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Effects of short coconut fiber on the mechanical properties, plastic cracking behavior, and impact resistance of cementitious composites

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HIGHLIGHTS

- Cementitious composites adding short coconut fiber were designed using DMDA method.
- The presence of coconut fiber remarkably improved flexural behavior of the composites.
- Coconut fiber positively affected the impact resistance of cementitious composites.
- Adding coconut fiber into the composites reduced the plastic cracking significantly.

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ABSTRACT

The present study examines the effect of adding random, short coconut fibers to various cementitious composites on the mechanical properties, plastic cracking, and impact resistance of these composites. Fibers underwent a washing and boiling pretreatment prior to being added to the composite mixture. Mixtures of the cementitious composites designed by Densified Mixture Design Algorithm (DMDA) method were made using different volume fractions of random, short coconut fiber (0%, 1%, 2.5%, and 4%) and different water-to-binder (W/B) ratios (0.3, 0.35, and 0.45). Furthermore, fly ash (FA) was used to fill the void between sand particles and ground blast furnace slag (GBFS) was used to substitute for the cement in the mix proportions. A variety of tests were conducted in accordance with the relevant standards to determine the properties of these coconut fiber cementitious composites. The findings show that higher volumes of coconut fiber in the mortar tend to reduce the density and to increase the superplasticizer dosage. The addition of coconut fiber and higher W/B ratios were associated with lower compressive strength and higher absorption. The 28-day flexural strength of cementitious sheets and the modulus of rupture, respectively, increased from 5.2 to 7.4 MPa and from 6.8 to 8.8 MPa, as the coconut-fiber-to-mortar ratio ranged from 0% to 4%. Adding coconut fiber positively influenced first-crack deflection, toughness indices, plastic cracking, and impact resistance in the composites.

1. Introduction

Agricultural waste is a serious environmental problem in many countries. Moreover, fruit by-products represent a significant and increasing proportion of this waste. In light of current social concerns for ecological sustainability the importance of resource recycling/reuse, finding economical uses for fruit by-products is one important approach to protecting the environment and to saving resources.

Natural fibers extracted from the residual peels, leaves, stems, and pulp of plants such as flax, sugarcane, pineapple, banana, coconut, sisal, jute, and oil palm consist primarily of cellulose, hemicellulose, and lignin. These fibers are a readily available, recoverable, and renewable resource. Unlike synthetic fibers, natural fibers are biodegradable, inexpensive, low density, nontoxic, available worldwide, energy efficient, and eco-friendly [1–4]. Brittle materials that are made using natural fibers have exhibited superior technical and economical feasibility to similar materials made with synthetic fibers [5]. Furthermore, natural fibers offer exceptional mechanical properties, including high toughness and flexibility, which enhance the ductility of relatively brittle cement matrixes [5–8]. Hence, these fibers satisfy the ecological and

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sustainable requirements for high-performance, reinforced cementitious composites.

Coconut fiber, extracted from the husk of coconuts, is cheap and locally available in many tropical and semitropical countries. Coconut fiber is capable of taking strain 4–6 times as compared to other natural fibers [9,10]. The potential of using coconut fiber to improve the performance of cementitious materials has received increasing attention from researchers in recent years. Coconut fiber is currently widely used in boards, roofing materials, concrete, and other building materials [5,11–13]. Cementitious composites that have been reinforced with coconut fiber and cast under 1–2 MPa of pressure are presently used as low-cost roofing materials [14]. Previous research has found that coconut fiber reinforced cementitious mixtures exhibit decreased workability due to the strong water-absorptive and retentive nature of coconut fiber [5]. Various techniques of pre-treating fibers such as immersion in slurried silica fume [4], washing and boiling in water [12], and treatment with alkali [2,15] have been applied to improve the characteristics of coconut fibers. The resin-fiber interfacial bonding was improved by using treated coconut fiber [16]. Prior research has shown that cementitious composites incorporating coconut fiber exhibit improved mechanical properties and decreased density and thermal behaviors [3,11,17]. The optimum length of coconut fiber that is used in coir-based cement board is 1–6 cm [12]. The modulus of rupture and the internal bond of coir-based green composites both increased as coir fibers were applied using surface modification [18]. Using pozzolanic materials [4,19] may decrease the alkalinity of the matrix and the hydration product of calcium hydroxide, both of which are associated with degradation in the natural fiber cementitious composites [20–23]. Nevertheless, few studies have analyzed simultaneously the microstructure, mechanical properties, impact resistance, and plastic cracking of cementitious composites that have been reinforced with random, short coconut fibers.

The aim of the present research was to investigate the effect of random, short coconut fiber on the microstructure, mechanical properties, plastic cracking, and impact resistance of cementitious mortars. Further, coconut fiber was applied using washed-and-boiled pretreatment process in order to improve the mechanical properties of the fiber. Six types of cementitious composites were produced with various coconut fiber contents (0%, 1%, 2.5%, and 4% by mortar volume) and different water-to-binder ratios (0.3, 0.35, and 0.45). 15% sand and 25% cement by weight were replaced, respectively, with fly ash (FA) and ground blast furnace slag (GBFS) in the production of these composites, which were designed using the Densified Mixture Design Algorithm (DMDA) method. The properties of the cementitious mortar were tested for flow, density, water absorption, compressive strength, flexural strength of sheet, modulus of rupture, toughness indices, impact resistance, plastic cracking, and scanning electron microcopy (SEM).

2. Materials and experimental works

2.1. Materials

The ordinary Portland cement (OPC) Type I that was used in the present study was produced by Taiwan Cement Corporation. Class F fly ash (FA) and ground blast furnace slag (GBFS) were produced by the Xingda thermal power plant and China Steel Corporation, respectively. The chemical and physical properties of the cement, FA, and GBFS are presented in Table 1. The particle size distributions of these materials are shown in Fig. 1.

Locally sourced crushing sand was used as the fine aggregate in the composites. The maximum size, fineness modulus, density, and water absorption of this crushing sand were 4.75 mm, 2.85, 2630 kg/m^3, and 1.37%, respectively. The tap water that was used as the mixing fluid came from the Taipei water factory. TamCem-53 polycarboxylate was added as a superplasticizer (SP) to improve the flowability of the fresh mixtures. This high-range water-reducing admixture, provided by Taiwan Pu Chemical Co., Ltd., is brown in color and has a specific gravity of 1.1.

Table 1
Chemical and physical properties of cement, FA, and GBFS.

Items	Cement	GBFS	FA
Chemical properties			
SiO_2(S)	20.08	39.20	63.9
Al_2O_3(A)	4.32	13.00	20
Fe_2O_3(F)	3.02	0.23	6.64
S+A+F	27.42	52.43	90.54
CaO	63.73	37.50	3.84
MgO	3.15	7.12	1.25
SO_3	2.85	1.99	1.32
Free CaO	1.05	–	–
TiO_2	0.26	–	–
Na_2O	0.32	0.00	0
K_2O	0.60	0.22	1.08
C_3S	40.10	–	–
C_2S	32.80	–	–
C_3A	8.90	–	–
C_4AF	10.50	–	–
Physical properties			
Fineness (cm^2/g)	3310	6000	3110
Specific gravity	3.15	2.85	2.28
Initial setting time (w/c = 0.47)	227 min	–	–
Final setting time	502 min	–	–

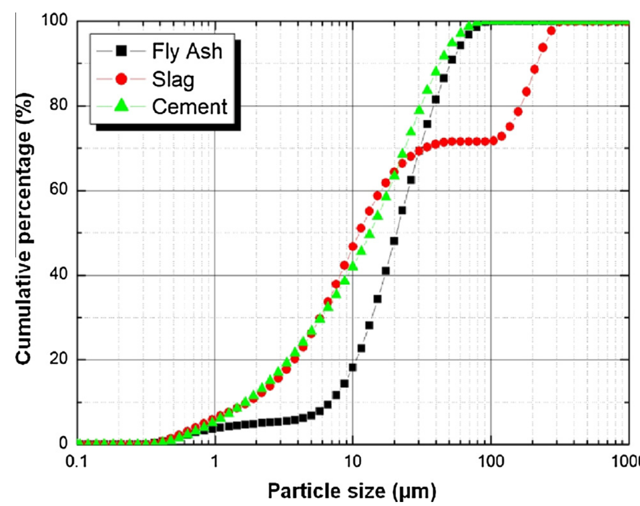

Fig. 1. Particle size distribution of cement, fly ash, and ground blast furnace slag.

Coconut fiber: Coconut fiber with a specific gravity of 1.28 and a length-to-diameter ratio of 40 was used in the present study. The raw coir fiber was washed, boiled for 2 h, dried at 100 °C in an oven for 24 h, and then cut into segments measuring an average 17 mmin length, which is classified as a "short fiber" [12]. The washing and boiling pretreatment for the coconut fiber removed impurities and improved the mechanical properties of the fiber [12,18]. Fig. 2 shows the appearance of the coconut fiber. Furthermore, images taken using the scanning electron micrograph (Figs. 3 and 4) show the rough surface and porous structure of the coconut fiber. The pretreatment process induced morphological changes that increased void volume and surface roughness [11,18].

2.2. Production of the coconut fiber cementitious composites

The DMDA method was used to calculate the mixture proportions that were used to produce the cementitious composites. This