Journal of Engineering Science and Technology
ICIST2022, Vol. 18, No. 1 (2023) 167 - 177

WATER AND STEAM CURING TYPES AND THREE NAOH MOLARITIES EFFECTS DUE TO FLY ASH BASED GEOPOLYMER CONCRETE COMPRESSIVE STRENGTH STUDY

FRANSISCA MARIA FARIDA[1,*], CATUR SETYAWAN KUSUMOHADI[1], JOHANNES JUSUF WIBISONO[2], ADANG SURAHMAN[3]

[1]Fire Safety Engineering Study Program, Engineering Faculty, Universitas Negeri Jakarta, Jl. Rawamangun Muka No. 1, Jakarta, 13220, Indonesia
[2]P.T. Rexaudia Sasada Sentosa, Jl. H. Agus Salim No. 32/4 gang senggol, Kebon Sirih, Menteng, Jakarta Pusat, 10340, Indonesia
[3]Civil Engineering Department, Institut Teknologi Bandung, Jl. Ganeca No. 10, Bandung, 40132, Indonesia
*Email: fransisca_farida@unj.ac.id, fransiscamf@gmail.com

Abstract

The curing process affects the compressive strength of the geopolymer concrete that has been burned. In the burned-out material, the modulus of elasticity and yield strength of the material will decrease due to the creep process. With regard to material problems due to fire, passive fire protection is one of the strategies to overcome them. The all strategies are active fire protection, passive fire protection, and safety management. This study presents the results of fire protection using Suralaya fly ash geopolymer concrete. The three molarities of the geopolymer concrete mix designs studied were 2M, 4M, and 6 M. Meanwhile, the base activators used were Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH). The experimental results were analysed by compressive strength testing to obtain the optimum value. The three results obtained from this study are the compressive strength value obtained from curing with steam is almost the same with that from curing with water, the compressive strength value of 2M geopolymer concrete is higher than 4M, and the compressive strength value of 6M geopolymer concrete is higher than the value of 6M. compressive strength of 6M geopolymer concrete. from 4M. Another finding is the higher the number activator molarity is not always advised by growing up the compressive strength of the resulting geopolymer concrete.

Keywords: Curing, Fire, Geopolymer, Molarity, Passive, Protection,

1. Introduction

Material was afire will run into creeping. In this situation, there is a decrease in the modulus of elasticity and yield strength. Due to it, material requires passive protection against fire [1]. Currently available fire-resistant protection materials are gypsum, stucco, concrete, intumescent paint, and bricks. Disadvantages of refractory materials today are gypsum takes a long time to work, there is a decrease in strength and spalling for stucco and concrete. On the other hand, intumescent paint requires surface preparation. While brick requires additional supporting insulation material.

Designing a building material with excellent heat resistance is crucial for protection against catastrophic fires. In order to handle these fire resistance material disadvantages, researches on the manufacture of new fire-resistance material are conducted, eq. fire insulation materials [2-4], silica [5-8], polymers [9], and geopolymers [10, 11]. At the moment, the construction industry uses Portland cement as a major material. Even Though Portland cement manufacturing process produces 5-7% of total carbon dioxide emissions [12]. Researchers are motivated in cutting down greenhouse gasses and the environmental solid wastes. In order to it, expansion researches have use Portland binder such as fly ash, silica fume, slag, red mud, etc., to supersede Portland cement [13, 14]. Among the recent research interests in the construction section, Geopolymers, represent a rising trend due to their significant performance in terms of strength and long term properties.

In this study, researchers have focused on using geopolymer concrete as a material for fire protection. Geopolymer materials have been investigated as they offer better heat resistance than traditional cement owing to their ceramic-like properties. Geopolymer was found by Davidovits [15]. It is a polymerization reaction of silica and alumina. One of the bright substitute materials with similar chemical composition of silica and alumina is fly ash. A selection to the production of ecological concrete is the development of geopolymer. Geopolymer is an inorganic alumina silica material which is formed from waste material containing silica and alumina under alkaline conditions. The three benefits of using geopolymers are durability, application, and characterization. Thermal, abrasion, acid, and freeze/thaw resistance are geopolymer durability resources. Meanwhile, application aspects from geopolymer are geopolymer concrete, geopolymer concrete panels, geopolymer concrete columns, and geopolymer concrete wall panels. The last geopolymer aspects are characterization, which consist of microstructure, FTIR, and XRD.

The measurement of mechanical properties from geopolymer concrete is worn as a basis for selecting materials. Compressive strength test is one of mechanical properties tests. Curing is needed in preparing geopolymer compressive strength test specimens due to the better formation of hydration gels in it. Curing temperature and conditions are crucial factors that determine the properties of geopolymers, but their impacts on the heat resistance of geopolymers remain unclear. Sajan et al. [16] investigated the impact of curing temperature, alkaline concentration, and curing period of fly ash based geopolymer to compressive strength of geopolymer. Three different concentrations of NaOH: 10 M, 12 M, and 14 M were used in this study. M denotes the molarity. The test results [16] present that the compressive strength of geopolymer is mostly determined by the curing temperature as contrasted to alkaline concentration and curing period. A competitive compressive strength of about 30 MPa is obtained from geopolymer samples cured at 60 °C and 80 °C even when prepared with less alkaline activator and cured for a shorter period. This surveillance is convinced by the microscopic analysis of samples at each curing temperature that explains the formation of microcracks, amount of unreacted fly ash, sodium-aluminosilicate hydrate crystals (NASH), calcium-silicate hydrate (CSH) crystals and efflorescence.

In addition, oven and microwave curing were used in [17]. It is found that specimen compressive strength results by microwave-cured are higher at the range from 5.5% to 15.5% than that by oven curing. Gultekin, A.; and Ramyar [17] finding is the energy consumption value by using microwave curing lower between 77.1% and 87% than that by using oven curing. Bai et al. [18] reported quick preparation of carbonized high titanium slag (CHTS) based geopolymer with better properties by using distinct curing techniques such as microwave irradiation and thermal heating. It is found that an efficient preparation method is by combining pre-curing treatment. Pre-curing treatment steps are thermal heating at 60℃ for 6 h, and microwave radiation at 210 W for 15 min. The compressive strength result of the geopolymer in this study reached 76.33 MPa. The better formation of hydration gels in geopolymer samples are obtained by applying a combination pre-curing process. Thus, a high-quality hydration structure with the lowest porosity and micro-cracks was obtained.

Celikten, and Erdogan [19] presented the mechanical and microstructural properties of geopolymer mortars before and after uplifted temperature subjection. Finely ground raw perlite (RP) and Class F Fly Ash (FA) are basic material for geopolymer mortar. Geopolymer mortars synthesis was executed at 90°C during 4, 8, and 24h. Mass ratios of RP/FA are 100/0, 75/25, 50/50, 25/75, and 0/100. Several tests regarding the hardened properties were conducted after curing for 7, 28, and 90 days. The geopolymer mortars were heated up to raised temperatures of 400°C, 600°C, and 800°C, individually. This study found that from the compressive strength results, at early ages, RP-based geopolymer mortars need 24 h or more heat curing time for the development of compressive strength test results. On the other hand, the increase in the *fc* of FA-based geopolymer mortars with the increase of thermal curing time from 8 h to 24 h was limited with respect to the RP-based geopolymer mortars. Gultekin, and Ramyar [20] conducted an investigation into high-temperature support of oven-and microwave-cured pumice-,perlite-,fly ash- and burnt clay based geopolymer. The investigation results were compared with that of the cement mortars. High-temperature impacts on the matrix microstructure are inspected by SEM. The transformation in the crystal structure were set by XRD analyses. High-temperature experiments were executed with 3h exposure to 450, 600, 750, and 900°C. [20] study found that both oven- and microwave-cured geopolymer mortars are more resistant to high-temperatures at all temperatures than their Portland cement counterpart.

Saludung et al. [21] presented geopolymers from fly ash and ground granulated blast furnace slag by using sodium silicate and sodium hydroxide solutions as alkaline solutions. Four different curing conditions, namely, heat curing (70 ◦C for 24 h), ambient curing (20 ◦C), water curing, and the combination of heat and water curing (70 ◦C for 24 h followed by water curing), were applied due to examine the effect of curing conditions on the high-temperature performance of geopolymer. At 28 d, the specimens were subjected to high temperatures (500 ◦C, 750 ◦C, and 950

◦C), and their mechanical and microstructural evolutions were examined. Saludung et al. [21] revealed that the curing condition significantly affects the properties of the unexposed geopolymer; the effect on its high-temperature performance is insignificant. Furthermore, all the specimens could maintain adequate compressive strength after exposure to the maximum temperature of 950 ◦C, promising the use of geopolymer for structural applications. Meanwhile, Alexander et al. [22] developed a mix proportion for geopolymer mortar cured at ambient temperature, utilizing the by-products of industries like fly ash (FA) and ground granulated blast-furnace slag (GGBS) as the binder. Proportions of FA and GGBS, molarity of NaOH solution, Na_2SiO_3 /NaOH ratio, and alkaline liquid/binder ratio are this study [22] criterion. The addition of GGBS at 10–30 % is suitable for achieving the compressive strength at ambient temperature curing. As a consequence, to assess the practical application of geopolymer mortar, microstructure studies at curing age of 90 days and durability tests over an exposure period of 180 days were conducted on F70:G30, F80:G20, F90:G10 mortar specimens and compared with ordinary Portland cement (OPC) control mixes. SEM, XRD, and FTIR results affirmed the polymerization process in the geopolymer and hydration in OPC. This study [22] found that the increased C-A-S-H gel formation in the microstructure of F70:G30 specimen denser than that of F80:G20 and F90:G10 specimens. The percentage of weight loss with the increase in temperature at curing age of 90 days was assigned by using TGA. It was found that the extent of disintegration of compounds at high temperatures is lower in geopolymer mortar (F70:G30) than in OPC mortar.

Besides curing, another factor that has an impact on geopolymers is NaOH Molarity. Yomthong et al. [23] examined two manufacturing parameters in preparation of high-strength fly ash based-geopolymer: concentrations of NaOH solution and curing regimes. It is found that a sharp rise in compressive strength to 55.7 MPa was observed when the solution concentration was increased from 4 to 6 molar (M). M indicates the molarity. The compressive strength was quite improved at further increase in the concentration up to 12 M. This is because of the increase of setting time of the paste. The other result from this study for the diver's regimes, the resulting compressive strength was not significantly different. The appropriate curing regime was the one at 90°C in the water-saturated atmosphere for 24 hours. It is followed by that at room temperature in the water-saturated atmosphere for 72 hours and finally at room temperature in a dry normal atmosphere for 72 hours.

Chen et al. [24] used ultra-fine fly ash (RUFA) as a basic material of RUFA geopolymer. The binder weight ratio was managed at the same level by differing the concentration of the NaOH solution. Escalating the concentration of NaOH also led to an upgrade in compressive strength. A high NaOH concentration of 12 mol/L resulted in compressive strength of 97.6 MPa at 28 days. Finally, increasing the concentration of NaOH increased the formation of the primary reaction geopolymerization product, N-A-S-H gel, resulting in a denser microstructure with lower porosity. Al-mashhadani et al. [25] made fly ash-based geopolymer concrete with various filling materials and the effect of different NaOH concentrations on the properties of the resulted composites. The used activating solution consisted of Na_2SiO_3 and NaOH and the studied molarities were 12 M and 8 M. Microstructural characterizations that included scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to measure strength, and physical properties, abrasion resistance, and freezing-thawing behavior. Al-mashhadani et al. [25] found that the response of including crushed limestone and waste foundry sand was useful in terms of the general properties of the fabricated specimens. In line with the response result, the microstructural analyses showed a compact matrix that could be treated in line with the obtained results from the other tests. Another finding in study [25] is the higher concentration of sodium hydroxide showed slightly better mechanical strength results compared to the samples with low sodium hydroxide molarity. The most significant improvement was approximately 3% for the 28th day's compressive strength results.

Saridemir et al. [26] aimed to anatomize the impacts of silica modulus (Ms modulus), Na concentration and fly ash (FA) content on the mechanical and microstructural properties of vapour-cured (at 75 ◦C for 8 h) ground granulated blast furnace slag (GGBFS)-based geopolymer mortars (GPMs). In the admixtures of 27 different GPM mixtures with 0, 25 and 50 % percentages of FA, the sodium silicate and NaOH were worn for the mortar production with at three different Ms of 0.25, 0.5 and 1.0, and the amount of activators was determined to provide 3, 6 and 9 % Na concentration as a percentage of total precursor (GGBFS or GGBFS + FA). Experimental results of this study [26] showed that the optimum Ms modulus was 0.5 for the vapour-cured mortars made with 0 % FA and was 1.0 for the vapour-cured mortars produced with 25 and 50 % FA. Another finding is the highest flexural strength (*Fs*), and compressive strength (*Cs*) values were achieved on the vapour-cured mortars made with 6 % Na, and 50 % FA.

Nakum et al. [27] considered the impact of changing the alkaline solution to flash ratio on the strength and workability of a self-compacted geopolymer concrete mix, including fly ash. Ratios of alkaline solution to fly ash used in order to create geopolymer concrete mixes are 0.6, 0.7, and 0.8. Whilst the ratio of sodium silicate (Na_2SiO_3) to sodium hydroxide (NaOH) remained constant at 3. The alkaline solution is made by mixing a sodium silicate (Na_2SiO_3) with three sodium hydroxide molarities (10 M, 12 M and 14 M correspondingly). Sampel was cured at 80°C for 24 h and kept at room temperature until testing. The finding of this study [27] is that the ratio of alkaline solution to fly ash increases, the workability of geopolymer concrete rises and the compressive strength falls. Another result is increasing the sodium hydroxide dose decreases the workability of fresh concrete but increases the compressive strength.

Many studies regarding curing and NaOH concentration have been conducted. Curing and NaOH concentration is demanded in setting up geopolymer compressive strength test specimens due to the better production of hydration gels in it. Curing temperature, curing conditions, and NaOH concentration are crucial factors that determine the properties of geopolymers. The purpose of this research is to figure out the consequence of curing type of twenty-eight days and three NaOH molarities of compressive strength fire resistance fly ash-based geopolymer concrete. Three NaOH molarities as same with NaOH molarities in study [23] are used in this study, that are 2, 4, and 6 M. M denotes molarity.

2. Material and Method

Materials and methods in order to make geopolymer concrete are explained in these two sections, respectively. Materials in this study consist of basic material (fly ash), alkaline solution (NaOH and Na_2SiO_3), and aggregate. Meanwhile, the method section consists of step by step procedures in order to make fly ash-based geopolymer concrete.

2.1. Materials

Geopolymer basic material that is used in this study is fly ash, which comes from Electrical Steam Power Plant-Suralaya. Figure 1 presents fly ash. Whilst Table 1 shows chemical composition from the result of XRF. In addition, Natrium Silicate (Na_2SiO_3) and Natrium Hydroxide (NaOH) are used as alkaline solutions. Meanwhile limestone with maximum size of 10 mm and specific gravity 2.57 used as a coarse aggregate. White sand from Bangka island with specific gravity of 2,56 and fineness modulus 2.9 is used as a fine aggregate.

Fig. 1. Fly ash.

Table 1. Fly ash chemical composition.

Formula	Concentration %
SiO_2	38.79
Fe_2O_3	21.84
Al_2O_3	18.51
CaO	12.23
SO_3	2.41
TiO_3	1.76
K_2O	1.66
P_2O_5	0.93
Cl	0.67
MnO	0.35
SrO	0.31
ZrO_2	0.13
Nd_2O_3	0.10
ZnO	0.07

2.2. Methods

Geopolymer concrete mixture used as can be seen in Table 2 were taken from [28]. NaOH solution was made 24 hours before. Mixing the NaOH solution and Na_2SiO_3 can be set a few hours before concrete blending. Fine and coarse aggregate were set under Saturated Surface Dry (SSD) condition. SSD is defined as the situation of an aggregate in which the outers of the particles are dry (i.e., surface suction would no longer take place), but the inter-particle voids are saturated with water. In SSD condition, aggregates will not affect the free water content of a composite material.

The blending process begins by mixing fly ash and the alkaline solution for 5-10 minutes. Coarse and fine aggregate were casted into the mixer which consists of fly ash and alkaline solution paste. Process of blending takes place around 10-15 minutes until analogous fresh concrete is formed. In the matter to obtain mechanical properties of fly ash geopolymer concrete, cylinder concrete specimens with the dimension 100/200 mm are used.

Table 2. Geopolymer concrete mix design percentage (kg/m^3).

		NaOH molarity		
No.	**Material**	**2M**	**4M**	**6M**
1	**Coarse aggregate (kg)**	37.26	37.26	37.26
2	**Fine aggregate (kg)**	31.74	31.74	31.74
3	**Fly ash (kg)**	20.53	20.53	20.53
4	**Na_2SiO_3 (kg)**	7.85	7.85	7.85
5	**NaOH (kg)**	0.20	0.37	0.52
6	**Water (kg)**	2.42	2.25	2.10

3. Results and Discussion

In order to get a wide range of compressive strength value, the test specimens were conducted by using 2 types of curing methods, either with steam curing or water curing. 2M, 4M, and 6M are three molarities that have been used in this study, as can be seen in Table 2. The compressive strength values of geopolymer concrete with steam curing and water curing are shown in Tables 3 and 4, respectively. On the other hand, 3 different molarity geopolymer concrete for compressive strength values of this study presented in Fig. 2. Two types of curing, eq. Water and Steam Curing were used in Fig. 2.

From Table 3 and Table 4. the value of the compressive strength test comes from five specimens. In Fig. 2. the greater the molarity of a reactant. the faster the reaction rate will take place. The higher the molarity means the denser and more molecules it contains. These molecules move and collide constantly so that the reaction will take place more quickly. On density 4 molar compressive strength value has decreased due to alkaline activator solution undergoes hardening faster. so the solution cannot be mixed homogeneously 100%. resulting in reduced volume solution in the proper mix design. It can be concluded that the higher the number activator molarity is not always advised by growing up the compressive strength of the resulting geopolymer concrete.

Table 3. Compressive strength of geopolymer concrete (MPa) with steam curing.

	Compressive Strength of Geopolymer Concrete (MPa)		
	Steam Curing		
Specimen	**2M**	**4M**	**6M**
1	5	5.18	20.26
2	5.58	4.17	16
3	6.27	4.29	18.27
4	5	4.68	14.89
5	5.36	4.88	21.97

Table 4. Compressive strength of geopolymer concrete (MPa) with water curing.

	Compressive Strength of Geopolymer Concrete (MPa)		
	Water Curing		
Specimen	**2M**	**4M**	**6M**
1	5.57	4.5	15.68
2	5.38	3.77	18.27
3	5.46	3.58	19.69
4	4.59	3.87	13.47
5	4	4.49	14.09

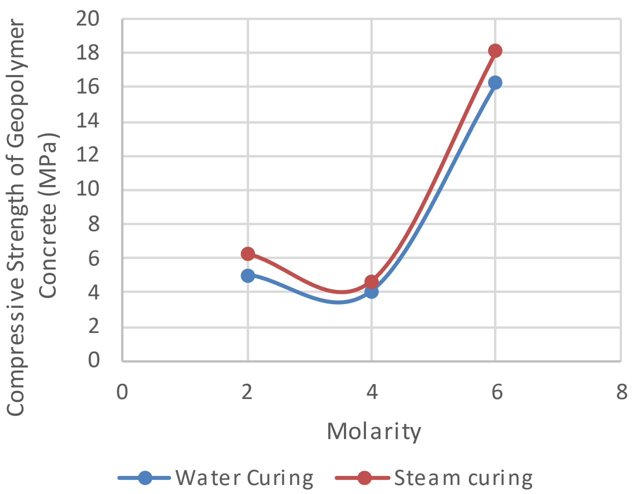

Fig. 2. Compressive strength of geopolymer concrete based on water curing and steam curing for 3 different molarities.

4. Conclusions

Compressive strength test as one of mechanical properties tests is used in this study in order to acknowledge the impact of curing type and three different molarities. According to the results of the tests obtained in this study. the following conclusion can be obtained as follows:

- The value of geopolymer concrete compressive strength of steam curing is slightly higher than that of water curing
- The value of geopolymer concrete compressive strength of 2M higher than that of 4 M.
- The value of geopolymer concrete compressive strength of 6M higher than that of 4 M.

Based on the first result. in order to facilitate workability in the field work. steam curing can be used to replace water curing. Whilst. according to second and third results. NaOH molarity of 6M has the highest compressive strength value than that of 2M and 4M. As a summary. the higher the number activator molarity is not always accompanied by increasing high compressive strength of the resulting.

Acknowledgments

The Author would like to acknowledge that this research is funded by BLU POK. Faculty of Engineering. State University of Jakarta. No.: 365/UN.39/HK.02/2022. 18th. April 2022 and P3MI 2020.

References

1. Farida, F.M.; Sofwan, A.; and Surahman, A. (2021). A review of preliminary experimental factors of making geopolymer paste as passive fire protection. *International Journal on Advanced Science Engineering Information Technology*, 11(2), 674-681.
2. Wang, J.; Zheng, X.; Zhu, Y.; Wang, Z.; Zhou, H.; and Yu, S. (2022). Covalently functionalized hierarchical MnO_2@LDH nanostructure as building blocks for fire-safe and mechanic-robust epoxy composites. *Applied Surface Science*, 592, 1-17.
3. Gnanachelvam, S.; Ariyanayagam, A.; and Mahendran, M. (2021). Effects of insulation materials and their location on the fire resistance of LSF walls. *Journal of Building Engineering*, 44, 1-14.
4. Kim, Y.U.; Chang, S.J.; Lee, Y.J.; No, H.; Choi, G.S.; and Kim, S. (2021). Evaluation of the applicability of high insulation fire door with vacuum insulation panels: experimental results from fire resistance, air tightness, and condensation tests. *Journal of Building Engineering*, 43, 1-10.
5. Qi, F.; Sun, J.; Zhu, G.; Li, H.; Wu, Y.; Li, S.; Yang, C.; Zheng, J.; and Zhang, Y. (2022). Recycling of blast furnace slag to prepare calcium silicate hydrate by mechanical-chemical co-activation and its application to silicate fireproof board. *Process Safety and Environmental Protection*, 165, 1-12.
6. Tian, J.; Yang, Y.; Xue, T.; Chao, G.; Fan, W.; and Liu, T. (2022). Highly flexible and compressible polyimide/silica aerogel with integrated double network for thermal insulation and fire-retardancy. *Journal of Materials Science & Technology*, 105, 194-202

7. Yan, M.; Fu, Y.; Pan, Y.; Cheng, X.; Gong, L.; Zhou, Y.; Ahmed, H.; and Zhang, H. (2022). Highly elastic and fatique resistant wood/silica composite aerogel operated at extremely low temperature. *Composites Part B*, 230, 1-11.
8. Lami-Mendes, A.; Potinha, A.D.R.; Alves, P.; Santos, P.; and Duraes, L. (2021). Progress in silica aerogel-containing materials for building thermal insulation. *Construction and Building Materials*, 286, 1-32.
9. Wi, S.; Yang, S.; Kim, Y.U.; Kang, Y.; and Kim, S. (2022). Toxicity characteristics and fire retardant performance of commercially manufactured organic insulation materials for buildings applications. *Construction and Building Materials*, 341, 1-11.
10. Amran, M.; Huang, S.S.; Debbarma, S.; and Rashid, R.S.M. (2022). Fire resistance of geopolymer concrete: a critical review. *Construction and Building Materials*, 324, 1-26.
11. Klima, K.M.; Schollbach, K.; Brouwers, H.J.H.; and Yu, Ki. (2022). Thermal and fire resistance of class f fly ash based geopolymers-a review. *Construction and Building Materials*, 323, 1-17.
12. Cadavid-Giraldo, N.; Velez-Galleego, M.C.; and Restrepo-Boland, A. (2020). Carbon emmisions reduction and financial effects of a cap and tax system on an operating supply chain in the cement sector. *Journal of Cleaner Production*, 275, 122-583.
13. Mijarsh, M.A.; Megat Johari, M.A.; and Ahmad, Z.A. (2015). Compressive strength of treated palm oil fuel ash based geopolymer mortar containing calcium hydroxide, aluminium hydroxide and silica fume as mineral additives. *Cement and Concrete Composites*, 60, 65-81.
14. Mehta, A.; Siddique, R.; Aggoun, S.; Lagod, G.; and Barnat-Huek, D. (2017). Influence of various parameters on strength and absorption properties of fly ash based geopolymer concrete design by Taguchi. *Construction and Building Materials*, 150, 817-824.
15. Davidovits, J. (2013). Geopolymer cement: a review. *Technical Paper*, 21, 1-11.
16. Sajan, P.; Jiang, T. ; Lau, C.K.; Tan, G.; Ng, K. (2021). Combined effect of curing temperature, curing period and alkaline concentration on the mechanical properties of fly ash-based geopolymer. *Cleaner Materials*, 1, 1-13.
17. Gultekin, A.; and Ramyar, K. (2022). Effect of curing type on microstructure and compressive strength of geopolymers mortar. *Ceramics International*, 48, 1-17.
18. Bai, C.; Deng, Y.; Zhou, Q.; Deng, G.; Yang, T.; and Yang, Y. (2022). Effect of different curing methods on the preparation of carbonized high-titanium slag based geopolymers. *Construction and Building Materials*, 342, 128023, 1-12.
19. Celikten, S.; and Erdogan, G. (2022). Effects of perlite/ fly ash ratio and the curing conditions on the mechanical and microstructural properties of geopolymers subjected to elevated temperatures. *Ceramics International*, 48, 27870-27877.
20. Gultekin, A.; and Ramyar, K. (2023). Investigation of high-temperature resistance of natural pozzolan-based geopolymers produced with oven and microwave curing. *Construction and Building Materials*, 365, 130059, 1-9.
21. Saludung, A.; Azeyanagi, T.; Ogawa, Y; and Kawai, K. (2023). Mechanical and microstructural evolutions of fly ash/ slag-based geopolymer at high temperatures: effect of curing conditions. *Ceramics International*, 49, 2091-2101.

22. Alexander, A.E.; and Shashikala, A.P. (2022). Studies on the microstructure and durability characteristics of ambient cured fa-ggbfs based geopolymer mortar. *Construction and Building Materials*, 347, 128538, 1-19.
23. Yomthong, K.; Wattanasiriwech, D.; Aungkavattana, P.; and Wattanasiriwech, S. (2021). Effect of naoh concentration and curing regimes on compressive strength of fly ash-based geopolymer. *Materials Today: Proceedings*, 43, 2647-2654.
24. Chen, K.; Ting-Lin, W.; and Liu, W. (2021). Effect of naoh concentration on properties and microstructure of a novel reactive ultra-fine fly ash geopolymer. *Advance Powder Technology*, 32, 2929-2939.
25. Al-mashhadani, M. M.; and Canpolat, O. (2020). Effect of various naoh molarities and various filling materials on the behaviour of fly ash based geopolymer composites. *Construction and Building Materials*, 262, 120560, 1-9.
26. Saridemir, M.; and Celikten, S. (2023). Effect of ms modulus, na concentration. and fly ash content on properties of vapor-cured geopolymer mortars, exposed to high temperature. *Construction and Building Materials*, 363, 1-12.
27. Nakum, A.V.; and Arora, N.K. (2022). The impact of alkaline solution to fly ash ratio with different molarities of sodium hydroxide on self- compacted geopolymer concrete. *Materials Today: Proceedings*, 62, 4168-4176.
28. Hardjasaputra, H.; Cornelia, M.; Gunawan, Y.; Surjaputra, I.V.; Lie, H.A.; Rachmansyah; and Ng-Pranata, G. (2019). Study of mechanical properties of fly ash-based geopolymer concrete. *IOP Conference Series: Materials Science and Engineering*, 615, 2019, 012009.