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Microstructures and mechanical properties of hemp fabric reinforced organoclay–cement nanocomposites

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HIGHLIGHTS

- Synthesis of hemp fabric reinforced nanoclay–cement nanocomposites.
- Mechanical properties increased with addition of nanoclay and hemp.
- 1 wt% nanoclay was optimum in enhancing strength and toughness.

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ABSTRACT

Cement eco-nanocomposites reinforced with hemp fabric (HF) and nanoclay platelets (Cloisite30B) are fabricated and investigated in terms of XRD, SEM, 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 and without HF. An optimum replacement of ordinary Portland cement by 1 wt% nanoclay is concluded from the current work. It is found that, 1 wt% nanoclay decreases the porosity and also significantly increases the density, flexural strength and fracture toughness of cement composite and HF reinforced nanocomposite. The microstructural analysis results indicate that the nanoclay behaves not only as a filler to improve microstructure, but also as an activator to promote pozzolanic reaction which modified cement matrix and improved the hemp fabric-matrix adhesion. The failure micromechanisms and energy dissipative processes in HF reinforced cement composite and nanocomposite are discussed in terms of microstructural observations.

1. Introduction

To date, one of the current tendencies in the building industry is to develop 'environmentally friendly materials' through utilizing natural fibres as alternative to synthetic fibres in fibre-reinforced concrete [1–3]. Another one is that some Portland cement is replaced by nanomaterials or supplementary cementitious materials (SCMs) [4]. Currently, nanotechnology has several applications in the polymer, ceramic and construction industries, particularly producing nanocomposites which have superior physical and mechanical properties [5]. In the construction industry, several types of nanoparticles have been incorporated into concrete composites such as nano-SiO_2, nano-Al_2O_3, nano-Fe_2O_3, nano-ZnO_2, 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 strength and fracture resistance properties [10,11]. They are cheaper, biodegradable and lighter than its counterpart 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. Synthesis (textile) fabrics such as polyethylene (PE) and polypropylene (PP) have used as reinforcement for cement composites, in which fabrics are made of multi-filaments. This system has superior filaments–matrix bond which improve mechanical properties such as tensile and flexural strength more than continuous or short fibres [15–19]. In contrast, the use of natural fibre sheets and fabrics in polymer matrix is reported in many studies than that used in cement based matrix. For example, using cellulose sheets in epoxy or viny-ester matrix have improved the fracture toughness significantly [5,20].

Indeed, despite all the advantages of natural fibres and fabrics and also nanoparticles, there are also some obstacles which have limited their applications in the cementitious composites. Firstly, for natural fibres, the interfacial bond between the natural fibre

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and the cement matrix is relatively weak and also the degradation of fibres in a high alkaline environment of cement adversely affects the mechanical and durability properties of natural fibre reinforced cement composites [21]. Some researchers have recently recommended that much research is needed to overcome these disadvantages [22]. Secondly, for all nanoparticles, one of the major issues is that increasing the content of nanoparticles leads to reduction of some mechanical properties such as the flexural strength of cement paste [23]. However, little or no research is reported on using of natural fabrics and nano particles (e.g. nanoclay) as reinforcement in cement-composites. In this study, a novel material which involves synthesizing cement eco-nanocomposites will be synthesized and investigated. Nanoclay is to be utilised to a partially replace cement at various ratios to produce nanocomposites. Hemp fabrics (HF) are to be utilised to reinforce the nanocomposites. The effects of different amounts of nano-clay on mechanical properties of HF reinforced cement nanocomposites are evaluated. The microstructure of the surface of hemp fabric and eco-nanocomposite has been investigated by XRD and scanning electron microscopy (SEM).

2. Experimental procedure

2.1. Materials

Hemp fabric (HF) and nanoclay platelets (Cloisite 30B) were used as reinforcements for the cement–matrix composites. The hemp fabric was supplied by Hemp Wholesale Australia Pty. Kalamunda, Western Australia as shown in Fig. 1. The chemical composition of and also the physical properties and structure of hemp fabric are shown in Tables 1 and 2 respectively [12,16]. The nanoclay platelets (Cloisite 30B) used in this investigation are based on natural montmorillonite clay (hydrated sodium calcium aluminium magnesium silicate hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2{\cdot}nH_2O$). Cloisite30B 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 is partially substituted by nanoclay with 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. The cement–nano-composite paste was prepared through adding water with a water/binder (nanoclay–cement) ratio of 0.48. The cement paste without nanoclay was considered as a control.

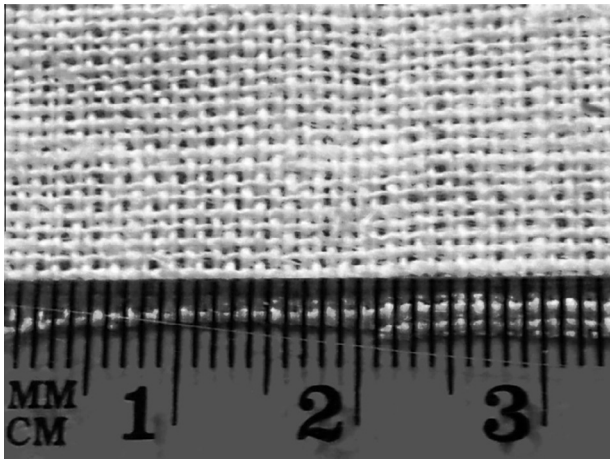

Fig. 1. Hemp fabric.

2.2.2. Hemp fabric reinforced nanocomposites

Two layers of hemp fabrics were used in hemp fabric reinforced nano-composites. The hemp fabrics were first soaked into the matrix in order to achieve a better penetration of the matrix in between the openings of the fabrics. The fabrication of the hemp fabric reinforced nanocomposite specimen was done in five steps. First, a thin layer of matrix was poured into the mould, then the pre-soaked hemp fabric was laid on top of it, then another layer of matrix was poured into the mould followed by the other pre-soaked hemp fabric and the final layer of matrix. The total amount of hemp fabric in each specimen was about 2.5 wt%. The mix proportions are given in Table 5.

2.2.3. Curing and specimens

For each series, three prismatic plate specimens of 300 × 70 × 10 mm in dimension were cast. All specimens were demolded after 24 h of casting and kept under water for approximately 56 days. Five rectangular specimens of each series with dimensions 70 × 20 × 10 mm were cut from the fully cured prismatic plate for each mechanical and physical test [16,23].

2.3. Characterisation

2.3.1. XRD

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 3° to 70° (2θ) in steps of 0.02° using a scanning rate of 0.5°/min. XRD patterns were obtained by using Cu Ka lines (λ = 1.5406 Å). A knife edge collimator was fitted to reduce air scatter.

2.3.2. Scanning electron microscopy (SEM)

Scanning electron microscopy imaging was obtained using a NEON 40ESB, ZEISS, equipped with energy dispersive spectroscopy (EDS). The SEM investigation was carried out in detail on microstructures and the fractured surfaces of samples. Specimens were coated with a thin layer of platinum before observation by SEM to avoid charging.

2.4. Physical properties

Measurements of bulk density and porosity were conducted to determine the quality of nanocomposites. The thickness, width, length and weight are measured in order to determine the bulk density. The calculation for density was carried out by using the following equation:

$$D = \frac{M}{V} \tag{1}$$

where D is the density in g/cm^3, M the mass of the test specimen (g) and V is the volume of the test specimen (cm^3).The value of apparent porosity P_S was determined using the Archimedes principle in accordance with the ASTM Standard (C-20) and clean water was used as the immersion water. The apparent porosity P_S was calculated using the following equation [25]:

$$P_S\% = \frac{m_s - m_d}{m_s - m_i} \times 100 \tag{2}$$

where m_d is themass of the dried sample, m_i the mass of the sample saturated with and suspended in water, m_s is the mass of the sample saturated in air.

2.5. Mechanical properties

Five specimens of each composition, all 70 × 20 × 10 mm, were used in the mechanical tests. Three-point bend tests were conducted using a LLOYD Material Testing Machine to evaluate the flexural strength, flexural modulus and fracture toughness. The support span used was 40 mm with a displacement rate of 0.5 mm/min. The flexural strength σ_F was evaluated using the following equation:

$$\sigma_F = \frac{3P_mS}{2BW^2} \tag{3}$$

where P_m is the maximum load at crack extension, S is the span of the sample, W is the specimen thickness (depth) and B is the specimen width. Values of the flexural modulus E_F were computed using the initial slope of the load–displacement curve, $\frac{\Delta P}{\Delta X}$ using the formula:

$$E_F = \frac{S^3}{4BW^3}\left(\frac{\Delta P}{\Delta X}\right) \tag{4}$$

In order to determine the fracture toughness, a sharp razor blade was used to initiate a sharp crack in the samples. The ratio of crack length to thickness (depth) ($\frac{a}{W}$) was about (1/3). The fracture toughness was calculated using the following equation [26]:

$$K_{IC} = \frac{p_mS}{BW^{3/2}} f\left(\frac{a}{W}\right) \tag{5}$$