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Application of thermal treatment on cement kiln dust and feldspar to create one-part geopolymer cement

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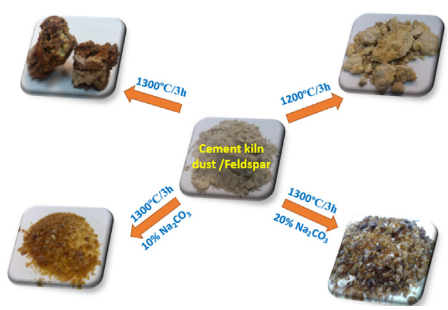
HIGHLIGHTS

- One-part geopolymer was prepared by thermal treatment of cement kiln dust/feldspar.
- Amorphous content increased with soda ash content.
- The temperature and treatment duration strongly affect the performance of geopolymer.
- One-part geopolymer cement can easily reacts with water like Portland cement.
- The optimum one-part geopolymer demonstrated strength of 52 MPa at 28-days of curing.

GRAPHICAL ABSTRACT



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ABSTRACT

The objective of this work is to prepare one-part geopolymer (OPG) cement using thermal activation of cement kiln dust (CKD) and feldspar (FS). A homogeneous CKD/FS dry-blend, at weight ratio of 60/40, was exposed to elevated temperature in the presence of soda ash (Na_2CO_3), yielding smelted glassy material. Rapid air cooling was conducted on the transformed material, followed by grinding to produce OPG-powder. Three main parameters including vitrification temperature (1200 and 1300 °C), heat treatment duration (2 h and 3 h), and Na_2CO_3 content (10 and 20 wt%), were examined. A partial transformation to amorphous structure was recorded after the exposure of CKD/FS to 1200 and 1300 °C for 2 h heat treatment duration (in the absence of Na_2CO_3). With the increase of treatment time (3 h at 1300 °C), the sintering of mineral was occurred, leading to the increase in their crystallinity. Thermal treatment in the presence of Na_2CO_3 has a potential impact on the transformation of CKD/FS to vitreous structure as confirmed by X-ray diffraction (XRD). Where, the use of 20 wt% Na_2CO_3 leads to produce glassy material, with 100% amorphous content, which can reacts with water to form binding material with 28-days compressive strength of 52 MPa.

1. Introduction

Cement production is increasing year-by year; where, its capacity was reached to 4100 million metric tonnes in 2017 all over of the world [1]. Cement manufacturing generates 5–7% of the total anthropogenic CO_2 [2]. Cement kiln dust (CKD) is a fine powder by-product generated from cement industry. Due to its high chemical activity [3], CKD regarded as one of the most dangerous pollutants for environment as well as human health [4]. The properties of CKD vary considerably depending on the composition of feeding materials of cement manufacturing [5]. Generally, CKD is mainly

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Table 1
Chemical compositions of the starting materials used.

Components		SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	SO_3	Cl	Na_2O	K_2O	Loss
CKD	Mass fractions	7.31	52.89	0.63	3.31	2.36	14.41	5.45	0.95	5.22	7.27
FS		72.31	1.95	0.32	0.90	14.189	0.18	0.15	3.08	4.92	1.68
NC		–	–	–	––	––	––	–	61.78	0.12	37.59

composed of partially calcined clinker and condensed volatile alkalis (Na_2O, K_2O) [6].

In order to decrease the harmful impact of CKD, several researchers were used CKD as a partial cement and concrete replacement [6–10]. Because of higher alkalinity of CKD, it was beneficially used as stabilizing agent for wastes [11–13] and it can be beneficially used in acidic water treatment [14]. It also used as an alternative activator for aluminosilicate materials such as fly ash (FA), granulated slag (GBFS) and meta-kaolin (MK) [15–18]. The re-use of CKD in cement industry and in building products have been previously conducted [19–22].

The present work aims at synthesizing one-part geopolymer (OPG) by thermochemical activation of CKD/FS blend. 60 wt% of CKD was dry mixed with 40 wt% feldspar (FS) in the presence of soda ash, as a commercial source of sodium oxide, followed by cooling and grinding to produce OPG which can react with water like Portland cement. Temperature, heat treatment duration, and soda ash content as the main parameters, were studied to reach the optimum OPG which gives the highest performance when mixed with water.

2. Experimental

The materials used in this investigation are cement kiln dust (CKD), feldspar (FS) and soda ash (Na_2CO_3: NC). CKD was supplied from Beni-Swief Cement Company, Egypt, FS was obtained from El-Wahat road, Giza, Egypt and NC was purchased from El-Gomhoraya Chemical Company, Egypt. The chemical compositions of the staring materials which analyzed by X-ray fluorescence spectrometer (Xios, PW1400) are listed in Table 1. The X-ray diffractogram (XRD) proved that FS is mainly composed of albite, microcline and quartz. The XRD-pattern of CKD exhibits different crystalline peaks related to quartz, lime, calcite and portlandite (Fig. 1).

The preparation of one-part geopolymer (OPG) was done by weighing 50 gm of homogeneous CKD/FS blend at weight ratio of 60/40 in platinum crucible followed by exposure to elevated temperatures (1200 and 1300 °C) for different heat treatment durations (2 h and 3 h) in the presence of different NC contents (0, 10 and 20% with respect to the weight of FS and CKD powder). The resulting smelted materials were immediately cooled by rapid air, followed by grinding to pass from 50 μm sieve. The process steps of OPG is shown in Fig. 2 as well as the detail of mixes composition and verification conditions are given in Table 2.

The fresh geopolymer paste was prepared by mixing OPG-powder with water (W) at W/OPG ratio of 0.29, then mixed for 5-min to achieve complete homogeneity. Untreated CKD/FS powder was activated by 20 wt% NC, as two-part geopolymer: TPG, for comparison purpose. The workable paste was transferred to stainless steel mold with dimensions of 2 × 2 × 2 cubic inch, then cured in 99 ± 1 relative humidity at 23 ± 2 °C. After 24 h, the hardened OPG-pastes were demolded and cured at the same conditions until the time of compressive strength testing reaches such as 3, 7 and 28-days. According to ASTM C109M [23], the compressive strength was carried out on three hardened OPC- specimens using five tons German-Bruf-Pressing Machine with a loading rate of 100 kg/min.

The amorphous content of thermally-activated CKD/FS was determined using XRD. Fourier transform infrared (FTIR) spectroscopy and thermogravimetric analysis (TGA) were conducted on the hardened pastes to assess the hydration reactivity of untreated and treated CKD/FS blend. The microstructure of the OPG-powder and its hardened paste was investigated by scanning electron microscopy (SEM). XRD was carried out using Philips PW3050/60 diffractometer using a scanning range of 5 to 50

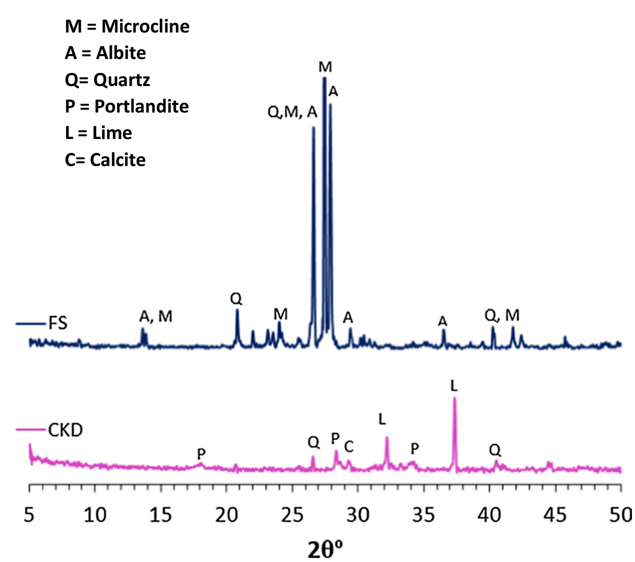

Fig. 1. XRD-patterns of feldspar (FS) and Cement kiln dust (CKD).

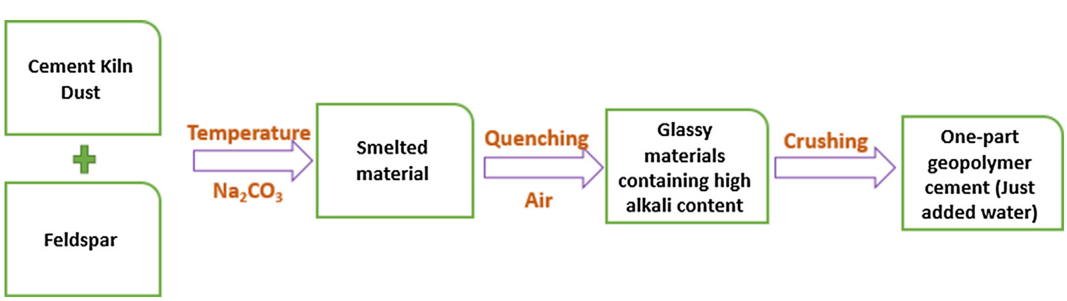

Fig. 2. Process steps of one-part geopolymer production.