VOL. 17, NO. 23, DECEMBER 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

THE EFFECT OF HOT STEAM CURING ON THE COMPRESSIVE STRENGTH AND FLEXURAL STRENGTH OF GEOPOLYMER CONCRETE

Octavia Nolan[1], Harianto Hardjasaputra[1,2] and Agustinus Agus Setiawan[1,2]
[1]Department of Civil Engineering, Faculty of Technology and Design, Universitas Pembangunan Jaya, Indonesia
[2]Centre for Urban Studies, Universitas Pembangunan Jaya, Indonesia
E-Mail: agustinus@upj.ac.id

ABSTRACT

This research was conducted to determine the effect of hot steam curing on the compressive and flexural strength of geopolymer concrete with variations of NaOH molarity. The specimens used in this study are cylinders with a size of 150 mm × 300 mm for the compressive strength test and beams with dimensions 150 mm × 150 mm × 600 mm for the flexural compressive strength test. The specimens were cured at 80°C, 90°C, and 100°C for 2 and 3 hours. Curing at room temperature was carried out after the hot steam curing process finished. The compressive and flexural strength tests were carried out when the specimens reached 28 days old. The result of the study showed that the 14 M mixture had greater compressive strength and flexural strength than 10 M. By increasing the temperature every 10°C and the duration of the hot steam curing for 1 hour, the compressive strength increased by an average of 5.97% and 3.07% and the flexural tensile strength by an average of 19.73% and 7.34%, respectively. Besides that, it can be proposed a multiple regression equation for compressive strength, namely $f'_c = 21{,}728 + 0{,}147x_1 + 1{,}040x_2 + 0{,}162x_3$ and multiple regression equation for tensile strength are $f_r = -2{,}270 + 0{,}061x_1 + 0{,}318x_2 + 0{,}029x_3$. Where f'_c is compressive strength, and f_r is flexural tensile strength, while x_1, x_2, and x_3 are temperature, curing time, and molarity of NaOH.

Keywords: geopolymer concrete, steam curing, compressive strength, flexural strength.

INTRODUCTION

Concrete is the most popular structural material consisting of hydraulic cement (portland cement), coarse aggregate, fine aggregate, water, and additional materials (admixture or additive). Aggregates greatly affect the quality of concrete because aggregates occupy 70% - 80% of the volume of concrete. In addition, cement plays an important role in the quality of concrete because cement functions as an adhesive in the hardening process, so that the aggregate grains are strongly and densely bonded to each other [1]. The production of Portland cement causes global warming, due to the emission of CO_2 gases that cause the greenhouse effect, resulting from the production process. To overcome the adverse effects of using Portland Cement, other materials are needed as a substitute for Portland Cement for the manufacture of concrete.

Davidovits in 1978 discovered non-organic natural materials through a polymerization process known as geopolymer [2]. To make geopolymer materials, materials containing silica and alumina are needed which are usually found in industrial by-products such as fly ash, which is obtained from burning coal [3].

Several factors that affect the quality of concrete, among others, are the quality of materials, workmanship, and curing (curing) of concrete. Concrete curing is a procedure carried out after the concrete has hardened and aims to ensure the hydration process. To speed up the hydration process, the concrete is treated with steam (steam curing). According to Irawan, Ekaputri, Aji, and Quarter (2012), the appropriate steam curing temperature for normal concrete and concrete using fly ash is around 70°C [4].

In addition, according to Hardjasaputra, Ekawati, Victor, Cornelia, and Rachmansyah (2019), geopolymer concrete with steam curing produces a high compressive strength of concrete that is only treated at room temperature [5]. The high concentration of NaOH also increases the alumina and silica binding capacity in fly ash, but it should be noted that increasing the concentration of NaOH can reduce the slump value so that the workability of the concrete is lower.

Based on the above background, this study aims to determine the effect of hot steam curing on the compressive strength and flexural strength of geopolymer concrete. This research is expected to address the needs of the construction sector to increase the strength of concrete through hot steam curing.

METHODOLOGY

Materials and Mix Design

The object used for this research is geopolymer concrete in the form of cylinders and blocks with hot steam curing. This study aims to accelerate the hydration process from increasing temperature and time on hot steam curing so that it can affect the compressive strength and flexural tensile strength of geopolymer concrete.

The variables used in this study were variations in molarity, namely 10 molarity and 14 molarity of NaOH, time variations for 2 and 3 hours, and using temperatures of 80°C, 90°C, and 100°C. The specimens used were 24 cylindrical geopolymer concrete and 24 beam geopolymer concrete with a cylinder size of 15 cm × 30 cm and a beam size of 15 cm × 15 cm × 60 cm. The quality of the concrete used is f'_c 30 MPa. The mix design of geopolymer concrete is calculated under the provision of Indonesian Standard SNI 7656: 2012. "Procedures for Selecting Mixtures for Normal Concrete, Heavy Concrete, and Mass Concrete" [6].

From the results of the coarse aggregate and fine aggregate tests that have been carried out, the results of the test recapitulation are summarized in Table-1.

Table-1. Properties of coarse aggregate and fine aggregate.

	Coarse Aggregate Test			
No	**Test**	**SNI**	**Standard**	**Result**
1	Specific Gravity	03-1969-2008	≥ 2,5	2,53
2	Fill Weight	03-4804-1998	≥ 1,4	1,43
3	Sludge Levels	03-4142-1996	≤ 1,0	0,83
4	Absorption	03-1996-2008	≤ 3,0	2,61
5	Aggregate Wear	2417-2008	≤ 40	16,43
	Fine Aggregate Test			
No	**Test**	**SNI**	**Standard**	**Result**
1	Specific Gravity	03-1969-2008	≥ 2,5	2,54
2	Fill Weight	03-4804-1998	≥ 1,4	1,47
3	Sludge Levels	03-4142-1996	≤ 7,0	3,83
4	Absorption	03-1996-2008	≤ 3,0	2,93
5	Fine Modulus	SK SNI-04-1989-F	1,5-3,8	3,24

The fly ash used in the geopolymer concrete mix comes from the Lontar PLTU in Banten. To determine the chemical composition in fly ash in accordance with the rules of SNI 2460-2014, an X-Ray Fluorescence (XRF) test was carried out. The XRF test was carried out at the Chemical Research Center, BRIN Puspitek Serpong. The results of the XRF fly ash of PLTU Lontar showed that SiO_2 + Al2O_3 + Fe_2O_3 had a total of 81.8% and 1% SO_3. This shows that the fly ash used in this study is classified into class F fly ash because the content of SiO_2, Al_2O_3, and Fe_2O_3 is more than 70% and SO_3 content is less than 3%.

The calculation of the mix design of the geopolymer concrete refers to SNI 7656-2012, but some modifications must be made, referring to the work by Hardjasaputra (2017) [7]. The modifications made are the weight of cement and the weight of water are added together, then the result will be the weight of geopolymer paste (a mixture of fly ash and alkaline activator). The comparison between fly ash and alkali activator is 2:1. Alkaline activator used in this study is a solution of NaOH and Na_2SiO_3 with a ratio of 1: 3. The mix design of geopolymer concrete per m^3 is summarized in Table 2.

Table-2. Mix design of geopolymer concrete per 1 m^3.

Molarity	**Total Weight**	***Fly Ash***	**Na_2SiO_3**	**NaOH**	**Water**	**Coarse Aggregate**	**Fine Aggregate**
10 M	2380	366,94	137,60	14,04	31,83	1152,64	676,95
14 M	2380	366,94	137,60	18,28	27,59	1152,64	676,95

Testing Method

The compressive strength test of geopolymer concrete was carried out according to ASTM C39/C39M-21 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens [8]. The test object used for this study is a cylinder with a diameter of 15 cm and a height of 30 cm. The compressive strength of the resulting concrete is calculated by the equation

$$f_c' = \frac{P}{A} \quad (1)$$

Where P is the ultimate load (N), A is the cross-section area of specimens (in mm^2), and f'c is the concrete compressive strength (MPa)

Meanwhile, the flexural strength test of geopolymer concrete was carried out based on ASTM C78/C78M-22Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) [9]. The test object used in this study was a beam measuring 15 cm × 15 cm × 60 cm. The value of the flexural strength of concrete is calculated by the equation:

$$f_r = \frac{PL}{bh^2} \tag{2}$$

Where P is the ultimate load (in N), L is the length of the specimen (in mm), b is the width of the specimen (in mm), h is the height of the specimen (in mm)

RESULTS AND DISCUSSIONS

Geopolymer Concrete Compressive Strength Results

The test object used for this study is a cylinder with a diameter of 15 cm and a height of 30 cm. The total compressive strength test specimens were 24 pieces consisting of 12 specimens for each molarity, i.e. 10M and 14M. The compressive strength test of concrete is carried out at 28 days of concrete age. The results of the compressive strength of concrete can be seen in Figure-2.

Figure-1 shows an increase in the value of the compressive strength of concrete with temperature variations of 80°C, 90°C, and 100°C. From the figure, it can be explained that, the higher the temperature in the hot steam curing, the higher the increase in the value of the compressive strength of the concrete. At 10 M, 90°C 3 hours and 100°C 3 hours increased respectively by 2.52% and 7.76% against 80°C 3 hours. At 14 M, curing for 90°C 3 hours increased by 3.72%, and at 100°C 3 hours there was a fairly high percentage increase of 12.71% against 80°C 3 hours. The average increase in compressive strength every 10°C is 5.97%.

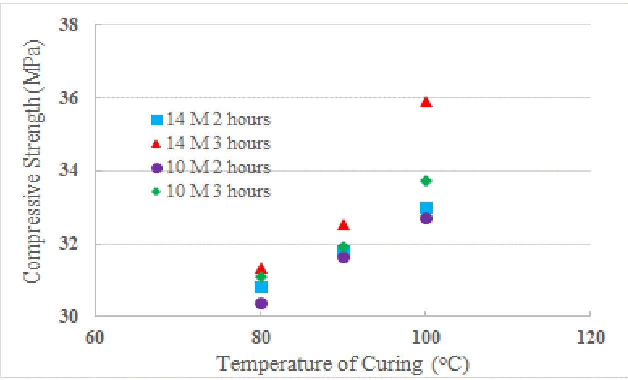

Figure-1. Compressive strength comparison of geopolymer hot steam curing concrete.

The variation of time in hot steam curing is a determining factor in increasing the compressive strength of concrete. From Figure-2 it can be seen that at 10 molarity, the temperature at 100°C for 3 hours increased by 3.01% against 100°C 2 hours, and 14M at 100°C 3 hours experienced a fairly high increase of 8.03% compared to 100°C 2 hours. The average increase in compressive strength for 1 hour is 3.06%.

It can be seen from Figure 2, at the last temperature of 100°C, 14M 2 Hours increased by 0.89% against 10 M 2 Hours and at 14M 3 Hours experienced a fairly large increase of 6.02% against 10 M 3 Hours. In addition to time and temperature, it can be seen that the greater the molarity, the greater the value of the resulting compressive strength but with a relatively small percentage.

Geopolymer Concrete Flexural Tensile Strength Results

The test object used in this study was a beam measuring 15 cm × 15 cm × 60 cm. The total flexural tensile strength test specimens were 24 pieces consisting of 12 specimens for each molarity, i.e. 10M and 14M. For the flexural tensile strength test, 24 specimens have been carried out. The flexural tensile strength test of concrete was carried out when the concrete was 28 days old. The planned concrete quality is 30 MPa. Figure-3 shows the test results for the flexural strength test with temperature variations of 80°C, 90°C, and 100°C which increase steadily. From the figure, it can be explained that the higher the temperature in the hot steam curing, the higher the increase in the flexural tensile strength of concrete. At 14M, curing for 90°C 3 hours increased by 13.2%, and at 100°C 3 hours there was a fairly high percentage increase of 22.3% against 80°C 3 hours. The average increase in flexural tensile strength every 10°C is 19.73%.

The variation of time on hot steam curing is a determining factor in increasing the flexural tensile strength of concrete. In Figure-2 it can be seen that at 100°C 3 hours, 10M experienced an increase of 4.65% against 100°C 2 Hours, and 14 M with 100°C 3 hours curing experienced a fairly high increase of 3.96% compared to 100°C 2 Hours. The average increase in flexural tensile strength for 1 hour is 7.34%. It can be seen from Figure-3, at the last temperature of 100°C, 14 M 2 Hours increased by 2.53% against 10M 2 Hours and at 14M 3 Hours experienced a fairly large increase of 1.83% against 10 M 3 Hours.

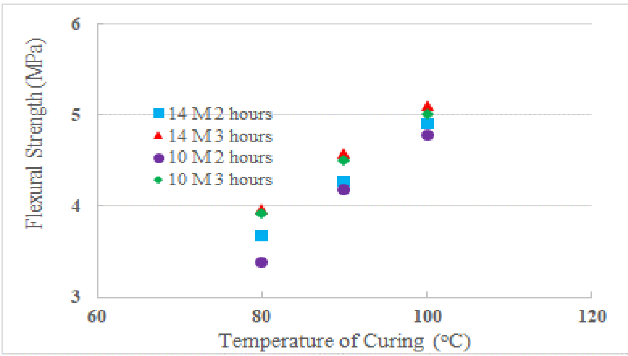

Figure-2. Flexural tensile strength comparison of geopolymer hot steam treated concrete.

Linear Multiple Regression Model

Because this study uses three independent variables, namely temperature, time, and molarity to the dependent variable, namely the compressive strength and flexural tensile strength of geopolymer concrete, multiple linear regression was used to determine the effect of temperature, steam curing time, and molarity on compressive strength and strength. Tensile strength of

ARPN Journal of Engineering and Applied Sciences

geopolymer concrete. The application used to obtain linear regression results is SPSS.

Table-3 shows the results of multiple regression analysis result using SPSS for the compressive strength of geopolymer concrete. Assuming 21.728 is 100% of the results of the compressive strength of concrete, then the effect of temperature is 0.68%, the effect of time is 4.79%, and the effect of molarity is 0.75%. It can be seen that the significant figures in table 9 also show that changes in temperature and molarity in hot steam curing have no significant effect on the compressive strength of concrete. While the time in hot steam curing has a greater influence on the compressive strength of geopolymer concrete.

Table-3. Compressive strength multiple linear regression results.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	21.728	2.445		5.925	.000
	Temperature	.147	.022	.833	6.639	.000
	Steam Curing Time	1.040	.361	.361	2.881	.020
	Molarity	.162	.090	.225	1.791	.111

Table-4 shows the results of multiple regression analysis result using SPSS for the flexural strength of geopolymer concrete. Assuming -2.270 is 100% of the results of the flexural tensile strength of concrete, then the effect of temperature is 2.69%, the effect of time is 14.01%, and the effect of molarity is 1.28%. It can be seen that the significant figures in Table-12 also show that changes in temperature and molarity in hot steam curing also don't have much effect on the flexural tensile strength value, but the duration of hot steam curing has a greater influence on the flexural tensile strength value of geopolymer concrete.

Table-4. Flexural tensile strength multiple linear regression results.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.270	.298		-7.622	.000
	Temperature	.061	.003	.940	22.653	.000
	Steam Curing Time	.318	.044	.300	7.239	.000
	Molarity	.029	.011	.109	2.615	.031

CONCLUSIONS

Based on the results of research on the effect of hot steam curing on the compressive strength and tensile strength of geopolymer concrete. Then the following conclusions can be drawn:

The value of compressive strength and flexural tensile will increase with increasing duration and temperature of hot steam curing. By increasing the temperature every 10°C and the duration of the hot steam curing for 1 hour, the compressive strength increased by – an average of 5.97% and 3.07% and flexible tensile strength by an average of 19.73% and 7.34%, respectively.

In this study, the optimal time and temperature for geopolymer hot steam curing have not been obtained, but from several literature studies conducted, it was found that geopolymer concrete hot steam curing for 12 to 24 hours at 90°C will provide optimal compressive strength and tensile strength. Higher values of molarity give better compressive and tensile strength values. However, from several literature studies, it is known that concentrations above 16 molarity can reduce pressure and flexibility because there is no initial geopolymerization stage. The multiple linear regression equation obtained from the effect of time, the temperature in hot steam curing, and molarity on the compressive strength of geopolymer concrete, is $f'_c = 21{,}728 + 0{,}147x_1 + 1{,}040x_2 + 0{,}162x_3$. Meanwhile, the flexural tensile strength of geopolymer concrete is $f_r = -2{,}270 + 0{,}061x_1 + 0{,}318x_2 + 0{,}029x_3$.

ACKNOWLEDGMENT

This research would like to thank the support of PT. Indonesia Power PLTU Banten 3 Lontar OMU and PT. Jaya Beton Indonesia who has provided support in the form of data and materials in thesis research.

REFERENCES

[1] Nurmaidah U. M. A. 2015. Use of Fine Aggregate with Different Location Source for Concrete Mix. ARBITEK: Jurnal Teknik Sipil and Arsitek. Universitas Medan Area. 1(2).

[2] Davidovits J. 2008. Geopolymer Chemistry and Applications 5th ed. Geopolymer Institute, Saint-Quentin, France. ISBN: 9782954453118

[3] Manuahe R., Sumajouw M. D. J. and Windah R. S. 2014. Compressive Strength of Geopolymer Concrete Based on Fly Ash. Jurnal Sipil Statik. 2(6): 277-278.

[4] Irawan C., Ekaputri J. J., Aji P. and Triwulan. 2012. Prediction of Compressive Strength of Fly Ash Mixed Concrete with Steam Curing Using Maturity Method. Jurnal Teknik ITS. 1 (1): 1-5.

[5] Hardjasaputra H., Ekawati E., Victor, Cornelia M. and Rachmansyah. 2019. Evalution of High Strength Fly Ash Based Geopolymer Concrete Technology with Steam Curing. Malaysian Construction Research Journal (MCRJ) Special Issue. 6(1): 1-6.

[6] Nasional B. S. 2012. SNI 7656: 2012. “Procedures for Selecting Mixtures for Normal Concrete, Heavy Concrete, and Mass Concrete. Jakarta: BSN.

[7] Hardjasaputra H. and Ekawati E. 2018. Research on the Design of Geopolymer Concrete Mixtures Based on Fly Ash PLTU Suralaya-Banten against Compressive Strength and Flexural Strength. Jurnal Ilmiah Teknik Sipil. 24-33.

[8] ASTM C39/C39M-21. 2021. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

[9] ASTM C78/C78M-22. 2022. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).

[10] Chang C. A., Lin H. D., Lo C. C. 1977. Tests of pattern change for automated detection of printing faults using computer vision systems. International Journal of Industrial Engineering. 4, 5-13.

[11] Chen W. F. 1911. Stability Design of Steel Frames. CRC Press. Florida. U.S.A.

[12] Liu B. L., Tzeng Y. M. 2000. Characterization study of the sporulation Kinetics of Bacillus thuringiensis. Biotechnology and Bioengineering. 68, 11-17.

[13] Abdullah M. M. A., Hussin K., Bnhussain M., Ismail K. N. and Ibrahim W. M. W. 2011. Mechanism and Chemical Reaction of Fly Ash Geopolymer Cement-a Review. Int. J. Pure Appl. Sci. Technol. 6(1): 35-44.

[14] Agamy M. H., Mohammed A. M., Abd Elnaby S. F. and Abd Elaziz, R. S. Effect of Elevated Temperature on Alkali Activated Slag and Fly Ash Based Geopolymer Concrete.

[15] Aleem M. A. & Arumaiaraj P. D. 2012. Geopolymer Concrete - a Review. International Journal of Engineering Sciences & Emerging Technologies. 1(2): 118-122.

[16] Alonso S. and Palomo A. 2001. Alkaline Activation of Metakaolin and Calcium Hydroxide Mixtures: Influence of Temperature, Activator Concentration and Solids Ratio. Materials Letters. 47(1-2): 55-62.

[17] Azarsa P. and Gupta R. 2020. Comparative Study Involving Effect of Curing Regime on Elastic Modulus of Geopolymer Concrete. Buildings. 10(2): 101.

[18] Chindaprasirt P., Chareerat T. and Sirivivatnanon V. 2007. Workability and Strength of Coarse High Calcium Fly Ash Geopolymer. Cement and Concrete Composites. 29(3): 224-229.

[19] Hardjito D., Cheak C. C. and Ing C. L. 2008. Strength and Setting Times of Low Calcium Fly Ash-Based Geopolymer Mortar. Modern Applied Science. 2(4): 3-11.

[20] Hamidi R. M., Man Z. and Azizli K. A. 2016. Concentration of NaOH and the Effect on the Properties of Fly Ash Based Geopolymer. Procedia Engineering. 148, 189-193.

[21] Irawati, T. 2009. Geopolymer Concrete of Fly Ash Manufacturing and Characterization.

[22] Jamdade, P. K. 2016. Effect of Temperature and Time of Curing on Strength of Fly Ash Based Geopolymer Concrete. Int. J. Inno. Res. Sci. Eng. Technol. 5, 9269-9274.

[23] Lianasari A. E., Anam M. S. and Sibarani N. N. Effect of Dry Curing Temperature and Duration on Mechanical Properties of Geopolymer Concrete Based on Ground Granulated Blast Furnace Slag.

[24] Lloyd N. A. and Rangan, B. V. 2010. Geopolymer Concrete: A Review of Development and

Opportunities. 35th Conference on Our World in Concrete & Structure, Singapore Concrete Institute, Singapore. 25-27.

[25] Mulyono T. 2005. Concrete Technology. Yogyakarta: Andi Offset.

[26] Nagral, M. R., Ostwal, T., and Chitawadagi, M. V. 2014. Effect of Curing Temperature and Curing Hours on the Properties of Geo-polymer Concrete. International Journal of Computational Engineering Research. 4(9): 1-11.

[27] Nasional B. S. 1989. SK SNI S-04-1989-F. Specification of Building Materials Part A, Non-Metal Building Materials. Jakarta: BSN.

[28] Nasional, B. S. 1990. SNI 03-1968-1990. Test Method for Fine and Coarse Aggregate Sieve Analysis.

[29] Nasional, B. S. 1996. SNI 03-4142-1996. Method of Testing the Amount of Material in Aggregate Passing Sieve No. 200 (0.075 mm).

[30] Nasional B. S. 1998. SNI 03-4804-1998. Method of Testing the Weight of the Fill and Air Cavity in Aggregate. BSN, Jakarta.

[31] Nasional, B. S. 2000. The Procedure for Making a Normal Concrete Mix Plan". SK SNI, 3, 2834-2000.

[32] Nasional B. S. 2008. SNI 1969-2008. Method of Testing Specific Gravity and Absorption of Coarse Aggregate Water. Kementrian Pekerjaan Umum, Badan Penelitian dan Pengembangan PU.

[33] Nasional B. S. 2008. SNI 1970: 2008. How to Test Specific Gravity and Fine Aggregate Water Absorption. BSN, Jakarta.

[34] Nasional B. S. 2008. SNI 1972-2008. About How to Test Concrete Slump. Badan Standarisasi Nasional, Jakarta.

[35] Ng, Y. S., Liew, Y. M., Heah, C. Y. and Abdullah, M. M. A. B. 2018. Effect of Molarity of Sodium Hydroxide on Fly Ash Geopolymer Tiles. In AIP Conference Proceedings, 2045 (1), 020101. AIP Publishing LLC.

[36] Nugraha P. and Antoni. 2007. Concrete Technology. Yogyakarta: Andi Offset.

[37] Paat F. E. S., Wallah S. E. and Windah R. S. 2014. Bending Tensile Strength of Fly Ash Based Geopolymer Concrete. Jurnal Sipil Statik. 2(7).

[38] Palomo A., Fernández-Jiménez A. and Criado M. 2004. Geopolymers: Same Basic Chemistry, Different Microstructures. Materiales de Construcción. 54(275): 77-91.

[39] Patankar S. V., Ghugal Y. M. and Jamkar S. S. 2014. Effect of Concentration of Sodium Hydroxide and Degree of Heat Curing on Fly Ash-Based Geopolymer Mortar. Indian Journal of Materials Science. 2014.

[40] Pratama Y. P. 2018. Compressive Strength of Normal Concrete and High Quality Concrete in Steam Curing and Immersion. Artikel Ilmiah. 3-4.

[41] Rajesh A. M., Joe, M. A. and Mammen R. 2014. Study of the Strength Geopolymer Concrete with Alkaline Solution of Varying Molarity. engineeringcivil. Com. 4, 19-24.

[42] Rommel E. and Rusdianto Y. 2012. The Use of Fly-Ash as Cementitious on High-Strength Concrete with Steam Curing. Media Teknik Sipil. 10(2).

[43] Sandeep L. H., Mohit K. A., Rupesh V. G., Dnyaneshwar R. G. and Vikas, V. W. 2016. Effect of Molarity on Geopolymer Concrete. Int. J. Adv. Res. Sci. Eng. (5).

[44] Setiati, N. R., and Irawan, R. R. 2018. Comparison of the Properties and Characteristics of Geopolimer Concrete and Portland cement Concrete for Structural Beam Strength. Jurnal Jalan-Jembatan. 35(2): 125-138.

[45] Škvára, F., Kopecký, L., Nemecek, J. and Bittnar, Z. D. E. N. I. K. 2006. Microstructure of Geopolymer Materials Based on Fly Ash. Ceramics-Silikaty. 50(4): 208-215.

[46] SNI 1974. 2011. How to Test the Compressive Strength of Concrete with a Cylindrical Test Object. Badan Stand. Nas. Indones. 20.

[47] SNI 2847. 2013. "Structural Concrete Requirement for Buildings. Badan Standarisasi Nasional.

[48] SNI 2460. 2014. Specification of Raw or Calcined Coal Fly Ash and Natural Pozzolan for Use in Concrete. Jakarta: Badan Standarisasi Nasional.

[49] Syafputra B. and Kurniawati E. K. 2020. Effect of Molarity Variation on Compressive Strength of Fly Ash Geopolymer Concrete with Quartz Sand Fine Aggregate. SANTIKA is a scientific journal of science and technology. 10(1): 1-9.

[50] Topark-Ngarm P., Chindaprasirt P. and Sata V. 2015. Setting Time, Strength, and Bond of High-Calcium Fly Ash Geopolymer Concrete. Journal of materials in civil engineering. 27(7): 04014198.

[51] Yewale V. V. and Nikam P. G. 2016. Evaluation of Efficient Type of Curing for Geopolymer Concrete. JournalNX. 293-295.

[52] Yunsheng Z., Wei S., Qianli C. and Lin C. 2007. Synthesis and Heavy Metal Immobilization Behaviors of Slag Based Geopolymer. Journal of hazardous materials. 143(1-2): 206-213.

[53] Zuhua Z., Xiao Y., Huajun Z. and Yue C. 2009. Role of Water in the Synthesis of Calcined Kaolin-Based Geopolymer. Applied clay science. 43(2): 218-223.