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Research Article

Investigation of The Usability of Certain Pozzolans in The Production of Geopolymer Mortar

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Keywords

Mortar,
Fly ash,
Waste glass,
Geopolymer,
Burnt coal waste.

Abstract

Humanity's social and cultural expectations have shifted from producer to consumer in today's world, and consumption behaviors have changed significantly compared to the past. The storage of industrial waste by-products resulting from human economic activities has emerged as a significant problem. The revaluation of by-products after industrial activities provides important benefits in terms of the circular economy. In this study, the feasibility of using fly ash, waste glass, and burnt coal waste as pozzolanic materials in alkali-activated mortars was investigated. In the study, a 12-molar (12M) NaOH solution was utilized as the alkali activator. The alkali activator-to-binder ratio was maintained at a constant 0.45 for all mixtures. After the mortar was produced, it was exposed to a curing temperature of 90°C for 72 hours. The data obtained from the mechanical tests showed that the highest compressive strength was achieved in the BCR20WG80FA0 sample at 25.99 MPa, while the highest flexural strength was obtained in the BCR20WG80FA0 sample at 5.15 MPa. The mechanical strengths obtained with the materials used show that the performance of waste glass and burnt coal waste is higher than that of fly ash. The findings suggest that these materials are viable candidates for enhancing environmental sustainability in construction.

1. Introduction

Industrial communities are expanding their capacity every day to meet the basic needs of the growing population [1]. This increased capacity brings with it the problem of storage [2]. For these products that need to be stored, additional measures must be taken in terms of both storage space and avoiding harm to the environment.

This solution creates additional economic burdens [3]. The most common area for the reuse of waste is building materials. The reuse of many types of waste in building materials can contribute to the circular economy and environmental sustainability.

The primary component responsible for the binding properties of construction materials is cement. However, cement production contributes significantly to greenhouse gas emissions, primarily carbon dioxide (CO_2). CO_2 emissions from this process, which relies on the calcination of limestone at approximately 1450°C, account for about 7% of total global greenhouse gas emissions. Furthermore, approximately 1.5 tons of natural resources must be consumed to produce 1 ton of cement [4]. This high emission rate and natural resource consumption seriously contradict the goals of global climate commitments such as the Paris Agreement (2015) and the Kyoto Protocol (1997), making it imperative to re-evaluate cement-based construction technologies. In this context, research has focused on sustainable materials; efforts have accelerated to develop alternative binding systems with the goals of conserving natural resources, increasing energy efficiency, and reducing environmental impacts. With climate change, global warming, and the excessive consumption of natural resources on the agenda today, research has turned to the search for new composite materials to replace cement.

In this context, alkali-activated materials, which have attracted significant attention in recent years, stand out as a strong alternative to traditional cementitious binders from both environmental and technical perspectives. First defined by Davidovits (1978), geopolymers are binders with an inorganic polymer structure formed by the activation of natural or industrial waste materials with high silica (SiO_2) and alumina (Al_2O_3) content using alkaline solutions. Their mechanism is based on the formation of a three-dimensional aluminosilicate gel network, unlike the calcium silicate hydrate (C-S-H) formation based on hydration in Portland cement [5]. Geopolymers produced by activating materials with amorphous structures using alkalis have been frequently studied in the scientific field in recent years [6]. Fly ash and waste glass are among the binders used in geopolymer production [7, 8, 9]. Fly ash is a by-product of coal combustion and is rich in minerals such as silica, alumina, and iron oxide. Waste glass is a material containing silica and lime [10]. Fly ash and waste glass are suitable for alkali activation due to their high amorphous silica and alumina content. Burned coal waste is a waste product resulting from the use of fossil fuels and can cause environmental problems if not disposed of properly. According to estimates by the World Coal Association (WCA), global coal production exceeded 7.6 billion tons in 2023, and this amount of waste is expected to increase in the coming years. Burnt coal waste can be recycled by using it in products such as cement and concrete [11, 12].

A review of the literature reveals that, although there are many studies on the production of geopolymers from waste materials, studies on the production of alkali-activated mortars from fly ash, waste glass, and burnt coal waste are quite limited. With this study, mortars were produced using industrial waste by-products, and their mechanical and physical properties were examined.

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2. Material and Methods

The objective of this study is to experimentally investigate the physical and mechanical effects of using fly ash, waste glass, and burnt coal waste in mortar production and to determine the optimal mixing ratios of these waste materials. To this end, mortars containing fly ash, waste glass, and burnt coal ash in different ratios will be produced, and their properties such as density, compressive strength, and water absorption will be determined.

2.1. Materials

In this study, burnt coal ash, glass obtained from construction waste, fly ash, and mixtures of these three materials were used as binders. CEN standard sand was used as fine aggregate, and sodium hydroxide (NaOH) solution was used as an alkali activator.

Coal ash is solid waste produced as a result of burning coal for energy production or industrial processes. This waste is formed by the combustion of the organic components of coal and the remaining inorganic components. The coal ash used in the study was sourced from the Çaykur Camiönü Tea Factory in Rize Province, as shown in Figure 1.

(a)

(b)

Figure 1. Rize Province Çaykur Camiönü tea factory (a) and the burnt coal waste used (b)

Waste glass refers to glass materials obtained from various industries and consumer products that cannot be reused. Glass bottles, jars, window panes, automobile glass, and other glass products fall under the waste glass category. These wastes are converted into reusable glass products through recycling processes. Figure 2 shows waste glass being ground into powder in a ball mill.

Figure 2. Used waste glass

Fly ash is a fine, powdery inorganic particle produced by the combustion of coal or other fossil fuels. This ash is discharged from the flue system along with flue gases and collected using systems such as electrostatic precipitators or bag filters. The fly ash used in the study, taken from the factory shown in Figure 3, is a siliceous fly ash of class F according to TS EN 450 [13]. The chemical contents of the materials used are provided in Table 1. The particle size distribution of the pozzolanic materials used is shown in Figure 4.

Table 1. Chemical contents of the materials used

Chemical Content (%)	Burnt coal waste	Waste glass	Fly ash
SiO_2	10.82	58.92	70.94
Al_2O_3	6.09	22.36	-
Fe_2O_3	9.33	6.36	-
CaO	-	-	8.36

Figure 3. Fly ash

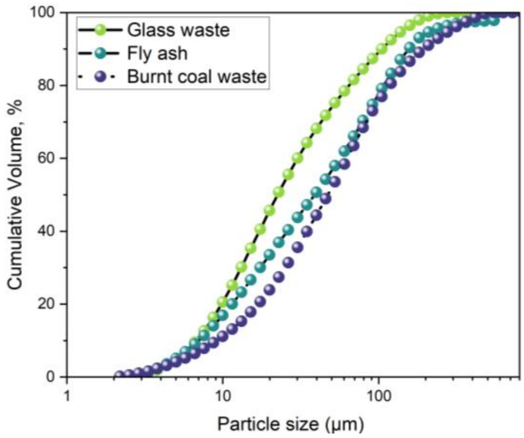

Figure 4. Particle size distribution

Standard sand is produced or selected in accordance with specific regulatory criteria. This sand is used specifically to test the performance of concrete and mortar mixtures. The physical and chemical properties of standard sand are determined by the European Committee for Standardization. All tests were conducted using Standard CEN sand. Standard sands consist of sand prepared in 1350 gram quantities (Figure 5).

Figure 5. Standard sand

Sodium hydroxide is a strong base containing sodium ions (Na^+) and hydroxide ions (OH^-). This compound, with the chemical formula NaOH, is typically found as a white, solid substance. Its aqueous solutions are strong alkalis with high pH Talues. Sodium hydroxide (NaOH), supplied in pellet form as a geopolymer alkali activator, has been dissolved into a solution with a 12 molar concentration, as shown in Figure 6. As seen in Figure 6, it has been prepared by dissolving it in water.

Figure 6. Alkaline activator solution

2.2. Methods

In the study, four different binder combinations were determined. These four combinations were randomly selected with the aim of improving the compressive strength values of mortars to be produced using coal ash, fly ash, and waste glass. Each combination was tested at a single age of 28 days and a curing temperature of 90°C for 72 hours. Three samples were produced for each test group, and prismatic mortar samples measuring 40x40x160 mm were prepared. The experiments were conducted at the Building Materials Laboratory of Recep Tayyip Erdoğan University. The amounts of water and sodium hydroxide were kept constant in the production of mortar samples, while burnt coal ash, waste glass, and fly ash were used in different amounts as shown in Table 2.

Table 2. Amounts of materials used in mixtures (g)

Sample Code	Burnt Coal Waste	Waste Glass	Fly ash	Binder material	Standard Sand	Water	NaOH
BCR20WG80FA0	90	360	0	450	1350	125.55	76.65
BCR20WG0FA80	90	0	360	450	1350	125.55	76.65
BCR0WG100FA0	0	450	0	450	1350	125.55	76.65
BCR0WG0FA100	0	0	450	450	1350	125.55	76.65
							-

Prior to the production of geopolymers, 76.65 grams of sodium hydroxide (NaOH) was mixed with 125.55 grams of water. The prepared solutions were then left to stand in closed containers for 24 hours before being used in mortar samples. When preparing the mortars, the mixer was run at low speed, and the binders were added first and mixed for 30 seconds. Then, sand was added to the binders and mixed for another 30 seconds at low speed, and finally, the alkali activator solution was added to ensure the mixture was homogeneous. After the entire alkali activator was poured into the mixture, it was mixed for another 60 seconds to prepare it for placement into the mortar sample molds. The resulting mortar was placed in two layers, with 60 strokes each time, into mortar sample molds measuring 40x40x160 mm. The molded specimens were kept in a climate chamber for 24 hours and then kept in an oven at 90°C for 72 hours. The specimens removed from the oven were stored in airtight transparent bags to protect them from environmental effects until the 28th day, when the compressive and flexural strength tests were applied.

3. Result and Discussions

3.1. Compressive Strength

The 28-day compressive strengths obtained from mortar samples through compression testing are shown in Figure 7. The highest compressive strength was obtained in the BCR20WG80FA0 sample at 25.99 MPa, while the lowest compressive strength was obtained in the BCR0WG100FA0 sample at 17.53 MPa. Replacing waste glass with 20% burnt coal ash improved the compressive strength by approximately 48%. Replacing 20% of the fly ash with burnt coal ash improved the compressive strength of the mixture by approximately 5%. Yusuf et al. (2025) [14] investigated the properties of concrete mixtures containing fly ash and waste glass in their study. They obtained a compressive strength of 46 MPa at 28 days for concrete in which 20% of the cement was replaced with fly ash, while they obtained a compressive strength value of 36.90 MPa for concrete specimens in which 20% was replaced with waste glass. At this point, it can be seen that fly ash mixtures perform approximately 25% better than waste glass mixtures. The findings of this study are consistent with the data from this literature review.

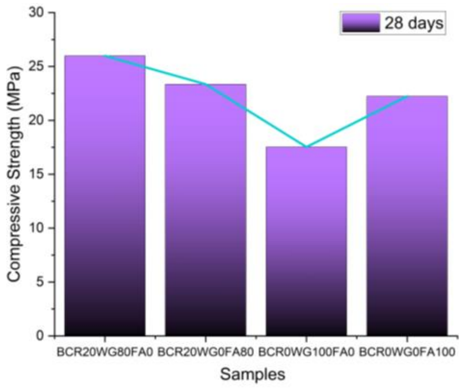

Figure 7. 28-day compressive strengths

3.2. Flexural Strength

The 28-day compressive strengths obtained from the flexural test on mortar samples are shown in Figure 8. The BCR20WG80FA0 sample exhibited the highest flexural strength of 5.15 MPa. The minimum flexural strength was obtained in the BCR0WG0FA100 sample at 4.16 MPa. Replacing waste glass with 20% burnt coal ash increased the flexural strength by approximately 16%, while replacing fly ash with burnt coal ash reduced the flexural strength by approximately 13%. It is understood that waste glass performs better than fly ash in terms of flexural strength.

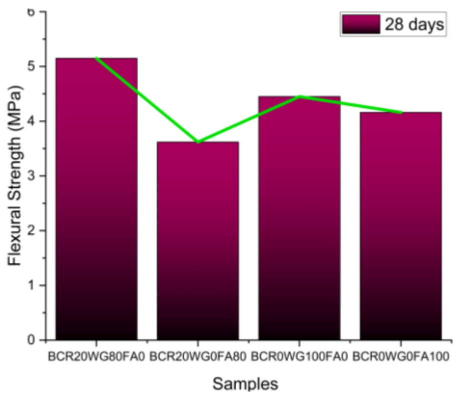

Figure 8. 28-day flexural strengths

4. Conclusions

In this study, the mechanical properties of geopolymer mortars produced using fly ash, waste glass, and burnt coal ash were evaluated. The results of the research can be summarized as follows:
1-Puzzolanic materials such as waste glass, fly ash, and burnt coal ash can be used in geopolymer mortars to optimize mechanical strength.
2-In geopolymer mortars with coal ash replacement, fly ash replacement exhibits higher performance for compressive strength, while waste glass replacement shows higher performance for flexural strength.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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