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Influence of expanded vermiculite on physical properties and thermal conductivity of clay bricks

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Abstract

Porous clay bricks lightened by adding 2.5, 5, 7.5 and 10 wt.% expanded vermiculite have been fabricated by semi-dry pressing process. The expanded vermiculite (in Yildizeli, Sivas, Turkey) was used as an additive into a brick raw material to produce the porosity. Chemical composition, phase identification, thermal behavior and microstructure of the raw materials were analyzed by XRF, XRD, TGA and SEM, respectively. The brick mixtures containing vermiculite at different proportions were formed, dried and then fired at 900 and 1000 °C for two hours. Properties such as drying and firing shrinkages, loss on ignition, bulk density, porosity, water absorption, compressive strength, thermal conductivity and microstructure of the samples were determined. It is found that the use of expanded vermiculite addition reduced the bulk density of the samples containing 10 wt.% additive down from 1.76 to 1.34 g/cm^3. It was observed that their porosity ratios up to 45% improved with increasing of vermiculite addition, whereas their compressive strengths ($_{min}$. 14 MPa) decreased. However, their strengths were still quite higher than that of required by the standards. Thermal conductivity of the porous samples with vermiculite of 10% decreased from 0.96 to 0.65 W/mK by raising porosity, which corresponds to a reduction of 32% compared to the reference sample. Increasing of the firing temperature also affected their mechanical and physical properties. In consequence, this study revealed that the brick samples produced with vermiculite addition could be used as an insulating material in construction applications.

Keywords: Lightweight bricks; Expanded vermiculite; Pore-forming; Thermal insulation; Physical properties

1. Introduction

Energy savings is recently the one of the most important issues in the world because of both economic and environmental concerns. Nowadays, almost one third of the overall energy consumed in the world is eventually used in buildings for heating and cooling [1–3]. Many countries aim to increase the energy efficiency of buildings. An important way of achieving better energy efficiency in buildings is to improve their thermal insulation properties. This can be done by either micro-pores generated by pore-maker additives before bricks were fired, or by introducing holes extending through the brick like in the case of a perforated brick [4,5]. Thus, there are two different thermal conductivity values of construction brick materials: first involves the bulk of the material constituting the walls, while the second involves equivalent thermal conductivity of the entire product consisting of large vertical perforations of rectangular cross-section [4,6]. In the former, when pore-making additives are used in clay brick, they burn and occurred micro-pores which help reduce thermal conductivity of the brick [7–9]. The latter is used widely by the brick industry to save clay material, to reduce the weight of the product and also to decrease thermal conductivity of the brick. The thermal performance of bricks depends on the geometry of the brick recesses and the material properties. The differences of thermal conductivity in function of product geometry are described another study by Sutcu et al. [10].

In general, thermal conductivity of the bulk clay bricks is approximately 1.0 ± 0.4 W/mK depending on their raw materials, processing, firing temperatures and fired densities [4,11–13]. These values can be reduced by addition of various organic and inorganic pore-makers into the brick raw material mixtures before firing

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[5,7–9,14–18]. When this is made into an extruded product with vertical perforations its thermal conductivity could be much lower as 0.08 W/mK [5,6]. Different pore-forming materials that act by thermal decomposition and volatilization (e.g. wood sawdust, polystyrene, organic residues, coal dust, powder limestone, paper-making sludge) and heat-resistant porous materials (e.g. pumice, diatomite and perlite) in brick body have been widely used [7–9,14–18]. Yet, very limited information on the usage of vermiculite as pore maker in brick and ceramic production has been reported [4,19]. In this study, expanded vermiculite in milled powder form as an inorganic pore-making additive is used for production of porous and lightweight clay bricks.

In the world, vermiculite ores is mostly found in South Africa (~ 41%), the USA (~ 21%) and China (~ 21%) [20]. In Turkey, totally 5.2 Mt reserve of vermiculite is reported by Mineral Research & Exploration General Directorate. The studies performed in recent years indicated that the most important deposits of Turkey are Karakoç mines (in Yildizeli, Turkey) where are more economic than the others due to the higher of their expansion ratios [21]. In the literature, the term of "vermiculite" is used to describe commercially exploited deposits of micaceous minerals (variable mixtures of different minerals like vermiculite, hydrobiotite and phlogopite) which can be exfoliated when heated rapidly to high temperatures [22]. Vermiculite mineral has a mica-like lamellar structure that quickly expands on heating to produce a lightweight material. Vermiculite is formed by weathering or hydrothermal alteration of hydrobiotite or phlogopite ($KMg_3AlSi_3O_{10}(F,OH)_2$) mineral phases [22,23]. When heated rapidly, vermiculite exfoliates as the interlayer water turns into steam, forcing the silicate layers apart from one another in an accordion-like expansion with expansion ratio of 20–30 times its original thickness depend on the temperature and time of processing [24–26]. The thermal expansion characteristics of Karakoc (in Turkey) deposits were determined in flame and electric furnace conditions and maximum expansion ratios were reported as 13 and 18 times, respectively [25]. In addition, its chemical exfoliation characteristics showed higher exfoliation rates. According to this study, these deposits included mostly vermiculite and phlogopite phases due to the alteration of micas [27,28].

Expanded vermiculite has very low density, good thermal and acoustic insulation properties, and also is a chemically inert and fire resistant material, which makes it attractive for use as lightweight aggregate and filler for heat insulation applications [29–33]. The aim of this study was to determine of feasibility of using the expanded vermiculite powder in production of clay brick samples and the effects on physical and mechanical properties and thermal conductivity of bricks.

Table 1
Properties of expanded vermiculite (*The data provided by the manufacturer*).

Color	Silver
Shape	Accordion shaped granule
Water holding capacity	240 wt%
Cation exchange capacity	90 meg/100 g
pH (in water)	6.1
Thermal conductivity value	0.063 W/mK
Combustibility	Non-combustible
Sintering temperature	1170 °C
Specific heat	0.22 kcal/kgK
Bulk density	140 kg/m^3

2. Materials and method

In this study, production of brick samples from vermiculite added clay mixtures were accomplished with the purpose of using as an insulating construction material. The effect of expanded vermiculite additive of 2.5%, 5%, 7.5% and 10% by weight in finely powder form on the physical and thermal properties of clay bricks is investigated. The clay raw material was obtained from a brick manufacturer (in Bartin, Turkey). The vermiculite was taken from Demircilik vermiculite quarry (in Yıldızeli, Sivas, Turkey). Expanded vermiculite is obtained by heating raw vermiculite at 600 °C for 10 s. The brick raw material and expanded vermiculite was initially subjected to pretreatments such as drying, milling and sieving. In this study, the raw materials with particle size smaller than 150 μm was used for brick production. The physical properties of the vermiculite are presented in Table 1.

The raw materials were initially characterized by chemical, mineralogical, thermal and microstructural analysis. The chemical composition of the raw materials was determined by the X-ray fluorescence (Spectro IQ II XRF) spectrometer. Their mineralogical phase content was identified by using a Phillips X'Pert Pro X-ray powder diffractometer (Cu-Kα radiation, $\lambda = 1.54056$ Å, 40 mA, 40 kV). The thermo-gravimetric and differential thermal analyses of the raw materials were performed at a heating rate of 10 °C/min in nitrogen atmosphere using the thermal analyzer instrument (Perkin Elmer Diamond TG/DTA). Also, their microstructural images and elemental maps were investigated by a scanning electron microscopy (FEI Quanta250 FEG SEM) analysis with energy dispersive X-ray spectrometer (EDS).

In this study, experimental flowchart for brick production process is shown in Fig. 1. Expanded vermiculite in powder form was added into the brick clay raw material at ratios of

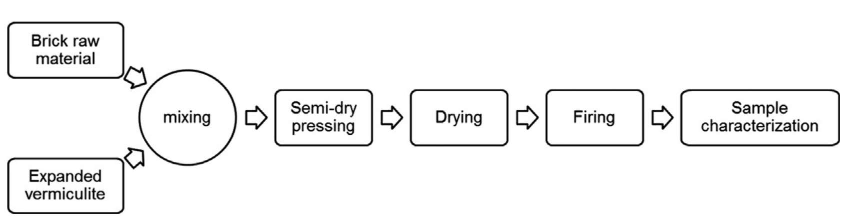

Fig. 1. Experimental flowchart for brick process.