The Effect of Adding Ketapang Fruit Ash on the Physical and Mechanical Properties of Geopolymer Concrete Based on High-Calcium Fly Ash Type C with Alkali Activator

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Abstract - *This study aims to analyze the effect of adding ketapang fruit ash on the physical and mechanical properties of geopolymer concrete based on high-calcium fly ash type C with an alkali activator. The research methods included chemical composition analysis of fly ash using X-Ray Fluorescence (XRF) and the preparation of concrete samples with varying concentrations of ketapang fruit ash (1%, 1.6%, 2.3%) and water content (3.6%, 3.0%, 2.3%), as well as curing durations (7, 14, and 28 days). The XRF analysis results revealed that fly ash from the Jeranjang Power Plant belongs to Class C, with major components being SiO_2 (34.8%), Fe_2O_3 (23.7%), CaO (23.0%), and Al_2O_3 (11.0%). Physical property tests indicated that the mass of concrete types I, II, and III remained relatively stable at 7, 14, and 28 days, although a slight decrease in mass was observed for concrete type I after curing, with a final mass of 6.8 kg. This decrease was attributed to environmental factors, composition, and rapid water evaporation. Mechanical property tests demonstrated a significant increase in compressive strength across all concrete samples as the concentration of ketapang fruit ash increased. The highest compressive strength was achieved by concrete type III with a ketapang fruit ash concentration of 2.3%, reaching 200 MPa at 7 days, 225 MPa at 14 days, and 270 MPa at 28 days. Furthermore, the addition of ketapang fruit ash improved the concrete's resistance to water penetration. These results suggest that incorporating ketapang fruit ash is an effective alternative for enhancing the quality of geopolymer concrete for structural applications.*

Keywords*: Geopolymer Concrete; Fly Ash; XRF Analysis; Physical Testing; Mechanical Testing; Ketapang Fruit Ash*

INTRODUCTION

The selection of building materials in the construction industry plays a crucial role in determining the quality and sustainability of structures. The growing demand for infrastructure in line with modern advancements has become a primary focus for engineers and construction experts to find or produce materials that are strong, durable, and efficient. Concrete, as one of the primary material choices in various construction projects, is widely known as a dominant structural component used in the development of infrastructure such as buildings, bridges, highways, and foundations (Manuahe, 2014). Concrete offers excellent load-bearing capacity, weather resistance, and versatility in various building applications due to its ease of maintenance (Hamdi et al., 2022). The composite material of concrete consists of a mix of cement, fine aggregates, coarse aggregates, water, and sometimes additives, with proportions adjusted to suit specific needs. Among these components, cement plays a pivotal role as the binder that determines the strength of concrete. However, the extensive use of cement poses significant challenges, both in terms of cost and environmental impact. Consequently, identifying alternative raw materials with chemical properties similar to cement is essential (Hepiyanto et al., 2019).

The use of cement as the main

component in concrete production has substantial negative effects, particularly as Indonesia's cement production increases to meet the demands of the construction industry. According to the Indonesian Cement Association (2018), cement consumption in 2017 reached 66.3 million tons, reflecting a 7% increase from the previous year. The negative impacts of cement plant activities can be categorized into three areas: raw material extraction, production processes, and material transportation (Sulasmi et al., 2022).

Raw material extraction, especially in limestone regions, has led to the depletion of water sources critical for local communities, exacerbating drought risks during dry seasons. The cement production process generates dust that pollutes the air, potentially causing respiratory issues and reduced lung function in nearby communities. Occupational exposure to dust worsens workers' health conditions, with a significant prevalence of pulmonary disorders, particularly among those without proper protective equipment or who smoke. Another notable effect is the increased risk of respiratory diseases from fine particulate matter (PM 2.5), especially in areas within 2 km of cement plants. Additionally, health issues such as anemia and skin irritation are common among residents living near cement facilities, particularly those closest to industrial activities. Thus, innovative alternatives are required to support environmentally friendly construction, such as geopolymer concrete (Bachtiar et al., 2016).

Geopolymer concrete is a type of concrete that incorporates silica and alumina elements, formed through the polymerization of inorganic materials. The materials used for geopolymer concrete are derived from industrial byproducts such as fly ash and nickel slag. This type of concrete is recognized as eco-friendly because its production requires less energy and its use helps reduce pollution (Syaputra et al., 2018; Utami et al., 2017).

Ketapang fruit (Terminalia catappa) is a potential waste material that remains underutilized. The natural fibers from ketapang fruit have significant potential due to their high reactive silica content compared to other fruits. Ketapang fruit is widely available in Indonesia (Durowaye et al., 2018). However, its utilization, particularly in Mataram City, is still suboptimal. The trees are commonly planted as shade trees, while the fruit is often discarded as waste. Research by Susilawati (2020) demonstrated that synthesizing composites using a mix of coconut coir fibers and ketapang fruit fibers with a Polyvinyl Acetate (PVAc) matrix was successful, indicating great potential for developing stronger and more environmentally friendly composite materials.

RESEARCH METHODS

The materials used in this research include fly ash, alkali activators (NaOH and Na_2SiO_3), fine and coarse aggregates, water, and cement. The study was conducted over four months at the Soil Chemistry Laboratory, Faculty of Agriculture, University of Mataram (UNRAM), and the Structural Laboratory, Faculty of Engineering, UNRAM. The research process was carried out in the following stages:

Fly Ash Preparation Stage

The binder material, fly ash, was sourced from the Jeranjang Power Plant, West Lombok. The chemical composition of the fly ash was analyzed using X-Ray Fluorescence (XRF) Spectrometry to determine the percentage composition of its constituent elements.

Test Sample Preparation Stage

Test samples were prepared by mixing all materials in various concentration ratios: cement (4.5%), fine aggregates (30%), coarse aggregates (45.5%), water (3.6%; 3.0%; 2.3%), NaOH (2.3%), distilled water (3.8%), water glass (Na_2SiO_3) (3.8%), fly ash (5.0%), and ketapang fruit ash (1%; 1.6%; 2.3%). The mixture was cast into cubic molds with dimensions of 15 cm^3.

The concrete samples were dried for varying curing durations of 7, 14, and 28 days. Subsequently, the samples underwent 24-hour curing by submersion in water prior to testing. The tests included physical testing and compressive strength testing using a Compression Testing Machine (CTM) to evaluate the mechanical properties of the geopolymer concrete.

The data collected were analyzed using descriptive statistical analysis to assess the impact of adding ketapang fruit ash on the mechanical performance of the concrete.

RESULTS AND DISCUSSION

Material testing was conducted in two stages: chemical composition analysis of the geopolymer material, specifically fly ash, using XRF testing as presented in Table 1, and mechanical and physical testing through compressive strength tests on the prepared concrete samples.

Chemical Composition Analysis of Fly Ash

Based on the results shown in Table 1, the fly ash from PLTU Jeranjang, West Lombok, has the highest SiO_2 content at 34.8%, followed by Fe_2O_3 (23.7%), CaO (23.0%), and Al_2O_3 (11.0%). This composition indicates that the fly ash is predominantly composed of silica, iron, calcium, and alumina. When summing the total content of the four primary components (SiO_2 + Fe_2O_3 + Al_2O_3), the percentage reaches 69.5%, with CaO accounting for 23.0%. According to the classification of fly ash based on the ACI (American Concrete Institute) Manual of Concrete Practice (1993), fly ash can be categorized into two classes, C and F, depending on the total content of SiO_2, Fe_2O_3, Al_2O_3, and CaO. Class C requires a minimum percentage of these three components at 50% and a CaO content of more than 10%, while Class F requires a minimum of 70% and a CaO content of less than 10%. Based on these results, the fly ash from PLTU Jeranjang is classified as Class C, as the total of SiO_2, Fe_2O_3, and CaO exceeds 50%, and its CaO content is greater than 10% (Marthinus et al., 2015).

Table 1. Results of Chemical Composition Analysis of Fly Ash from PLTU Jeranjang, West Lombok

No.	Chemical Composition *Fly Ash*	Percentage
1.	SiO_2	34,8
2.	Fe_2O_3	23,7
3.	CaO	23,0
4.	Al_2O_3	11,0
5.	SO_3	3,36
6.	TiO_2	1,43
7.	K_2O	1,25

Class C fly ash generally contains a higher amount of calcium oxide than Class F fly ash. It is produced from the combustion of lignite or sub-bituminous coal, which has higher calcium content (Irlan et al., 2020). Class C fly ash is not only pozzolanic but also exhibits cementitious properties, enabling it to react independently with water or alkalis without requiring external activators. These properties make Class C fly ash a potential contributor to improving the strength and durability of geopolymer concrete. Additionally, fly ash serves as a binder in concrete production, with a longer setting time compared to conventional binders (Qomaruddin et al., 2018; Indayani et al., 2019).

Research Results on Physical and Mechanical Properties Testing

The physical and mechanical properties testing involved six concrete samples, divided into two groups based on the drying period. The first group consisted of three concrete samples (I, II, and III), subjected to drying periods of 7, 14, and 28 days. These variations in drying duration were selected to evaluate the development of compressive strength over time. The results of the physical property measurements, specifically the concrete mass, are presented in Table 2 below.

Table 2. Results of Physical Testing: Concrete Mass Measurements

Concrete Code	Mass Before Curing (Kg)	Mass After Curing (Kg)		
		7 Days	14 Days	28 Days
Concrete I	7,1	7,2	6,8	6,8
Concrete II	7,1	7,3	7,1	7,1
Concrete III	7,1	7,1	7,1	7,1

Table 2 presents the results of physical testing on concrete mass based on the concrete's age. It shows that the mass of concrete samples I, II, and III remained relatively stable at 7, 14, and 28 days, although a slight decrease was observed in concrete I after curing, with a mass of 6.8 kg. This reduction could be attributed to environmental factors, composition, and the rapid evaporation of water, which reduced the concrete's mass. The results of mechanical testing can be seen in Table 3 and Figure 1.

Table 3. The Results of Mechanical Properties Testing

Concrete Code	Compressive Strength (MPa) at Concrete Age (Days)		
	7	14	28
Concrete I	125	135	120
Concrete II	180	200	235
Concrete III	200	225	270

Figure 1. The Results of Mechanical Properties Testing

Table 3 shows the results of mechanical property testing on three types of concrete. The tests measured the compressive strength of concrete at 7, 14, and 28 days. The results indicated an increase in compressive strength with the concrete's age, except for concrete I. This reduction in compressive strength might be attributed to the prolonged mixing time, which tends to lower the compressive strength of the concrete (Prihantono, 2007). Concrete III exhibited the highest compressive strength among the three types at all ages—7, 14, and 28 days. Variations in curing duration or increasing concrete age resulted in a corresponding increase in compressive strength. Longer curing durations or increasing concrete age promote the development of compressive strength (Faqihuddin et al., 2021).

The results of mechanical and physical property testing in Tables 2 and 3 indicate a positive correlation between the mechanical and physical properties of geopolymer concrete. The addition of ketapang ash in varying concentrations contributed to an increase in compressive strength and a reduction in water absorption, except for concrete I, which showed a slight decrease in compressive strength at 28 days. Concrete samples II and III, with ketapang ash concentrations of 1.6% and 2.3%, respectively, exhibited lower water absorption compared to concrete I. This indicates that concrete II and III had better resistance to water penetration.

Moreover, concrete II and III demonstrated continued increases in compressive strength with longer curing durations compared to concrete I. These results suggest that ketapang ash enhances the mechanical and physical properties of geopolymer concrete. Higher concentrations of ketapang ash corresponded to greater compressive strength and resistance to water penetration. Furthermore, according to research by Putri (2022), there is a relationship between the effect of alkali activator activity and curing duration on the compressive strength of geopolymer concrete.

CONCLUSION

Based on the research findings, XRF analysis revealed that fly ash from PLTU Jeranjang, West Lombok, is classified as Class C according to the ACI (American Concrete Institute) standards. The highest percentage composition was SiO_2 at 34.8%, followed by Fe_2O_3 (23.7%), CaO (23.0%), and Al_2O_3 (11.0%). The addition of ketapang ash improved the compressive strength of geopolymer concrete, with the highest compressive strength achieved by concrete sample III: 200 MPa at 7 days, 225 MPa at 14 days, and 270 MPa at 28 days. Concrete with higher ketapang ash content demonstrated lower water absorption, indicating better resistance to water penetration. The utilization of ketapang fruit ash and fly ash in geopolymer concrete shows potential as an eco-friendly alternative to reduce the use of conventional cement.

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