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Fiber-reinforced cementitious composites incorporating glass cenospheres – Mechanical properties and microstructure

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HIGHLIGHTS

- Lightweight cementitious composites were developed using glass cenosphere (GC).
- GC helps in producing LWCs but increases the porosity due to higher water demand.
- Higher porosity of LWCs may severely affect the overall properties.
- GC amount should be limited to 30 wt% for adequate specific strength requirements.

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ABSTRACT

The effects of glass cenosphere particles on the properties of fiber-reinforced cement-based composites are explored in this study. Lightweight glass cenospheres were used as fillers in the cementitious composites and incorporated in various proportions. The developed composites were evaluated for mechanical strength parameters including compressive strength, flexural strength, tensile strengths, and elastic modulus. Microstructural investigations were also carried out. The results showed that utilizing glass cenospheres up to 30% (by cement weight) leads to adequate mechanical strength where the corresponding specific strength of 28 kPa/kg m^{-3} could be achieved. Microstructural analyses further revealed that increased porosity due to glass cenospheres incorporation is primarily responsible for strength loss with increasing weight fraction.

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1. Introduction

The distinctive advantages of lightweight concrete have led the researchers to explore and investigate new filler materials. The typical advantages of lightweight concrete over normal concrete are the reduced dead loads leading to smaller cross-sections of structural members as well as foundations, convenient fabrication, shipping, transportation, and installation in the case of precast structural members, and reduced overall construction cost. Furthermore, it offers exceptional durability to chemical and frost attack with lower permeability [1], greater fire resistance [2] and improved thermal insulation [3]. The unit weight of LWC ranges from 1200 to 1800 kg/m^3 [1] while for structural LWC, the ACI Committee 213 recommends the range as 1120–1920 kg/m^3 [3].

Conventional lightweight aggregates like expanded perlite [4–7], expanded vermiculite [8], expanded shale [9], foamed slag [10,11], expanded polystyrene beads [12,13], and expanded clay [14] have been used in the past and have proven successful in achieving the desired unit weight to the acceptable standards of lightweight concrete. However, the resulting low strength associated with their incorporation hampered their use in structural (load-carrying) applications in buildings. This is so because these aggregates have higher water absorption and lower mechanical crushing strength which hampers their use in producing structural lightweight composite [14].

Use of glass as aggregate in cement-based composites, for producing lightweight products has been an area of interest and many researchers tried to investigate the properties of resulting composites [15–22]. This is so because the glass aggregate has lower water absorption and higher mechanical crushing strength relative to that of conventional lightweight aggregates used in cement mortars and concretes [23]. Spiesz et al. [24] used expanded glass and produced thermal insulating composites with density ranging

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from 1280 to 1490 kg/m^3, depending on the amount of LWA used, and the compressive strengths obtained were 22–31 MPa. In another study, durability properties were evaluate for concrete with glass aggregate and no detrimental effects were identified [19]. Similarly at 30% volume fraction, a corresponding compressive strength of 35.3 MPa was found for waste glass aggregate [25]. Nemes and Jozsa [23] obtained very promising results (density range; 1400–2000 kg/m^3 and compressive strength range; 15–50 MPa) by incorporating a new expanded glass aggregate.

This experimental study advances the studies on glass-based aggregates for cement composites by evaluating the mechanical properties and microstructural characteristics of the composites developed from a micro-particle sized material; the glass cenosphere (GC). GC is alumino-silicate material with hollow spherical particles in various sizes. The study aims at developing structural lightweight cementitious composite using an alternative lightweight aggregate i.e. GC and evaluating its feasibility of with emphasis on mechanical and microstructural properties. The study would be useful for applications in precast structural members, exterior wall panels, roofing tiles, false ceilings, and likewise.

2. Materials and methods

2.1. Materials

Ordinary Portland cement (OPC), satisfying the requirements of ASTM C150 [26], type 52.5 from Green Island, Hong Kong was used in the study. Glass cenosphere (GC) particles were obtained from 3 M Hong Kong Limited. The GC particles are white colored, bulk density 380 kg/m^3, surface area 95.71 m^2/g, and iso-static crushing strength of 27.58 MPa [27]. The corresponding particle size distribution and microstructures for GC and OPC, done by laser granulometry (Coulter LS230) and scanning electron microscopy, are shown in Fig. 1 and Fig. 2. Poly-Vinyl Alcohol (PVA) fibers were also added into the mix enhanced flexural and tensile behavior of the resulting composites [28]. The PVA fibers used were 39 μm in diameter and 15 mm long, having tensile strength of 1600 MPA, 6% elongation and 41 GPa Young's modulus. The chemical composition of the raw materials, done by X-ray fluorescence spectrometry (XRF), is reported in Table 1. Glass cenospheres (GCs) contained significantly higher amount of lime and crystalline silica with small amounts of alumina as well. The chemical composition classifies them as alumino-silicate hollow micron sized particles (cenospheres). However, GCs are different to fly ash cenospheres which have amorphous silica and relatively higher amount of alumina [28–34]. It was found that glass cenospheres had higher surface area to weight ratio which pointed out their feasibility for producing lightweight composites.

2.2. Specimen preparation

The designed mix proportions, with varying weight fractions of glass cenospheres, are given in Table 2. A control mixture, without any glass cenosphere, was also designed. The objective of using various amounts of glass cenospheres was to determine the effects on the mechanical properties of the composites. So, various weight fractions were chosen to determine the trend of strength change with incorporation of these particles. The cement composites are inherently brittle, and the addition of glass cenospheres are more likely to increase the brittleness due to the characteristic properties of lightweight composites [35]. In order to develop suitable composites suitable for use in buildings or structures, enhanced ductility and toughness are imperative which are achieved by incorporating discontinuous reinforcement such as fibers. PVA fibers were used in this study as they are hydrophilic and there inclusion in cementitious composites may introduce strain hardening [30,36]. In this study, 1.5% (by binder weight) of PVA fibers were incorporated to address the issue of brittleness and enhance the toughness which can lead to the development of composites suitable for building structural applications. The flowability and cohesiveness of the mixtures were achieved by varying the water content and using a polycarboxylate ether based admixture (ADVA 105 by Grace Canada

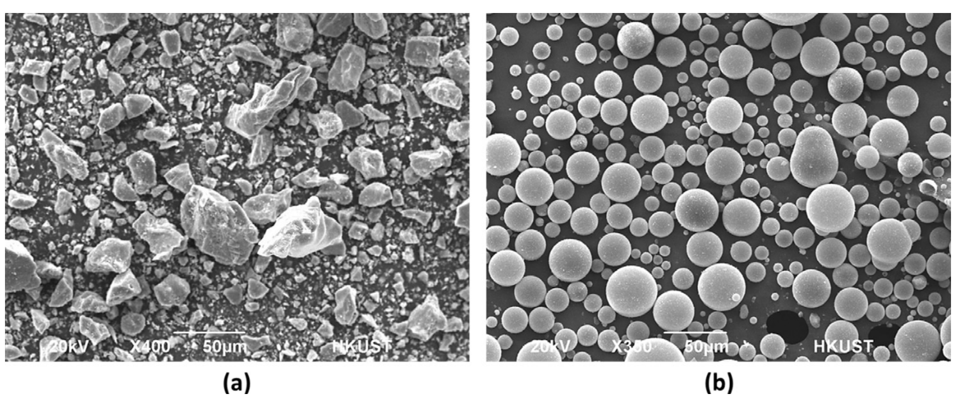

Fig. 1. Scanning electron microscopic images (a) Cement, and (b) GC.

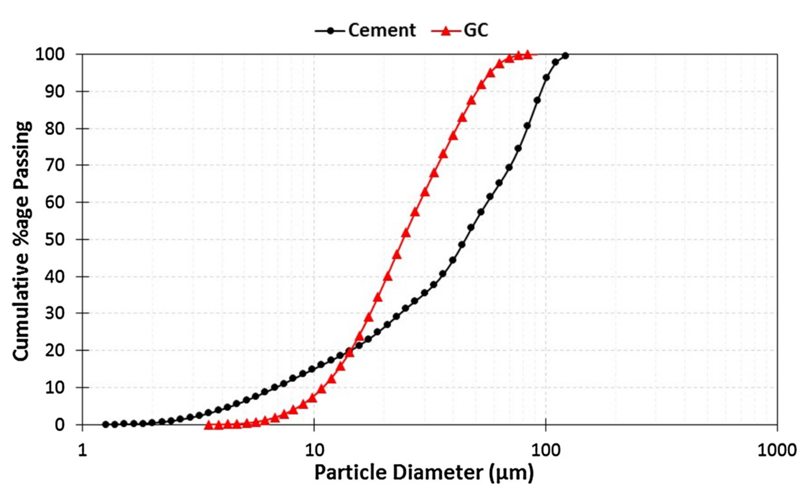

Fig. 2. Particle size distribution of raw materials.

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