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Uçucu Kül Bazlı Geopolimer Tuğlanın Yüksek Fırın Cürufu İkamesiyle Isı İletim Katsayısının İyileştirilmesi

Improvement Of Heat Conductivity Coefficient Of Fly Ash-Based Geopolymer Brick By Substitution Of Blast Furnace Slag

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ÖZET

Tarihin bilinen en eski malzemelerinden olan tuğla, zamanla gelişimini sürdürerek günümüze kadar gelmeyi başaran bir yapı malzemesidir. Teknolojinin gelişmesiyle tuğla sürekli revize edilmiştir. Son zamanlarda araştırmacılar, tuğla bünyesine atık malzemeler ikame ederek geopolimer tuğla üretimine yönelmiştir.

Bu çalışmada, uçucu kül bazlı geopolimer tuğlaya yüksek fırın cürufu ikamesinin ısı iletim katsayısına etkisinin araştırılması amaçlanmıştır. Çalışmada, farklı oranlarda (%10, 30, 50 ve 70) yüksek fırın cürufu kil ile yer değiştirilmiştir. %20 oranında uçucu kül sabit tutulmuş, Alkali aktivasyon için 8 ve 10 M sodyum hidroksit, %4 ve %8 oranında kalsiyum hidroksit kullanılarak geopolimer tuğla üretimi yapılmıştır. Numunelere ısı iletim katsayısı tayini deneyi uygulanmıştır. Sonuç olarak; yüksek fırın cürufu, sodyum hidroksit ve kalsiyum hidroksit ikamesinin artmasıyla ısı iletim katsayısında azalma olduğu görülmüştür. En iyi sonuç, 0,26 W/mK ile %70 oranında yüksek fırın cürufu, 10 M sodyum hidroksit ve %8 kalsiyum hidroksitten üretilen tuğla numunelerinden elde edilmiştir. Bunun yanı sıra geopolimer tuğlanın endüstriyel atıkların bertaraf edilmesi için etkin bir yol olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Yüksek fırın cürufu, uçucu kül, geopolimer tuğla, tuğla

ABSTRACT

Brick, one of the oldest materials known in history, is a building material that has come up to the present day by continuing its development over time. However, with the development of technology, the brick has been continuously revised. Recently, researchers have turned to the production of geopolymer bricks by substituting waste materials into the brick structure.

In this study it is aimed to research the effect of blast furnace slag substitution on the heat conduction coefficient of fly ash-based geopolymer brick. In the study, blast furnace slag was replaced with clay in different proportions (10, 30, 50, and 70%). Furthermore, 20% of the fly ash was kept constant, 8 and 10 M of sodium hydroxide for alkaline activation, and 4% and 8% of calcium hydroxide were used to produce geopolymer bricks.

The heat conductivity coefficient determination experiment was applied to the samples. As a result, it was observed that the heat conductivity coefficient decreased with the increase of blast furnace slag, sodium hydroxide, and calcium hydroxide substitution. The best results were obtained from brick samples produced from 70% blast furnace slag, 10 M sodium hydroxide, and 8% calcium hydroxide with 0.26 W/mK. In addition, it has been concluded that geopolymer brick is an effective way to dispose of industrial waste.

Keywords: Blast furnace slag, fly ash, geopolymer brick, brick

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1. INTRODUCTION

Due to the high energy requirement and consumption of natural resources, clay and shale are mainly used as raw materials in brick production, which are environmentally friendly and uneconomical. For this reason, the research of alternative construction materials has received growing attention in recent years. In addition to insufficient landfills, industries are known to dump large amounts of waste materials, which are economical and environmental problems (Zeyad et al., 2021; Faried et al., 2021; Tayeh et al., 2021; Amin et al., 2021; Calis et al., 2021; Hamada et al., 2020).

Using waste materials in brick production can reduce storage problems and the consumption of resources (Zhang, 2013). Besides, this approach helps reduce energy consumption by avoiding incineration or high effort to dispose of waste and make better use of it.

Researchers used a wide variety of waste materials (for example, fly ash, blast furnace slag, mine, rice husk ash, cotton waste, oyster shell, and wood shavings) as substitutes or additives in brick production (Ahmari et al., 2012; Kumar et al., 2013; Wang et al., 2016; Sukmak et al., 2013; Abdullah et al., 2015; Zawrah et al., 2016; Venugopal et al., 2021; Apithanyasai et al., 2018; Ahmari et al., 2013; Ahmari et al., 2013; Madani et al., 2020; Tayeh et al., 2021).

The name "geopolymer" was first used by Davidovits (Davidovits, 2008) to describe inorganic aluminosilicate polymers produced by synthesizing natural materials such as metakaolin or industrial by-products such as fly ash (Wongpa et al., 2010;O'Connor et al., 2010; Kani et al., 2009; Hardjito et al., 2010) and blast furnace slag with highly alkaline activators (Bakharev et al., 1999).

Geopolimerizasyon technology, environmental and economic benefits of recycling waste materials because of aluminosilicate-rich industrial by-products as an alternative way for the production of bricks by using various wastes have been introduced (Kuranchie et al., 2016; Apithanyasai et al., 2020). This process involves a chemical reaction between aluminosilicate materials obtained from industrial by-products and a highly concentrated aqueous alkaline hydroxide or silicate solution that produces a durable material with an amorphous polymeric structure (Tayeh et al., 2019; Al Saffar et al., 2018). Geopolymers exhibit a wide range of properties, including high compressive strength, low shrinkage, high-temperature resistance (Barbosa et al., 2003), and acid and fire resistance (Wu H-C et al., 2007; Duxson et al., 2007).

All over the world, a lot of research is being done on the use of waste materials (Barbosa et al., 2000)]to prevent an increasing threat to the environment or to modernize existing waste disposal techniques by making them more affordable and environmentally friendly (Swanepoel et al., 2002).

Surul et al. (2021) reported a decrease in porosity and an increase in bulk density and compressive strength with increasing firing temperature of ground granulated blast furnace slag and fly ash added bricks; porosity and water absorption increased, ash density and compressive strength and thermal conductivity decreased with the increase of fly ash amount. They stated that there is an increase in compressive strength with an increase in the granulated blast furnace slag content and that the binary brick containing 30% GGBS +10% FA exhibits almost the same properties as the control brick. Apithanyasai et al. (2020) produced geopolymer bricks by using waste foundry sand (WFS), fly ash (FA), electric arc furnace slag (EAF slag), 8M sodium hydroxide (NaOH), and sodium silicate (Na2SiO3) with a ratio of Na2SiO3/8M NaOH = 2.5 with 98% purity. They stated that the environmental impact of geopolymer brick production is lower than concrete production in every respect. In their study, Ganesh et al., (2020) produced geopolymer bricks using Ground Granulated Blast Furnace Slag (GGBS), M-Sand and Alkali solution. They reported that geopolymer bricks based on GGBS could be designed with better engineering properties. Youssef et al. (2019) investigated the reuse potential of waste brick (WB) by alkaline activation in a new geopolymer brick. They have established that there is effective feasibility for the recovery of industrial waste and its transformation into a valuable product for the construction industry. Jindal et al. (2020) produced geopolymer using blast furnace slag as the binder material and NaOH and Na_2SiO_3 as alkali activators; they determined that rice husk ash improved the mechanical properties of the geopolymer; in addition, they found that blast furnace slag had a positive effect on permeability by preventing micro-pores that may occur in concrete thanks to its grain size.

In this study, it was aimed to investigate the effect of the substitution of blast furnace slag on fly ash-based geopolymer brick on the heat transmission coefficient.

2. MATERIAL AND METHOD

2.1. Material

2.1.1. Clayey soil

The clay soil, the raw material of the geopolymer brick produced in the study, was taken from within the borders of Kırşehir province. The elements contained in the soil are given in Table 1. When the table was examined, it was seen that the highest element value was Silicon (Si), with 38.35%.

Table 1. The weights of the elements contained in the soil used in the production of geopolymer bricks

Element	Weight (%)
Si	38.35
Al	9.22
Fe	7,45
O	21,78
Nb	5.62
K	2.70
Ca	15.92

2.1.2. Blast furnace slag

In the study's scope, blast furnace slag, the waste of Kardemir Iron and Steel Factory, was used. The chemical components of blast furnace slag are given in Table 2. In the table, the highest value belongs to SiO2, with 41.97%, and a high percentage of CaO, $Al2O_3$, and MgO compounds were found.

Table 2. Chemical compositions of blast furnace slag used in the study

Composition	SiO_2	Al_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	Mn_2O_3	I.L.
%	41,97	10,51	35,66	6,78	1,47	0,35	0,79	0,53	2,20	0,58

IL: Ignition Loss

2.1.3. Fly ash

The fly ash used in the experimental study was supplied from Seyitömer Thermal Power Plant, and the chemical composition of the fly ash used is given in Table 3. In the table, SiO2 has the highest value, with 51.74%. In addition, CaO, MgO, Fe2O3, and Al2O3 compounds are also found in fly ash. Class F fly ash was used in the study.

Table 3. Chemical compositions of fly ash used in the study

Composition	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	Na_2O	K_2O	SO_3	Na_2O (equivalent)	Free CaO
(%)	51,74	7,29	5,90	9,08	18,87	0,75	2,35	2,74	1,85	0,25

2.1.4. Sodium hydroxide

Sodium hydroxide (NaOH) is also frequently used in many industrial fields, especially in the chemical industry. One of these areas is the construction area. Sodium hydroxide is slippery, odourless, and white. In addition, it has a good degree of moisture retention. The chemical values of sodium hydroxide used in the experimental study are given in Table 4.

Table 4. Chemical values of Sodium Hydroxide [Web ileti. Date of Access: 20.12.2022]

Chemical's Name	Sodium hydroxide
Chemical Formula	NaOH
Molecular Weight	39,997 g/mol
Intensity	2.13 g/cm^3
Melting point	318 ^oC

2.1.5. Calcium hydroxide

Calcium hydroxide, obtained by adding water to quicklime, also has a wide range of uses in the construction field. Its colour is white, and it is powdery. When it reacts with water, it forms a pasty consistency. The chemical values of calcium hydroxide are given in Table 5.

Table 5. Chemical values of Calcium Hydroxide [Web ileti. Date of Access: 20.12.2022]

Chemical's Name	Calcium hydroxide
Chemical Formula	$Ca(OH)_2$
Molecular Weight	74,093 g/mol
Intensity	2,21 g/cm^3
Melting point	580 ^oC

2.1.6. Mixture water

The city mains water of Kırşehir province was used in the geopolymer brick samples produced within the scope of the study.

2.2. Method

2.2.1. Production of geopolymer brick samples

In our experimental study, firstly, sodium hydroxide with a concentration of 8 and 10 M and calcium hydroxide, which will be used in a ratio of 4% and 8%, were used to create a solution to participate in the production. 8 moles of sodium hydroxide 320 g and 10 moles of sodium hydroxide 400 g were used. To create a solution, 1 liter of water was separately dissolved in a glass beaker. The same process was applied to calcium hydroxide, which was used in a 4% and 8% ratio.

In the second phase, clay soil, the raw material of geopolymer brick, was taken from the January by quartering method and ground in a roller crusher grinding machine to obtain 1 mm undersize material. Then, the same process was applied to blast furnace slag taken from Kardemir Iron and Steel Plant and fly ash taken from Seyitömer thermal power plant.

After the solid materials were prepared, production was started using the recipe quantities given in Table 5. In the table, REF means reference sample; YFC10 means 10% blast furnace slag added geopolymer brick; YFC30 means 30% blast furnace slag added geopolymer brick; YFC50 means 50% blast furnace slag added geopolymer brick; YFC70 means geopolymer brick with 70% blast furnace slag added. In the study, the rate of fly ash was fixed at 20%. Therefore, clay/Blast furnace slag ratios were determined as 70:10, 50:30, 30:50, and 10:70, and mixture water was determined as 20% of the mixture.

Table 6. Mixture recipe

	Clay (%)	Blast Furnace Slag (%)	Fly Ash (%)	Sodium Hydroxide (M)	Calcium Hydroxide (%)
REF	100	--	--	--	--
YFC10-8-4	70	10	20	8	4
YFC30-8-4	50	30	20	8	4
YFC50-8-4	30	50	20	8	4
YFC70-8-4	10	70	20	8	4
YFC10-8-8	70	10	20	8	4
YFC30-8-8	50	30	20	8	4
YFC50-8-8	30	50	20	8	4
YFC70-8-8	10	70	20	8	4
YFC10-10-4	70	10	20	10	8
YFC30-10-4	50	30	20	10	8
YFC50-10-4	30	50	20	10	8
YFC70-10-4	10	70	20	10	8
YFC10-10-8	70	10	20	10	8
YFC30-10-8	50	30	20	10	8
YFC50-10-8	30	50	20	10	8
YFC70-10-8	10	70	20	10	8

At the production stage of the study, clay, fly ash, and blast furnace slag, which are dry materials, were first subjected to a medium-setting mixing process for 60 seconds in the mixer to form a dry homogeneous mixture.

After the mixing process in an aqueous solution with NaOH and CaOH piset a heavy clay, fly ash and blast furnace slag mixture on low speed for 90 seconds and poured into a dry mixing process are reviewed. It was then mixed at a high setting of 90 sec. The produced brick dough was poured into moulds measuring 4x4x16 cm after the mould was lubricated. 60 Strokes were made for the compression process.

Geopolymer brick samples were kept in the mould for one day. Then the semi-finished brick samples were left to dry in a semi-open area to dispose of the water in their bodies. After the drying process was completed, it was baked in high-temperature electric ovens by gradually increasing the temperature.

After the cooking process, the samples were allowed to cool slowly in the oven. It is not removed from the oven immediately after cooking because there are no problems on the samples, such as calama or breakage caused by sudden temperature changes.

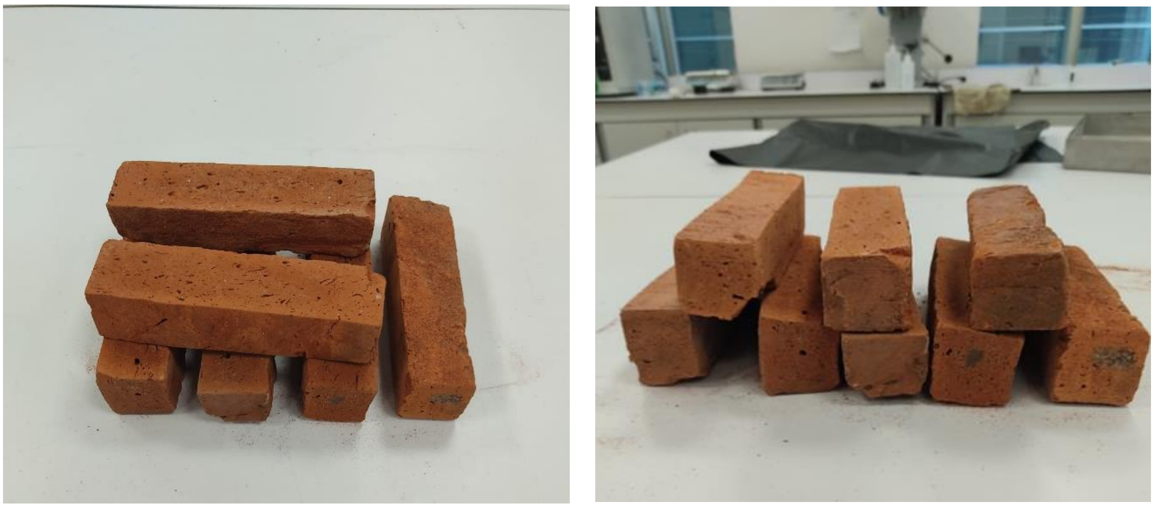

Figure 1. Produced geopolymer brick samples

3.2.2. The experiment of Heat, and conduction coefficient determination, applied to geopolymer brick samples

There are two parts with a brass cylinder and a brass disc inside and insulated to prevent heat transfer with the outside. Parts made of different materials can be placed between the cylinder parts, and temperature changes can be measured. The desired thermal values can be calculated with the help of various values and formulas. Whichever part's temperatures are to be measured, the cables are placed in the sections on that part. For this event, first of all, power is provided at a fixed value. This should become the regime when measuring temperatures. After that, the temperature values are read over. Finally, the necessary procedures are carried out with cooling water. The experimental setup is given in Figure 2.

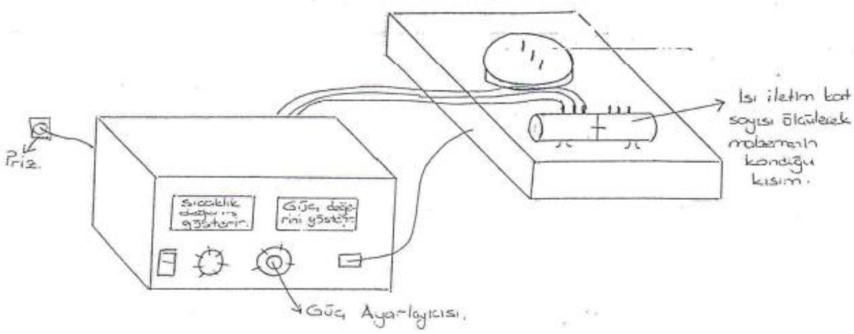

Figure 2. Experiment setup for determination of heat conduction coefficient

3. FINDINGS

Determination of the heat conduction coefficient of geopolymer bricks experimental results are given in Figure 3. When sodium hydroxide is taken as a basis in the figure, it was seen that there is a decrease in the heat conduction coefficient with an increase in the amount of sodium hydroxide. When calcium hydroxide is taken as a basis, it has been seen that there is an improvement in the heat conduction coefficient by increasing the amount of calcium hydroxide again. It was observed that there was a decrease in the heat conduction coefficient with an increase in the amount of blast furnace slag in all categories. It is believed that the reason for this is that the internal structure of blast furnace slag is hollow and lightweight. It is observed that the lowest heat conduction coefficient is obtained from YFC70-10-8 brick samples with 0.26 W/mK. When this value is compared with other studies, it has better thermal insulation properties than boron waste added (Al Amara et al., 2020), ferrosilicon slag and alumina waste added (Ahmed et al., 2021), traditional perforated brick (TS EN 772,1, 2012), fly ash based (Feng et al., 2015) geopolymer brick.

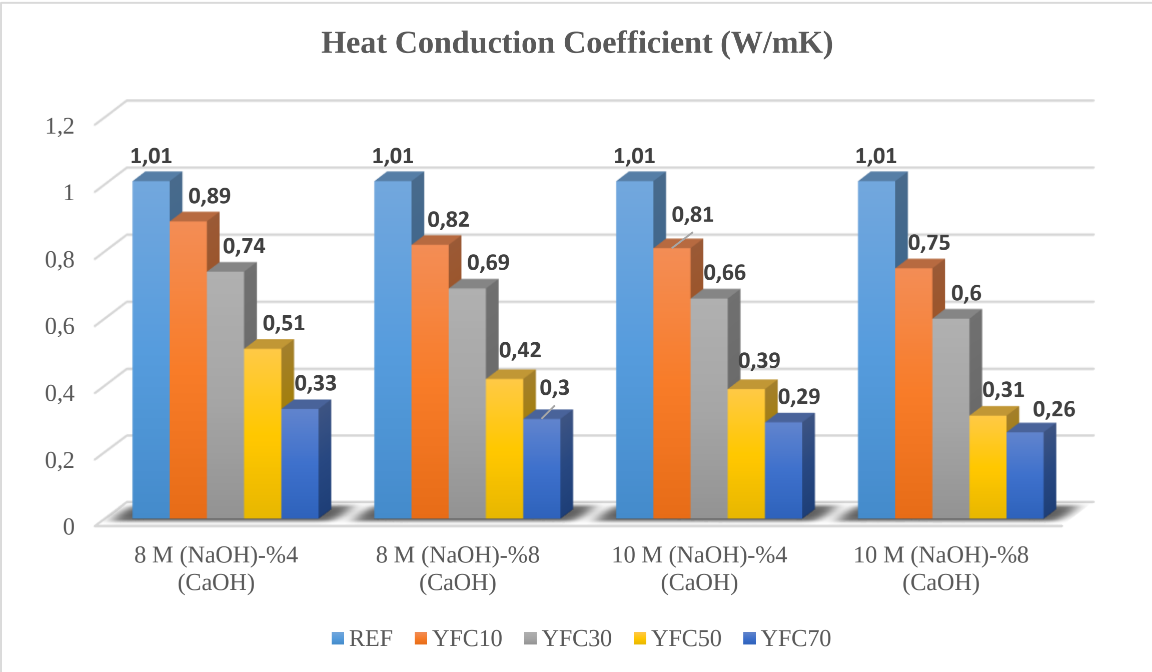

Figure 3. Graph of heat conduction coefficient values

4. CONCLUSION AND RECOMMENDATIONS

The reuse of industrial wastes is one of the most appropriate methods to minimize the destruction they have made in nature. Therefore, waste is used in many sectors, especially in construction. In this study, the effect of blast furnace slag, which is one of the industrial wastes, on the heat conduction coefficient of fly ash-based geopolymer brick was investigated and the results obtained are listed below.

• The heat conduction coefficient of geopolymer brick samples prepared at a sodium hydroxide concentration of 8 M is higher than that of samples prepared at a sodium hydroxide concentration of 10 M.

• The heat conduction coefficient of geopolymer brick samples prepared at 8% calcium hydroxide concentration is lower than those prepared at 10 M sodium hydroxide concentration.

• Among all blast furnace slag-added samples, the best thermal conductivity coefficient of 0.26 W/mK was obtained from 10 M (NaOH)-8% CaOH samples.

• It has been determined that there is a decrease in the heat conduction coefficient with the increase of blast furnace slag.

• Porous and lightweight materials should be selected in order to reduce the heat conduction coefficient, in other words, to increase the thermal insulation property.

• There will be no need for additional insulation costs in buildings constructed with bricks with improved thermal insulation properties.

• Environmental and human health will be protected from an eventful point of view by evaluating the wastes.

In conclusion, it was found that there is no disadvantage when blast furnace slag can be used in brick production. Although, in addition, it is thought that it will be a very important step in terms of reducing environmental pollution and its effects on human health, it is thought that industrial waste can be used not only for brick but also for the improvement of different materials.

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