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Recycling and utilization assessment of waste fired clay bricks (Grog) with granulated blast-furnace slag for geopolymer production

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ABSTRACT

In the present study, the alkali-activation process potential of the industrial by-product called waste fired clay bricks (Grog) as well as the effects of the addition of another industrial by-product known as granulated blast-furnace slag (S) on the properties of the final products has been studied. Granulated blast-furnace slag has been employed as 20%, 40%, 60% and 80% replacement of waste fired clay bricks (Grog) in the production of geopolymers. At the same time, the effects of curing time on the properties of geopolymers were investigated. The study proved a successful method for the feasibility of recycling and valorization process of two industrial by-products and converts them into valuable geopolymer products. These potential recycling processes can generate significant benefits for environmental sector and many economic impacts to the construction materials sector by using it as alternative raw material resources for the production of the geopolymer.

1. Introduction

Brick is one of the most common masonry units as a building material due to its properties as construction material. Conventional bricks are produced from raw materials mixture of clay, as a plastic material, with the addition of sand, as non-plastic material, and burned in the kiln at firing temperature ranging from 850 to 950 °C. The worldwide annual production of bricks is currently about 1391 billion units and the demand for bricks are expected to be continuously rising as the construction process increasing over the worldwide (Zhang, 2013).

Waste fired clay bricks (Grog) is a solid waste material produced during the manufacturing process of clay bricks. These crushed portions of grog are not of commercial use and considered as a solid waste material which caused many serious environmental problems. In Egypt, a huge amount of clay bricks is produced every year and used in construction activities. The amount of waste fired clay bricks (Grog) generated by the Egyptian clay bricks industry sector is about 3–7% by weight of total production, suggesting that millions of tons of such waste materials are generated and disposed in huge landfills in Egyptian brick factories each year (Farag et al., 2011). Recycling and valorization process of a lot of industrial by-product and waste materials have become a problem urgently facing our future for environmental protection trends. In the light of environmental standards aiming at limiting the use of the dump, the creation of new techniques for recycling as well as wastes valorization process capable also of exploiting the industrial wastes into new valuable products acquires an increasing importance for the industrial and environmental sectors (Abdul Kadir and Mohajerani, 2011).

Many attempts have been made to incorporate waste fired clay bricks (Grog) into the production process of different building materials. Recycling process for such industrial wastes by including them into many building materials is considered as a practical solution for many pollution problems. The utilization of these wastes will lead to reducing many environmental problems due to their disposal. However, the waste materials can only be recycled if the properties and the environmental behavior of the newly formed products comply with the specific requirements and interrogated with the relevant environmental standards (Abdul Kadir and Mohajerani, 2011).

Ground granulated blast-furnace slag (S or slag), is a waste material generated from the iron blast furnace and subsequently quenched, and

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its composition is essentially that of an overcharge balanced calcium alumino-silicate framework. Sometimes added to geopolymer systems, it is well known to increase compressive strength and enhance strength development at ambient temperatures (Davidovits and Sawyer, 1985).

The use and assessment of many materials contain aluminosilicate mineral such as metakaolin, ground granulated blast-furnace slag and types of fly ash as potential raw materials for the production of geopolymer have been extensively investigated and reported (Pacheco-Torgal et al., 2008; Bernal et al., 2012; Puertas and Fernández-Jiménez, 2003; Lampris et al., 2009) and there is increasing interest in investigating the suitability of using other materials. Geopolymer technology is considered to be a relatively new technique, suitable for waste disposal process and for the full stabilization of substances that would otherwise cause much more environmental pollution. It is noted that researchers have been studied many different industrial by-product wastes containing silica and alumina, such as red mud (Hajjaji et al., 2013), rice husk ash (He et al., 2013), coal ashes (Papa et al., 2014), glass residue waste (Kourti et al., 2010), blast furnace slag (Hu et al., 2008), and fly ash and blast furnace slag (Nath and Kumar, 2013), construction and demolition wastes (Komnitsas et al., 2015) and ceramic waste materials (Reig et al., 2013a,b). The results indicate that many of these industrial by-product wastes are promising materials for the synthesis of geopolymers.

Reig et al. (2013a,b) aimed to optimize the alkali-activation process of waste fired clay bricks by investigating the effects of different parameters on the mechanical strength and microstructure of produced geopolymers. Puertas et al. (2006) investigated the alkali-activation process of ceramic waste materials by using sodium hydroxide and sodium silicate solution. Although the achieved compressive strengths were ranging between 7 and 13 MPa, it was concluded that further investigations were required to understand the influence of different parameters of the alkali-activation process on the final properties of the binders formed.

Geopolymerization is a technology that relies on the chemical reaction of amorphous silica and alumina rich solid materials with a high alkaline solution at ambient or slightly elevated temperatures to develop a new form of inorganic polymer or geopolymer which considered as amorphous to a semi-crystalline aluminosilicate material. Geopolymer is a three-dimensional silicon aluminate structure consisting of linked SiO_4 and AlO_4 tetrahedra by sharing all the oxygen atoms (Davidovits, 1988, 1991, 1994; Duxson et al., 2007; Majidi, 2009; Shi et al., 2006; Dimas et al., 2009; He et al., 2012). Due to the sound properties as well as significant environmental benefits of geopolymer products, geopolymer technology has been drawing great interest (Andini et al., 2008; Chindaprasirt et al., 2009; Somna et al., 2011). Geopolymer not only provides performance comparable to ordinary Portland cement in many applications but has additional advantages, including abundant of raw material resources, a rapid hardening, high mechanical strength, excellent durability due to chemical attack resistance, contaminants immobilization and significantly reduction in energy consumed and greenhouse gas emissions. These characteristics and advantages have made geopolymer of great research interest as a new ideal material for sustainable development (Zhang, 2013). Komnitsas and Zaharaki (2007) studied, geopolymers can generally deliver a great reduction in CO_2 emission and require less energy compared with ordinary Portland cement products. Thus, geopolymers can be regarded as a 'green concrete' (Sumajouw et al., 2007).

The present work is aimed at assessment and utilization of some industrial by-product wastes as source based material for geopolymer production that could be used for construction or restoration purposes. In this study, waste fired clay bricks (Grog) was creatively introduced to recycling and valorization process and we discuss its suitability for geopolymerization synthesis process in associated with a different percentage of ground granulated blast-furnace slag (S). The starting materials of industrially by-products waste involved in this study were characterized by different techniques. Moreover, the geopolymer products were characterized to determine the physico-mechanical properties; X-ray diffraction analysis (XRD); Fourier transform infrared spectroscopy (FTIR) analyses and scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy (EDX). Results obtained in this study will enrich the studies of geopolymer chemistry properties and provide a promising alternative way to reutilize industrially by-products waste economically and environmentally.

Table 1 – Chemical composition of starting materials, wt.%.

Oxides	Content (wt.%)	
	Waste fired clay bricks (G)	Ground granulated blast-furnace slag (S)
SiO_2	50.16	26.15
Al_2O_3	15.95	7.43
Fe_2O_3	15.09	1.31
CaO	4.39	44.38
Na_2O	2.43	0.75
K_2O	1.48	0.53
TiO_2	2.10	0.98
MnO	0.16	5.25
MgO	2.13	5.52
SO_3	2.78	2.90
BaO	0.06	4.72
P_2O_5	0.24	0.03
Cl	0.46	0.00
LOI[a]	2.10	0.00

[a] LOI, loss on ignition at 950 °C.

2. Experimental procedure

2.1. Materials and methods

The waste fired clay bricks (G) used in this study were derived from Misr-Brick Company located in Helwan province, Egypt. Water cooled granulated blast-furnace slag was sourced from iron and steel factory located in Helwan province, Egypt. Fig. 1 shows some photos for the starting materials which caused huge environmentally problems in their factories and area surrounded. Due to the large volume of wastes and the limitation of available landfill space, the disposal and utilization process of such wastes is an important issue.

The starting materials were prepared by crushing and pulverization process in a ball mill for 30 min and for particle size screening, measured on a Mastersizer 2000 laser analyzer (Malvern, UK). Fig. 2 shows the particle size distribution of starting materials, the average particle size (d_{50}) of milled waste fired clay bricks (G) and granulated blast-furnace slag (S) powders are 1100 and 2300 nm, respectively. The specific gravity of waste fired clay bricks and granulated blast-furnace slag were 0.6695 and 2.67 respectively. The specific surface area of starting raw materials measured by BET technique using (Micromeritics, ASAP2020), were 5.19 and 1.75 m^2/g with average particles size based on BET calculation 1155.90 and 3386.06 nm respectively, as shown in Fig. 3. The main oxide compositions of starting raw materials chemically analyzed by XRF technique were reported in Table 1. The mineral composition phases of starting raw materials were identified by XRD technique using (Panalytical X'pert pro) diffractometer with Ni filter, Cu K_α radiation at a scan speed of 0.5 min^{-1}. FTIR spectra of starting raw materials were acquired using a JASCO FT/IR-6100. The IR spectra were recorded between 400 and 4000 cm^{-1} with a resolution of 4 cm^{-1} at room temperature.

For preparing geopolymer formulations, appropriate amounts of starting raw materials in predetermined proportions, as shown in Table 2, were taken and ball