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Physical and mechanical properties of randomly oriented coir fiber–cementitious composites

Özge Andiç-Çakir [a], Mehmet Sarikanat [b,*], Hikmet Bahadir Tüfekçi [a], Cihan Demirci [a], Ümit Halis Erdoğan [c]

[a] Department of Civil Engineering, Ege University, İzmir, Turkey
[b] Department of Mechanical Engineering, Ege University, İzmir, Turkey
[c] Department of Textile Engineering, Dokuz Eylul University, İzmir, Turkey

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ABSTRACT

In this study; important mechanical and physical properties of cement composites prepared with fine aggregate and coir fibers were investigated. In addition to control mortar mixtures without fiber addition, coir fiber incorporated composites were prepared by adding 0.4%, 0.6% and 0.75% coir fiber by weight of total mixtures, respectively. The effect of coir fibers on the mechanical properties of composites under compressive and flexural loads, water absorption capacity and thermal conductivity of mortars were investigated. Moreover, similar mixtures were prepared with alkali treated coir fibers having same ratios and the findings were discussed. As a result, fiber incorporation affects water absorption capacity of mortars, enhances their mechanical and thermal properties and decreases their unit weight. These effects become more significant by increasing amount of fibers and when alkali treated coir fibers are replaced with untreated ones.

1. Introduction

Recently, glass, carbon, and aramid fibers have been widely used as reinforcing materials in polymeric composites for structural applications. However, these fibers are resistant to biodegradation and can decrease the service life of the composite structure. Natural fibers from vegetables such as jute, coir, sisal and pineapple have advantages in comparison with man-made fibers in that they are renewable and biodegradable. Moreover, these fibers have low density, high toughness and acceptable strength properties, plentifully available, energy-efficient, economical and eco-friendly [1–2]. They are increasingly adopted to replace man-made fibers (glass, carbon fiber, etc.) in the industrial applications [2–4]. Natural fibers may be used as reinforcement to overcome the subsistent deficiencies in cementitious materials. Currently, there has been maintained interest in utilizing natural fibers in cement composites and in fabricating products based on them with a view to have alternate building materials [5–9]. The potential use of natural fibers has also been attractive in developing countries, where they are often available in tropical plants and agricultural wastes that currently have limited economic value [10].

Many studies in the literature pointed out various advantages in the use of natural fiber reinforced cement composites, e.g., increased flexural strength, post-crack load bearing capacity, improved bending strength, etc. [8–9,11–17].

Al-Oraimi and Seibi measured the mechanical properties of natural fiber and synthetic fiber reinforced concrete and they reported that using a low percentage of natural fiber improved the mechanical properties of concrete and had similar performance when compared to synthetic fiber reinforced concrete [16]. Razak and Ferdiansyah reported that the use of small volumes (0.6–0.8%) of *Arenga pinata* fibers show capacity to increase the toughness in cement based composites [18]. The work performed by Lee et al. investigated compressive and flexural properties of hemp fiber reinforced concrete and their results indicated that hemp fiber reinforced concrete has increased flexural toughness by 144% [19]. Reis et al. shows that the mechanical performance of fiber polymer concrete depends on the type of fiber, e.g., coconut and sugar cane bagasse fiber increases polymer concrete fracture toughness while banana pseudo stem fiber does not. The use of coconut fibers shows even better flexural strength than synthetic fibers [20]. In another study, Wang et al. reported that flexural toughness of cementitious composites with coir fiber increased by more than 10 times [21].

Natural and artificial impurities on the surface of vegetable fibers are considered harmful for its adhesion with the matrix

* Corresponding author. Address: Ege Üniversitesi, Mühendislik Fakültesi, Makina Mühendisliği Bölümü, 35100 Bornova, İzmir, Turkey. Tel.: +90 232 3115388; fax: +90 232 3888562.
E-mail address: mehmet.sarikanat@ege.edu.tr (M. Sarikanat).

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during the composite manufacturing. Therefore, surface treatments were generally applied to natural fibers in order to improve resin-fiber interfacial adhesion in composite manufacturing. The most widely used chemical treatments on natural fibers are acid, hydrolysis and alkaline treatment [17,19,22–26]. Among the methods in improving the adhesive character of the coir fiber, alkaline treatment may be considered to be the most economical technique; the main disadvantage is the deterioration in the fiber strength during the treatment [2]. All ester-linked molecules of the hemicellulose and other cell-wall components can be cleaved by alkali, increasing the hydrophilicity and hence the solubility of the material [27].

In this study, the effect of coir fiber reinforcement on some important mechanical and physical properties of cement based composites was investigated. The effects of fiber surface treatment and mixing ratios are also discussed. Mechanical and physical properties of cement composites were determined according to relevant standards and the results were compared to control mortars.

2. Materials and methods

2.1. Materials

Coir fibers were trimmed from coir mats, with an average length of 2 cm were used in this study. The fibers (untreated or surface-treated) were added to mortar mixtures in varying amounts. The characterization of mortar ingredients are given below.

CEM I 42.5 R type Portland cement conforming to the requirements of TS EN 197-1 was used for preparing mortars in this study. The chemical composition of the cement was given in Table 1, some important mechanical and physical properties of cement were presented in Table 2. The data were provided from the cement manufacturer.

CEN reference sand conforming to the requirements of TS EN 196-1 was used to prepare mortars. The reference sand is natural rounded sand with total SiO_2 content more than 98%. Particle size distribution of reference sand satisfies the grading limits given in Table 3.

A third generation concrete/mortar superplasticizer provided from the market conforming to the requirements of TS EN 934-2 was used to adjust the workability of mortar mixtures in this study. Technical details given by the manufacturer are listed in Table 4.

2.2. Methods

2.2.1. Surface treatment of coir fibers

In order to remove the natural and artificial impurities alkalization procedure was performed. Coir fibers were soaked in 5% NaOH solution for 2 h at room temperature. Afterwards, coir fibers were further washed with distilled water including a few drops of acetic acid. Then, the coir fibers were washed with fresh distilled water until all the sodium hydroxide was eliminated. At the end of this procedure, the fibers were dried at 60 °C for 24 h.

Table 1
Chemical composition of cement (provided from the manufacturer).

CEM I 42.5 R	Oxide composition (%)
SiO_2	18.53
Al_2O_3	5.010
Fe_2O_3	2.740
CaO	63.51
MgO	1.060
Na_2O	0.400
K_2O	0.750
SO_3	3.140
Cl	0.004

Table 2
Mechanical and physical properties of cement (provided from the manufacturer).

Compressive strength (MPa)	2 days	24.3
	7 days	39.9
	28 days	47.0
Fineness	Blaine specific surface (cm^2/g)	3880
	0.090 mm sieve residue (%)	1.0
	0.032 mm sieve residue (%)	22.4

Table 3
Particle size distribution of CEN reference sand (TS EN 196-1).

Square mesh sieve (mm)	Cumulative sieve residue (%)
2.00	0
1.60	7 ± 5
1.00	33 ± 5
0.50	67 ± 5
0.16	87 ± 5
0.08	99 ± 1

Table 4
Technical information about superplasticizer (provided from the manufacturer).

Chemical base	Modified polycarboxylates based polymer
Density (at +20 °C)	1.10 ± 0.02 g/cm^3
pH value	3–7
Water soluble chloride ion content	Max. 0.1%

2.2.2. Coir fiber characterization tests

2.2.2.1. Determination of density of coir fiber. Pre-dried coir fibers were used for density measurement. The density of coir fiber was measured by Archimedes method with ethanol in accordance with ASTM D 3800-99. The density of coir fibers was determined as 1.37 g/cm^3.

2.2.2.2. X-ray photoelectron spectroscopy (XPS) analysis. The chemical changes on the coir fiber surfaces introduced by surface treatments were determined by using XPS analysis. The XPS spectra were obtained by using a Specs ESCA instrument, equipped with a non-monochromatic Mg Kα radiation source at a power of 200 W (10 kV, 10 mA) and EA 200 hemispherical electrostatic energy analyzer. In order to determine the concentration of functional groups, Gaussian–Lorentzian functions were used for curve fitting of C1s spectra.

2.2.2.3. Yarn tensile test method. In order to determine the tensile strength of untreated and surface-treated fibers, yarn tensile test was conducted by using Shimadzu AUTOGRAPH AG-IS Series universal testing machine at contact speed of 0.1 mm/min. Minimum of 15 measurements for each coir type were mounted on cardboard end tabs via quick-setting polyester adhesive. The samples were mounted such that each specimen had a gauge length of 20 mm.

2.2.3. Preparation and workability determination of mortar mixtures

Mortar mixtures were prepared in accordance with TS EN 196-1 standard procedure. Each batch for three specimens consists of 1350 g reference sand, 450 g cement, 225 g water. In addition to control mortar mixtures without fiber addition, coir fiber