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High performance self-consolidating cementitious composites by using micro carbonized bamboo particles

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ABSTRACT

Nanotechnology has revolutionized every field of science by opening new horizons in production and manufacturing. In construction materials, especially in cement and concrete, the use of nano/microparticles and fibers has opened new ways from improved mechanical properties to enhanced functionalities. Generally, the production or manufacturing processes of nano/micro-sized particles are energy intensive and expensive. Therefore, it is very important to explore new methods and procedures to synthesize less energy intensive, cost effective and eco-friendly inert nano/micro-sized particles for the utilization in the cement composites. The research presented here describes the procedures for the production of inert, micro-sized, carbonized particles from bamboo. Four types of inert carbonized particles were produced from bamboo by using different procedures. Furthermore, the developed inert carbonized particles were utilized in the preparation of cement composites and effects of their inclusion on the performance of cement composites were studied. Three wt% additions i.e. 0.05, 0.08, 0.20 of cement were investigated for each category of inert particles. The mechanical characterization of specimens suggested that 0.08 wt% addition of inert carbonized bamboo particles enhances the flexural strengths and toughness of cement composites by 66% and 103% respectively.

1. Introduction

Concrete is the most used manmade material on the planet. It is produced by mixing cement aggregates, water and some mineral and/or chemical admixtures/additives [1]. The use of additives/admixtures enables to achieve the desired performance of cement composites and makes them more economical and ecofriendly. Thus, many researchers have studied the utilization of nano/micro-sized materials as partial replacement of cement including fly ash, silica fume, ground granulated blast furnace slag, limestone powder, bentonite, metakaolin, glass powder, rice husk, coconut shell and wheat straw ashes [2–9]. The studies indicate that the use of these supplementary cementitious materials (SCMs) have several positive effects on the performance of cementitious composites such as improved workability, consistency, thixotropy, compressive strength and durability [9–11]. However, concrete is a quasi-brittle material which can be very strong in compression (>200 MPa ultimate strength), but presents generally a low resistance in tension and consequently a limited bending strength. It is also characterized by a relatively low fracture toughness. Studies show that cement, aggregate and mineral admixture can improve the toughness of concrete, but the effect is not obvious [12]. Therefore, to improve the ductility of cement composites many researchers have tried to use fibers of various sizes for decades. Some examples of fibers that are generally used are steel, sisal, hemp, polyvinyl alcohol (PVA), polypropylene (PP), and many others [13–15]. Moreover, in recent years, particular attention has been paid to the distribution of fibers: very small and well dispersed fibers may control the microcracks in the matrix from the very beginning of their opening [12]. To this aim, nanomaterials such as carbon nanotubes (CNTs), carbon nanofibers (CNFs), graphene, nanocrystalline cellulose, calcium carbonate whiskers and nano-SiO_2 particles were also investigated for improving the ductility and strength of cement composites [16–23]. The basic aim of all the above mentioned work is generally the same; that is to

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Abbreviations

CMOD	crack mouth opening displacement
CNFs	carbon nano fibers
CNTs	carbon nanotubes
CPB	chemically treated, pyrolyzed bamboo
CPBA	chemically treated, pyrolyzed and annealed bamboo
EDX	energy dispersive X-ray spectroscopy
FESEM	field emission scanning electron microscopy
HRWRA	high range water reducing admixture
PB	pyrolyzed bamboo
PBA	pyrolyzed and annealed bamboo
PP	polypropylene
PVA	polyvinyl alcohol
SCMs	supplementary cementitious materials
TGA	thermal gravimetric analysis

prevent cracks generation and to block their propagation in the cement composites. Each method has its own pros and cones: some of them are costly and others might be difficult to use. Therefore, it is necessary to look into this issue from another approach such as by using the proposed micro-sized inert carbonized particles that are not only cheap but also easy to work with, contrarily to CNTs, for example. Recent research showed that the use of micro-sized carbonized hemp hurds and coconut shell particles in the cement matrix enhances the strength and fracture toughness of cement composites [24,25]. To this aim, bamboo is found to be a suitable candidate due to its abundant production all over the world [26]. Moreover, bamboo charcoal produced from bamboo residues after a high temperature treatment under nitrogen is a mature technology [27]. Thus, in this study, bamboo pieces were carbonized and ground to produce micro-sized inert particles. Then the inert carbonized bamboo particles were used as an additive in cement composites and their effects on the flexural strength, ductility and fracture energy properties of cement composites were studied.

2. Experimental program

2.1. Materials

Ordinary Portland cement (Type-1, grade 52.5) conform to ASTM C150 (standard specification for Portland cement) requirements was used. The chemical composition and physical properties of cement are presented in Table 1 [28]. In order to achieve sufficient workability of the cement composites, a high range water reducing admixture (HRWRA), based on modified acrylic polymers and conform to the requirements of UNI EN 934-2:2012 (admixture for concrete, mortar and grout) was used. The admixture HRWRA used in the present research work is a liquid based product possessing 30.5% solid content and density of 1.09 g/cm^3. The bamboo, used for the production of inert carbonized particles was obtained from the Piedmont region, Italy. The detailed procedure of inert carbonized bamboo particles production and their characterization is discussed in following paragraphs.

2.2. Synthesis of carbonized bamboo particles

Bamboo stems were chopped down in small pieces (approximately 20–30 mm in length and 2–3 mm in thickness) to get higher exposed surface area in the subsequent processes. After chopping the bamboo pieces were washed thoroughly with distilled water to remove dust and attached clay particles if any, and then kept in oven for 48 h at 105 ± 5 °C to remove the moisture completely. The carbonized bamboo particles were prepared by two methods i.e. with and without chemical treatment. The chemical treatment was carried out to partially disintegrate the organic structure of bamboo before pyrolysis and the effects of chemical treatment on the final properties of carbonized particles was investigated. For chemical treatment, the bamboo pieces were soaked in 0.25 M (1% w/v) aqueous solution of sodium hydroxide (NaOH) for 10 days in atmospheric conditions. Then the bamboo pieces were washed thoroughly with distilled water and dried in oven (at 105 ± 5 °C for 48 h). Carbonization of the bamboo pieces was carried out in a quartz reactor under inert atmosphere (argon gas flow at 0.2 bar) at 850 °C. The furnace heating ramp was adjusted at 1 °C/s until temperature reached 850 °C and then the temperature was maintained for 1 h. The as obtained bamboo after carbonization was abbreviated as PB (pyrolyzed bamboo). The PB was further annealed at 850 °C for 2 h under inert atmosphere, to obtain amorphous free and more graphitized form of carbonized bamboo particles, abbreviated as PBA (pyrolyzed and annealed bamboo). The chemically treated bamboo was also pyrolyzed (under similar conditions as mentioned above), and named as CPB (chemically treated, pyrolyzed bamboo) and further annealed, designated as CPBA (chemically treated, pyrolyzed and annealed bamboo).

The particle sizes of all the four types of carbonized bamboo were reduced to 1–2 μm by following a sequence of hand grinding (mortar and pestle), ball milling and attrition milling (for 1 h with 2 mm alumina balls). After grinding, the powders were dried in oven (at 50 °C) and stored in airtight containers until further use. The properties of the synthesized bamboo particles as observed in EDX analysis are reported in Table 2.

2.3. Preparation of cement composites

The required quantity of carbonized bamboo particles and admixture were added into the measured quantity of distilled water and the mixture was sonicated for 15 min. After sonication, the mixture was transferred to the mixing bowl (Janke and Kunkel homogenizer) and mixing speed was set at 440 rpm while the cement was added gradually in the initial 60 s. The mixing speed was kept constant for further 60 s. Then the speed was increased to 630 rpm and maintained for 120 s, making the total mixing time of four minutes. After mixing, the cement paste was poured into

Table 1
Chemical Composition of cement.

Composition	CaO	SiO_2	Al_2O_3	Fe_3O_4	SO_3	MgO	K_2O
Content (% by mass of cement)	44.00	9.50	26.50	2.50	12.00	1.30	0.60

Table 2
Properties of used inert carbonized bamboo particles.

Property	PB	PBA	CPB	CPBA
Carbon (C) %	59.01	82.34	76.58	82.45
Oxygen (O) %	38.41	15.46	21.88	14.25
Silicon (Si) %	1.78	1.18	0.81	0.67
Calcium (Ca) %	0.79	1.00	0.73	1.08
Avg. particle size (d_{50}) μm	1.22	1.66	1.58	1.43