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Sustainability for Blast Furnace Slag: Use of Some Construction Wastes

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Abstract

Blast furnace slag is a by-product from blast furnaces which is used to produce iron. Blast furnace slag has been used extensively as a successful replacement material for Portland cement in concrete materials to improve durability, produce high strength and high performance concrete, and brings environmental and economic benefits together, such as resource conservation and energy savings. Construction wastes define as relatively clean and heterogeneous building materials which are generated from various construction activities. Among them, ceramic, brick, and marble wastes can be included. These kinds of wastes can be used successfully as replacement materials in the cement mortar or concrete mixing. The use of alternative aggregate is a natural step towards solving part of the depletion of natural aggregate, and the alternative aggregate processed from waste materials which would appear to be an even more sensible solution. Recycled aggregates, such as ceramic, brick, and marble wastes, in the blast furnace slag concrete have been investigated in the limited number of studies to date. In the literature, use of these wastes in the concrete produced by blast furnace slag, as replacement materials in cement have not found adequate attention. Therefore, in the present study, the effects of ceramic, brick, and marble wastes used as fine/coarse aggregates on the properties of blast furnace slag investigated. Thus, the contribution of these wastes on the sustainability of blast furnace slag concrete was presented in a detailed manner. Consequently, construction waste aggregates and blast furnace slag can be used to improve the mechanical properties, workability, and chemical resistance of the conventional concrete mixtures. Since the construction waste and blast furnace slag wastes are available in vast amounts in Turkey, it is economically and environmentally suitable to use these materials as aggregates in the production of more durable concrete mixtures.

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Keywords: Blast furnace slag, cement, concrete, construction waste aggregates, sustainability

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1. Introduction

In recent years, both the growth in the industrial production and the consumption increase in nature have led to a fast decline in available natural resources. A high volume of production has also generated a considerable amount of waste materials which have adverse impact on the environment (Binici, Shahb, Aksogan,& Kaplan, 2008). The scale of such problems makes them prudent to investigate other sources of raw materials in order to reduce the consumption of energy and available natural resources (O'Farrell et al., 2006; Baronio and Binda, 1997). In this regard, waste reuse and recycling are among modern society's environmental priorities, and considerable effort is still devoted to achieve these objectives (Martinez-Abella, Vazquez-Herrero,& Perez-Ordonez, 2012). Industrial wastes (e.g., slag, fly ash, and those of brick, ceramic, and marble) play an important role in the sustainable development of the construction industry. These wastes as a partial replacement of aggregate in mortar or concrete is very important because it presents many advantages such as the reduction in the consumption of natural resources and in the environmental pollution (Khanzadi and Behnood, 2009; Demir and Orhan, 2003; El-Hemaly et al., 1986). Concrete is a vital tool in the beneficial use of these materials in construction. The environmental impact of the production of raw ingredients (i.e., cement and fine and coarse aggregates) of concrete is considerable (Baali, Naceri, Rahmouni,& NouiMehidi, 2011).

The blast furnace slag is an industrial by-product from iron and steel industry. The concrete made with the blast furnace slag has many advantages, including improved durability, workability and economic benefits (Douglas, Wilson,& Malhotra, 1987). Marble has been used as an important building material, especially for decorative purposes for centuries. During sawing, shaping, and polishing process, about 25% of the processed marble turns into dust or powder form. Turkey has 40% of the total marble deposits in the world such that 7,000,000 tons of marble have been produced in Turkey annually and 75% of it has been processed in nearly 5000 processing plants. It is obvious that the waste material of these plants reaches millions of tons, thus making the stocking of this amount of waste impossible (Alyamac & Ince, 2009). Disposal of this waste material is one of the environmental problems worldwide today (FA-MW). But marble waste can be successfully and economically used to improve some properties of concrete (Geseoglu, Güneyisi, Kocabag, Bayram,& Mermerdas, 2012). Ceramic wastes, which are durable, hard and highly resistant to biological, chemical and physical degradation forces, cannot be recycled by any existing process. The use of inorganic industrial residual products in the production of concrete will lead to sustainable concrete design and a greener environment (Khaloo, 1995). The amount of waste in the different production stages of the ceramic industry ranges from 3% to 7% of daily production (Meyer, 2009). Clay-brick waste, which is rich in Al_2O_3 and SiO_2, is a significant component of construction and demolition (C&D) waste and is only partially recycled with the bulk ending up in landfills, thereby greatly diminishing both its yield and value as a potential renewable resource material for the manufacturing of new building products. Development of new generation building products, based on calcium silicates and made with clay-brick waste fines will provide enormous economic and environmental benefits to the society in general (Gutovic, Klimesch,& Ray, 2005).

In the literature review, the studies that related with both the use of one of the construction wastes (ceramic, brick, and marble) and blast furnace slag in the concrete were limited in number.

In the present study, the effects of ceramic, brick, and marble wastes used as fine/coarse aggregates on the properties of blast furnace slag concrete were investigated by an in-depth literature review. Thus, the contributions of these wastes on the sustainability of blast furnace slag were presented in a detailed manner. Consequently, both the use of wastes and their effects as fine/coarse aggregates in a sustainable concrete were examined.

2. Construction Wastes Addition in Blast Furnace Slag Based Concrete Results

2.1. Blast Furnace Slag Concrete with Marble Waste Addition

Binici, Shahb, Aksogan and Kaplan (2008) examined durability of conventional concrete which containing coarse aggregate such as granite or marble waste and fine aggregate such as ground blast furnace slag (GBFS) or river sand. The results were compared with those of conventional concretes containing limestone as coarse aggregate. Slump, air content, slump loss and setting time of the fresh concrete were determined. Furthermore, the compressive strength, flexural- and splitting-tensile strengths, Young's modulus of elasticity, resistance to abrasion, chloride penetration and sulphate resistance were also determined. The specimen groups and their contents were given in Table 1. MC2 specimen was marble aggregate and GBFS-based concrete specimens.

Table 1. Content of concrete specimens (Binici, Shahb, Aksogan,& Kaplan, 2008).

Specimens	Coarse Aggregates	Fine Aggregates
MC1	Waste Marble	River Sand
MC2	Waste Marble	GBFS
GC1	Waste Granite	River Sand
GC2	Waste Granite	GBFS
C1[1]	Limestone	River Sand
C2[2]	Limestone	GBFS

According the results, the setting times of the control concretes were longer than those of marble concrete (MC) and granite concrete (GC) concretes. The use of the marble, granite and GBFS reduced both the initial- and final setting times of the concrete. Also, a decrease in both the air content and slump value of the concrete was observed for all the specimens that included GBFS. Hence, the decrease in slump and air content can be attributed to the activity of GBFS. Compressive strength and abrasion resistance of the concrete were strongly influenced by its marble, granite and GBFS content. MC2 showed considerably higher resistance to chloride and sulphate attack than all the others. The results indicate that the addition of marble and granite into concrete reduces the chloride penetration depths by about 70%. In the specimens containing marble and GBFS there is a much better bonding among the additives, cement and aggregates. Furthermore, it may be said that marble and GBFS replacement rendered a good condensed matrix. The increased durability of concrete can be attributed to the glass content and chemical composition of the GBFS. Some mechanical values of specimens (MC2, GC2 and control) were listed in Table 2.

Table 2. Comparison of some mechanical values of concrete specimens included marble / granite waste and control specimens (Binici, Shahb, Aksogan,& Kaplan, 2008).

Specimens [3]	Compressive Strength (MPa)	Flexural Strength (MPa)	Splitting-Tensile Strength (MPa)	Young's Moduli Of Elasticity (GPa)
MC2	47,2	6,9	3,5	36,1
GC2	44,0	6,3	3,2	33,6
C1	25,1	3,9	2,1	21,3
C2	35,2	4,3	2,4	23,2

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[1] Control Specimen Type 1.

[2] Control Specimen Type 2.

[3] All values in Table 2 were determined for 28 days and these values were average of three specimens.

In other study, Guneyisi, Gesoglu and Ozbay (2009) investigated the effects of binary and ternary use of marble powder with GGBFS on the fresh properties of self-compacting mortars (SCMs). The fresh properties of SCMs were tested for mini-slump flow diameter, mini-V-funnel flow time, initial and final setting times, and viscosity. Moreover, the hardened properties were tested for compressive strength and ultrasonic pulse velocity. For this purpose, a total of 19 SCMs mixtures were prepared in which the binder was composed of binary or ternary blends of Portland cement (PC), marble powder (MP), and GBFS at varying replacement levels. The mixture descriptions of SCMs mixtures were listed in Table 3.

Table 3. Mixture descriptions of specimens of SCMs mixtures (Guneyisi, Gesoglu,& Ozbay, 2009).

Mixture No.	Mix description	Mixture No.	Mix description
M1	Control - PC	M11	15MP-5GBFS
M2	5MP	M12	5MP-35GBFS
M3	10MP	M13	10MP-30GBFS
M4	15MP	M14	15MP-25GBFS
M5	20MP	M15	20MP-20GBFS
M6	20 GBFS	M16	5MP-55GBFS
M7	40 GBFS	M17	10MP-50GBFS
M8	60 GBFS	M18	15MP-45GBFS
M9	5MP - 15GBFS	M19	20MP-40GBFS
M10	10MP-10GBFS		

The test results supported that using MP in the binary blends slightly increased the need of superplasticizer of the mixtures whereas with the use of GGBFS, a gradual fall was observed in the amount of superplasticizer used. V-funnel flow times of ternary blends were measured in between those the binary blends. Ternary use of MP and GBFS diminished the negative effect of MP and decreased the viscosity of mortars underneath the viscosity of control mortar. There was a clear trend that the binary and ternary of MP and GGBFS with PC prolonged the initial and final setting times of SCMs. The ternary blends of MP and GGBFS with PC had relatively lower compressive strength vales than that of binary blends of PC+MP blends.

Colangelo and Cioffi (2013) reported that sustainable production of artificial aggregates using three different samples of solid industrial wastes (cement kiln dust (CKD), granulated blast furnace slag and marble sludge) by a cold bonding pelletization process. Cold bonded artificial aggregates were characterized by determining physical and mechanical properties of two selected size fractions of the granules for each studied mixture. Eighteen types of granules were employed in C28/35 concrete manufacture where coarser natural aggregate were substituted with the artificial ones. In this study, two different types of cement kiln dust, named CKD1 and CKD2, a GBFS and a marble sludge (MS) were employed to produce cold-bonding pellets. The CKD1 and CKD2 samples were representative of plants operating in different conditions and were collected by electrostatic precipitators and bag houses, respectively. CKD1 and CKD2, together with GBFS, were employed as binding agents in the preparation of pelletization mixtures. Furthermore, MS was added as filler to improve physical and mechanical properties of pellets. Two series of binding mixtures, named M1–M6 and M7–M12 contained different amounts of CKD1 and CKD2, respectively. In these series, GBFS to CKD ratios were 1, 2 and 4, respectively. The filler amount was fixed at 70%, in the mixtures M1–M3 and M7–M9, and 80% in the mixtures M4–M6 and M10–M12. All the mixtures compositions were reported in Table 4.

Table 4. Pellets composition (wt %) (Colangelo & Cioffi, 2013).

Mixtures	CKD1	CKD2	GBFS	MS	Mixtures	CKD1	CKD2	GBFS	MS
M1	15	–	15	70	M7	–	15	15	70
M2	10	–	20	70	M8	–	10	20	70
M3	6	–	24	70	M9	–	6	24	70
M4	10	–	10	80	M10	–	10	10	80
M5	7	–	13,5	80	M11	–	7	13,5	80
M6	4	–	16	80	M12	–	4	16	80

Normal Strength Concrete C 28/35 (UNI EN 206–2006) mixes were designed by using eighteen types of pellets. In particular, two size classes, whose dimension varied in the ranges of 4–12 mm and 12–20 mm, respectively, of the artificial aggregates M1, M3, M4, M7, M9 and M10 were employed as substitution of coarser natural ones. The aggregates were chosen considering the maximum amount of CKD (systems M1 and M7), the maximum amount of CKD + MS (systems M4 and M10) and highest compressive strength (systems M3 and M9). According the test results, the highest strength is always showed by the concrete containing M9 type aggregate. This mixture was made with 6% of CKD2, 70% of MS and 24% of GBFS. Moreover, it can also be seen that all the specimens have density values < 2000 kg/m^3 that is the limit indicated in UNI EN 206-1:2006 standard for lightweight structural concrete (LC).

2.2. Blast Furnace Slag Concrete with Brick Waste Addition

Baali, Naceri, Rahmouni and NouiMehidi (2011) investigated the possibility to make a mortar with ternary sand (natural and artificial fine aggregates). For this study, three sands used: a dune sand (DS), a slag sand (SS), and brick sand (BS) at different proportions in mortar. The artificial fine aggregate consisted of both blast furnace slag and waste brick fine aggregate in order to use it as fine aggregate. In this work, they studied quality and grain size distribution of ternary sand which consisting of both slag sand and brick sand and properties of fresh and hardened mortar were analyzed. A ternary sand mixture made using 70% dune sand (DS) and 30% slag sand (SS) and brick sand (BS) combined. Five series of ternary aggregate mixtures and one reference control mixture (100% DS) prepared. The physical properties of natural and artificial sands were determined according to analysis results. While DS has the lowest porosity value, SS has the highest porosity value. Moreover while DS presents a fine particle size distribution, SS presents a coarse particle size distribution. Therefore, both particle size distribution and porosity of ternary sand improved with incorporated optimum percentages of artificial and dune sands. According to the results of the slump test, amount of slag in the mixtures increased slump value of mortars decreased. The use of artificial fine aggregates (slag sand and brick sand) for each curing age reduced the dry densities of all mixtures with increasing the artificial waste fine aggregates, because the variation of density and water absorption of waste fine aggregates (SS and BS) is higher than that of natural sand (DS). The results obtained specify in a clear way that the incorporation of artificial sand 30% (30% of SS and BS) in the dune sand (70% DS) improved the mechanical strengths (compressive and flexural strengths) of the mortars tested to base of the ternary mixtures. This can be explained by the fact why nature (chemical composition) and the grain-size distribution are the principal parameters which influence the increase in the mechanical behavior of the mortar tested.

In other study, Işıkdag and Topcu (2013) used ground granulate blast-furnace slag was used in Horasan mortars to obtain improvements on physical and mechanical properties. Horasan mortar is mortars type that containing brick or tile powder and lime in Ottoman and Cocciopesto in ancient Roman. The ground granulate blast-furnace slag was used instead of crushed tile and tile powder as aggregate at various proportions. In addition, lime was used as a binder in the mortars. The physical and mechanical tests were conducted on mortars and the exposure of freeze and thaw on mechanical properties was examined. The microstructure, chemical composition and thermal analysis were investigated by SEM-EDS, XRD and TGA. The specimens were produced by replacing 0–10–20–30–40% ratios of GGBS instead of crushed tile (CT) and tile powder (TP), individually, and 15% lime was added as a binder while mixing. According to result, generally, higher compressive and flexural strengths were observed on specimens for TP+GGBS series in comparison of CT+GGBS series (see Fig.1.). The highest compressive and flexural strengths were obtained from TP+GGBS (%40) at the age of 28 days. However, compressive and flexural strengths of all specimens decreased with the exposure of freeze and thaw cycles owing to repetition of strains in pores filled with water. These specimens also had high resistance under freeze and thaw tests compared to other series of specimens. According to SEM and XRD analysis, TP and CT both had lower puzzolanic activity owing to firing process over 900 ^{0}C during production however; due to mechanical tests, larger surface area of TP leads slightly higher hydraulic property compared to that of CT.

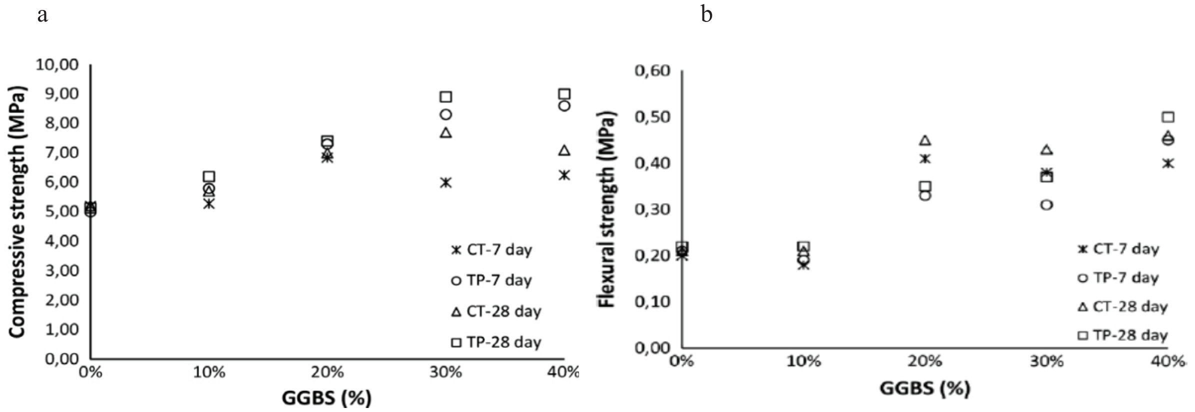

Fig.1. (a) Compressive strength of specimen; (b) Flexural strength of specimens (Işıkdag & Topcu, 2013).

2.3. Blast Furnace Slag Concrete with Ceramic Waste Addition

Higashiyama, Sappakittipakorn, Mizukoshi and Takahashi (2014) developed the mortar manufactured ceramic waste aggregate (CWS) as an eco-efficient construction material with incorporated ground granulated blast furnace slag (GGBS). The compressive strength development and durability of the CWA mortar with GGBS were investigated. Carbonation and chloride ingress, which are two main issues regarding the durability of cement-based materials were studied. In the mixture proportion, the water–binder (W/B) ratio was kept constant at 0.5 by weight and CWA–binder (S/B) ratio was also kept constant at 2.0 by weight. The CWA mortar without the GGBS as a control mixture was compared with the modified mixtures in which the cement was partially replaced with GGBS at 15%, 30%, and 45% by weight. In the study, the ceramic wastes were broken by using a hammer and a jaw crusher to small piece ranging from 50 to 100 mm size. Next, by using a cone crusher, these pieces were crushed into small grains at a particle size of 30 mm or smaller. These particles have sharp, knife-like edges at this stage, which would be still dangerous to supply as aggregate for mortar and concrete. Therefore, removal of the sharp edges from the CWA was subsequently achieved by a grinding machine. Finally, the particle sizes ranging from 0.075 to 5.0 mm, as displayed in Fig.2.

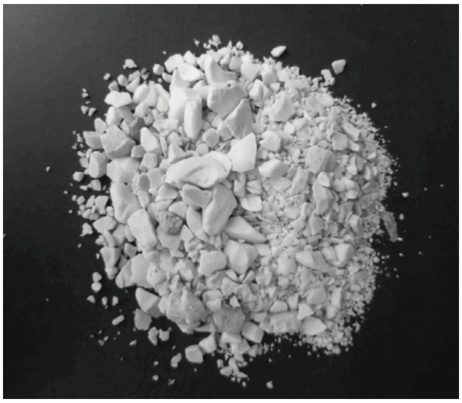

Fig.2. Ceramic Waste Fine Aggregate (Higashiyama, Sappakittipakorn, Mizukoshi,& Takahashi, 2014).

From the overall test results in this study, replacement of cement in the CWA mortar by 15–30% GGBS provides the best compromise between improvements in compressive strength (tabulated in Table 5) and resistance to chloride ingress, and the tendency for higher GGBS additions to promote carbonation. However, for improving resistance to chloride ingress, the higher (45%) GGBS replacement level is more effective. As the carbonation and chloride ingress are time dependent, these tests presented herein are being continued up to 96 weeks of exposure.

Table 5. Compressive strength development (Higashiyama, Sappakittipakorn, Mizukoshi,& Takahashi, 2014).

Mixture	GGBS Replacement (%)	Compressive Strength (N/mm^2)		
		7 days	28 days	91 days
CWAM0	0	34.7	55.3	60.8
CWAM15	15	36.5	57.5	70.8
CWAM30	30	34.3	58.3	71.5
CWAM45	45	31.3	52.5	61.9

3. Conclusions

According to literature search results, it can be concluded that limited studies were achieved related to the recycling of the construction wastes (such as ceramic, brick, and marble) and blast furnace slag in the concrete together. Generally, results of these studies, construction waste aggregates and GBFS can be used to improve the mechanical properties, workability, and chemical resistance of the conventional concrete mixtures. Since the construction waste and GBFS wastes are available in vast amounts in Turkey, it is economically and environmentally suitable to use these materials as aggregates in the production of more durable concrete mixtures.

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