J. For. Res. (2015) 26(1):247–251
DOI 10.1007/s11676-014-0003-y

ORIGINAL PAPER

Effect of carbon nanotube on physical and mechanical properties of natural fiber/glass fiber/cement composites

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Received: 25 February 2013 / Accepted: 16 April 2013 / Published online: 8 January 2015

Abstract The objective of this investigation was to introduce a cement-based composite of higher quality. For this purpose new hybrid nanocomposite from bagasse fiber, glass fiber and multi-wall carbon nanotubes (MWCNTs) were manufactured. The physical and mechanical properties of the manufactured composites were measured according to standard methods. The properties of the manufactured hybrid nanocomposites were dramatically better than traditional composites. Also all the reinforced composites with carbon nanotube, glass fiber or bagasse fiber exhibited better properties rather than neat cement. The results indicated that bagasse fiber proved suitable for substitution of glass fiber as a reinforcing agent in the cement composites. The hybrid nanocomposite containing 10 % glass fiber, 10 % bagasse fiber and 1.5 % MWCNTs was selected as the best compound.

Keywords Cement hybrid nanocomposites · Multi-wall carbon nanotubes · Bagasse fiber · Physical and mechanical properties

The online version is available at http://link.springer.com

Corresponding editor: Chai Ruihai

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Introduction

Glass–fiber is the most common of all reinforcing fibers in cement composites due to its advantages such as high tensile strength and stiffness, high water and chemical resistance, excellent insulating properties and good fire resistance (Enfedaque et al. 2012). Adding glass–fiber to cement composites as a reinforcing agent by incorporating a small amount of fibers in cement mortar was used to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness (Enfedaque et al. 2010). The use of glass fiber for manufacturing cement composites has been investigated by number of researchers (Enfedaque et al. 2012, 2010; Purnell et al. 2000; Shah et al. 1988).

Previous research showed that the use of glass fiber in the composites had several disadvantages such as non-biodegradability, high density, high cost and health problems for workers due to the skin irritations caused during processing and handling (Kazemi et al. 2008). For this reason, some fibers such as carbon, polypropylene and natural fibers were introduced to substitute for glass fiber in cementitious composites (Tonoli et al. 2011; Zakaria and Abdul Awal 2011).

With the advent of natural fibers in cement composites, a new group of composites was produced and named wood–cement composites. Wood–cement composites are a class of construction materials made by binding together wood particles or fibers with cement paste or mortar. These composites can also be made from non-wood agricultural fibers (e.g. sisal, bamboo, kenaf and flax) and other lingocellulosic wastes (e.g. bagasse, wheat straw, paper mill sludge, newsprint) (Cheumani et al. 2011).

One of the natural fibers that is widely produced in the world is bagasse fiber. Bagasse is the residue after sugarcane stalks are crushed for sap extraction. Approximately 320 kg of bagasse is produced per metric ton of processed sugarcane (Lee and Mariatti 2007). Compared to glass fibers, bagasse fibers, which are natural fibers, have lower density and cost and are renewable and biodegradable. These composites also have low thermal conductivity, reduce environmental pollution by recycling bagasse fiber, and do not emit formaldehyde as do typical composite panels (such as MDF and Particle board) during their service life (Younesi Kordkheili et al. 2012). Previous research showed that the main disadvantage of cement type panels made from bagasse fiber was vulnerability to moisture and reduced mechanical properties as compared to panels made with polypropylene fiber or glass fiber (Pehanich et al. 2004; Aggarwal 1995). To counter these disadvantages, researchers tested new cement composites (Ball and Wackers 2001; Liang et al. 2003) and found the best products to be hybrid composites and nanocomposites. Hybrid composites manufactured from two reinforcing agents (natural and synthetic fiber) had desirable properties such as being lightweight, easy to construct, economical, demountable, recyclable and reusable (Abeysinghe et al. 2013). Use of nano-materials (such as carbon nanotubes or nanoclay) to produce nanocomposites is another suggested method to overcome the negative effects of cementitious composites (Younesi Kordkheili et al. 2012).

Although there are some advantages of hybrid composites and nanocomposites (Musso et al. 2009; Chong and Garboczi 2002), there are no reports of performance by hybrid nanocomposites. To exploit the advantages of composites and produce cement composites of higher quality, cement hybrid nanocomposites including bagasse fiber, glass fiber and CNTs were manufactured and investigated the physical and mechanical properties of produced panels.

Materials and methods

Chopped E-Glass fibers of 25 mm length and aspect ratio of 1,250–3,570 were supplied by Diba Glass Fiber Company and were used as a reinforcing agent in the composites. Commercially manufactured Portland cement (type II) and bagasse fiber supplied by a local company were used to produce experimental panels. Bagasse fibers were initially soaked in water for 2 days to enhance their disintegration quality before being dried in a laboratory oven at 80 °C for 3 days. Average dimensions and tensile strength of the bagasse fibers provided by the supplier are 1.4 mm in length, 0.5 mm in diameter, 2.9 in length/diameter, and 120.2 in tensile strength. Multi-wall carbon nanotubes (MWCNT) with average diameter and length of 50 nm and 500 nm, respectively, were provided by the Research Institute of Petroleum Industry. Nanotube material was mixed with acetone in an ultrasonic mixer so that the mixture could be uniformly dispersed in a suspension, thereby minimizing the aggregation size of the MWCNT. Sonification was carried out for 4 h before acetone was allowed to evaporate. A rotating drum was employed for 5 min to a mix of Portland cement, water, $CaCl_2$, bagasse fiber, glass fiber and nanotubes to be converted into a homogeneous compound.

Eight types of panels with different ratios of raw material were manufactured (Table 1). The amount of $CaCl_2$ was fixed at 3 % for all types of samples. In addition to the above ratios, the cement composites contained 20 % glass and bagasse fibers manufactured for comparison properties between the composites reinforced with bagasse and glass fibers at a fixed level. Neat cement was also manufactured as a control sample for investigating the effect of MWCNTs, bagasse and glass fiber as a reinforcing agent. In the case of cement-based panels, the cement to water ratio was two. Water was eliminated by applying vacuum to the mats that had been poured into a mold similar to the other specimens manufactured using different ratios of raw materials. A computer controlled press was employed to compress the mats at a pressure of 30 kg/cm^2 at room temperature for 24 h. The sample mats were held for 24 days at ambient temperature before they were cured at 75 °C for 10 h in a laboratory oven.

Water absorption and thickness swelling of the samples

Water absorption and thickness swelling tests of the panels were performed according to the ASTM C 67-03a standard.

Five specimens of each type of panel were dried in an oven for 24 h at 100 ± 3 °C. Weight and thickness of dried specimens were measured to ±0.001 g and ±0.001 mm, respectively. The specimens were then immersed in distilled water for two weeks at 20 ± 2 °C. Weights and thicknesses of the specimens were measured at timed intervals during the two-week immersion process after excessive water was rinsed from their surface. Water absorption was calculated as a percentage using the following equation:

$$WA(t) = \frac{W(t) - W_0}{W_0} \times 100 \quad (1)$$

where WA(t) is the water absorption (%) at time t, W_O is the oven dried weight and $W(t)$ is the weight of specimen at a given immersion time t.

Thickness swelling was calculated as a percentage using Eq. 2:

$$TS(t) = \frac{T(t) - T_0}{T_0} \times 100 \quad (2)$$

Table 1 Composition of the cement hybrid nanocomposites (see legend in Fig. 1)

Panels type	Cement (%)	Bagasse fiber (%)	Glass fiber (%)	Multi-wall carbon nanotubes (%)[a]	$CaCl_2$ (%)
CB10G10	77	10	10	–	3
CB10 G10 N 0.5	77	10	10	0.5	3
CB10 G10 N 1	77	10	10	1	3
CB10 G10 N 1.5	77	10	10	1.5	3
CB15 G5	77	15	5	–	3
CB20 G5 N 0.5	77	15	5	0.5	3
CB20 G5 N1	77	15	5	1	3
CB20 G5 N1.5	77	15	5	1.5	3
CG	80	–	20	–	–
CB	80	20	–	–	3
C	100	–	–	–	–

[a] Based on cement dry weight

where TS(t) is the thickness swelling (%) at time t, T_0 is the initial thickness of specimens, and T(t) is the thickness at time t.

Mechanical tests

Three-point bending of the panels was carried out according to the ASTM C 67-03a standard by employing an Instron 1,186 with load cell of 50 KN. The impact strength of the samples was carried out using equipment Model Zwick 5102.

Results and discussion

Water absorption and thickness swelling of the hybrid nanocomposites are listed in Figs. 1 and 2, respectively. Water absorption and thickness swelling increased with increasing immersion time and reached a plateau at saturation point. The composites made from 20 % bagasse fiber exhibited greatest water absorption and thickness swelling. The hybrid composites made from 5 % glass fiber and 15 % bagasse fiber exhibited higher water absorption and thickness swelling compared to those made from 10 % glass fiber and 10 % bagasse fiber. In contrast to bagasse fiber, glass fiber is intrinsically water resistant and hydrophilic due to its fewer water residence sites. Hence, with increased glass fiber content, there were fewer water residence sites and therefore less water was absorbed. Increase of bagasse fiber content from 10 to 15 % increased water absorption and thickness swelling. Since lingocellulosic materials such as bagasse fibers are hygroscopic and hydrophilic, they have reactive OH groups in cellulose and hemicellulose structures that can absorb moisture from their surroundings. Composites containing 20 % glass fiber exhibited the lowest water absorption and thickness swelling (Figs. 1, 2). Hydrophobic properties generally have a positive effect on physical and mechanical properties of composites and broaden their range of use in final applications. Adding multi-wall nanocarbon tubes had a positive effect on the hygroscopic characteristics of the cement hybrid composites. At a constant level of glass fiber, increasing MWCNTs from 0.5 to 1.5 % decreased

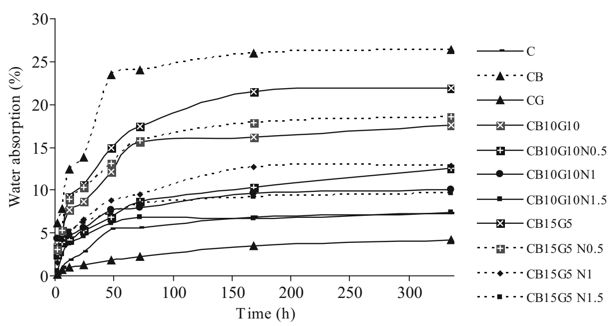

Fig. 1 Water absorption behavior of the studied composites

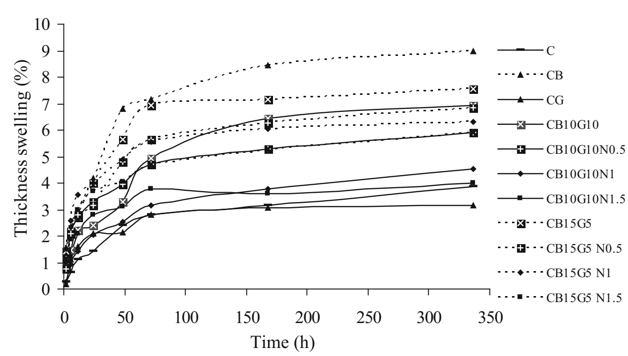

Fig. 2 Thickness swelling behavior of the studied composites

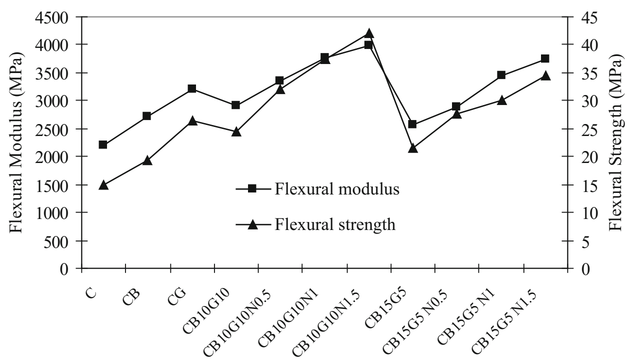

Fig. 3 Flexural properties of the studied composites

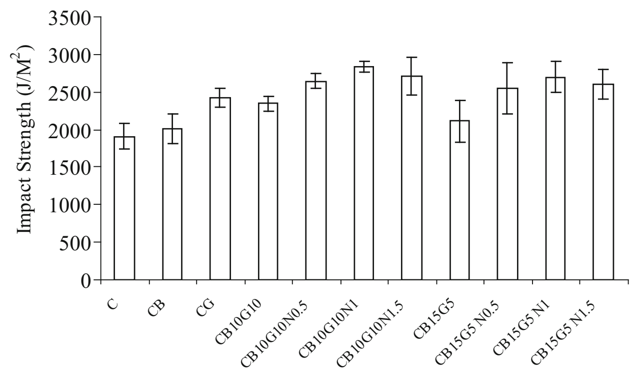

Fig. 4 Impact strength of the studied composites

water absorption and thickness swelling. In the woody composites, water saturates the cell wall through the porous tubular structure of the natural fiber and fills the voids of the composites. Because composite voids and the lumens of bagasse fibers were filled with MWCNTs, they prevented the penetration of water by capillary action into the deeper parts of the composite as described by Younesi Kordkheili et al. (2013).

Also, MWCNTs are naturally waterproof which causes an increase in water resistance properties of the manufactured composites. Younesi Kordkheili et al. (2012) reported that increasing MWCNTs from 0.5 to 1.5 % reduced water absorption and thickness swelling in bagasse fiber-cement composites.

A flexural modulus of the samples is displayed in Fig. 3. The use of bagasse and glass fibers as well as MWCNTs as reinforcing agents of cementitious composites had a positive effect on their flexural modulus. At constant content of MWCNTs, the composites manufactured from 10 % glass fiber exhibited higher flexural modulus as compared to composites produced from 5 % glass fiber. The flexural modulus of the composites is a primary function of the modulus of individual components (Kazemi and Younesi Kordkheili 2011). Since the flexural modulus of glass or bagasse fiber is considerably higher than for neat cement, the flexural modulus of the panels containing the fibers was higher than for neat cement. Also the higher flexural modulus of the composites manufactured from glass fiber rather than bagasse fiber (at fixed level = 20 %) can be related to the higher flexural modulus of glass fiber rather compared to bagasse fiber.

MWCNTs increased flexural properties of the panels. In the presence of 10 % bagasse fiber and 10 % glass fiber, the flexural modulus of samples with 0.5, 1 and 1.5 % MWCNTs were 19, 29 and 34 % higher than for neat cement, respectively. Panels containing 15 % bagasse fiber and 5 % glass fiber with 0.5, 1 and 1.5 % MWCNTs had a flexural modulus 14, 33 and 43 % higher than did panels made with neat cement. Increased flexural properties of composites with 1.5 % carbon nanotubes can be attributed to the greater stiffness of carbon nanotubes and their high aspect ratio. Salvetat et al. (1999) investigated the elastic behavior of carbon nanotubes and reported that the flexural modulus of such panels was approximately 1 TPa. In addition to the high strength and elastic constants of MWCNTs, they have extremely high aspect ratios, with values typically higher than 1,000:1 and as high as 2,500,000:1 (Zheng et al. 2004).

Increasing the content of carbon nanotube, glass fiber and bagasse fiber increased the overall flexural strength of the neat cement panels (Fig. 3). The flexural strength of fiber-reinforced cement-based composites is affected by adhesion between the matrix and fibers. Due to carbon nanotube size, MWCNTs can be evenly distributed in the composites and improve adhesion between the fibers and the cement (Musso et al. 2009; Li et al. 2007), indicating that carbon nanotubes have a positive effect on the flexural strength of the carbon nanotube reinforced cement composites.

The composites incorporating glass fiber exhibited higher flexural strength than composites made of bagasse fiber. Also, the composites with higher content of glass fiber (10 %) had higher flexural strength rather than composites with 5 % glass fiber. (Nouri and Morshedian 1995) also reported that the flexural modulus and flexural strength values of glass fiber-cement composites were higher than neat cement.

Generally, the panels incorporating 10 % glass fiber and 1.5 % MWCNTs exhibited the highest flexural modulus and flexural strength. The composites manufactured from 20 % glass fiber had higher flexural modulus and flexural strength than composites made from 20 % bagasse fiber or from neat cement.

Figure 4 illustrates the effect of bagasse and glass fiber loading and MWNCTs on the un-notched impact strength of cement hybrid nanocomposites. Adding carbon nanotubes, bagasse and glass fibers to the neat cement generally increased the impact strength of the samples. Cement is a brittle material but when reinforcing agents are used as reinforcement, the resulting flexibility and energy absorption capacity of the panels increases (Majumdar and Nurse 1974). Panels incorporating 1 % MWCNTs and 10 % bagasse fiber had the highest un-notched impact strength, whereas neat cement exhibited the lowest impact strength. Glass and bagasse fiber can control cracks in the concrete and improve the impact strength of the composites. For high impact properties a slightly weaker adhesion between fiber and cement should result in a higher degradation of impact energy, supporting fiber-pullout. On the contrary, good adhesion results in abrupt fiber fracture with minor energy degradation. Due to the MWCNT size and aspect ratio, it yields more efficient crack bridging at the very preliminary stage of crack propagation within composites (Musso et al. 2009).

Conclusions

Bagasse fibers, glass fibers, and MWCNTs as reinforcing agents of neat cement increased the physical and mechanical properties of manufactured panels. Bagasse fiber was a suitable substitute for glass fiber as a reinforcing agent in cement composites. Addition of MWCNTs yielded positive effects on the physical and mechanical properties of the glass and bagasse fiber cement hybrid nanocomposites. Composites with 20 % bagasse fiber exhibited the highest water absorption and thickness swelling values, whereas those made from 20 % glass fiber exhibited the lowest values. Composites with 10 % glass fiber and 1.5 % MWCNTs exhibited the highest flexural modulus and flexural strength. Panels having 1 % MWCNTs and 10 % bagasse and glass fibers exhibited the highest un-notched impact strength. Neat cement generally exhibited the lowest flexural properties and un-notched impact strength.

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