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Strength and microstructure evaluation of recycled glass-fly ash geopolymer as low-carbon masonry units

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HIGHLIGHTS

- Geopolymerization of recycled glass and flyash to produce a recycled masonry unit.
- Evaluation of unconfined compressive strength with respect to different chemical compositions and curing conditions.
- Microstructure analysis with scanning electron microscope.

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ABSTRACT

The objective of this research was to evaluate the strength development of industrial by-products, namely Recycled Glass (RG) and Fly Ash (FA) in the manufacture of low carbon masonry units. A low carbon concept for manufacturing masonry units using RG-FA geopolymers was explored by applying low curing temperature of 50 °C and a low curing period of just 3–7 days. RG, being rich in silica was used as a filler material. FA, being a silica and alumina rich industrial by-product was used as a precursor in the RG-FA geopolymers. A liquid alkaline activator (L) comprising of a sodium hydroxide-sodium silicate solution was used for the alkali activation of 30% content of FA in the RG-FA blend. Factors found to affect strength development of the RG-FA geopolymers were: (1) the ratio of sodium hydroxide and sodium silicate in the liquid activator, (2) application of a low curing temperature of only 50 °C, (3) short curing periods of just 7 days and (4) the L/FA ratios. A geopolymer composed of a 70% Na_2SiO_3:30% NaOH ratio with a L/FA ratio of 0.625 was found to be the most efficient combination to provide the required unconfined compression strengths for manufacturing masonry. The usage of RG-FA geopolymers as low carbon masonry units was found to be viable using a low curing period of just 7 days and a curing temperature of just 50 °C. The RG-FA geopolymers had sufficient compressive strength be used as structural masonry units and needed only a low amount of heat treatment to achieve the minimum strength requirement. Optimally, 30% of FA was found to be sufficient for geopolymerization to occur for this novel low carbon RG-FA masonry units. Furthermore, the core materials needed to produce RG-FA masonry units were industrial by-products, the sustainable usage of which would contribute significantly to efficient waste management, through the production of aesthetically pleasing masonry units.

1. Introduction

Industrial by-products are traditionally designated as waste materials that possess no commercial value [1]. Recycling these traditional waste materials will enable them to be used sustainably in various construction applications [2–4]. Industrial waste materials are increasingly being used by the construction industry in various civil engineering applications. Industrial waste products

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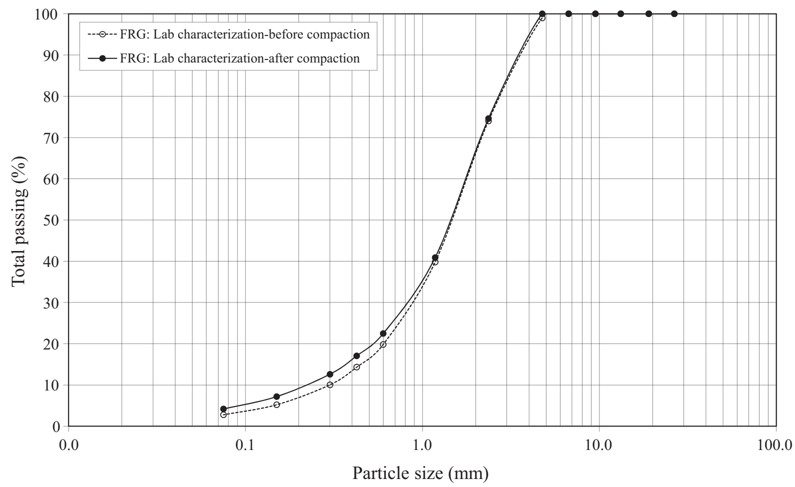

Fig. 1. Particle size distribution of RG.

Table 1
Chemical composition of RG and FA.

Chemical composition (%)	RG	FA
SiO_2	80.12	75.45
Al_2O_3	3.98	12.01
Fe_2O_3	0.69	3.96
CaO	13.58	2.72
MgO	N.D.	N.D.
SO_3	0.44	0.78
Na_2O	N.D.	N.D.
K_2O	0.56	2.97

Remark: N.D. = Not detected

that have generated interest in recent years include Recycled Glass (RG) and Fly Ash (FA).

RG is the by-product of crushing mixed colour bottles and other glass products collected from both municipal and industrial waste streams [5]. RG mainly comprises sand-sized particles with a small percentage of silt-sized particles. RG has recently been used in civil engineering applications such as roads [6–9], footpaths [10] and pipe bedding [11]. In Australia alone, approximately 1.0 million tonnes of RG is destined for landfill annually [3].

FA, a rich aluminosilicate material, is an industrial by-product of coal combustion power plants and is an abundantly available industrial waste material. In the civil engineering field, FA has been used to reduce the heat generated during concrete hydration [12], as an additive to stabilize soft soils [13–15], and as a structural fill material [16]. FA has also been used successfully in recent years as a source material, or precursor, for geopolymers in civil engineering applications [17].

Geopolymers are a group of cementitious materials that has garnered increasing interest as masonry units [18,19] due to the low carbon emission and minimal energy consumption. The chemical process to produce geopolymers involves the co-polymerisation of alumina and silica components whereby aluminosilicate-rich materials are dissolved by highly alkaline solutions such as sodium hydroxide (NaOH). Sodium silicate (Na_2SiO_3) can further increase the strength of the geopolymer [20] due to the gel-like product derived from the aluminosilicate-sodium silicate reaction [21]. Geopolymers are touted for their low carbon emissions, low energy consumption and their promotion of industrial waste by-products as precursors in the geopolymerization process. Alternative waste materials are increasingly being sought for use as low-carbon masonry units. In recent years, some attempts have been made to manufacture masonry using FA and

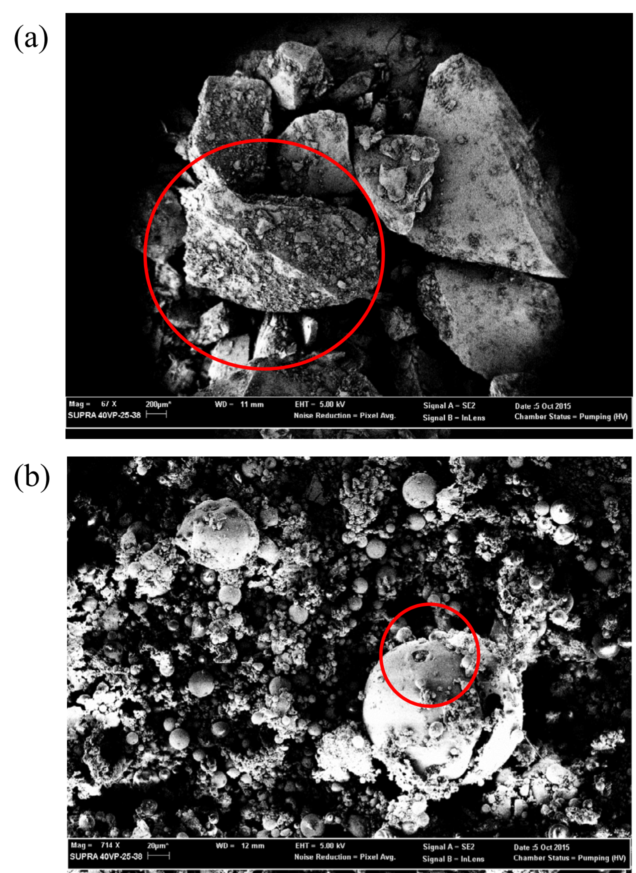

Fig. 2. Scanning Electron Microscopy (SEM) images of: (a) RG and (b) FA.

calcium carbide residue [18,22] or water-treatment sludge [23,24] as geopolymers.

This paper aims to investigate mixing RG at controlled ratios with FA, NaOH and Na_2SiO_3 to determine the optimum L/FA ratio to produce a viable low carbon RG-FA geopolymer masonry unit. In addition, the effects of Na_2SiO_3:NaOH ratios and curing times on the RG-FA geopolymer were investigated. The unconfined compressive strength (UCS) of various specimens were evaluated, under short curing durations of 3 and 7 days and a low temperature of just 50 °C, to evaluate the mechanical performance of RG-FA geopolymer as masonry units. In order to meet the