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Characteristics of fired clay bricks with pumice additive

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A R T I C L E I N F O

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A B S T R A C T

Production of porous and lightweight clay bricks with enhanced thermal conductivity is studied. Pumice was used as an additive to an earthenware brick to produce the pores. SEM-EDS, XRD, XRF and TG-DTA analysis of the raw materials was initially performed. Mixtures containing brick raw materials and pumice were prepared at different proportions (up to 40 wt.%). The semi-dry mixtures were compressed by a hydraulic press under 20 MPa pressure into the mold, and the green bodies were dried, and then fired at 900 °C and 1000 °C for 2 h. The loss on ignition values of fired samples was investigated, as well as, the bulk density, apparent porosity and water absorption measurements by Archimedes method. Thermal conductivities and mechanical strengths of the fired samples were also measured. Results showed that the use of pumice decreased the fired density of the bricks. Thermal conductivity of the brick with added 40% pumice produced (<0.65 W/m K) showed more than 30% reduction compared to the reference brick without additive (0.96 W/m K). Their compressive strengths were highly higher than that required by the standard.

1. Introduction

The energy consumption of fossil origin in a country, and the pollution due to the same one, mainly CO_2, represent a strategic, economic and environmental problem of first order. In this way, the Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change. Countries that sign this protocol pledge to decline their emissions of CO_2. The Protocol has been globally accepted by more than 160 countries. These countries are struggling closely with their major utility, energy, oil and gas and chemicals conglomerates in order to reduce green house gasses, especially CO_2, emissions. Recently, energy consumption of buildings all around the world is a high-priority and important subject. In this respect, building sector has been studied as part of a broader examination in relation to a rational fuel use and emissions in countries including Turkey. The aim is to decrease energy consumption in the buildings for the best thermal protection of the internal enclosure [1]. Buildings today account for about 40% of energy consumption in developed countries according to the Organization for Economic Co-operation and Development [2]. This represents 36% of the global CO_2 emissions in the world [3]. About 30% of this energy or heat loss occurs through the walls [4]. An important way of achieving better energy efficiency in buildings is to improve their thermal insulation properties [5,6].

Bricks are the most commonly construction materials used for building enclosures. They are specially required to have adequate physical and mechanical properties as well as a good thermal insulation behavior. Fired clay bricks, the best known type of brick and also one of the known oldest construction materials, are mostly prefered to form the enclosure [3] due to its simple and reliable construction technique, relatively low cost and a low maintenance cost, their phsical and mechanical properties, long durability of brick structures and equilibrium hygroscopic moisture presenting a healthy and comfortable ambient in buildings [7]. In addition to the heat isolation property of fired bricks, they can also be used to construct load carrying walls since the usage of these bricks is permitted to construct buildings with three stairs in many countries including Turkey, Ukraine, Spain.

Brick quality significantly depends on properties of raw materials and their compositions, production procedure, firing method, temperature and time. Sintering improves durability of brick. Sintering is bonding mechanism of clay particles, and that can only be achieved under the influence of heat effect [8]. Besides, thermal performance of bricks depends on geometry of the brick recesses that is discussed in some studies [1,5].

Construction industry generally uses large amount of clay bricks in most of buildings [9]. If these bricks are improved by proper processing, they can have significantly lower thermal conductivity and transmittance properties which mean a lower heat loss

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Table 1
Mixture proportions.

Mix code	Firing temperature/time	Brick clay (wt.%)	Pumice (wt.%)
A1	900 °C/2 h	100	0
A2	900 °C/2 h	90	10
A3	900 °C/2 h	80	20
A4	900 °C/2 h	70	30
A5	900 °C/2 h	60	40
B1	1000 °C/2 h	100	0
B2	1000 °C/2 h	90	10
B3	1000 °C/2 h	80	20
B4	1000 °C/2 h	70	30
B5	1000 °C/2 h	60	40

through the walls of houses [10]. When the pores are introduced into bricks, their thermal conductivities are reduced. This can be done by micropores, like the closed pores created by addition of various organic and inorganic pore-making additives into brick raw material mixtures before bricks were fired [11].

Some different pore-forming materials such as wood saw dust, polymers, leather residues, polystyrene, organic residues, coal dust, powder limestone, paper-making sludge and mineral additives that act by thermal decomposition and volatilization in brick body have been widely used [4,5,11–18]. Also heat-resistant porous materials such as diatomite, zeolite, vermiculite and perlite have been evaluated in the ceramic brick structures [6,19–25].

Pumice is a natural puzzolan of volcanic origin produced by release of gases during cooling and solidification of lava which is generally rhyolitic in composition. Porous structure of pumice is formed by the formation of bubbles or trapping millions tiny air voids when gases in molten lava are trapped during cooling. Air voids are elongated and parallel to one another and are sometimes interconnected. Pumice generally has been used as aggregate in lightweight concrete in many countries [26]. In particular, it can be found in the Mediterranean area such as Turkey, Italy, Greece and Spain. In the USA, it is mined mainly in the Rocky Mountains and Pacific Coast States [27]. There are about 18 billion tons pumice deposits worldwide. In Turkey, pumice deposits are about 2.8 billion tons possessing about 15.8% of total world deposits [28].

Pumice has low density, good thermal, acoustic insulation properties and it is fire resistant material, which makes it attractive for use as lightweight aggregate for heat insulation brick applications [29,30]. Pumice has been widely used to produce lightweight concrete [26,31–33]. However, very limited information on the usage of pumice as pore maker in fired clay brick production has been reported. Thus, the aim of this study was to determine the feasibility of using the pumice in production of clay brick samples and the effects on physical and mechanical properties and thermal conductivity of bricks.

2. Materials and methods

In this study, brick samples with pumice were prepared to obtain an insulating building material. Effect of pumice addition in the ratio of 10%, 20%, 30% and 40% by weight in powder form on physical, mechanical and thermal properties of bricks is investigated. Mixture proportions are given in Table 1. Clay and pumice were obtained from a brick manufacturer (in Bartin, Turkey). Clay and pumice were firstly subjected to pretreatments such as drying, milling and sieving. Raw materials, smaller than 150 μm in size, were used for brick production. Mixtures were mechanically blended with about 15 wt.% of total weight sprayed water for 30 min in a laboratory mixer to obtain homogeneity and consistency which are of great importance to modify properties of bricks. Three brick samples with 20 mm × 60 mm × 100 mm in size for each test were semi-dry pressed into a mold with a hydraulic press under 20 MPa pressure as seen from Fig. 1. And then samples removed from the mold were kept in ambient conditions for overnight. Samples were dried at 40 °C for 20 h and then at 100 °C for 18 h in oven. After drying, the samples were fired in a laboratory-type electrical furnace (Protherm PLF12/15) at the rate of 5 °C/min until the dwell temperatures of 900 °C and 1000 °C for 2 h.

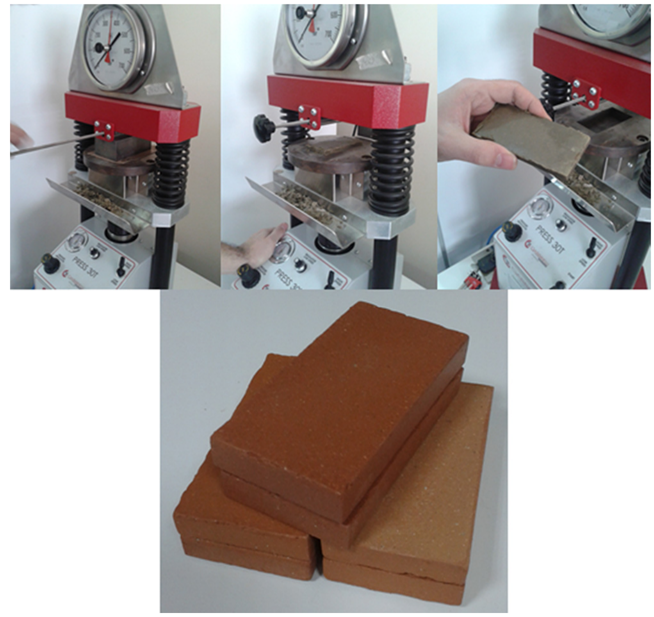

Fig. 1. Brick production.

Fired brick samples were characterized for physical, mechanical and thermal conductivity properties. Bulk density, apparent porosity and water absorption values were measured with Archimedes method. Their compressive strengths were determined. Thermal conductivities of the brick samples were performed by the C-Therm TCi Thermal Conductivity Analyzer with modified transient plane source at ambient conditions method, a non-destructive technique allowing us to obtain the thermal conductivity and effusivity of the samples tested [34–36].

2.1. Thermal conductivity measurements

Despite the typical error of the Thermal Conductivity Analyzer is less than 0.4%, a mathematical treatment of the error is studied in this research, because it is important on the thermal performance of this material.

The basic procedure to study and minimize the error in the thermal measurements is the following:

- A minimum of three different specimens under three different thermal and moisture condition of each material is tested.
- Each test is composed of a minimum of ten thermal measurements.
- The characteristic thermal conductivity value is obtained taking into account the mean value in each specimen, under the three different thermal and moisture conditions, for the ninety thermal tests ($3 \times 3 \times 10 = 90$). Thermal conductivity measurement is shown in Fig. 2.

3. Results and discussion

3.1. Characterization of the raw materials

Chemical composition, thermal gravimetric analysis and X-ray diffraction analysis of the clay and pumice raw materials are primarily performed. Chemical compositions of clay and pumice