The Effect of Using Palm Kernel Shell Ash and Rice Husk Ash on Geopolymer Concrete

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Abstract. As already known, cement production is one of the biggest contributors to CO2 emissions due to combustion processes that require high temperatures. This can trigger global warming so the solutions to reduce or even eliminate the use of cement continue to be developed. Geopolymer concrete is one solution to reduce the use of cement in the construction industry in the world. This study has the main objective to examine the effect of the use of palm kernel shell and ash rice husk ash in geopolymer concrete mixes on the strength of geopolymer concrete then compared with the use of palm kernel shell ash and rice husk ash on Portland cement concrete. In this study concluded that increasing the strength of geopolymer concrete with the use of palm kernel shell ash and rice husk ash tends to be insignificant when compared to the increase in strength in Portland cement concrete. The changes in the concentration of NaOH solution is more effective to increase the strength of geopolymer concrete.

1 Introduction

Geopolymer concrete is a solution in construction industry to reduce cement production which is one of the causes of high CO2 emissions on earth. Cement contains limestone, clay, silica, and iron ore which are heated to 1200 - 1500 °C [6] so the cement production process makes large number of CO2 gas emissions which cause global warming. Geopolymer concrete itself is a concrete that uses geopolymer paste as an aggregate binder. Geopolymer paste is formed from chemical reactions involving the polymerization process between alkaline activator solutions with silica (Si) and aluminium (Al) materials to form a Si – O – Al polymer bond. The alkaline solution used in general is the polysilicate material that dissolved in NaOH or KOH solution [4].

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One of the material that can be used to make geopolymer concrete is fly ash. Fly ash is commonly produced by coal – fired power station. In Indonesia, there is a 35,000 MW electricity production project, which has caused a lot of power station construction that spread throughout Indonesia. When the construction is done and the power station is active, the production of fly ash will increase so the utilization of the fly ash in Indonesia is important because according to government regulations number 101 of 2014 in Indonesia, fly ash is included as B3 (hazardous and toxic materials) waste that can't be discarded directly to the environment.

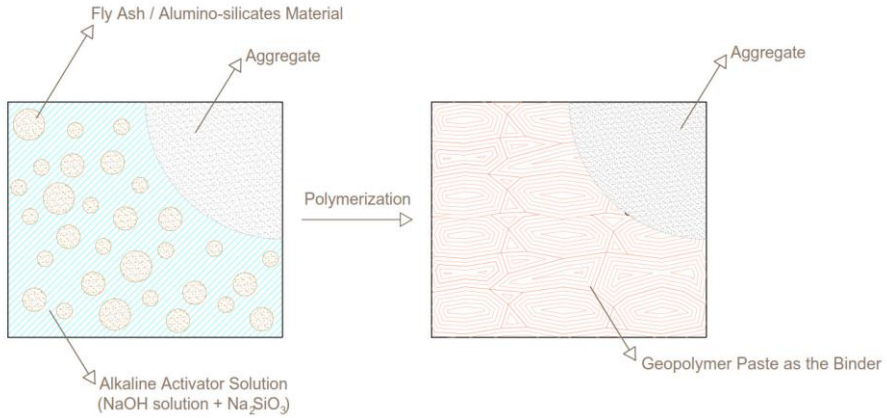

Fig. 1. Schematic of polymerization reaction between alkaline solutions with flyash to generate geopolymer paste as the binder

The use of palm kernel shell ash and rice husk ash itself is an effort to increase the strength of geopolymer concrete. This is based on the main material in the process of forming geopolymer paste is a material containing of silica (Si) and aluminium (Al). This can be concluded because geopolymer cement is formed from Si – O – Al (sialate) bond series so that it is needed materials that contains lots of silica (Si) and aluminium (Al) so that the use of palm kernel shell ash and rice husk ash is expected to increase the strength of geopolymer concrete.

In previous studies, the use of palm kernel shell ash and rice husk ash proved to be able to increase the strength of Portland cement concrete because the addition of SiO2 from palm kernel shell ash and rice husk ash to the cement mixture could convert calcium hydroxide which is a weak part of Portland cement concrete bond into Calcium Silicate Hydrate [2]. Silica containing material (SiO2) commonly used in Portland cement concrete production is fly ash, but there are other materials that can replace fly ash, namely palm kernel shell ash and rice husk ash. Palm kernel shell ash and rice husk ash are also included as waste that is not used and has no economic value so it is suitable for use in concrete production processes. In addition, based on the results of XRF (X-Ray Fluorescence) or XRD (X-Ray Diffractometer) palm kernel shell ash and rice husk ash have similar mineral content with fly ash, namely high SiO2 concentration.

The results of XRF (X – Ray Fluorescence) test of palm kernel shell ash in the table 1 shows that the palm kernel shell ash in Portland cement concrete production has a SiO2 concentration of 51.39% where the concentration exceeds SiO2 concentrations in fly ash in general. Whereas in the palm kernel shell ash section at the time of making geopolymer concrete in this study it was found that SiO2 concentration only reached 15.27%, but had a high CaO concentration reaching 38.28%.

Table 1. Result of XRF (X – Ray Fluorescence) Palm Kernel Shell Ash [7, 8]

No	Formula	Willy Hotama (2014) Portland Cement Concrete	Judith Indrajaya (2018) Geopolymer Concrete
		Concentration (%)	Concentration (%)
1	SiO_2	51.39%	15.27%
2	Fe_2O_3	10.26%	4.71%
3	CaO	7.79%	38.28%
4	K_2O	5.92%	5.04%
5	MgO	5.53%	4.34%
6	Al_2O_3	4.78%	2.67%
7	P_2O_5	3.59%	2.88%
8	SO_3	2.26%	2.15%
9	Na_2O	1.97%	20.68%
10	Cl	1.83%	1.42%
11	Other	4.68%	2.56%

Table 2. Result of XRD (*X – Ray Diffractometer*) Rice Husk Ash [9]

No	Formula	Concentration (%)
1	SiO_2 (Amorphous)	97.69%
2	SiO_2 (Cristobalite)	0.55%
3	$Al\ Si_2\ O_6\ (OH)_2$ (Montmorilonite)	0.22%
4	$K_{0.7}\ Al_2\ ((OH)_2\ Al\ Si_3\ O)$ (Muscovite)	0.38%
5	$Ca\ Al_2\ Si_2\ O_8$ (Anorthite)	1.15%

Table 3. Result of XRF (*X – Ray Fluorescence*) Rice Husk Ash [5]

No	Formula	Concentration (%)
1	SiO_2	91.45%
2	K_2O	2.27%
3	P_2O_5	1.60%
4	CaO	1.24%
5	SO_3	1.13%
6	Cl	0.99%
7	Fe_2O_3	0.62%
8	ZnO	0.27%
9	MnO	0.24%
10	TiO_2	0.12%
11	Nd_2O_3	0.01%
12	Rb_2O	0.01%

Based on table 2 and table 3 above, it can be seen that rice husk ash has a much higher SiO2 concentration compared to fly ash which reaches ± 90% so that the use of rice husk ash in geopolymer concrete is expected to help increase the strength of geopolymer concrete.

Based on previous research, the increase in compressive strength of Portland cement concrete with the use of palm kernel shell ash and rice husk ash was quite high. The increase of compressive strength of Portland cement concrete with the use of palm kernel shell ash can be seen in the table below.

Table 4. Result of Research on The Effect of Palm Kernel Shell Ash on Portland Cement Concrete [7]

Object	Palm Kernel Shell Ash	Age (Days)	fc' (MPa)	Increment (%)
Portland Cement Concrete	0%	28	32.04	-
Portland Cement Concrete	5%	28	35.23	9.96
Portland Cement Concrete	10%	28	43.50	35.77

Based on the table 4, it can be seen that the increase in compressive strength produced by Portland cement concrete using palm kernel shell ash in 5% is 9.96% and for Portland cement concrete using 10% palm kernel shell ash is 35.77%.

Next is a table that shows the increase in compressive strength of Portland cement concrete with the use of rice husk ash.

Table 5. Result of Research on The Effect of Rice Husk Ash on Portland Cement Concrete [9]

Object	Rice Husk Ash	Age (Days)	fc' (MPa)	Increment (%)
Portland Cement Concrete	0%	28	51.59	35.18
Portland Cement Concrete	10%	28	69.74	

Based on the table above, it can be seen that the use of rice husk ash can significantly increase the strength of Portland cement concrete. The increment can reach into 35.18%, so the idea to do the research on the effect of using palm kernel shell ash and rice husk ash in order to increase the strength of geopolymer concrete is done is this research.

2 Material and method

2.1 Material

The materials used to produce geopolymer concrete production in this study are this materials below:

- Fly Ash → Fly ash class F from coal – fired power station of Suralaya, Banten
- Coarse Aggregate → Screening with a maximum size of 1 cm
- Fine Aggregate → Bangka sand, the sand is washed and sifted to pass the sieve no. 30
- Sodium Hydroxide (NaOH) → NaOH in solid form with ASC brand that is produced by PT. Asahimas Chemical Group with 98% concentration
- Sodium Silicate (Na_2SiO_3) → commonly referred as waterglass with a percentage of Na_2SiO_3 58% and water 42%

- Palm Kernel Shell Ash → the ash obtained from burning the palm kernel shell up to a temperature of 600 °C then the combustion results are ground and sifted to pass the sieve no. 100
- Rice Husk Ash → the ash obtained from burning the rise husk up to a temperature of 600 °C then the combustion results are ground and sifted to pass the sieve no. 100

2.2 Method

The following will explain the methods used for the production of palm kernel shell ash, rice husk ash, and geopolymer concrete. Palm kernel shell ash and rice husk ash were produced in this research using the same method. The method to produce palm kernel shell ash and rice husk ash is by combustion using combustion oven.

2.2.1 Production Method of Palm Shell Ash and Rice Husk Ash

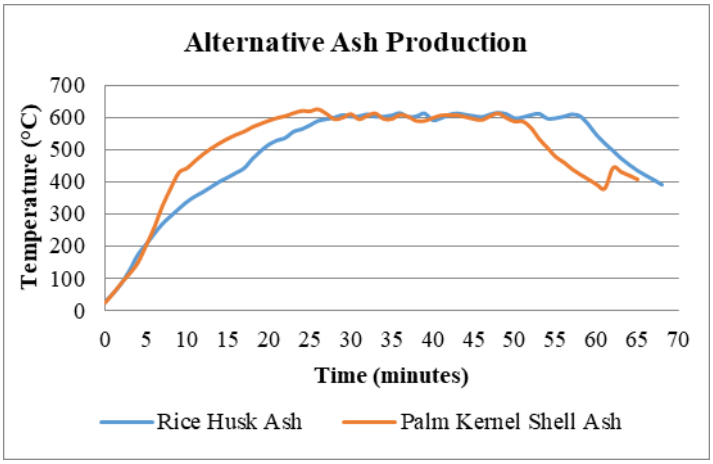

Fig. 2. Burning Temperature

Palm kernel shell ash and rice husk ash are burned to a temperature of ± 600 °C then temperature restriction is carried out for ± 30 minutes as shown in the graph above. After the combustion process is complete, it is followed by grinding the combustion result of the palm kernel shell and rice husk ash. Milling is done by Los Angeles machine for ± 2 hours so that it becomes palm kernel shell ash and rice husk ash.

2.2.2 Casting Method of Geopolymer Concrete

The casting method used in this study begins with the formation of geopolymer paste. The formation of geopolymer paste is carried out by mixing aluminosilicate material and alkaline activator solution for ± 5 minutes. After the geopolymer paste is formed, then the aggregate in saturated surface dry condition is put into a concrete mixer. Mixing of geopolymer paste with aggregate was carried out for ± 7 minutes to form fresh geopolymer concrete. After the fresh geopolymer concrete has been formed, a slump test is carried out to measure concrete workability. The measurement of workability of fresh geopolymer concrete is carried out by slump test in accordance with SNI – 1972 – 2008.

3 Result and discussion

3.1 Mix design

This study uses mix design with a composition of 73% aggregate and 27% geopolymer paste. Alkaline solution ratio : fly ash is 1 : 2, the ratio of coarse aggregate : fine aggregate is 65 : 35, and the ratio of Na2SiO3 : NaOH solution is 3 : 1. The table below is a mix design for 1 m3 of a normal geopolymer concrete and 1 m3 of concrete alternative geopolymer + ash used to do geopolymer concrete production in this study.

Table 6. Example of Mix Design of 1 m^3 of Geopolymer Concrete with 8M NaOH Solution Concentration

No	Material		Amount ($kg/m^{3)}$
1	Gravel		1128.70
2	Sand		608.32
3	Fly Ash		428.31
4	Na_2SiO_3		160.61
5	NaOH solution 8M	NaOH solid	13.65
6		Water	39.89

Table 7. Example of Mix Design 1 m^3 of Geopolymer + Ash Alternative Concrete with 8M NaOH Solution Concentration

No	Material		Amount ($kg/m^{3)}$
1	Gravel		1128.70
2	Sand		608.32
3	Fly Ash		385.48
4	Alternative Ash (10%)		42.83
5	Na_2SiO_3		160.61
6	NaOH solution	NaOH solid	13.65
7		Water	39.89

The percentage of palm kernel shell ash and rice husk ash in this study was determined as much as 5%, 7.5%, and 10% of the total weight of fly ash needed to produce 1 m3 of geopolymer concrete. In addition there are 2 types of NaOH solution concentrations used to make geopolymer concrete in this study, namely 8M and 12M.

(a) First Phase (b) Second Phase

Fig. 3. Process of Mixing, First Phase (Fly Ash + Alkaline Solution) and Second Phase (Aggregate + Geopolymer Paste)

The more use of palm kernel shell ash or rice husk ash in geopolymer concrete mix, the slump value decreases. This is probably due to the higher SiO2 or CaO concentration than the two types of ash compared to fly ash. This can be seen in the table of fresh geopolymer concrete slump values below.

Table 8. Value of Slump Test for Fresh Geopolymer Concrete

No	Mix Design	Alternative Ash Type	Alternative Ash Percentage (%)	Slump (cm)
Concentration 8 Mol				
1	GC1-8M	-	-	5
2	GC1-5%-8M	Palm Kernel Shell Ash	5%	4.5
3	GC1-7.5%-8M	Palm Kernel Shell Ash	7.5%	2.5
4	GC1-5%-8M	Rice Husk Ash	5%	4.5
5	GC1-10%-8M	Rice Husk Ash	10%	3
Concentration 12 Mol				
6	GC2-12M	-	-	5.5
7	GC2-5%-12M	Palm Kernel Shell Ash	5%	5
8	GC2-10%-12M	Palm Kernel Shell Ash	10%	2
9	GC2-5%-12M	Rice Husk Ash	5%	4
10	GC2-10%-12M	Rice Husk Ash	10%	2.5

3.2 Results of the effect of using palm kernel shell ash and rice husk ash toward compressive strength of geopolymer concrete

The effect of using palm kernel shell ash and rice husk ash toward compressive strength of 28 days geopolymer concrete with the concentration of 8M NaOH solution with steam curing method in this research is shown in the graphic below.

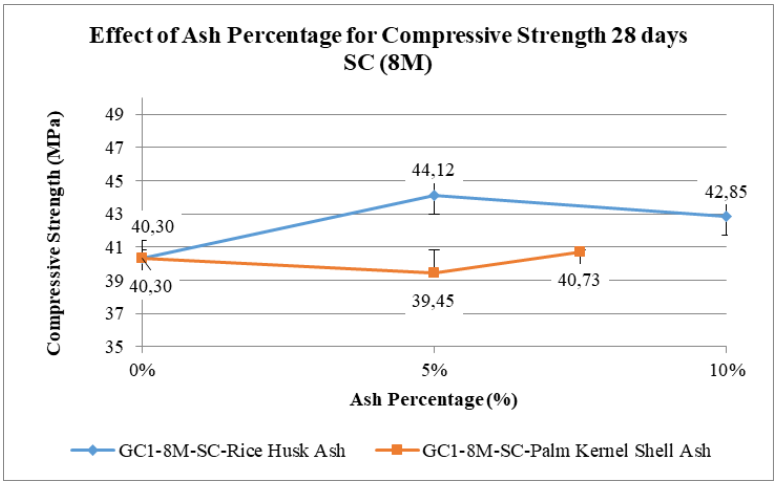

Fig. 4. Effect of Alternative Ash Percentage on The Compressive Strength of 28 Days Geopolymer Concrete with 8M NaOH Solution Steam Curing

From the graph above, it's shown that the use of palm kernel shell ash and rice husk ash with the concentration of 8M NaOH solution with steam curing in this research does not have significant effect on the compressive strength of geopolymer concrete.

Next is the graph of geopolymer concrete with the concentration of 12M NaOH solution with RTC (room temperature curing) method.

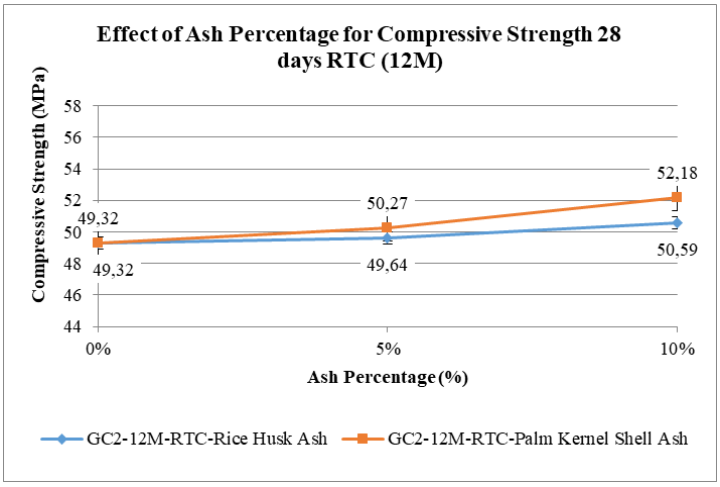

Fig. 5. Effect of Alternative Ash Percentage on The Compressive Strength of 28 Days Geopolymer Concrete with 12M NaOH Solution Room Temperature Curing

From the graph above, it can be seen that the increment of compressive strength is arguably nothing because the increment from the compressive strength of geopolymer concrete from the graph above is only 1 – 3 MPa.

Next is the graph of the effect of alternative ash percentage on 28 days geopolymer concrete compressive strength with the concentration of 12M NaOH solution with steam curing method.

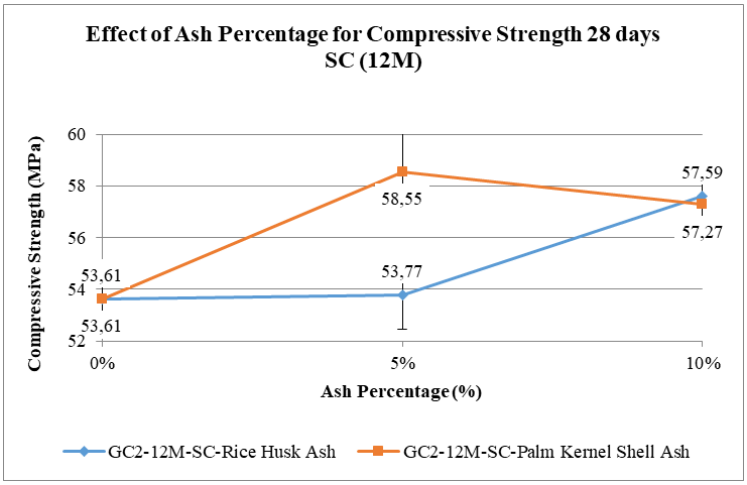

Fig. 6. Effect of Alternative Ash Percentage on The Compressive Strength of 28 Days Geopolymer Concrete with 12M NaOH Solution Steam Curing

From the graph above, it can be seen that the usage of 5% palm kernel shell ash is able to increase the compressive strength of geopolymer concrete up to ± 5 MPa, while the use of 10% rice husk ash able to increase the compressive strength of geopolymer concrete up to ± 4 MPa.

Fig. 7. Failure Pattern of Geopolymer Concrete Compressive Strength Test Object

The following is the increment percentage of geopolymer concrete compressive strength based on alternative ash type and the alternative ash percentage in this research.

Based on the table 9, it can be seen that the use of palm kernel shell ash and rice husk ash only able to increase the compressive strength of geopolymer concrete by the number of between 0.30 – 9.48%. When being compared to the increment of the use of palm kernel shell ash and rice husk ash in Portland cement concrete, the use of palm kernel shell ash and rice husk ash in the geopolymer concrete is far less effective because the use of palm kernel shell ash and rice husk ash in the Portland cement concrete able to increase the compressive strength by ±35%.

Table 9. The Increment Percentage of 28 Days Geopolymer Concrete Compressive Strength Based on Alternative Ash Type and Alternative Ash Percentage

No	Specimen	Alternative Ash Type	Alternative Ash Percentage	Curing Method	Compressive Strength (MPa)	Increment
Concentration 8 Mol						
1	GC1-8M-SC	-	0%	Steam Curing	40.30	-
2	GC1-5%-8M-SC	Palm Kernel Shell Ash	5%		39.45	-
3	GC1-7.5%-8M-SC	Palm Kernel Shell Ash	7.5%		40.73	1.07%
4	GC1-5%-8M-SC	Rice Husk Ash	5%		44.12	9.48%
5	GC1-10%-8M-SC	Rice Husk Ash	10%		42.85	6.33%
Concentration 12 Mol						
6	GC2-12M-RTC	-	0%	Room Temperature Curing	49.32	-
7	GC2-5%-12M-RTC	Palm Kernel Shell Ash	5%		50.27	1.93%
8	GC2-10%-12M-RTC	Palm Kernel Shell Ash	10%		52.18	5.80%
9	GC2-5%-12M-RTC	Rice Husk Ash	5%		49.64	0.65%
10	GC2-10%-12M-RTC	Rice Husk Ash	10%		50.59	2.58%
11	GC2-12M-SC	-	0%	Steam Curing	53.61	-
12	GC2-5%-12M-SC	Palm Kernel Shell Ash	5%		58.55	9.21%
13	GC2-10%-12M-SC	Palm Kernel Shell Ash	10%		57.27	6.83%
14	GC2-5%-12M-SC	Rice Husk Ash	5%		53.77	0.30%
15	GC2-10%-12M-SC	Rice Husk Ash	10%		57.59	7.42%

3.3 Results of the effect of using palm kernel shell ash and rice husk ash toward flexural strength of geopolymer concrete

This research also produce beam test object to investigate the flexural strength of geopolymer concrete for both that without the use of alternative ash or using alternative ash. The test to find flexural strength of geopolymer concrete is done by UTM (Universal Testing Machine) with the model of simple beam, the load is a point load on the center of the beam. The following is the the effect of alternative ash percentage on 28 days geopolymer concrete flexural strength with the concentration of 8M NaOH solution with steam curing method.

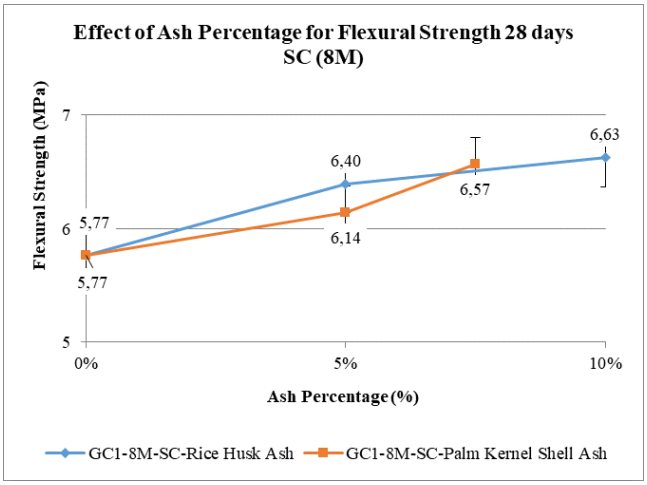

Fig. 8. Effect of Alternative Ash Percentage on The Flexural Strength of 28 Days Geopolymer Concrete with 8M NaOH Solution Steam Curing

From the graph above, the use of palm kernel shell ash and rice husk ash as the alternative ash is able to increase the flexural strength of geopolymer concrete. The increment of flexural strength by using 5% palm kernel shell ash is 0.37 MPa, while for the usage of 7.5% palm kernel shell ash the increment in flexural strength is 0.80 MPa. For the increment of flexural strength caused by the usage of rice husk ash 5% is 0.63 MPa, while for the usage of 10% rice husk ash the increment of the flexural strength is 0.86 MPa.

The following is the effect of alternative ash percentage on 28 days geopolymer concrete flexural strength with 12M NaOH solution concentration with RTC method.

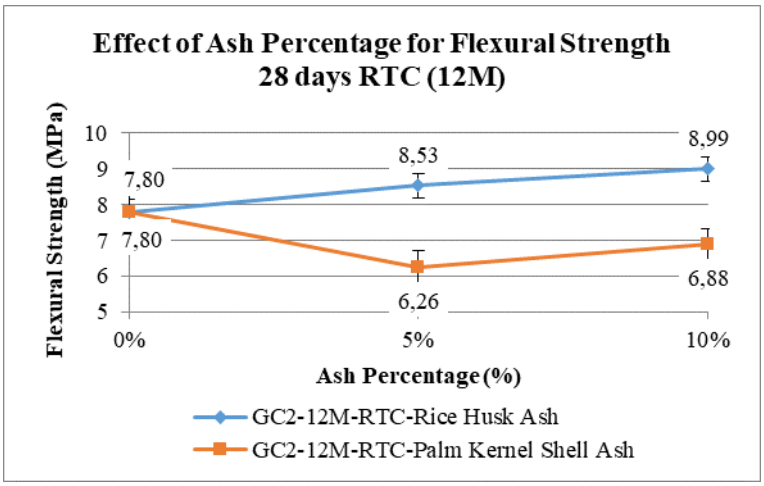

Fig. 9. Effect of Alternative Ash Percentage on The Flexural Strength of 28 Days Geopolymer Concrete with 12M NaOH Solution Room Temperature Curing

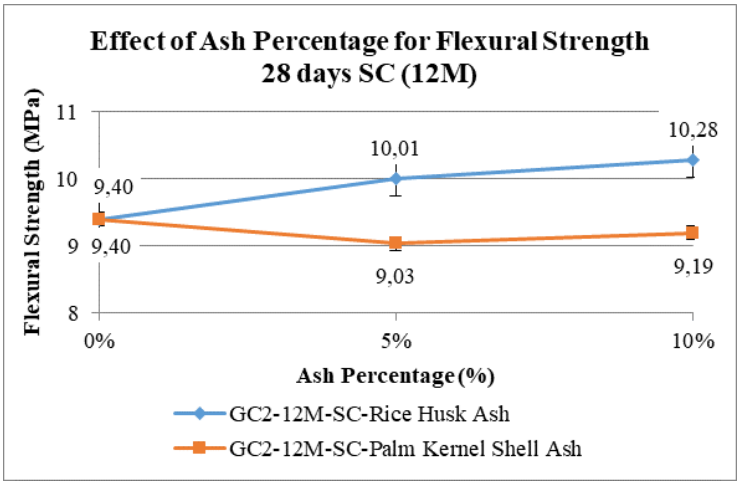

Fig. 10. Effect of Alternative Ash Percentage on The Flexural Strength of 28 Days Geopolymer Concrete with 12M NaOH Solution Steam Curing

From the graphic above, it can be seen that the flexural strength of geopolymer concrete with the usage of palm kernel shell ash is below the normal geopolymer concrete. While for the usage of rice husk ash, the flexural strength of the geopolymer concrete is above the normal geopolymer concrete.

Fig. 11. Failure Pattern of Geopolymer Concrete Flexural Strength Test Object

The following is the increment percentage of geopolymer concrete flexural strength based on alternative ash type and the alternative ash percentage in this research.

Table 10. The Increment Percentage of 28 Days Geopolymer Concrete Flexural Strength Based on Alternative Ash Type and Alternative Ash Percentage

No	Specimen	Alternative Ash Type	Alternative Ash Percentage	Curing Method	Flexural Strength (MPa)	Increment
Concentration 8 Mol						
1	GC1-8M-SC	-	0%	Steam Curing	5.77	-
2	GC1-5%-8M-SC	Palm Kernel Shell Ash	5%		6.14	6.41%
3	GC1-7.5%-8M-SC	Palm Kernel Shell Ash	7.5%		6.57	13.86%
4	GC1-5%-8M-SC	Rice Husk Ash	5%		6.40	10.92%
5	GC1-10%-8M-SC	Rice Husk Ash	10%		6.63	14.90%
Concentration 12 Mol						
6	GC2-12M-RTC	-	0%	Room Temperature Curing	7.80	-
7	GC2-5%-12M-RTC	Palm Kernel Shell Ash	5%		6.26	-
8	GC2-10%-12M-RTC	Palm Kernel Shell Ash	10%		6.88	-
9	GC2-5%-12M-RTC	Rice Husk Ash	5%		8.53	9.36%
10	GC2-10%-12M-RTC	Rice Husk Ash	10%		8.99	15.26%
11	GC2-12M-SC	-	0%	Steam Curing	9.40	-
12	GC2-5%-12M-SC	Palm Kernel Shell Ash	5%		9.03	-
13	GC2-10%-12M-SC	Palm Kernel Shell Ash	10%		9.19	-
14	GC2-5%-12M-SC	Rice Husk Ash	5%		10.01	6.49%
15	GC2-10%-12M-SC	Rice Husk Ash	10%		10.28	9.36%

Based on the table above, it can be seen that the use of palm kernel shell ash and rice husk ash only able to increase the flexural strength of geopolymer concrete by the number of between 6.41 – 15.26%. However, the flexural strength of geopolymer concrete with the usage of palm kernel shell ash with 12M NaOH solution is decreased. The decrease of the flexural strength of geopolymer concrete with the usage of palm kernel shell ash with 12M NaOH solution is probably because of the decrease of workability of the fresh geopolymer concrete when the palm kernel shell ash is used in the mixture

3.4 The effect of NaOH solution concentration toward compressive strength and flexural strength of geopolymer concrete

In this section, the effect of NaOH solution concentration toward the strength of geopolymer concrete will be shown. The following is the effect of NaOH solution concentration toward compressive strength of geopolymer concrete.

Table 11. Geopolymer Concrete Compressive Strength Increment Percentage Based on The Change of NaOH Solution Concentration

No	Specimen	Alternative Ash Type	Alternative Ash Percentage	NaOH solution Molarity	Curing Method	Compressive Strength (MPa)	Increment
0% Alternative Ash							
1	GC1-8M-SC	-	0%	8M	Steam Curing	40.30	33.03%
2	GC2-12M-SC			12M		53.61	
5% Alternative Ash							
3	GC1-5%-8M-SC	Rice Husk Ash	5%	8M	Steam Curing	44.12	21.87%
4	GC2-5%-12M-SC	Rice Husk Ash		12M		53.77	
5	GC1-5%-8M-SC	Palm Kernel Shell Ash	5%	8M		39.45	48.42%
6	GC2-5%-12M-SC	Palm Kernel Shell Ash		12M		58.55	
10% Alternative Ash							
7	GC1-10%-8M-SC	Rice Husk Ash	10%	8M	Steam Curing	42.85	34.40%
8	GC2-10%-12M-SC	Rice Husk Ash	10%	12M		57.59	

From the table 11, it can be seen that the increment of the concentration of NaOH solution able to increase the compressive strength of geopolymer concrete up to 48.42%, it's far more effective than the usage of alternative ash. For the increment of flexural strength because of the increment of NaOH solution concentration is shown in the table below.

From the table 12, it can be seen that the increment of the concentration of NaOH solution from 8M to 12M is able to increase the flexural strength of geopolymer concrete up to 62.91%. The increment of flexural strength because of the NaOH solution concentration change is more significant than the increment of flexural strength because of the usage of palm kernel shell ash and rice husk ash that only up to 15.26%.

Table 12. Geopolymer Concrete Flexural Strength Increment Percentage Based on The Change of NaOH Solution Concentration

No	Specimen	Alternative Ash Type	Alternative Ash Percentage	NaOH solution Molarity	Curing Method	Flexural Strength (MPa)	Increment
0% Alternative Ash							
1	GC1-8M-SC	-	0%	8M	Steam Curing	5.77	62.91%
2	GC2-12M-SC			12M		9.40	
5% Alternative Ash							
3	GC1-5%-8M-SC	Rice Husk Ash	5%	8M	Steam Curing	6.40	56.41%
4	GC2-5%-12M-SC	Rice Husk Ash		12M		10.01	
5	GC1-5%-8M-SC	Palm Kernel Shell Ash	5%	8M		6.14	47.07%
6	GC2-5%-12M-SC	Palm Kernel Shell Ash		12M		9.03	
10% Alternative Ash							
7	GC1-10%-8M-SC	Rice Husk Ash	10%	8M	Steam Curing	6.63	55.05%
8	GC2-10%-12M-SC	Rice Husk Ash	10%	12M		10.28	

4 Conclusion

Based on the research that has been done, the conclusion are shown in the following section:

- The usage of palm kernel shell ash and rice husk ash in the mixture of geopolymer concrete didn't give the significant increment of compressive strength. The increment percentage of compressive strength because of the usage of alternative ash in this research are 0.3 – 9.48%, more less than the increment percentage of compressive strength of the usage of palm kernel shell ash and rice husk ash in Portland cement concrete that can reach up to 35%.
- Geopolymer concrete with the usage of alternative ash showed the increment percentage of flexural strength from 6.41% up to 15.26%. Even the decrease in flexural strength actually occurs in geopolymer concrete with the concentration of 12M NaOH solution using palm kernel shell ash.
- Changes in the concentration of NaOH solution were far more effective than the use of palm kernel shell ash and rice husk ash to increase the strength of geopolymer concrete.

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