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Characteristics of hemp fabric reinforced nanoclay–cement nanocomposites

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ABSTRACT

Cement eco-nanocomposites reinforced with hemp fabric (HF) and nanoclay platelets (Cloisite 30B) are fabricated and investigated in terms of X-ray diffraction, scanning electron microscopy, physical and mechanical properties. Results indicated that the mechanical properties generally increased as a result of the addition of nanoclay into the cement matrix with HF. An optimum replacement of ordinary Portland cement with 1 wt% nanoclay decreased the porosity and also significantly increased the density, flexural strength and fracture toughness of HF-reinforced nanocomposite. The microstructural results indicate that the nanoclay behaves not only as a filler to improve the microstructure, but also as an activator to promote the pozzolanic reaction and thus improved the adhesion with hemp fabric. The failure micromechanisms and energy dissipative processes in HF-reinforced cement composite and HF-reinforced nanocomposite are discussed in terms of microstructural observations. These cement eco-nanocomposites can provide new insights for the development of new 'environmental-friendly nanomaterials' for building applications such as the construction of sandwich panels, ceilings and roofs.

1. Introduction

Nowadays, in the building industry, natural fibres and nanomaterials have been gaining increasing attention due to two reasons. One is to develop 'environmentally friendly materials' through utilizing natural fibres as alternative to synthetic fibres in fibre-reinforced concrete [1–3]. Another is to improve the properties of Portland cement matrix by adding nanoparticles [4]. Recently, nanoparticles are used in polymer, ceramic and construction materials, particularly producing nanocomposites which have superior physical and mechanical properties [5]. In the construction industry, several types of nanoparticles have been incorporated into concretes such as nano-SiO_2, nano-Al_2O_3, nano-Fe_2O_3, nano-ZnO_2, nano-$CaCO_3$, nano-TiO_2, carbon nanotubes and nano-metakaolin in order to improve the durability and mechanical properties of concrete [6–9].

Natural and cellulose fibres are used in polymer and cement matrices to improve their tensile/flexural strength and fracture resistance properties [10,11]. They are cheaper, biodegradable and lighter than synthetic fibres. Some examples of natural fibres are: cotton, sisal, flax, hemp, bamboo, coir, wheat straws and others [12–14]. On the other hand, one of the most effective techniques to obtain a high performance cementitious composite is by reinforcement with textile (fabrics), which are impregnated with cement paste or mortar. Synthetic (textile) fabrics such as polyethylene (PE) and polypropylene (PP) have been used as reinforcement for cement composites, in which fabrics are made of multi-filaments. This system has superior filament-matrix bonding which improve mechanical properties such as tensile and flexural strength more than continuous or short fibres [15–20]. In contrast, the use of natural fibre sheets and fabrics is more prevalent in polymer matrix when compared to cement-based matrix. For example, using cellulose sheets in epoxy or viny-ester matrix have improved the fracture toughness significantly [5,21].

Despite the advantages of natural fibres and fabrics and also nanoparticles, there are still obstacles which limit their applications in the cementitious composites. Firstly, for natural fibres, the interfacial bond between the natural fibre and the cement matrix is relatively weak and also the degradation of fibres in a high alkaline environment of cement matrix adversely affects the mechanical and durability properties of natural fibre reinforced cement composites [22]. Some researchers have recently recommended that much research is needed to overcome these disadvantages [23]. Secondly, for all nanoparticles, one of the major issues is that increasing the content of nanoparticles leads to

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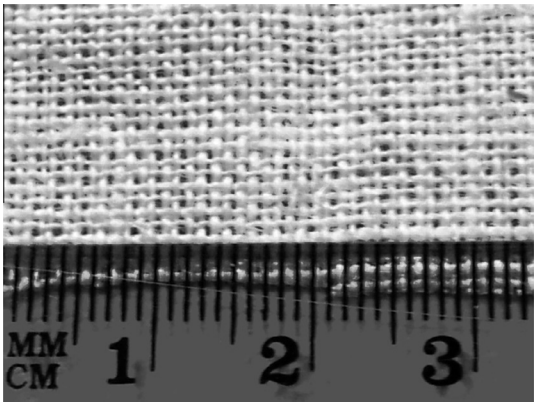

Fig. 1. Optical micrograph of hemp fabric.

reduction of some mechanical properties such as the flexural strength of cement paste [24]. However, little or no research is reported on using of natural fabrics and nanoparticles (e.g. nanoclay) as reinforcement in cement-composites.

In this paper, a novel material which involves synthesizing cement eco-nanocomposites has been investigated. Nanoclay was utilised as partial replacement of cement at various contents to produce the nanocomposites and hemp fabrics (HF) were used to reinforce these nanocomposites. The effects of different amounts of nanoclay on mechanical properties of HF-reinforced cement nanocomposites have been evaluated. The microstructures of hemp fabrics and eco-nanocomposite were investigated using X-ray diffraction and scanning electron microscopy.

2. Experimental procedure

2.1. Materials

Hemp fabric (HF) and nanoclay (Cloisite 30B) were used as reinforcements for the cement-matrix composites. The HF was supplied by Hemp Wholesale Australia Pty. Kalamunda, Western Australia as shown in Fig. 1. The chemical composition and physical properties of hemp fabric are shown in Tables 1 and 2, respectively [12,16]. The nanoclay (Cloisite 30B) used in this investigation are based on natural montmorillonite clay (hydrated sodium calcium aluminium magnesium silicate hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$). Cloisite 30B is a natural montmorillonite modified with a quaternary ammonium salt, which was supplied by Southern Clay Products, USA. The specification and physical properties of Cloisite 30B are outlined in Table 3 [5]. Ordinary Portland cement (OPC) was used in all mixes. The chemical composition and physical properties of OPC are listed in Table 4 [2].

2.2. Sample preparation

2.2.1. Nanocomposites

In this study, the OPC was partially substituted with nanoclay of 1%, 2% and 3% by weight of OPC. The OPC and nanoclay were first dry mixed for 5 min in Hobart mixer at a low speed and then mixed for another 10 min at high speed until homogeneity was achieved.

Table 2
Properties and structure of hemp fabric [12,16].

Fabric thickness (mm)	0.43
Fabric geometry	Woven (plain weave)
Yarn nature	Bundle
Filament size (mm)	0.04253
Number of filaments in a bundle	24
Bundle diameter (mm)	0.21
Opening size (mm)	0.3
Fabric Density (g/cm^3)	0.6
Modulus of elasticity (GPa)	38–58
Tensile strength (MPa)	591–857

The cement–nanocomposite paste (matrix) was prepared through adding water with a water/binder (nanoclay–cement) ratio of 0.48.

2.2.2. Hemp fabric reinforced nanocomposites

Firstly, hemp fabrics were washed with water and dried for 4 h at room temperature before beginning the casting, in order to reduce the effect of water absorption (hydrophilic effect) by hemp fabrics. Pacheco-Torgal and Jalali [23] indicated that hemp fibre has the lower water absorption (about 85–105%) compared to other natural fibres, such as, bamboo (145%), sisal (110%) and banana (407%). Secondly, eight layers of hemp fabrics were used in hemp fabric reinforced nanocomposites, in which their positions were placed above and below the centre of the nanocomposite sample over the depth of the specimen. Before each hemp fabric was laid into the mould, the hemp fabric was initially soaked into the nanocomposites matrix for 5 min, and then it was laid on polished timber slab and left under heavy weight 20 kg for about 3–4 min, this step is very critical in order to achieve a better penetration of the matrix in between the openings of the fabrics and to reduce air bubbles and voids inside the fabric. The fabrication of the hemp fabric reinforced nanocomposite specimen was done in sequential steps. First, a thick layer of matrix (about 12 mm depth) was poured into the mould, then the fresh pre-soaked hemp fabric (about 0.7 mm depth) was laid on top of it. After that another thin layer of matrix (about 1.5 mm depth) was poured into the mould followed by the other fresh pre-soaked hemp fabric and then the final thick layer of the matrix (about 12 mm depth). Finally, the mould was placed on a concrete vibrating table for several seconds to reduce the air bubbles and voids inside the specimens. The total amount of hemp fabric in each specimen was about 2.4 wt%. The mix proportions are given in Table 5.

2.2.3. Sample curing

For each series, four prismatic plate specimens of $40 \times 40 \times 160$ mm^3 in dimension were cast. All specimens were demolded after 24 h of casting and kept under water for approximately 56 days [25].

2.3. Characterisation

2.3.1. X-ray diffraction

The samples were measured on a D8 Advance Diffractometer (Bruker-AXS) using copper radiation and a LynxEye position sensitive detector. The diffractometer were scanned from 7° to 70° (2θ) in steps of 0.015° using a scanning rate of 0.5°/min. XRD patterns

Table 1
Chemical analysis of hemp [12].

	Cellulosic residue (wt%)	Pectin (wt%)	Hemicellulose (wt%)	Lignin (wt%)	(Wax, fat, protein) (wt%)
Hemp fibre	56.1	20.1	10.9	6	7.9