International Review of Civil Engineering (I.RE.C.E.), Vol. 13, N. 4
ISSN 2036 - 9913
July 2022

Mix Design Formulation and Stress-Strain Relationship of Fly Ash-Based Workable Geopolymer Concrete: an Experimental Study

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Abstract – *Geopolymer concrete is known as a concrete made by one of cementitious materials in order to reduce carbon dioxide (CO_2) emissions for sustainable development purposes. Instead of using Portland cement for a mortar matrix, mineral residues as a result of power plant processes so-called fly ash are used to replace completely the existence of cement in a concrete structure. A large amount of chemical compounds such as silicon dioxide or silica (SiO_2), aluminum oxide (Al_2O_3) and iron(III) oxide or ferric oxide (Fe_2O_3) contained in fly ash can substitute Portland cement as a chemical binder in concrete materials. Fly ash Class F which contains more than 70% of SiO_2, Al_2O_3 and Fe_2O_3 in total with less than 10% of calcium oxide (CaO) has been investigated yielding compressive strengths similar to or even higher than the conventional concrete using Portland cement. In order to obtain a strong chemical binder between aggregates and fly ash, an activator containing a mixture of sodium hydroxide (NaOH) and sodium metasilicate (Na_2SiO_3) is applied here, where two types of Na_2SiO_3 (Be52 and Be58) are employed. Further, workability is investigated by comparing Na_2SiO_3 type Be52 and Na_2SiO_3 type Be58, with maintaining an acceptable compressive strength. Then the results of proportional mix design variations for geopolymer concrete are analyzed in terms of the modulus of elasticity and the Poisson's ratio as well as its stress-strain relationship compared to the conventional concrete.* **Copyright © 2022 Praise Worthy Prize S.r.l. - All rights reserved.**

***Keywords**: Fly Ash-Based Geopolymer Concrete, Mix Design, Workability, Compressive Strength, Stress-Strain Relationship*

Nomenclature

Al	Aluminum
Al_2O_2	Dialuminum dioxide
Al_2O_3	Aluminum oxide
CaO	Calcium oxide
CC	Conventional Concrete
fib	Fédération internationale du béton
CO_2	Carbon dioxide
CSI	Cement Sustainability Initiative
C-S-H	Calcium Silicate Hydrate
E	Modulus of elasticity
E_c	Modulus of elasticity of concrete
ε_c	Current strain
$\varepsilon_{fc'}$	Strain at the maximum strength
ε_x	Lateral strain
ε_y	Longitudinal strain
FAGC	Fly Ash-based Geopolymer Concrete
FAWGC	Fly Ash-based Workable Geopolymer Concrete
FeO	Ferrous oxide
Fe_2O_3	Iron(III) oxide or ferric oxide
f_c'	Compressive strength of concrete
GCCA	Global Cement and Concrete Association
ITZ	Interfacial Transition Zone
K	Kalium
K_2O	Potassium oxide
MD	Mix Design
MGC	Metakaolin-based Geopolymer Concrete
MgO	Magnesium oxide
Na	Natrium
NaOH	Sodium hydroxide
Na_2SiO_3	Sodium metasilicate
N-A-S-H	Sodium aluminosilicate hydrate
O	Oxygen
OH	Hydroxide
OPC	Ordinary Portland Cement
PPC	Portland Pozzolan Cement
SCGC	Self-Compacting Geopolymer Concrete
SGC	Slag-based Geopolymer Concrete
SEM - EDX	Scanning Electron Microscopy - Energy Dispersive X-ray
Si	Silicon
SiO_2	Silicon dioxide
Si_2O_5	Poly(sialate-siloxo)
SO_3	Sulfur trioxide
TiO_2	Titanium dioxide
ν	Poisson's ratio
WBCSD	World Business Council for Sustainable Development
XRF	X-Ray Fluorescence
σ_c	Current stress

https://doi.org/10.15866/irece.v13i4.21515

I. Introduction

Concrete materials have a prominent role in numerous civil engineering constructions since most of building structures utilize concrete as a main building material, for instance, high rise buildings, long span bridges, rigid pavement highway, as well as many concrete buildings which require high safety such as nuclear power plant, offshore oil rig platforms, and military base anchorage.

Due to the use of concrete materials in the aforementioned building constructions, the necessity of Portland cement as a mortar matrix is indeed extremely high up to now. This circumstance causes a great amount of Portland cement production, which yields high emissions of carbon dioxide (CO_2) during its processes, and it provides a huge impact for damaging the environment, particularly in the contribution of climate change. As mentioned in [1], global production of cement per year has achieved more or less 2.8 billion tons and it is predicted to reach up to 4 billion tons annually. Moreover, cement production is one of the major sources that contribute to the emergence of greenhouse gasses with the average of 5% from all human activities produced greenhouse gas emissions [2].

In industrial sector, the Ordinary Portland Cement (OPC) production process is responsible approximately 8% of total CO_2 emissions consuming about 15% of total industrial energy [3], where China produces 60% of the global cement manufacture [4]. Furthermore, in some countries or regions including China, obsolete technologies for manufacturing Portland cements yield more air pollution than the production using improved technologies that deliver great impacts for environmental damage [5]. Therefore, some technologies for capturing CO_2 in order to reduce carbon emissions have been studied extensively [6], [7]. In contrast to utilizing technologies for reduction the CO_2 emission in cement manufacturing processes, an extreme effort is carried out by replacing cement itself with other cementitious materials for constructing many concrete structures.

Mineral residues as a result of coal combustion processes in a power plant so-called fly ash have required constituents to substitute the Portland cement as a binder in a mortar matrix. In cement industries, fly ash is normally mixed with cement namely Portland Pozzolan Cement (PPC). As mandated in the code [8], two classes of fly ash are defined, i.e. Class C and Class F. The difference between the two classes is the different chemical amount of silicon oxide (SiO_2), aluminum oxide (Al_2O_3) and iron(III) oxide or ferric oxide (Fe_2O_3).

These three compounds should exist in a large amount in cementitious materials to be capable for replacing cement in a concrete structure, whereas calcium oxide (CaO) should be included in fly ash with the specified amount mentioned in the code. Fly ash Class C contains more than 50% of the total amount of SiO_2, Al_2O_3 and Fe_2O_3 as well as more than 20% of CaO. Meanwhile, fly ash Class F should have substance more than 70% of SiO_2, Al_2O_3 and Fe_2O_3 in total, also less than 10% of CaO.

In this contribution, fly ash Class F is used to replace the Portland cement in the mortar paste of concrete due to the pozzolanic nature and the higher amount of mineral compounds than the fly ash Class C to be formed as a Fly Ash-based Geopolymer Concrete (FAGC) which consist of a polymeric silico-oxide-alumino as mentioned in [9]. In order to obtain a strong chemical binder, an alkali activator as a mixture of sodium hydroxide (NaOH) and sodium metasilicate (Na_2SiO_3) is added to the fly ash Class F to react and yield cementitious compounds. Here, the solution of NaOH with the molarity of 12 M is employed, while two types of Na_2SiO_3, i.e. Be52 and Be58, are applied in order to obtain good workability during execution.

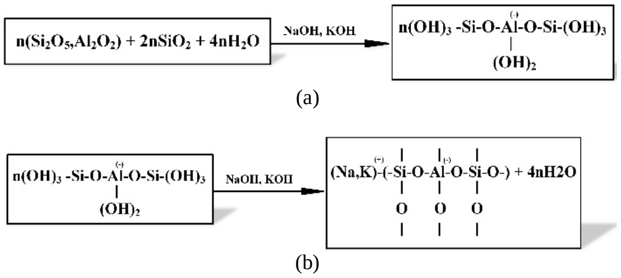
Moreover, several variations of the proportional mix design for a Fly Ash-based Workable Geopolymer Concrete (FAWGC) are implemented in this contribution, since no available standard exists for geopolymer concrete mix design.

The present paper is aimed to formulate experimentally a FAWGC using the optimum result obtained from the proportional variations of provided mix design with a fixed concentration of NaOH (12 M) and the aforementioned Na_2SiO_3. Some casted geopolymer concrete cylinders are compressively tested at the specified age. Then, the results are compared to the Conventional Concrete (CC) using Portland cement with the similar proportional mix design. In addition, the mix design of the FAWGC is analyzed in terms of its modulus of elasticity and its Poisson’s ratio as well as its stress-strain relationship compared to the OPC-based concrete.

The paper is organized as follows. The background of using geopolymer concrete is summarized and its description is explained. Next, the experimental method is elaborated in detail and, finally, the experimental investigations are analyzed as well as discussed to evaluate the results.

II. Fly Ash-Based Geopolymer Concrete

The term “geopolymer” means a polymeric framework containing silico-oxide-alumino (sialate) as stated in [9], whereas its chemical reaction depends on the ratio of SiO_2 and Al_2O_3 in the compound system [10]. Moreover, according to [11], a geopolymerization in the system occurs depending on temperatures. The process of polymerization could be one of the three formulations, i.e. poly(sialate) –Si–O–Al–O–, poly(sialate-siloxo) –Si–O–Al–O–Si–O– or poly(sialate-disiloxo) –Si–O–Al–O–Si–O–Si–O– [12] occurred in three steps involving dissolution of Si and Al atom, decomposition of precursor ion to be monomer, and polycondensation of monomers being polymer structures [13]. Hence, the geopolymer materials are generated as the result of the aforementioned polymerization with the side result of H_2O. These schematic processes of the last two steps are depicted in Figs. 1(a), (b), while the whole process of geopolymerization is displayed in Fig. 2.



Figs. 1. (a) Decomposition of precursor ion to be monomer, (b) polycondensation of monomers being polymer structures [13]

As mentioned previously, the Portland cements yield high carbon emissions causing environmental damage.

Since the Global Cement and Concrete Association (GCCA) through the World Business Council for Sustainable Development (WBCSD) and the Cement Sustainability Initiative (CSI) provides database for worldwide cement production, many countries make serious efforts to reduce the emissions by replacing the OPC with waste material-based cements namely geopolymer cements such as blast furnace slag, bottom ash or fly ash [14]-[18]. Furthermore, as a result of environmental processes during the building's service life, OPC-based materials are straightforward to be corroded due to carbon dioxides and corrosive ions contained therein [19]. Due to these challenges and in order to produce the environmentally friendly building materials, the geopolymer cements are used to replace OPC paste covering aggregates in concrete materials.

The first geopolymer cement has been pioneered and patented by [20], where a mineral composition is formed of a poly(sialate-siloxo) material acquired by adding a mixture of alumino-silicate oxide (Si_2O_5, Al_2O_2). In addition to reducing the carbon emissions and avoiding the early corrosion, the geopolymer materials have been investigated to be a promising sustainable product for making building and construction materials such as concretes and fiber reinforced composites as well as fire resistant and industrial materials [21], [22]. Moreover, other advantageous attributes are covered by using the geopolymer as high compressive strengths, eminent chemical resistance, low permeability and high durability [19], [23]-[27]. While the aforementioned waste materials, i.e. blast furnace slag, fly ash and bottom ash, are mostly used for geopolymer concrete, calcined-clay mineral of kaolinite so-called metakaolin is also utilized based on the classification of calcium contents from low to high calcium in the geopolymer materials [23], [28], [29]. According to [24], Metakaolin-based Geopolymer Concrete (MGC) has higher durability and compressive strength than the OPC-based concrete, yet its manufacture is complicated. Meanwhile, the chemical reactions in the Slag-based Geopolymer Concrete (SGC) produce high strength and acid-resistant materials [30].

However, its process decreases the high temperature resistance and increases the creep-shrinkage deformation [31]. On the other side, the Fly Ash-based Geopolymer Concrete (FAGC) has more superiority including the better mechanical properties, good impermeability and smaller deformation than SGC [19] as well as simpler manufacturing processes than MGC [21]. Recently, using the specific mix design to obtain better workability, FAGC has been formulated to be Self-Compacting Geopolymer Concrete (SCGC) with maintaining the high compressive strength for structural retrofitting [32].

Moreover, other industrial waste materials so-called sugar cane bagasse ash could be used as supplementary cementitious materials in concrete manufacture [33].

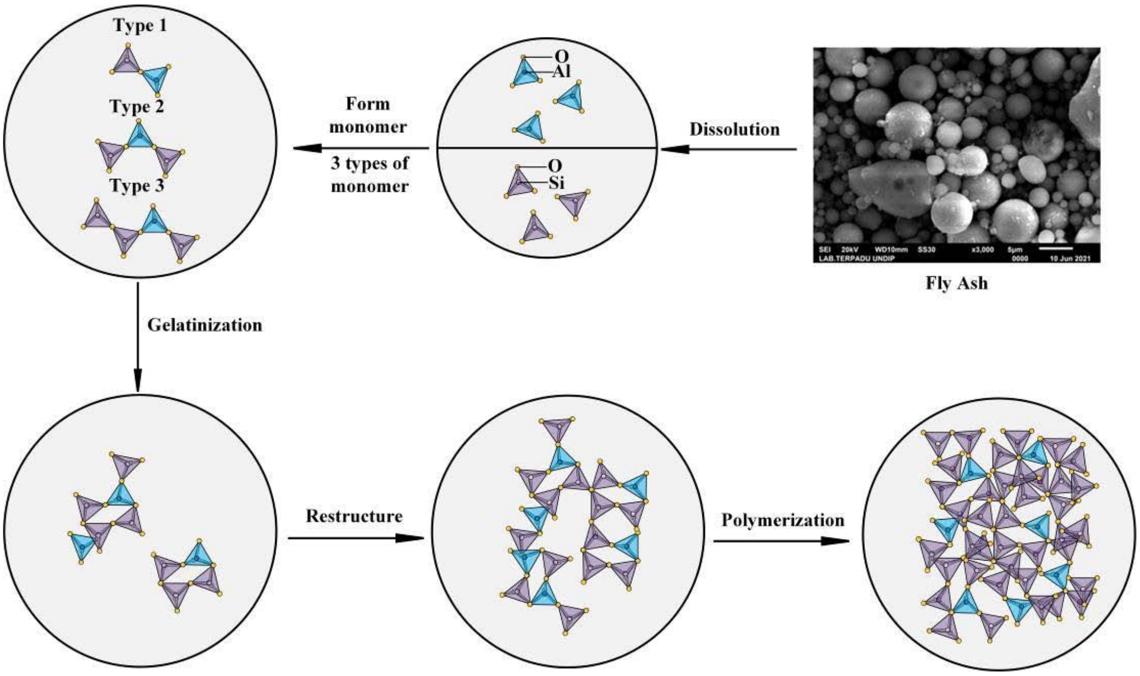


Fig. 2. Schematical process of polymerization [18]

In term of durability, the FAGC has good resistances to chemical compounds reacting in the environment during the building's service life. Two of them have been mentioned previously as chloride corrosion resistance [34]-[37] and acid resistance [38], [39]. Furthermore, the FAGC also has good resistances to sulfate [40]-[44] and carbonation [45]-[48]. Besides, the FAGC resists to freeze-thaw conditions under expansion and seepage pressure as well investigated in [49], [50]. Other feature contained in the FAGC is the composition of sodium aluminosilicate hydrate (N-A-S-H) gel rather than the calcium silicate hydrate (C-S-H) gel in the OPC-based concrete. The N-A-S-H gel has a pore filling effect, so that the porosity in the FAGC is reduced [51], [52]. Due to its filling effect into the pores, strong bonding between aggregate and paste namely the Interfacial Transition Zone (ITZ) in the FAGC is established. Hence, weak regions surrounding the aggregates barely exist [53].

Meanwhile, the high porosity of the OPC-based concrete causes high probability in damaging its structural integrity, particularly the emergence of microcracks around the ITZ, which eventually leads to the whole structural failure. By the aforementioned advantages, replacing entirely the OPC with the fly ash-based geopolymer material for concrete is highly recommended for sustainable civil engineering constructions in the future. Therefore, fly ash is selected herein rather than other waste materials as bottom ash or blast furnace slag to substitute the OPC in concrete structures. In overall aspects, the FAGC is promising to replace the existence of OPC-based concrete completely for construction and building materials due to great performance, excellent durability, and sustainability.

III. Experimental Work

The recent study of the FAGC is carried out experimentally starting from the analysis of its material properties including the aggregates, fly ash as a chemical binder and alkali activator employing the mixture of NaOH and Na_2SiO_3 with a specific ratio. Subsequently, the proportional mix design of the FAGC is varied to obtain a targeted compressive strength of 25 MPa for general structural concrete as well as good workability.

Thus, the FAGC is expected to be the Fly Ash-based Workable Geopolymer Concrete (FAWGC). The casting of concrete cylinders (diameter of 15 cm and height of 30 cm) for the FAWGC and the CC specimens as well as their curing are then conducted prior to the specimen testing at the specified age of 7 days, 14 days, 28 days, 56 days and 90 days. All the aspects of the experimental work are performed at the Material and Construction Laboratory, Department of Civil Engineering, Universitas Diponegoro, Semarang, Indonesia.

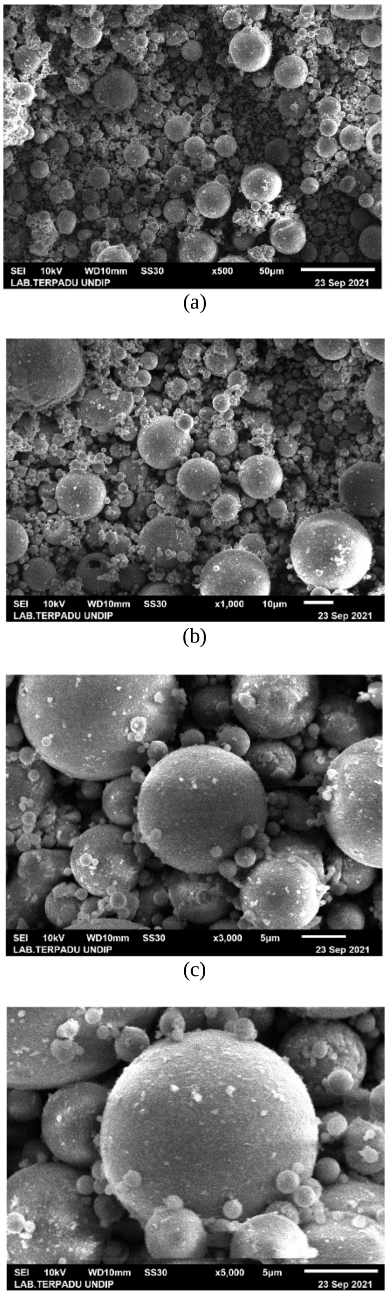
III.1. Material Properties of FAWGC

Prior to mixing the FAWGC materials, their properties have been analyzed including the specific gravity, mud level and sieve analysis of both fine and coarse aggregates such that all of them satisfy the standard specification for concrete aggregates according to the code [54].

The ideal gradation for aggregates is required to reduce the porosity of concrete materials with maximum coarse aggregate size of 10 mm, so that the expected compressive strength could be maintained. The aggregates used with good quality for this research are obtained from the local quarry. As mentioned previously, the FAWGC requires the chemical reaction from binder and its activator during the polymerization process involving the fly ash and alkali activator. Fly ash materials obtained from the quarry at the Tanjung Jati B Power Plant in Jepara, Indonesia are used herein. In order to ensure the fly ash employed is categorized as class F.

Two kinds of composition test are carried out, i.e. Scanning Electron Microscopy–Energy Dispersive X-Ray (SEM–EDX) and X-Ray Fluorescence (XRF). In SEM testing, the texture, the shape, and the size of a nanometer-scaled material sample are analyzed, whereas the material composition of a sample is quantitatively and qualitatively analyzed using the EDX. Meanwhile, the XRF test analyzes the chemical composition as well as the ingredient concentration contained in the material using the spectrometry method. The analysis results are shown in Table I and Table II for SEM–EDX and XRF, respectively, with the SEM display in Figs. 3 and the EDX graphic in Fig. 4. From the EDX results, the Tanjung Jati B fly ash could be classified as class F since the average of total sum of SiO_2, Al_2O_3 and FeO is 76.77%, which is larger than 70% as mandated in [19], while CaO is around 8%. Analogously, by the XRF analysis, the mean sum of the three components is 83.99% with around 8% of CaO. Indeed, the low calcium fly ash with less than 10% of CaO (class F) [19] results in high compressive strength as well as good durability as investigated in [44], [55]. Therefore, the fly ash class F from the Tanjung Jati B Power Plant is admissible to be used as the binder in the present FAWGC. In order to yield strong chemical reaction in the FAWGC, the alkali activator made by the mixture of sodium hydroxide (NaOH) and sodium metasilicate (Na_2SiO_3) with a specific ratio is implemented herein. The effect of NaOH solution with molarity between 8 M and 16 M to the compressive strength of the FAGC has been investigated [44], [55] concluding that the higher the molarity applied, the higher its compressive strength obtained.

Furthermore, the FAGC with 12 M of NaOH solution with Na_2SiO_3/NaOH ratio of 2.5 has the maximum compressive strength [56]-[58]. Thus, the 12 M of NaOH with the ratio of 1:2.5 between NaOH and Na_2SiO_3 is used for this experimental study. For Na_2SiO_3, the two types Be52 and Be58 are employed in this contribution in order to formulate the workable geopolymer concrete (FAWGC), where the texture of Be52 is more dilute than Be58. It should be noted that in this research, no superplasticizer is added to the geopolymer paste for obtaining the good workability of the FAGC.



(a)

(b)

(c)

(d)

Figs. 3. SEM analysis of Tanjung Jati B fly ash with the magnification of (a) ×500, (b) ×1000, (c) ×3000, (d) ×5000

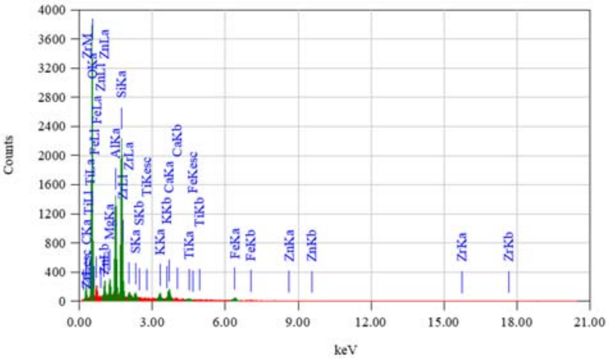


Fig. 4. EDX graphic of Tanjung Jati B fly ash

TABLE I

EDX ANALYSIS RESULTS OF TANJUNG JATI B FLY ASH

Components	Sample 1 [%]	Sample 2 [%]
MgO	2.75	2.52
Al_2O_3	19.50	18.45
SiO_2	40.58	40.22
SO_3	2.42	2.50
K_2O	2.31	2.36
CaO	5.68	7.16
C	8.54	8.55
FeO	11.54	18.24

TABLE II

XRF ANALYSIS RESULTS OF TANJUNG JATI B FLY ASH

Components	Sample 1 [%]	Sample 2 [%]
MgO	1.136	1.0641
Al_2O_3	16.159	16.1751
SiO_2	41.0993	40.9878
SO_3	1.4751	1.3962
K_2O	3.0186	2.9448
CaO	8.1477	8.1691
TiO2	1.5017	1.5961
Fe2O3	26.217	26.5587
Others	1.2457	1.108

Therefore, the mix combination of aggregates, binders, and alkali activators would determine the workable result yielding the FAWGC.

III.2. Mix Design of FAWGC

Since no available standardization of geopolymeric mix design, several variations of proportional mix design have been implemented by the ratio of aggregates: binder (including alkali activator) as 70% : 30%, 65% : 35% and 60% : 40% denoted as MD-1, MD-2 and MD-3, respectively.

These proportions have been similar to the ratio of aggregate : paste (cement and water) in the CC as controlled specimens. While the fixed ratio of coarse aggregates : fine aggregates has been taken as 60% : 40%, the fixed ratio between the binder (fly ash) and its activator has been 65% : 35%.

As mentioned previously, the activator itself had a ratio of NaOH: Na_2SiO_3 as 1 : 2.5 with 12 M of NaOH solution.

In order to examine the workability of the proposed FAWGC, the type Be52 and Be58 for Na_2SiO_3 have been employed with no added water for enhancing the workability. Furthermore, erroneous water proportion could increase the porosity and eventually decrease the concrete compressive strength. The summary of applied mix design is listed in Table III, where its normalized proportion for each variation can be seen in Table IV.

TABLE III

SUMMARY OF USED MIX DESIGN

Mix design components	Ratio
Aggregate : (binder + activator)	70% : 30%; 65% : 35%; 60% : 40%
Coarse aggregate : fine aggregate	60% : 40%
Binder (fly ash) : activator (NaOH + Na_2SiO_3)	65% : 35%
NaOH (12 M) : Na_2SiO_3	1 : 2.5

TABLE IV
NORMALIZED PROPORTION OF MIX DESIGN VARIATIONS

Ingredients	MD-1	MD-2	MD-3
Coarse aggregate	42%	39%	36%
Fine aggregate	28%	26%	24%
Binder (fly ash)	19.5%	22.75%	26%
NaOH (12 M)	3%	3%	4%
Na_2SiO_3	7.5%	8.75%	10%
Total	100%	100%	100%

In order to control the proposed FAWGC, the CC specimens have been also prepared with the proportional mix design variations similar to that of the FAWGC.

Components of binder and activator in the FAWGC have been replaced by the cement paste (cement and water).

Here, no superplasticizer has been added to the mix design in order to improve the workability. Moreover, the slump test for both the FAWGC and the CC has been conducted in order to investigate the workability.

III.3. Curing Method

According to numerous previous investigations [17], [34]-[36], [38], [44], [49], [55], [59]-[62], curing methods for the FAGC have been mostly heat cured using dry oven at high temperatures varying from 40 °C to 95 °C.

This method has not been straightforward to be carried out and it has been expensive since this condition requires high-cost curing apparatus. Indeed, curing at high temperatures yields the high compressive strength of the FAGC.

However, the general curing condition for the FAWGC cylindrical specimens in this contribution has been performed similar to the curing method for the CC using only wet gunny bags at the room temperature. By this curing method, the higher compressive strength of the low cost FAWGC has been expected than the one of the CC.

III.4. Testing Methods

The curing condition has been carried out after the specimens have been released from the cylindrical molds up to one day prior to testing. Here, the compressive strengths of the FAWGC specimens have been investigated at the age of 7 days, 14 days, 28 days, 56 days and 90 days.

In addition, the modulus of elasticity and the Poisson's ratio of the FAWGC have been also examined.

Figs. 5(a) and (b) depict the compressive test and the modulus of elasticity (as well as the Poisson's ratio) test set-up, respectively, using the computer-controlled compression testing machine connected to the data logger.

In order to record displacements and strains of the test specimen, the Linear Vertical Displacement Transducer (LVDT) and the strain gauge have been installed, respectively. Furthermore, two layers of Teflon have been utilized at the top and the bottom cylinder specimen in order to reduce confinement effects from the loading platens.

(a)

(b)

Figs. 5. FAWGC test set-up: (a) compressive test, (b) modulus of elasticity and Poisson's ratio test

IV. Results and Discussion

After cured at the specified age, the cylinder specimens have been compressively tested with six specimens for each age of the respective mix design. The compressive strength at 7, 14, 28, 56 and 90 days have been recorded, while the modulus of elasticity and the Poisson's ratio have been investigated only at the concrete age of 90 days. These tests have been performed to both the FAWGC and the CC. In order to identify both the FAWGC and the CC for each mix design variation, all the specimens have been recognized as FAWGC-1, FAWGC-2 and FAWGC-3 for MD-1, MD-2 and MD-3, respectively, as well as CC-1, CC-2 and CC-3 for the mix design variations of the CC with respect to the corresponding FAWGC mix design.

IV.1. Slump of FAWGC

Since the workability of concrete is one of the issues investigated in the present experimental study, the vertical slump test for both the FAWGC and the CC has been carried out using the Abrams cone prior to molding the concrete mixes. Table V summarizes the results of the slump test for both concretes of each mix design. As can be seen in the table, quite good workability has been obtained using Na_2SiO_3 type Be52 since its texture is more dilute than Na_2SiO_3 type Be58. While slump values of Be52 have varied between 120 mm and 160 mm, the slump values of Be58 have been all zero. It means that the

FAWGC mix using Na_2SiO_3 type Be58 is not workable. Either superplasticizer or water should be added into the mix for enhancing the workability.

However, this effort would decrease the concrete compressive strength. Due to these results, the FAWGC mix design using Na_2SiO_3 type Be58 is not recommended to be selected, even though the compressive strengths have been quite high similar to the one of using Na_2SiO_3 type Be52. From Table V, the specimen coded FAWGC-3 had the highest slump values among others, since the proportion of alkali activator has been the highest among the three mixes. Similarly, as displayed in Table VI, the highest water proportion in the CC-3 mix yields the highest slump values. Indeed, the amount of either activator or water would eventually influence the concrete strength.

IV.2. Compressive Strength of FAWGC

As mentioned before, all the specimens of both the FAWGC and the CC have been compressively tested at the age of 7, 14, 28, 56, and 90 days using the compression apparatus.

Then the maximum load obtained by this testing has been converted to the compressive strength f_c' listed in Table VII and plotted as a graphic showed the relation between the strength versus the tested age for the FAWGC using Be52 and the CC depicted in Fig. 6 and Fig. 7, respectively.

TABLE V
FAWGC VERTICAL SLUMP VALUES

Specimen code	Average slump values [mm]	
	Be52	Be58
FAWGC-1	221.7	0
FAWGC-2	275.0	0
FAWGC-3	285.0	0

TABLE VI
CC VERTICAL SLUMP VALUES

Specimen code	Average slump values [mm]
CC-1	166.7
CC-2	235.0
CC-3	270.0

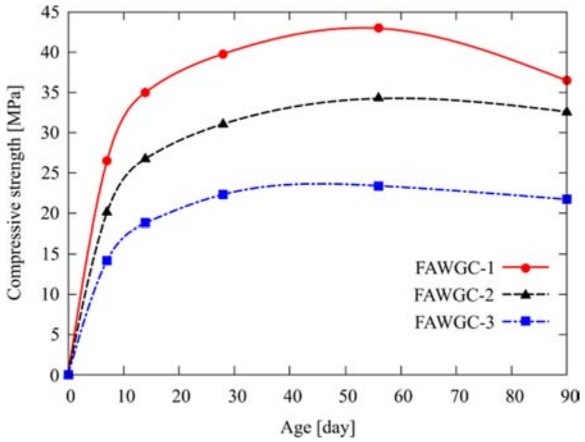


Fig. 6. FAWGC strength with respect to tested age

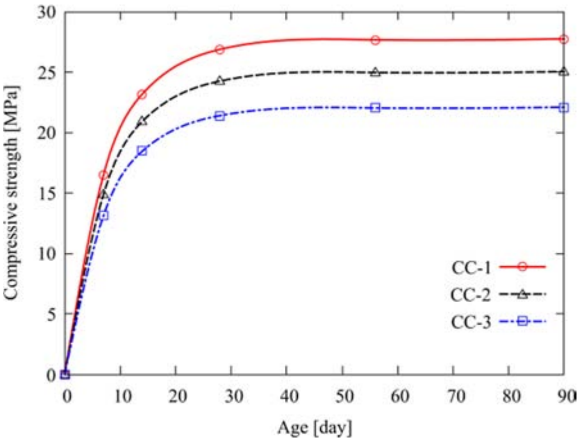


Fig. 7. CC strength with respect to tested age

TABLE VII
SUMMARY OF COMPRESSIVE STRENGTH FOR EACH TESTED AGE

Specimen code	Average compressive strength f_c' [MPa]				
	7 days	14 days	28 days	56 days	90 days
FAWGC-1	26.43	34.86	39.76	42.93	36.42
FAWGC-2	20.06	26.75	31.06	34.22	32.57
FAWGC-3	14.15	18.77	22.31	23.38	21.69
CC-1	16.50	23.19	26.88	27.67	27.75
CC-2	14.89	20.93	24.26	24.97	25.04
CC-3	13.14	18.47	21.41	22.04	22.10

From Fig. 6, it can be concluded that the maximum strength for the FAGC occurs at the age of 56 days, whereas its strength decreases at the age of 90 days. This phenomenon is in contrast to the compressive strength of the CC, which slightly increases after the age of 28 days as seen in Fig. 7. Fig. 8 shows the compressive strength comparison between the FAWGC and the CC for all the mix design variations. By comparing the FAWGC and the CC strength for the similar variations, for instance FAWGC-1 with CC-1, the strength increases of 37%, 43%, 48%, 57% and 32% for the geopolymer concrete occurred at the age of 7, 14, 28, 56 and 90 days, respectively. While 21%, 24%, 28%, 38% and 31% of the compressive strength have increased for FAWGC-2 with respect to CC-2, the very low increase of strength has occurred for FAWGC-3 with respect to CC-3 as only 5%, 1%, 4% and 6% at 7, 14, 28 and 56 days, respectively. Nevertheless, at 90 days, the strength of FAWGC-3 has even decreased as 2% compared to CC-3.

By these results, the FAWGC mix design with composition 70% : 30% for aggregates : binder (including alkali activator) or MD-1 has yielded the highest compressive strength among others. All these results have been obtained using Na_2SiO_3 type Be52 for being more workable than Na_2SiO_3 type Be58 as investigated previously in terms of slump value.

IV.3. Stress-Strain Relationship

In order to record strains and displacements, strain gauges and LVDTs for both vertical and horizontal directions have been installed on the three tested specimens for each mix design variation.

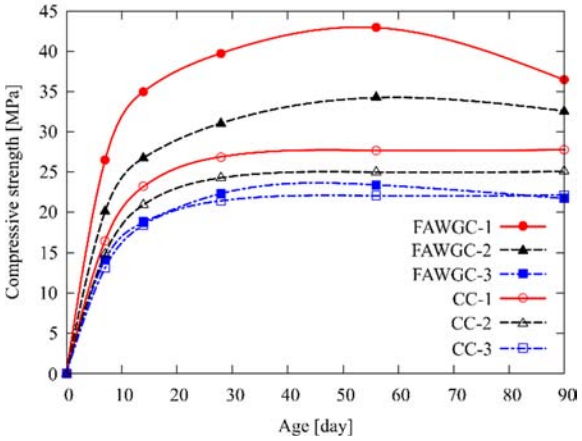


Fig. 8. Strength comparison between FAWGC and CC

For stresses, the applied load read by the load cell has been converted to the resulting stresses. Hence, the stress-strain relationship of the proposed FAWGC could be plotted. Fig. 9 shows the stress-strain curves for the three specimens with MD-1 denoted as FAWGC-1a, FAWGC-1b and FAWGC-1c. Moreover, in a similar condition, the stress-strain relationship has been also obtained from the other two mix design variations.

However, for instance, only the FAWGC-1 results are displayed in Fig. 9. Furthermore, the results for all three-mix design of MD-1, MD-2 and MD-3 have been averaged then plotted in terms of the stress and strain values in a diagram as seen in Fig. 10. Based on Fig. 10, the stress-strain relationships for different mix design of MD-1, MD-2 and MD-3 are obtained. Clearly, the FAWGC-1 has the highest maximum stress among others. In order to create the stress-strain curve for general geopolymer concrete, the obtained stress and strain in Fig. 10 should be normalized by dividing the current stress (σ_c) with respect to the maximum strength (f_c') and the current strain (ε_c) with respect to the strain at the maximum strength $\left(\varepsilon_{f_c'}\right)$ for Y and X axes, respectively. Hence, the normalized stress-strain curve is depicted in Fig. 11. By using the similar way, the normalized stress-strain curve for conventional concrete is obtained as well.

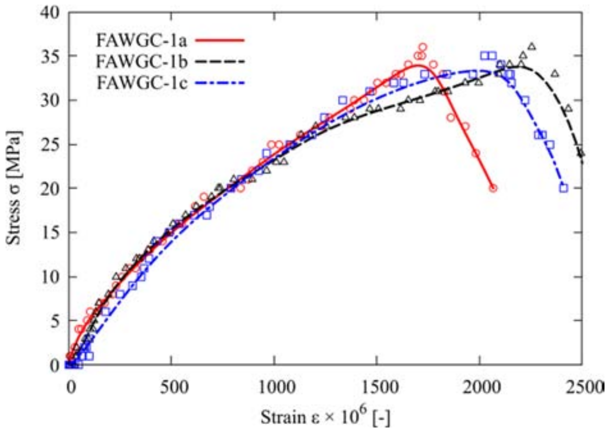


Fig. 9. Stress-strain relationship of FAWGC-1 for three specimens

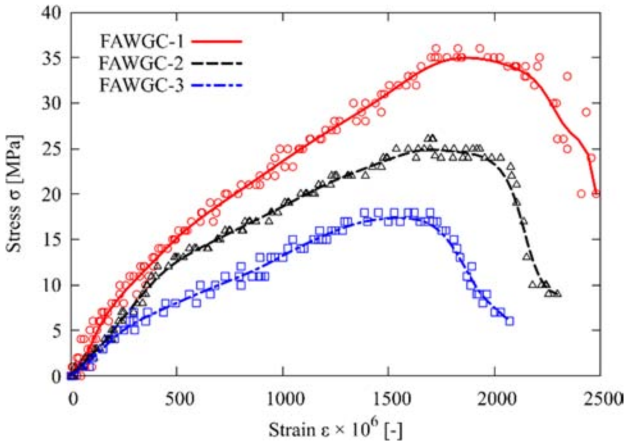


Fig. 10. Stress-strain relationship of FAWGC for different mix design

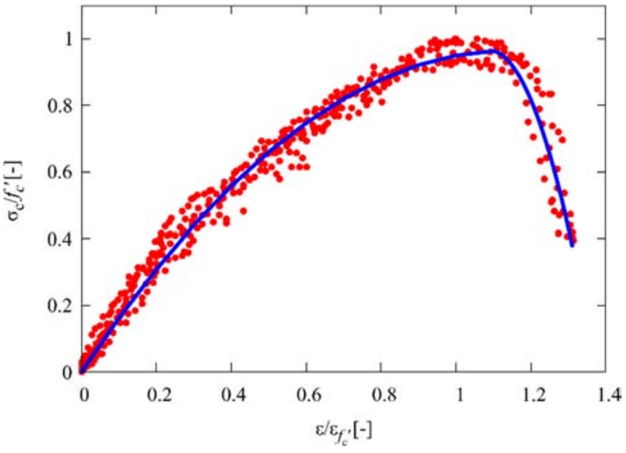


Fig. 11. Normalized stress-strain relationship of geopolymer concrete

The trend of the proposed geopolymer curve and the controlled conventional concrete are plotted in a diagram with other renowned concrete models, i.e. *fib* Model Code [63] and the oldest model introduced by Hognestad [64] as displayed in Fig. 12. From the figure, the geopolymer concrete (FAWGC) has a higher compressive strength than the conventional concrete of all models, while the CC curve is slightly underestimated compared to both the *fib* Model Code and the Hognestad Model.

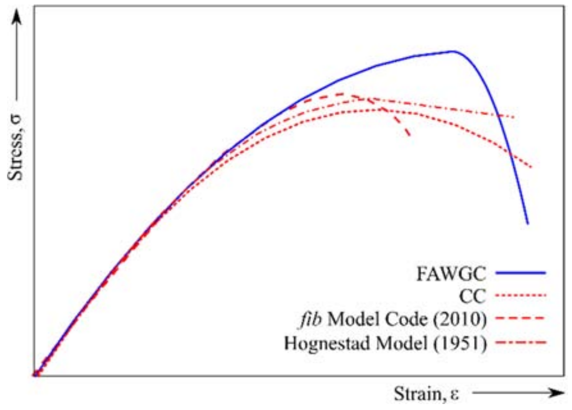


Fig. 12. The proposed stress-strain curve of geopolymer concrete compared to other models of conventional concrete

IV.4. Modulus of Elasticity and Poisson's Ratio

As can be seen in Fig. 12, a quite similar modulus of elasticity (E) for all the stress-strain curves can be found.

Nevertheless, the proposed FAWGC has a slightly higher E than the normal concrete. The modulus of elasticity for concrete materials is computed at its elastic region, approximately 40% of its maximum strength. By using Fig. 11, the following equations are obtained:

$$\frac{\sigma_c}{f_c'} = 0.4 \quad \Rightarrow \quad \sigma_c = 0.4 f_c' \tag{1}$$

$$\frac{\varepsilon_c}{\varepsilon_{f_c'}} = 0.27 \quad \Rightarrow \quad \varepsilon_c = 0.27\varepsilon_{f_c'} \tag{2}$$

Meanwhile, the maximum strength f_c' obtained experimentally is 36.25 MPa with the corresponding strain $\varepsilon_{f_c'}$ is 0.00182626. By utilizing Equations (1) and (2), σ_c and ε_c are 14.5 MPa and 0.000493, respectively.

Then the modulus of elasticity E_c is simply computed as follows:

$$E_c = \frac{\sigma_c}{\varepsilon_c} \tag{3}$$

so that the value of E_c is 29,411.76 MPa. In order to obtain the relation between the modulus of elasticity and the compressive strength mathematically, the following equation is generally used:

$$E_c = x\sqrt{f_c'} \tag{4}$$

Substituting E_c= 29,411.76 MPa and f_c' = 36.25 MPa to Equation (4) yields x = 4884.86. Thus, Equation (4) becomes:

$$E_c = 4884.86\sqrt{f_c'} \tag{5}$$

The proposed Equations (5) could be utilized for computing the modulus of elasticity of geopolymer concrete if the compressive strength is known. This formula is slightly different compared to the identical formula in the code for conventional concrete as $E_c = 4700\sqrt{f_c'}$. By this investigation result, it can be concluded that the modulus of elasticity for geopolymer concrete is slightly higher than the modulus of elasticity for conventional concrete. This contribution has also investigated the Poisson's ratio ν of the FAWGC using the strain gauge's reading experimentally as mentioned before. It is obtained by computing the ratio of the lateral strain ε_x to the longitudinal strain ε_y as follows:

$$\nu = \frac{\varepsilon_x}{\varepsilon_y} \tag{6}$$

where the recorded average ε_x and ε_y have been 0.0003485 and 0.0001725, so that the average value of ν for the proposed FAWGC has been obtained as 0.202.

This value is quite similar to the Poisson's ratio of the common conventional concrete as 0.2. By this investigation, it can be concluded that the Poisson's ratio for the geopolymer concrete is similar to the normal concrete.

V. Conclusion

This research work has investigated the mix design formulations of Fly Ash-based Geopolymer Concrete (FAGC) using three different variations of aggregates : binder (including alkali activator) compositions as 70% : 30%, 65% : 35% and 60% : 40% proportional to the Conventional Concrete (CC) mix. The fixed proportion of coarse aggregate : fine aggregate as 60% : 40%, binder : alkali activator as 65% : 35% and NaOH 12M : Na_2SiO_3 as 1 : 2.5 have been implemented herein.

General curing method using wet gunny bags for the FAGC has been applied similarly to the one of the CC in order to reduce the curing cost with very straightforward method. Results of slump test investigation have been that the use of Na_2SiO_3 type Be52 has yielded the Fly Ash-based Workable Geopolymer Concrete (FAWGC) compared to the use of Na_2SiO_3 type Be58. Around 120 to 160 mm of slump value for Be52 has been obtained, while Be58 has resulted in zero slump value, which has not been workable. In terms of compressive strengths, the mix design of 70% : 30% for aggregates : binder and alkali activator has yielded the highest strength among others beyond 40 MPa, exceeding the targeted compressive strength of 25 MPa for the general building structure. The maximum strength of geopolymer concrete has been achieved at 56 days, whereas it has decreased toward 90 days. In fact, the normal curing method at room temperature could produce high strength geopolymer concrete, without the need to use the special treatment as heat cured with high temperatures. The stress-strain relationship of the FAWGC has been obtained. The modulus of elasticity for the FAWGC has been higher than the one of the CC for similar mix design proportion. Using the specific formula, the relation between the modulus of elasticity and the compressive strength for the FAWGC could be obtained as in the standard code for the CC. Moreover, the Poisson's ratio of the FAWGC is quite similar to the CC with the value around 0.20. Overall, the proposed FAWGC is promising for replacing the CC in building materials for sustainable purposes. Future works for self-compacting fly ash-based geopolymer concrete are going to be investigated with the application in structural strengthening, retrofitting, or repair.

Acknowledgements

The authors gratefully acknowledge the financial support of the World Class Research funding by Universitas Diponegoro through the decreed number 11-

20/UN7.6.1/PP/2021.

References

[1] M. Schneider, M. Romer, M. Tschudin, H. Bolio, Sustainable cement production – present and future, *Cement and Concrete Research,* Vol. 41 : 642-650, 2011.

[2] I. Amato, Green cements : Concrete colutions, *Nature,* Vol. 494 : 300-301, 2013.

[3] M. B. Ali, R. Saidur, M. S. Hossain, A review on emission analysis in cement industries, *Renewable and Sustainable Energy Reviews,* Vol. 15 : 2252–2261, 2011.

[4] W. Shen, Y. Liu, B. Yan, J. Wang, P. He, C. Zhou, X. Huo, W. Zhang, G. Xu, Q. Ding, Cement industry of china: Driving force, environment impact and sustainable development, *Renewable and Sustainable Energy Reviews,* Vol. 75 : 618–628, 2017.

[5] M. Uwasu, K. Hara, H. Yabar, World cement production and environmental implications, *Environmental Development,* Vol. 10: 36–47, 2014.

[6] J. Li, P. Tharakan, D. Macdonald, X. Liang, Technological, economic and financial prospects of carbon dioxide capture in the cement industry, *Energy Policy,* Vol. 61 : 1377–1387, 2013.

[7] K. Vatopoulos, E. Tzimas, Assessment of CO_2 capture technologies in cement manufacturing process, *Journal of Cleaner Production,* Vol. 32 : 251–261, 2012.

[8] ASTM C618–19, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete* (ASTM International, 2019).

[9] Y. Huang, M. Han, The influence of α-Al_2O_3 addition on microstructure, mechanical and formaldehyde adsorption properties of fly ash-based geopolymer products, *Journal of Hazardous Materials,* Vol. 193 : 90-94, 2011.

[10] K. Pimraksa, P. Chindaprasirt, A. Rungchet, K. Sagoe-Crentsil, T. Sato, Lightweight geopolymer made of highly porous siliceous materials with various Na_2O/Al_2O_3 and SiO_2/Al_2O_3 ratios, *Materials Science and Engineering,* Vol. A 528 : 6616-6623, 2011.

[11] D. Feng, J.L. Provis, J.S.J. van Deventer. Thermal activation of albite for the synthesis of one-part mix geopolymers, *Journal of the American Ceramic Society,* Vol. 95 : 565-572, 2012.

[12] J. Davidovits, Chemistry of Geopolymeric Systems Terminology, *Proceedings of the International Conference on Geopolymers,* pp. 9-40, France, 1999.

[13] H. Xu, J.S.J. van Deventer, The geopolymerisation of alumino-silicate minerals, *International Journal of Mineral Processing, Vol.* 59 : 247-266, 2000.

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

[15] J. Davidovits, 30 years of successes and failure in geopolymer applications: Market trends and potential breakthroughs, *Proceedings of the Geopolymer Conference,* Australia, 2002.

[16] J. Davidovits, *Geopolymer Chemistry and Applications,* 5th Edition (Geopolymer Institute, Saint-Quentin, France, 2020).

[17] A. Palomo, M.W. Grutzeck, M.T. Blanco, Alkali-activated fly ashes: A cement for the future, *Cement and Concrete Research,* Vol. 29 : 1323-1329, 1999.

[18] Dawood, E., Mohammed, W., Characteristics of Green Mortar Containing Fly Ash with the Addition of Different Plasticizers, (2021) *International Review of Civil Engineering (IRECE),* 12 (3), pp. 167-175.
doi: https://doi.org/10.15866/irece.v12i3.19541

[19] Q. Fu, W. Xu, X. Zhao, M. Bu, Q. Yuan, D. Niu, The microstructure and durability of fly ash-based geopolymer concrete: A review, *Ceramics International,* Vol. 47 : 29550–29566, 2021.

[20] J. Davidovits, J.L. Sawyer, *Early high-strength mineral polymer,* US Patent No. US4509985A, 1985.

[21] B. Singh, G. Ishwarya, M. Gupta, S.K. Bhattacharyya, Geopolymer concrete: A review of some recent developments, *Construction and Building Materials,* Vol. 85 : 78-90, 2015.

[22] Formisano, A., Galzerano, B., Durante, M., Marino, O., Liguori, B., Mechanical Response of Short Fiber Reinforced Fly Ash Based Geopolymer Composites, (2018) *International Review of Mechanical Engineering (IREME),* 12 (6), pp. 485-491.
doi: https://doi.org/10.15866/ireme.v12i6.14826

[23] P. Duxson, A. Fernández-Jiménez, J.L. Provis, G.C. Lukey, A. Palomo, J.S.J. van Deventer, Geopolymer technology: the current state of the art, *Journal of Material Science,* Vol. 42 : 2917-2933, 2007.

[24] C. Li, H. Sun, L. Li, A review: The comparison between alkali-activated slag (Si + Ca) and metakaolin (Si + Al) cements, *Cement and Concrete Research,* Vol. 40 : 1341-1349, 2010.

[25] J. Davidovits, Geopolymers: inorganic polymeric new materials, *Journal of Thermal Analysis,* Vol. 37 : 1633-1656, 1991.

[26] Salih, M., Ahmed, S., Mix Design for Sustainable High Strength Concrete by Using GGBS and Micro Silica as Supplementary Cementitious Materials, (2020) *International Review of Civil Engineering (IRECE),* 11 (1), pp. 45-51.
doi: https://doi.org/10.15866/irece.v11i1.17784

[27] Alwash, M., Alwash, J., Jassim, H., Impact of Different Curing Techniques on Some Mechanical Properties of Self-Compacting Concrete Containing Silica Fume, (2022) *International Review of Civil Engineering (IRECE),* 13 (3), pp. 208-215.
doi:https://doi.org/10.15866/irece.v13i3.21494

[28] B. Lothenbach, K. Scrivener, R.D. Hooton, Supplementary cementitious materials, *Cement and Concrete Research,* Vol. 41 : 1244-1256, 2011.

[29] T. Luukkonen, Z. Abdollahnejad, J. Yliniemi, P. Kinnunen, M. Illikainen, One-part alkali-activated materials: A review, *Cement and Concrete Research,* Vol. 103 : 21-34, 2018.

[30] J.L. Provis, J.S.J. van Deventer, *Geopolymers: Structure, Processing, Properties and Application* (Woodhead Publishing Limited, Cambridge, England, 2009).

[31] C.D. Atiş, C. Bilim, Ö. Çelik, O. Karahan, Influence of activator on the strength and drying shrinkage of alkali-activated slag mortar, *Construction and Building Materials,* Vol. 23 : 548-555, 2009.

[32] Purwanto, P., Han, A., Ekaputri, J., Nuroji, N., Prasetya, B., Self-Compacting-Geopolymer-Concrete (SCGC) Retrofitted Haunch, (2021) *International Journal on Engineering Applications (IREA),* 9 (4), pp. 180-189.
doi: https://doi.org/10.15866/irea.v9i4.20652

[33] Mangi, S., Memon, Z., Khahro, S., Memon, R., Memon, A., Potentiality of Industrial Waste as Supplementary Cementitious Material in Concrete Production, (2020) *International Review of Civil Engineering (IRECE),* 11 (5), pp. 214-221.
doi: https://doi.org/10.15866/irece.v11i5.18779

[34] C. Gunasekara, D. Law, S. Bhuiyan, S. Setunge, L. Ward, Chloride induced corrosion in different fly ash based geopolymer concretes, *Construction and Building Materials,* Vol. 200 : 502-513, 2019.

[35] K. Kupwade-Patil, E.N. Allouche, Examination of chloride-induced corrosion in reinforced geopolymer concretes, *Journal of Materials in Civil Engineering,* Vol. 25 (Issue 10) : 1465-1476, 2013.

[36] A. Noushini, A. Castel, J. Aldred, A. Rawal, Chloride diffusion resistance and chloride binding capacity of fly ash-based geopolymer concrete, *Cement and Concrete Composites,* Vol. 105 : 103290, 2020.

[37] T. Yang, X. Yao, Z. Zhang, Quantification of chloride diffusion in fly ash–slag-based geopolymers by X-ray fluorescence (XRF), *Construction and Building Materials, Vol. 69 : 109-115, 2014.*

[38] T. Bakharev, Resistance of geopolymer materials to acid attack, *Cement and Concrete Research,* Vol. 35 (Issue 4) : 658-670, 2005.

[39] M.A.M. Ariffin, M.A.R. Bhutta, M.W. Hussin, M.M. Tahir, N. Aziah, Sulfuric acid resistance of blended ash geopolymer concrete, *Construction and Building Materials,* Vol. 43 : 80-86, 2013.

[40] T. Bakharev, Durability of geopolymer materials in sodium and magnesium sulfate solutions, *Cement and Concrete Research,* Vol. 35 (Issue 6) : 1233-1246, 2005.

[41] M.A.R. Bhutta, W.M. Hussin, M. Azreen, M.M. Tahir, Sulphate resistance of geopolymer concrete prepared from blended waste fuel ash, *Journal of Materials in Civil Engineering,* Vol. 25 (Issue 10) : 1465-1476, 2013.

[42] I. Ismail, S.A. Bernal, J.L. Provis, S. Hamdan, J.S.J. van Deventer, Microstructural changes in alkali activated fly ash/slag geopolymers with sulfate exposure, *Materials and Structures,* Vol. 46 : 361-373, 2013.

[43] H.E. Elyamany, A.E.M.A. Elmoaty, A.M. Elshaboury, Magnesium sulfate resistance of geopolymer mortar, *Construction and Building Materials,* Vol. 184 : 111-127, 2018.

[44] D. Hardjito, S.E. Wallah, D.M.J. Sumajouw, B.V. Rangan, On the development of fly ash-based geopolymer concrete, *ACI Materials Journal,* Vol. 101 : 467-472, 2004.

[45] S.A. Bernal, J.L. Provis, B. Walkley, R.S. Nicolas, J.D. Gehman, D.G. Brice, A.R. Kilcullen, P. Duxson, J.S.J. van Deventer, Gel nanostructure in alkali-activated binders based on slag and fly ash, and effects of accelerated carbonation, *Cement and Concrete Research,* Vol. 52 : 127-144, 2013.

[46] Z. Li, S. Li, Carbonation resistance of fly ash and blast furnace slag based geopolymer concrete, *Construction and Building Materials,* Vol. 163 : 668-680, 2018.

[47] K. Pasupathy, M. Berndt, A. Castel, J. Sanjayan, R. Pathmanathan. Carbonation of a blended slag-fly ash geopolymer concrete in field conditions after 8 years, *Construction and Building Materials,* Vol. 125 : 661-669, 2016.

[48] M.S. Badar, K. Kupwade-Patil, S.A. Bernal, J.L. Provis, E.N. Allouche, Corrosion of steel bars induced by accelerated carbonation in low and high calcium fly ash geopolymer concretes, *Construction and Building Materials,* Vol. 61 : 79-89, 2014.

[49] R. Zhao, Y. Yuan, Z. Cheng, T. Wen, J. Li, F. Li, Z.J. Ma, Freeze-thaw resistance of Class F fly ash-based geopolymer concrete, *Construction and Building Materials,* Vol. 222 : 474-483, 2019.

[50] M. Zhao, G. Zhang, K.W. Htet, M. Kwon, C. Liu, Y. Xu, M. Tao, Freeze-thaw durability of red mud slurry-class F fly ash-based geopolymer: Effect of curing conditions, *Construction and Building Materials,* Vol. 215 : 381-390, 2019.

[51] Z. Zhang, J.L. Provis, A. Reid, H. Wang, Fly ash-based geopolymers: The relationship between composition, pore structure and efflorescence, *Cement and Concrete Research,* Vol. 64 : 30-41, 2014.

[52] Y. Ma, J. Hu, G. Ye, The pore structure and permeability of alkali activated fly ash, *Fuel,* Vol. 104 : 771-780, 2013.

[53] W.K.W. Lee, J.S.J. van Deventer, The interface between natural siliceous aggregates and geopolymers, *Cement and Concrete Research,* Vol. 34 (Issue 2) : 195-206, 2004.

[54] ASTM C33, *Standard Specification for Concrete Aggregates* (ASTM International, 2013).

[55] D. Hardjito, B.V. Rangan, *Development and properties of low-calcium fly ash-based geopolymer concrete,* Research Report-GC1, Curtin University of Tecnology, Perth, Australia, 2005.

[56] M.M.A. Abdullah, H. Kamarudin, H. Mohammed, I.K. Nizar, A.R. Rafiza, Y. Zarina, The relationship of NaOH molarity, Na_2SiO_3/NaOH ratio, fly ash/alkaline activator ratio, and curing temperature to the strength of fly ash-based geopolymer, *Advanced Materials Research,* Vol. 328-330 : 1475-1482, 2011.

[57] A.M.M. Al Bakri, H. Kamarudin, I.K. Nizar, M. Binhussain, Y. Zarina, A.R. Rafiza, Correlation between Na_2SiO_3/NaOH ratio and fly ash/alkaline activator ratio to the strength of geopolymer, *Advanced Materials Research,* Vol. 341-342 : 189-193, 2012.

[58] A.M.M. Al Bakri, H. Kamarudin, I.K. Nizar, A.V. Sandu, M. Binhussain, Y. Zarina, A.R. Rafiza, Design, processing and characterization of fly ash-based geopolymers for lightweight concrete application, *Revista de Chimie,* Vol. 64 (Issue 4) : 382-387, 2013.

[59] J. Temuujin, A. Minjigmaa, B. Davaabal, U. Bayarzul, A. Ankhtuya, T. Jadambaa, K.J.D. MacKenzie, Utilization of radioactive high-calcium Mongolian fly ash for the preparation of alkali-activated geopolymers for safe use as construction materials, *Ceramics International,* Vol. 40 (Issue 10) : 16475-16483, 2014.

[60] M.Z. Lakhssassi, S. Alehyen, M. El Alouani, M. Taibi, The effect of aggressive environments on the properties of a low calcium fly ash based geopolymer and the ordinary Portland cement pastes, *Materials Today: Proceedings,* Vol. 13 (Issue 3) : 1169-1177, 2019.

[61] D.S. Perera, O. Uchida, E.R. Vance, K.S. Finnie, Influence of curing schedule on the integrity of geopolymers, *Journal of Material Sciences,* Vol. 42 : 3099-3106, 2007.

[62] J.G.S. van Jaarsveld, J.S.J. van Deventer, G.C. Lukey, The effect of composition and temperature on the properties of fly ash- and kaolinite-based geopolymers, *Chemical Engineering Journal,* Vol. 89 : 63-73, 2002.

[63] Federation Internationale du Beton (fib), *Model Code for Concrete Structures* (Ersnt & Sohn A Wiley Brand, 2010).

[64] E. Hognestad, *A Study of Combined Bending and Axial Load in Reinforced Concerete Members* (University of Illnois Engineering Experiment Station Bulletin Series No. 399, 1951).

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