Reviews on the Different Sources Materials to the Geopolymer Performance

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ARTICLE INFO	ABSTRACT
	Geopolymer is manufactured from the aluminosilicate source material in example fly ash, silica fume, kaolin, ground granulate blast slag (GGBS), boiler ash and volcano ash reactivated via alkaline solution. But the different types of source materials in geopolymer that rich with alumina, silica and calcium can give an effect on correlation, geopolymer strength and porosity. The different contents of alumina, silica and calcium can give different performance of geopolymer. Therefore the improvement geopolymer performance is based on varying parameters which are source materials content, alkaline activators types, and the curing method; thus producing a high strength concrete with less continuous pores.

INTRODUCTION

New binder materials, known as „geopolymer' which has been introduced by Davidovits in 1978 was describe a group of mineral binder with chemical composition similar to natural zeolitic materials but with amorphous microstructure. Geopolymer cements are developing into the focus of increasing research efforts as the need to reduce global CO_2 emissions increase. Displaying excellent mechanical strength and resistance to attack by aggressive environments, these materials represent an opportunity to simultaneously improve both environmental and engineering performance compared to traditional technology [1, 2]. Geopolymer are new binder contrived from an aluminosilicate source material such as fly ash, silica fume, ground granulate blast slag (GGBS) and kaolin [3]. The different source materials contributed to the different chemical content and the chemical content can influence the geopolymer performance. It reported that the particle size, calcium content, alkali metal content, amorphous content, morphology and origin of the fly ash affected the properties of geopolymers [4]. Geopolymerization process is the synthesized of geopolymer by polycondensation reaction of geopolymeric precursor and alkali polysilicate. The geopolymerization process involved three separated but inter-related stages which are: (1) dissolution of Si and Al atoms from the source material through the action of hydroxide ions, (2) transportation or orientation or condensation of precursor ions into monomers, (3) setting or polycondensation/polymerisation of monomers into polymeric structures [5]. Geopolymers are a class of cementitious aluminosilicate binder materials, with significant potential in a variety of applications including as a high-performance, low CO_2 alternative to ordinary Portland cements [6].

From the previous research, fly ash has been used as one of the source materials in geopolymer. Fly ash can be classified into two classes which are Class C (high calcium fly ash) and Class F (low calcium fly ash) in determined the correlation between source materials elemental characteristic and geopolymer strength from statistical point of view [3]. Fly ash also was possesses good quality mechanical properties and durability in aggressive environments [7]. Besides that, silica fume was used as source materials in formation of geopolymer which is rich in silica content and also raw material produced as by-products that can replace purpose-made Portland cement. Silica fume has been research as one of the source materials by adding the silica fume content and test based on the geopolymer porosity, water absorption and strength [8]. Another source material of geopolymer is kaolin which is containing rich chemical compound of silica and alumina but less than silica fume. The increase of silica and alumina content from kaolin leads to an improvement in the compressive

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strength of the geopolymer [9]. In the meantime, ground granulate blast slag (GGBS) is one of the source materials needs fewer primary energy and required in producing concrete, had enhanced the durability of structure is improved. According to the past research, GGBS activated with alkaline solution can be used to make slag concrete with satisfactory workability and strength properties [10]. The slag is mixture of lime, silica and alumina, which are the same oxides that make up Portland cement but different proportion. The performance of early age strength GGBS concrete was low strength but as the curing period is extended, the strength increase. The reason is when the time of the formation of calcium hydroxide short, the pozzolanic reaction is slow [11]. Then, boiler ash was one of the major wastes from the palm oil processing industry where has been study on the effect of calcinations towards producing geopolymer paste. The calcinations temperature of the boiler ash influenced the chemical composition, morphology of particles and also the strength of hardened geopolymer [12]. The volcano ash has a good potential to be commercialized as artificial geopolymer aggregate. The major constituents are SiO_2, Al_2O_3 and Fe_2O_3 with total 76.5% > 70% which is suitable to be used as a raw material for geopolymer. Volcano ash has been study based on various curing temperature to the specific gravity of geopolymer artificial aggregate, water absorption, material characterization and microstructure properties [13].

Raw materials:

The alkaline activator that has been used in the previous research was the combinations of sodium hydroxide with sodium silicate and potassium hydroxide with potassium silicate. Alkaline liquids were found as significant factor affecting the mechanical strength, where combination of sodium silicate and sodium hydroxide gave the highest compressive strength [1]. It has been suggested to optimizing the amount of alkali in order to increased compressive strength of geopolymer with high levels of aggregate [14].

Fly ash is one of the residues produced in combustion, and comprises the fine particles that rise with the outlet gases in the electrical power plant station. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned [4]. The Class C (high calcium fly ash) is from Manjung power plant station while Class F (low calcium fly ash) is imported from China. According to the previous research, compressive strength of fly ash based geopolymer depends on the strength of geopolymer binder and the present of calcium content in the chemical composition [3].

Meanwhile silica fume is by-product from ferrosilicon alloy production. The chemical composition of silica fume is given in Table 1. Another research on silica fume, the constituent materials used was condensed silica fume (CSF) in the form of stabilised slurry in which the mass ratio of CSF solids to water is 1:1. CSF was fine natural sea dredged sand which complied with grade F of BS 882:1983 and 10 mm single size crushed limestone aggregate [15].

In the meantime, metakaolin (MK) is a thermally activated alumina-silicate materials obtained by calcining kaolin clay within the temperature range 650 - 800°C [16]. It contains typically 50-55% SiO_2 and 40-45% Al_2O_3 and is highly reactive. Metakaolin is a primary product while other type of artificial pozzolans is secondary by-product. The chemical composition of metakaolin is shown in Table 1 [17].

Ground granulate blast slag (GGBS) was produced from an iron industry as by-product material. From the past research, the addition of GGBS is observed to have a good improvement in setting time and compressive strength [18]. This improvement was because of the formation of cementitious C-S-H gel which improved the setting time and hardening of geopolymer [19]. Another research reported that, by adding GGBS up to 50-60% replacement as the curing period is extended, the strength increase. The calcium content in GGBS influenced the strength by the present calcium hydroxide that lead to the pozzolanic reaction [11].

The raw boiler ash was obtained from palm oil processing factory in Penang, Malaysia. Since the boiler ash consist of larger particle of kernels, unburn palm oil nutshells and clinkers; hence it required grinding process to refine the particles sizes. After that, the boiler ash was sieved passing through 100 μm sieve to remove coarser particles. Then, the boiler ash was heated at 800ºC and 1000ºC for 1 hr to increase the reactivity of the boiler ash [12].

Volcano ash is one of the efforts to diminish the high quantity of volcano mud from East Java, Indonesia. The major constituents are SiO2 with 38.5%. The content of Al2O3 for volcano ash is 14.2%. The content of Fe2O3 is 23.8%. The total of SiO2+Al2O3+Fe2O3 > 70% indicated that this volcano ash can be used as pozzolan materials. The geopolymer artificial aggregate was examined with various curing temperature of 500°C, 600°C and 800°C [13]. The chemical composition of fly ash, silica fume, metakaolin, GGBS, boiler ash and volcano ash was showed in Table 1.

Sample Preparation:

According to the research on fly ash [3], the testing based on two types of fly ash which are Class C and Class F. This research consists of 6 mix proportions that tested for each percentage which are 10%, 20%, 30%, 40%, 50% and control. The alkaline solution that has been used is sodium hydroxide (NaOH) and sodium silicate solution (Na_2SiO_3). The fresh paste is cast into moulds with dimension 50 x 50 x 50mm. The duration of

curing process involve of 1, 7, and 28 days. In this process, the specimen is placed at room temperature at 25°C to 32°C.

Table 1: Chemical composition of fly ash, silica fume, metakaolin, GGBS, boiler ash and volcano ash.

Chemical Composition	Fly Ash [3]	Silica Fume [15]	Metakaolin [17]	GGBS [18]	Boiler Ash [12]	Volcano Ash [13]
SiO_2	56.01	92.00	53.20	32.97	40.60	38.50
Al_2O_3	29.80	0.46	43.90	17.97	3.71	14.20
Fe_2O_3	3.58	1.60	0.38	0.72	15.74	23.76
TiO_2	1.75	Nil	1.68	Nil	0.35	1.76
CaO	2.36	0.29	0.02	35.08	19.60	5.62
MgO	0.30	0.28	0.05	10.31	1.30	Nil
K_2O	0.73	0.61	0.10	Nil	13.80	4.31
Na_2O	0.61	0.51	0.17	Nil	Nil	Nil
SO_3	Nil	0.19	Nil	0.72	0.44	0.78
P_2O_5	0.44	Nil	Nil	Nil	2.73	Nil
Loss on ignition	0.40	1.00	0.50	0.58	-	-

For the mixture of fly ash and silica fume [8], it was mixed with predetermined quantity of activator solution for 5 minutes. Then the mixture was transferred into 50 x 50 x 50 mm cube moulds. Table vibration was provided for 2 minutes to expel any entrapped air. After 60 minutes, the cubes were cured in an oven for a period of 48 hours at 85°C and then allowed to cool inside the oven. Specimens were removed and stored at room temperature until testing day. Based on another research [15] the cementitious content (OPC & CSF) of the different mixes was maintained at a constant value of 470 kg/m³. Water, CSF slurry and super plasticizer were first thoroughly mixed together and then poured onto the coarse aggregate in the pan mixer. After mixing for 20 seconds the fine aggregate was added and mixed in for a further period of 20 seconds. This was followed by the cement which was mixed in until a total mixing time of 2 minutes was achieved. The mixes were immediately cast into 100 mm cube moulds and compacted on a vibrating table. After 24 hours the remoulded cubes were cured in water at temperatures of 20°C for periods from 4 days to 91 days.

Besides that, for the study of metakaolin [17], the concrete mixtures were prepared in the laboratory using a pan mixer. Cubes of 100 x 100 x 100 mm in dimension and cylinders of 100 mm in diameter and 200 mm in height were cast in steel mould and compacted on a vibrating table. The cubes and cylinders were removed from the moulds 24 hours after casting, and were allowed to cure in water at 27°C. The 100 mm cubes were used for the determination of compressive strength at 3, 7, 28 and 90 days. The compression load was applied using a Denison compression machine with 3000-kN capacity, at the rate of 0.3 N/mm² s. Two series of concrete mixes were prepared at the water-to-binder (w/b) ratios of 0.3 and 0.5. Each series included three MK mixes with 5%, 10%, and 20% metakaolin and a control mix without any mineral admixture. MK was used as a replacement of cement on a weight to weight basis. The maximum nominal size of the coarse aggregate was 10 mm for the concrete with a w/b of 0.3 and 20 mm for the concrete with a w/b of 0.5.

The study of fly ash and GBFS was mixed in different proportions and used for geopolymerisation. The amount of GBFS in the mixture was varied from 0 to 50%. For physical testing such as setting time and compressive strength, the liquid (sodium hydroxide solution) to solid ratio (by weight) was maintained at 0.35. All the samples were prepared at 27 ± 2 °C and under humidity of 65%. Compressive strength was measured on cube shape samples of size 7 x 7 x 7 cm. The cubes were prepared by mixing each batch with alkali solution and casting the resulting paste into moulds [18]. Another research of GGBS was provided by a cement manufacturer in Turkey. A total of 32 mixtures were prepared where all the concrete mixtures were mixed for a total of 4 minutes in a laboratory pan mixer. From each concrete mixture, forty-two 150 mm cubic were cast for the determination of the compressive strength. Casting of cubes was conducted in two layers. Each layer was compacted by internal vibration and top surface was levelled and smoothed using a trowel. After casting, all the moulded specimens were covered with plastic sheets and water saturated burlap and left in the curing room for 24 hours at the temperature of 23 ± 2 °C. After 24 hours, concrete specimens were remoulded and cured in 20 ± 2 °C lime-saturated water until the time of the compressive strength testing [11].

The boiler ash consists of larger particle of kernels, unburn palm oil nutshells and clinkers; it required grinding process to refine the particles sizes. After that, the boiler ash was sieved passing through 100 μm sieve to remove coarser particles. Then, the boiler ash was heated at 800 ºC and 1000 ºC for 1 hr to increase the reactivity of the boiler ash. The ratio of solid/liquid (S/L) and sodium silicate/ NaOH used in this study were constant for all mixtures. The geopolymer paste was produced by mixing the boiler ash with alkaline activator for a few minutes using mechanical mixer until homogeneous mixture was obtained and the mix design was listed in Table 2 below. After that, the geopolymer mixture were placed in 50mm x 50mm x 50mm mould and

cured at 80 ºC for 24 hr. The compressive strength was tested on three hardened geopolymer samples at 28 days [12].

The materials used are volcano ash to be reacting with the geopolymer binder alkaline activator consisting of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions. The sodium hydroxide and sodium silicate was first mixed and stir until homogeneous solution was achieved to form as alkaline activator. The ratio Na_2SiO_3/NaOH used was 0.6. Geopolymer pastes were prepared by mixing volcano ash with the alkaline activator. The ratio of volcano ash/alkaline activator was 1.7. The mixing material was mixed for five minutes to obtain a homogeneous paste mixture. The paste need to be palleted then dry at the temperature 60°C for 30 minutes to get the shape of the aggregate with 14-20 mm sizes. Then the pelletized artificial geopolymer aggregate was sintered at temperature 500, 600 and 800 °C for 1 hour. The grain size distribution must meet the ASTM C 33 requirement for the use as artificial aggregate [13].

RESULT AND DISCUSSION

Based on my research, the results of compressive strength decrease when increases of replacing low calcium fly ash. Table 2 shows that the different chemical composition of low calcium fly ash and high calcium fly ash with alkali-activated based on the geopolymer binder gave the effect to the strength. The higher percentage of high calcium fly ash showed the greater value of compressive strength compare to the higher percentage of low calcium fly ash. Compressive strength of control mixture (A0) is 41.89MPa; with the 10% (A1) replacement of low calcium fly ash the strength down to 35.77MPa and with the highest replacement 50% (A5) of low calcium, the strength down to 23.26MPa. Van Jaarsveld et. al. [4] reported that the particle size, calcium content, alkali metal content, amorphous content, and morphology and origin of the fly ash affected the properties of geopolymers. It was also revealed that the calcium content in fly ash played a significant role in strength development and final compressive strength as the higher the calcium content resulted in faster strength development and higher compressive strength.

Table 2: Compressive Strength for each mix proportion [3].

Mix Code	Compressive strength (MPa)		
	1 days	7 days	28 days
A0	13.31	26.48	41.89
A1	11.91	25.19	35.77
A2	11.19	26.65	29.64
A3	10.57	23.76	36.66
A4	8.10	19.05	25.48
A5	7.98	20.68	23.26

From the study of silica fume, the addition of silica fume caused an increase in compressive strength of mortar specimens. Mortar specimens prepared with fly ash (FM) recorded strength of 26 MPa after 28 days. Significant increase of strength occurred for FM1 specimen (31 MPa) which contained 2.5% silica fume. Similarly, the compressive strength further increased (36 MPa) with additional silica fume of 5%. It amounted to a strength increase of 19.23% and 38.46%. The present of silica fume indicated the lower percentage of porosity where porosity has been reported to be chief micro structural variable limiting the mechanical properties of geopolymer [20]. From the other research on silica fume, Table 3 shows that by increasing the replacement of silica fume, it also increase the strength. For high fume contents (24% and 28%), at 28 days the inhibiting layer of reaction product around the fume particles will not be fully developed. Therefore continued reaction of fume with lime will result in further strength enhancement relative to that of the reference mix. The addition of fume also has an accelerating effect on the hydration rate of the cement, and the fume itself reacts with lime to produce additional strength enhancing gel. Hence there are three interdependent variables influencing strength development and the overall result [15].

Table 3: Compressive Strength of Condensed Silica Fume (CSF) at 20°C [15].

Mix. No	CSF (%)	Temp. (°C)	Compressive Strength (N/mm^2)				
			4 Days	7 Days	14 Days	28 Days	91 Days
1	0	20	60.2	66.3	72.9	76.7	87.7
2	12		58.4	66.3	80.6	86.7	88.2
3	16		57.5	69.1	80.1	91.5	94.1
4	20		49.6	62.1	78.1	84.4	95.5
5	24		54.5	65.5	79.2	84.2	102.7
6	28		65.0	76.8	92.1	99.7	119.8

The results of the compressive strength test are shown in Table 4, where each value is averaged from the results of three cubes. The results show that the MK used in this study is superior to silica fume in terms of the strength enhancement of concrete. Among different replacement levels, the use of MK at the replacement level

of 10% performed the best, which resulted in the highest strength increase over the control concretes at all the test ages, particularly at the age of 3 days. It can also be seen from Table 4 that at the age of 3 days, the MK replacement resulted in a higher strength increase for concretes with a higher w/b ratio than with a lower w/b ratio. This observation is contrary to the observation that fly ash contributes better to the early strength development at a lower w/b ratio than a higher w/b ratio [17]. This difference can be attributed to the difference between the strengthening mechanisms of metakaolin and fly ash in concrete. In MK concretes, MK contributes to the strength of concrete at early ages mainly by the fast pozzolanic reaction.

Table 4: Compressive Strength of MK replacement [17].

w/b	Mix	Compressive Strength (MPa)			
		3 days	7 days	28 days	90 days
0.3	Control	68.50	81.10	96.50	102.50
	5 % MK	73.00	88.20	103.60	112.90
	10 % MK	85.90	99.80	116.80	120.30
	20 % MK	70.80	87.6	99.60	113.80
0.5	Control	28.60	41.20	52.10	60.40
	5 % MK	32.60	45.90	57.10	66.50
	10 % MK	40.40	55.20	66.20	71.60
	20 % MK	30.00	43.20	58.40	69.10

Figure 1 shows the compressive strength of samples cured at 27°C for 1–28 days. The compressive strength increased with GBFS content. The increase in compressive strength was more prominent when more than 15% GBFS was added. This result is also in agreement of setting time of the samples. The increase in strength with time is mainly due to C–S–H formation. The result of compressive strength measured after casting and curing of samples at 27°C for 48 h. raw fly ash (RFA) has shown 10 MPa of compressive strength, which increased with increase in GBFS content. This increase was more prominent when 25% or more GBFS was added. Maximum compressive strength 45 MPa was reported when 50% GBFS was added. The improvement in setting time and compressive strength can be explained by the formation of cementitious C–S–H gel, which improved the setting and hardening of geopolymer [16]. According to the Figure 2, it shows that by adding the GGBS the strength increase as the curing period from 0-364 days. Based on the result, the strength percentage from 7 to 356 days on the first mixture is 59.7%, the second mixture is 73.1%, the third mixture is 84.4%, the fourth mixture is 100.4%, the fifth mixture is 107% and the sixth mixture is 110.4%. Therefore, it can be seen that the reaction of pozzolanic when present of calcium hydroxide lead to the better strength [11].
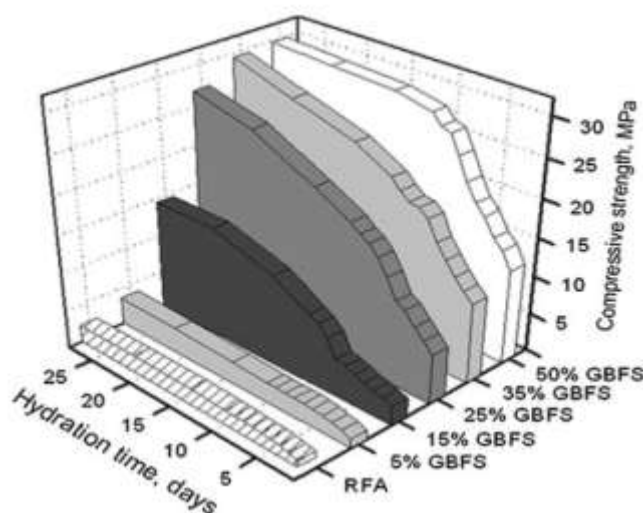

Fig. 1: Effect of GGBS addition on the compressive strength at 27°C [18].

The Figure 3 shows the result of the compressive strength of geopolymer at 28 days. The result presented geopolymer sample from 800 °C calcined boiler ash (BA2) produced the maximum compressive strength which is 19.4 MPa. In the meantime, the lowest compressive strength obtained is 7.4 MPa from 1000 °C calcined boiler ash (BA3). The compressive strength was increased when the boiler ash was calcined at 800 °C then drops when the calcined temperature increased up to 1000 °C.

The Figure 4 shows the result of the specific gravity and water absorption of artificial geopolymer aggregate of volcano ash at various sintering temperature. The higher sintering temperature will result in lower specific gravity value. The specific gravity of artificial geopolymer aggregate was in the range of 1.7-2.0 g/cm^3. The lower specific gravity could be achieved at higher temperature (>800 °C). The highest water absorption was

found at sintering temperature of 600 °C with 16.0 %. The lowest water absorption can be found at sintering temperature of 500 °C with 9.9 %. The range of water absorption for artificial geopolymer aggregate with volcano ash was 9-16 %. The water absorption can be modulated by controlling the expansion sintering temperature.
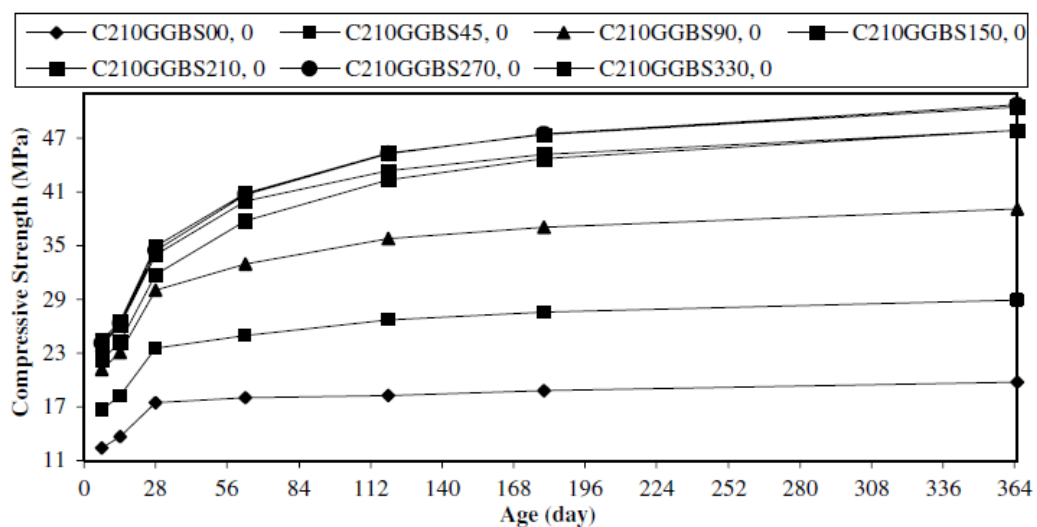

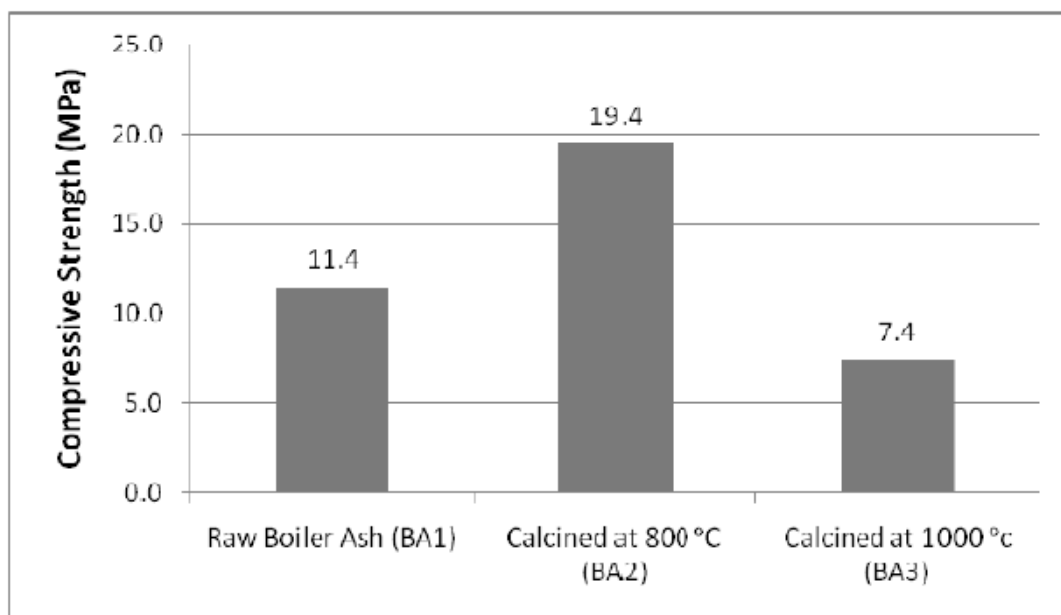**Fig. 2:** Compressive strength of GGBS according to the curing day [11].

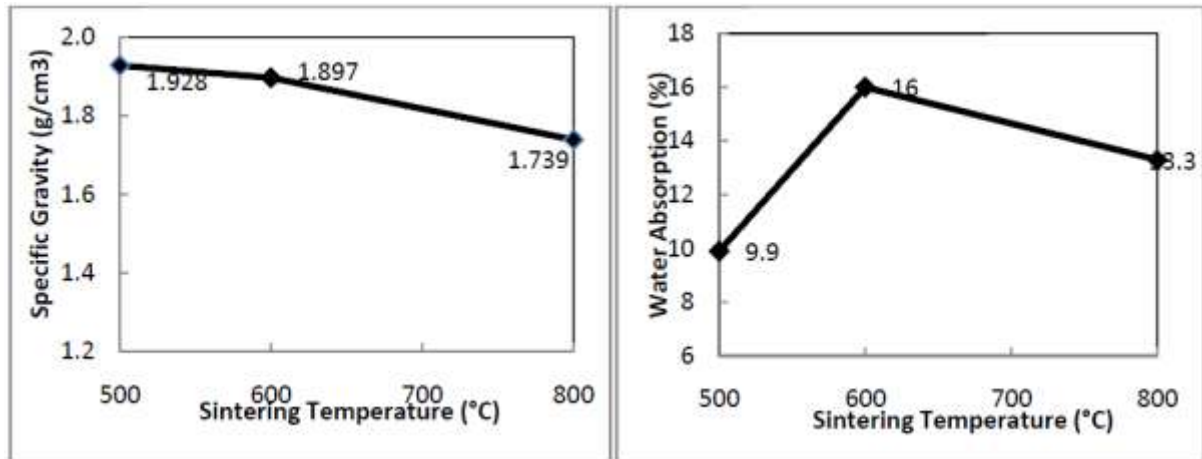**Fig. 3:** Result of compressive strength of geopolymer at 28 days [12]

Fig. 4: The specific gravity and water absorption of artificial geopolymer aggregate of volcano ash at various sintering temperature [13].

Conclusion:

As the conclusion, there are many source materials of geopolymer that lead to the different chemical composition and different properties. Variety of source materials in geopolymer from many researchers concluded that the effect of variety source materials influenced the geopolymer performances. Based on this effect, further study on combination of variety of different source materials to the geopolymer performance can be conducted.

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