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Effect of fabric orientation on mechanical properties of cotton fabric reinforced geopolymer composites

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ABSTRACT

This paper presents the thermal, mechanical and fracture behaviour of fly-ash based geopolymer composites reinforced with cotton fabric (0–8.3 wt.%). Results revealed that fly-ash based geopolymer can prevent the degradation of cotton fabric at elevated temperatures. The effect of cotton fabric orientation (i.e., horizontal or vertical) to the applied load on flexural strength, compressive strength, hardness and fracture toughness of geopolymer composites is also investigated. The results showed that when the fabrics are aligned in horizontal orientation with respect to the applied load, higher load and greater resistance to the deformation were achieved when compared to their vertically-aligned counterparts.

1. Introduction

In recent years, environmental awareness in construction industry has focused on finding environmentally friendly alternative material for Portland cement which is the main cause of the global warming. The use of Portland cement as the main component in the production of concrete is responsible for about 6% of the CO_2 emission worldwide [1,2].

In recent years, a new class of environmental-friendly and sustainable inorganic aluminosilicate polymers (also known as geopolymers) has emerged as an alternative to cements. These inorganic compounds improve the greenness of normal concrete and at the same time maintain comparable and even better properties. They possess good mechanical properties, inflammability, acid resistance and durability, and thus can be readily prepared at room temperature with less CO_2 emission than Portland cement [3–6].

Although geopolymers have desirable thermal stability and other favourable attributes, they suffer from brittle failure like most ceramics. This limitation can be readily overcome by the incorporation of short fibres or unidirectional long fibres into the geopolymer matrix. These fibres are able to improve the mechanical properties of the matrix by preventing the microcracks from propagating and thus enable them to fail in ductile mode rather than brittle mode, which increase their range of applications [7–9]. Hitherto, the most common fibre reinforcements used in geopolymer composites is based on inorganic fibres such as carbon and basalt fibres [10–13].

Current concerns over the environment and climate change have given rise to an interesting interest in replacing the synthetic fibres currently used in geopolymer composites or other brittle matrices with natural fibres. Natural fibres are low cost, low density, less health risk, renewable, recyclable and display good mechanical properties when compared to man-made fibres [14–19]. However, the conventional methods of mixing of natural fibres into the resins have usually been based on mechanical blending or stirring. This process does not allow the incorporation of large volume fraction of fibres and also has the tendency to cause fibre damage, fibre agglomeration and/or generation of air-bubbles during sample preparation [20].

In the present work, the authors report the use of cotton fabric to reinforce the geopolymer matrix, and verify the viability of developing a green composite material, using geopolymer as matrix and cotton fabric as the reinforcement. The cotton fabric reinforced geopolymer composites were subjected to flexural and impact tests, in order to determine their flexural strength, fracture toughness and impact strength. Thermogravimetric analysis (TGA) and scanning electron microscopy (SEM) were used to investigate their thermal behaviour, microstructure and failure mechanisms. Results suggest that this is a promising area of investigation, adding significantly to the body of literature on natural and green alternatives to concrete.

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Table 1
Chemical composition of fly-ash.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
50%	28.25%	13.5%	1.78%	0.89%	0.38%	0.32%	0.46%	1.64%

Table 2
Formulations of samples.

Sample	Fabric layers	Fibre content (wt.%)
Composite 0	0	0
Composites 1	10	4.5
Composites 2	20	6.2
Composites 3	40	8.3

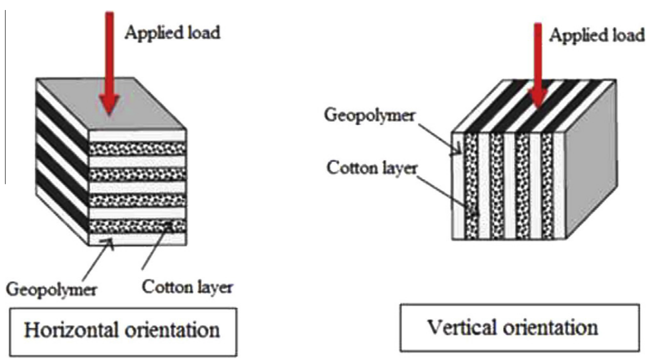

Fig. 1. Schematic drawing showing the orientation of cotton fabrics with respect to the applied load.

2. Materials and experiments

Cotton fabric (CF) of 30 cm × 7.5 cm was used to reinforce the geopolymer composites. Low calcium fly-ash (ASTM class F), collected from Collie power station in Western Australia, was also used as the source material of the geopolymer matrix. The chemical composition of fly-ash (FA) is shown in Table 1. 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 compositions of sodium silicate used were 14.7% Na_2O, 29.4% SiO_2 and 55.9% water by mass.

Composite samples were prepared by spreading a thin layer of geopolymer paste in a well-greased wooden moulds followed by carefully laying the first layer of woven cotton fabric on that layer. Thereafter, the fabric was fully impregnated (wet out) with geopolymer paste by a roller with the process repeated for the desired number of cotton fibre layers. Each specimen contained different layers of cotton fabric (see Table 2). For each specimen, the final layer was geopolymer paste. The alkaline solution to fly-ash ratio was fixed at 0.35 whereas the ratio of sodium silicate solution to sodium hydroxide solution was maintained at 2.5. The composite specimens were placed on a vibration table in order to ensure better penetration of the matrix between the fabric openings and to remove the entrapped air voids. The specimens were also pressed under 25 kg load for 3 h. Subsequently, the specimens were covered with plastic film and cured at 80 °C in an oven for 24 h. The samples were de-moulded and kept in room condition for 28 days before testing.

3. Characterisation

3.1. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) was carried out for cotton fibres, unreinforced geopolymer and cotton fabric reinforced

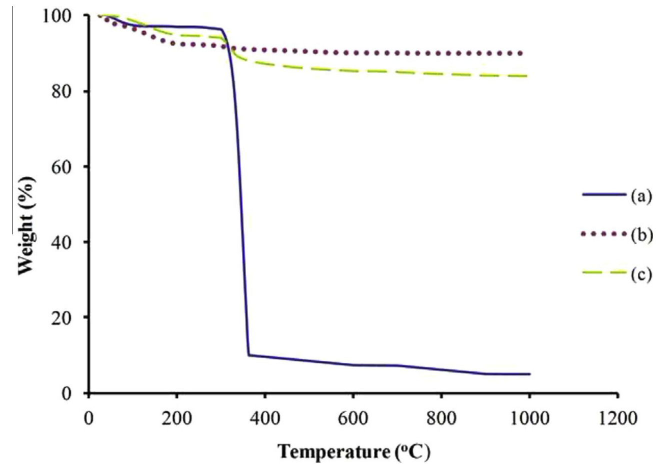

Fig. 2. TGA curves of: (a) cotton fibres, (b) pure geopolymer and (c) geopolymer composite.

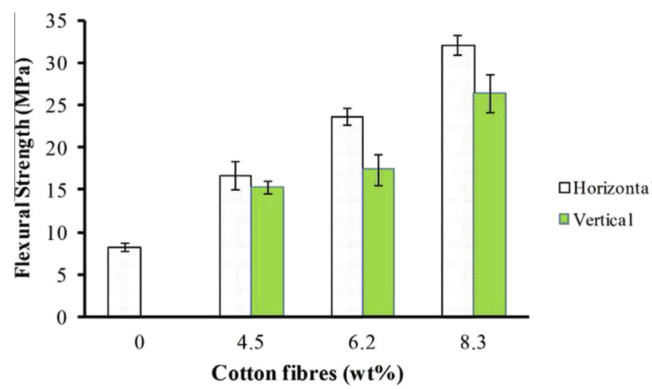

Fig. 3. Flexural strength of geopolymer composites as a function of fibre content.

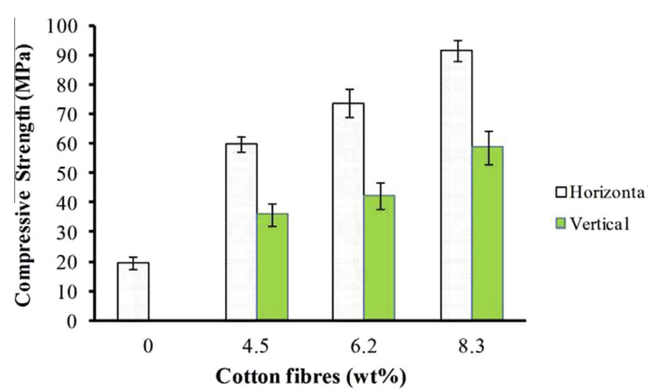

Fig. 4. Compressive strength of geopolymer composites as a function of fibre content.

geopolymer composites at a heating rate of 10 °C/min under atmospheric condition. The temperature range scanned between 50 °C and 1000 °C. The weight of all specimens was maintained around 15 mg.

3.2. Scanning Electron Microscopy (SEM)

A Zeiss Evo 40XVP scanning electron microscope was used to examine the microstructures of fly-ash and geopolymer composites. The specimens were mounted on aluminium stubs using car-