Construction and Building Materials xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Construction and Building Materials

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

Development and incorporation of lightweight waste-based geopolymer aggregates in mortar and concrete

Yliniemi [a], Paiva [b], Ferreira [b,c], Tiainen [d], Illikainen [a,*]

[a] Fiber and Particle Engineering Research Unit, P.O. Box 4300, 90014 University of Oulu, Finland
[b] Civil Engineering Dept./CICECO, University of Aveiro, 3810-193 Aveiro, Portugal
[c] Civil Engineering Dept./RISCO, University of Aveiro, 3810-193 Aveiro, Portugal
[d] Laboratory of Inorganic Chemistry, Center for Molecular Materials, P.O. Box 3000, 90014, University of Oulu, Finland

HIGHLIGHTS

- Lightweight geopolymer aggregates were manufactured from fly ash and mine tailings.
- Geopolymer aggregates have similar or better physical properties than LECAs.
- Rheology of the mortar paste is similar for LECAs and geopolymer aggregates.
- Geopolymer aggregates produced higher-strength mortars and concretes than LECAs.

ARTICLE INFO

Article history:
Received 10 June 2016
Received in revised form 23 October 2016
Accepted 3 November 2016
Available online xxxx

Keywords:
Lightweight aggregates
Rheology
Geopolymers
Mortar
Concrete

ABSTRACT

Using industrial side streams as artificial aggregate precursors could increase waste utilization and save natural reserves. In this study, lightweight geopolymer aggregates were manufactured from fluidized bed combustion fly ash and mine tailings using high shear granulation and alkali activation. The results showed that geopolymer aggregates had physical properties comparable to commercial lightweight expanded clay aggregates (LECAs). Mortar and concrete prepared with geopolymer aggregates had higher mechanical strength, a higher dynamic modulus of elasticity, and higher density than concrete produced with LECAs, while the rheology and workability was the same.

1. Introduction

The usage of lightweight aggregates (LWAs) in concrete is steadily increasing, as some of their properties, including reduced dead weight, higher insulating coefficients, and superior sound-dampening qualities, are better than those of normal-weight aggregates [1].

Natural LWAs, such as pumice, scoria, and tuff, have long been used as concrete aggregates [2]. However, with the increasing demand and non-availability of natural LWAs, methods for producing artificial LWAs have been developed. The most common artificial LWAs are lightweight expanded clay aggregates (LECAs), which are produced by expanding natural clay at about 1200 °C in rotary kilns. To save natural raw materials, prevent damaging mining activities, and increase waste utilization, there has been a great deal of research on manufacturing artificial LWAs from industrial side streams. The most common methods for producing artificial LWAs from industrial waste are high-temperature sintering [3–7] and cement-based pelletization [8–12]. Another much less studied method is the granulation of wastes using alkali activators [13–15]. This method (i.e., geopolymerization) is economically sound, as it avoids the high costs of sintering and using cement. During the granulation, the surfaces of the precursor particles are wetted by the alkali activator. The reactive material dissolves and forms an alumino-silicate gel, which binds the particles together. The process results in spherical granules and surface dry granules.

Previous studies [15–17] have shown that geopolymer LWAs with satisfactory physical properties can be produced, even from low-reactivity and heavy metals containing fly ash. However, it is not clear how such aggregates perform in real mortar and concrete. As geopolymer aggregates may have different densities and levels of water absorption, the rheology (i.e., workability) of the cement mixture may change depending on the aggregates used. The intrin-

* Corresponding author.
E-mail address: mirja.illikainen@oulu.fi (Illikainen).

http://dx.doi.org/10.1016/j.conbuildmat.2016.11.017
0950-0618/

sic properties of LWAs also affect the properties of hardened mortar and concrete, such as their mechanical strength and capillarity.

Artificial LWAs are produced from mine tailings and fly ash using alkali activation and high shear granulation. The physical and mechanical properties of geopolymer aggregates are compared with commercial LECAs. Mortars and concretes are produced with LECAs and geopolymer aggregates and the rheology, mechanical strength, dynamic modulus of elasticity, capillarity, and density are determined. The aim of the research is to evaluate the performance of geopolymer aggregates in mortars and concretes.

2. Materials and methods

2.1. Materials

Two fluidized bed combustion (FBC) fly ashes and two mine tailings were chosen as geopolymer aggregate precursors. Fly ash 1 and fly ash 2 came from an electricity and heat power plant that uses wood and peat as fuel. Mine tailing 1 was obtained from a gold mine, and mine tailing 2 was obtained from a copper and zinc mine. The chemical composition of the raw materials is presented in Table 1.

The raw materials were granulated using a high-shear granulator (Eirich R01) and a sodium silicate solution as an alkali activator. The geopolymerization process is explained in detail in [15]. In brief, the process was as follows: (1) dry raw materials were weighed, mixed, and added to the drum; (2) the impeller and drum were switched on, and approximately 15 g of sodium silicate solution was added to prevent dusting; and (3) sodium silicate was added by the drop until the desired aggregate size (2–10 mm in diameter) was achieved. Each geopolymer aggregate batch was sealed in airtight plastic bags and stored in ambient conditions for 28 days. The sodium silicate solution used for granulation was Zeopol® 25 (Huber), which has a SiO_2/Na_2O-molar ratio of 2.5 and a water content of approximately 66 wt%.

The particle density and water absorption of the aggregates were determined according to the EN 1097-6 standard [18]. The loose bulk density and voids were determined according to the EN 1097-3 standard [19]. The particle size distribution was determined according to the EN 933-1 standard [20].

As reference materials, two sizes of LECAs were used. The LECA filler had a particle size distribution of 0–3 mm, and LECAs 4–12.5 had a particle size distribution of 4–12.5 mm. For all mortar and concrete samples, CEM II/B-L 32.5 N cement was used. Siliceous sand was used as an additional aggregate in the mortar and concrete.

2.2. Preparation of mortars and concretes

Mortar and concrete samples were prepared by adding water, then cement and sand, and then mixing them in a mixer for three minutes. The aggregates and extra water (the water absorption

Table 1
Chemical composition, loss on ignition, and average particle size of the geopolymer aggregate raw materials.

	Fly ash 1	Fly ash 2	Mine tailing 1	Mine tailing 2
CaO, XRF (%)	16.2	13.8	11.7	10.9
SiO_2, XRF (%)	42.4	40.2	49.8	25.3
Al_2O_3, XRF (%)	9.4	10.1	10.7	7.0
Fe_2O_3, XRF (%)	14.8	22.3	9.1	25.7
Na_2O, XRF (%)	1.7	1.3	3.1	–
K_2O, XRF (%)	3.6	2.5	1.3	0.8
MgO, XRF (%)	3.7	2.8	6.7	6.6
P_2O_5, XRF (%)	3.7	3.3	0.2	0.1
TiO_2, XRF (%)	0.3	0.3	1.3	0.4
SO_3, XRF (%)	3.2	2.4	4	13.6
Cl, XRF (%)	0.2	0.1	0	0.0
Moisture (%)	0.1	0	0.2	0.3
Loss on ignition 525 °C (%)	0.1	0.1	0.2	1.6
Loss on ignition 950 °C (%)	1.0	0.5	13.6	8.8
Particle median size <50% (μm)	14.7	20.7	130.4	126.1

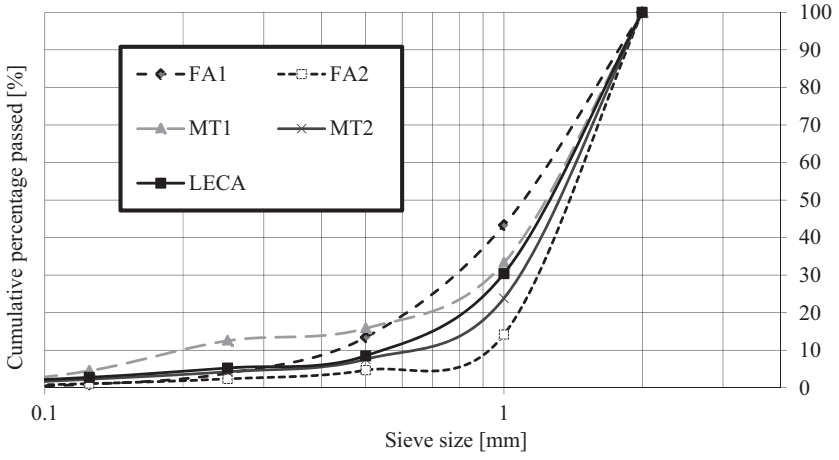

Fig. 1. Aggregate size distributions for the mortar samples. FA: fly ash geopolymer aggregates; MT: mine tailing geopolymer aggregates.

Please cite this article in press as: Yliniemi et al., Development and incorporation of lightweight waste-based geopolymer aggregates in mortar and concrete, Constr. Build. Mater. (2016), http://dx.doi.org/10.1016/j.conbuildmat.2016.11.017