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# Recycled glass as a supplementary filler material in spent coffee grounds geopolymers

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## HIGHLIGHTS

- Recycled glass (RG) evaluated as a supplement to spent coffee ground (CG) geopolymers.
- RG provides mechanical and chemical strength supplementation to CG geopolymer.
- Heat-treated activated RG + CG geopolymers can achieve 10 MPa at 7-days compressive strength.

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## ABSTRACT

Recycled glass (RG) is a demolition waste, rich in silica and with a high shear strength and has been used as a replacement material for sand in various construction applications. Spent coffee grounds (CG) is a waste material derived from brewing coffee and has been recently studied as a recycled construction material, due to its physical resemblance to sandy soils. Geopolymerization, is a green process which produces cementitious compounds using aluminosilicate-rich materials and alkaline liquids. In this research, a new geopolymer construction material was produced using RG as a supplementary filler material to stabilize CG. Fly ash (FA) and slag were used as the precursors to induce geopolymerization in this new RG + CG construction product. To maximize the potential strength of the geopolymer, fine RG was added into geopolymer mixes in proportions of 25%, 50%, and 75% to observe the effects on the final RG + CG product strength. The mixes were compressed into cylindrical specimens, cured at room temperature (i.e., 21 °C) and 50 °C for 7 and 28 days, and tested for their unconfined compressive strength (UCS) to observe the effect of the various RG replacement ratio on the strength of CG geopolymers. Scanning electron microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDS) were used to further explain the role of RG in influencing strength development. Higher RG contents were found to lead to higher UCS values. A lower liquid-to-precursor (L/P) ratio was required to achieve a saturation point in strength development. RG was found to provide mechanical strength and supplementary chemical bonding strengths by dissolving and contributing $Si^{+}$ ions to form geopolymeric substances.



## 1. Introduction

Glass is an amorphous solid which constitutes largely of silica ($SiO_2$) [1]. It is widely used to make containers, beakers, and bottles to hold liquid, and as a construction material in building facades, doors and windows due to its transparent nature, which allows maximum sunlight into a building. Glass is an easily recyclable product which can be crushed, melted and then remolded into various shapes and sizes [2]. However, currently large quantities of used glass are either landfilled or stockpiled for future use because current logistics and recasting technologies do not result in an economical nor efficient glass recycling process [3]. On the other hand, other wastes containing silica are widely recycled. For example, post-consumer glassware can be ground, mixed with foaming agents, and heated to produce a porous foamed-glass which is

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**Table 1**
Test plan for the strength assessment of RG + CG geopolymers.

| Test type | RG:CG:P (by dry mass) | $Na_2SiO_3$: NaOH | L/P (by mass) | Curing temperature (°C) | Curing duration (days) |
|---|---|---|---|---|---|
| Modified proctor compaction | 20RG:50CG:30FA | 70:30 | 0.8, 1.0, 1.2, 1.4, 1.6 | N/A | N/A |
| | 35RG:35CG:30FA | 70:30 | 0.4, 0.6, 0.8, 1.0, 1.2 | N/A | N/A |
| | 50RG:20CG:30FA | 70:30 | 0.2, 0.4, 0.6, 0.8, 1.0 | N/A | N/A |
| | 20RG:50CG:30S | 70:30 | 0.8, 1.0, 1.2, 1.4, 1.6 | N/A | N/A |
| | 35RG:35CG:30S | 70:30 | 0.4, 0.6, 0.8, 1.0, 1.2 | N/A | N/A |
| | 50RG:20CG:30S | 70:30 | 0.2, 0.4, 0.6, 0.8, 1.0 | N/A | N/A |
| UCS | 20RG:50CG:30FA | 70:30 | 0.8, 1.2, 1.6, 2.0 | 21, 50 | 7, 28 |
| | 35RG:35CG:30FA | 70:30 | 0.6, 1.0, 1.4, 1.8 | 21, 50 | 7, 28 |
| | 50RG:20CG:30FA | 70:30 | 0.4, 0.8, 1.2, 1.6 | 21, 50 | 7, 28 |
| | 20RG:50CG:30S | 70:30 | 0.8, 1.2, 1.6, 2.0 | 21, 50 | 7, 28 |
| | 35RG:35CG:30S | 70:30 | 0.6, 1.0, 1.4, 1.8 | 21, 50 | 7, 28 |
| | 50RG:20CG:30S | 70:30 | 0.4, 0.8, 1.2, 1.6 | 21, 50 | 7, 28 |

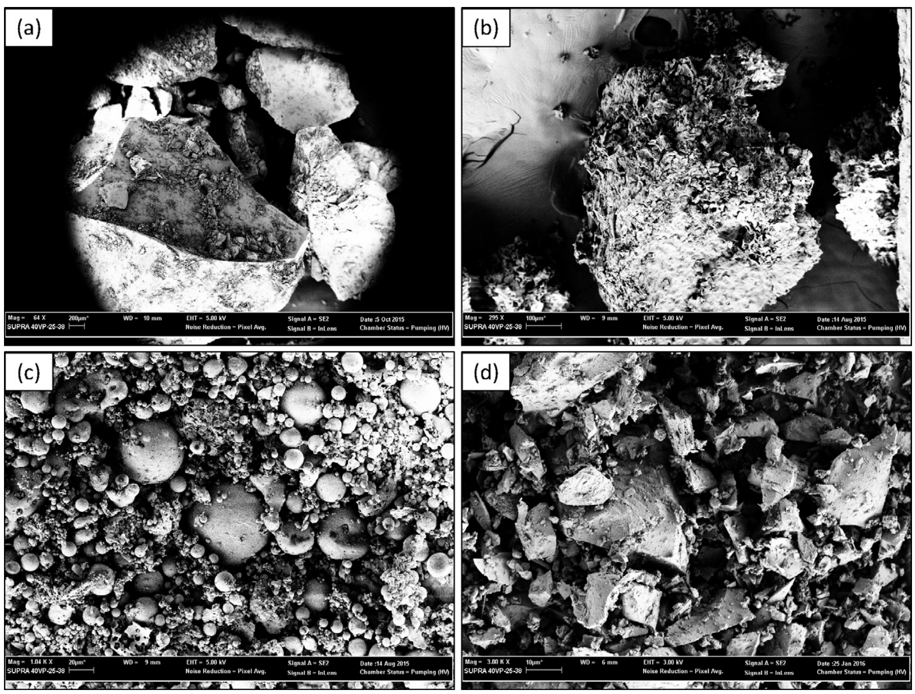


**Fig. 1.** SEM images of: (a) RG, (b) CG, (c) FA, and (d) Slag.

**Table 2**
Chemical composition of RG, FA, and Slag by XRF analysis.

| Chemical composition (%) | RG | CG | FA | Slag |
|---|---|---|---|---|
| $SiO_2$ | 83.57 | N.D. | 75.45 | 35.21 |
| $Al_2O_3$ | 2.43 | N.D. | 12.01 | 13.09 |
| $Fe_2O_3$ | 0.86 | 4.13 | 3.96 | 0.45 |
| CaO | 12.53 | 32.15 | 2.72 | 43.55 |
| MgO | N.D. | N.D. | N.D. | 5.93 |
| $SO_3$ | 0.28 | N.D. | 0.78 | 0.85 |
| $K_2O$ | 0.33 | 45.31 | 2.97 | 0.92 |
| $TiO_2$ | N.D. | 18.41 | N.D. | N.D. |

N.D. = Not Detected.

light-weight and possesses significant load-bearing strength [4]. Another example is silica fume, the by-product of silicon and silicon-alloy manufacturing, is a waste product associated with glass and is used as a supplementary cementing agent for concrete due to its high silica content [5].

In Australia, approximately 1 million tons of waste glass is collected annually [6]. Crushed glass obtained from municipal and industrial sources in Australia is considered as a construction and demolition (C&D) waste [6] and can be reused as recycled glass (RG) in a number of construction activities. Medium and fine sized RG particles have been found to possess high shear strengths [7], suitable for use as a recycled material in construction applications such as embankment fills [8,9], masonry units [10–12], and earth retaining structures [13]. Sand-sized RG can also be used as a fine aggregate, and has been previously bound with a fly ash geopolymer to produce masonry units with a recorded 3-days UCS of 12 MPa [14]. Powdered RG was found to be a good pozzolan which may be used to potentially replace cement because of the large total exposed surface which enables silica to be readily leached by alkaline solutions [15,16]. However, the main concern with using RG as a supplementary cementing agent or construction material, is the alkali-silica reaction between the alkali found in concrete and alkaline activator liquids and the silica in RG. Alkali-silica reaction is an expansive reaction which cracks concretes and reduces mortar durability, but using ground or pulverized RG significantly minimizes the occurrence of alkali-silica reaction [17].

The aforementioned process, in which silica is leached by alkaline solutions, is observed in the formation of geopolymers. Geopolymerization involves the breaking down of aluminosilicate-rich materials by highly alkaline liquids to form