Construction and Building Materials 111 (2016) 237–250

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

The influence of bagasse fibre and fly ash on the long-term properties of green cementitious composites

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HIGHLIGHTS

- Investigation of the long term physical properties of a new green hybrid fibre reinforced cementitious composite.
- Investigation of the long term mechanical properties of a new green hybrid fibre reinforced cementitious composite.
- Investigation of the effect of fly ash and bagasse fibre contents on long term physical and mechanical properties.
- Natural curing in weathering conditions.
- Insightful investigation of the physical mechanism of the physical and mechanical behaviour via SEM test.

ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form 5 January 2016
Accepted 20 February 2016

Keywords:
Bagasse fibre
Cementitious composites
Fly ash
Long-term
Mechanical properties
Steel fibre

ABSTRACT

Both the long-term physical and mechanical properties of new green cementitious composites reinforced with bagasse fibre and steel fibre with ultra high volume of fly ash are investigated in this paper. Newly cast specimens were cured in the lab for the first 28 days, then these specimens were moved outside to be cured in weather conditions for up to 10 months. The physical properties (including bulk density, apparent porosity and water absorption), mechanical properties (such as compressive strength, Young's modulus and modulus of rupture) are investigated experimentally at the age of 28 days, 3 months, 6 months and 10 months. SEM tests are also conducted to study the microstructure of the new composites. Through comparison with the mechanical behaviour of the composites at the age of 28 days, the long-term effect on the physical and mechanical properties of the composites are discussed, and the impact of fly ash content and bagasse fibre content on the composites under the weathering conditions are also analysed. The experimental results show that the compressive strength, Young's modulus, modulus of rupture and tensile strength of the composites decrease with the reduction of the content of fly ash and bagasse fibre, but bending toughness of the material increases with fly ash content and peaks as fly ash to cement ratio achieves 2.0. The mechanical properties of the new composites are found to be comparable to those of conventional concrete and they are very promising green and sustainable construction and building materials for the next generation infrastructures.

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1. Introduction

Since the concept of environmental sustainability was introduced in 1970, the possibility of using natural fibre to improve the mechanical properties of cementitious composites has attracted the interest of researchers. Natural fibre-reinforced concrete, by randomly adding discrete short natural fibres or recycled materials in cementitious composites, could greatly reduce the adverse impact to the sustainable environment, and also expresses substantially improved short-term mechanical properties [1–7].

However, the long-term mechanical properties of natural fibre reinforced cementitious composites have been a long-term concern. After suffering from the attack from the cementitious alkali media, natural fibres always present degraded mechanical properties, and thus the mechanical properties of the composites are also degraded [8,9]. The main reason for the degradation of mechanical properties of the natural fibres lies in the alkali media and the hydration reaction of the cementitious matrix. The alkaline pore water, produced during the ordinary Portland cement hydration, dissolves the amorphous materials of natural fibres [10,11], and this weakens the link between individual fibre cells resulting in a reduction of the tensile strength [12]. The alkaline hydrolysis of the cellulose molecules leads to degradation of the molecular

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http://dx.doi.org/10.1016/j.conbuildmat.2016.02.103
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chains and reduction in its tensile strength [10,11]. Furthermore, the fibre mineralization process, i.e. the crystallization of the hydration product of cement in the individual fibres, also causes the decrease in the fibre flexibility and strength [12].

The early studies on natural fibre reinforced cementitious composites were not paid much attention due to the degradation of the material properties of the composites especially in alkali media [13,14] and also the fragile feature of natural fibre. However, through specific modification, such as kraft pulping [15,16], alkali treatment [17], acid treatment [18], natural fibres have been proven to be capable of improving the mechanical behavior of the composites even after long-term weathering conditions [12,19–25]. In addition, low alkali material is also reported as an effective way to improve the long-term mechanical properties of the composites [3,19–21,26,27]. When low alkali material is used as a major component of an alternative hydraulic binder to partially replace cement, the corresponding degradation of the natural fibres can be reduced [8]. Fly ash, a by-product of coal industry, is a low alkali material, and it has been reported to be effective in improving both the short- and long-term mechanical properties of cementitious composites in many aspects, especially the outstanding ductility of the composites when applied in high volume [28,29]. Furthermore the application of fly ash to replace the cement partially poses positive advances in protecting sustainable environment by reducing the emission of CO_2 during the manufacturing of the cement and also by the recycling use of the industrial waste.

Bagasse fibre is the by-product of the cane sugar industry, and the studies on the mechanical behaviour of reinforced cementitious composites demonstrated that the bagasse fibres the delayed setting behavior and improved the basic mechanical properties of the composites [30,31]. Also, bagasse fibre could improve the long-term durability of fibre-reinforced cementitious composites when the composite specimens were cured through long-term curing conditions like weather curing, wetting and drying cycles or water immersion [1]. Recently new green cementitious composites reinforced with bagasse fibre and steel fibre with ultra-high volume of fly ash have been developed by the authors and the short-term mechanical behaviour of the new composites have been studied [32]. Steel fibre with the volume fraction of 0.7% is used together with bagasse fibre, as the cementitious composites containing steel fibre content between 0.5% and 1% exhibited better tensile strength and ductility [33]. Bagasse fibres were treated with both NaOH solution and silane solution firstly and then applied together with steel fibre to improve the mechanical properties of the composites. The influence of fly ash content on the short-term mechanical properties of the composites was studied by varying the fly ash to cement ratio from 1.2 to 1.6 and 2.0 with the bagasse fibre content fixed at 3% by volume, and the influence of bagasse fibre content on the short-term mechanical behavior of the composite was evaluated by varying the fibre content from 3% to 8% and 12% of volume fraction with fly ash to cement ratio fixed at 1.6. The mechanical tests conducted at the age of 7 days, 14 days, and 28 days demonstrated that the compressive strength, Young's modulus, modulus of rupture and tensile strength of the composites decreased with the deduction of the content of the fly ash and bagasse fibre, but the bending toughness and tensile ductility of the material increased with fly ash content and peaked with fly ash to cement ratio of 2.0. It was found that the mechanical properties of the composites were comparable to those of conventional concrete and were very promising green and sustainable construction materials with strong potential to be used in engineering practice. However, the long-term physical and mechanical behavior of the composites was not known.

In this paper, the long term physical behaviour, including bulk density, apparent porosity and water absorption, and the long term mechanical behaviour of the new composites, including compressive strength, Young's modulus, bending behaviour, are investigated experimentally at the age of 28 days, 3 months, 6 months, and 10 months. Newly cast specimens were cured in the lab for the first 28 days, then these specimens were moved outside to be cured in weather conditions for up to 10 months. The influence of fly ash content on the mechanical properties of the composites is studied by varying the fly ash to cement ratio from 1.2 to 1.6 and 2.0 with the bagasse fibre content fixed at 3% by volume. The influence of bagasse fibre content on the mechanical behavior of the composite is evaluated by varying the fibre content from 3% to 8% and 12% of volume fraction with fly ash to cement ratio fixed at 1.6. SEM tests were also conducted to study the microstructure of the composites and to explain the change of the physical and mechanical properties of the composites with age. Finally research findings are concluded.

2. Green hybrid fibre-reinforced cementitious composites

New green eco-friendly and sustainable cementitious composites have been developed by the authors recently by using industrial wastes including bagasse fibres and high volume fly ash and the fundamental mechanical properties under short term were tested [32]. The long-term mechanical properties of composites are studied in this paper. For the completeness of the paper and easy reference, the design of the new green composites is briefly introduced herein.

The new green cementitious composites are comprised of cement, sand, water, ultra-high volume of fly ash, water reduce agent reinforced with bagasse fibres and steel fibres. The steel fibres are used to achieve the tensile strength and stiffness for the composites. The fibres utilized are coppered micro steel fibres WSF0213, which is provided by Ganzhou Daye Metallic Fibres Co., Ltd., with its geometry and material property parameters presented in Table 1. The volume fraction of steel fibre is fixed at 0.7%, as the cementitious composites containing steel fibre content between 0.5% and 1% showed better tensile strength and ductility [33].

Bagasse fibres are used in the composite to obtain good ductility. The original bagasse fibres used were achieved from Australian Prime Fibre Company, and they were refined in the vertical crushing machine by SOILCRETE AUSTRALIA Company. The crushed bagasse fibres were then sieved using a 2.36 mm screen to remove the coarse parts.

To reduce the bagasse fibre degradation by the chemical attack from the highly alkaline cementitious matrix, the fibres were boiled in a 3% NaOH solution with fibre concentration of 6.4 g/L at a temperature of 100° for 2 h so as to remove the non-cellulose part of the bagasse fibres. Then, the bagasse fibres were dried in an oven, and soaked in 6% silane solution for 2 h aiming

Table 1
Specifications of the applied fibres.

Fibre	Tensile strength (MPa)	Young's modulus (GPa)	Specific gravity (g/cm^3)	Diameter (μm)	Length (mm)	Aspect ratio
Steel fibre	2600	200	7.8	200	13	65
Bagasse fibre	197.8	81	1.26	180	16.09	89.4

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