Cement and Concrete Composites 73 (2016) 105–113

Contents lists available at ScienceDirect

Cement and Concrete Composites

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

Production of mortars using novel glass-ceramic porous spherical particles with chemical composition into SiO_2-CaO-Al_2O_3-MgO quaternary system as replacement of sand aggregates

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A R T I C L E I N F O

Article history:
Received 11 August 2014
Received in revised form
4 April 2016
Accepted 11 July 2016
Available online 14 July 2016

Keywords:
Glass-ceramic
Spherical particles
Crystalline blast furnace slags
Mortars
Aggregates
Thermal conversion

A B S T R A C T

A novel production of new aggregate for mortars based on glass-ceramic porous spherical particles into SiO_2-CaO-Al_2O_3-MgO quaternary system is reported. Crystalline blast furnace slags (c-BFS) are transformed into new glass-ceramic porous spherical materials with lower density than their precursor. The conversion occurs by c-BFS projection into an oxygen/Liquefied Petroleum Gas (LPG) plume-flame. The aim of the present work is to evaluate these new materials as aggregates to replace the sand in conventional mortars formulations in order to indicate a potential way to reduce the use of this mineral resource and also how industrial wastes can be transformed in useful materials with direct application into the construction materials field. The characterization of the precursor and products were carried out by optical microscopy; scanning electron microscopy (SEM), high resolution transmission electron microscopy (HR-TEM), X-ray diffraction (XRD) and their densities were measured by Helium pycnometry. Additionally, the compressive strengths at different aging times (7, 14 and 28 days), from a control sample and diverse mortars based on glass-ceramic porous spherical particles were evaluated. Finally, thermal conductivities from all the specimens cured at 28 days were also measured.

1. Introduction

The production of new non-expensive lightweight materials that can be used in cementing systems and would help, for instance, with thermal and acoustic insulation of building infrastructures, is one of the current challenges in the area of advanced materials researches. Additionally, there are needs to generate new global applications from industrial by-products such as metallurgical slags [1–3], plastic-media-blasting and blasting residues [4], fly ash [5], iron-flakes [6] among others, in order to contribute with the environment conservation. Then, the development of a new material that contributes to simultaneously solve the above requirements would have great industrial impact over the environmental conservation and also will help diverse social areas.

It is well established that the major contributor to climate change is the increase in greenhouse gases, which cause a direct increase in the temperature of our planet. Consequently, in recent years, different countries have reported the increases of death during the last winter seasons related to extreme temperature changes and the insufficient building insulation capacities, for instance, in the specific case of rural houses. In addition, the production of advanced insulation systems with lightweight aggregates is growing and the demand of this kind of construction materials is a requirement for infrastructures such as houses, schools, roads, dams, sewers, hospitals among others, in order to improve their thermal/acoustic insulation properties based on cements and concretes [7,8]. It is important to mention that the production of these kinds of advanced materials will have a direct impact with saving energy for the smart building construction in

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http://dx.doi.org/10.1016/j.cemconcomp.2016.07.009
0958-9465/

the near future.

On the other hand, the conversion of blast furnace slags (BFS) into advanced materials has been studied in recent years, however, the uses of conventional methods generally involve melting processes which require special refractories premium molds and high temperatures that increases the cost of these processes [2,9,10]. In the same way, E. Saucedo-Salazar et al. [1] have produced spherical glass-ceramic materials from BFS by an Ar-He Plasma projection process. As a result, the produced spheres had a density decrease up to 7% or less, compared to the precursor used. The obtained spheres shown maximum diameter between 80 and 95 μm with glass-ceramic structures that have a mixture of crystalline phases such as: akermanite ($Ca_2MgSi_2O_7$), gehlenite ($Ca_2Al_2SiO_7$) and merwinite ($Ca_3MgSi_2O_8$). Thereafter, the same research group produced glass spheres from three kinds of BFS with several ages of production and using an oxygen-natural gas flame that makes more economic and feasible the technology scaling compared with the Ar-He Plasma process. The produced spherical particles shown an optimal density reduction of 16% in comparison to their BFS precursors [3]. In addition, it is known that mechanical properties of glass-ceramics are better than those for granite and marble, as construction materials; moreover, glass-ceramics also exhibit other excellent properties which are beneficial for particular applications for example, high strength, good thermal shock resistance and low expansion [9].

In a similar manner, it is well known that the reactivity of the BFS is directly influenced by the slag properties such as: glass content, chemical composition, mineralogical composition, fineness and the type of activation provided, among others. However, the glass content of slags is considered to be the most significant variable and certainly the most critical to hydraulicity [11–13]. Therefore, a structural conversion from crystalline-BFS to semi-amorphous materials (glass-ceramic) will improve the latent hydraulicity and pozzolanic properties of c-BFS that is used in the present work, giving the possibility to recover this kind of waste that has minimal industrial applications [14].

In this research, the production and characterization of glass-ceramic porous spherical particles from crystalline BFS, and the evaluation of this new material as sand substitute in mortar systems are presented. The glass-ceramic porous spherical particles show pozzolanic activity when are mixed with ordinary Portland cement (OPC). Moreover, thermal conductivity of the specimens was measured in order to relate it with their mechanical properties. The new mortars are lighter than the conventional mortars used for construction of building systems.

2. Material and methods

For the production of the glass-ceramic porous spherical particles, a commercial flame gun was used. A blend of oxygen and Liquefied Petroleum Gas (LPG) was used to form the flame-plume. The process and optimal projection parameters such as: Oxygen, Liquefied Petroleum Gas (LPG) feeding rates, and feeding distance were reported in a previous work [3]. For this research an industrial highly crystalline blast furnace slag (c-BFS) was pretreated by a mineralogical processing prior to the thermal projection process. This pretreating process includes: crushing, drying, grinding and sieving. Finally, a mixture of particles with sizes under 38 μm was selected to be used in this work.

2.1. The conversion of c-BFS into glass-ceramic porous spherical particles

As was mentioned, the projection experimental parameters are reported in a previous publication [3]. However, for this work, the production parameters were evaluated and adjusted in order to produce glass-ceramic porous spheres with high quality (e.g. porous spherical particles with lower density and more vitreous microstructures). This methodology assures the repeatability during the production process and the reliable control on the flame stability. The optimal projection parameters to obtain the highest quantity of glass-ceramic porous spheres with lower density than their c-BFS precursor are as follows: Liquefied Petroleum Gas (LPG), gas flux of 6 L/min; Oxygen gas flux = 1 L/min; feeding distance of 2 cm. The c-BFS powders feeding dosification angle (°) was studied in order to understand the influence of this new parameter on the glass-ceramic porous spheres production, four different feeding dosification angles were evaluated: 1°, 5°, 10° and 15°. Finally, the plume-flame temperature was measured for all the experiments using an infrared thermometer gun with capacity between −20 °C and 3000 °C. The constant plume-flame temperature was 2000 °C under the experimental conditions shown previously.

The Fig. 1 shows the setup of the projection system for the production of the glass-ceramic porous spherical particles. Basically, the projection system consists of (1) a commercial flame gun, with controllers for gases and nozzle water cooler system; (2) a dosificador-vibrating powders system; and (3) a cylindrical chamber for the spherical particles collection.

On the other hand, the proposed mechanism in this research for the spherical particles formation is shown in Fig. 2. (1) The precursor of small particles (under 38 μm) are semi-melted and gas formation is coming up, the plume projection from the commercial gun produces a turbulent regimen that generates the circular movement of the particles, (2) that promotes the coalescence of the smaller particles; in this way the particle viscosity is reduced and (3) spherical particles are formed for agglomeration of particles that are in semi-plastic stage, (4) simultaneously, internal bubbles are formed, increasing the spheres sizes and, if the glass viscosity reduction is enough, the bubbles superficial force is reduced, and the smaller bubbles are absorbed by the bigger ones, (5) finally, some bubbles can migrate to the surface of spherical particles; increasing the particles diameters, which can be related to the particles mass expansion and with a final superficial area increasing.

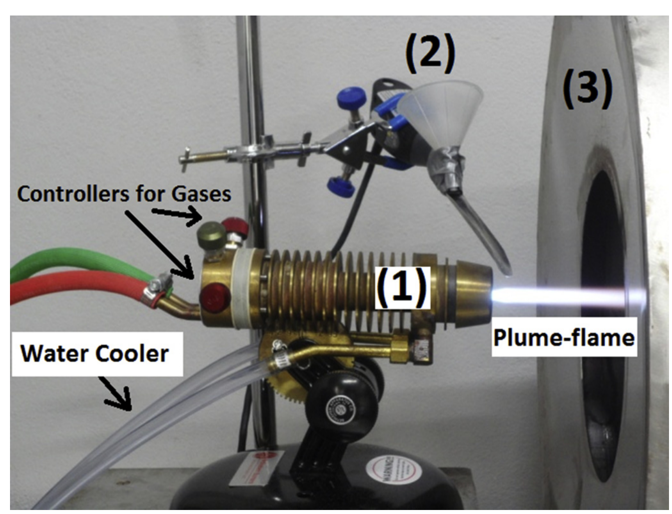

Fig. 1. Setup of the projection system for the production of the glass-ceramic porous spherical particles.