HBRC Journal (2016) 12, 13–24

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

A novel method to produce dry geopolymer cement powder

H.A. Abdel-Gawwad [a,*], S.A. Abo-El-Enein [b]

[a] Housing and Building National Research Center, Giza, Egypt
[b] Faculty of Science, Ain Shams University, Cairo, Egypt

Received 20 March 2014; revised 2 June 2014; accepted 11 June 2014

KEYWORDS

Geopolymer cement powder;
Dry activator;
Granulated blast-furnace slag;
Calcite

Abstract Geopolymer cement is the result of reaction of two materials containing aluminosilicate and concentrated alkaline solution to produce an inorganic polymer binder. The alkali solutions are corrosive and often viscous solutions which are not user friendly, and would be difficult to use for bulk production. This work aims to produce one-mix geopolymer mixed water that could be an alternative to Portland cement by blending with dry activator. Sodium hydroxide (SH) was dissolved in water and added to calcium carbonate (CC) then dried at 80 °C for 8 h followed by pulverization to a fixed particle size to produce the dry activator consisting of calcium hydroxide (CH), sodium carbonate (SC) and pirssonite (P). This increases their commercial availability. The dry activator was blended with granulated blast-furnace slag (GBFS) to produce geopolymer cement powder and by addition of water; the geopolymerization process is started. The effect of W/C and SH/CC ratio on the physico-mechanical properties of slag pastes was studied. The results showed that the optimum percent of activator and CC content is 4% SH and 5% CC, by the weight of slag, which give the highest physico-mechanical properties of GBFS. The characterization of the activated slag pastes was carried out using TGA, DTG, IR spectroscopy and SEM techniques.

Introduction

Later in 1972, Joseph Davidovits coined the name "geopolymers" [1] to describe the zeolite like polymers. Geopolymers are the alumino-silicate polymers which consist of amorphous and three dimensional structures formed from the geopolymerization of alumino-silicate monomers in alkaline solution [2]. Investigations have been carried out on calcined clays (e.g., metakaolin [3–9]) or industrial wastes (e.g., fly ash [10–14] or metallurgical slag [15,16]).

Geopolymerization is a complex process and until now it is not fully understood [17]. A reaction pathway involving the

* Corresponding author. Tel.: +20 1004540743.
E-mail address: hamdyabdelgawwad@yahoo.com (H.A. Abdel-Gawwad).
Peer review under responsibility of Housing and Building National Research Center.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.hbrcj.2014.06.008
1687-4048

polycondensation of orthosialiate ions (hypothetical monomer) is proposed by Davidovits [18].

According to researchers [1,19,20], three steps are suggested in the geopolymerization process: (1) dissolution in alkaline solution; (2) reorganization and diffusion of dissolved ions with formation of small coagulated structures and (3) polycondensation of soluble species to form hydrated products. Geopolymers are well-known of their excellent properties compared to ordinary Portland cement (OPC), which are high compressive strength [21–25], low shrinkage [21,23], acid resistance [21,26], fire resistance and no toxic fumes emission [24], low thermal conductivity [21,22], excellent heavy metal immobilization [17], high temperature stability [17], low manufacturing energy consumption for construction purposes and engineering application [21], etc. They are potentially found as being used in construction engineering [17], fire proof [27], biomaterials [17], and waste treatment [17], etc. New applications are still being discovered. The geopolymerization process differs from the OPC which manufacturing involves the calcination of limestone at a high temperature with excess energy consumption and emits large amount of green house gas into the atmosphere. The production of 1 ton of OPC releases approximately 1 ton of CO_2 [28]. Thus, an alternative material was found with less energy consumption, less carbon dioxide (CO_2) emission and added with good physic-mechanical properties to solve the problem arised from OPC production. Now, it is accepted that geopolymers have emerged as an alternative to OPC.

Blended geopolymer came out by the sense to improve the porosity as well as the strength and other properties. The addition of moderate amount of calcium carbonate to a geopolymer has significant improvements on the geopolymer structure and properties [29,30].

This work aims to prepare cement powder by blending dry activator with granulated blast-furnace slag (GBFS). Formerly, geopolymer mortars and concretes were directly formed by the reaction of alumino-silicates sources with alkaline solution. Here, the alkali activator in the form of dry powder is blended with GBFS to produce blended cement powder. Sodium hydroxide (SH) reacts with calcium carbonate (CC) to produce dry activator composed of calcium hydroxide (CH), sodium carbonate (SC) and pirssonite: sodium calcium carbonate (P) according to the following equations:

$$2NaOH\,(aq.) + CaCO_3 \rightarrow Na_2CO_3 + Ca(OH)_2 \quad (1)$$

$$Na_2CO_3 + CaCO_3 + 2H_2O \rightarrow Na_2Ca(CO_3)_2 \cdot 2H_2O\,(Pirssonite)) \quad (2)$$

The amount of CH, SC and P increases with the concentration of SH and consumption of CC.

There are two reasons to utilize calcium carbonate in the production of dry activator. Firstly, sodium hydroxide reacts with calcium carbonate to produce calcium hydroxide and sodium carbonate and pirssonite Eqs. (1) and (2) and secondly, the remaining calcium carbonate from the reaction acts as a filler material which decreases porosity and increases the compressive strength of activated slag [29,30].

This process was investigated in this work to produce blended cement powder. The important parameters involved in the blended cement powder are SH concentration, SH:CC ratio, and (W/C) ratio. This blended cement powder, if succeeded, could be an alternative to OPC which can be used to produce mortar and concrete by addition of small amounts of water.

Experimental

Materials

Granulated blast-furnace slag (GBFS) was purchased from Helwan Steel Company, Egypt. Calcium carbonate was obtained from Arabic Chemical Company. Sodium hydroxide (SH) powder of 99% purity was obtained from Fisher Scientific Company.

The chemical composition of granulated blast furnace slag and calcium carbonate as determined by X-ray Fluorescence (XRF) is seen in Table 1. Fig. 1a and b shows the mineralogical composition of GBFS and CC. Particle size analysis of dry activator (DA) and GBFS using a Coulter LS130 optical size analyzer is shown in Fig. 2.

Blended cement powder synthesis

The Granulated blast furnace slag (GBFS) was first passed through a magnet to remove any contamination of iron and then ground in a steel ball mill. Alkali activator (SH) solution was mixed with calcium carbonate (CC^-) powder and dried in an oven at 80 °C for 8 h then followed by pulverization to a fixed particle size to produce the dry activator powder. The activator was blended with GBFS. The details of mix proportions of blended cement powders are shown in Table 2.

Preparation of cement pastes

Each blended cement powder was placed on smooth, non absorbent surface, a crater was formed in the centre and water was poured into the crater. The dry mixture was slightly toweled over the remaining mixture to absorb the water for about one minute. The mixing operation was then completed by continuous and vigorous mixing by means of an ordinary gauging trowel for about three minutes. The paste was placed in one cubic inch moulds and manually pressed strongly at the corner along the surface of the mould. After compaction of the top layer, the surface of the paste was smoothed by a thin edged trowel. The hardened slag pastes were cured in 100% relative humidity at 37 ± 2 °C up to 28 days.

Characterization methods

Compressive strength

This test was carried out on four specimens according to ASTM C109 M [31]; the surface of the specimens was carefully polished on fine paper in order to remove irregularities. To help transmit the load to the specimen's faces uniformly pieces of cardboard 2 mm in thickness were placed on both faces. Compressive strength measurements were carried out using a five tonne German Brüf Pressing Machine with a loading rate of 100 kg/min.

Water absorption

The water absorption measurements, ASTM C1403-13 [32], were done by weighing the saturated specimens (W1) and dried