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Utilization of waste glass to enhance physical–mechanical properties of fired clay brick

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ABSTRACT

The aim of this study was to investigate the enhancement of physical–mechanical properties of fired clay brick by incorporating waste glass in order to reduce the firing temperature. The ground waste glass was incorporated to the clay body at the dosages of 0, 5 and 10% by weight. Three temperatures viz., 900, 950 and 1000 °C were used for firing. Compressive strength, water absorption, density, and porosity of the fired clay bricks were tested. The study showed that the incorporation of up to 10 wt.% of waste glass to clay bricks and fired at the temperatures of 900–1000 °C enhanced the properties of fired clay bricks. The SEM micrographs showed the increased glass phase and reduced porosity with waste glass addition. The use of 10 wt.% waste glass and firing at 900 °C yielded bricks with similar strength compared to that of normal clay brick fired at 1000 °C. This allowed the use of low firing temperature of 900 °C instead of the normally used 1000 °C. The study also revealed that in addition to the glass phase fused-bond with the clay brick bodies, the fusion of crystalline quartz in clay also played an important role in enhancing the properties of clay bricks. As a conclusion, waste glass can be utilized in making brick to enhance the physical–mechanical properties of the fired clay brick or to lower the firing temperature.

1. Introduction

Fired clay bricks are construction materials which have been used since ancient times and currently display different states of deterioration in numerous historic buildings (Cultrone et al., 2005). Nowadays, bricks are still being used for the same purpose (Karaman et al., 2006). However, the higher quality fired brick is essential for modern construction. Bricks have been designed to become more homogenous and porous, harder and stronger due to the ceramic bond from the fusion phase of silica and alumina constituents in clay (Adeola, 1977). The firing process sinters the particles of clay together to form a bond which gives the bricks its characteristic strength and durability (Phonphuak and Chindaprasirt, 2014). The sintering process is achieved by heating silicon dioxide or quartz (SiO_2) which occurs naturally in clay and shale to high temperatures, causing it to melt. Upon cooling, the quartz forms a bond between adjacent clay or shale particles at the points of contact.

The brick production is an energy intensive process. The average specific energy consumption for fired clay brick in the United Kingdom was reported at 706 kWh/ton of brick (Industrial Energy Efficiency Accelerator, 2015). Owing to the high energy demands of the sintering process, additives called fluxes are often used to lower the temperature required to form the glassy phase bond. The brick industry can easily accommodate by-product materials because the making of brick is relatively uncomplicated (Turgut, 2012). Common additive is a soda-lime-silica glass (SiO_2–Na_2O–CaO) (Grimshaw, 1971). In fact, soda-lime-glass is a vitreous silicate generated during the maturation of clay bodies. The reducing clay body maturation temperature is a strong indication that the addition of soda-lime-glass to clay body could increase the efficiency of firing and is thus a value-added application for recycled glass fines (Mustafi et al., 2011).

One waste material which has potential as a brick additive is waste glass (soda-lime glass). In European Union, approximately 9 million ton of waste glass was collected in 2010 (Eurostat Statistics Explained, 2010). As a brick additive, glass acts as a flux owing to its

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sodium oxide (Na_2O) content and its noncrystalline composition, thus lowering the temperature required for sintering bricks. In addition, the increased glassy phase in the finished brick has the potential for improvement in both structural and durability properties, while reducing manufacturing costs (Chidiac and Federico, 2007). A number of researchers have investigated the use of waste glass particularly in ceramic industry. Example includes waste glass incorporated as an alternative ceramic raw material or as a fluxing agent in cement and/or concrete, stoneware tile and brick (Shao et al., 2000; Shayan and Xu, 2004; Hwang et al., 2006). As an additive, waste glass, when incorporated into a mixture, could induce the vitrification in clay bricks, resulting in higher density, less water absorption, and lower drying shrinkage (Loryuenyong et al., 2009). However, there is still a need to relate the effect of waste glass on strength, porosity and firing shrinkage characteristics of fired clay brick. In this research, the effects due to the use of waste glass were investigated in laboratory and the firing behavior, physical–mechanical properties and microstructure were discussed.

2. Materials and methods

2.1. Preparation of the test specimens

The clay used in this study was typical clay from a well known local area for making bricks. Chemical analyses of clay and waste glass (soda-lime glass) were carried out using X-ray fluorescence technical (Horiba Mesa-500 w). The chemical composition of raw materials is given in Table 1. The waste glass was first crushed for 1 h using a ball mill. The particle-size distribution test was carried out for waste glass using sieve size analysis. The results of the particle size analysis are shown in Fig. 1. The mineralogical composition of clay and waste glass were achieved using an X-ray diffractometer technique (XRD: X'Pert PRO MPD, Philips, Netherlands). The major crystalline phases found in clay were quartz, muscovite and rutile (Fig. 2) and waste glass contained only glassy phase (Fig. 3).

2.2. Specimen preparation

In order to compare the clay brick (0% waste glass) and bricks made of clay and glass (5% and 10% waste glass), each batch of specimens was mixed in a porcelain ball mill to ensure homogenous mixing. In normal brick production, however, normal mixing would be sufficient to save time and cost. Then, 20–25% of water was added and mixed to obtain plastic condition of mixture. Soft-mud rectangular clay bricks with dimension of 140 mm × 65 mm × 40 mm were formed using brick hand molding. The clay brick specimens were air-dried at room temperature (25–30 °C) for 24 h, and then over dried at 110 ± 5 °C for another 24 h to remove water content. The green specimens were fired at three temperatures viz., 900, 950 and 1000 °C. The time taken to reach the required temperature was 8 h and the specimens were kept at this temperature for 1 h.

Table 1
Chemical compositions of raw materials.

Composition	Clay (wt.%)	Waste glass (wt.%)
SiO_2	58.76	68.70
Al_2O_3	21.34	21.34
MgO	–	2.45
CaO	0.21	9.86
Fe_2O_3	5.10	0.65
MnO	1.18	–
TiO_2	0.93	0.12
Na_2O	–	13.67
K_2O	3.10	1.00
LOI	8.74	–

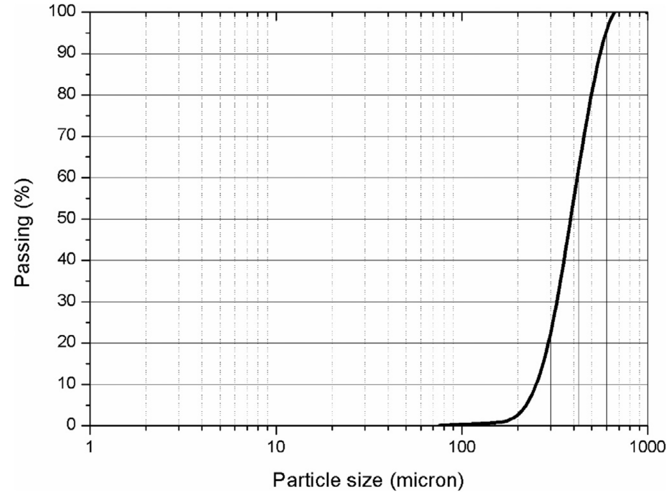

Fig. 1. Particle size analysis of waste glass.

2.3. Testing method for the physical and mechanical properties of specimens

Shrinkage was determined by direct measurement of specimen length before and after firing. The linear drying shrinkage and total linear shrinkage were measured and compared to the length before shrinkage in accordance with the standard of ASTM C326-09 (2014). Archimedes method based on ASTM C373-14a (2014) was used to determine the water absorption, bulk density, apparent density and apparent porosity. The compressive strengths of specimens were measured in accordance with ASTM C773-88 (2011). The reported results of all tests were the average of 10 samples.

3. Results and discussion

The bricks in this research were manufactured from clay and waste glass by controlling the optimum sintering temperatures and ratio. The properties of fired clay bricks are shown in Fig. 4(a)–(d).

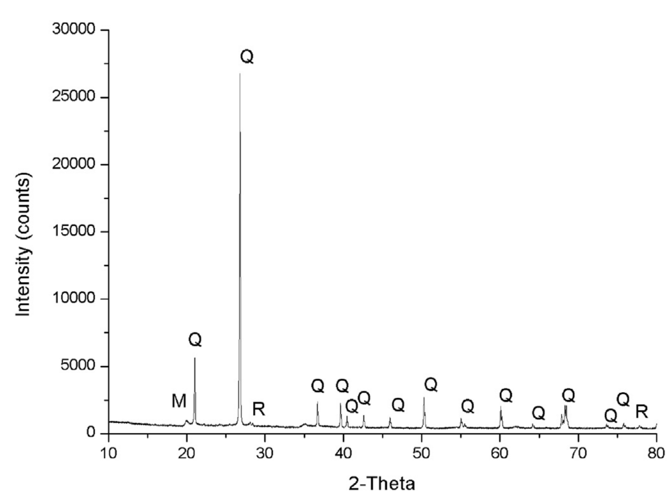

Fig. 2. XRD pattern of clay material (Q = quartz, M = muscovite, R = rutile).