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Effect of borogypsum on brick properties

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HIGHLIGHTS

- The suitability of adding borogypsum to the brick was tested over a range of brick compositions.
- Borogypsum increases the porosity during firing.
- Significiant decrease in bulk brick density was obtained.
- Better compressive strength values were obtained with additions up to 10 wt.%.

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ABSTRACT

The boric acid production industry generates a large amount of waste that pollutes and damages the environment. This study aims to characterize and evaluate the possibility of using the boric acid production waste (Borogypsum: BG) generated by the boric acid production industry in Emet–Turkey, as an additive raw material for the production of bricks and to improve the brick properties. The suitability of adding waste to the brick was tested over a range of brick compositions. Bricks containing 0 to 15% BG by weight were produced and tested for compressive strength and freeze/thaw durability according to the Turkish Standards (TS) for fired clay bricks. The results showed that the brick samples containing 10 wt.% BG had the best compressive strength before and after water absorption tests. The brick bodies produced from the brick clay with BG had technological characteristics in agreement with the ASTM and TS standards for ceramic bricks and tiles.

1. Introduction

The use of waste can contribute to product diversification, decrease final costs, and provide alternative raw materials to several industrial sectors [1].

Recycling of wastes, generated by the industries, as alternative raw materials is not a new thing and has been done successfully in many countries. The reasons that motivate these countries generally are: the exhaustion of the natural resources; the conservation of not renewable resources; improvement of the population health and security; preoccupation with environmental matters; reduction in wastes disposal costs. The construction industry is the most indicated technological activity sector to absorb solid wastes, due to the large quantity of raw materials used by the sector as well as by the large volume of final products in construction [1]. Garcia et al. [2] investigated the assessment of olive mill solid residue as an additive in lightweight brick production. Türkel and Aksın [3], carried out a comparative study on the use of fly ash and phosphogypsum in the brick production. Villarejo et al. [4] investigated the effect of incorporation of ash from biomass incinerator as raw material on the production of ceramic bricks for their application in construction. In another study [5] it has been shown that, sewage sludge from sewage treatment plants can be regarded as an interesting raw material for the fabrication of clay bricks fired at normal temperatures. Characteristics of acid resisting brick made from quarry residues and waste steel slag have been studied by Mahllawy [6], and environmentally inert brick, with good commercial characteristics, was made using these wastes. Algin and Turgut [7] has shown that, the cotton waste and limestone powder waste combination provides results, which are of potential to be used in the production of lighter and economical new brick material. The use of recycled paper processing residues in making porous brick has been studied by Sutcu and Akkurt [8] and successful production of insulation bricks with reduced thermal conductivities has been achieved.

There are about 150 known boron-containing minerals, and of these only kernite ($Na_2B_4O_7{\cdot}4H_2O$), tincal ($Na_2B_4O_7{\cdot}10H_2O$),

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probertite ($NaCaB_3O_9{\cdot}5H_2O$), ulexite ($NaCaB_5O_9{\cdot}8H_2O$), colemanite ($Ca_2B_6O_{11}{\cdot}5H_2O$) and szaibelyite ($MgBO_2$ OH) are of significant commercial importance [9–11]. The estimated world reserves of borate minerals are 69.7% in Turkey; 8.2% in Kazakhistan; 6.50% in The United States; 3.8% in China; 6.6% in South America; 2.8% in Russia and all other sources 1.6%; based on B_2O_3. The United States and Turkey are the world's two largest producer of boron compounds [12–14]. Of the total world borates, Turkey produces 42%;the United States 35%; China and Russia 12% and all other sources 11%, based on B_2O_3 [13]. World borate consumption in the United States is 30%; in Western Europe 37%; in Japan 5% and in all other countries 28% [9]. In Turkey, borates have been known since the 13th century [13].

Boric acid, one of the most commonly used boron compound, is used to prepare a variety of glasses, including fiber glass, heat resistant borosilicate glass and sealing glasses. It is also used to make porcelain. A major application of boric acid is to prepare a number of boron compounds including inorganic borate salts, boron halides, borate esters, fluoroborates and many boron alloys [15]. In The United States, boric acid is primarily made from sodium borate minerals, whereas in Europe boric acid is produced from crushed colemanite ore imported from Turkey, by reaction with sulfuric acid at 90 °C. Byproduct gypsum ($CaSO_4{\cdot}2H_2O$) and gangue (montmorillonite and dolomite) are filtered, and the hot mother liquor is cooled to crystallize boric acid. The weak liquor is recycled to the reactor [9]. The boric acid production reaction can be written as follows:

$$2CaO3B_2O_35H_2O + 2H_2SO_4 + 6H_2O \rightarrow 2(CaSO_4 \cdot 2H_2O) + 6H_3BO_3 \quad (1)$$

Colemanite ores may contain different minerals and therefore, the composition of the by products may differ.

In Turkey, boric acid is produced from colemanite concentrate and ore. Etimaden Inc. is today the world's leading manufacturer of boric acid, with manufacturing sites in Bandırma and Emet, Turkey. In 2011 boric acid and tailing (BG) produced at these factories were $330 \cdot 10^3$ t/y and $650–700 \cdot 10^3$ t/y respectively.

Large amounts of waste containing boron are disposed from the plants annually leading to a variety of environmental and storage problems. It is very important for the sustainable development of this industry and for environmental protection that economical disposal of industrial by-products increases every year. BG is a valuable raw material due to its boron content, but B_2O_3 causes water and soil pollution.

In recent years, a series of investigations have been carried out to reduce the harmful effects of the waste from this industry [16–24]. In a study [16], the conversion temperatures of BG to hemihydrate and soluble anhydrite structures were determined and compared to those of natural gypsum. In addition, the physical and mechanical properties of cements prepared using BG and hemihydrate BG as cement additives were investigated. Demirbaş [17] have presented new data on the recycling of lithium from BG with water and studied its leaching kinetics. Demir and Keleş [18] have measured radiation transmission of concrete produced by using BG and colemanite concentrator waste for 59.54–80.99 keV gamma rays. Demirbaş et al. [19] have presented new data on the leaching of boric acid from boronic wastes. Delfini et al. [20] have settled the leaching conditions in order to obtain a suitable as removal from BG, with the aim of reducing the environmental impact of the chemical process. Erdoğan et al. [21] have investigated the potential of boron in Turkey, commercial most-used compounds of boron and their production trends according to years and analyses of boronic samples obtained from different sources. Boncukoğlu et al. [22] have investigated the evaluation of the reactor waste in borax production to recover B_2O_3 and therefore to reduce the toxic effect of the waste. Cau Dit Coumes and Courtois [23] have determined the sensitivity of the solidified waste forms characteristics on a variation in the concentrations of four components of the waste (boron, chloride, sulfate and phosphate). In a study, the boric acid extraction from colemanite ore in aqueous media saturated by CO_2 and SO_2 gases was studied [24]. Incorporation of gypsum waste in ceramic block production was studied by Castro et al., and they concluded that gypsum waste can be used in the production of ceramic blocks without causing adverse technical and environmental impact [25].

The use of waste materials in the production of cement and concrete has become common place because it offers cost reduction, energy savings and arguably superior products. BG has been investigated for use in the cement industry as an alternative to gypsum [26–31]. In these previous studies, BG with different B_2O_3 ratios was mixed with clinker to observe its effects on the physical and chemical properties of the cement.

Kavas et al. [26] have investigated the possibility of using BG instead of natural gypsum in fly ash–cement matrix. Elbeyli et al. [27] suggested that calcined BG in cement application decreases soundness and markedly increases the setting time and 28-day compressive strength of the mortar compared to that of untreated BG. Boncukoğlu et al. [28] showed that BG up to 10% of the cement could be used as a set retarder. However, increasing the BG level in Portland cement from 5% to 20% causes a decrease in compressive strength and tensile strength [28]. Erdoğan et al. [29] concluded that refined BG can be used for Portland and trass cements. Demirbaş and Karslıoğlu [30] suggested that refined BG can be added to cement up to 12%. Chandara et al. [31] focused on clarifying the influence of waste gypsum in replacing natural gypsum in the production of ordinary Portland cement and they concluded that it can be used as an alternative material to natural gypsum in the production of ordinary Portland cement.

The literature survey revealed that BG has not been utilized in brick production. In this research, BG was evaluated to determine its usefulness as an additive to brick clay to improve the brick's properties. As a part of this research, the possibility of replacing a portion of the brick clay with BG to improve certain brick properties was studied. Bricks made of brick clay containing BG were expected to exhibit a lower density and enhanced freeze–thaw resistance. Bricks containing 0 to 15% BG by weight were produced and tested for compressive strength and freeze/thaw durability according to the Turkish Standards for fired clay bricks.

2. Materials and methods

This section describes the materials and methods used to investigate the feasibility of using BG for brick production and characterize the structural properties of the resulting bricks.

2.1. Brick testing materials

The materials used to produce the bricks were received from the Boric Acid Plant in Emet and from Uysal Brick Factory in Afyon, Turkey. Brick clay was first crushed at the plant by an impact crusher and then screened to obtain grains less than 1 mm in size. BG was first dried and then dry screened to less than 1 mm in the laboratory. Chemical and mineralogical analyses of the raw materials were carried out according to standard procedures. The chemical analysis of the raw materials were performed using X-Ray fluorescence spectroscopy technique (XRF-Rikagu, ZSX Primus II model). Crystalline phases were analyzed by X-ray diffraction (XRD) (Phillips X'Pert Pro) on a Panalytical X-Pert diffractometer equipped with Cu-Kα radiation. A scan speed of 0.1 2θ/min was employed in the 20–85° 2θ range and 0.01° $2\theta\ s^{-1}$ goniometer speed. Raw material or fired brick sample was finely ground and well mixed in agate mortar before being pressed into Al holder for XRD analysis.

2.2. Brick manufacturing method

To manufacture the bricks used in this research, an electronic scale (0.01 g precision) was used to weigh the appropriate amount of BG. BG samples were first mixed with water for dispersion and to dissolve the constituents of BG, such as