Literature Review On Geopolymer Mortar Using Agricultural Waste As Precursor

Faiz Sulthan

Abstract: Alternative replacement material cement as a binder in concrete that is currently developed is the geopolymer material. Geopolymer is the result of the polymerization process material that contains silica (Si) and aluminum (Al) derived from natural materials, agricultural waste or industrial waste. Material results of agricultural wastes that can be used as precursors include rice husk ash, bagasse ash and palm oil fuel ash. Agricultural waste materials eligible to be processed into the material forming geopolymer. Chemical compounds criteria based on testing X-Ray Fluorescence (XRF) and refer to ASTM C 618 is known that industrial waste materials are feasible to be developed as a precursor. Criteria for the mechanical properties of materials such as mortar compressive strength testing also showed good results, geopolymer using 100% bagasse ash can also achieve the compressive strength of mortar at 18.34 MPa. For materials rice husk ash and palm oil fuel ash is only used by 50% and mixed with 50% fly ash, compressive strength results showed with rice husk ash of 21.50 MPa and palm oil fuel ash of 20.70 MPa.

Index Terms: Geopolymer, fly ash, bagasse ash, palm oil fuel ash, rice husk ash.

1 Introduction

Concrete is one of the dominant materials used as a material for building structures. The strength of the concrete material is influenced by the composition and constituent materials, one of which is cement. Cement is a material which reacted with water to form a unity that is solid and will be the glue in the composition of concrete building blocks. Cement clinker is produced through the combustion process with temperatures reaching ±1500^{o}C. The cement forming combustion produces carbon dioxide (CO_2) which is released into the air and can pollute the environment [1]. Carbon dioxide is the largest supplier of gas emissions that cause the greenhouse effect and the conditions become an issue of global warming. Carbon dioxide emissions due to the global cement industry in 2015 reached 8% of total greenhouse gas emissions [2]. It becomes imperative to find a solution to reduce global warming, one of which is to replace the cement material with other material alternatives in concrete so that the concrete material developed without cement. Alternative replacement material cement as a binder in concrete that is currently developed is the geopolymer material. Geopolymer was first discovered by Professor Joseph Davidovits in 1978. Geopolymer formed from the alkali-activated and the material forming (precursor). Alkali-activated is a mixture of compounds of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) which is used to react the content of silica (Si) and aluminum (Al) in the precursor resulting in a process of polymerization [3]. Geopolymer is the result of the polymerization process material that contains silica (Si) and aluminum (Al) derived from natural materials, agricultural waste or industrial waste. Material results of agricultural wastes that can be used as precursors include rice husk ash, bagasse ash and palm oil fuel ash. This study will be discussed on the use of agricultural waste which results rice husk ash, bagasse ash, and palm oil fuel ash are used as a geopolymer precursor based on literature review.

- *Faiz Sulthan is Civil Engineer in Ministry of Public Works and Housing, Indonesia. E-mail: faiz.sulthan@pu.go.id*

2 Geopolymer

Geopolymer is a material alternative to cement as a binder concrete. Geopolymer formed from the polymerization process material that contains silica (Si) and aluminum (Al), which can be derived from natural materials, agricultural waste or industrial waste. Geopolymer was first discovered by Professor Joseph Davidovits in 1978. Geopolymer work together with fine aggregate in concrete building blocks called a geopolymer mortar. Mortar geopolymer formed from precursor that are environmentally friendly. Geopolymer mortar forming materials can be derived from the burning of waste materials such as fly ash, bagasse ash, palm oil fuel ash, rice husk ash, and others. The use of materials from waste combustion into alternative high cement replacement material will be carbon dioxide emissions. Precursor in geopolymer work to form a binding agent when reacted with alkali-activated. Alkali-activated is a chemical used as activators of precursors required for the polymerization process. In general, the alkali activator is a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). NaOH is alkali compounds which when reacted with water to be highly reactive and release heat. Sodium hydroxide serves to accelerate the reaction between the silica (Si) and alumina (Al) by adding the Na + ions to produce a strong bond polymerization. Sodium hydroxide is first dissolved in water in accordance with molarity be used [4]. NaOH and Na_2SiO_3 can be seen in Fig.1.

(a)

(b)

Fig.1 *Alkali-activated, (a) NaOH, (b) Na_2SiO_3*

3 Advantages of Geopolymers over Conventional Concrete

Geopolymer concrete has many advantages over conventional concrete. Based on research [5], geopolymer concrete has a high bond so that it has a higher tensile strength than conventional concrete. Geopolymer concrete also has excellent resistance to acids, fire and resistance to acid and has a low creep and shrinkage. [6] examined the ratio of geopolymer cement blocks and blocks. Blocks are used measuring 190 mm x 230 mm x 100 mm. Care cement blocks made by soaking in water, while the block is left in the open air geopolymer. Cement blocks using mortar composition 1: 6 ratio of precursors and fine aggregate of 1: 1 using a precursor of fly ash and ground granulated blast furnace slag (GGBS) in the ratio of 80:20 and the concentration of NaOH 14 M. Experimental results show the compressive strength test 28 days geopolymer block has a higher compressive strength of 24.56 MPa, while cement blocks at 7.4 MPa. Geopolymer block specific gravity is also lower in the amount of 1870.7 kg/m3 while the cement blocks of 1891.3 7 kg/m3. The same study regarding the comparison of geopolymer concrete and conventional concrete is done by [7]. Test object used is concrete size of 150 mm x 150 x 150 mm. Curing geopolymer concrete is done by being treated in an oven at a temperature of 80oC. The composition of the geopolymer using precursors fly ash Type F and ground granulated blast furnace slag (GGBS) with coarse aggregate size less than 20 mm. Alkali-activated using a combination of NaOH and Na2SiO3 with variations NaOH concentration of 8M, 10M, 12M, 14M, and 16M and additions superplasticizer, Experimental results show that the compressive strength of geopolymer concrete is greater than conventional concrete. Geopolymer concrete compressive strength value of 31.40 MPa whereas conventional concrete for 31.25 MPa. Geopolymer concrete is better than conventional concrete in many aspects such as strength, resistance to the environment, construction and resistance to high temperatures. Geopolymer concrete technology also progressing rapidly.

4 Agricultural Waste as Geopolymer Precursor

4.1 Rice Husk Ash

Rice husk ash from burning rice husk waste from agricultural production of rice. Rice husk is a skin that encloses a grain of rice, bran which will separate and become waste or effluent. Traditionally, rice husk ash is used as an ingredient kitchen utensil washers and fuel in the manufacture of bricks. Rice mill always produce enough rice husks will be waste material. When grain is milled, 78% of its weight will be rice and will generate 22% by weight shuck. Rice husk ash after the combustion process can be seen in Fig.2.

Fig.2 *Rice husk ash*

Husk skin consists 75% combustible material and 25% by weight will turn to ashes. Rice husk burned at a temperature of 600-850ºC and produce rice husk ash containing silica (Si) and aluminum (Al), silica content of rice husk ash reaches 85-90%. The high silica content makes the alternative rice husk ash cement replacement materials and geopolymer precursor. The use of rice husk ash as a cement substitute can also increase the value of concrete compressive strength and flexural strength to 10-25% [8]. Rice husk ash can be used as a substitute for cement or concrete admixture because it has a high pozzolanic. Based on research conducted by [9] regarding the effect of rice husk ash to the compressive strength and tensile strength of concrete sides, showed that rice husk ash as a cement replacement with a replacement percentage of 20% can improve the strength of concrete up to 10.5%, and to increase tensile strength of concrete split up 11%.

4.2 Bagasse Ash

Bagasse ash from waste sugar industry which can be used as additives (admixture) on geopolymer concrete or as precursor. Utilization of bagasse ash is one of the alternative precursors for the content of silica (Si) and aluminum (Al) in it. Bagasse ash after the combustion process can be seen in Fig.3.Bagasse ash is composed of 50% cellulose, 25% hemicellulose and 25% lignin. Bagasse ash produced by burning sugar cane waste at a temperature of 700-900ºC depending on the water content in the sugarcane bagasse. The burning of a ton of sugar cane waste to a moisture content of 50% can generate bagasse ash as much as 26% of the combustion products. The result of combustion residues produces chemical composition is dominated by SiO_2 content [10].

Fig.3 *Bagasse ash*

Bagasse ash can replace most of the cement used to improve concrete strength and workability of fresh concrete (workability), so it can act as an admixture. Replacement10-25% bagasse ash in cement showed the optimum compressive strength bagasse ash percentage of 15% with an increase of 44 MPa to 52.2 MPa, Workability also increased based on the concrete flow is from 61 mm to 222 mm [11].

4.3 Palm Oil Fuel Ash

Palm oil fuel ash is from burning palm shells, fibers and empty fruit bunches of oil palm on the palm oil industry. Palm ash produced from the combustion at temperatures 800-1000ºC, from this combustion ash generated by the content of silica (Si) and aluminum (Al). The content of silica and aluminum found in palm ash making it as one of the ingredients that can be used as a precursor. Palm oil fuel ash with a high level of refinement is a binder material (pozzolan) reactive. The use of palm ash geopolymer concrete increases the compressive strength and tensile strength of up to 20%, this was due to the high silica content and fineness of palm ash enhance bonding of the polymer on geopolymer concrete [12]. Palm ash after the combustion process can be seen in Fig.4.

Fig.4 *Palm oil fuel ash*

5 Characteristics Comparison of Geopolymers Using Agricultural Waste

5.1 X-Ray Fluorescence (XRF) Test

The content of silica and aluminum in a material becoming one of the parameters to select a material whether it can be used as precursor. Results of testing X-Ray Fluorescence (XRF) to determine the oxide chemical content of rice husk ash materials, ash bagasse, palm ash and fly ash based on standards ASTM C 618 [13] can be seen in Table 1.

Table 1 *The chemical composition of geopolymer precursor*

Chemical compounds	Percentage (%)			
	Rice husk ash (Surabaya city)	Bagasse ash (Palembang city)	Palm oil fuel ash (Jambi city)	Fly ash (Aceh city)
Silikon Dioksida (SiO_2)	75.10	94.68	55.94	36.37
Aluminium Oksida ($Al2O_3$)	1.56	0.24	1.85	15.21
Besi (III) Oksida (Fe_2O_3)	0.64	0.80	1.53	22.27
Calsium Oksida (CaO)	0.00	1.77	8.10	14.14
Magnesium Oksida (MgO)	2.06	0.00	8.11	4.7
Sulfur Trioksida (SO_3)	0.04	0.43	1.77	2.87
Lost on ignition (LOI)	19.81	2.80	5.13	1.96
(SiO_2) + (Al_2O_3) + (Fe_2O_3)	77.30	95.72	59.32	73.85

Based XRF testing shows that the most widely-containing material (SiO_2 + Al_2O_3 + Fe_2O_3) is bagasse ash, fly ash, rice husk ash and palm oil fuel ash. Chemical content on any such material cannot be used as a reference if the material has certain advantages in the mechanical properties of geopolymer, because the reaction of each ingredient to different activators.

5.2 Geopolymer Mortar Compressive Strength Test

The compressive strength is one of the main performances of the mortar establishment. The composition of the mixture, and the quality of the constituent material influence on the compressive strength of mortar, so as to measure the constituent material performance test of compressive strength geopolymer be the main parameter. The test specimen is pressed with a load of up to collapse as shown in Fig.5.

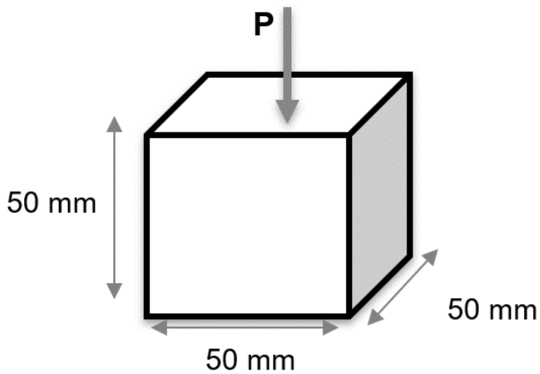

Fig.5 *Palm oil fuel ash*

Mortar compressive strength calculation refers to the testing standards of ASTM C109-07 [14] were calculated using the following equation:

$$fc' = \frac{P}{A} \quad (1)$$

where:
fc' = compressive strength (N/mm^2)
P = force (N)
A = surface area (mm^2)

Using a precursor consisting of rice husk ash, bagasse ash, palm oil fuel ash and fly ash, carried out literature studies based on previous research on geopolymer mortar compressive strength results with these materials. The results of the study of literature can be seen in Table 2. Based on Table 2 known geopolymer using 100% fly ash has a compressive strength of mortar 28 days high of 45.76 MPa, and uses 100% bagasse ash can also achieve the compressive strength of mortar at 18.34 MPa. For materials rice husk ash and palm oil fuel ash is only used by 50% and mixed with 50% fly ash, compressive strength results showed with rice husk ash of 21.50 MPa and palm oil fuel ash of 20.70 MPa. This shows that the content of precursor chemical compounds affects the compressive strength of mortar. A material contains (SiO_2 + Al_2O_3 + Fe_2O_3) is high and proportional geopolymer mortar premises can create a high compressive strength. The content of these compounds should be proportionate, because on the bagasse ash, although the cumulative total has a high value but just great on the value of SiO_2 alone, and the value of Al_2O_3 + Fe_2O_3 small, so that the compressive strength of mortar geopolymer obtained is still under geopolymer which using fly ash.

Table 2 *Geopolymer mortar compressive strength test*

Precursor Type	**The composition of the geopolymer**				**28-day compressive strength (MPa)**
	Fine aggregate / precursor	Alkali-activated/ precursor	Na_2SiO_3 / NaOH	NaOH molarity	
50% of rice husk ash + fly ash 50% [15]	2:00	0:45	2.75	14 M	21.50
100% bagasse ash [16]	2.75	0:42	1:00	14 M	18.34
50% of palm oil fuel ash + fly ash 50% [17]	2:00	0:42	2:00	14 M	20.70
100% fly ash [17]	2:00	0:42	2:00	14 M	45.76

6 Conclusion

Based on the results of literature review on geopolymer mortar using agricultural waste as precursor, it can be concluded that geopolymer is necessary to reduce the use of cement which have an impact on global warming. Infrastructure development is very large making material would need very high. Besides, a lot of waste material is not utilized as recycle materials. Agricultural waste materials eligible to be processed into the material forming geopolymer. Chemical compounds criteria based on testing X-Ray Fluorescence (XRF) and refer to ASTM C 618 [13] is known that industrial waste materials are feasible to be developed as a precursor. Criteria for the mechanical properties of materials such as mortar compressive strength testing also showed good results, compared with normal mortar made of cement which has a compressive strength of 20 MPa, mortar geopolymer with this waste material can still achieve it. However, when compared with the precursor fly ash, waste materials such as rice husk ash, bagasse ash and palm oil fuel ash is still below the quality of fly ash within the parameters of the mechanical properties of the compressive strength of mortar.

References

[1] NRMCA, 2008. Concrete CO_2 Fact Sheet. NRMCA Publication Number 2PCO2. USA: National Ready Mixed Concrete Association.
[2] PBL, 2016. Trends in global CO_2 emissions: 2016 Report. PBL Publication number: 2315. PBL Netherlands Environmental Assessment Agency.
[3] Davidovits, J., 1994. Properties of Geopolymer Cements, First International Conference on Alkaline Cements and Concrete, Kiev Ukraina.
[4] Hardjito, D., Wallah, S. E., Sumajouw, D. M. J., and Rangan, B. V., 2004. On the Development of FA-Based Geopolymer Concrete, ACI Materials Journal. Vol. 101, No. 6.
[5] Muttashar, M., Lokuge, W., and Karunasena, W., 2014. Geopolymer Concrete: The Green Alternative with suitable structural properties, Australasian Conference on the Mechanics of Structures and Materials (ACMSM23), Vol.1, Byron Bay, NSW, 9-12.

[6] Kishan, L., and Radhakrishna, 2013. Comparative Study of Cement Concrete and Geopolymer Masonry Blocks, International Journal of Research in Engineering and Technology (IJRET).
[7] Balaraman, R., Vinodh, K. R., Nithiya, R., and Arunkumar, S., 2016. Comparative Study of Geopolymer Concrete in Flyash with Conventional Concrete, International Journal of Civil Engineering and Technology (IJCIET). Vol.7, Issue 4, 24-36.
[8] Karla, M., Srivastav, G., and Thakur, A., 2015. The Study on Use of Rice Husk Ash, International Journal of Science and Engineering, Vol.3, Special Number ICRAESM.
[9] Khassaf, S. I., Jasim, F. K., and Mahdi, F. K., 2014. Investigation the Properties of Concrete Containing Rice Husk Ash to Reduction the Seepage in Canals, International Journal of Scientific and Technology Research (IJSTR). Vol.3, Issue 4, 348-354.
[10] Kawade, U. R., Rathi, V. R., and Vaishali, D. G., 2013. Effect of use of Bagasse Ash on Strength of Concrete, International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET). Vol.2, Issue 7, 2997-3000.
[11] Anand, A., and Mishra, A. K., 2016. Comparative Study of Concrete Strength by Partially Replacing Cement with Sugarcane Bagasse Ash and Fly Ash, International Journal of Science, Engineering and Technology Research (IJSETR). Vol.5, Issue 4, 1063-1069.
[12] Liu, Michael Yong Jing., Chua, Choon Peng., Alengaram, U. Johnson., and Jumaat, Mohd Zamin., 2014. Utilization of Palm Oil Fuel as Binder in Lightweight Oil Palm Shell Geopolymer Concrete, Materials Science and Engineering.
[13] ASTM C 618-86, 2005. Standard Spesification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, Annual Books of ASTM Standards, USA: Association of Standard Testing Materials.
[14] ASTM C 109M-16a, 2007. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens), Annual Books of ASTM Standards, USA: Association of Standard Testing Materials.
[15] Saloma., Hanafiah., Elysandi, D. O., and Meykan, D. G., 2017. Effect of Na_2SiO_3/NaOH on mechanical properties and microstructure of geopolymer mortar using fly ash and rice husk ash as precursor, AIP Conference Proceedings.
[16] Saloma., Hanafiah., and Pratiwi, K. I., 2016. Effect NaOH Concentration on Baggase Ash Base Geopolymerization, EDP Sciences.
[17] Saloma., Iqbal, M. M., and Aqil, I., 2017. Sulfate resistance of fly ash-based geopolymer mortar, AIP Conference Proceedings.