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Research article

Effect of olive mill waste addition on the properties of porous fired clay bricks using Taguchi method

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ABSTRACT

Production of porous clay bricks lightened by adding olive mill waste as a pore making additive was investigated. Factors influencing the brick manufacturing process were analyzed by an experimental design, Taguchi method, to find out the most favorable conditions for the production of bricks. The optimum process conditions for brick preparation were investigated by studying the effects of mixture ratios (0, 5 and 10 wt%) and firing temperatures (850, 950 and 1050 °C) on the physical, thermal and mechanical properties of the bricks. Apparent density, bulk density, apparent porosity, water absorption, compressive strength, thermal conductivity, microstructure and crystalline phase formations of the fired brick samples were measured. It was found that the use of 10% waste addition reduced the bulk density of the samples up to 1.45 g/cm^3. As the porosities increased from 30.8 to 47.0%, the compressive strengths decreased from 36.9 to 10.26 MPa at firing temperature of 950 °C. The thermal conductivities of samples fired at the same temperature showed a decrease of 31% from 0.638 to 0.436 W/mK, which is hopeful for heat insulation in the buildings. Increasing of the firing temperature also affected their mechanical and physical properties. This study showed that the olive mill waste could be used as a pore maker in brick production.

1. Introduction

The construction industry plays a major role in the economic development of countries, since it is directly related with many industries such as steel and other metals, cement and concrete, brick, tiles and glass etc. One of these sectors is brick sector. Two main bricks, cement based and clay based, commercially are manufactured. But, fired clay bricks have been preferred commonly by building manufacturer due to its low cost when compared to the cost of cement based one. Also, clay based bricks have superior properties such as high strength and durability, chemical, fire, freeze-thaw and corrosion resistances etc. (Kornmann, 2007). As one of the oldest building materials used in the world, clay brick is a quite durable product that has a long-term life performance. Still so many structures built with fired clay bricks have serviced for centuries.

Recently, there has been a consciousness to protect environment. As a requirement of this consciousness, usage of clay which is obtained from nature has been considered as destroyer the environment. In this respect, clay usage in some countries has been restrained due to the reduction of clean raw material sources (Chen et al., 2011). Nowadays, the demand to clay based fired bricks has been increased. In this conflict, reuse or recycling of industrial and agricultural wastes can be a problem-solving technique. Currently, many kinds of wastes from different industries have substantially arisen with increasing of the manufacturing. According to industrial ecology concept developed for a sustainable future, industry by products can be used as raw materials in other industries. Thus, we transform from a consumption society to a sustainable society. For this reason, many wastes can be evaluated in brick body by replacing the clay with wastes. So, more clay based brick production is possible by using less clay. Many studies have been reported about bricks produced for different purposes such as load bearing, decorative, refractory and heat isolation (Velasco et al., 2014; Zhang, 2013; Sutcu and Akkurt, 2009; Sutcu et al., 2012). Several industrial waste materials such as marble processing waste, fly ash, mining tailings, metallurgical slags, biomass incinerator ashes etc.

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have been used (Chen et al., 2011; Pérez-Villarejo et al., 2012; Zhang, 2013; Velasco et al., 2014; Sutcu et al., 2015; Bories et al., 2014). Recently, the feasibility of using woody agricultural wastes such as rice husk, straw, sunflower seeds, olive stone, grapes and cherries seeds, sawdust as pore forming agent, in bricks, were reported (Velasco et al., 2014; Bories et al., 2014; Barbieri et al., 2013; Gorhan and Simsek, 2013; Muñoz et al., 2014).

Lightweight clay bricks provide energy efficiency in buildings. For producing a brick with high heat isolation capacity, the voids or perforations and a micro-porous structure in brick body are essential (Sutcu et al., 2014). For obtaining a porous structure in the brick body, pore-making materials must be used. In this point, different wastes from different industries can be used (Velasco et al., 2014; Zhang, 2013; Sutcu et al., 2015; Bories et al., 2014; Barbieri et al., 2013; Gorhan and Simsek, 2013; Muñoz et al., 2014). One of them is olive mill waste. Olive mill waste is produced from processing of olives to obtain olive oil. Average olive oil production in the Mediterranean region of the EU in recent years has been 2.2 million tons, representing around 73% of world production (European Commission, Directorate-General for Agriculture and Rural Development, 2012). Turkey which is one of the biggest olive and olive oil producers in the world has about 7–10% of world olive production. The waste from olive mill processes is considered a serious source of environmental pollution, because the total waste generation is nearly 75% of the olive harvest. In regard to solid wastes resulting from olive oil production, the Ministry of Environment in Turkey has permitted the combustion of dried olive oil mill wastes, with the condition that the emission limits are met (Azbar et al., 2004). The use of olive mill wastewater in the brick production has been studied by researchers for its physical durability and stability (Mekki et al., 2008). La Rubia-García et al. (2012) presented that the incorporation of 10 wt% olive mill solid residue (wet pomace) is beneficial to produce good-quality lightweight bricks. In sustainable approach, evaluation of wastes in brick production presents a good perspective to obtain porous structure in brick body for the increased thermal performance.

Although several kinds of wastes have been used in brick production, optimization of these wastes in brick production has been generally ignored. It is well-known that an optimization is very crucial to obtain the aims targeted (Arsenović et al., 2015). Taguchi is one of the optimization methods that presents a better path in order to increase the quality and to design (Roy, 1990; Zirehpour et al., 2014).

The aim of this work is to investigate the use of olive mill waste as a pore forming additive in clay brick and its effect on the physical, mechanical and thermal properties of the clay based bricks. An experimental design was selected to optimize the manufacturing process of porous bricks with olive mill waste.

2. Experimental

2.1. Materials and method

The production of fired bricks from mixtures of clay raw material and olive mill waste additive was studied. The olive mill waste was obtained from a local olive oil processing factory in Izmir, Turkey. The clay was obtained from a brick manufacturer in Manisa, Turkey. The raw materials were dried, milled and sieved under 100 mesh for brick production. The chemical composition and crystalline phases of the clay was determined by the X-ray fluorescence (XRF) and X-ray diffraction (XRD) spectrometer. The thermal analysis of clay material and olive mill waste was performed by thermo-gravimetric analysis (TGA). Also, the morphology of the olive mill waste was investigated by scanning electron microscopy (SEM) analysis.

The clay brick mixtures with and without olive mill waste addition were prepared in a mechanical mixer. The mixtures with sprayed water up to fifteen weight percentage of total mixture weight were mechanically mixed for 30 min to get a uniform consistency. Semi-dry mixtures were compressed with a pressure of 20 MPa. Cylindrical pellets of 20 mm were dried in an oven maintained at 40 °C for 12 h and then at 110 °C for 24 h. The dried samples were fired in an electrical furnace at the heating rate of 2.5 °C/min until 600 °C, and then heating is continuous with 10 °C/min heating rate up to elevated temperatures of 850, 950 and 1050 °C for 2 h. In order to achieve strength, generally the bricks are fired around 1000 °C depend on clay type, processing and additive type and amount. In this study, three specific temperatures were selected to investigate the effect of olive mill waste addition and firing temperature on the physical properties, thermal conductivity and compressive strength of the bricks.

Factors influencing the brick manufacturing process were analyzed by an experimental design to find out the most favorable conditions for the production of bricks. The optimum process conditions for brick preparation were investigated by studying the effects of mixture ratios (0, 5 and 10 wt%) and firing temperatures (850, 950 and 1050 °C). Bulk density, apparent porosity and water absorption values of the fired samples were measured by Archimedes method (ASTM Standard C20, 2005). The compressive strengths and thermal conductivities of samples were tested. The compressive strength of fired clay brick samples was measured at a cross head speed of 0.5 mm/min in a universal testing machine with a testing capacity of 100 kN. Thermal conductivity of the brick samples was performed by the C-Therm TCi Thermal Conductivity Analyzer with modified transient plane source at ambient conditions. Microstructural and phase analysis of fired brick samples was also investigated by SEM and XRD, respectively.

2.2. Statistical experimental design

In order to infer the influence of olive mill waste addition (0 wt %, 5 wt% and 10 wt%) and firing temperature (850 °C, 950 °C and 1050 °C) on the thermal conductivity and compressive strength of fired bricks, Taguchi approach was employed. According to Taguchi (3^2) orthogonal array design, nine experiments with three replicates was applied by using the factors. The aim was to identify the more important factor effects in addition to recognizing if there was any significant interaction between the factors.

The quality characteristics of a product may change under investigation, weight of a factor in the response is the signal of the desired effect, in the experimental design. However, when an experiment is conducted, there are numerous factors not designed into the experiment which influence the outcome. These external factors are called the noise factors and their effect on the outcome of the quality characteristic under test is termed "the noise". The signal to noise ratio (S/N ratio) measures the sensitivity of the quality characteristic being investigated in a controlled manner, to those external influencing factors (noise factors) not under control (Roy, 1990).

The S/N ratio was performed in two steps. First, the Mean Square Deviation (MSD) of the set is calculated. For the thermal conductivity property, lower value is better for the fired bricks. Therefore, the smaller is better quality characteristic was selected and MSD was calculated by the equation (1),

$$\mathrm{MSD} = \left(x_1^2 + x_2^2 + x_3^2 + \ldots + x_n^2\right) \Big/ n \tag{1}$$

where x is the response value and n is the number of replicates.