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RESEARCH OF PHYSICAL AND MECHANICAL PROPERTIES OF BLENDED BRICKS WİTH FLY ASH BASED, BLAST FURNACE SLAG ADDITION

Hakan Çağlar [*1], Arzu Çağlar [2]
[*1] Civil Engineering, Kastamonu University, Turkey
[2] Building Control, Kastamonu University, Turkey

Abstract

In this study, it is aimed to make improvements on blended brick (1) which is the first building material has a history of at least 10,000 years. To the blended brick which is a traditional material was kept constant at 5% the addition of fly ash which is industrial waste. It was aim of determine of the effect on the physical and mechanical properties of the blended brick using different ratios (5%, 10%, 15% and 20%) blast furnace slag. In the first stage, the production of fly ash-based blast furnace slag doped sample of blended brick was performed. In the second stage, a variety of experiments were applied to determine the physical and mechanical properties of the blended brick sample. As a result; It has been determined that unit volume weight and compressive strength decreases with the use of industrial wastes in blended brick production. They have occured an increase in porosity and capillary water absorption values. The use of industrial wastes in the production of blended bricks will contribute both improve the properties of the bricks and the reduction of wastes left to the environment.

Keywords: Flay Ash; Blast Furnace Slag; Brick; Physical Property; Mechanical Property.

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1. Introduction

The brick one of the most important elements in the construction industry (2) and its manufacturing is one of the oldest industries from 8000 BC to this day (3). Brick is a burnt block obtained after the burning of clay in a furnace (4). It is a large-scale building material, which is generally used in the construction of exterior and interior walls at building (5).

One of the important factor determinants of brick quality is the property of clay. The clay used in the production must be made of very fine granules and when mixed with water, it must become the plastic dough which can be given the desired shape (6).

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One of the biggest disadvantages of traditional brick production is the rapid consumption of fertile soils in brick production. China is top of the largest brick producing countries worldwide (7). India is the second largest country with annual production of 180 billion tons of bricks (8). 300 million tons of fertile soil is consumed per day for the production of bricks in India (9). The production of bricks in Ontario (Canada) is about 700 million per year (10). Therefore, to overcome this problem, some countries such as China limit the use of clay for brick production (11).

Blended brick has lower strenght than factory bricks. In addition, in terms of strength and durability, it was observed that these bricks were weaker than cement blocks (7). To overcome these deficiencies, different pozzolanic materials is added to the blend bricks (12). Various researchers have investigated the use of different waste materials in bricks. Waste glasses can be used as an additive in brick. Using waste glass, bricks that is increased compressive strength and water absorption property were produced (13). In clay bricks, agricultural wastes such as sugarcane pouch ash and rice husk ash can be used (14,15). In addition to agricultural wastes, industrial by-products such as fly ash, blast furnace slag, silica fume and boron waste are also used as additives in brick production (16).

In this study, fly ash that is one of the industrial wastes was used. Fly ash that is one of the industrial by-products and which is formed during the burn of coal for energy production, causes environment pollution. For this reason, the recycling of fly ash as raw waste material for the construction sector is a solution process very useful aspect economical and environmental (17). The properties of fly ash, are vary depend on the type of burned coal, the type of combustion equipment used and the fly ash collection mechanism used (18). The fly ash is a waste that is physically very fine, dusty, predominantly silica-containing, spherically shaped particles and has an excellent pozzolanic property (19). Its color can vary according to the combustion properties of coal. Unburned carbon gives a black color to the fly ash when the combustion process is not sufficient. The color of the fly ash which is formed as a result of complete combustion is lighter than the other (20). The amount of fly ash emerging in the world is about 600 million tons per year (21). In addition, clay which is the main raw material of the bricks, has been understood to develop the properties of the bricks produced by mixing with the fly ash at certain rates (22).

Various research was conducted on the use of fly ash as an additive in brick production (24, 24). Fly ash added bricks compared to clay bricks, fly ash added bricks have been seen to obtained 10% lighter bricks (8). Also, fly ash is increased strength and reduced water absorption (5). Leiva et al. (25) found that reduction of compressive strength was obtained by firing the bricks below 1000 ° C and increasing the amount of fly ash additive. Çiçek and Çinçin (26) reported the superior thermal conductivity of fly ash bricks compared to traditional clay bricks. Fly ash added bricks generally have smooth edges compared to clay bricks (8). In many parts of the world, fly ash is used instead of cement (27). Moreover, the production cost of fly ash bricks is 2% lower compared to clay bricks (28). Therefore, the use of fly ash in blended brick production is important in terms of cost effectiveness, strength and durability of bricks. All of these studies showed that fly ash bricks have higher water adsorption, low resistance towards abrasion, low strenght toward fire and high porosity (9).

Another waste used in the study is blast furnace slag. Blast furnace slag which is contained a large amount of silica and alumina and having an amorphous structure is showed pozzolanic properties

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if they are ground to very fine grains (29). Milled blast furnace slags have different usage styles such as serve as binders (30). Blast furnace slag is generally used as a suitable material for the construction industry. It is used as an auxiliary material to strength construction materials, increase their durability and achieve high performance. It also provides some economic and environmental benefits, such as energy and waste material savings (31).

In this study, in the blended brick, which is a traditional material, the fly ash which is industrial waste has kept constant at a rate of 5%. It was aim to determine the effect on physical and mechanical properties of blended brick produced using different ratios (5%, 10%, 15% and 20%) of blast furnace slag. Firstly, fly ash-based blast furnace slag doped sample had produced. Then, various experiments had performed to determine the physical and mechanical properties to the sample of the blended brick produced.

2. Materials and Methods

2.1. Materials

Fly Ash (FA) is an ash which the remaining a result of the burning of coal in steam power plants. It has cement fineness and pozzolanic properties (32). The fly ash used in the study and the chemical composition given in Table 1; It was obtained from the Seyitömer Thermal Power Plant. In the experiments, F-type fly ash was used which had a bulk density of 0.88 g/cm^3, a specific gravity of 1.58 g/cm^3, a specific surface area of 0.125 m^2/g, and a pH of 8.3, which was lighter than the other fly ash.

Table 1: Chemical Analysis of Seyitömer Fly Ash (33)

Compound	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	Na_2O	K_2O	SO_3	Na_2O (equ.)	Indep. CaO
(%)	52.,4	7,47	5,75	9,30	18,91	0,88	2,17	2,25	2,31	0,20

Blast furnace slag (BFS), iron ores are subjected to melt and heat up to high temperatures in blast furnaces. Coking coal is used as fuel. In these furnaces, the carbon of the coking coal with the effect of temperature is create carbon monoxide and carbon dioxide gases to united with the oxygen in the iron oxide of ore. It leaves the material called slag together with the molten iron when these gases leave the furnace. The melt materials are collected from the lower end of the furnace. Since the densities are different, the iron the lower part of the melt materials, the slag the upper part has formed. When the hot liquid slag comes into contact with water, it turns into particles of 1-10 mm grain size. The slag is a by-product which is granulated by sudden cooling with water. This material containing aluminum, silica and lime may be mixed with very little lime or cement. Because this situation gives the property of binding, it is accepted a pozzolan (34). The blast furnace slag used as additive material was obtained from the Karabük Iron and Steel Factory. Clay soil; the clay soil used as the main material was obtained from the clayey soil pile within the boundaries of Taşköprü district of Kastamonu province. It was seen that silicon (Si) element is the most common element in the blended brick which is investigated at Kastamonu University Center Research Laboratory Application and Research Center (Table 2). In addition, aluminum (Al), calcium (Ca), oxygen (O), iron (Fe) and magnesium (Mg) elements are located in clay structure.

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Table 2: Clay mineralogy

Element	O	Mg	Al	Si	Nb	K	Ca	Fe
Weight (%)	21,83	1,87	8,67	38,49	5,21	2,06	14,95	6,93

2.2. Method

2.2.1. Production of Fly Ash-Based, Blast Furnace Slag Additive Blended Brick Samples

The production of blended brick samples has made in the Emek Brick Factory in Boyabat district of Sinop province.

The study started with the removal of the main material from the clayey soil piles in the district of Taşköprü in Kastamonu province. The clayey soil sample taken by the quartering method was ground in the laboratory type roller hammer and then 1 mm sieve material was obtained. The fly ash and blast furnace slag to be used as additive in the experiment were subjected to the same treatments. The recipe for the mixture prepared for brick dough is given in Table 3. The kneading water was added to each mixture in 20% of the total weight of the material. In the study, reference (REF), 5%FA and 5%BFS doped blended brick sample (5%FA+5%BFS), 5% FA and 10% BFS doped blended brick sample (5%FA+10% BFS), 5%FA and 5% BFS doped blended brick sample (5%FA +15%BFS) and 5% FA and %20BFS doped blended brick sample (5%FA+20%BFS).

Table 3: Mixing prescription

Prescription	Clay soil (%)	BFS (%)	FA (%)	Water (%)
REF	100	-	-	20
%5FA +%5BFS	90	5	5	20
%5FA +%10BFS	85	10	5	20
%5FA +%15BFS	80	15	5	20
%5FA +%20BFS	75	20	5	20

Firstly, fly ash, blast furnace slag and clay soil samples has been turned into furnace dry in the furnace. Dough to be created mixture was weighed in the proportions given in the prescription with the precision scale and taken into the mixing bowl. All materials were mixed with water after the dry mixture was made. The obtained brick dough was left to rest for 24 hours in a way that would not lose its moisture. After resting, it was mixed until no air bubbles were left in mixer (5 minutes). After the kneading process is finished, the mixture prepared in plastic consistency was poured into steel molds. After they were waited 24 hours in normal weather conditions, they were removed from the molds. The extracted brick samples were allowed to dry in a half-open area for 7 days. At the end of the 7 days, they were fired by increasing the temperature gradually in time adjustable electric ash furnace at 900 ° C. Samples of brick removed from the furnace were brought to room temperature (Figure 1).

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Figure 1: Cooling of samples

2.2.2. Physical Experiments Applied to Samples

Weight Per Unit of Volume

The samples of doped blended brick produced in 4x4x16 cm dimensions were placed in the oven which had a temperature of 105 ± 1 ° C. The samples were dried to until constant mass for 12 hours. The samples dried in this way were cooled until room temperature and then the size was 0.01 mm sensitivity was measured by caliper. The masses of the samples were measured with precision scales and the weight per unit of volume was determined (35).

Capillary Water Absorption

The samples were dried until the constant weight in the drying oven. The samples removed from the drying oven were kept in the laboratory for 1 hour and brought to room temperature. The dry weight of the cooled samples was weighed with the help of precision scales (m_{first}). Because they must not come into contact with water, all sides of blended brick samples which are bottom surface dimensions 4x4 cm are covered with paraffin in 1 cm height. The bottom surfaces of the coated samples were placed in water-filled vessel which was 1 cm high which touched the surface of the water and with grid. At certain times of the samples (60, 120 and 180 min) weight measurements were made. After 180 minutes, the samples were weighed (m_{end}). The values found were replaced in (1). Thus, capillary water absorption amount was calculated (36).

Capillary water absorption (capillarity) (g): $m_{end}-m_{first}$ **(1)**

Porosity

In order to determine the porosity values of the doped samples, they were boiled in a container for 3 hours and bring to waterlogged situation. Samples were taken from the container and their hanging weights in water were measured (P_3). After measurement, the samples were wiped dry with a dry cloth and was bring to dry-surface situation. Then, the waterlogged surface dry weights were measured (P_2). The samples were dried in the drying oven at +105 ^oC for 24 hours and weighed again after they were constant-weight (P_1). The values found were replaced in (2) and the porosity values were calculated (35).

Porosity (%) = $((P_2-P_1) / (P_2-P_3)) \times 100$ **(2)**

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2.2.3. Mechanical Experiments Applied to Samples

Compressive Strength

The samples were dried at +105 0C in the dry oven until constant-weight. The compressive strength value of the dried samples was calculated by dividing the breaking load to the surface area (4x4 cm) (37).

3. Results and Discussions

The data obtained by physical and mechanical experiments of the blended brick samples shows in Table 5. When the table is examined; the REF sample were seen the highest weight per unit of volume with 1.91 g/cm^3, while 5%FA + 20%BFS added blended brick samples had the lowest weight per unit of volume with 1, 85 g/cm^3. According to the capillary water absorption test data, the REF sample has the lowest value with 99,1 g capillary water absorption amount, the 5%FA + 5%BFS added blended brick sample has the highest value with 102,5 g capillary water absorption amount. The REF sample had the lowest porosity with a ratio of 21,1%, while the 5%FA+20%BFS sample had the highest porosity with a rate of 26,2%. As a result of the compressive strength test to determine the mechanical properties, It was determined that the 5%FA+ 20%BFS added blended brick was the lowest compressive strength with 2,98 MPa, the REF sample has the highest compressive strength with 4,45 MPa.

Table 4: Physical and mechanical values of blended bricks

	Physical Values			**Mechanical Values**
	Weight Per Unit of Volume (g/cm^3)	**Capillary water absorption (g)**	**Porosity (%)**	**Compressive Strength (MPa)**
REF	1,91	99,1	21,1	4,45
%5FA +%5BFS	1,90	99,8	22,3	4,02
%5FA +%10BFS	1,88	100,6	23,4	3,87
%5FA +%15BFS	1,87	101,4	25,5	3,40
%5FA +%20BFS	1,85	102,5	26,2	2,98

3.1. Weight Per Unit of Volume

The sample values obtained as a result of the weight per unit of volume test which is one of the physical properties are given in Figure 2. When the figure is examined; it was determined that the amount of fly ash was kept constant and with the increase amount of blast furnace slag the weight per unit of volume values of the samples were decreases. The reason of the decrease can be explained as the density of the fly ash is greater than the density of the clay. There is no limitation for the weight per unit of volume of the brick in TS 705 (38), which is related to blended brick. However, the use of bricks which was low weight per unit of volume in building structure will help to reduce the overall weight of the building. This situation will help to increase the performance of buildings in earthquake zones.

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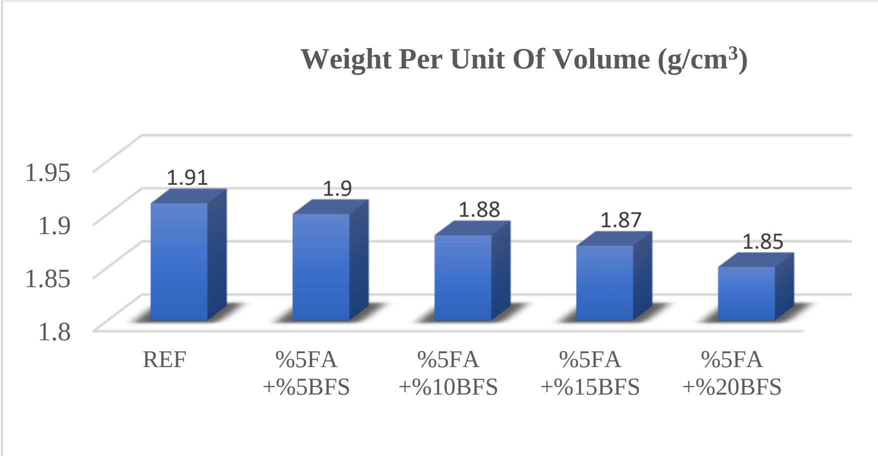

Figure 2: Weight per unit of volume values of brick samples

3.2. Capillary Water Absorption

The rate of capillary water absorption of the materials is associated with clearance ratio in their structures, the volume, size and inter-pore bonds of the open pores related to the material surface (39). The capillary water absorption test data, which is one of the experiments to determine the physical properties of the blended brick samples, is presented in Figure 3. According to the result of the experiment, it was seen that the amount of capillary water absorption increased with the increase of the amount of additive. This situation can be explained by the high-water absorption capacity of fly ash (40, 41). An increase in the amount of capillary water absorption of the blended brick that is used as an external wall filler is created an undesirable situation for the structure. It was thought that the reason of the high of amount of capillary water absorption is that the samples of blended brick, fired at 900 ^{0}C, cannot be reached to sufficient sintering (42).

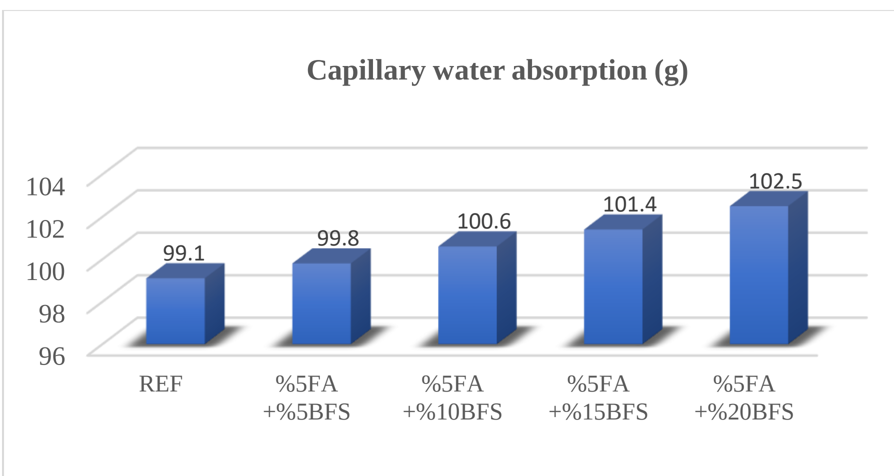

Figure 3: Capillary water absorption values of brick samples

3.3. Porosity

The values of porosity, which is known as the void ratio, are given in Figure 4. When the graph is examined; With the increase in the amount of BFS porosity values are seen to increase. Increasing

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the amount of porosity is a positive situation for the weight per unit of volume value. However, capillary water is a negative situation for the amount of absorption. In other words, the increase of porosity will lead to increase the amount of capillary water absorption despite the fact that it creates a light construction material.

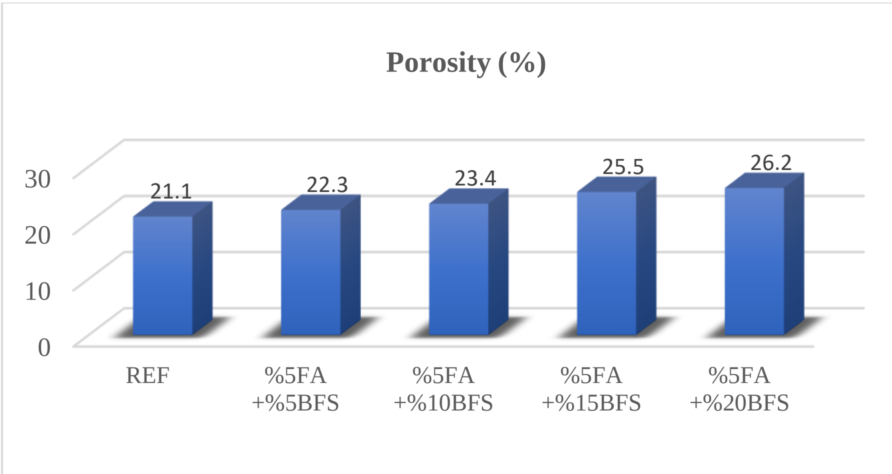

Figure 4: Porosity values of brick samples

3.4. Compressive Strength

Compressive strength is one of the most important parameters used to ensure engineering quality in construction materials (42). As a result of the experiments, the FA was kept constant and It has been seen that by increasing the blast furnace slag, the compressive strength of the samples decreased (Figure 5). Although BFS increases the compressive strength of the brick sample (42) it needs a high calcination temperature of 1050 °C in order to provide higher strength of blended brick that is included fly ash (43). The best result in the study was obtained from 5%FA+5%BFS added blended brick.

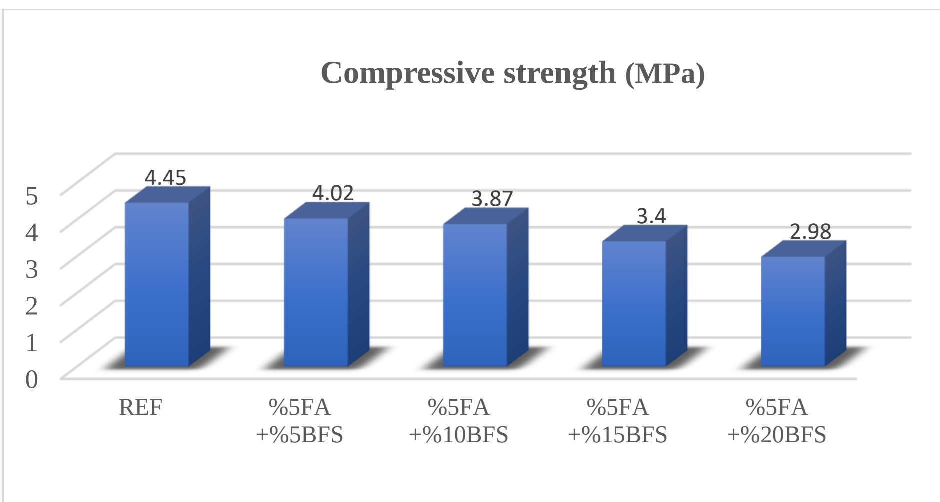

Figure 5: Compressive strength values of brick samples

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4. Conclusions and Recommendations

In this study, physical and mechanical properties of blended bricks containing fly ash-based blast furnace slag were investigated. As a result of the experiments; With the increase in the of amount of blast furnace slag, in the weight per unit of volume values reduction were occurred. This reduction in the unit weight of the blend bricks will increase the performance of the structures in the earthquake affected areas and will help to reduce the total weight of the structures. In the study, it was seen that by increase of the amount of additive was increased porosity and the capillary water absorption values. When the compressive strength that is one of the mechanical properties is examined, it has been determined that there is a decrease in the compressive strength by increase of amount of waste. The use of fly ash and blast furnace slag in the production of blended brick samples is thought to be an effective way to disposal these wastes. The use of waste materials in threshing brick production is provided benefits the protection of natural resources such as fertile soil and the improvement of the properties of the blended bricks.

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*Corresponding author.
E-mail address: hcaglar@ kastamonu.edu.tr