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INFLUENCE OF FLY ASH AND BLAST FURNACE SLAG ON CHARACTERISTICS OF GEOPOLYMER NON-AUTOCLAVED AERATED CONCRETE

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Abstract. Geopolymer materials are known as sustainable and environmental material. The main constituents of geopolymer material are alumina and silicon, which can be activated in an alkaline environment. In this paper, the reaction of alumino-silicate materials in the alkaline agent is investigated on geopolymer non-autoclaved aerated concrete (GNAAC). The main constituents of GNAAC are fly ash (FA), blast furnace slag (BSF), lime, gypsum, aluminium powder, and alkaline solution. In the mix proportions, FA and BSF are used to replace crushed sand and cement. The results indicate that the GNAAC can be produced similarly as traditional autoclaved aerated concrete. Besides, the flow diameter of the mixture using blast furnace slag is lower than that of fly ash. The temperature and expansion ability decrease with an increase in FA/BFS – Lime and alkaline content. Furthermore, the compressive strength of GNAAC can be determined by synthesizing geopolymer without steam and pressure curing conditions.

Keywords: geopolymer, fly ash, blast furnace slag, autoclaved aerated concrete, strength.

1. INTRODUCTION

Autoclaved aerated concrete (AAC) is known as lower embodied energy than traditional concrete to apply in solve construction methods for urbanization. The foaming agent's reaction with cement, sand, lime, and gypsum is obtained by high temperature and pressure condition to produce tobermorite formation. Aerated autoclaved concrete relatively homogeneous to compare to regular concrete and non-fired brick in microstructure and composition. Their characteristics depend on the type of cementitious binders in manufacturing technology, such as mixing by fly ash, blast furnace slag, methods of pore-formation, and curing condition [1-3].

Nowadays, geopolymer is currently utilized in building construction as a replacement for cementitious materials. Geopolymer belongs to inorganic polymers and chain structures formed on a backbone of aluminium (Al) and silicon (Si) ions. Raw materials of geopolymer should contain an amount of Si and Al. The geopolymerization process, known as the hardening process, is an exothermic polycondensation reaction involving alkali activation by caution in solution. This process depends on many parameters, including the chemical and mineralogical composition of the starting materials, curing temperature, curing time, water content, and the concentration of the alkaline solution. Hence, geopolymer synthesis involves mixing an alkali liquid with Si and Al content in activated raw materials to produce hardening materials [4-8].

Fly ash and blast furnace slag are known as waste materials from thermal power and steel industries containing activated Si and Al. Thus, fly ash is a by-product of coal combustion residue, and blast furnace slag is a by-product of pig iron production in a blast furnace. They consist of silicates, alumino-silicates, and calcium-alumina-silicates, similar to the mineral composition of cement or pozzolanic material [9-10].

In this research, fly ash and blast furnace slag are used as raw materials to replace the components of the original AAC mixtures, which are cement and crushed sand. The properties of geopolymer non-aerated autoclaved concrete (GNAAC), such as workability, temperature, expansion degree, and compressive strength, have been determined.

2. EXPERIMENT PROCESS

2.1. Materials

The experiment was conducted using fly ash (FA), blast furnace slag (BSF), lime, calcined gypsum, aluminium powder, and an alkaline solution. The specific gravity and fineness of blast furnace slag (BSF) are 2.55 g/cm^3 and 3600 cm^2/g, respectively. Fly ash (FA) used in this study is dry low-calcium (class F) fly ash, according to ASTM C618. This fly ash has a specific gravity of 2.5 g/cm^3, and total alumino-silica content is about 83.6% by weight. Chemical compositions of fly ash and blast furnace slag are shown in Table 1. The fineness of aluminium powder is less than 0.075mm. Alkaline solution (AS) ranged from 5-15% by weight is used to react with solid components.

Table 1. Chemical compositions of fly ash and slag.

	Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O & Na_2O	MgO	SO_3	LOI
Fly ash	(%)	51.7	31.9	3.48	1.21	1.02	0.81	0.25	9.63
Slag	(%)	35.9	13	-	38.13	1.01	7.5	-	1.15

*LOI: Loss of Ignition

Table 2. Mix proportions GNAAC with fly ash and blast furnace slag.

Mixture	**FA (kg)**	**BSF (kg)**	**L (kg)**	**G (kg)**	**Al (kg)**	**AL (l)**	**W (l)**
F1L1	300	0	200	20	2.5	18.75	356.25
F1L2	300	0	200	20	2.5	37.5	337.5
F1L3	300	0	200	20	2.5	56.25	318.75
F2L1	318	0	182	20	2.5	18.75	356.25
F2L2	318	0	182	20	2.5	37.5	337.5
F2L3	318	0	182	20	2.5	56.25	318.75
F3L1	333	0	167	20	2.5	18.75	356.25
F3L2	333	0	167	20	2.5	37.5	337.5
F3L3	333	0	167	20	2.5	56.25	318.75
S1L1	0	300	200	20	2.5	18.75	356.25
S1L2	0	300	200	20	2.5	37.5	337.5
S1L3	0	300	200	20	2.5	56.25	318.75
S2L1	0	318	182	20	2.5	18.75	356.25
S2L2	0	318	182	20	2.5	37.5	337.5
F2L3	0	318	182	20	2.5	56.25	318.75
S3L1	0	333	167	20	2.5	18.75	356.25
S3L2	0	333	167	20	2.5	37.5	337.5
S3L3	0	333	167	20	2.5	56.25	318.75

2.2. Testing

The mix proportion of GNAAC with 500 kg/m^3 dry in density is investigated. The ratio of fly ash/ blast furnace slag – lime ranged from 1.5 to 2 by weight is investigated. The proportion of GNAAC with fly ash and blast furnace slag is shown in Table 2. The standard ASTM C956 and C39 were used to evaluate the workability (flow), expansion properties, and strengths (at 7 and 28 days) of GNAAC specimens, as shown in Fig. 1 and 2.

Figure 1. Flow test.

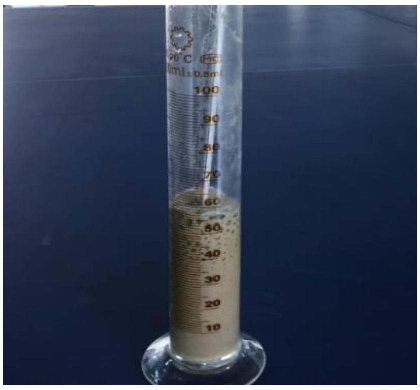

Figure 2. Expansion test.

3. FIGURES AND TABLES

3.1. Influence of fly ash and slag on the flow of GNAAC

In this study, the content of aluminium and silicon in GNAAC using FA is varied by the ratio of fly ash and lime. The effects of aluminium and silicon contents are presented by the value of CaO/ SiO_2 and $CaO/ (SiO_2 + Al_2O_3)$ shown in Fig. 3a. According to this figure, with an increase of fly ash/lime ratio, both CaO/ SiO_2 and $CaO/ (SiO_2 + Al_2O_3)$ ratio decrease from 1.05 to 0.8 and 0.68 to 0.52, respectively. In the mixture using fly ash, the ratio of SiO_2/Al_2O_3 is 1.84 by weight. Based on the previous research [7], the networks of geopolymer materials is varied between poly (sialate) in the case of SiO_2/Al_2O_3 ratio ranged from 1 to 2 and poly (sialate-siloxo) in the case of SiO_2/Al_2O_3 ratio ranged from 2 to 3. Thus, poly(sialate) can be the final product of the reaction between fly ash and alkaline environment.

In terms of workability, the flow diameter of three mixtures F1, F2, and F3 decreases approximately 16 to 30% when alkaline liquid changes from 5 to 15% by weight, as shown in Fig. 3b. However, the mixture with higher fly ash content has a contrary trend compared with the flow diameter. When the fly ash/lime ratio increases from 1.5 to 2, the flow diameter value increases by about 41.7% in the case of mixture F1, 49.5% and 62% for mixture F2 and F3, respectively. It is indicated that fly ash particles can be increased in workability, but alkaline content affected the fresh mixture's plastic viscosity.

By comparison, the flow diameter of the BFS mixture is lower than that of FA with the same lime content, as seen in Fig. 1c and 1d. On the other hand, the results illustrated in Fig. 3c indicate that the workability of the mixture containing a higher BFS/lime ratio is also high in flow diameter. Besides, the workability of BFS mixture is lower about 30% than that of FA and more reducing with increase in alkaline content, as seen in Fig. 3d. The results can be explained that spherical particles of FA are smoother than the rough surface of BFS. In general, all mixtures' workability is significantly affected by FA/BFS ratio and alkaline content.

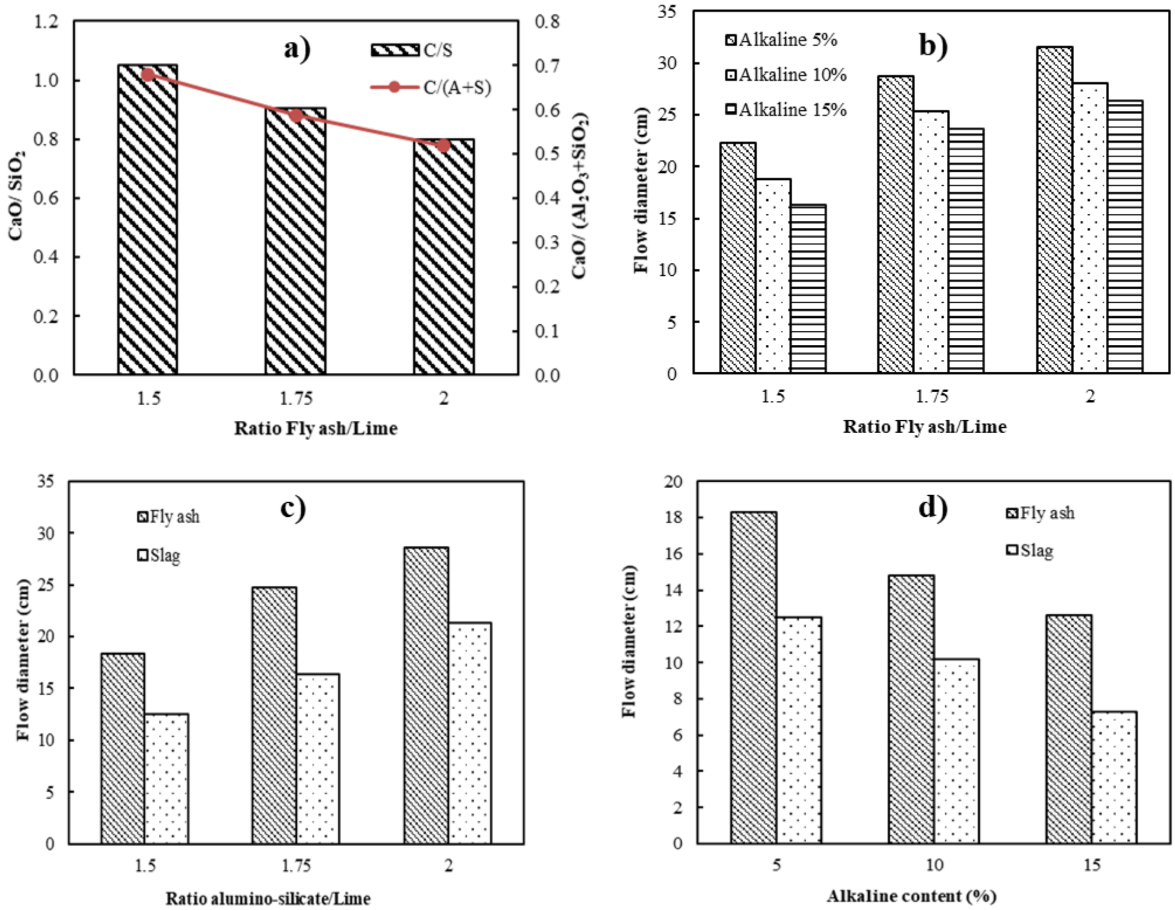

Figure 3. Influence of fly ash and slag on workability.

3.2. Influence of fly ash and slag on expansion properties of GNAAC

As seen in Fig. 4a and Fig. 4b, the foamed mixture F1L1 is shown to value 70^{0}C and 95% in the temperature and expansion degree, respectively. The temperature expansion of mixtures F1 slightly decreased from 70 to 67^{0}C with added alkaline content from 5 to 15% at FA/Lime ratio of 1.5. While in the mixture F2 and F3, the temperature expansion decreased to 55^{0}C – 58^{0}C.

Furthermore, mixtures F2 and F3 significantly reduce expansion ability when fly ash and alkaline content increase. It is seen that the temperature expansion is mainly conducted by a chemical reaction between lime and alkaline liquid, and it is generally correlated with the degree of reactivity. The aluminium powder then reacts with calcium hydroxide, formed on lime and alkaline liquid reaction to form large-volume hydrogen. It is also indicated that there is a reasonable reaction between aluminium powder and alkaline environment during fly ash existing.

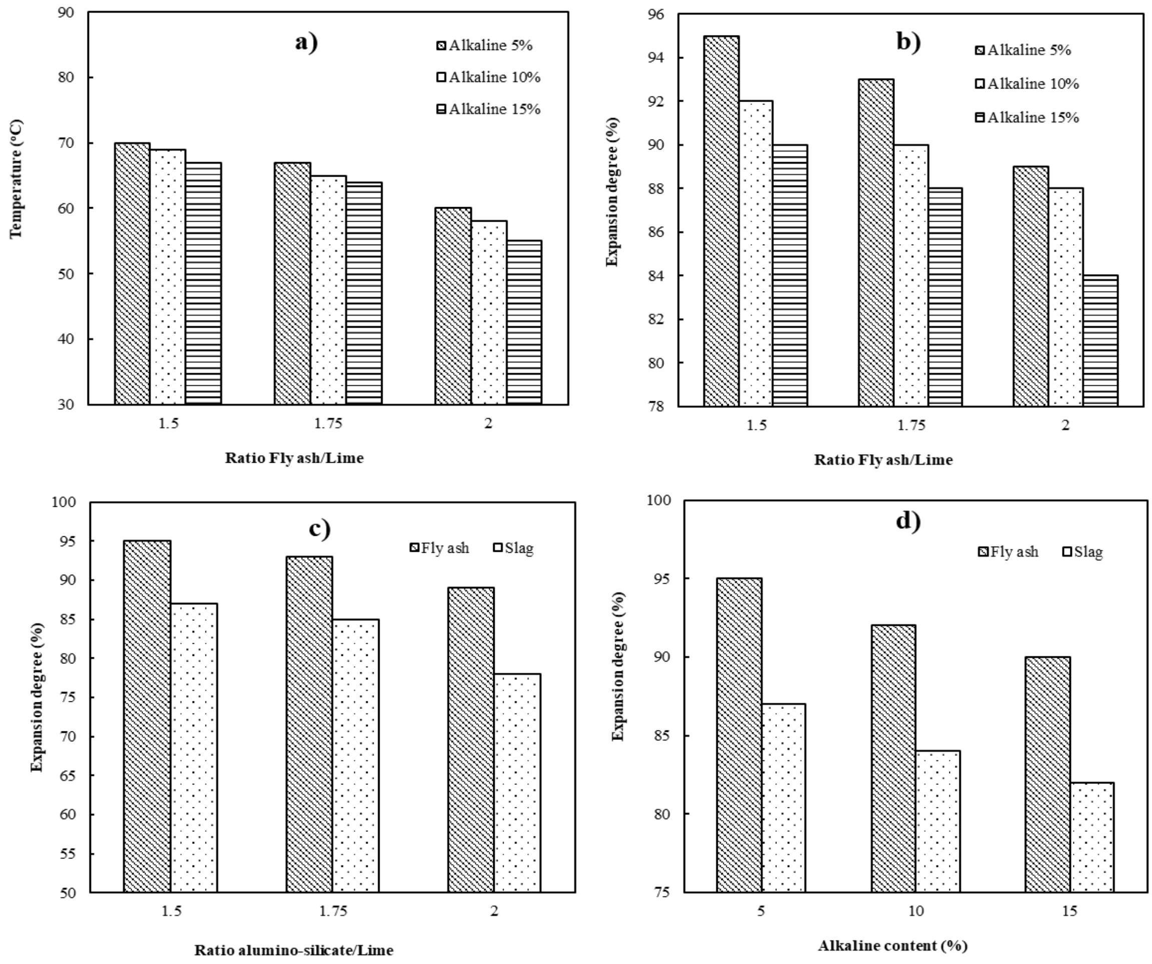

Figure 4. Influence of fly ash and slag on expansion temperature and expansion ability.

Moreover, Fig. 4c presents the relationship between ratio of alumino-silicate/lime and expansion degree in mixtures using BFS and FA. According to Fig. 4c, the expansion degree in BFS is lower than FA 10-12% with the same lime content. Mixing with alkaline liquid, the expansion degree of mixture BFS is also lower than FA, as seen in Fig. 4d. It can be indicated that the expansion degree of FA and BFS mixture are relative with temperature and flowability. Hence, the measurement in flow-diameter and reaction temperature can be designed in the volume of porosity.

3.3. Influence of fly ash and slag on compressive strength of GNAAC

Overall, the compressive strength of GNAAC is affected by the content of FA and BSF. As shown in Fig. 5a, the compressive strength of mixture F1L1 is about 1.6 and 2.3 N/mm^2 at 7-day and 28-day, respectively. While the compressive strengths of F2L1 are (1.5 and 2.2 N/mm^2), and (1.3 and 1.6 N/mm^2) for F3L1 at 7-day and 28-day, respectively.

The geopolymerization process plays a significant role in strength development by the presence of calcium content in fly ash and lime in an alkaline environment. Moreover, the strength of GNAAC is not only depended on the amount of alumino-silicate but also the expansion degree of GNAAC's mixture. Hence, even F2L1 and F3L1 have higher fly ash/lime ratio; they show lower strength than F1L1. However, the strength of GNAAC can increase up to 30% with an increase of alkaline content, as seen in Fig. 5b. It is known that the synthesis of geopolymerization can be improved by adding Na_2O.

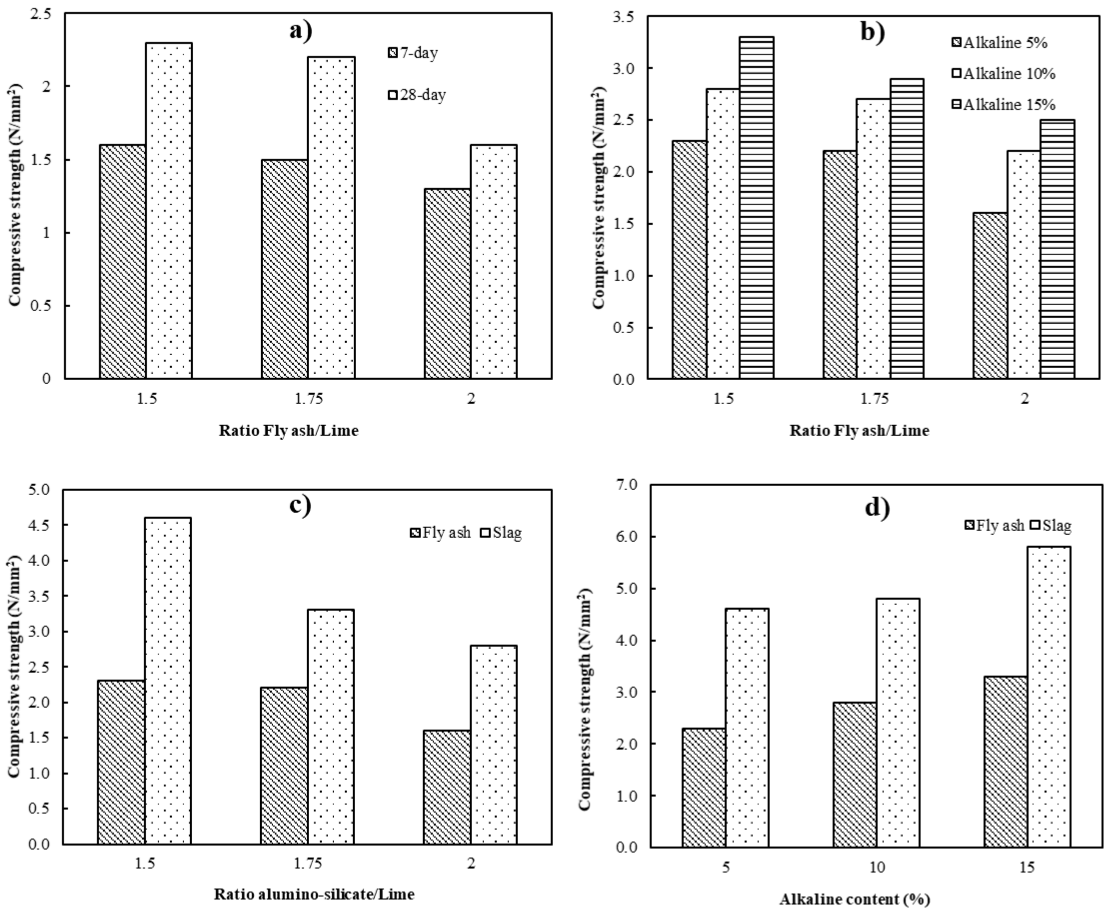

Figure 5. Influence of fly ash and slag on the compressive strength of GNAAC.

On the other hand, Fig. 5c and 5d show the relationship between the ratio of alumino-silicate – Lime and strength in BFS and FA mixture. Based on two these figures, the strength of BFS mixtures is higher 30-40% than that of FA mixtures after 28-day curing. It is noted that the BFS particle with 43% content of alumino-silicate is lower than that of FA (83%). However, BFS raw material, which contains the SiO_2/Al_2O_3 ratio of 1.84, can be obtained the poly*(*silixo*)* in the final structure. Thus, the reaction of a mixture using BFS can strongly happen. Therefore, GNAAC can match well *with* the requirements of AAC-4 and AAC-6 in the ASTM 1693-09.

4. CONCLUSION

The research on the effect of fly ash and blast furnace slag on GNAAC has some results as following:

- Firstly, the workability increases with a high fly ash/blast furnace slag – lime ratio but decreases with alkaline liquid content. The flow diameter of the BFS mixture reduces about 30% compared with the FA mixture.

- The temperature and expansion ability tend to decrease with an increase in FA/BFS – Lime and alkaline content. The reaction of aluminium powder and alkaline environment can reduce using a large amount of FA/BFS and alkaline liquid. Besides, a mixture with BFS showed lower porosity than that of FA in foamed concrete.

- Finally, the compressive strength of GNAAC can be determined by synthesizing geopolymer without steam and pressure curing conditions after 28-day. The compressive strength of GNAAC also satisfies the requirements AAC-4 and AAC-6 in ASTM 1693-09, with FA and BFS, respectively.

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