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THE EFFECT OF FLY ASH/ALKALINE ACTIVATOR RATIO IN CLASS F FLY ASH BASED GEOPOLYMERS

Dumitru Doru BURDUHOS NERGIS[1], Mohd Mustafa Al Bakri ABDULLAH [2], Petrică VIZUREANU[1]

[1] Gheorghe Asachi Technical University of Iasi, Faculty of Materials Science and Engineering, 41 D. Mangeron Blvd., 700050, Iasi, Romania
[2] Center of Excellent Geopolymer and Green Technology, School of Materials Engineering, University Malaysia Perlis, P. O Box 77, D/A Pejabat Pos Besar Kangar, Perlis 01000, Malaysia

Abstract

This study focused on the effect of fly ash/alkaline activator ratio and Na2SiO3/NaOH ratio in class F based geopolymers. The objective of this study is to observe the variation of the compressive strength of the final product depending the solid/liquid ratio. In order to form the geopolymer, various parameters were changed during the geopolymerisation process. The fly ash/alkaline activator ratio studied was: 1.5; 2.0; 2.5. The geopolymeric pasta was heated up to 400 °C, 600 °C and 800 °C. After heating the compressive value of geopolymer, with the fly ash and alkaline activator ratio equal to 2 and Na2SiO3/NaOH ratio of 2.5, decreased with approximative 40 MPa comparative with the value of the sample obtained from the same composition dried for 7 days at normal temperature.

Keywords: *geopolymers, fly ash, fly ash/alkaline activator ratio, Na_2SiO_3/NaOH ratio.*

Introduction

Geopolymers are a class of ceramic materials total inorganic [1], based on alumina and silica, which are chemical balanced by alkaline ions from group I (Li^+, Na^+, K^+) [2]. Thus materials are rigid gels, obtained in normal boundary condition or cured at high temperature [3] and it can be converted in crystalline materials or glass [4]. Any geopolymer can be splitted into two main constituents, the base material and the activator (an alkaline liquid). The major constituent is the base material, it must be rich in silicon and aluminum, it can be a natural mineral, such as clays [5-7], kaolin [8-10], or waste, such as ash [11], slags [12] etc.

Ash is a secondary product derived from coal combustion in power plants. From burning of the coal sprayed in the combustion chambers, carbon and volatile materials are produced. However, some impurities of clay, quartz, etc. merge in exhaust gases and when discharged from the burners they are captured in the gas filters. With the cooling of the exhaust gases, the fused materials solidify in glass spherical particles called fly ash [13]. Due to the fusion-in-suspension, fly ash particles are generally solid spheres and tubular ecosystems with some globe-shaped particles that contain smaller spheres.

The chemical and mineralogical composition depends to a large extent on the composition of coal, given that there are many types of coal (anthracite, bituminous lignite or

Corresponding author: doru.burduhos@tuiasi.ro

sub-bituminous lignite) burnt in many stations, the properties of this ashes can be very different depending on source and collection method [14].

According to the standard of natural calcined or non-calcined pozzolanic materials (ASTM C618), there are two categories of fly ash. [15] (Table 1).

In the furnace firing zone, coal burning produces heat up to 1500 °C. At this temperature, inorganic minerals (quartz, calcite, gypsum, pyrite, feldspar, etc.) are combined in small liquid drops. These drops are evacuated from the furnace's combustion chamber together with exhaust gases. Once leave out the firing zone, these drops get a spherical shape of glass particle. Fly ash is collected from the gases evacuated by mechanical and electrostatic precipitators. Bottom ash can also be used to make geopolymers [16].

Table 1. Types of ashes according to ASTM C618 standard

Class	Description according ASTM C618	Chemical requires
F	Fly ash produced by burning bituminous coal or anthracite that meets the chemical condition. This ash class has pozzolonic properties.	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 70\%$
C	Fly ash produced by the combustion of sub-bituminous coal or lignite that meets the chemical condition. This class has, besides pozzolonic properties, cementitious properties. *)	$SiO_2 + Al_2O_3 + Fe_2O_3 \geq 50\%$

***)** Some class C ashes may contain more than 10% calcium oxide.

Experimental

The fly ash used in the experiment belongs to the ASTM C618 class F class because the sum of the major oxides percent exceeds 70%, according to equation (1) established from the data in table 2:

$$SiO_2 + Al_2O_3 + Fe_2O_3 = 83.09\% \qquad (1)$$

Table 2. Fly Ash Composition (weight percents)

Oxide	Percentage (%)	Oxide	Percentage (%)
SiO_2	52.11	Na_2O	0.42
Al_2O_3	23.59	K_2O	0.80
Fe_2O_3	7.39	P_2O_5	1.31
TiO_2	0.88	SO_3	0.49
CaO	2.61	MnO	0.03
MgO	0.78	LOI	9.59

LOI - loss on ignition

For a better description of the raw material used, a XRD analyze was performed, the results are presented in the picture below (fig. 1).

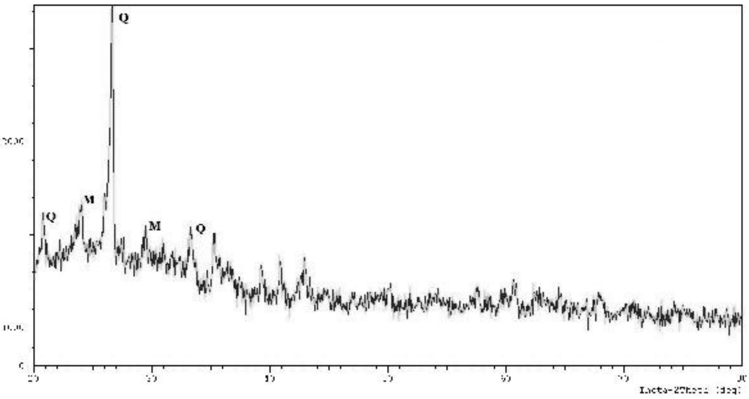

Fig. 1. X Ray Pattern (XRD) for raw Fly Ash, Q = quartz, M = mullite

Table 3. Mix Design Details for Various Ratios of Fly Ash/Alkaline Activator and Na_2SiO_3/NaOH

Fly ash/ Alkaline Activator Ratio	Na_2SiO_3/NaOH Ratio	Fly Ash (g)	Na_2SiO_3 (g)	NaOH (g)
1.5	0.5	505	115	225
	1.0		170	170
	1.5		205	135
	2.0		225	115
	2.5		240	95
	3.0		255	85
2.0	0.5	565	95	190
	1.0		140	140
	1.5		170	115
	2.0		190	95
	2.5		200	80
	3.0		210	70
2.5	0.5	605	80	160
	1.0		120	120
	1.5		145	95
	2.0		160	80
	2.5		170	70
	3.0		180	60

Results and Discussion

At normal temperatures, the reaction rate of the pozzolonic material is lower than the hydration rate of the cement, so fly ash-based concrete must be **cured** under "special" conditions in order to benefit of all the properties of this compound. When using a very large amount of ash in a concrete, it is recommended that the curing time to be at least 7 days. If it is desired to decrease the curing temperature, other additions may be added to the material.

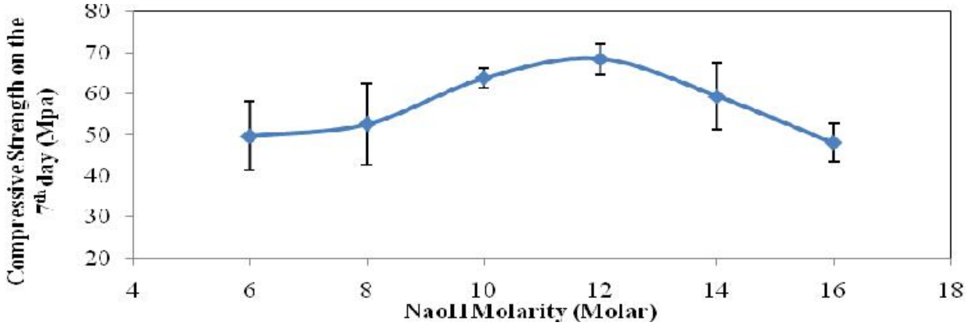

Fig. 2. Compressive Strength of Various NaOH Molarities

The compressive strength (Fig. 3) of the geopolymeric composites is closely related to the amount of activator used as well as its concentration. For the activated geopolymer with a ratio of 2.5 Na_2SiO_3/NaOH of 1.5%, the compressive strength obtained after 7 days was about 40 MPa, for 2% of about 70 MPa, and for 2.5% of about 55 MPa.

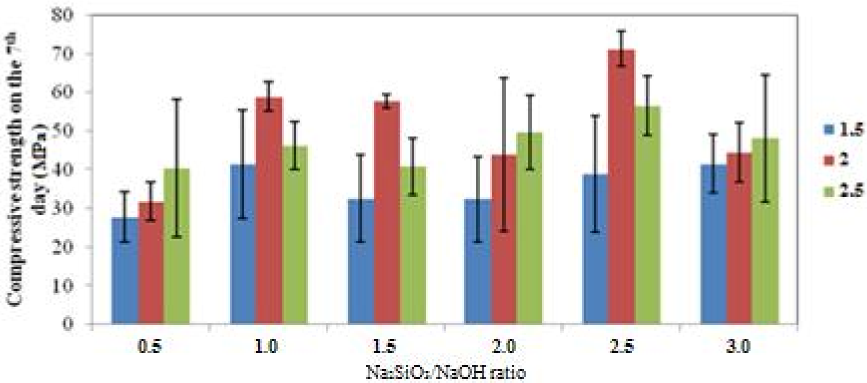

Fig. 3. Compressive Strength of Various Proportions of Reactants

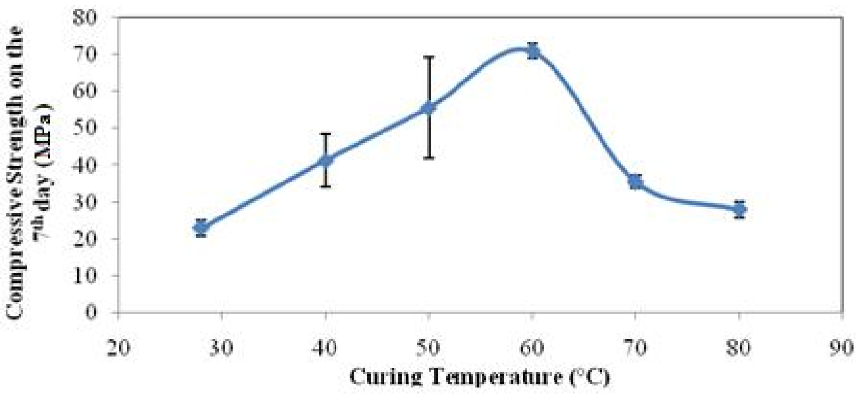

Fig. 4. Compressive Strength for Various Curing Temperatures (°C)

Fig. 5. The optimum Fly ash-based geopolymers with optimum compressive strength of 8.61 MPa, Fly Ash/Activator ratio= 2.0 and $Na_2SiO_3/NaOH$ ratio = 2.5, after heat treatment at 400°C, 600°C, and 800°C

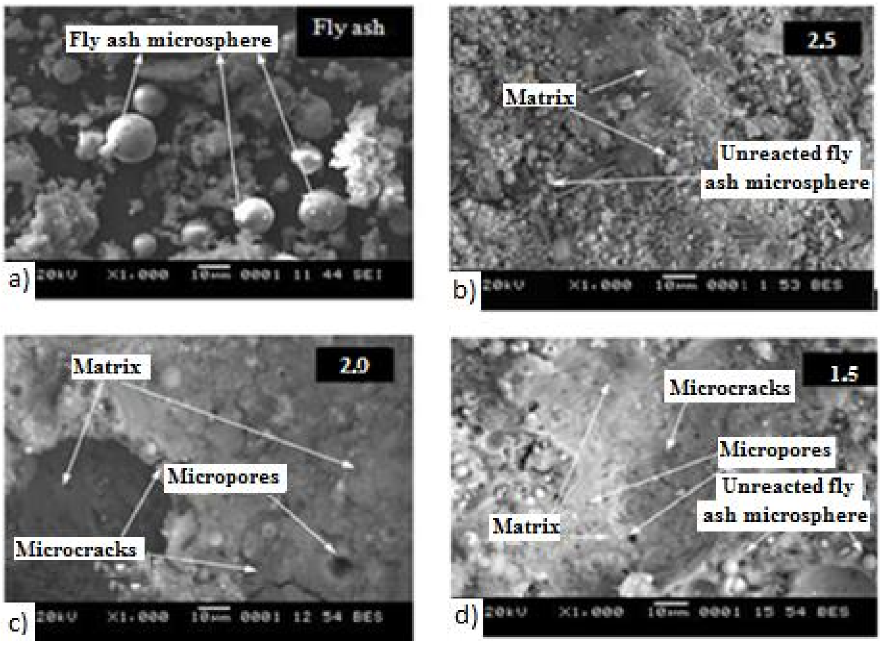

Fig. 6. SEM micrographs of the original a) fly ash and the synthesized geopolymers at activator/fly ash ratios of b) 2.5, c) 2.0, and d) 1.5 and $Na_2SiO_3/NaOH$ solution ratio of 2.5

Heating of the geopolymeric paste at high temperature has a negative effect on compressive strength, the optimal value being only 8,61 MPa for the geopolymer with the ratio of fly ash to activator 2.0 and the ratio of $Na_2SiO_3/NaOH$ of 2.5, heated at 400 °C, 600 °C and 800 °C (Fig. 7).

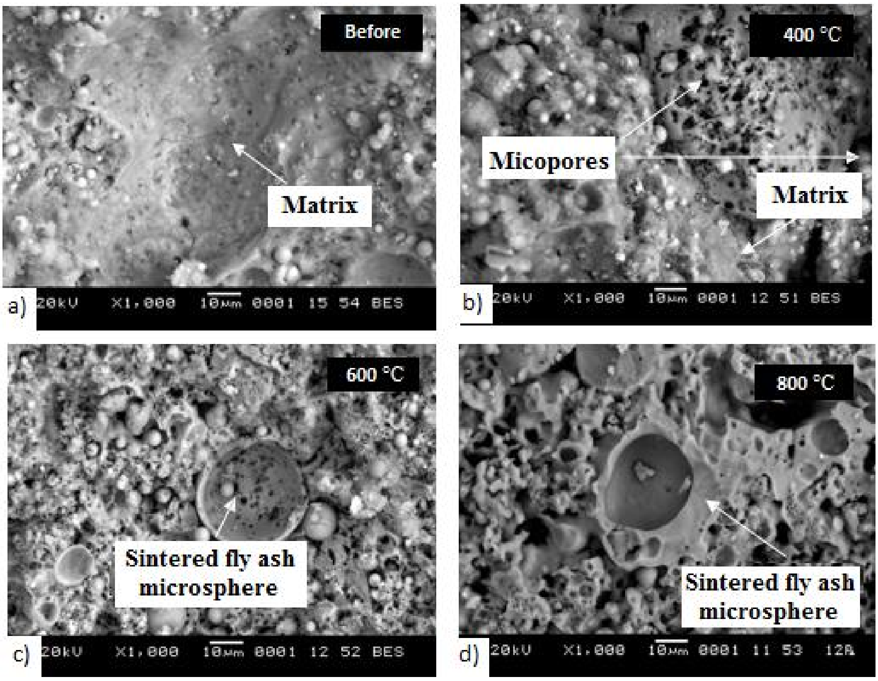

Fig. 7. SEM micrographs of fly ash-based geopolymers,
a) before heat treatment and after heat treatment at b) 400 °C, c) 600 °C and d) 800 °C.

Conclusion

The properties of the final geopolymer are directly depending of: Si/Al ratio, base material, particle dimensions, alkaline activator concentration, calcium quantity, time of synthesizing/hardening and geopolymerization temperatures.

According to our study, after heating, the compressive strength value of geopolymer, with the fly ash and alkaline activator ratio equal to 2 and Na_2SiO_3/NaOH ratio of 2.5, is decreasing with approximate 40 MPa, comparative with the value of the sample obtained from the same composition cured for 7 days at normal temperature.

The value of compressive strength after 7 days for the geopolymer with fly ash/alkaline activator ratio 2 was (i) 60 MPa for 1.5 Na_2SiO_3/NaOH ratio, (ii) 40 MPa for 2.0 **Na_2SiO_3**/NaOH ratio and (iii) 70 MPa for 2.5 Na_2SiO_3/NaOH.

Curing at high temperature has a negative effect on compressive strength, the optimal value obtained was 8.61 MPa.

References

[1] L. Yun-Ming, H. Cheng-Yong, L. Li, N. A. Jaya, M. M. A. B. Abdullah, T. S. Jin, K. Hussin, *Formation of one-part-mixing geopolymers and geopolymer ceramics from geopolymer powder*, **Construction and Building Materials, 156,** 2017, p. 9–18.

[2] J. Davidovits, *Properties of geopolymer cements*, **Proceedings First International Conference on Alkaline Cements and Concretes**, 1994, pp. 131-149.

[3] A. A. Adam, *The effect of temperature and duration of curing on the strength of fly ash based geopolymer mortar*, **Procedia Engineering**, **95**, 2014, pp. 410 – 414

[4] J. L. Bell, P. E. Driemeyer, M. W. Kriven, *Formation of Ceramics from Metakaolin-Based Geopolymers. Part II: K-Based Geopolymer*, **J. Am. Ceram. Soc., 9**2, 2009, p. 607-615.

[5] J. Peyne, J. Gautron, J. Doudeau, E. Joussein, S. Rossignol, *Influence of calcium addition on calcined brick clay based geopolymers: A thermal and FTIR spectroscopy study*, C**onstruction and building materials, 152**, 2017, pp. 794-803.

[6] I. Perna, T. Hanzlicek, P. Boura, A. Lucanik, *Application of a clay-slag geopolymer matrix for repairing damaged concrete: Laboratory and industrial-scale experiments*, **Materials testing, 59**, 2017, pp. 929-937.

[7] S. Louati, S. Baklouti, B. Samet, *Geopolymers Based on Phosphoric Acid and Illito-Kaolinitic Clay*, A**dvances in materials science and engineering,** 2016, p. 7.

[8] I. Balczar, T. Korim, A. Kovacs, E. Mako, *Mechanochemical and thermal activation of kaolin for manufacturing geopolymer mortars - Comparative study,* ***Ceramics international**, **42**, 2016, pp. 15367-15375.*

[9] M. I. El-Dessouky, M. R El-Naggar, *Re-use of waste glass in improving properties of metakaolin-based geopolymers: Mechanical and microstructure examinations*, C**onstruction and building materials, 132,** 2016, p. 543-555.

[10] R. Ahmad, M. M. A. Abdullah, K. Hussin, A. V. Sandu, *XRD and FTIR study of the effect of Ultra High Molecular Weight Polyethylene (UHMWPE) as Binder on Kaolin Geopolymer Ceramics,* **Advanced materials engineering and technology**, **1835**, 2017, 020030. 10.1063/1.4981852.

[11] M. Z. N. Khan, F. U. A. Shaikh, Y.F. Hao, H. Hao, *Effects of Curing Conditions and Sand-to-Binder Ratios on Compressive Strength Development of Fly Ash Geopolymer*, **Journal of materials in civil engineering**, **30**, 2017.

[12] K. Onoue, T. A. Bier, *Optimization of alkali-activated mortar utilizing ground granulated blast-furnace slag and natural pozzolan from Germany with the dynamic approach of the Taguchi method,* C**onstruction and building materials**, **144**, 2017, pp. 357-372.

[13] T. Subramani, P.Sakthivel, *Experimental Investigation On Flyash Based Geopolymer Bricks*, **International Journal of Application or Innovation in Engineering & Management**, **5**, 2016, pp. 216-227.

[14] R. Shadnia, L. Y. Zhang, *Experimental Study of Geopolymer Synthesized with Class F Fly Ash and Low-Calcium Slag*, **Journal of materials in civil engineering**, **29**, 2017, pp. 10.

[15] ASTM C618-05, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*, **American Society of Testing and Materials**, West Conshohocken, PA, 2005.

[16] L. M. Deraman, M. M. A. B. Abdullah, L. Ming, H. Kamarudin, Z. Yahya, *The Strength of Bottom Ash-Based Geopolymer Brick with Inclusion of Fly Ash,* **Materials Science Forum,** 2016, 841. 26-29. 10.4028/www.scientific.net/MSF.841.26.

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