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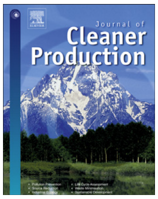

Investigation on characteristic properties of potassium borate and sodium borate blended perlite bricks

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The aim of this study is investigation of brick reproducibility using expanded perlite aggregate as the main raw material. Na-Borate and K-Borate are used as additive material in the production of perlite bricks. Engineering parameters such as weight per unit of volume, mechanical strength of produced control brick (with a dimension of 50 × 100 × 100 mm) were determined and optimized. As a result of the study, the lowest value of weight per unit of volume and the highest value of strength were ascertained as 522 kg/m^3 and 23 kg/cm^2 for the samples which were produced at a 50 bar pressure and 400 °C with 1 h burning period and a water to binder ratio of 0.90. Also, denser volume was observed in the microstructure investigation by addition of Na-Borate and K-Borate to perlite brick mixtures.

1. Introduction

The use of building materials such as bricks, pumice concrete, gas concrete and insulation bricks produced from raw materials such as different sand, gravel, cement, gypsum, lime, perlite and pumice has become increasingly common worldwide (Mutuk and Mesci, 2014; Sadek, 2014). Turkey is located in active seismic zones, isolation parameters have been developed, energy needs have become increasingly widespread and precautionary obligations have increased (Turgut, 2012). This situation has resulted in a shift to alternative and cheaper sources for the production of light building materials (Celik, 2010; Hodge et al., 2010). Expanded perlite is a commonly used material for the manufacture of lightweight building materials (Topcu and Isıkdag, 2007). The commercial product, commonly designated as expanded perlite, is produced by heating the material to 760–1100 °C, thereby converting its indigenous water to vapor and causing the material to expand 4 to 20 times its original volume while forming lightweight high-porosity aggregates (Sengul et al., 2011; Topcu and Isıkdag, 2008). The heating process does not change the perlite density (2.2–2.3 kg/dm^3) but the bulk density decreases to 60–80 g/dm^3 (Celik et al., 2013).

Many researchers have studied the characteristic properties of the perlites and their use as construction materials. Çobanlı (1993) obtained lightweight building materials with high thermal insulation by using expanded perlite, clay and boron waste. The study conducted by Ayberk (1995) highlighted that perlite is usable in various forms in buildings due to its insulation and fire resistance properties. In another study, Ceylan and Ebeoğlugil (2002) used clay and expanded perlite for the production of light bricks with high heat insulation and investigated the properties of the building material. In the manufacture of light building material, Padfield (1998) produced materials from perlite, clay and bentonite mixture which can take perfect shape. Shi et al. (2005) conducted a further study which used Portland cement as a binder, and glass powder and fly ash as mineralogical waste. In this study the chemical and physical properties were determined and, what is more, the increase in compressive strength was found to be dependent on the curing temperature. Demirboğa et al. (2001) investigated the compressive strength of concretes made up of mixtures of expanded perlite (EPA) and pumice aggregates (PA). According to their results, unit weights of all concrete groups decreased from 1154 to 735 kg/m^3 with the increase of EPA in the mixtures. The compressive strengths increased by 52%, 85%, 55% for 7-day samples, and 80%, 84%, 108% for 28-day samples due to 20%, 40%, and 60% of EPA (used in place of PA), added into the mixtures. Another study was performed by Sengul et al. (2011) on cement based lightweight concrete production with expanded perlite. They investigated the effects of expanded perlite on the mechanical

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properties, including compressive strength, modulus of elasticity, water absorption and capillarity coefficient of the mixtures, and thermal conductivity of lightweight concrete. The mixtures were prepared by partially replacing natural aggregate by expanded perlite from 0% to 100% with steps of 20%. According to obtained results, unit weights of lightweight concretes in oven-dry state varied between 354 and 1833 kg/m^3. The compressive strength was decreased from 28.8 MPa to 0.1 MPa with increasing in perlite content. E-modules were also reduced. The thermal conductivity was substantially decreased from 0.6 W/mK to 0.13 W/mK with the use of perlite. Water absorption and sorptivity coefficient was increased with the higher perlite contents. In a study conducted in Greece, it was found that the regional perlite can be used as a building material in the industrial construction industry according to chemical, physical and mineralogical tests carried out on crude and over-dry lightweight aggregate samples (Fragoulis et al., 2005). Topcu and Isıkdag (2008) investigated the properties of concrete containing EPA considering cement types (CEM II 32.5R and CEM I 42.5R), dosages (300, 350 and 400) and replacement ratios (0, 15, 30, 45 and 60%). Destructive and nondestructive tests were performed at the end of 28 days. In experiments, the minimum unit weight of concrete mixture was 1800 kg/m^3 at the dosage of 300, and compressive strengths of EPAC (expanded perlite aggregate concrete) were obtained between 20 and 30 MPa at the replacement ratios of 30% considering cement types. Authors reported that EPAC can be used as lightweight concrete with adequate replacement ratios, despite some losses in mechanical properties.

In addition to the above, experimental studies have been performed on the water retaining properties of the frangible soft-particulate unsaturated material (Jamei et al., 2011; Kua and Kamath, 2014). Won et al. (2011) produced polymer mortar combined with high-strength polypropylene fibers which can be used in the repair of numerous concrete structures. Benk and Coban (2012) developed lightweight, insulated, waterproof or water-repellent materials from lightweight aggregate such as pumice and/or expanded perlite without using cement or plaster type binder. Munoz et al. (2013) stated that one of the most important factors, in terms of the thermal behavior of the outer wall, is the thermal conductivity of the clay in the brick and pointed out that the fire clay improves the conductivity of the pulp which acts on the thermal and mechanical properties. Karakoç (2013) investigated the permanent compressive strength of concrete composed of expanded perlite aggregate (EPA) and pumice aggregates. EPA and PA replacements of fine aggregate were used 10%, 20%, and 30%. Test results showed that the compressive strength of concrete cooled in water cooling after being exposed to the effect of different mixture with EPA and PA is higher than that cooled in natural and furnace. Based on the test results, the compressive strength of concrete cooled in water, furnace and natural cooling decreased by an average of 78%, 81% and 83% when compared to control samples.

Scientific studies and research on the production of lightweight building materials with perlite in the construction industry have recently increased in Turkey. However, expanded perlite is not preferred for lightweight concrete production in which it is used as the main raw material in applications. It is due to that the compressive strength values of lightweight concrete decrease by use of EPA. This decrease in compression strength is due to the lower strength and high porosity of perlite. It is also due highly crushable behaviour of EPA on loading (Torres and Garcia-Ruiz, 2009). The desired strength in lightweight concrete with perlite can be achieved with a larger volume of cement, which will further increase the cost. The strength of lightweight concrete is not related only to its density, it is related to factors like the strength of the mortar matrix (Lo et al., 2007). Therefore, in this study, optimization parameters used in the perlite brick production were determined in apart from cementitious material. Moreover the engineering properties of the bricks were investigated.

2. Experimental studies

2.1. Materials

2.1.1. Expanded perlite

Expanded perlite was used as the main raw material in the production of building material. Perlite aggregates were obtained from the perlite deposits in Eti Mine Works General Management, Izmir (Cumaovası)/Turkey and made available for brick production by expanding them at 800 °C in the factory furnaces. In the facility, the samples were expanded to 0.2–2 mm in size and 150–180 kg/m^3 in density. Table 1 shows the results of the chemical analyses of the perlite. Fig. 1 shows the Scanning Electron Microscopy (SEM) image of the surface structure of the perlite.

2.1.2. Carboxymethylcellulose (CMC)

In the experiments, carboxymethylcellulose (CMC) was used as a chemical binder. CMC was used in order to provide natural air-drying of the bricks by reshaping them during pressing and to prevent the deterioration of the samples before being fired.

2.1.3. Coal powder

Coal powder is viewed as petroleum coke product waste used for clinker burning. It was preferred as an additive in the experiments and used with the intention that it would enable homogenous burning of the samples. Coal powder has around 6000 calories. The coal powder was sieved with a 1 mm sieve and discontinuities were removed after it was milled in the laboratory and then added to the mixture as an additive.

2.1.4. K and Na Borate

In the studies, potassium borate ($K_2B_5O_7$) and sodium borate ($Na_2B_5O_7$) were used as natural binders. Boron compounds were produced in the R & D laboratories of Boren (National Boron Research Institute).

2.2. Methods

The first phase of the production of the brick samples was performed by the reaction of CMC with water without the use of a natural binder. The production of the perlitic bricks was carried out using molds 50 × 100 × 75 mm in size. Different series were designed by adding 6% Sodium Borate and Potassium Borate into the brick mixtures. The water/aggregate ratio of the doped perlite bricks was 0.90. Control series was produced without using the Sodium Borate and Potassium Borate. Table 2 shows mixture ratios intended for unit volume.

In the production of sodium and potassium borate mixed perlite bricks, raw materials used in the laboratory studies were mixed in a mechanical mixer for 30 min and placed in molds. In this study, each brick was placed in the mold and compacted at 50 bar. The samples were removed from the mold and cured at 400 °C for 2 h (Fig. 2). The unit weight values of boron-doped bricks produced in the experiments were determined by keeping them in the natural

Table 1
The results of the chemical analysis of the expanded perlite (%).

Component	SiO_2	Al_2O_3	Na_2O	K_2O	Fe_2O_3	CaO + MgO	Other
Content, %	70.68	13.04	3.54	4.34	1.04	3.78	3.38

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