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Effect of nanoclay on durability and mechanical properties of flax fabric reinforced geopolymer composites

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ABSTRACT

The main concern of using natural fibres as reinforcement in geopolymer composites is the durability of the fibres. Geopolymers are alkaline in nature because of the alkaline solution that is required for activating the geopolymer reaction. The alkalinity of the matrix, however, is the key reason of the degradation of natural fibres. The purpose of this study is to determine the effect of nanoclay (NC) loading on the mechanical properties and durability of flax fabric (FF) reinforced geopolymer composites. The durability of composites after 4 and 32 weeks at ambient temperature is presented. The microstructure of geopolymer matrices was investigated using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). The results showed that the incorporation of NC has a positive impact on the physical properties, mechanical performance, and durability of FF reinforced geopolymer composites. The presence of NC has a positive impact through accelerating the geopolymerization, reducing the alkalinity of the system and increasing the geopolymer gel.

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1. Introduction

Ordinary Portland Cement (OPC) is believed to be responsible of generating 5% of the global carbon dioxide emission [1]. One of the most attractive alternatives of OPC is geopolymer binder due to its comparable mechanical properties to the OPC. The development of geopolymer concrete is not only important because they are environmental friendly materials, but also due to their wide range of raw waste materials to produce worthy construction matrices, resulting in low cost material with similar mechanical properties to that of cement concrete [2]. Geopolymers are produced by activating a solid aluminosilicate source such as coal derived fly-ash, meta-kaolin and slag with alkaline solutions, amorphous networks of tetrahedral SiO_4 and AlO_4 connected by sharing oxygen atoms [3]. The formation of geopolymer gel can be described by Eq. (1) [3].

$$n(\mathrm{Si_2O_5},\mathrm{Al_2O_2}) + 2n\mathrm{SiO_2} + 4n\mathrm{H_2O} + \mathrm{NaOH} \rightarrow \mathrm{Na^+} + n(\mathrm{OH})_3-\mathrm{Si}-\mathrm{O}-\underset{\underset{(\mathrm{OH})_2}{|}}{\mathrm{Al^-}}-\mathrm{O}-\mathrm{Si}-(\mathrm{OH})_3 \quad (1)$$

Hitherto, nanomaterials have received increased attention in geopolymer and cement research; especially in producing nanocomposites that possess superior mechanical properties [4–6]. Several kinds of nanomaterials have been incorporated efficiently in geopolymer pastes. For instance, it has been found that nano-silica and nano-alumina particles have the ability to reduce the porosity and water absorption of geopolymer matrices [6]. In another study [7], nano-alumina and nano-silica particles have been incorporated in geopolymer matrices giving them higher mechanical performance. The nanoparticles are not only acting as fillers, but also enhancing the geopolymeric reaction. A further study on the effect of adding carbon nanotubes (CNT) to flyash-based geopolymer has shown an increase in the mechanical and electrical properties of geopolymer nano-composites when compared to the control paste [8]. Wei and Meyer reported the properties of cement/nanoclay composites, where the nanoparticles reduce the porosity of cement matrices, as well as improve the strength of cement matrix through pozzolanic reactions [9].

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Farzadnia et al. [10] reported that incorporation of 3 wt% halloysite nanoclay into cement mortars increased the compressive strength by up to 24% compared to the control sample. In a previous study, we investigated the effect of nanoclay (Cloisite 30B) on the mechanical and thermal properties of geopolymer composites [11]. Nanoclay particles were found to help developing denser geopolymer matrices, thereby producing geopolymer with superior mechanical performance.

Despite the potential improvement of properties of geopolymers, the geopolymer matrix still suffers from brittle failure readily under applied force and generally exhibits low mechanical strength [12,13]. One way to resolve this limitation is through utilizing natural fibres to fabricate fibre-reinforced geopolymer composites. The advantages of using natural fibres in composites include the low density, flexibility and the high specific modulus [14,15]. Cotton fibres and fabrics have been used to improve the fracture toughness and mechanical performance of geopolymer composites [16,17]. Also, flax and wool fibres have presented positive effects when incorporated in geopolymer matrices; they significantly improved the mechanical properties of the natural fibre reinforced geopolymer composites [[18]–1]. In our previous work, geopolymer composites were reinforced with woven flax fabric and tested for mechanical properties such as flexural strength, flexural modulus, compressive strength, hardness, and fracture toughness. The results showed that all mechanical properties were improved by increasing the flax fibre contents, and showed superior mechanical properties over the pure geopolymer matrix [19]. In a further study, geopolymer matrices were reinforced with a combination of nanoclay (NC) and flax fabrics (FF) and it was found that the addition of NC to geopolymers improved the adhesion between the natural fibres and the matrices due to the high amount of geopolymer gel formed, resulting in higher mechanical results [20].

However, there are concerns in utilizing natural fibres in alkali-based matrices. The main concern is regarding the long-term durability of natural fibre reinforced composites. Natural fibres can be degraded and damaged in high-alkaline environment; thereby adversely affecting the mechanical properties and durability of the composites [21–23]. Natural fibre degradations in alkaline environments was studied by Gram [24] and he described the degradation mechanism as the decomposition of hemicellulose and linen which leads to the splitting of natural fibres into micro-fibrils [24]. This effect has been observed using SEM in the case of jute fibres in cement matrix, where the natural fibres split-up and fibrillised resulting in reduction in the tensile strength of jute fibres by 76% [25]. To reduce the degradation impact, nanoparticles can play an important role. The effect of nanoclay particles on the durability of flax fibres reinforced cement composites at 28 days and after 50 wet/dry cycles has been investigated by Aly et al. [21]. Samples loaded with 2.5 wt% nanoclay particles showed lower deterioration in the flexural strength when compared to its counterpart control samples. This was attributed to the effect of nanoparticles in reducing the degradation of flax fibres.

According to the best of knowledge of authors, no study has been reported on the durability of natural fibres in geopolymer matrices. The presence of nanoclay particles is anticipated to reduce the degradation of natural fibres by consuming certain amounts of alkaline solution, which reduces the alkalinity of the medium. Nanoclay is also expected to produce higher amount of geopolymer gel, increases in matrix density, fibre-matrix adhesion, and the concomitant improvement in mechanical properties. In this paper, in order to improve the durability and reduce the degradation of flax fabric (FF) in geopolymer composites, geopolymer matrices were modified by the addition of nanoclay (NC) particles. This study presented the effect of different loadings of nanoparticles on the durability and mechanical properties of FF-reinforced geopolymer nanocomposites. The medium to long term durability of all samples has been discussed in terms of flexural strength obtained at 4 and 32 weeks. The microstructure was investigated using X-ray diffraction, Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM).

Table 1
Formulation of samples. Each samples is a mix of: 1.0 kg Eraring flyash, 214.5 g sodium hydroxide (8 M) and 535.5 g sodium silicate.

Sample	NC (g)	FF (layers)
GP	0	0
GPNC-1	10	0
GPNC-2	20	0
GPNC-3	30	0
GP/FF	0	10
GPNC-1/FF	10	10
GPNC-2/FF	20	10
GPNC-3/FF	30	10

2. Experimental procedure

2.1. Materials

Low-calcium flyash (ASTM class F) with specific gravity 2.1 obtained from the Eraring power station in NSW was used to prepare the geopolymeric nano-composites. The alkaline activator for geopolymerisation was a combination of sodium hydroxide solution and sodium silicate grade D solution. Sodium hydroxide flakes with 98% purity were used to prepare the solution. The chemical composition of sodium silicate used was 14.7% Na_2O, 29.4% SiO_2 and 55.9% water by mass.

Flax fabric (FF) and nanoclay (Cloisite 30B) were used for the reinforcement of geopolymer composites. The fabric, supplied by Pure Linen Australia, is made up of yarns with a density of 1.5 g/cm^2. The nanoclay (NC) with specific gravity of 1.98 has been provided by Southern Clay Products, USA.

To prepare the geopolymer pastes, an alkaline solution to fly ash ratio of 0.75 was used and the ratio of sodium silicate solution to sodium hydroxide solution was fixed at 2.5. The concentration of sodium hydroxide solution was 8 M, which was prepared and combined with the sodium silicate solution one day before mixing.

2.2. Preparation of geopolymer nanocomposites

The nano-clay particles (NC) were added to the flyash at the loadings of 1.0, 2.0 and 3.0% by weight. The flyash and nanoparticles were first dry mixed for 5 min in a covered mixer at low speed and then mixed for another 10 min at high speed until homogeneity was achieved. The alkaline solution was then added slowly to the flyash/nanoparticles mixture in a Hobart mixer at a low speed until the mixture became homogeneous, followed by further mixing for another 10 min on high speed. The resultant mixture was then poured into wooden moulds. The wooden moulds were then placed on a vibration table for 2 min before they were covered with a plastic film and cured at 80 °C for 24 h in an oven before demolding.

2.3. Preparation of FF-composite and nanocomposites

Similar mixtures were prepared to produce the FF-nanocomposites. Four samples of geopolymer pastes reinforced with ten layers of FF (see Table 1) were prepared by spreading a thin layer of the paste in a well-greased wooden mould and carefully placing the first layers of FF on it. The fabric was fully saturated with the paste by a roller, and the process repeated for ten layers; each specimen contained a different weight percentage of nanoclay particles. The samples were then left under heavy weight (20 kg) for 1 h to reduce entrapped air inside the samples.

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