INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 14 NO. 1 (2023) 48-56

© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Effect of Alkali Activator Ratio on Mechanical Properties Geopolymer Concrete Based on Ground Granulated Blast Furnace Slag

Angelina Eva Lianasari[1*], Naufal Muhammad Syafig[1]

[1]Universitas Atma Jaya Yogyakarta, Yogyakarta, 55281, INDONESIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2023.14.01.006
Received 02 August 2022; Accepted 07 February 2023; Available online 14 February 2023

Abstract: Cement is the primary material of concrete. In the calcination process during cement manufacturing, 0.869 tons of CO2 gas are produced for every 1 ton of clinker. That process affects global climate change. This condition causes a new technology called geopolymer concrete. Geopolymer concrete substitutes cement with material that reacts in an alkali activator. PT Krakatau Steel in West Java, manufacturing iron steel with a blast furnace, produces large quantities of waste (slag) of 80 tons/hour. The blast furnace slag contains SiO_2 and Al_2O_3 is called GGBFS (Ground Granulated Blast Furnace Slag). GGBFS can react with an alkali activator, which can be a substitute cement. This research was carried out using GGBFS as a base for geopolymer concrete. This research wants to know the effect of the alkali activator ratio on the mechanical properties of geopolymer concrete based on GGBFS. The concrete specimen was made with ratios alkali activator of 5:2, 4:2, and 3:2. The alkaline liquids used in this research are sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) with a concentration of 8M. The curing process in this experiment is about 24-hour dry curing at a temperature of 60°C. The mechanical properties of concrete showed that 5:2 obtained the highest compressive strength, 57.65 MPa (at 7 days) and 58.48 MPa (at 28 days), and modulus elasticity was 31815.92 MPa, split tensile strength was 2.74 MPa, and modulus of rupture was 3.87 MPa.

Keywords: Geopolymer concrete, Ground Granulated Blast Furnace Slag

1. Introduction

Infrastructure development increased the use of concrete materials. That condition increased cement consumption because cement is the primary component of concrete. The cement manufacturing process caused 0.869 tons of CO_2 gas for every ton of clinker during the calcination. Thus, cement contributes to environmental contamination for 8% of worldwide CO_2 emissions and affects global climate change. Some concrete technologies are used to minimize the consumption of cement. Cement substitute materials must have precise amounts of SiO_2 and Al_2O_3, including fly ash, kaolin, slag, zeolite, and rice husk ash, among others frequently referred to as pozzolanic materials. Substituting cement using pozzolanic materials as a composite concrete material can be done partially or totally. It has often been practiced to replace cement with pozzolanic materials partially. Geopolymer concrete replaces all cement with pozzolanic materials. The cement hardening process in geopolymer concrete is replaced with a pozzolan polymerization reaction aided by an activator. Geopolymer concrete is recognized as a "green" material with less CO_2 emission and less energy consumption than the widely used Portland cement (PC) concrete.

---

*Corresponding author: eva.lianasari@uajy.ac.id

Geopolymer concrete requires an alkaline activator as a pozzolanic reagent so that the hardening process occurs after the polymerization reaction. The qualities of geopolymer concrete (setting time and mechanical properties) are significantly impacted by the cement substitute ingredients' physical, pH value, and chemical content. The polymerization reaction is sensitive to different raw materials (particle size, distribution particle, crystallization degree), different alkali-activators (Sodium/potassium hydroxide, Sodium/potassium silicate, and the ratio of these two), different Si/Al ratios, different water/ash ratios, different curing conditions (temperature, moisture degree, curing time). In this geopolymer concrete research, sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) were used as alkali activators, and the pozzolanic material was waste slag from PT. Krakatau Steel (Ground Granulated Blast Furnace Slag/GGBFS).

Ground Granulated Blast Furnace Slag/GGBFS used in this experiment, is a waste material of the iron/steel manufacturing process. GGBFS is a wasted material from PT Krakatau Steel. GGBFS is produced by heating iron ore, limestone, and coke to 1500ºC. This process transpires in a blast furnace, resulting in slag/liquid slag and molten iron formation. SiO_2, Al_2O_3, and some oxides are present in liquid slag. Then, slag is granulated by cooling. Granules are dried and crushed to a fine powder. Ground Granulated Blast Furnace Slag (GGBS) is a fine powder used as a binder to manufacture geopolymer concrete.

Geopolymer mortar based on GGBFS mortar for substituting conventional cement mortar in construction practices has been confirmed (Singh A., Singh S., Mudgal M., Kumar A., 2021). The compressive strength test of geopolymer concretes based on GGBFS was 57.42 MPa in 28 days. The alkaline liquids used in this research are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), with a concentration of 8M and a design ratio of 2.5. A proportion of alkali activator to GGBFS of 26%: 74% and the ratio between coarse and fine aggregates was 65:35 (Padmanaban and Sreerambabu, 2018).

In geopolymer concrete, the alkali activator reacts with alumina (Al), and silica (Si) is contained in the pozzolanic material (GGBFS). Sodium hydroxide (NaOH) is a strong polymer bond, and sodium silicate (Na_2SiO_3) does as a catalyst, accelerating the polymerization reaction. Sodium hydroxide (NaOH) is an alkali compound that is effective and reactive when mixed with water.

Sodium hydroxide reacts with silicon and aluminum to form a strong base polymer bond. Sodium silicate (Na_2SiO_3) aids in accelerating polymer processes. When sodium silicate is dissolved in water, it forms an alkaline solution (Lianasari. A., Atmajayanti. A., Efendi. B., Sitindaon. N., 2013). Another research with high molarity in alkali activator gives results in a higher compressive strength of geopolymer concrete (Hardjito and Rangan, 2005).

Geopolymer concrete requires a different treatment/curing method than conventional concrete. Heat is essential for the polymerization reaction of alkali activator and GGBFS in geopolymer concrete. The most effective technique of curing geopolymer concrete is to heat it in an oven (dry curing). Another method of curing geopolymer concrete is to leave it at room temperature (ambient curing). This study and experiment used two curing methods: dry curing and ambient curing. After molding concrete, it is left to remain at room temperature for 24 hours before being heated in an oven at 60ºC for 24 hours. The geopolymer concrete was then cooled and sealed in a plastic bag until testing. The strength of geopolymer concrete improved at higher temperatures and the optimum strength was found to be 60°C oven curing (Yewale, V., Shirsath. M.N., Hake. S.L., 2016).

2. Research Method

This research focuses on an experimental study with primary data collected directly from the geopolymer concrete base on GGBFS specimen tests. PT Krakatau Semen Indonesia supplied GGBFS in this research. Testing was carried out in Structure and Building Materials Laboratory, Department of Civil Engineering, Faculty of Engineering, Universitas Atma Jaya Yogyakarta. The study aims to examine the effect of the alkali activator ratio on the mechanical properties of GGBFS-based geopolymer concrete. Compressive strength, split tensile strength, flexural strength, and modulus of elasticity were tested on concrete. The fresh concrete was observed for its setting time and workability. Compressive strength, split tensile strength, and modulus of elasticity was tested using a standard cylinder (150x300 mm, ASTM 39). The flexural strength was determined using a beam without reinforcement. The dimension was 100x100x500 mm, and a third-point load test, ASTM C78. The compression test of concrete was done at 7-days and 28-days, and another test was done at 28-days.

GGBFS as a base for geopolymer concrete in this study with variations of ratio sodium silicate solution to sodium hydroxide solution (alkali activator) was 5:2; 4:2; and 3:2. While the concentration of the NaOH solution was taken as 8M. The ratio of water to binder was 0.25. The curing process used a 24-hour dry curing method at a temperature of 60ºC and next ambient curing (covered with plastic). The proportion of GGBFS versus activator was taken as 70%:30% by weight (Lianasari, A.E., Lisantono, A., and Sudjati., J.J., 2021). The specimens of the concrete test are seen in Fig. 1 and the research arrangement is illustrated in the following flow chart (Fig. 2).

a. Compressive test b. Modulus of elasticity test

b. Modulus of rupture test c. Splitting test

Fig. 1 - The specimen of the concrete test

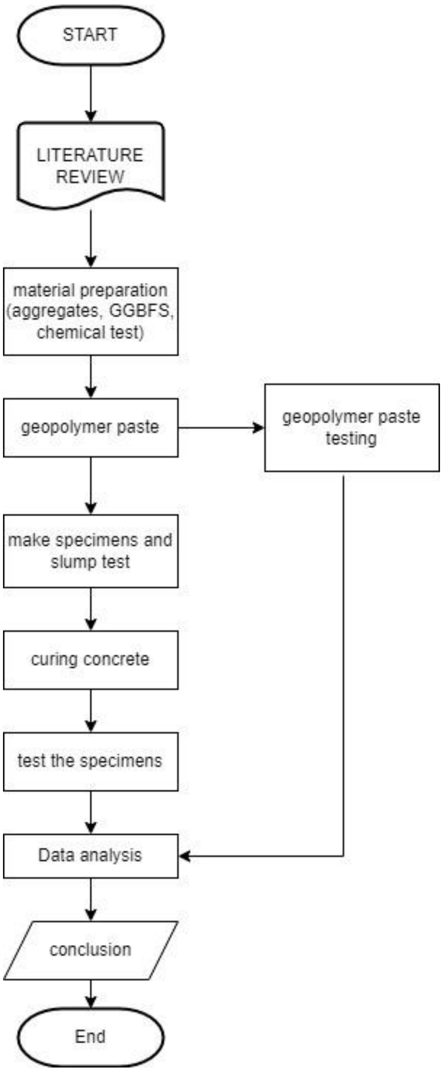

Fig. 2 - The research flow chart of geopolymer concrete based on GGBF

3. Results and Discussion

3.1 Ground Granulated Blast Furnace Slag (GGBFS)

The ground granulated blast furnace slag used in this study supply from PT Krakatau Cement, Indonesia. The specific gravity of GGBS is about 2.828 g/cm^3. Chemical analysis of GGBFS was performed using X-ray fluorescence (XRF) at the Institut Pertanian (Instiper) in Yogyakarta. The results of analyzing the chemical of the GGBFS used in this study are summarized in Table 1.

Table 1 - The chemical composition of GGBFS

Chemical elements	% Massa
Silica Dioxide (SiO_2)	25,8
Aluminum Oxide (Al_2O_3)	15,38
Calcium Oxide (CaO)	0,52
Sulfur Oxide (SO_3)	0,41
Iron (Fe)	1,34
Magnesium Oxide (MgO)	12,36
Potassium Oxide (K_2O)	0,46
Sodium Oxide (Na_2O)	1,21
Loss of Ignition (LOI)	0,88

Fig. 3 - GGBFS (Ground Granulated Blast Furnace Slag)

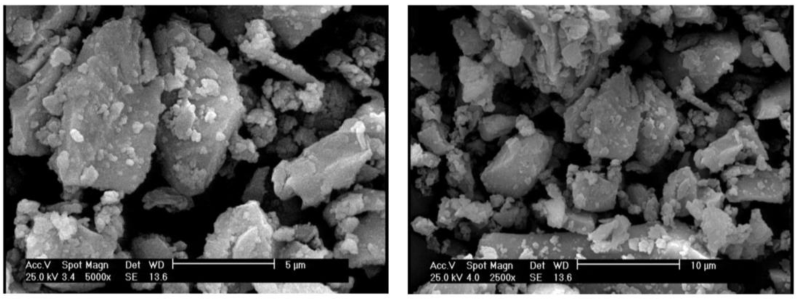

Fig. 4 - Scanning Electron Microscope (SEM) micrograph particle GGBFS (Ramezanianpour. A. A., Moeini. M. A., 2018)

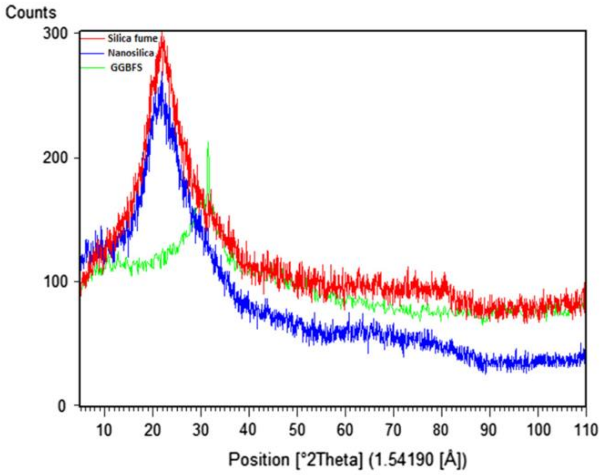

Fig. 5 - X-ray diffraction patterns of GGBFS, nano-silica, and silica fume (Ramezanianpour. A. A., Moeini. M. A., 2018)

The shape of the GGBFS particle is a box with some spherical particles. According to the form of the GGBFS particles, this will affect the ease of producing fresh concrete (workability). The X-ray diffraction pattern generated in Figure 5 using the EQuniox3000 machine demonstrates that the silica and alumina in GGBFS are reactive (effective as pozzolanic materials). Due to the low degree of crystallinity detected, the diffraction pattern shows that the GGBF is in the amorphous phase. (Ramezanianpour. A. A., Moeini. M. A., 2018)

3.2 Aggregate

The coarse and fine aggregates were checked during the experiment. This test was designed to determine whether the aggregate condition qualified in ASTM C33/C33M-08 to ensure that geopolymer concrete has a good quality. The maximum size of a coarse aggregate is 20 mm and the minimum 4.75 mm The result for the aggregates is mentioned in Table 2.

Table 2 - The result of the aggregate test

Description	Specific Gravity	Absorption	LA-test	Fineness Modulus	organic	Percentage of mud
Coarse aggregates	2.526	4.24%	33.84%	6.221	-	-
Fine aggregates	2.841	1.554%	-	3.755	Color no 5	8.62% (must be washed)

3.3 Mixed Design

Table 3 below describes the planning design of geopolymer concrete material composition for a volume of 1 m^3. The concrete specimen was made with a ratio alkali activator of 5:2; 4:2; and 3:2. The alkaline liquids used in this research are sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) with a concentration of 8M. The curing process is about 24-hour dry curing at a temperature of 60°C and next ambient curing (covered with plastic).

Table 3 - Mixed design geopolymer concrete per-m^3, w/b = 0.25

alkali activator ratio	GGBFS (kg)	Na_2SiO_3 (lt)	NaOH (lt)	Coarse aggregates (kg)	Fine aggregates (kg)
3:2	627.8	93.6	62.4	1149.3	696.1
4:2	627.8	104	52	1149.3	696.1
5:2	627.8	111.4	44.6	1149.3	696.1

3.4 Geopolymer Paste Setting Time

The test of the initial setting time geopolymer paste was by Indonesian standard. SNI 03-6827-2002. Initial setting time testing of geopolymer paste was carried out using a Vicat needle. This test was carried out at room temperature, and the time was recorded first when the alkaline solution was added to GGBFS. The results obtained show that geopolymer paste with a 3:2 alkali activator ratio needs a 45-minute for the initial set. But the difference with other ratios is only about 5 minutes. In this research, the flash setting did not occur. So that condition made it easier to process the concrete. Table 4, figure 5, and figure 6 below show the setting time tests on GGBFS-based geopolymer paste using several alkali activator ratios.

Table 4 - Setting time for geopolymer paste based on GGBFS established on alkaline activator ratio

Interval (minute)	Penetration (mm)		
	Ratio 3:2	Ratio 4:2	Ratio 5:2
0	43	43	43
5	43	43	43
10	42	41	40
15	40	38	35
20	35	32	30
25	12	7	5
30	5	2	1
35	3	1	0
40	1	0	-
45	0	-	-

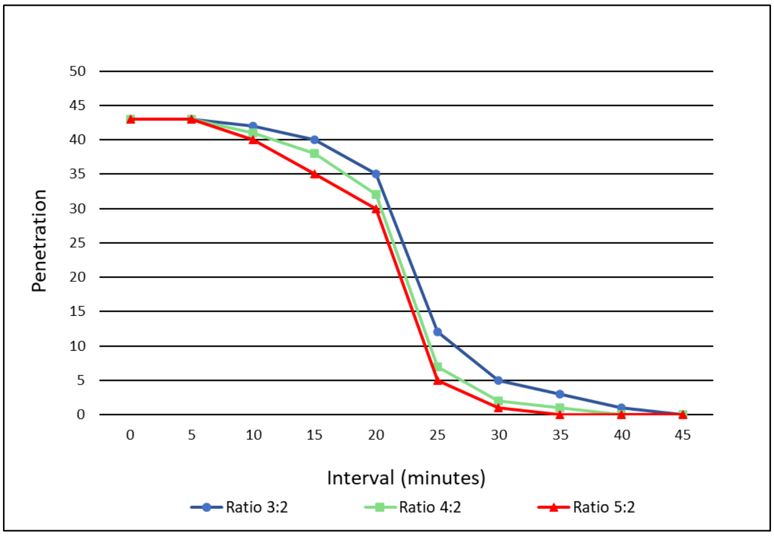

Fig. 5 - Setting time geopolymer paste

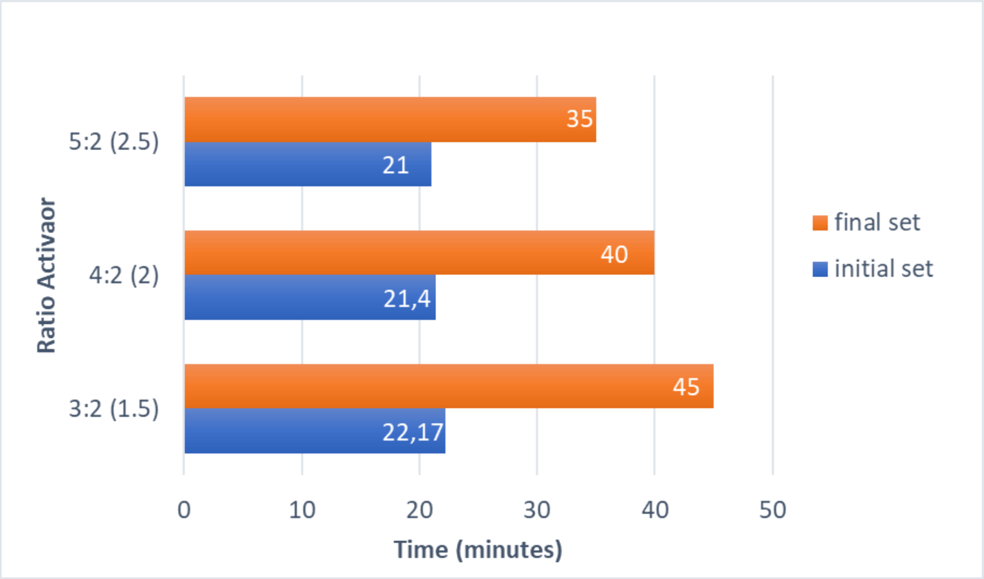

Fig. 6 - Comparison of initial and final setting time geopolymer paste with variation ratio activator

3.5 Workability

The slump test was used to determine the workability of this GGBFS-based geopolymer concrete. The slump test of fresh geopolymer concrete was by the standard. ASTM-C143/C143-M10. Table 5 shows the slump test of all specimens of fresh geopolymer concrete with all variations of alkali activator ratio. The fresh geopolymer concrete's slump value indicates how easily freshly mixed concrete is cast. So that consolidated, with minimal loss of homogeneity. The alkali activator ratio of 5:2 had the lowest slump value.

Table 5 - Slump test

Alkali activator ratio	Slump(mm)
3:2	170
4:2	155
5:2	130

All variants of the fresh concrete specimen have a high slump value (table 5). The slump value of fresh concrete indicates how easily freshly concrete can easily be mixed, placed, consolidated, and finished with minimal loss of homogeneity. According to SNI 1972:2008 standard, the slump test value of less than 15 mm indicates that concrete is not plastic enough. and concrete with a slump more significant than 230 mm is not cohesive enough. And the result of slump test findings indicated that this geopolymer concrete mix is quite flexible and cohesive, suggesting it is easy to work without segregation.

3.6 Property of Concrete

Specimens of geopolymer concrete were tested after curing for 7 days (compressive strength) and 28 days (specific gravity, compressive strength, modulus elasticity, split tensile, modulus of rupture/flexure strength). The testing of properties geopolymer concretes with standards: ASTM C39/C39M for compressive strength, ASTM C496 for split tensile strength, ASTM C78-02 for flexural strength, and for modulus of elasticity of concrete with ASTM C469-02.

Table 6 - GGBFS-based geopolymer concrete test results

alkali activator ratio	specific gravity (kg/m^3)	f'c. 7 days (MPa)	f'c. 28 days (MPa)	fct. 28 days (MPa)	MoR. 28 days (MPa)	Modulus Elasticity (MPa)	Theoretical deflection
3:2	2239.03	47.43	48.34	2.36	3.77	24563.99	0.01359
4:2	2244.42	54.18	55.34	2.50	3.82	28780.02	0.00962
5:2	2259.13	57.65	58.48	2.74	3.87	31815.92	0.00824

According to Table 6, geopolymer concrete based on GGBFS can be categorized into normal concrete because their specific gravity ranges between 2200 and 2300 kg/m^3. In this study, the GGBFS had a specific gravity of 2.828 g/cm^3. less than cement's 3.10 – 3.30 g/cm^3.

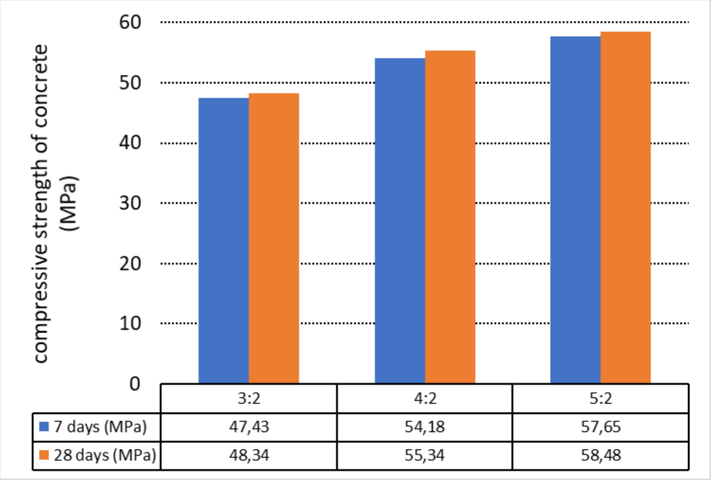

Fig. 7 - Compressive strength of geopolymer based on GGBFS

Figure 7 shows that the compressive strength of geopolymer concrete increased in direct proportion to the alkali activator ratio. If the alkali activator increases. Then compressive strength is increased too. The compressive strength of geopolymer concrete at 7 days approaches 28 days. That indicates that geopolymer concrete strength can be reached faster than normal concrete. Normal concrete needs 28 days to gain its strength. Results revealed that the alkali activator ratio of 5:2 has the optimum impact. the results show the highest compressive strength rate compared to other ratios (57.65 MPa at 7 days and 58.48 MPa at 28 days). Table 6 and figure 7 show that the increased ratio activator increased the compressive strength of geopolymer concrete. The increased compressive strength because of the increased amount of Na_2SiO_3. Na_2SiO_3 functions as a catalyst to accelerate the polymerization reaction, making the concrete harden faster.

The modulus of elasticity value indicates the stiffness of the concrete and gives the deformation when the concrete is loaded. The increase in the value of the modulus of elasticity corresponds to the increased compressive strength of the concrete. The value of this elastic modulus is proportional to both the compressive strength and the concrete strain Lianasari. A., Atmajayanti. A., Efendi. B., Sitindaon. N., 2013.

The split tensile strength and flexural strength (modulus of rupture) of geopolymer concrete were tested, to show the properties of concrete. One of the important properties of concrete is tensile strength as structural loads make concrete vulnerable to tensile cracking. The tensile strength of concrete is much lower than its compressive strength. The splitting tensile strength test is performed on hardened concrete to determine its tensile strength. Since concrete is brittle, it is weak in tension and can cause cracks. So it is essential to conduct the tensile strength test of concrete. According to table 7, the split tensile strength of geopolymer concrete based on GGBFS was between 2.3 and 2.8 MPa. The flexural strength was higher than split tensile stress, between 3.7 and 3.9 MPa. According to several prediction equations for the split tensile strength and flexural strength of concrete, the result of this experiment was lower than empiric formulas by ACI 318 (American Concrete Institute), Australian standard AS3600, and European code CEB-FIP, Bellum, R. R., Muniraj, K., Madduru, S. R. C., 2019. The aggregate's condition could cause the low split tensile and flexural strength. Crushing aggregates of the abrasion test were high at 33.84 percent. The condition of the geopolymer paste is used as an aggregate adhesive, as shown in figure 8 of the split tensile test. The results showed that the coarse aggregate breaks during the split tensile test of the concrete. The split tensile strength is used to estimate cracks caused by loading. The modulus of rupture test was used to determine the theoretical maximum flexural strength achieved at the beam specimen. The results indicated that a 5:2 activator ratio gave the highest modulus of rupture, 3.87 MPa. However, the experimental results were lower than the theoretical value prediction (table 7).

Table 7 - Split tensile and flexural strength

Alkali activator Ratio	**fct (Mpa)**				**fcf (MPa)**	
	research	**ACI 318-99**	**Australian standard AS3600**	**European code CEB-FIP**	**research**	**ACI 318-99**
		$0.56.\sqrt{f'c}$	$0.4.\sqrt{f'c}$	$0.3.f'c^{2/3}$		$0.62.\sqrt{fc}$
3:2	2.36	4.10	2.78	3.98	3.77	4.31
4:2	2.50	4.39	2.98	4.36	3.82	4.61
5:2	2.74	4.51	3.06	4.52	3.87	4.74

Fig. 8 - Concrete split tensile test

4. Conclusion

The decreased activator ratio causes a longer setting time of geopolymer concrete, lower compressive strength, lower modulus elasticity, lower split tensile strength, and lower modulus of rupture. But the decreased activator ratio causes an increased slump value, which indicates how easily freshly mixed concrete is.

Acknowledgment

We express our gratitude to PT. Krakatau Semen Indonesia for supplying GGBFS and PT. Solusi Bangun Indonesia Tbk for supplying other concrete components. We are also thankful to the Head and Staff of the Laboratory of Structures and Materials. Department of Civil Engineering. Faculty of Engineering. Universitas Atma Jaya Yogyakarta provides the facilities and equipment necessary for the research.

References

ASTM C143/C143M – 10. Standard Test Method for Slump of Hydraulic-Cement Concrete. ASTM Standard Book.

ASTM C33/C33-M08. Standard Specification for Concrete Aggregates. ASTM Standard Book.

ASTM C39/C39M, 2003. Standard Test Method for Compressive Strength of Cylindrical

ASTM C469-02. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. ASTM Standard Book.

ASTM C496-96. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. ASTM Standard Book.

ASTM C78. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). ASTM Standard Book.

Concrete Specimens. ASTM Standard Book.

Hardjito, D. and Rangan, B.V. (2005). Development and Properties of Low-calcium Fly Ash Based Geopolymer LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE By Faculty of Engineering Curtin University of Technology. Australia : University of Technology Perth. January. 48.

Lianasari, A. E., Lisantono, A., and Sudjati, J. J. (2021). Shear behavior of fly ash-based geopolymer R/C beam with bauxites as coarse aggregates: Experimental program. International Journal of GEOMATE, 20(79), 155–160. https://doi.org/10.21660/2021.79.j2039

Lianasari, A.E., Atmajayanti, A., Efendi, B., and Sitindaon, N. (2013). Effect of using solid fly ash and husk ash on the compressive strength of polymer concrete.. Conference Proceeding “Konferensi Teknik Sipil 8 (KoNTekS 8”). October 2013. http://e-journal.uajy.ac.id/id/eprint/7451

Padmanaban and Sreerambabu. (2018). Geo Polymer Concrete With Ggbs (Ground Granulated Blast. International Journal Of Engineering Sciences & Research Technology. 7(2). 629–636.

Ramezanianpour. A. A. and Moeini. M. A. (2018). Mechanical and durability properties of alkali-activated slag coating mortars containing nano-silica and silica fume. Construction and Building Materials. 163(February). 611–621.

Singh. A., Singh. S., Mudgal. M., and Kumar. A. (2021). Ground granulated blast furnace slag-based Geopolymer Mortar activated with low concentration alkali. Indian Journal of Engineering & Materials Sciences. 28(August). 350–357.

SNI 03-6827-2002. (2002). Metode Pengujian Waktu Ikat Awal Semen Portland dengan Menggunakan Alat Vicat untuk Pekerjaan Sipil. Badan Standardisasi Nasional Indonesia. 6827.

SNI 1972-2008. (2011). Cara uji slump beton. Badan Standar Nasional Indonesia.

Yewale. V. V. Shirsath. M. N.. & Hake. S. L. (2016). Evaluation of Efficient Type of Curing for Geopolymer Concrete. International Journal of New Technologies in Science and Engineering. 3(8). 10–14.