Ceramics International 44 (2018) 7588–7598

Contents lists available at ScienceDirect

Ceramics International

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

Characteristics of heat insulating clay bricks made from zeolite, waste steel slag and expanded perlite

Pedram Farnood Ahmadi[a], Abdollah Ardeshir[a,*], Amir Mohammad Ramezanianpour[b], Hamid Bayat[a]

[a] Department of Civil and Environmental Engineering, Amirkabir University of Technology (Tehran Polytechnic), 424 Hafez Ave, Tehran 15875-4413, Iran
[b] Faculty of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Keywords:
Lightweight clay brick
Thermal insulation
Physico-mechanical properties
Taguchi approach
Zeolite
Ground granulated blast-furnace slag

ABSTRACT

In order to lessen the energy loss of buildings during the operation phase, and also considering the importance of sustainable construction, producing bricks having more desirable thermal characteristics has become essential. In this study, insulation bricks composed of expanded perlite (EP), natural zeolite, ground granulated blast furnace slag (GGBFS) and clay were fabricated. The effect of replacing clay with GGBFS, zeolite and EP in amounts up to 15%, 15%, and 50% respectively on the bricks' properties was investigated. Mix proportion parameters of bricks were analyzed using the Taguchi method. Various properties of bricks including density, weight loss, shrinkage, apparent porosity, water absorption, resistance to freezing and thawing, compressive strength, thermal conductivity, and microstructural analysis of fired bricks were examined and compared against standard requirements for bricks. Overall, the results showed that while satisfying the standard requirements, bricks containing the aforementioned additives had lower thermal conductivity compared to normal bricks, and therefore, they could be utilized as heat insulation materials.

1. Introduction

According to the survey of world energy resources by the World energy council in 2013, the global primary energy demand may increase up to 50% until 2050, while contribution of the developing countries to this increase would be about 80%. Considering the increase rate of the global primary energy demand, some specialists have predicted the depletion of fossil fuel reserves within 50 years. About 40% of the global primary energy demand is related to the building sector, while the energy savings in the building sector could be possibly be in the range of 20–40%. In this regard, a building's energy consumption or demand can be reduced by energy saving techniques (the active and passive techniques). Thermal insulation is one of the most important categories of the passive design techniques. So, using insulating materials with the optimum thickness in building walls can have an effect on the building's dynamic energy performance [1]. It should be noted that the heat loss through the walls constitutes about 50% of the total energy consumption of buildings. Therefore, energy saving is a critical issue in the building sector due to both environmental and economic concerns, and the improvement of thermal insulation properties can be a crucial way to achieve better energy efficiency [2]. According to the European standard EN 823, the thermal transmittance (U-value) of walls, which is known as the rate of heat transfer through one square meter of a structure divided by the difference in temperature across the structure, should be 0.4–0.7 w/m^2 k, the lower the better [3].

On the other hand, considering the need for sustainable development and environmental protection, a wide variety of waste materials have been used to produce building materials, including bricks, with improved physical, mechanical and thermal properties [4–9]. In general, production of insulation materials with low thermal conductivity and usage of sustainable wastes are two dominant aspects that will lead to producing energy efficient, eco-friendly construction materials. In this regard, prototype bricks have been developed by incorporating locally available waste materials. For example, bricks have been made in which glass powder, oil palm fibres, and palm oil fly ash were used along with lime and crusher dust as filler and binding materials. By incorporating oil palm fibres into the mixture, the compressive strength decreased while the thermal conductivity of the bricks was improved. High level of incorporation of fibres satisfied the standard requirements [10]. Moreover, sugarcane bagasse ash, quarry dust and lime powder have been utilized in order to make energy efficient bricks and also contribute to solid waste management. The outcomes showed that the produced bricks were mechanically superior to normal bricks while having a lower K value [11]. In another research, the effect of natural

* Corresponding author.
E-mail addresses: pm.farnood@aut.ac.ir (P. Farnood Ahmadi), ardeshir@aut.ac.ir (A. Ardeshir), ramezanian@ut.ac.ir (A.M. Ramezanianpour), bayat94@aut.ac.ir (H. Bayat).

https://doi.org/10.1016/j.ceramint.2018.01.175
Received 18 November 2017; Received in revised form 20 January 2018; Accepted 21 January 2018
0272-8842/

zeolite, ferrochromium slag as a waste material and combinations on mechanical, physical, thermal conductivity, and microstructure properties of clay bricks was studied. It showed that thermal conductivity of some samples was improved, and the sample containing 30% by weight of natural zeolite had the minimum compressive strength and thermal conductivity. Bricks made with ferrochromium slag and zeolite satisfied the requirements and could be used as construction materials [12].

Replacing normal aggregates partially or totally by lightweight aggregates in order to make the structure of construction materials more porous is a strategy towards achieving lower density and higher heat resistance properties. Lightweight aggregates are mainly categorized into two types: artificial aggregates such as expanded shale or clay, expanded vermiculite, expanded perlite and sintered fly ash, etc., and natural aggregates like pumice, diatomaceous earth, volcanic cinders, scoria, etc. [13–15]. Recently, various lightweight aggregates have been used in fabrication of bricks and different types of construction materials, and subsequently the effects of them on mechanical, physical and thermal properties of bricks and insulation materials have been investigated [16–20]. In a study, to make autoclaved lightweight bricks, diatomite, hydrated lime and gypsum as the main ingredients were mixed. Based on the results, it was concluded that calcination of diatomaceous earth contributes to additional pozzolanic reaction and better thermal and mechanical properties, so diatomaceous earth with its porous cellular structure can be used for making lightweight bricks [21]. Similarly, the porous structure of pumice has a significant effect on the porosity and thermal insulation performance of bricks. It was observed that bricks made with 10–40% pumice presented acceptable compressive strength. Apparent porosity of bricks increased and the thermal conductivity of brick with added 40% pumice improved by about 30% compared to the reference brick. With respect to the results, in comparison to traditional insulation bricks made with clay, bricks containing pumice had preferable properties [18]. When perlite ore (the glass lava rock) is heated to its softening temperature, which ranges between 900 °C and 1200 °C, it expands up to 20 times its original volume. This accounts for its low weight and excellent insulating properties [22]. Due to the thermal and acoustic insulation properties of perlite as well as its lightness, nearly 65% of perlite resources are consumed by the construction industry. In a study, bricks in standard sizes were prepared at different perlite-clay ratios. Ultimately, the best mixture containing 30% perlite was found to meet the expected standard requirements [23]. The feasibility of using expanded perlite as the main raw material and Na-borate/ K-borate as additive material was studied in the manufacturing of perlite bricks. Optimization factors used in the lightweight brick production were determined and the engineering characteristics of the bricks were investigated [24]. Also, by blending expanded perlite, colemanite, carboxymethyl cellulose, coal dust and water, lightweight bricks were produced with modified physicomechanical properties [25].

The above literature review revealed that no research has been conducted on utilization of a combination of ground granulated blast furnace slag (GGBFS), natural zeolite, and expanded perlite (EP) in fabrication of clay bricks. Therefore, in this paper, the main objective was to determine the possibility of using GGBFS, natural zeolite, and their combination with EP in fabrication of lightweight clay bricks with a relatively low cost. Furthermore, considering the importance of waste material recycling and improvement of thermal resistance of bricks, this study will support construction sustainability, and alleviate the negative environmental impacts of waste materials.

2. Materials and methods

2.1. Raw materials

In this research, production of bricks from the combination of clay as the main raw material and additives including ground granulated blast furnace slag (GGBFS), natural zeolite and expanded perlite (EP) was carried out. The GGBFS was obtained from Madaen Cement factory in the greater East Industrial zone, Esfahan, Iran. The clay raw material was obtained from Techno Ajor manufacturing company in Tehran, Iran. Natural zeolite was obtained from Afrand Tusca Company, Tehran, Iran. The particle size distribution of clay, zeolite and GGBFS was measured based on the hydrometer method [26], the results of which are shown in Fig. 1. EP was acquired from perlite deposits in Zanjan Mine (Omran Mooman Chabahar Company), Zanjan, Iran. With respect to the composition of the perlite ore, in order to achieve maximum expansion and make the production of EP more environmentally friendly, the Perlite ore was made economically utilizable for producing insulating brick by heating it at 900 °C. The density of EP ranged between 60 and 150 kg/m^3. The particle size of EP was selected to be 841 μm (remaining on the No. 20 sieve) to achieve lower thermal conductivity and density. The chemical composition of raw materials was determined by X-ray fluorescence elemental analysis (XRF) spectrometer. The qualitative determination of major crystalline mineralogical phases in the raw materials was achieved by means of EQuniox 3000 X-ray Diffractometer with Cu Kα radiation and 2θ scanning at 5–118°. To measure the amount of weight change of materials, thermogravimetric analysis (TGA) was conducted. The scanning electronic microscopy (SEM) test was also used to investigate the microstructure of materials.

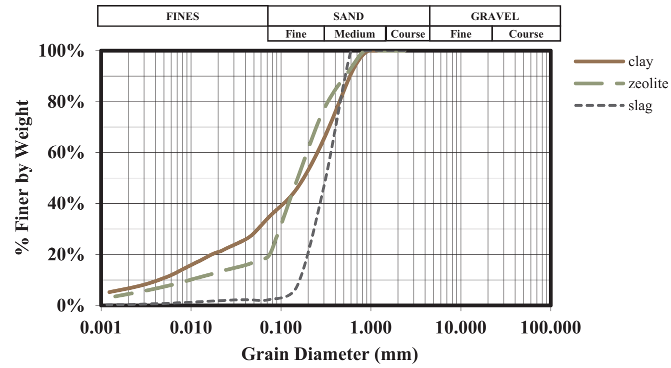

Fig. 1. Particle size distributions for zeolite, GGBFS and clay.

2.2. Preparation method and firing procedure

In order to investigate the possibility of brick fabrication, the systematic and statistical Taguchi approach was applied to optimize the design parameters economically [14,27]. With respect to the control factors and uncontrollable (noise) factors, signal to noise ratio (S/N) analysis was selected based on two Eqs. (1) and (2) to minimize the effects of noise factors [28,29]. According to the L9 orthogonal array, instead of 81 combinations, 9 suggested batches containing clay with GGBFS, natural zeolite and EP were designed for the current research. Details of the Taguchi design is presented in Table 1, and the mixture proportions for about 6 l of mortar is given in Table 2. The mixtures were blended with a mechanical mixer. The batches were first made homogeneous in the mixer for 5 min. After dry mixing, water was added to dry mixtures at three levels, namely 17, 19 and 21 wt% of the total

Table 1
Taguchi factors and factor levels.

Levels	Factors			
	Perlite (% by volume)	Zeolite (% by volume)	GGBFS (% by volume)	Water (wt%)
1	0	0	0	17
2	25	7.5	7.5	19
3	50	15	15	21