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Evaluation of the Use of Fine Aggregates of Quartz Sand and Fly Ash in Geopolymer Concrete Based on Potassium Hydroxide Binder on the Compressive Strength and Absorbency of Concrete

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Abstract

The development of concrete construction has the impact of increasing cement production and damaging the balance of nature because every 1kg of cement production produces CO_2 emissions of 0.5 - 0.7 kg. To reduce this iMPact, geopolymer concrete innovation was formed. Geopolymer concrete is formed from the polymerization reaction of silica (Si) and alumina (Al) compounds found in quartz sand and fly ash waste from burning coal which has binding properties like cement. Fly ash reacts with alkaline activators of potassium hydroxide (KOH) and sodium silicate (Na_2SiO_3). The research method used is a quantitative method with experimental studies in the laboratory. Geopolymer concrete mix design refers to previous research. Geopolymer concrete test objects are cylindrical with a size of 100 x 200 mm. There are 2 variations of the composition of alkali activator forming geopolymer concrete, namely 8M KOH concentration, alkali activator ratio of 1:1 mol ratio and 10M KOH, alkali activator ratio of 1:1.5 mol ratio. The composition of fly ash and quartz sand for each binder was 20%:80%, 40%: 60%, 50% : 50%, 60% : 40%, 80%:20% with a total of 36 samples. Testing compressive strength and absorption at the age of 14 and 28 days. The results of the compressive strength obtained ≤ 50 MPa where the concrete does not include high quality concrete and not for the needs of precast construction. The results of average concrete absorption reached 3,72%, which already met the permissible absorption of a maximum of 10%.

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Introduction

The impact of using cement in concrete construction is global warming. According to Wojtacha (2021) based on United States Geological Survey (USGS) statistics, every 1 kg of cement production produces CO_2 emissions of 0.5 - 0.7 kg. The portland cement industry accounts for 5% of Co2 emissions out of a total of 7% worlwide. For every 1 ton of production, portland cement releases the same amount of carbon dioxide [1]. Based on research from the Norwegian CICERO International Climate Center on global carbon research and projects, CO_2 emissions from construction work worldwide from 2002-2021 increased from 1.4 billion tons of CO_2 to 2.9 billion tons of CO_2 [2]. Therefore, efforts are needed to prevent the adverse effects caused by the use of cement, namely by finding a substitute material that is similar in properties to cement in the formation of concrete. The natural composition is taken from materials rich in Silica (SiO_2) and Alumina (Al_2O_3) such as fly ash from burning coal and quartz white sand because if and reacted with KOH alkaline activator liquid can produce a mixture that is binding like cement called geopolymer concrete. This study aims to determine several things such as the effect of fly ash fine aggregate and quartz white sand in the manufacture of geopolymer concrete, knowing how to react potassium hydroxide as an alkali activator in geopolymer concrete and to determine the compressive strength and absorption of geopolymer concrete.

Theory

Geopolymer concrete is a concrete innovation that does not contain cementitious materials in it but is formed from natural inorganic Silica and Alumina compounds such as fly ash from burning coal and rice husk ash that have gone through a polymerization process [3]. Geopolymer concrete is developed based on the formation of CSH hydrate (Calcium Silicate Hydrate; $3CaO.2SiO_2.3H_2O$) from the hydration reaction of water and portand cement which is typically used as a binder in concrete mixes [4]. Geopolymer materials consist of a chemical composition similar to Zeolite, but Zeolite does not have an amorpous microstructure , SiO_2 and Al_2O_3 which are synthesized will form a structure that is chemically similar to natural rocks which will form Si-O-Al polymer bonds resulting from the polymerization of Silica and Alumina compounds forming an alkaline activator(polysilicate) binder and forming clumps of atomic or particle arrays from these process compounds which will produce polymer bonds with different characters depending on the composition of the SiO_2 and Al_2O_3 materials used [5].

Fine aggregates containing Silica (SiO_2) compounds that have been reacted with chemical compounds usually called alkali activators in the concrete making process can produce concrete with high compressive strength coMPared to the compressive strength of normal concrete. Quartz sand is sand derived from rocks containing minerals such as quartz and feldspar which have a combined composition such as Silica (SiO_2), Alumina (Al_2O_3), Ferrous Oxide (Fe_2O_3), Titanium Oxide (TiO_2), Calcium Oxide (CaO), Potassium Oxide (K_2O), and Calcium Peroxide (CaO_2) [6] . In the process of making geopolymer concrete, quartz sand must be used that passes a small sieve so that the sand gradation is finer. The finer the aggregate gradation, it will form concrete that has few pores, making it possible to increase the compressive strength of the concrete [7].

Fly ash is a material classified as silica alumino material in which there is absolutely no cementious material such as Portland cement, so it is referred to as a "pozzolon" material and replacing the use of Portland cement material with fly ash more than 60% in concrete results in a higher compressive strength value than normal concrete [5]. The fineness of fly ash plays an important role in geopolymer activators, where the finer the surface of fly ash, the higher its ability and strength and the earlier the heating process [8]. In Potassium Hydroxide (KOH) activator, there are hydroxide compounds that react chemically with alumina and silica on fly ash. In the polymerization process, the compound reaction will release carbon dioxide [9]. Sodium Silicate Activator (Na_2SiO_3) reacts Al and Si elements in fly ash to form fast polymerization bonds, this compound acts as an adhesive material like cement [10].

Several factors determine the curing of geopolymer concrete, such as the composition of alkali activator, the ratio of alkali to fly ash and the temperature applied during curing. The higher the curing temperature, the lower the hardening time. A faster polymerization process results in 70% of the strength within 3-4 hours during curing [11].

Research Hypothesis

H1. Geopolymer concrete using a ratio of fly ash and quartz sand based on Potassium Hydroxide with alkali activator Sodium Silicate (Na_2SiO_3) will form concrete with a compressive strength of $\geq$50 MPa which includes high quality concrete so that it can be used as a precast concrete construction requirement.

H2. Geopolymer concrete using a ratio of fly ash and quartz sand based on Potassium Hydroxide with alkali activator Sodium Silicate (Na_2SiO_3) will form concrete with a compressive strength of $\leq$ 50 MPa which is not included in high quality concrete but can still be used as a precast concrete construction requirement.

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H3. Geopolymer concrete using a ratio of fly ash and quartz sand based on Potassium Hydroxide with alkali activator Sodium Silicate (Na_2SiO_3) will form concrete with a compressive strength $\leq$ 50 MPa which does not include high quality concrete and cannot be used as a precast concrete construction requirement.

Geopolymer concrete is still relatively new in construction, therefore there is no underlying SNI. However, there are several past studies that have made *geopolymer* concrete mix compositions including:

a. Palomo et al (1999) in Ekaputri (2007), examined *geopolymer* concrete measuring 10 x 10 x 60 mm with the addition of alkaline activator SiO_2: K_2O or SiO_2: Na_2O with a range of 0.63 - 1.23M using class F *fly ash* with a mass ratio with alkaline activators between 0.23 - 0.3 as many as 4 solutions. The resulting compressive strength is $\geq$ 60 MPa with oven curing at 65°C for 24 hours on a combination of Sodium Silicate and Sodium Hydroxide [12].

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b. Setiawati (2018), conducted a study of cube-shaped *geopolymer* concrete using a comparison of the composition of class F *fly ash* ranging from 5% to 12.5% with each sample totaling 12 pieces. It is known that the highest compressive strength of concrete is obtained in *geopolymer* concrete with the largest *fly ash* composition ratio of 40.5 MPa on the 28th day [13].

c. Based on research conducted by Solikin (2021), with the composition of class F *fly ash* versus 1: 1 *slag* in *geopolymer* concrete ranging from alkali activator concentrations of Na_2SiO_3 and NaOH 8 - 16 Molar. Concrete treatment using curing with a 24-hour oven. The highest compressive strength value is 65.17 MPa at 16M concentration and the lowest compressive strength at 8M concentration is 51.7 MPa [14].

Method

The research used an experimental quantitative method through observations in the laboratory.

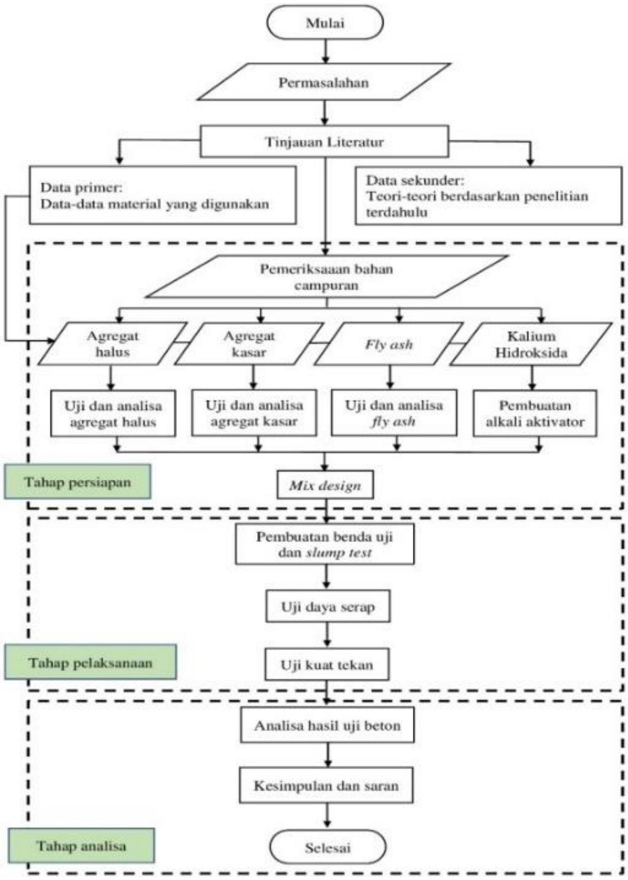

Figure 1. Flowchart of Geopolymer concrete testing stages

Research Variable

Research variables are the completeness of a group of people or objects with several different variations to draw a conclusion [15]. The independent variables (A) are the cause of changes in the dependent variable (B) including alkali activators (KOH & Na_2SiO_3), size and variety of fine aggregates (fly ash & white quartz sand), coarse aggregate size, water used and concrete age. While the dependent variable (B) which is affected by the independent variable (A) is the slump test, concrete absorption test and concrete compressive strength.

Data and analysis

A. Physical Properties Testing

The results of the fissio properties test can be seen in the table below.

TABLE 1. RECAPITULATION OF MATERIAL PYSHICAL PROPERTIES TESTING

Pengujian	**Pasir kuarsa**		**Kerikil**		***Fly ash***
	Standar	***Hasil***	***Standar***	***Hasil***	
Berat volume	-	0,182 kg/dm^3	-	0,326 kg/dm^3	-
Analisa saringan	-	Zona 3	-	Zona 4	-
Kadar air	3-5%	5,684%	3-5%	0,227%	-
Berat jenis & penyerapan	2,5-2,7 g/cm^3; 2-7%	2,624 g/cm^3; 8,114%	2,58-2,83 g/cm^3; 2-7%	2,438 g/cm^3; 6,731%	-
Kadar lumpur	5%	3,239%	1%	0,89%	-
Pengujian pH	-	-	-	-	9,4

B. Chemical properties testing

Chemical testing of materials includes test that can be seen below.

Composition of quartz sand content

To determine the composition of the content of quartz sand, an analysis was carried out using the Energy DispersiveX-Ray (EDX) tool. The following are the results of EDX testing of quartz sand.

white sand 3070

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
C	6	2013	9.3178	7.7348	11.7105	1.7875	19.1831
O	8	60362	69.8935	58.0193	65.9436	8.1523	11.6639
F	9	209	0.4804	0.3988	0.3817	0.2061	42.8996
Al	13	7671	2.2352	1.8555	1.2505	0.1351	6.0431
Si	14	122507	38.5390	31.9916	20.7137	1.6304	4.2304
		Sum	**120.4660**	**100.0000**	**100.0000**		

Figure 2. EDX test results of quartz sand

The most content contained in it is the element Oxygen (O) as much as 58.02%. Polymerization content such as Silicate (Si) is quite high at around 32% and Alumina (Al) is low at 1.86%.

Composition of gravel content

The following image is the result of EDX testing of gravel.

siantan 3 3076

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
C	6	11024	30.6904	22.8796	33.0229	4.2633	13.8912
O	8	46200	61.0233	45.4927	49.2929	7.2630	11.9019
Mg	12	17643	6.3051	4.7004	3.3527	0.3660	5.8046
Al	13	27658	8.7184	6.4996	4.1760	0.4357	4.9969
Si	14	49617	14.9268	11.1279	6.8688	0.6512	4.3625
K	19	10759	4.0337	3.0071	1.3333	0.1569	3.8890
Fe	26	6830	8.4410	6.2927	1.9534	0.2996	3.5492
		Sum	**134.1387**	**100.0000**	**100.0000**		

Figure 3. Results test EDX of gravel

Based on the image of the gravel EDX test results above, the most content contained in it is the element Oxygen (O) as much as 45.49%. Polymerization contents such as Silicate (Si) and Alumina (Al) are low at 11.13% and 6.5%, respectively.

Composition of KOH content

The following image is the result of EDX testing of Kalium Hidroksida (KOH).

KOH 3068

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
C	6	1490	3.2020	3.3238	5.8666	0.6770	21.1426
O	8	25704	46.8715	48.6545	64.4681	5.8816	12.5483
Al	13	54634	14.3518	14.8977	11.7052	0.6948	4.8412
K	19	86053	31.9100	33.1239	17.9601	1.0071	3.1562
		Sum	96.3354	100.0000	100.0000		

Figure 4. Results tests EDX of KOH

KOH contains the most oxygen (O) element as much as 48.655%. Silica (Si) is not contained in it, but there is Alumina (Al) but it is quite low at 14.898%.

Composition of Na_2SiO_3

The following image is the result of EDX Sodium Silicate/Waterglass testing (Na_2SiO_3).

Waterglass 3066

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
C	6	428	4.5715	4.5103	7.1299	1.3664	29.8888
O	8	21119	50.9210	50.2390	59.6210	6.5187	12.8016
Na	11	13526	17.9735	17.7327	14.6455	1.1670	6.4927
Si	14	41680	27.8916	27.5180	18.6036	1.1977	4.2940
		Sum	101.3576	100.0000	100.0000		

Figure 5. Hasil pengujian EDX Na_2SiO_3

Sodium Silicate is expected to increase the Silica (Si) content in the geopolymer concrete polymerization process, but this chemical compound only contains 27.518% Silica and partially contains Oxygen (O) of 50.239%.

Composition of Fly ash

Testing of fly ash content was carried out using the SEM-EDX method at the Civil Engineering Laboratory of Universiti Sarawak Malaysia (UNIMAS)..

Fly Ash 3069

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
C	6	26205	48.4869	37.0741	48.8555	6.0718	12.5225
O	8	38694	51.9480	39.7205	39.2946	6.2761	12.0816
Na	11	2102	0.9347	0.7147	0.4921	0.0917	9.8105
Mg	12	4623	1.4188	1.0849	0.7065	0.1066	7.5156
Al	13	32893	8.5461	6.5346	3.8333	0.4264	4.9889
Si	14	42499	10.7574	8.2253	4.6355	0.4772	4.4356
Ca	20	9907	3.5067	2.6813	1.0589	0.1374	3.9170
Fe	26	6003	5.1851	3.9647	1.1236	0.1959	3.7779
		Sum	130.7839	100.0000	100.0000		

Figure 6. Hasil pengujian EDX *fly ash*

As can be seen in Figure 6, the Si and Al contents are very small at only 8.225% and 6.535% while the CaO compound is quite high at around 42.402%. Canadian CSAA3001 Standard divides fly ash types based on the CaO content and Loss Of Ignition (LOI) therein, namely type F with CaO ≤ 15% and LOI < 8%; type CI (15% < CaO < 20% and LOI < 6% and type CH (CaO > 20% and LOI < 6%. The more CaO content in fly ash, the lower the type (ASTM C618).

Based on the above statement, fly ash falls into type CH or the lowest type according to standardization. These characteristics indicate that the composition of fly ash content is not good as a geopolymer concrete mix material..

C. Test Item Sample

There were 48 cylindrical test pieces measuring 100x200 mm.

1. M8-1 GC2-8: Geopolymer Concrete with a ratio 20% fine aggregate and 80% fly ash
2. M8-1 GC4-6: Geopolymer Concrete with a ratio 40% fine aggregate and dan 60% fly ash
3. M8-1 GC5-5: Geopolymer Concrete with a ratio 50% fine aggregate and dan 50% fly ash
4. M8-1 GC6-4: Geopolymer Concrete with a ratio 60% fine aggregate and 40% fly ash
5. M8-1 GC8-2: Geopolymer Concrete with a ratio 80% fine aggregate and 20% fly ash
6. M10-1,5 GC4-6: Geopolymer Concrete with a ratio 40% fine aggregate and 60% fly ash
7. M10-1,5 GC5-5: Geopolymer Concrete with a ratio 50% fine aggregate and 50% fly ash
8. M10-1,5 GC6-4: Geopolymer Concrete with a ratio 60% fine aggregate and 40% fly ash

TABLE 2. TOTAL MATERIAL REQUIREMENTS

Sampel	**Agg. ksr (gr)**	**Agg. hls (gr)**	***Fly ash* (gr)**	**Alkali aktivator**	
				KOH	***Na_2SiO_3***
M8-1 GC2-8	3300	13200	1100	2200	2200
M8-1 GC4-6	6600	9900	2200	1650	1650
M8-1 GC5-5	8250	8250	2750	1375	1375
M8-1 GC6-4	9900	6600	3300	1100	1100
M8-1 GC8-2	13200	3300	4400	550	550
M10-1,5 GC4-6	6600	9900	2200	1320	1980
M10-1,5 GC5-5	8250	8250	2750	1100	1650
M10-1,5 GC6-4	9900	6600	3300	880	1320

Result and Discussion

A. Slump Test

A concrete plant, also known as a batch plant or batching plant or a concrete batching plant, is equipment that combines various ingredients to form concrete [16]. Geopolymer concrete has poor workability characterized by very small slump values. This poor workability is caused by the initial bonding time of the concrete mixture being too fast due to the nature of the chemicals used..

B. Compressive Strength Test

All geopolymer concrete samples were tested for compressive strength [17], [18] at 14 & 28 days of concrete age. The following is a recapitulation table of the compressive strength test results.

TABLE 3. COMPRESSIVE STRENGTH OF KOH 8M GEOPOLYMER CONCRETE

Sampel	**Rerata 14 hari (MPa)**	**Rerata 28 hari (MPa)**
M8-1 GC2-8	0	0
M8-1 GC4-6	0,93	1,93
M8-1 GC5-5	0,17	0,37
M8-1 GC6-4	0,2	0,23
M8-1 GC8-2	0	0

Figure 7. Testing of 8M KOH geopolymer concrete

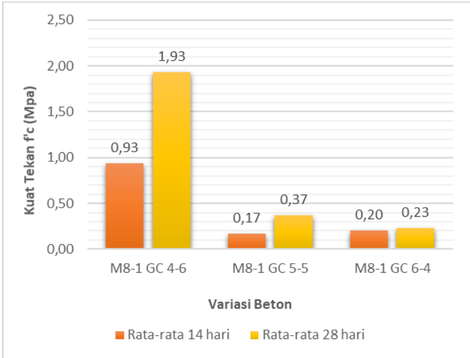

Figure 8. Compressive strength of 8M KOH geopolymer concrete

Concrete with 20%: 80% and 80%: 20% did not produce compressive strength because the composition of fly ash is too little or too much so that it does not bind other materials properly.

TABLE 4. COMPRESSIVE STRENGTH OF KOH 10M GEOPOLYMER CONCRETE

Sampel	Rerata 14 hari (MPa)	Rerata 28 hari (MPa)
M10-1,5 GC4-6	2,03	3,03
M10-1,5 GC5-5	1,83	2,13
M10-1,5 GC6-4	0,4	0,48

Figure 9. Test results of 10M KOH geopolymer concrete

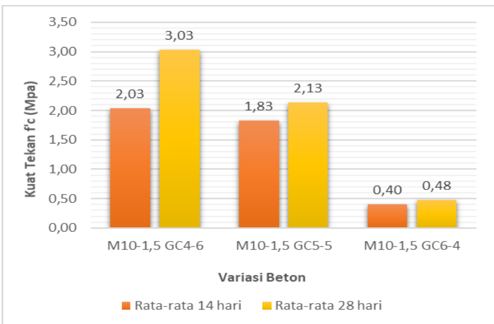

Figure 10. Compressive strength of 10M KOH geopolymer concrete

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The compressive strength of concrete will be higher when the molarity concentration increases, but it is more corrosive. As the ratio increases, the compressive strength will increase but within certain limits. The addition of Sodium Silicate (Na_2SiO_3) to the concrete mix can accelerate the polymerization process in fly ash. There is an optimum point in the alkali activator mass ratio so that if it exceeds this point, the strength of the concrete will decrease.
Treatment of concrete through oven temperature affects the compressive strength of concrete because oven temperature at a certain point can accelerate the polymerization process of geopolymer. The higher the oven temperature, it will increase the strength of concrete in a certain range that ranges from 70 ° C to 80 ° C and will experience a decrease above that temperature [19].

C. Absorbency of concrete

After weighing the dry weight, the test specimen sample is soaked for ± 24 hours and then weighed again in a wet state.

Figure 11. Proses perendaman sampel beton *geopolymer*

TABLE 5. ABSORBENCY OF KOH 8M GEOPOLYMER CONCRETE

Sampel	Bk (Kg)	Bb (Kg)	DSA (%)
M8-1 GC2-8	1,33	1,4	5
M8-1 GC4-6	3,7	3,82	1,78
M8-1 GC5-5	2,7	2,8	3,7
M8-1 GC6-4	2,02	2,15	6,61
M8-1 GC8-2	2,87	2,92	1,74

Figure 12. Absorbency test results of 8M KOH geopolymer concrete samples

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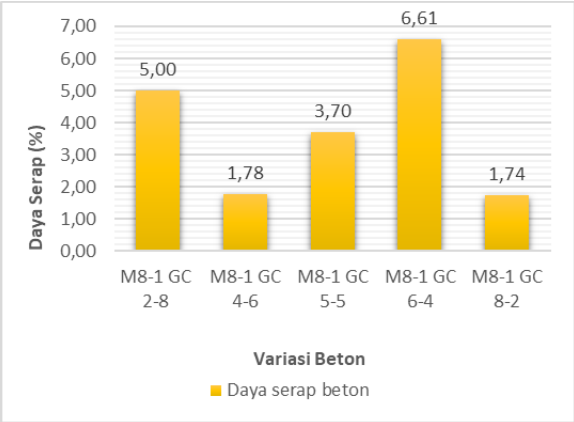

Figure 13. Absorbency of 8M KOH geopolymer concrete

The absorption capacity of geopolymer concrete from the five concrete variations namely M8-1 GC 2-8, M8-1 GC 4-6, M8-1 GC 5-5, M8-1 GC 6-4 and M8-1 GC 8-2 produces relatively small absorption values.

TABLE 6. ABSORBENCY OF KOH 10M GEOPOLYMER CONCRETE

Sampel	Bk (Kg)	Bb (Kg)	DSA (%)
M8-1 GC4-6	3,68	3,77	2,26
M8-1 GC5-5	2,9	3	3,45
M8-1 GC6-4	1,5	1,58	5,56

Figure 14. Absorbency test results of 10M KOH geopolymer concrete samples

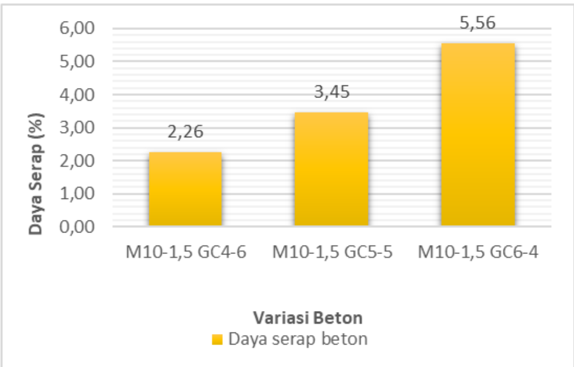

Figure 15. Absorbency of 10M KOH geopolymer concrete

The maximum water absorption requirement is 10% listed in SK-SNI S-04-1989-F [20]. From the test results above, it can be concluded that all concrete variations have good water absorption ability. This is due to the use of small-sized materials and the average diameter of fly ash particles passing sieve no.200 which is smaller than the size of other materials so that it can cover the pores of the concrete. The method of manufacture using a mixer or manually can affect the binding force between all materials. The process of mixing materials using a mixer will be more evenly mixed than mixing manually.

Conclusion

Composition test results of Silica (Si) and Alumina (Al) content in the material: (1) Quartz sand 32% and 1.86%; (2) Gravel 11.13% and 6.5%; (3) Potassium Hydroxide 0% and 14.898%; (4) Sodium Silicate 27.518% and 0%; and (5) Fly ash 8.225% and 6.535%. From the test results, the Si/Al content ratio was summed up and was 2.65. The Si/Al ratio for concrete is between 2-3, but the Si and Al content in fly ash from PT. PLTU Bengkayang 2 x 50 MW amounted to 8.225% and 6.535%, which is classified as lowgrade fly ash. The slump value of all concrete samples is 0 where the mixture is difficult to solidify due to the too fast setting time of the concrete.

The average compressive strength of 28-day-old concrete with KOH 8M with an alkali activator ratio of 1:1 at variations of quartz sand: fly ash 20:80%, 40:60%, 50:50%, 60:40% and 80:20% are 0 MPa; 1.93 MPa; 0.37 MPa; 0.23 MPa and 0 MPa. The highest compressive strength is in the 40:60% variation with 1.93 MPa. The average compressive strength of 28-day-old concrete with 10M KOH with an alkaline ratio of 1:1.5 at variations of quartz sand: fly ash 40:60%, 50:50%, and 60:40% are 3.03 MPa; 2.13 MPa and 0.48 MPa. The highest compressive strength is at 40:60% variation with 3.03 MPa. The ratio of quartz sand: fly ash is optimal at 40:60%. 10M KOH produces higher compressive strength than 8M KOH and the alkali activator ratio of 1:1.5 is more optimal when coMPared to the 1:1 ratio. The average water absorption of all geopolymer concrete variations is 3.76% which is lower than the maximum water absorption requirement of 10%.

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