Impact of Cement Kiln Dust on the Characteristics of Alkali-activated Concrete

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https://doi.org/10.29227/IM-2025-02-02-023

Submission date: *2025-02-21* | Review date: *2025-05-13*

Abstract

The influence of cement kiln dust (CK) on alkali-activated concrete is investigated in this work. AAC was produced with the use of alkali activator solutions. The application of an alkaline solution of Na2SiO3 and NaOH depends on the activation of pumice dust (PD) and the beginning of the alkali reaction process in the geopolymer paste. Using varying weight ratios between 0% and 30%, CK was employed as a partial replacement for PD. It also used CK in different weight percentages-0%, 5%, 10%, 20%, and 30%-as a partial substitute for PD. Workability, compressive strength, porosity, unit weight, and water absorption guided an analysis of AAC's characteristics. The findings indicated that slump flow dropped as CK rates rose. Furthermore, the geopolymer concrete using 30% CK demonstrated a notable 23% improvement in compressive strength at the 90-day test age. Moreover, the samples of geopolymers concrete showed a significant 20% water absorption decrease.

Keywords: *Cement kiln, volcanic pumice, alkali-activated concrete, strength, porosity*

1. Introduction

Ordinary Portland cement is the most often used in the building sector. Consequently, cement manufacture utilizes a lot of energy, consumes non-renewable resources, and causes harm to the natural environment. The production of cement releases carbon dioxide into the atmosphere, which contributes to climate change and global warming. Researchers are concentrating their efforts on discovering methods to decrease the amount of cement that is produced by developing whole or partial substitutes for cement [1]. Industrial waste materials that are often used as cement substitutes in the manufacture of alkali-activated concrete are blast furnace slag, fly ash, and silica fume. Volcanic pumice dust (PD) and cement kiln dust (KD) are also added to the list of industrial wastes [2]. In addition, agricultural waste ash such as palm oil fuel ash can be used to produce geopolymer concrete [3]. These products are used to lessen the negative effects that landfills have on the environment. Landfills may include dangerous garbage that has high concentrations of heavy metals. Researchers have devised several alternatives, including the creation of novel bonding technologies like geopolymers and the synthesis of environmental cement binders. There are several factors that influence the usage of industrial waste that contains aluminosilicate to create geopolymer concrete. The manufacturing of geopolymer concrete may need the use of alkaline additives, which are important for initiating early reactions. The fresh and hardening qualities of geopolymer concrete demonstrate how these alkaline additives function [4 Early reactions in geopolymer concrete might occur if it is cured between 60°C and 90°C. These curing temperatures also produced an early hydration reaction and gave the material, after one day, compressive strength of up to 30 MPa [5]. Moreover, manufacturing geopolymers depends on making sure the silica to alumina ratio is suitable and balanced [6]. Inadequate aluminosilicate ratios are present in a broad variety of geopolymer raw materials sourced from throughout the globe. More ingredients with a balanced molar ratio of SiO2/Al2O3 may be added to achieve the optimal ratio of completion of the geopolymer process. So, make geopolymer concrete better in terms of its physical and mechanical properties [6, 7]. To enhance the alumina-to-silica ratio, however, it makes use of additional materials such as fly ash and electric arc furnace slag, which are alkali cleavage materials. Geopolymer reactions may also be triggered by complementary materials that are rich in alumina and calcium. These components are essential to produce geopolymer gel, a dense and robust alkaline activator. Their process involves making C-S-H, C-A-S-H, and N-A-S-H, which are all forms of calcium aluminosilicate hydrate [8]. Preparing geopolymers with a supplementary supply of calcium or alumina increases early compressive strength and decreases setting time, according to certain prior studies [9, 10]. Thus, alkali-activated concrete may have its characteristics enhanced by using supplementary materials like KD, which has a high calcium concentration. In addition to requiring heat treatment, alkali-activated concrete made with PD has a low early strength and a lengthy setting time, according to previous research [11, 12]. So, without employing heat treatment, this research examines how adding KD as a supplement ingredient affects setting time and early strength.

2. Materials and methods

Materials were selected for this experiment with an eye toward meeting ASTM standards [13]. Chemical composition may be investigated using X-ray fluorescence (XRF), as shown in Table 1. The physical characteristics and chemical contents of PD and KD are shown in fig. 1 and table 1, respectively. A cement mill in the Gaza area of southern Saudi Arabia was surveyed from a south-facing angle to gather the KD, which is a waste product of grinding cement. Processing dust (PD) from a quarry in the southern Saudi Arabian province of Jazan, which processes lightweight aggregates, was used in the experiment. The ASTM 2000 specifications were satisfied by the desert sand's specific gravity of 2.65 and fineness modulus of 2.8.

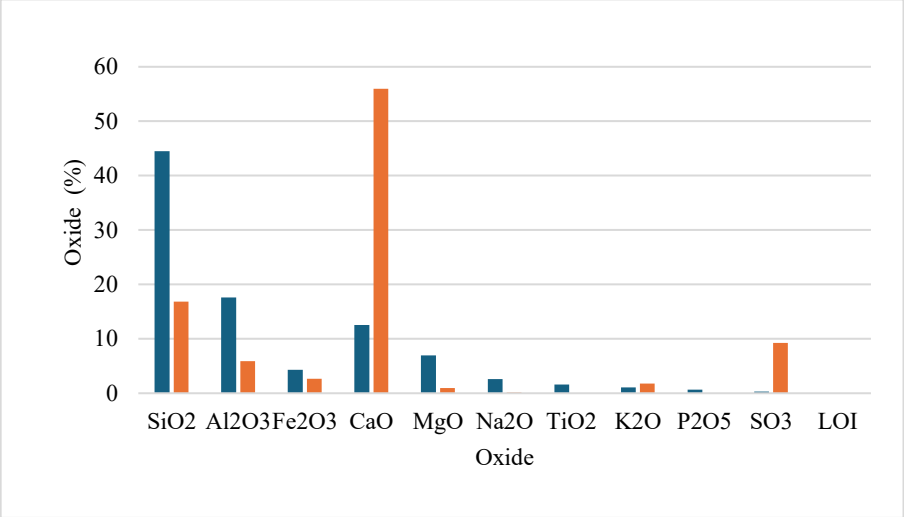
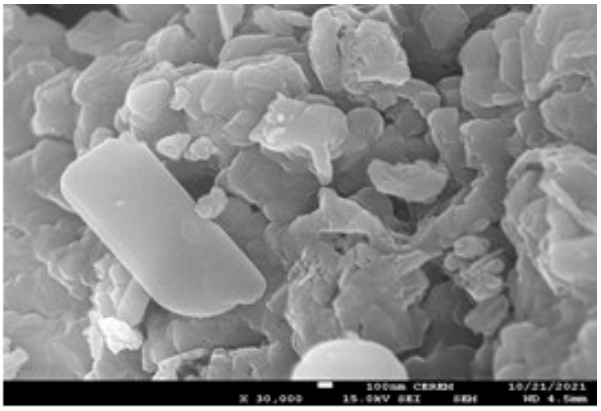


Fig. 1. Composition Analysis of PD and KD.

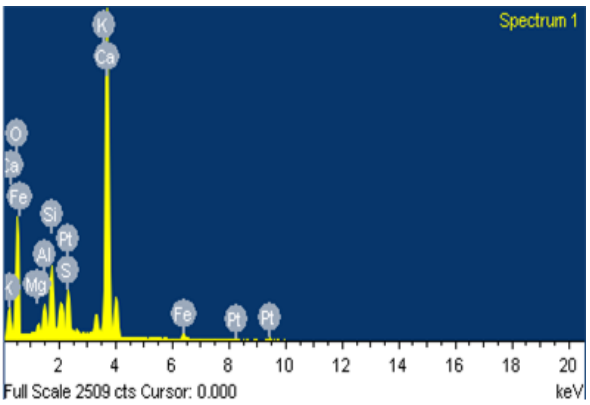
Tab. 1. The physical characteristics of PD and KD

Material	Specific gravity	Mean Diameter (μm)	Surface area (m^2/kg)
CKD	2.86	7.19	327
VPD	2.61	4.96	429

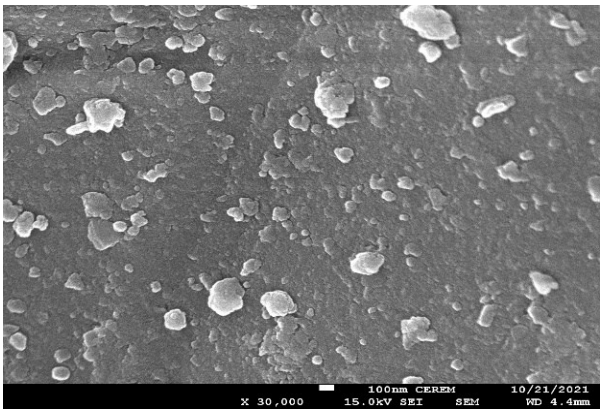
In this study, the raw materials utilized include PD and KD, as illustrated in Figure 2. The PD and KD forms, along with their chemical composition, were analyzed using EDX and SEM techniques



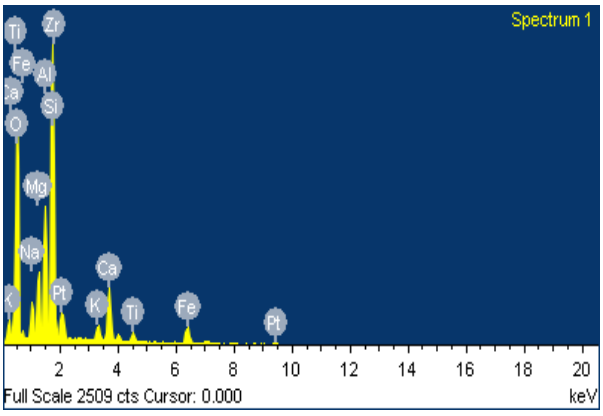
(a) SEM investigation of KD



(b) EDX investigation of KD



(c) SEM investigation of PD



(d) EDX investigation of PD

Fig. 2. SEM and EDX investigation of KD and PD

Tab. 2. Blended PD/(PC or KD) concrete mixture (kg/m^3)

Mix	PD	KD	Sand	Na_2SiO_3	NaOH
	Kg/m^3				
VPD	736.1	-			
VK5%	699.3	36.8			
VK10%	662.5	73.6	1140.2	273.4	109.4
VK20%	588.9	147.2			
VK30%	515.3	220.8			

Testing procedures: The performance of fresh geopolymer concrete was assessed through the execution of flow table tests, following the methodologies outlined in the ASTM C230 guidelines. The test for compressive strength was performed utilizing cubic specimens measuring 50 x 50 x 50 mm³, in accordance with the methods specified in BS EN 12390-3. The assessments for porosity (p) and water absorption (A) were carried out on cubic samples with dimensions of 50x50x50 mm utilizing a vacuum saturation system [13]. The calculation of porosity (p) was performed utilizing Equations 1 and 2, detailed as follows:

$$P = \left(\frac{W_2 - W_4}{W_2 - W_3}\right) * 100, \quad (1)$$

$$A = \left(\frac{W_2 - W_4}{W_4}\right) * 100, \quad (2)$$

In this context, W2 represents the weight of the specimen when it is under saturated and dry surface conditions in air (g). W3 denotes the weight of the specimen that has been saturated in water (g), while W4 indicates the weight of the specimen that has been oven-dried in air (g).

The assessment of bulk density (unit weight) was carried out in accordance with the standards set forth in BS 1881: Part 114[14], utilizing cubic samples measuring 50 × 50 × 50 mm.

3. Results and discussion

3.1 Flow table

Figure 3 presents the flow table for PD-based geopolymer concrete, illustrating the outcomes of the simulation regarding how varying the rate of KD addition affects the flow table of the geopolymer mixture. With the rising rate of PD replacement by KD, there is a noticeable decrease in the diameter of the flow table. The flow diameter of the PD-based geopolymer concrete was measured at 270 mm. As the proportion of PD mass replaced diminished from 5% to 20% to 30%, the associated flow diameters contracted to 240 mm, 220 mm, 190 mm, and 165 mm. A calcium concentration reaching as high as 55.98% of KD mass may be responsible for the observed reduction in flow. SO_3 constitutes a notable proportion of KD, reaching up to 9.23% by mass, and plays an essential role in initiating chemical reactions.

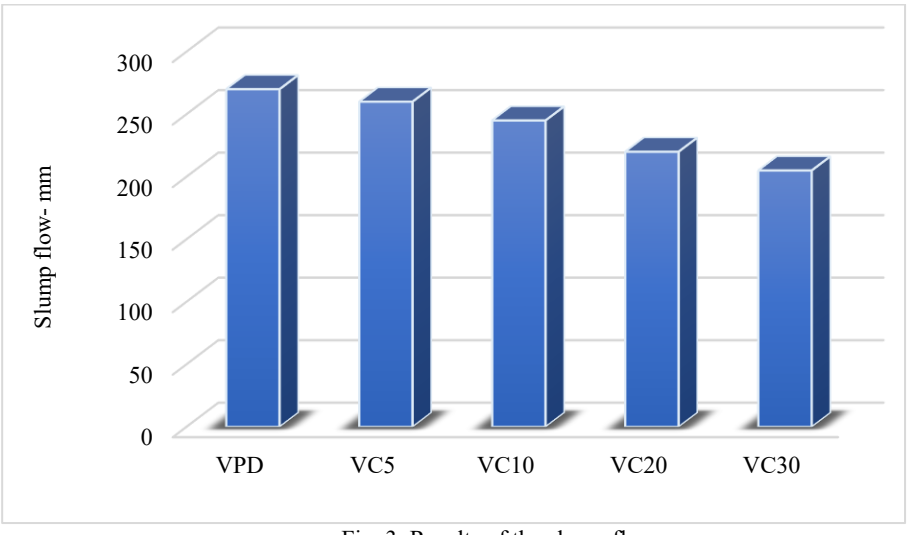


Fig. 3. Results of the slump flow.

3.2 Compressive strength

The findings of the compressive strength evaluation for each specimen are illustrated in Figure 4, which was generated following 7, 28, and 90 days of curing. The details are organized in alphabetical sequence. A study was conducted to investigate the impact of KD content, particularly at levels reaching 30 weight percent, on the progression of compressive strength in alkaline-activated PD. The research examined a variety of blends ranging from VK0% to VK30%. Following a week of testing, the compressive strengths of the various combinations demonstrated a notable rise: 22.4 MPa for mixture VPD and 23.3 MPa for mixture VC30. Following a period of 28 days, there is a notable enhancement in compressive strength, particularly with an increase from 22.4 to 27.9 MPa, as both the curing

duration and KD content are elevated. The compressive strength observed over the 90-day testing period reached 26.3 MPa for VPD and 28.4 MPa for VC30. This provides a concise overview of the flow table's restricted diameter, which adversely impacted its functionality. The compressive strength of geopolymer concrete diminished when KD substituted 20% and 30% of the concrete, leading to a slight decline in the workability of the geopolymer concrete. This could stem from the collaborative interaction between PD and KD, as the response rate typically increases with a higher presence of KD. The reaction rate of blended PD-KD tends to exhibit a heightened sensitivity to temperature. At a PD concentration of 70 wt.% or higher, the reaction exhibits a slower pace in comparison to KD at lower temperatures. When these players serve as substitutes for high-level KD, their performance can occasionally suffer. When temperatures exceed 60 degrees Celsius, the reaction rate in the current HAC present in VD-KD experiences a notable increase. The article further explains that alkaline hydroxide (NaOH) and Ca(OH)2, derived from KD content, can be utilized to attain alkalinity. This contributes to reducing the levels of alkalis that are present during the initial hydration processes. Over time, there is a consistent increase in the concentrations of alkalis, as evidenced by the progressive enhancement in compressive force results. This additionally results in the formation of C-A-S-H, alongside the synthesis of N-A-S-H [14]. This aligns with previous studies indicating that natural pozzolana, a type of volcanic material, could be utilized in the production of geopolymer concrete. Additionally, the byproducts generated by the cement sector contribute to the initial setting of the geopolymer blend [11, 12].

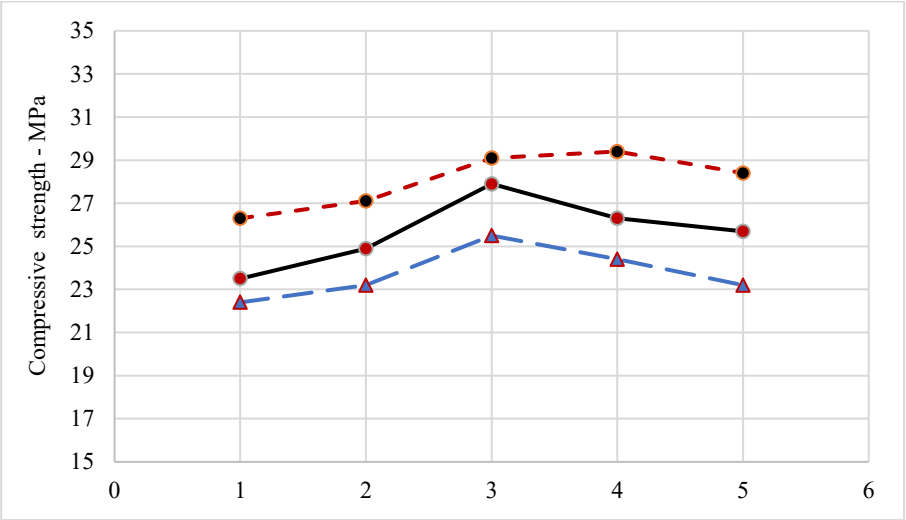


Fig. 4. Results of compressive strength

3.3 Unit weight

The results of unit weight testing on geopolymer concrete samples after 28 days are presented in Figure 5. With the increase in KD levels, there was a slight rise in the unit weight values of the control samples. After a period of 28 days during which the KD level reached 30 wt%, the unit weights of PD, VK5, VK10, VK20, and VK30 saw an increase, measuring 2164, 2172, 2186, 2198, and 2212 kg/m3, respectively. The reference mixture (PD) possesses a unit weight of 2.61 kg/m3, whereas KD exhibits a unit weight of 2.86 kg/m3. The variation in unit weight may be due to the incorporation of a denser material, along with the hydrolytic interaction occurring between the gel binder and the alkaline activator solution. This interaction additionally altered the composition of the gel binder. The combination of the activator used in this study with 30 wt% KD resulted in increased unit weight measurements, suggesting that the activator contributed to the formation of a denser cementitious structure within the (C,N)-A-S-H gel binder.

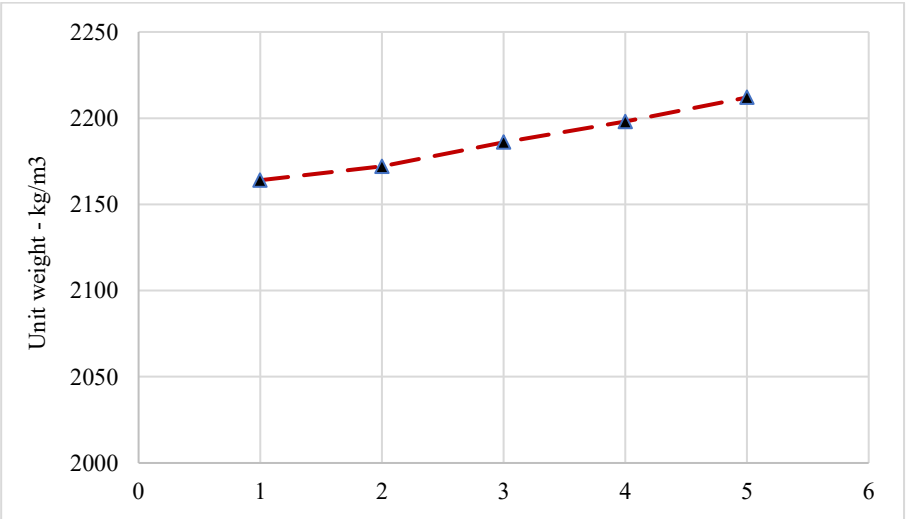


Fig. 5. Results of unit weight

3.4 Porosity

Figure 6 illustrates the findings from the porosity test conducted at 28 days of age. With the increase in the KD replacement rate, the porosity of the geopolymer concrete samples diminished. The porosity of the samples decreased most significantly at a replacement level of up to 30 wt% when compared to the reference combination. Following a duration of 28 days, the porosity measurements recorded were 17.8% for the VPD samples and 14.9% for the VK30 samples. This was accomplished by replacing 30% of the PD and KD by weight. The combined effects of the blended PD and KD, along with the packing influence, led to this phenomenon, resulting in a dense microstructure.

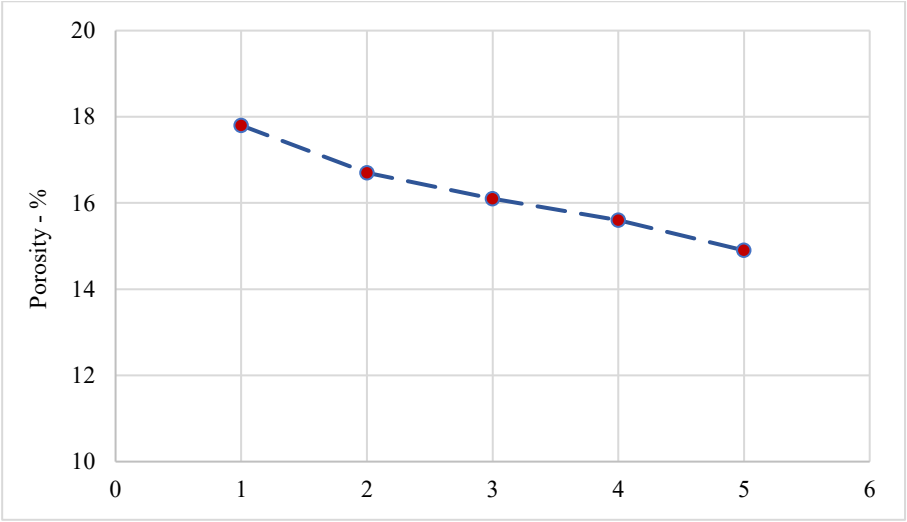


Fig. 6. Results of porosity

3.5 Water absorption

Figure 7 illustrates the outcomes of the water absorption tests performed on geopolymer concrete samples, which were prepared by activating PD and KD with alkali at a test age of 28 days. The porosity of geopolymer concrete samples exhibited a reduction with the increasing quantity of KD utilized as a partial replacement for PD. The results indicate that substituting up to 30% by weight resulted in the smallest proportion of apertures in comparison to the reference mixture. With the increase of KD content to 30% by weight, the porosity values for VPD, VK5, VK10, VK20, and VK30 decreased from 8.7%, 8.6%, 8.2%, 7.6%, to 6.9%, respectively. The observed behavior resulted in the formation of a microstructure characterized by increased density and reduced porosity, stemming from the effectiveness of packing and the synergistic interactions between the KD and PD mixes.

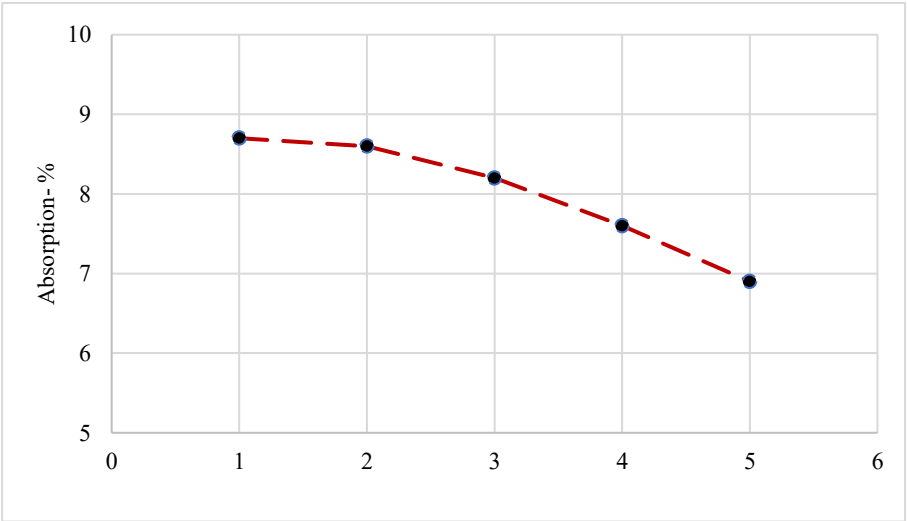


Fig. 7. Results of water absorption

4. Conclusion

The findings indicate that the properties of geopolymer concrete could be enhanced through the intercalation of KD, with a replacement content of PD varying between 5% and 30%. The conclusions that can be derived are as follows:

1. One outcome of substituting 30% of the PD in geopolymer concrete with KD was a reduction in the slump flow diameter to 205 mm. The control mixture exhibited a diameter measuring 270 mm.
2. Following the 90-day age evaluation, the compressive strength of geopolymer concrete, which included KD as a partial replacement for 30% of the mass of PD, increased by 23% in comparison to the control samples. The control samples served as a basis for comparison to arrive at this conclusion.

3. A reduction of 30% in the ratio of PD to KD in geopolymer concrete resulted in a 20% decrease in the water absorption rate when compared to the control samples.
4. The optimal formulation for PD-KD hybrid geopolymer concrete was identified as a 20% mass replacement of PD with KD, leading to the highest compressive strength achieved.

References

1. Johari, M., et al., Influence of supplementary cementitious materials on engineering properties of high strength concrete. Construction and Building Materials, 2011. 25(5): p. 2639-2648.
2. Nabil, N., E.A. Kishar, and D.A. Ahmed, Effect of elevated temperatures on the performance of metakaolin geopolymer cement Incorporated by cement kiln dust. 2021.
3. Safari, Z., et al., Mechanical characteristics of pumice-based geopolymer paste. Resources, Conservation and Recycling, 2020. 162: p. 105055.
4. Fernández-Jiménez, A., et al. Specific examples of hybrid alkaline cement. EDP Sciences.
5. Qu, B., et al., Characterisation of pre-industrial hybrid cement and effect of pre-curing temperature. Cement and Concrete Composites, 2016. 73: p. 281-288.
6. Apithanyasai, S., N. Supakata, and S. Papong, The potential of industrial waste: using foundry sand with fly ash and electric arc furnace slag for geopolymer brick production. 2020. 6(3): p. e03697.
7. Kouamo, H.T., et al., The effect of adding alumina-oxide to metakaolin and volcanic ash on geopolymer products: A comparative study. 2012. 35: p. 960-969.
8. Mohseni, E., et al., Evaluation of mechanical and durability properties of fiber-reinforced lightweight geopolymer composites based on rice husk ash and nano-alumina. 2019. 209: p. 532-540.
9. Pham, T., and B. Materials, Enhanced properties of high-silica rice husk ash-based geopolymer paste by incorporating basalt fibers. 2020. 245: p. 118422.
10. Jindal, P. Jangra, and A. Garg, Effects of ultra fine slag as mineral admixture on the compressive strength, water absorption and permeability of rice husk ash based geopolymer concrete. 2020. 32: p. 871-877.
11. Almalkawi, A., et al., Potential of using industrial wastes for production of geopolymer binder as green construction materials. 2019. 220: p. 516-524.
12. Zabihi, S., Tavakoli, and E.J. Mohseni, Engineering and microstructural properties of fiber-reinforced rice husk–ash based geopolymer concrete. 2018. 30(8): p. 04018183.
13. Neville, A.M., Properties of concrete. Vol. 4. 1995: Longman London.
14. Mijarsh, M., et al., Influence of SiO2, Al2O3, CaO, and Na2O on the elevated temperature performance of alkali-activated treated palm oil fuel ash-based mortar. Structural Concrete, 2021. 22: p. E380-E399