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The Effect of Material Ratios on Technical Properties in Fly Ash and Blast Furnace Slag Based Aluminum Chip Reinforced Geopolymer Mortars

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Abstract – In this article, it is investigated how the increase in aluminum chips ratio affects the spread diameter, flexural strength, compressive strength and electrical conductivity of fly ash basis (UA) series and blast furnace slag based (YA) series aluminum chips reinforced geopolymer mortars. It was observed that there was a decrease of 11.29% in spread diameter for the UA series from UAO to UA15, while the YA series showed a decrease of 19.62%. The increase in aluminum chip waste content resulted in a significant decrease in flexural strength and compressive strength of the material. Furthermore, it was stated that the increase in the aluminum chips ratio had an effect on the electrical conductivity of the material. Samples produced with blast furnace slag had lower resistivity and higher electrical conductivity than samples produced with fly ash. The importance of aluminum waste and aluminum shavings ratio in terms of sustainability was emphasized. The recycling and reuse of waste aluminum contributes to energy savings and reduction of environmental impact, while at the same time prolonging the life of materials and conserving natural resources. As a result, it was seen that the increase in the aluminum chip ratio had a significant effect on the material properties. It was concluded that careful management of aluminum waste, promoting recycling processes and evaluating alternative production methods are a critical step in achieving sustainability goals.

Keywords – Waste Aluminum Chips, Alkali Activated Mortars, Electrical Conductivity, Strength, Workability

I. INTRODUCTION

Geopolymer concrete has emerged as a sustainable alternative to traditional Portland cement (PC) due to its lower greenhouse gas emissions, lower cost, and efficient utilization of industrial by-products [1], [2], [3]. The cement industry makes a significant contribution to global carbon dioxide emissions, accounting for approximately 5-7% of the total. The production of PC itself releases a substantial amount of CO_2 [4].

In order to address these environmental concerns and reduce the consumption of PC, researchers have focused on incorporating supplementary cementitious materials (SCMs) such as fly ash, silica fume, and others. These materials can be obtained from low-cost sources or industrial by-products, which makes them more sustainable options [5]. However, one of the most promising developments in this field is geopolymer concrete.

It involves the production of binders using alumina and silica derived from materials such as geopolymer concrete, fly ash, rice husk ash and others. These used samples react chemically with alkaline activating solutions to form a cross-linked three-dimensional alumino-silicate network. These polymerization materials show high strength when done faster by curing at high temperature during the chemical reaction [6], [7].

Almutairi et al. conducted a research on the real-world applications of geopolymer concrete in various infrastructures. They stated that geopolymer concrete has been successfully used in projects such as roads, bridges, buildings, and precast elements. In their study, they emphasized its high strength, durability, and resistance to fire and chemical attacks, making it suitable for a wide range of construction applications [8].

Castel and Foster performed the RILEM pull-out test, which is a known method to measure the bond strength in their study. Thus, he investigated the bond strength of geopolymer concrete using both degraded and plain steel reinforcing bars. The geopolymer binder used in the study consisted of 85.2% low-calcium fly ash and 14.8% ground granulated blast furnace slag (GGBFS). In the experiments, they aimed to find the bond strength progression from 24 hours to 28 days under different temperature curing conditions. The results revealed that a 48 hour heat-curing time at 80°C is essential to create a strong bond strength close to Portland cement (OPC) concrete with a pressure of 45 MPa. This suggests that geopolymer concrete can exhibit comparable bond performance to OPC-based concrete when subjected to appropriate heat curing. The study also highlighted the suitability of geopolymer concrete for precast applications, as high early-age bond strength could be achieved through intensive heat curing [9].

Honorio, Carasek, and Cascudo proposed multi-scale modeling approach informed by the dynamics of ions, presented a tool to understand and predict the electrical conductivity and resistivity of cement-based materials. This scale modeling approach provides information about the variability and uncertainty of these properties at different scales and can contribute to the characterization and design of durable concrete structures [10].

Filazi, Yilmazel, and Pul investigated the effect of incorporating waste aluminum reinforcement on the electrical conductivity of alkali-activated mortar samples made with fly ash. The mortar samples were prepared by substituting waste aluminum at different weight percentages (0%, 10%, 15%, and 20%) depending on the binder ratio. While the use of waste aluminum led to a slight decrease in workability and durability, the study suggests that it can provide certain benefits in terms of sustainability and cost-effectiveness. The addition of waste aluminum reinforcement had a negative impact on the workability and strength of alkali-activated mortar samples but showed promise in terms of electrical conductivity. The study highlights the potential advantages of using waste materials in construction, considering specific material properties along with sustainability and cost-effectiveness [11].

Ahmed and Kamal (2022) focused on the development of smart conductive cement-marble using green magnetite nanoparticles (Fe_3O_4) synthesized through a plant-mediated approach. The aim of the research was to examine the effects of water/cement ratio, conductive filler content, and industrial wastes (steel slag and mill scale) on the electrical resistance and compressive strength of the prepared marbles. For comparison purposes, traditional cement marbles were also prepared and tested. The experimental results indicate that as the conductive filler content increases, the electrical resistance of the marble decreases, while the compressive strength increases. In the optimal formulation, the electrical resistance was determined to be 8.83 Ω.m and the compressive strength was 36.08 MPa. Consequently, the formulation parameters of the smart conductive cement mortar contribute to understanding the relationship between electrical resistance and compressive strength, providing valuable insights for the design and implementation of innovative and sustainable infrastructure materials [12].

II. Materials and Method

A. Material

The study utilized a standard sand conforming to the specifications of TS EN 196-1[13] standards, known as the CEN reference sand. This particular sand was produced at the Limak Trakya Cement factory. The chemical and physical properties of the Fly Ash and Blast Furnace Slag used in the research are provided in Table 1. As they were obtained directly from the respective factories, it is important to note that both the Fly Ash and Blast Furnace Slag were used in their original form without undergoing any grinding process.

Table 1. Physical and chemical properties of Fly Ash (UA) and Blast Furnace Slag (YA)

Contents (%)	UA	YA
SiO_2	30,02	35.2
Al_2O_3	12,52	17.51
Fe_2O_3	5,42	0.68
CaO	38,78	37.7
MgO	1,75	5.51
SO_3	0.69	0.69
Na_2O	0.41	0.42
K_2O	0,66	1.71

Physical Properties		
Blaine's thinness (cm^2/g)	2345	3940
Specific gravity (g/cm^3)	2.68	2.89

The experimental study utilized solid potassium hydroxide (KOH) and sodium silicate solution (Na_2SiO_3) with a purity of 98% as alkali activators. The Na_2SiO_3 solution had the following chemical composition by weight: SiO_2 (26.5%), Na_2O (8.3%), and H_2O (6.2%). Figure 2 presents the sodium hydroxide and sodium silicate used as activators. Potable tap water was employed in the experimental study.

B. Experiment Design

The mixing ratios of the alkali-activated mortars produced in this experimental study are given in Table 2.

Table 2. Mortar mixing ratios

Sample	UA (g)	YA (g)	KOH (g)	Na2SiO3 (g)	Sand (g)	Water (g)	Al Chip (g)
UAO	450	-	32	127	1350	146	0
UA5	450	-	32	127	1350	146	22,5
UA10	450	-	32	127	1350	146	45
UA15	450	-	32	127	1350	146	90
YAO	-	450	32	127	1350	146	0
YA5	-	450	32	127	1350	146	22,5
YA10	-	450	32	127	1350	146	45
YA15	-	450	32	127	1350	146	90

Samples of geopolimer mortar with aluminum chip are shown in Figure 1.

Figure 1. Samples of AAC mortar with Additive Aluminum Chip

C. Spread Test

In this study, the slump values of all fresh mortar samples were obtained according to the TS EN 1015-3 [18] standard. The experiments were conducted using the methods and parameters specified in this standard. The slump values were determined and recorded following the procedures outlined in the standard. This standard serves as a widely used reference point for evaluating the workability of cement and mortar and ensuring quality control.

D. Compression Tests

The geopolymer mortar mixtures were cured at 110°C in an oven for 24 hours. Prismatic mortars with dimensions of 40×40 mm^2, as shown in Figure 1, were then removed from the oven and subjected to flexural and compression tests according to TS EN 196-1 [13] standard, at a laboratory temperature of 23±2°C.

E. The Electrical Conductivity Test

In the experimental setup designed to measure electrical conductivity, a digital multimeter and a DC power supply were used. A constant voltage of 30V was applied to each sample using the DC power supply. The digital multimeter was used to measure the current passing through the sample based on the applied voltage. The measurements were taken according to a two-point DC conductivity measurement setup. Measurements were taken from at least 5 different locations on the samples. The average of these values was calculated to obtain the actual value. This was done to ensure more objectivity in the results if there was not a homogeneous mixture in the materials that make up the samples. Resistance values of the material were calculated from the obtained voltage and current values. The resistance values of each sample were then used to determine the electrical conductivity.

Table -3 Test results from blast furnace slag and fly ash

Blast Furnace Slag			
Sample No	Resistance Value (MΩ)	Resistivity (MΩm)	Conductivity (μS/m)
YA0	0.000	0.000	0.000
YA5	43.83	1.753	0.57
YA10	19.87	0.794	1.259
YA15	7.920	0.316	3.164

Fly Ash

Sample No	Resistance Value (MΩ)	Resistivity (MΩm)	Conductivity (μS/m)
UA0	0.000	0.000	0.000
UA5	84.210	3.368	0.296
UA10	55.172	2.228	0.448
UA15	18.823	0.752	1.329

III. Results And Discussion

3.1 Results of the Spreading Test

The spreading values of waste aluminum chips geopolymer mortars based on fly ash and blast furnace slag are shown in Figure 2.

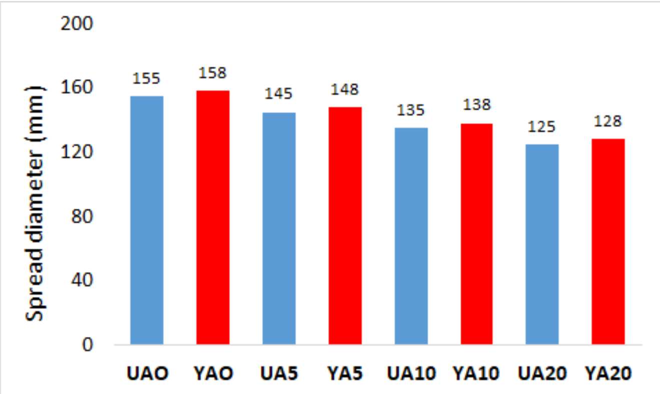


Figure 2. Spread diameter

There is an approximate 3.23% decrease in slump diameter when transitioning from UA0 to UA5. There is an approximate 6.45% decrease in slump diameter when transitioning from UA0 to UA10. There is an approximate 11.29% decrease in slump diameter when transitioning from UA0 to UA15.

There is an approximate 3.16% decrease in slump diameter when transitioning from YA0 to YA5. There is an approximate 6.33% decrease in slump diameter when transitioning from YA0 to YA10. There is an approximate 19.62% decrease in slump diameter when transitioning from YA0 to YA15.

According to the comparison results, the rate of decrease in slump diameter is lower in the UA series compared to the YA series. In the UA series, the slump diameter decreases by 11.29% when transitioning from UA0 to UA15, while in the YA series, the slump diameter decreases by 19.62% when transitioning from YA0 to YA15. This indicates that the increase in aluminum chip content has different effects on slump diameter between the UA series and the YA series.

In conclusion, when examining the experimental data, it can be said that the increase in aluminum chip content has a reducing effect on slump diameter in both the UA series and the YA series. Higher aluminum chip contents appear to decrease the workability of the material."

3.2 Compressive Strength Test

The graph drawn according to the data obtained from the compression tests of the mortar samples is given in Figure 3.

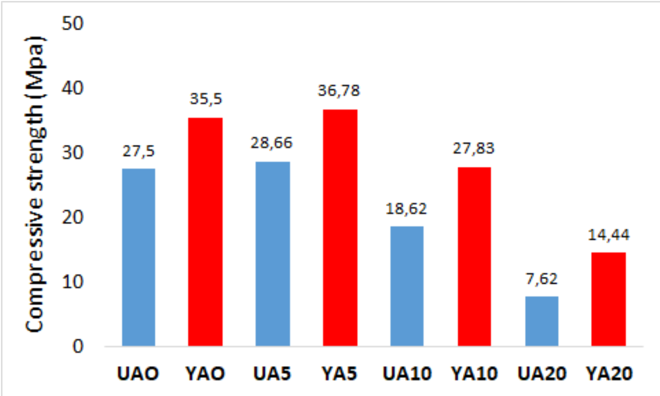


Figure 3. Compressive Strength

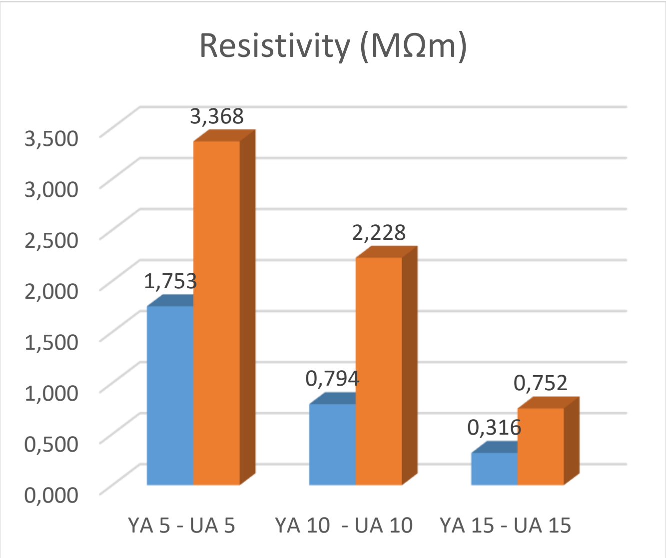
According to the conducted study, the proportional changes in Compressive strength between the UA series and the YA series can be expressed as follows:

There is an approximate 5.47% increase in flexural strength when transitioning from UA0 to UA5. There is an approximate 32.18% decrease in flexural strength when transitioning from UA0 to UA10. There is an approximate 71.99% decrease in flexural strength when transitioning from UA0 to UA15. There is an approximate 3.17% increase in flexural strength when transitioning from YA0 to YA5. There is an approximate 21.56% decrease in flexural strength when transitioning from YA0 to YA10. There is an approximate 66.10% decrease in flexural strength when transitioning from YA0 to YA15.

Based on these results, it can be observed that there is a significant decrease in flexural strength as the UA series progresses from UA0 to UA15. On the other hand, the YA series also experiences a decrease in flexural strength as it progresses from YA0 to YA15, but at a lower rate compared to the UA series. Based on the given data, it can be inferred that the aluminum waste creates voids within the material and this affects the compressive strength. Previously, it was observed that an increase in aluminum chip content reduces the slump diameter in both the UA series and the YA series. Now, considering that the aluminum waste creates voids, these voids may weaken the structural integrity of the material and lead to a decrease in compressive strength.

3.3 Electrical Conductivity Test Results

The graph drawn according to the data obtained from the electrical resistivity and conductivity tests of the mortar samples is given in Figure 4.



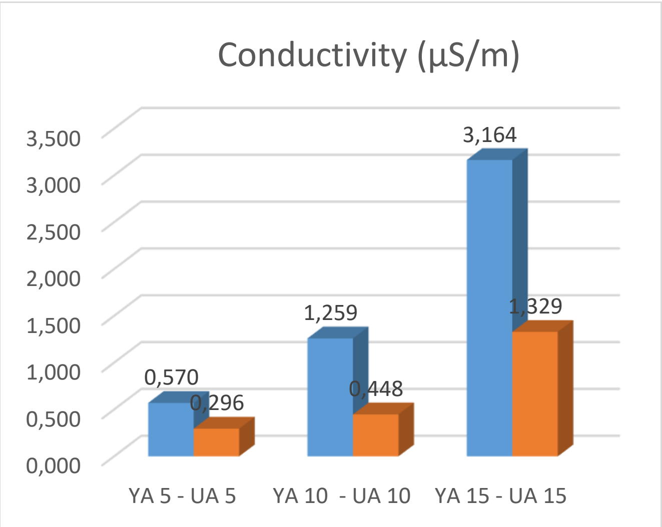


Figure 4. Comparison of electrical conductivity and resistivity values of samples produced with blast furnace slag and fly ash

The comparison of electrical conductivity and resistivity of samples made with high furnace slag and fly ash is presented in Figure 4. It was found that the addition of aluminum chips to high furnace slag and fly ash resulted in a decrease in electrical resistivity and an increase in electrical conductivity. In high furnace slag, the electrical conductivity of the sample with 10% aluminum chip content increased by 2.2 times compared to the sample with 5% content. Similarly, when 15% aluminum chip content was added, there was a 2.51-fold increase in electrical conductivity compared to the 10% content. In samples produced with fly ash, the electrical conductivity of the sample with 10% aluminum chip content increased by 1.51 times compared to the sample with 5% content. Likewise, when 15% aluminum chip content was added, there was a 2.98-fold increase in electrical conductivity compared to the 10% content. According to the obtained data, it was observed that when 5% aluminum chip content was added, the sample produced with high furnace slag was 1.92 times more conductive than the sample produced with fly ash. When 10% aluminum chip content was added, the sample produced with high furnace slag was observed to be 2.81 times more conductive than the sample produced with fly ash. When 15% aluminum chip content was added, the sample produced with high furnace slag was observed to be 2.38 times more conductive than the sample produced with fly ash.

IV. CONCLUSION

In conclusion, considering the data, it is observed that an increase in aluminum chip content has a reducing effect on the slump diameter in both the UA series and the YA series materials. While a 11.29% decrease in slump diameter was observed as the UA series progressed from UA0 to UA15, this rate was determined as 19.62% for the transition from YA0 to YA15.

Furthermore, the data also indicate that an increase in aluminum chip content has a negative effect on the flexural strength and compressive strength of the material. Significant decreases in flexural strength and compressive strength were observed as the UA series progressed from UA0 to UA15, and a similar decrease was observed in the YA series. In addition to the increase in aluminum chip content, the creation of voids by aluminum waste may also contribute to the decrease in compressive strength.

These results demonstrate that the aluminum chip content has a significant impact on the material properties, reducing the slump diameter, decreasing the flexural strength, and affecting the compressive strength.

Through the evaluation of the data, it was observed that both the aluminum waste and aluminum chip content have a significant effect on the material properties. An increase in aluminum chip content reduces the slump diameter, decreases the flexural strength, and affects the compressive strength of the material.

This indicates the important role of aluminum waste in sustainability. Aluminum waste can be recycled and utilized in new production processes. This enables the reduction of waste and more efficient utilization of natural resources.

From a sustainability perspective, recycling and reuse of aluminum waste contribute to energy savings and reduced environmental impact. Additionally, reducing waste during the recycling process helps alleviate waste storage issues and minimize environmental impact.

Regarding electrical conductivity, samples produced with high furnace slag are superior to those produced with fly ash. The lower void content in samples produced with high furnace slag allows for easier passage of electrical current. This results in lower resistivity and higher electrical conductivity of the material.

Therefore, careful management of aluminum waste and aluminum chip content, as well as the promotion of recycling processes, are important steps towards achieving sustainability goals. Material recycling and waste management help us use resources more efficiently, reduce environmental impacts, extend the lifespan of materials, and preserve natural resources."

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