Construction and Building Materials 144 (2017) 373–384

Contents lists available at ScienceDirect

Construction and Building Materials

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

Review

Utilization of fly ash cenosphere as lightweight filler in cement-based composites – A review

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HIGHLIGHTS

- Researches on fly ash cenosphere (FAC) containing cement-based composites (FACC), from 1984 till to date, have been reviewed.
- The mechanical, structural, durability-related, time-dependent, and functional properties of FACC are summarized.
- Various properties of FACC are compared with concretes containing conventionally used lightweight aggregates.
- Developing trends and future prospects for the use of FAC are discussed.

ARTICLE INFO

Article history:
Received 9 December 2016
Received in revised form 8 March 2017
Accepted 25 March 2017

Keywords:
Fly ash cenosphere
Lightweight
Microsphere
Cement-based composites
Sustainable development
Durability

ABSTRACT

Fly ash cenospheres (FACs) are the hollow spherical particles obtained during coal burning process in coal fired power plants. FAC has been used as a lightweight filler (LWF) material in producing lightweight cementitious composites (LWC) since 1984 and currently many researchers are widening the knowledge in this area. In this paper, the research activities and outputs regarding the application of FAC in civil engineering are reviewed systematically. The influences of FAC on the mechanical, functional and structural properties as well as on the durability of FAC incorporated cement-based composites (FACC) are summarized. The higher specific strength of the composites modified by FAC can be attributed to the thicker and tougher FAC shell as well as the partial pozzolanic activity of FAC particles in cementitious systems. Future prospects for its use are also suggested in this paper.

Contents

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http://dx.doi.org/10.1016/j.conbuildmat.2017.03.188

1. Introduction

Lightweight concrete (LWC) has gained considerable attention from researchers in the last few decades, though its use can be traced back to 3000 BC [1]. The reasons for such augmented curiosity are its distinctive advantages over normal weight concrete: 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. Moreover, LWC offers exceptional durability to chemical and frost attack with lower permeability [2], greater fire resistance [3] and improved thermal insulation [4]. The unit weight of LWC ranges from 1200 to 1800 kg/m^3 [2] while for structural LWC, the ACI Committee 213 recommends the range as 1120–1920 kg/m^3 [4]. To be able to attain the desired unit weight with satisfactory mechanical and structural characteristics, cautious selection and efficient application of lightweight filler (LWF) materials is of paramount importance.

Conventionally, various fillers are used as lightweight aggregate (LWA) in cementitious composites to attain reduced unit weight with better mechanical and functional properties. These include natural materials e.g. pumice [5,6] and palm oil shells [7,8] as well as synthetic or processed materials employing treatment of the parent rock (heat treatment of naturally occurring or waste materials) like expanded perlite (EP) [9–13], waste glass [14–16], volcanic ash [17,18], expanded shale [19,20], expanded polystyrene beads (EPS) [21–24], glass microspheres [25,26], and some other materials [5,8,27–31]. These materials could be successfully employed in developing LWC, however a number of issues associated with their use in cementitious composites has hindered their use as a structurally sound and viable option, which are due to low mechanical strength, porous nature, and higher water absorption of these aggregates. Some of these issues are:

1. Lower mechanical strength of the resulting concrete
2. Brittle behavior of the resulting concrete
3. Greater porosity and more air voids in the microstructure
4. Greater CO_2 emissions associated with the production aspects (mechanical and heat treatment)
5. Consumption of natural resources compromising sustainability

EP was used in an attempt to produce LWC and the resulting concretes had density in the range 1112–1756 kg/m^3 with corresponding compressive and flexural strength values of 1.77–12.21 MPa and 0.71–3.73 MPa, respectively [32]. Su et al. [33] studied the hydration heat effect of cement incorporated with EP and based on the isothermal calorimetry measurements and thermogravimetric tests, they concluded that EP delays the hydration rate in LWC. Also, expanded glass was used for producing thermal insulating LWC with density ranging from 1280 to 1490 kg/m^3, depending on the amount of LWA used, and the compressive strengths obtained were 22–31 MPa [34]. Further, Lo et al. [35] explained that the reason for the low strengths of LWC was the inferior strength properties of LWAs used in the production. Moreover, the higher porosity of LWAs was also pointed out to be one of the reasons of low strength of LWC.

The first study that particularly focused on FAC dates back to 1984 by Montgomery and Diamond [36] and since then researchers have been investigating fly ash cenospheres (FACs) to produce LWC which may potentially address the aforementioned points to a significant extent. This is so, because FACs are hollow aluminosilicate particles obtained as residue from coal fired power plants [36–39]. Along with bottom ash and fly ash, a significant proportion of residue waste consists of thin-walled and spherical particles which are relatively larger in size (10–400 μm) than fly ash [40]; termed as cenospheres. The color of FACs is greyish white and the chemical composition is almost similar to that of fly ash [41]. It is considered as a valued industrial waste byproduct because of the chemical composition [42] and as such its beneficial use promotes sustainable development.

China produced more than 600 million tons of coal fly ash in 2015 [43], double than in 2005. This clearly shows that rapid urbanization and utilization of coal for power production has drastically increased the per annum waste generation. Although fly ash has already been used as a supplementary cementing material (SCM) as a means to substitute cement in concrete, the amount used is small, leaving a great portion behind to be wasted in landfills. Utilizing FACs as LWA not only minimizes the waste to a greater degree but also the mechanical and durability related properties of the resulting composites may possibly be improved, (due to its chemical composition) with the added incentive of reduced unit weight. This may potentially enhance the functional properties such as thermal insulation, as well.

Although, much research has been done on FAC containing cement composites (FACC), but surprisingly no review papers on the subject area have been published yet. This indicates the need for a comprehensive review encompassing not only the developments to date, but also critically evaluating the properties of FACs in regard to its effects in FACC and proposing the potential future applications.

This paper reviews and critically analyzes the latest advancements in FAC utilization in cement-based composites. The properties of FAC are presented and evaluated at length while the rheological, mechanical, structural, microstructural, durability-related, time-dependent, and functional properties of FACC have