_3$ whiskers can reduce the cost of fiber reinforced cementitious composites.

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ABSTRACT

A new kind of fiber hybridization containing steel fibers, polyvinyl alcohol (PVA) fibers and cheap calcium carbonate ($CaCO_3$) whiskers (approximately $230 per ton) was designed to improve the mechanical response and shrinkage performance as well as reduce the production cost of fiber reinforced cementitious composites. Compressive response, flexural response, drying shrinkage and plastic shrinkage of this designed hybrid fiber reinforced composites were presented. The results indicated that the designed hybrid fiber shows a significant positive hybrid effect on mechanical response and plastic shrinkage of cementitious composites. Steel fibers are more effective in restricting drying shrinkage. PVA fibers and $CaCO_3$ whiskers are more effective in restraining plastic shrinkage. Good mechanical response and satisfactory shrinkage performance of the designed hybrid fiber reinforced cementitious composites make it possible to partly replace the steel fibers and PVA fibers by using $CaCO_3$ whisker, thus helping to decrease the production cost of fiber reinforced cementitious composites for large scale construction project applications in the future.

1. Introduction

Shrinkage is one of the natural characteristics of portland cement materials [1]. Its baneful influence is further aggravated by the high brittleness of cementitious composites. Because of this, shrinkage generally leads to cracking in cementitious composite materials and structures, which further degrades their service life [2]. The usage of fibers is one of the effective ways to reduce the brittleness and shrinkage of cementitious composites. There are a variety of commercialized fibers (single fiber or hybrid fibers) and the feasibility of their usages in cementitious composites are well documented [3–8]. But the high production cost of fiber reinforced cementitious composites may be one of the dissatisfactory traits. Other cheaper fibrous materials should be taken into consideration not only from the perspective of improving mechanical and shrinkage performance but also economical efficiency.

In this study, a new kind of cheap fibrous material, calcium carbonate whisker ($CaCO_3$ whisker), was introduced into the traditional steel and PVA hybrid fiber reinforced cementitious composites [9,10]. The steel fibers and PVA fibers were partly replaced by $CaCO_3$ whiskers. These aim at designing a new fiber hybridization to improve the mechanical response and shrinkage performance as well as reduce the production cost of fiber reinforced cementitious composites. In the following sections, the proceeding methods, compressive response, flexural response, drying shrinkage and plastic shrinkage of the designed hybrid fiber reinforced cementitious composites will be presented and discussed. Some key conclusions will be given at the end of this paper.

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Table 1
Properties of raw materials.

Raw materials	Density (g/cm^3)	Size	Mechanical property
Cement	3.2	45 μm sieve residue 14.16%	–
Quartz sand	2.65	Fineness modulus 2.51 Medium sand	Moh's hardness 7
Steel fiber (Straight)	7.8	Length 13 mm	Tensile strength ⩾ 2000 MPa
		Diameter 200 μm	
PVA fiber	1.29	Length 6 mm	Tensile strength 1100 MPa
		Diameter 31 μm	Elastic modulus 41 GPa
$CaCO_3$ whisker	2.86	Length 20–30 μm	Tensile strength 3–6 GPa
		Diameter 0.5–2 μm	Elastic modulus 410–710 GPa

2. Materials and methods

Cement (P·O 42.5R), fine sand, steel fiber, PVA fiber and $CaCO_3$ whisker were the raw materials used in this study. Their properties and chemical constituents are shown in Tables 1 and 2, respectively. The morphology and XRD pattern of $CaCO_3$ whisker are shown in Fig. 1.

The mix proportion of fibers is given in Table 3. The water–cement ratio (W/C) was 0.3 and the sand–cement ratio (S/C) was 0.5. A mixture (Plain) without any fiber or whisker was used as a control.

The amount of water reducing agent (Polycarboxylic acid type, ASTM C494 type F, water reducing ratio 24.1%) varied from 0.5 to 1.5 wt.% of cement content to assure the mixtures maintained the similar flow and can be cast easily. The mixing procedures are shown in Fig. 2.

The flow of fresh mortar mixtures was evaluated according to ASTM C230 and ASTM C1437-07. Briefly, the diameter of the mortar along the four lines scribed on the table top was measured after removal of the forming cone and dropping the sample 13 mm, 25 times. All mixtures achieved a spread diameter of about 200 mm. Before casting, 2 ml tributyl phosphate was added to reduce air bubbles caused by fiber loading. The air content of each mortar group was measured according to ASTM C185-08 and were between 0.5% and 2%. Afterwards, the fresh mixture was placed into the mould (all the specimens were cast in three lifts) and vibrated on a vibration machine for 60 s.

The specimens with a size of 40 mm × 40 mm × 160 mm were used to determine the drying shrinkage of various composites after 1 day curing in a standard curing box of cement according to ASTM C157. The drying shrinkage sample test ages were 7, 14, 28, 56, 90 and 180 days.

The dosage of fibers used in plastic shrinkage test was half of the values in Table 3. Because the fiber content in Table 3 is too high to create plastic shrinkage crack, thus no further comparison and analysis for the plastic shrinkage of various fiber reinforced composites can be achieved. All the composites were named by adding a "-H", for example, SF-H and HySP-H. The steel mould (Fig. 3a) of dimension 300 × 300 × 40 mm^3 was made to perform the plastic shrinkage test. A thin polyethylene sheet was placed over the base to eliminate base friction between

Table 2
Chemical constituent of raw materials (wt.%).

Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	CO_2	MgO	K_2O	SO_3	Na_2O	P_2O_5	MnO
Cement	61.13	21.45	5.24	2.89	2.37	2.08	0.81	2.50	0.77	0.07	0.06
Whisker	54.93	0.29	0.11	0.07	42.07	2.14	–	0.31	–	–	–

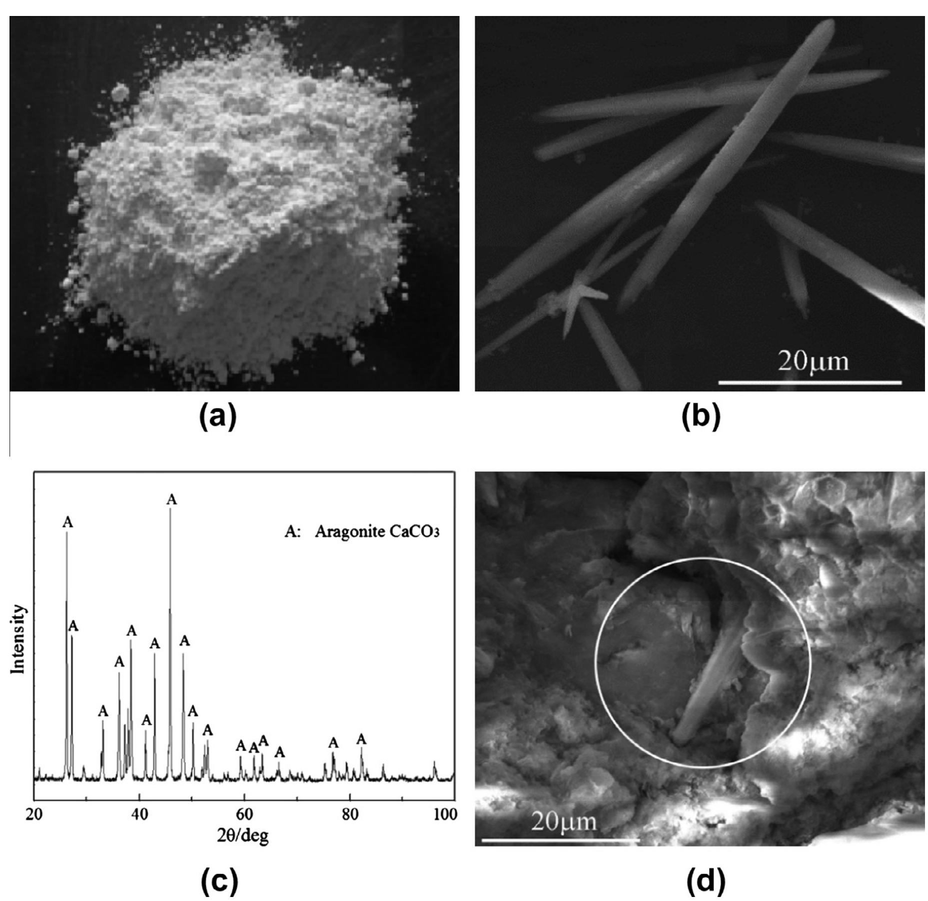

Fig. 1. Images of (a) Macro-morphology of $CaCO_3$ whisker; (b) Micro-morphology of $CaCO_3$ whisker; (c) XRD pattern of whisker (Aragonite $CaCO_3$) and (d) Whisker in cement matrix.