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Preparation of ceramic wall tiling derived from blast furnace slag

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Abstract

Blast furnace slag, the by-product of Turkish iron and steel production, has gradually been added to ceramic wall tile compositions. The effects of blast furnace slag have been studied by measuring the linear shrinkage, water absorption, dried strength, fired strength, thermal expansion coefficient and color value of tiles. A basic mixture, suitable for producing ceramic wall tiles with raw materials provided from the Yurtbay Ceramic Company (Eskişehir/Turkey), with the same composition as used in industry, was prepared. Compositions were prepared with blast furnace slag (BFS) waste replacing limestone and kaolin in the basic mixture, either partially or totally. The microstructures of sintered tiles and phase compositions were studied using a scanning electron microscope (SEM) and X-ray diffraction (XRD). The SEM result shows that anorthite containing a glassy phase has a higher amount of CaO content with an increase of blast furnace slag. The mechanical properties were measured according to ISO-EN 10545-4. When the observed samples are compared with a standard, the samples with waste show high strength due to the amount of crystalline phases and a low thermal expansion value. The experiment reveals that the addition of 33% BFS in ceramic wall tiles results in about a 25% increase in strength. The results also indicate that blast furnace slag is a potential secondary raw material for the production of wall tiles.

Keywords: Waste; Blast furnace slag; Ceramic wall tiles; Anorthite

1. Introduction

The evolution of waste has become an important social and environmental problem due to population growth and increasing industrialization. In 2010, methods of disposal of solid waste, according to the Turkish Statistical Institute's (TurkStat) database, were as follows: 1,023,142 thousand tonnes of municipal solid waste was collected, whereas 423,142,44 and 556 thousand tonnes was disposed of in controlled landfills, incinerated and composted, in Turkey. A total of 846,833 thousand tonnes of waste was disposed of without any control [1]. This waste constitutes many serious problems related to storage, transportation, and air and environmental pollution. The utilization of industrial waste for the production of building materials, concrete and cement is important for preventing environmental pollution, reducing production costs and saving energy. Thus, the need to develop new methods for recycling such waste is of great importance.

Iron ore tailing, steel slag and blast furnace slag (BFS) are examples of solid industrial waste which has been converted into value added products in recent years [2,3]. BFS is a by-product of steel production, discharged from blast furnaces in the steel smelting process, essentially consisting of SiO_2, CaO, Al_2O_3, MgO, along with other compounds such as FeO, TiO_2, and MnO_2 [4]. A large proportion of this slag is drenched in water, resulting in a glassy granulated material with latent hydraulic properties [5].

Influenced by the situation in the Turkish economy in 2014, finished steel consumption in Turkey declined that year, thereby affecting the volume of domestic finished steel output, according to a report released by the Turkish Iron and Steel Producer' Association (TCUD). As stated in the report, Turkey's

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finished steel output decreased by 0.9% to 36.09 million metric tons (mt) in 2014. In this year, Turkey's long product output totalled 25.72 million mt, down 3.1%, with its flat product output increasing by 5.1% to 10.38 million mt, both on a year-on-year basis. Meanwhile, 71.3% of the total finished steel output consisted of long products and 28.7% was accounted for by flat products. Again in 2014, Turkey's finished steel consumption decreased by 1.9%, year on year, to 30.74 million mt. For the same period, the consumption of long products in the country decreased by 3.3% to 16.14 million mt, while flat product consumption declined by 0.2% to 14.6 million mt, both year on year. In addition, for 2014, 52.5% of total finished steel consumption was for long products, while 47.5% was accounted for by flat products [6].

In the literature many researchers have pointed out the benefits of industrial waste for influencing the properties of building materials, concrete and cement. Research carried out by Lu et al. [4] shows that mixing of a certain amount of blast furnace slag (BFS), fly ash (FA) fluxed with potash feldspar and borax can be used to produce glass–ceramic glazes of low density, low water absorption, perfect stain resistance, as well as acid and alkali resistance. In another study, Sarkar et al. [7] investigated the possibility of developing vitreous ceramic tiles using steel melting electric arc furnace slag. They found that slag, to an extent of 30–40 wt% with other conventional raw materials, was used for sintering in the temperature range 1100–1150 °C. Other researchers have considered the production of glass–ceramic. Folgueras et al. [8] used a mixture of different proportions of blast furnace slag and fly ash to produce glass of the system SiO_2–MgO–CaO–Al_2O_3–R (R = Fe_2O_3, MnO_2, TiO_2). In their study, the glass–ceramic was characterized, with regard to behavior during sintering and crystallization, by determining bulk density and the arising crystalline phases. Kaya and Turan [9] produced opaque and transparent frits for both single and double firing glazes by adding BFS of different ratios in their study. They discovered that utilization of BFS in the production of value-added products, such as glass wool and glass fiber, was also successfully undertaken. Meanwhile, in addition to these studies, for the purpose of solid waste recycling, BFS can be mixed with other solid waste, such as clay, kaolin and quartz, and metallurgical and sewage sludge [10–13].

Ceramic bodies, for example tiles, are heterogeneous materials, consisting mainly of natural raw material mixtures, wide ranging in composition [14]. For this reason, such bodies can tolerate different types of waste, such as fly ash and blast furnace slag [15]. The main component of such waste is calcium–aluminium–silicate glass. However, fly ash is relatively abundant in Al_2O_3, while BFS is abundant in CaO.

In the present work, the authors focus on the utilization of BSF on the physical and chemical properties as well as the thermal expansion coefficient (CTE) of ceramic wall tile bodies. Furthermore, the phase–microstructure relationships of these tiles are investigated. Wall tile bodies are characterized by X-ray diffraction (XRD) and secondary electron microscopy (SEM) for the evolution of new phases and structural changes. The research objective of the study is to investigate the recycling and the utilization of BFS waste as a secondary raw material for wall tile body preparation in order to provide economic and environmental benefits to country.

2. Experimental procedure

2.1. Processing

The basic material for the present study is BFS waste product from the Erdemir Iron-steel Production Facility, Turkey. The chemical composition and particle size distribution of Erdemir blast furnace slag are reported in Table 1 [16]. The chemical compositions of the other raw materials used in wall tile body formulation are provided from the Yurtbay Ceramic Company (Eskisehir/Turkey) and are presented in Table 2. The constituents of the different mixtures are presented in Table 3. Standard wall tiling and BFS containing body compositions were prepared by wet milling (100 g water for 20 min), using a laboratory ball mill (residue < 2.5–3%, at 45 μm). The slip taken from the mill was

Table 1
The chemical composition and grain size distribution of BFS.

Chemical composition	Mean wt%	Grain size distribution (mm)	Range
CaO	32.7	+6.35	1% max.
MgO	7.3	−6.35, +3.15	2% max.
SiO_2	41.2	−3.15, +1.60	16–19%
Al_2O_3	14.3	−1.60, +1.00	33–37%
S	0.8	−1.00, +0.40	35–40%
MnO	0.8	−0.40, +0.15	3–6%
FeO	0.8	−0.15	6% max.
K_2O	0.9	Humidity	7–20%
TiO_2	1.1	Bulk density (t/m^3)	1–1.3

Table 2
The chemical analysis of raw materials (wt%).

Raw materials	[a]Weight loss	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Clay 1	7.52	61.58	22.98	1.29	3.02	0.34	0.53	0.49	2.24
Clay 2	10.00	58.00	25.62	–	4.38	0.47	0.18	0.40	0.85
Clay 3	6.81	64.46	21.32	1.08	2.48	0.70	0.41	0.45	2.27
Clay 4	6.02	66.87	20.20	1.17	2.11	0.14	0.85	0.09	2.42
Kaolin	0.09	72.72	16.31	0.55	0.62	0.47	0.16	1.15	2.15
Limestone	43.00	0.70	0.42	–	0.08	55.78	–	–	–
Sand	0.92	93.25	3.72	–	0.34	0.48	–	–	1.29

[a]Weight loss was determined at 1000 °C.

Table 3
Fractional (by unit weight) constituents of the mixtures.

Tile	Total amount of clay	Sand	Limestone	Kaolin	BFS
Std	40	7	11	42	–
D1	40	7	5	42	6
D2	40	7	–	42	11
D3	40	7	–	21	33