International Journal of GEOMATE, July, 2024 Vol.27, Issue 119, pp.112-119
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.119.3974
Geotechnique, Construction Materials and Environment

EFFECT OF CURING TIME AND LIQUID ALKALINE ACTIVATORS ON COMPRESSIVE STRENGTH DEVELOPMENT OF FLY ASH AND BAMBOO LEAF ASH-BASED GEOPOLYMER CONCRETE

Parea R. Rangan[1], *M. Tumpu[2], A. T. Arrang[1], A. Yunianta[3] and F. Rachim[4]

[1]Civil Engineering Department, Faculty of Engineering, University of Christian Indonesia, Toraja, Indonesia
[2]Disaster Management Study Program, The Graduate School, Hasanuddin University, Makassar, Indonesia
[3]Civil Engineering Department, Yapis University, Jayapura, Indonesia
[4]Civil Engineering Department, Fajar University, Makassar, Indonesia

*Corresponding Author, Received: 08 June 2023, Revised: 15 Oct. 2024, Accepted: 11 Nov. 2024

ABSTRACT: Substitute materials are used to modify the properties and characteristics of concrete, for example, to increase strength and improve performance (workability) in concrete. Waste materials from the environment can be used as a substitute material in the concrete mix. One of the efforts is to utilize bamboo leaf ash. Research on bamboo leaf ash as a basic ingredient with sodium hydroxide and sodium silicate added as activators was carried out to determine the characteristics of each parameter on the compressive strength of geopolymer concrete. The method used in this research is an experimental method of conducting laboratory tests using a cylindrical mould measuring 5 cm × 10 cm. The number of cylindrical specimens made was 81, with three molar variations, namely 10, 12, and 14 M. The tests were carried out at the ages of 3, 7, and 28 days. Based on the results of laboratory research, it was shown that geopolymer concrete made from fly ash and bamboo leaf ash had a compressive strength that met the initial planned compressive strength of 20 MPa, and the highest compressive strengths produced from specimens coded CU B3 and CU C3 were 20.892 and 21.911 MPa, respectively. So geopolymer concrete with a mixture composition of 80% fly ash and 20% bamboo leaf ash with a molar variation of 14 M and a mixed composition of 70% fly ash and 30% bamboo leaf ash with a molar variation of 14 M can be used for construction.

Keywords: Geopolymer concrete, Fly ash, Bamboo leaf ash, Alkaline activators, Compressive strength

1. INTRODUCTION

The basic ingredients of concrete are generally cement, sand, crushed stone, and water. Concrete has undergone many developments. One of the most technological developments in concrete is the discovery of a combination of concrete and reinforcing steel materials that are combined into one construction, known as reinforced concrete [1-3].

In terms of cement derivative products, lightweight concrete has been developed; a cement paste or mortar is defined as lightweight concrete with a density of 400–1,850 kg/m3 and has random air voids made from a mixture of foam agents in the mortar. Lightweight concrete has high flowability, low cement content, and efficient use of aggregates [4, 5]. Portland cement production is under scrutiny due to high carbon dioxide emissions. Conventional Portland cement is produced by pulverizing hydrolyzed calcium silicate and mixing it with gypsum [6]. The calcination process in the kiln can reach more than 1250°C and produce carbon dioxide (CO_2) as a by-product of combustion. One ton of cement produced will release one ton of CO_2 into the air, which can cause a greenhouse effect and an increase in the earth's temperature [7, 8]. Therefore, another alternative is needed to replace cement and reinforcement in reinforced concrete mixtures that produce environmentally friendly concrete at more affordable prices. One effort to reduce the use of cement is the development of geopolymer materials. A number of studies have shown that geopolymer binders can form concrete, and concrete made with geopolymer made from fly ash has physical characteristics similar to concrete made from cement [9, 10]. Among them is the development of concrete using organic binders such as alumina-silicate polymer, or what is known as geopolymer, which is a synthesis of geological materials found in nature that are rich in silica and aluminum content [11-13].

Geopolymer elements include industrial by-products, such as fly ash from coal combustion residue. Fly ash material used in the manufacture of concrete can react chemically with alkaline liquids at certain temperatures to produce mixed materials that have cement-like properties [14]. The geopolymer material is combined with rock aggregate to produce geopolymer concrete without using any more cement [15]. In the manufacture of geopolymer concrete, the materials used as concrete binders are fly ash, chemical additives in the form of sodium hydroxide, and sodium silicate activators (Na_2SiO_3) [16].

The effect of burnt bamboo leaf ash as a geopolymer concrete mixture has the benefit of containing silica (SiO_2), which has reactive properties and can become a hard and stiff material. Therefore, the results of burning bamboo leaves can be used as a mixture in concrete. Bamboo leaf ash was chosen based on research conducted by Maranan et al. (2016) [17], who stated that bamboo leaf ash has pozzolanic properties. Amu & Adetuberu (2010) [18] also mentioned that burning bamboo ash leaves at 600ºC for 2 hours produces 75.9% silica.

In fly ash-based geopolymer binders, bamboo leaf ash, and alkaline solutions react with fly ash to form alumina-silica binders without the addition of cement. The geopolymer binder then bonds the aggregate to form mortar or concrete. In several research studies using fly ash geopolymer as a binder material to replace cement, it seems that hot temperatures in the oven are always required to develop and increase the strength of concrete. Therefore, oven heat is needed to make geopolymer concrete from bamboo leaf ash and fly ash. This is expected to provide the heat needed for each use of fly ash geopolymer to develop concrete strength and reach normal concrete strength.

In Toraja, a small number of people use bamboo leaves as roofing material for tropical and sub-tropical buildings, while most are disposed of as waste, which has the potential to pollute the environment because if bamboo leaves are burned incompletely, they produce carbon monoxide (CO) gas, which is harmful to health, and if thrown away when it rains, they can clog the flow of water in ditches, which can cause flooding, so the presence of bamboo leaf waste needs to be addressed. This study aims to analyze the effect of curing time and liquid alkaline activators (NaOH and Na_2SiO_3) on the use of bamboo leaf ash and fly ash on the strength of geopolymer concrete.

2. MATERIALS AND METHOD

2.1 Bamboo Leaf Ash

Bamboo plants have many uses, including as a building material, especially in tropical and subtropical regions. In terms of benefits, bamboo is not only in the stems but also in the bamboo leaves, but many people do not know the benefits of burning bamboo leaves. With the combustion process, bamboo leaf ash has the benefit of containing silica (SiO_2), which has reactive properties and can react to become a hard and stiff material. The ash content of bamboo leaves is 20% with a silica content of 75.90% – 82.86%, which is the second largest after rice husk ash, which is equal to 93.2%. Therefore, the results of burning bamboo leaves can be used as a mixture in concrete.

In this study, bamboo leaf ash was used as a pozzolanic material, which, together with fly ash, was activated using an alkaline activator. Burning bamboo leaves begins with drying the bamboo leaves in the sun. The dried bamboo leaves are then put into a drum and then burned at 105.5°C to get ash, which is shown in Figure 1. The bamboo leaf ash is then filtered on sieve no. 200, shown in Figure 2.

It can be seen that bamboo leaf ash is a material that is more than 90% retained in sieve no. 200. Table 2 shows the results of testing the chemical characteristics of bamboo leaf ash based on the results of the XRF test. It can be seen that bamboo leaf ash is dominated by silica compounds (SiO_2) of 72.60%, K_2O of 16.93%, CaO of 6.43%, P_2O_5 of 4.16%, Fe_2O_3 of 3.13%, and Cl of 2.54%. While the small compounds that were read from the straw ash were MnO, TiO_2, Rb_2O, ZnO, SrO, Nb_2O_5, and MoO_3, it is hoped that the silica contained in the straw ash can form strong bonds with other materials to form crystals in the geopolymer mortar. So that it can configure a compact structure that has a robust composition.

Fig.1 The process of burning bamboo leaves

Fig.2 Bamboo leaf ash

Table 1. Physical characteristics of bamboo leaf ash

Materials characteristic	Standard	Results
Specific gravity	SNI 03-1964-2008	2.38
Water absorption	SNI 1970-2008	61.37%

Table 2. Chemical characteristics of bamboo leaf ash

No.	Oxide compounds	Content (%)
1	SiO_2	72.60
2	K_2O	16.93
3	CaO	6.43
4	P_2O_5	4.16
5	Loss on ignition (LOI)	3.20
6	Fe_2O_3	3.13
7	Cl	2.54
8	MnO	0.412
9	TiO_2	0.206
10	Rb_2O	0.0195
11	ZnO	0.0198
12	SrO	0.0169
13	Nb_2O_5	0.0057
14	MoO_3	0.0069

2.2 Fly Ash

Based on the American Coal Ash Association [19], fly ash is a product of combustion waste in steam power plant furnaces that has a smooth, round shape and is pozzolanic in nature. Whereas ASTM C-618 [20] defines fine grains as residue from burning coal or coal powder.

Table 3 shows the physical characteristics of fly ash. Based on Table 3, the results of the inspection of the specific gravity of fly ash were 2.88, where the specific gravity of fly ash was greater than the specific gravity of straw ash and laterite soil. This is because, according to ACI Committee 226, where fly ash has fine grains, which pass sieves No. 200 >90% and No. 325 (45 micron) 5-27%. Table 4 shows the chemical characteristics of fly ash.

Table 3. Physical characteristics of fly ash

Materials characteristic	Standard	Results
Specific gravity	SNI 03-1964-2008	2.78
Sieve analysis	ASTM D-1140-54	> 90% passed No.200

ASTM C 618-03 [20] divides fly ash into three categories, namely class N, class F, and class C. The minimum content of SiO_2, Al_2O_3, and Fe_2O_3 compounds is 70% for fly ash in the class N and class F categories, while the class C category is between 50% and 70%.

The CaO content in fly ash in class N and F categories is relatively smaller compared to class C categories, where the CaO content is greater than 10%. Meanwhile, according to Temuujin, J., et al. (2010) [21], the CaO element contained in fly ash in the class F category is less than 20%. Therefore, based on ASTM C618-03 [24], and Temuujin, J., et al. (2010) [21], the fly ash used in this study shown in Table 4 is type F fly ash (low calcium fly ash). Class F fly ash, which is the result of industrial production, is preferred for the use of geopolymer concrete because it contains a lot of amorphous aluminium silicate and has great workability.

Table 4. Chemical characteristics of fly ash

No.	Oxide compounds	Content (%)
1	SiO_2	44.69
2	Al_2O_3	15.73
3	Fe_2O_3	10.25
4	CaO	14.12
5	MgO	2.78
6	K_2O	0.73
7	Na_2O	0.49

Fig.3 Fly ash

In this study, using fly ash from PLTU Jeneponto which is shown in Figure 3. Jeneponto fly ash has pozzolanic properties, and to obtain cementitious properties, quick lime, hydrated lime, or cement must be added. The first reaction is the reaction of calcium with water, which causes a hydration reaction caused by lime. The second reaction is the reaction of geopolymerization between silica and alumina, which is activated by alkali. Fly ash has a specific area of 170-1000 m^2/kg. The average particle size of sub-bituminous coal fly ash is 0.01 mm–0.015 mm, the surface area is 1-2 m^2/g, and the particle shape is mostly spherical, that is, most of it is spherical, resulting in better workability [22].

2.3 Alkaline Activator

In the manufacture of geopolymer concrete, an alkaline activator is needed, which functions to react the chemical content in the fly ash so that the geopolymer paste can bind to the aggregate. The activator commonly used is sodium silicate (Na_2SiO_3). Sodium silicate functions to accelerate polymerization reactions; coal with a certain quality is used in combustion; and the level of optimization of the combustion process will greatly affect the levels of chemical content in fly ash [23].

Several studies have proven that sodium silicate can be used as an admixture in concrete. This sodium silicate and sodium hydroxide are one of the alkaline solutions that play an important role in the polymerization process. This is because sodium silicate has the function of accelerating the polymerization reaction. The reaction occurs more rapidly in alkaline solutions that contain a lot of hydroxides.

2.4 Aggregates

Aggregate is the concrete component that plays the most important role in determining the strength. In concrete, there is usually 60%–80% by volume of aggregate. This aggregate must be graded in such a way that the entire mass of concrete can function as a whole, homogeneous, and dense object, where the small aggregate functions as a filler in the gaps between the large aggregates.

Table 5. Properties of aggregates

Material Characteristics	Standard	Results
Coarse Aggregate		
Sludge content (%)	SNI 03-4142-1996	2.99
Volume weight (gr/cm^3)	SNI 03-1973-1990	
• Dense condition		1.58
• Loose condition		1.35
Water content (%)	SNI 03-1971-1990	1.28
Bulk specific gravity	SNI 1969-2008	2.56
SSD spesifuc gravity		2.61
Apparent spesific gravity		2.68
Water absorption (%)	SNI 1969-2008	1.75
Fine Aggregate		
Sludge content (%)	SNI 03-4142-1996	1.63
Volume weight (gr/cm^3)	SNI 03-1973-1990	
• Dense condition		1.46
• Loose condition		1.34
Water content (%)	SNI 03-1971-1990	9.59
Bulk specific gravity	SNI 1970-2008	2.18
SSD spesifuc gravity		2.35
Apparent spesific gravity		2.62
Water absorption (%)	SNI 1970-2008	7.76

In this study, coarse and fine aggregates were used to produce geopolymer concrete. Aggregates are obtained from a stone crusher located in Tana Toraja. Table 5 shows the results of examining the coarse and fine aggregates used in this study.

Based on the results of testing the characteristics of coarse aggregate (crushed stone) and fine aggregate (sand), it can be seen that the aggregate used meets the specifications of the Indonesian National Standard for the required concrete materials.

2.5 Compressive Strength

The compressive strength test of concrete referred to in SNI 03-1974:1990 was carried out at the ages of 3, 7, and 28 days. Loading method by placing a concrete cylinder with a diameter (d) of 5 cm and a height (h) of 10 cm on the UTM (universal testing machine) compressive strength tester centrically.

The press machine is run automatically with a constant addition of load (P) ranging from 2 to 4 kg/cm^2 per second on the cross-sectional area (A) until the cylinder is crushed. The maximum load that occurs during the test is recorded as a P value.

2.6 Research Method

The research was carried out experimentally in the laboratory. In addition, a survey was also conducted to find out the sources and availability of concrete-forming materials, especially fibers derived from bamboo. The stages of this research started with the process of preparing equipment and providing materials, inspecting materials, planning and manufacturing, and testing test objects.

This research was carried out by mixing geopolymer concrete forming materials such as coarse aggregate, fine aggregate, bamboo leaf ash, fly ash as a substitute for cement, sodium hydroxide, sodium silicate, and water as an alkaline activator at mixed contents, as shown in Table 6.

Mixing was carried out for a duration of 5 minutes for all molar variations. Then the mixture is put into a cylindrical test object with a mould size of 5 cm × 10 cm and given a code. After making dry test specimens and removing them from the mould, the test specimens were treated with air curing or water curing for 3 days, 7 days, or 28 days. And curing the oven for 24 hours at a temperature of 60°C. After reaching the predetermined age of concrete, the specimen is lifted from the soaking tub to be dried one day before the concrete compressive strength test is carried out. Making a mix design is done by testing the initial mix so that the number of test objects obtained in one mix is then converted to 1 m^3. In each variation of this study, we used a total of 3 test objects. So that, the total test object needed is 81 pieces. The standards used in testing concrete-forming materials are the American Society for Testing and Materials (ASTM) standard and the Indonesian National Standard (SNI).

Table 6. Sample compositions

No	Mixture content				Code
	Molarity variation	Activator variation N_aOH: $N_{a2}SiO_3$	Bamboo leaf ash	Fly Ash	
1	10 M	1: 1.5	10%	90%	A1
		1: 1.5	20%	80%	B1
		1: 1.5	30%	70%	C1
2	12 M	1: 1.5	10%	90%	A2
		1: 1.5	20%	80%	B2
		1: 1.5	30%	70%	C2
3	14 M	1: 1.5	10%	90%	A3
		1: 1.5	20%	80%	B3
		1: 1.5	30%	70%	C3

3. RESULTS AND DISCUSSION

3.1 Mixtures Design

The design composition of the geopolymer concrete mixture in a volume of 1 m^3 made from bamboo leaf ash, fly ash, coarse aggregate, fine aggregate, and alkaline activator (NaOH and Na_2SiO_3) is shown in Table 7. In this study, the ratio of bamboo leaf ash to fly ash is 10%–90%, 20%–80%, and 30%–70%. From the initial mix trials, the geopolymer concrete composition design was obtained at optimal conditions. NaOH and $Na2SiO_3$ solutions were used as alkaline binders.

The amount of water used is also taken into account to obtain the optimal water content for an optimal and homogeneous mixture. The molarity concentrations of NaOH used in this study consisted of three, i.e., 10 M, 12 M, and 14 M.

It can be seen that the greater the concentration of NaOH, the greater the amount of NaOH used. At concentrations of 10 M, 12 M, and 14 M, 3.60 kg, 4.32 kg, and 5.04 kg of NaOH were used. It can be seen that the ratio between alkali and total material at 10 M, 12 M, and 14 M is 7.98%, 14.77%, and 17.82%, respectively. This phenomenon shows that at 14 M has the largest ratio of alkali and total material. The greater the molarity causes the geopolymerization reaction that does not take place perfectly. This is indicated by the appearance of effofluorence ($NaOH + CO_2 \rightarrow$ sodium carbonate). The effofluorence that occurs causes many cavities to occur in the geopolymer mortar so that the compressive strength value decreases. Clearly, this issue potentially impacts the overall structural performance to effectively withstand various type of loads and stresses.

Table 7. Mix design (1 m^3)

Materials (gram)	Molarity (M)		
	10	12	14
NaOH	3.60	4.32	5.04
Na_2SiO_3	16.47	19.76	23.06
Fine aggregate	1.83	1.83	1.83
Coarse aggregate	1.93	1.93	1.93
Water	0.36	0.36	0.36
	10:90%		
Bamboo leaf ash	0.07	0.07	0.07
Fly ash	0.62	0.62	0.62
	20:80%		
Bamboo leaf ash	0.14	0.14	0.14
Fly ash	0.56	0.56	0.56
	30:70%		
Bamboo leaf ash	0.21	0.21	0.21
Fly ash	0.49	0.49	0.49

3.2 Compressive Strength

Figure 4 shows a comparison of the compressive strength values for all test objects at concentrations of 10 M, 12 M, and 14 M geopolymer concrete made from bamboo leaf ash, fly ash, coarse aggregate, fine aggregate, and alkaline activators (NaOH and Na_2SiO_3).

The compressive strength test above shows that a mixture of 70% fly ash and 30% bamboo leaf ash as a substitute for cement with added activators sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) has a molar variation of 10 M or 400 gr with a ratio of 1: 1. Five specimens with CU code (air curing) C1 at 28 days of age have the highest compressive strength of 18.854 MPa. These results indicate that 10 M can increase the compressive strength of geopolymer

The compressive strength test above shows that a mixture of 70% fly ash and 30% bamboo leaf ash as a substitute for cement with added activators sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) with a molar variation of 12 M or 480 gr with a ratio of 1:1.5 specimens with CU (air curing) code C2 at the age of 28 days had the highest compressive strength of 20.076 MPa.

Test above shows that a mixture of 70% fly ash and 30% bamboo leaf ash as a substitute for cement with added activators sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) has a molar variation of 14 M or 560 gr with a ratio of 1:1.5. Five specimens coded CU (air curing) C2 at the age of 28 days had the highest compressive strength of 21.911 MPa.

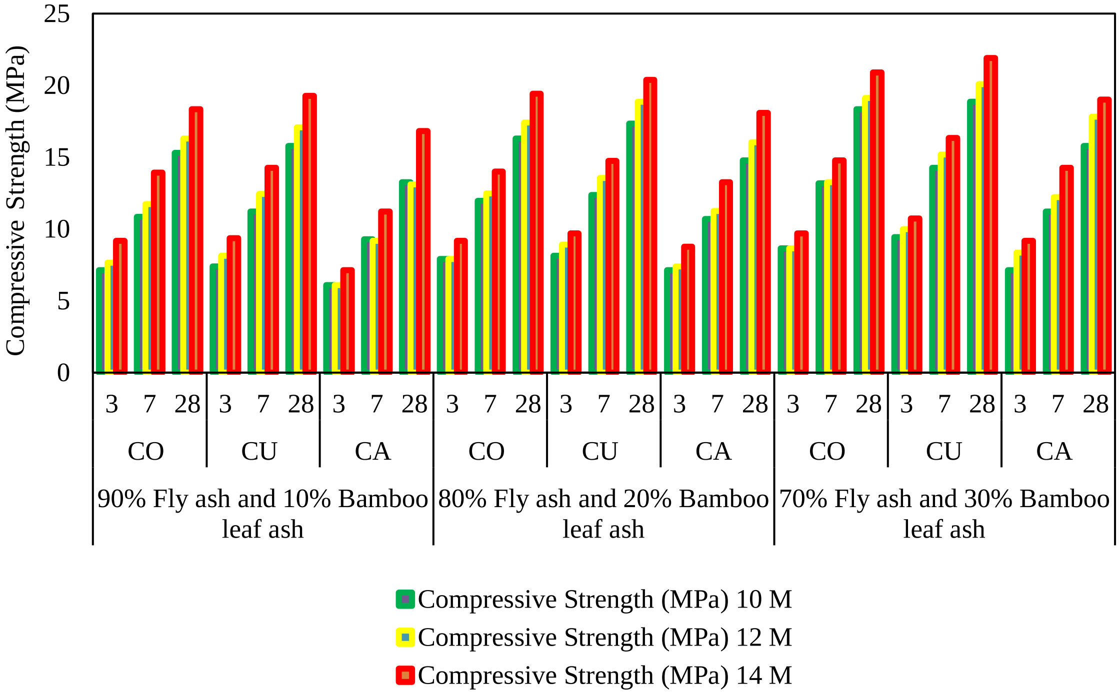

Fig.4 Comparison of compressive strength for all test objects

Based on Figures 10, it can be seen that the compressive strength value increases with increasing curing time for geopolymer concrete for all test objects. The unification of all geopolymer materials greatly affects the hardness value of geopolymer materials. This can be caused by the molarity concentration used so that the alkaline activators (NaOH and Na_2SiO_3) can properly bind the geopolymer material. Some geopolymer particles agglomerate, layer, and elongate.

As seen in Figure 10, the compressive strength. In addition, in this study, a compressive strength test was carried out on geopolymer mortar using geopolymer constituent materials (bamboo leaf ash and fly ash), which passed sieve no. 200. The compressive strength test of geopolymer material that passes sieve no. 200 is a comparison with the compressive strength value of geopolymer concrete using variations in the size of the material used so that the effect of material size on the mechanical characteristics of geopolymer mortar can be known. This shows that the smaller or finer the geopolymer material used, the greater its compressive strength value. The size of the material will be directly proportional to the resulting compressive strength value.

With the comparison of the concrete compressive strength of the cylinder test object above, it can be concluded that the graph has increased with the increasing age of the concrete. This indicates that the increase in compressive strength continued from the curing age of 3, 7, and 28 days due to the ongoing polymerization process, which forms stronger chemical bonds within the material's matrix.

The graph above also shows the difference in concrete compressive strength depending on the type of treatment performed on it. Air curing has a concrete compressive strength greater than oven curing and water curing. But oven curing has a greater compressive strength than water curing. This shows that the compressive strength of the resulting concrete is influenced by the type of treatment given to it. The perfect polymerization reaction causes the geopolymer materials (bamboo leaf ash and fly ash) to blend properly so that it affects the hardness and density of the test object.

Materials that pass Sieve No. 200 is one of the factors that affect the properties of geopolymer mortar, including compressive strength [13]. The physical properties of the mortar are closely related to its durability. Durability is measured by damage caused by internal and external factors in the mortar itself. Mortar usually has various pore distribution characteristics that can affect its transport properties, such as absorption, diffusion, and sorptivity, which determine the quality of the mortar.

It can be seen that the compressive strength value of the specimen with air curing is greater than that of the water-cured specimen. This is because the polymerization reaction on the air-cured specimen occurs perfectly compared to the water-cured specimen.

The decrease in compressive strength due to water immersion and heat from curing the oven is caused by ions from the alkaline activator and silica from bamboo leaf ash and fly ash, which can react with the geopolymer mortar binder, thereby reducing the bonding power between the binder (alkaline activator) and the material of geopolymer concrete (bamboo leaf ash, fly ash, and aggregates). Weak exposure to water and oven heat can result in significant microstructural reorganization in mortar. Penetration of sulphate ions into the material not only originates from the precipitation of sulphate-bearing phases (such as ettringite and eventually gypsum) but also results in the dissolution of calcium hydroxide and C-S-H decalcification. In addition, sulphates can cause cavities in the geopolymer mortar, causing a decrease in the weight and compressive strength of the geopolymer mortar.

4. CONCLUSIONS

1. The composition of the mixture and the molar variation in the compressive strength of the resulting concrete is very influential; the higher the molar variation is given, the greater the compressive strength of the resulting concrete. This is shown by the highest compressive strength obtained from the molar variation of 14 M. However, the reduced composition of the mixture and the addition of bamboo leaf ash will increase the compressive strength of the resulting concrete. There is a test object with a mixture of 90% fly ash and 10% bamboo leaf ash with a molar variation of 14 M producing the highest compressive strength of 19.261 MPa; a test object with a mixture of 80% fly ash and 20% bamboo leaf ash with a molar variation of 14 M CU (air curing) produced the highest compressive strength of 20.382 MPa; and a test object with a mixture of 70% fly ash and 30% bamboo leaf ash with a molar variation of 14 M produced a concrete compressive strength of 21.911 MPa.
2. Based on the results of laboratory research, it was shown that geopolymer concrete made from fly ash and bamboo leaf ash had a compressive strength that met the initial planned compressive strength of 20 MPa, and the highest compressive strength produced from specimens coded CU B3 and CU C3 obtained optimum results of 20.892 MPa at the composition of a mixture of 80% fly ash and 20% bamboo leaf ash with a molar variation of 14 M and 21.911 MPa on a mixed composition of 70% fly ash and 30% bamboo leaf ash with a molar variation of 14 M can be used for construction.
3. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) can release silica and alumina in the amorphous phase and can be used as a binder for geopolymer mortar made from straw ash, fly ash and laterite soil without heating. These materials react with alkaline solutions to form alumina-silica binders without the use of cement resulting in Si-O-Al polymer bonds. The polymerization reaction that takes place makes the test object harden without the oven heating process.
4. The results of this study can be used to support the use of waste materials (fly ash and laterite soil) and local materials (straw ash) as geopolymer mortar-forming materials. In addition, it can also support the development of eco-friendly (environmentally friendly) national infrastructure without the use of oven heat for the polymerization reaction to take place. However, this research can also be developed to increase the compressive strength of geopolymer mortar, which resembles that of conventional concrete in general.

5. ACKNOWLEDGMENTS

This work was supported by the Indonesian Christian University of Toraja Faculty of Engineering internal grant. The geopolymer concrete specimens were prepared and conditioned at the Eco Material and Concrete Laboratory at the Department of Civil Engineering, Indonesian Christian University Toraja, Indonesia. The authors would like to express their sincere thanks to Dr. Rael Rabang Matasik, Israel Padang, MT, Yohans Sunarno, MT and M. Yusuf Satria, S.Kel, for this research through their assistance with providing helps during this research.

6. REFERENCES

[1] Tumpu M., and Mabui D. S., Effect of Hydrated Lime ($Ca(OH)_2$) to Compressive Strength of Geopolymer Concrete. International Conference on Science and Applied Science (ICSAS), AIP Conf. Proc. 2391, 070011-1-070011-7.

[2] Mansyur and Tumpu M., Compressive Strength of Normal Concrete Using Local Fine Aggregate from Binang River in Bombana District, Indonesia. Applied Science (ICSAS), AIP Conf. Proc. 2391, 070011-1-070011-6.

[3] Mansyur and Tumpu M., Compressive Strength of Non-Sand Concrete with Coarse Aggregate in Kolaka District as Yard Pavement. Applied Science (ICSAS), AIP Conf. Proc. 2391, 070011-1-070011-6.

[4] Parung H., Tumpu M., Tjaronge M. W., Amiruddin A. A., Walenna M. A., and Mansyur, Crack Pattern of Lightweight Concrete under Compression and Tensile Test.

Annales de Chimie: Science des Materiaux, Vol. 47, Issue 1, 2023, pp. 35–41.
[5] Amiruddin A. A., Parung H., Tjaronge M. W., Irmawaty R., Mansyur, and Tumpu M., Influence of Prefabricated Lightweight Concrete as Infill Wall on The Strength Due to Cyclic Loading. International Journal of GEOMATE, Vol. 22, Issue 93, pp: 114-121.
[6] Rangan P. R., Irmawaty R., Tjaronge M. W., Amiruddin A. A., Bakri B., and Tumpu M., The Effect of Curing on Compressive Strength of Geo-polymer Mortar Made Rice Straw Ash, Fly Ash and Laterite Soil. IOP Conf. Series: Earth and Environmental Science 921 (2021) 012009.
[7] Mansyur, Amiruddin A. A., Parung H., Tjaronge M. W., and Tumpu M., Utilization of Sea Water to Production of Concrete in Terms of Mechanical Behavior. IOP Conf. Series: Earth and Environmental Science 921 (2021) 012009.
[8] Sunarno Y., Tjaringe M. W., and Irmawaty R., Preliminary study on early compressive strength of lightweight concrete using Ordinary Portland Cement (OPC) and Portland Composite Cement (PCC). IOP Conf. Ser.: Earth Environ. Sci. 419 (2020) 012033.
[9] Detphan S., and Chindaprasirt P., Preparation of Fly Ash and Rice Husk Ash Geopolymer. International Journal of Minerals, Metallurgy and Materials. Vol. 16, Issue 6, 2009, pp. 720-726.
[10] Dinakar P., Babu K. G., and Santhanam M., Durability Properties of High-Volume Fly Ash Self Compacting Concrete. Cement and Concrete Composites, Vol. 30, Issue 10, 2008, pp. 880-886.
[11] Rangan P. R., and Tumpu M., Marshall Characteristics of Quicklime and Portland Composite Cement (PCC) as Fillers in Asphalt Concrete Binder Course (AC-BC) Mixture. Annales de Chimie - Science des Matériaux Vol. 47, Issue 1, 2023, pp. 51-55.
[12] Gunasekara C., Law D. W., and Setunge S., Long Term Permeation Properties of Different Fly Ash Geopolymer Concretes. Construction and Building Materials, Vol. 124, 2016, pp. 352-362.
[13] Djwantoro H., and Vijaya R. B., Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete. Research Report GC 1, Curtin University of Technology, 2005.
[14] Matalkah F., Soroushian F., Balchandra A., and Peyvandi A., Characterization of Alkali-Activated Nonwood biomass Ash-Based Geopolymer Concrete. Journal Materials in Civil Engineering, Vol. 29, Issue 4, 2016, pp. 864-870.
[15] Mehta A., and Siddique R., Strength, Permeability and Micro-Structural Characteristics of Low-Calcium Fly Ash Based Geopolymers. Construction and Building Materials, Vol. 141, 2017, pp. 325-334.
[16] Mehta A., and Siddique R., Sulfuric Acid Resistance of Fly Ash Based Geopolymer Concrete. Construction and Building Materials, Vol. 146, 2017, pp. 136-143.
[17] Maranan G. B., Manalo A. C., Benmokrane B., Karunasena W., and Mendis P., Behaviour of Concentrically Loaded Geopolymer-Concrete Circular Columns Reinforced Longitudinally and Transversely with GFRP Bars. Engineering Structures, Vol. 117, 2016, pp. 422-436.
[18] Amu O. O., and Adetuberu A. A., Characteristics of Bamboo Leaf Ash Stabilization on Lateritic Soil in Highway Construction. International Journal of Engineering and Technology, Vol. 2, Issue 4, 2010, pp. 212-219.
[19] American Coal Ash Association. 2014. CCP Production and Use Survei. https://www.acaa-usa.org/Portals/9/Files/PDFs/2014-Production-and-Use-Survey-Presentation.pdf.
[20] ASTM C618-03 (2003). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.
[21] Temuujin J., Riessen A. V., and MacKenzie K. J. D., Preparation and Characterisation of Fly Ash Based Geopolymer Mortars. Construction and Building Materials, Vol. 24, Issue 10, 2010, pp. 1906-1910.
[22] Davidovits J., Environmentally Driven Geopolymer Cement Applications. Geopolymer Conference, Melbourne, Australia, 2002.
[23] Aluah R., Oni O., Fadairo A., and Pothana P., Enhancing the Performance of Class G Cement for Subsurface Gas Storage and Well Completion: Synergistic Impact of North Dakota's Fly Ash and Eggshell Powder. Powder Technology, Vol. 440, 2024.
[24] Babaee M., and Castel A., Chloride-Induced Corrosion of Reinforcement in Low-Calcium Fly Ash-Based Geopolymer Concrete. Cement and Concrete Research, Vol. 88, 2016, pp. 96-107.