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Properties investigation of fiber reinforced cement-based composites incorporating cenosphere fillers

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HIGHLIGHTS

- Lightweight fiber-reinforced cementitious composites were developed using fly ash cenosphere (FAC).
- FAC proved as excellent material for producing strong lightweight composites.
- The excellent mechanical properties are due to pozzolanic activity of FAC particles.
- Porosity associated with FAC incorporation governs the properties of FAC composites.
- Higher porosity of composites should be avoided by limiting FAC amount to 50 wt%.

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ABSTRACT

The objective of this research study is the in-depth evaluation of the characteristics of fiber reinforced cement-based composites containing fly ash cenospheres (FACs) as lightweight filler material. The resulting composites showed excellent mechanical properties with higher specific strength as 34.69–24.11 kPa/kgm^{-3}. The 28 – day compressive, flexural and tensile strengths were determined in the range of 55.92–30.38 MPa, 9.29–5.38 MPa, and 3.51–1.66 MPa, respectively. The higher pozzolanic activity of FACs contributed towards the better mechanical properties even at lower density. Microstructural analyses of the composites were carried out by SEM, nitrogen adsorption, and mercury intrusion porosimetry (MIP) while TGA was used for phase identification and phase transformation studies, respectively. The results indicated that FAC is a promising material for producing strong and lightweight structural members for use in building construction which can promote sustainable development. However, excessive FACs content in the composite may lead to higher porosity due to hollow spherical shape and chemical composition of FAC particles which affects the mechanical behavior and durability of cement-based composite.

1. Introduction

Fly ash cenospheres (FACs) are hollow alumino-silicate spheres which are obtained as residue from the coal fired power plants [1–4]. These are thin-walled, spherical and relatively larger in size (10–300 μm) than fly ash [5]. The color is greyish white and the composition and shape are similar to that of fly ash [6]. These are considered as a valuable industrial waste because of their chemical composition [7] and as such their beneficial use would help sustainable development. Due to their hollow nature, the particle density typically ranges from 600 to 900 kg/m^3 [8] which make them suitable for producing lightweight composites.

During the past few years, researchers have been investigating the properties of cenospheres modified composites (such as cement, metal and ceramic) incorporating cenospheres [2,7,9–20] which led to the increased attention in producing cementitious composites utilizing FACs and studying their various properties to be effectively used in building construction elements [5,6,8,12,18,21–26]. Blanco et al. [6] fabricated the lightweight cement composite by incorporating FACs with the lowest possible density, ranging from 1090 to 1510 kg/m^3 with compressive strength oscillating between 27 and 33 MPa, by using the particle packing theory. McBride and Shukla [5] studied the mechanical properties of the above concrete and employed bimaterial fracture

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mechanics to further study the interface behavior of the FACs and cement. The highest specific compressive strength they could achieve was 11.6 kPa/kgm^{-3}. Moreover, Wang et al. [8] investigated the alkali-silica reactivity of cement composites containing cenospheres and deduced that the pozzolanic activity of cenospheres may affect the mortar expansion. Kwan and Chen [2] used FACs to increase the packing density and strength of composites while improving the rheological properties of fresh paste. Chia et al. [27] evaluated the long-term creep and shrinkage of concretes containing cenospheres and compared with their similar findings on normal concrete; it was found that concrete containing cenospheres had the highest creep primarily because of the lower values of elastic moduli while the total shrinkage was the lowest. In addition, many works have also been conducted in the recent years on fiber reinforced concrete containing cenospheres. Pichor [12] studied the flexural strength and modulus of rupture for concretes containing polyvinyl alcohol (PVA) and polypropylene (PP) fibers with different volume fractions of cenospheres and it was concluded that fibers can not only improve the flexural behavior but also they help further reduce the density of resulting concrete at higher fiber volume fraction. Moreover, it was shown that PVA fibers are superior, as compared to PP fibers, in improving the ultimate flexural behavior. Wang et al. [24] analyzed the flexural behavior of composites having fixed cenospheres content with varying volume content of steel and polyethylene fibers and it was emphasized that fibers effectively enhance the flexural behavior in such composites while shrinkage reducing admixture, if used, may densify the paste-matrix thereby further improving the strength properties. Huang et al. [22] developed engineered cementitious composites (ECCs) using various industrial waste byproducts, including fly ash, iron ore tailings and FACs, and deduced that FACs were beneficial in reducing the overall density of resulting composite while maintaining sufficient levels of mechanical properties.

Although the mechanical properties of the FACs modified cementitious materials have been an area of interest for the researchers in the past, studies on detailed microstructural investigations on cement composites incorporating FACs are deficient. Moreover, the studies on porosity/pore size distribution as well as thermal properties of FACs composites are also lacking. The present study focuses on investigating the properties of cement composites incorporating varying amounts of FACs with the in-depth study on the microstructure and characteristics of hydration products. Pozzolanic activity of the FACs was estimated by the thermal analysis techniques whereas the pore characteristics were evaluated by nitrogen and mercury intrusion methods.

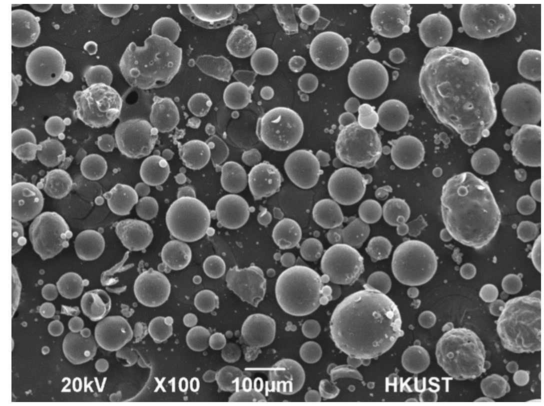

Fig. 1. Scanning Electron microscopic image of FACs.

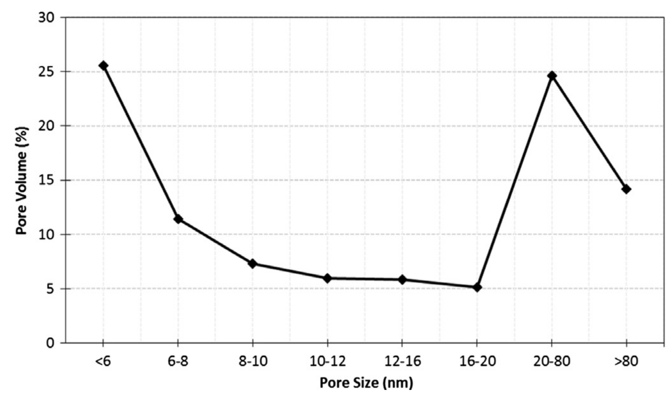

Fig. 2. BET analysis of FAC particles.

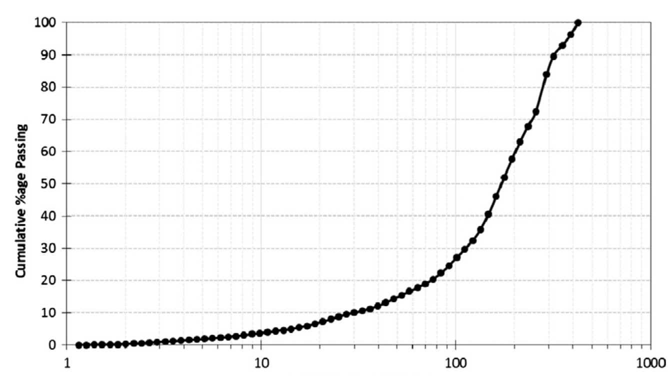

Fig. 3. Particle size distribution of FACs.

2. Materials and experimentation program

2.1. Materials

Ordinary Portland cement (OPC), ASTM type I, was used in the study. Silica fume was used as supplementary cementing material for improved properties of the composites. Cenospheres possessing bulk density of 720 kg/m^3 and specific surface area of 6.02 m^2/g with particle size ranging up to 400 μm, were used in the study. The scanning electron microscopic (SEM) image and particle size distributions (laser granulometry, Coulter LS230) are shown in Fig. 1 and Fig. 3, respectively. It is found that a significant fraction of the particles lie within the range of 50–400 μm while almost 5% particles are larger than 400 μm. The surface area and pore size of FAC were quantified by the Brunauer-Emmet-Teller (BET) analysis (nitrogen adsorption method) [28] and the results are shown in Fig. 2. The results showed the presence of pores of various sizes from under 6 nm to over 80 nm. PVA fibers (from Kuraray Co., Ltd, Japan; Dimension, 39 μm diameter × 12 mm length; Yield strength, 1600 MPa; Elastic modulus, 41 GPa; elongation, 6%) were also incorporated to enhance the flexural and tensile behavior of the composites. The chemical compositions (oxides) of the raw materials as obtained from X-ray fluorescence spectrometry (XRF) are listed in Table 1.

2.2. Mixture proportioning and sample preparation

Six (06) mix proportions of the cementitious composite with FACs to binder ratio from 0.30 to 0.70, as tabulated in Table 2. Silica fume was used as supplementary cementing material. Silica fume has been known to improve the packing ability, mechanical strength and durability of cementitious matrix [29–31] which is