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ORIGINAL RESEARCH PAPER

Evaluating the performance of alkali activated concrete with fly ash, lime and GGBS

Sonal Banchhor*, Meena Murmu and Shirish V Deo

Department of Civil Engineering, National Institute of Technology, Raipur-492010, India

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ABSTRACT

Alkali Activated Concrete (AAC) is a moderately new form of concrete that has gotten a lot of interest in recent decades owing to its environmental advantages and features. However, further research into the effects of various proportions of fly ash, ground granulated blast furnace slag (GGBS), and lime on the characteristics of calcium-based AAC is still needed. This work aims to provide detailed information about the characteristics of AAC with various concentrations of fly ash, GGBS, and lime in order to produce the best combinations for engineering applications. The alkali activators in this investigation are sodium hydroxide and calcium silicate. All concrete mixes are examined for workability, strength, and durability for knowing the impact of fly ash, GGBS, and lime on AAC performance. The results specify that the increase in dosage of GGBBS diminishes the workability. The accumulation of only lime and GGBS shows optimum strength and durability results. In this study further regression analysis has been carried out for predicting the strength of the AAC. The regression equation was developed using the response surface approach for reliably predicting experimental outcomes with an acceptable margin of error.

KEYWORDS

alkali activated materials, lime, GGBS, fly ash, workability, strength, durability

1. INTRODUCTION

Concrete is the most extensively employed material owing to the ease with which raw materials can be obtained, as well as its strength and durability. Cement is used as a binder in concrete [1]. The cement manufacture emits a huge amount of greenhouse gases [2]. There is a need to minimize the cement utilization in concrete. In this scenario researchers are studied the utilization of alkali activated materials (AAM) in concrete [3, 4]. As a substitute to Ordinary Portland cement (OPC), the use of AAM as a binder exhibits higher strength and durability attributes [5]. To minimize the greenhouse gas excretion in cement manufacturing, the use of AAM as a concrete binder has a considerable impact.

The development of AAM utilizes alkali activators and supplementary materials like fly ash, silica fume, steel slag, and GGBS [6–9]. The hardened paste has been generated and improves the strength and durability in AAC, by the chemical reaction between a solid alumina silicate and an alkali activator [10, 11]. Industrial derivates like silica fume, GGBS, fly ash, and steel slag are the primary precursors for AAM production. Due to the inexpensive accessibility and sufficient composition of silica and alumina, fly ash has been extensively used as appropriate raw material in AAC. When cured at high temperatures, AAC produced with fly ash has exceptional strength and durability [12–15]. At normal temperatures, fly ash's reactivity is very low to activate by alkali activators [16–18]. For precast concrete members, this curing condition may be appropriate, but not appropriate for cast-in situ concrete in practise. In order to broaden the range of possible applications for AAC, a new form of AAC that does not need a high temperature cure must be developed. In addition, the heat curing process's costs and energy usage will be lowered.

*Corresponding author.
Department of Civil Engineering, National Institute of Technology, Raipur-492010, India,
Tel.: +91-7974927762.
E-mail: sonaltikariha15@gmail.com

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To overcome the limitations outlined above, researchers aimed to improve the fly ash reactivity in an alkaline atmosphere [19]. The addition of calcium containing materials along with fly ash in AAC would accelerate fly ash dissolution and increases the development of reaction products [20]. The concrete properties are affected by the accumulation of slag. Many researchers have explored the effect of slag on performance of AAC considering type, dosage of activator, water content and curing conditions [3, 21]. The slag source and replacement level for fly ash can dominantly influence the properties of AAC [3, 22].

Alternatively, the utilization of lime in OPC systems may help with energy saving and carbon reduction, and this has been widely used [23]. The accumulation of lime also improves the performance by the filler effect [24]. The effect of lime addition in AAC is studied in [25] and reported that the results are comparable with Portland cement up to lime content 68 wt%. There has been very limited research reported on the properties of AAC with fly ash, slag, and lime. The main endeavour of the work is to investigate the performance of AAC with various dosages of GGBS and fly ash were added together with lime.

2. METHODS

2.1. Materials

In this work low calcium fly ash, GGBS and lime were utilized as a precursor and calcium silicate, sodium hydroxide are alkali activators. Energy Dispersive X-ray Analysis (EDX) is an X-ray technique used to identify the elemental composition of materials. The samples are examined at 30–35 kV accelerating voltages by an SEM (Zeiss EVO50). Samples were gold coated before samples were taken to examination, using sputter coating Emitech K575. The elemental composition of GGBS and fly ash are listed in Table 1. As fine aggregate, locally accessible river sand conforming to Zone-II specifications was utilized. The natural sand having maximum size of 4.75 mm with specific gravity of 2.69 was chosen as fine aggregate. In accordance with IS: 383-2016 [26] coarse aggregates of 10 and 20 mm with specific gravity of 2.6 and 2.7 are utilized. The alkaline activator was developed by combining sodium hydroxide (NH) with potable water and calcium silicate solution (CS).

Table 1. The elemental chemical composition of fly ash and GGBS

Component	Fly ash (Wt. %)	GGBS (Wt.%)
O	42.34	34.23
AL	9.87	6.98
Na	0.54	0.49
Ca	19.72	42.67
Au	2.40	1.39
Si	19.12	13.43
Cl	0.96	-
K	1.63	0.12
Fe	2.03	0.67
S	1.39	0.02

2.2. Concrete mix proportions

In this study the AAC mix proportions are prepared by varying different proportions of fly ash and GGBS along with lime as shown in Table 2. Also, the parameters considered in this work are illustrated in Table 2. The mixing of concrete has been done in the concrete laboratory at National Institute of Technology Raipur. The coarse aggregate, fine aggregate, and admixtures were poured into the mixer and mixed for 2 min. For proper mixing, half quantity activators were added to concrete and it was mixed thoroughly for two minutes. The remaining quantity of activators was added and concrete was mixed for 2–4 min up to getting a homogeneous mix. The casting of cubes and beams start after the testing of fresh concrete properties such as slump cone.

The mix proportion details are listed in Table 3. Using the factors that have the greatest impact on compressive strength, eleven trial mixes were created by altering the slag and fly ash concentration, along with the lime content. Binder content, CS/NH ratio, density, and activator to binder ratio, were all maintained at the same level. The aggregates, GGBS, fly ash, and lime were mixed well along with activators, super plasticizers and mixed for around 5 min. Following mixing, the concrete is poured into steel moulds for preparing the concrete samples for testing. Following casting, the test specimens are allowed to cure in the open air for a period of time before being kept at room temperature. The test was performed on 7 and 28-day maturities. To get the findings, the test was conducted on three distinct samples.

For the mix proportions listed in Table 3 workability tests are conducted by slump cone test, strength tests are carried out by compressive and flexural strength tests. Similarly, durability tests are carried out by electrical resistivity and acid attack tests.

2.3. Testing methods

The workability of AAC is often poorer than OPC concrete, due to the existence of silicate in AAC, which causes it to be sticky. Nonetheless, even with a low slump value, AAC compacts nicely on a vibrating table. As a result, the workability of AAC is graded according to the compaction condition, as illustrated below [27]. When AAC reaches 90 mm or more slump, it is considered a very workable. Due of the high vibration of compaction, AAC with slump values

Table 2. Details of parameter used in this study

Parameter	Proportion
Binder Content	400 kg m^{-3}
CS/NH	2.46
Al/Bi	50%
Density	2,400 kg m^{-3}

Table 3. Mix proportions of concrete

Mix proportions	Ingredient contents (kg m^{-3})						
	Fly ash	Lime	GGBS	Calcium silicate	Sodium hydroxide	Fine aggregate	Coarse aggregate
AAC0	400	0	0	143.0	58.0	650.0	1,150
AAC1	320	80	0	143.0	58.0	650.0	1,150
AAC2	310	80	10	143.0	58.0	650.0	1,150
AAC3	298	80	22	143.0	58.0	650.0	1,150
AAC4	282	80	38	143.0	58.0	650.0	1,150
AAC5	266	80	54	143.0	58.0	650.0	1,150
AAC6	250	80	70	143.0	58.0	650.0	1,150
AAC7	170	80	150	143.0	58.0	650.0	1,150
AAC8	90	80	230	143.0	58.0	650.0	1,150
AAC9	10	80	310	143.0	58.0	650.0	1,150
AAC10	0	80	320	143.0	58.0	650.0	1,150

between 50 and 89 mm is classed as medium workability, while AAC with below 50 mm slump is treated as poor workability. As a result, these criteria were used in this work to assess the best AAC concrete mix in terms of workability. After mixing of concrete for all concrete mixes the slump cone test has been conducted to study the workability as per IS: 1199-2004 [28]. After testing the workability of concrete the cube specimens having size of 100 × 100 × 100 mm and beam specimens having size of 100 × 100 × 500 mm are casted for testing the compressive and flexural strength of concrete. The samples are cured in normal room conditions having temperature 24–26 °C and a relative humidity of 55–65%. All the concrete samples were tested in triplicate for a curing interval of 7 and 28 days as per IS: 516-2006 [29]. A Leader RCONTM Concrete Electrical Resistivity Meter was used for measuring the concrete electrical resistance. For this study, 100 × 100 × 100 mm cubes were used. The test has been performed on 7 and 28 days cured samples on triplicate. The test has been performed as per ASTM C 1202 standards [30]. The acid resistance of concrete cube specimens was determined using the ASTM C 267 standards. The 28 days samples of size 100 × 100 × 100 mm were utilized for this test. These cubes kept in water containing 5% of H_2SO_4 solution in plastic tubs for 28 days. The weight and strength loss of cubes immersed in H_2SO_4 solution as compared to initial samples has been recorded for understanding the acid attack on AAC mixes.

3. RESULTS AND DISCUSSION

3.1. Workability

The slump cone test details are depicted in Fig. 1. From Fig. 1 it is recognized that concrete mix AAC0 and AAC1 has a slump value of over 90 mm and these mixes are regarded as highly workable mixes. The remaining other mixes slump values are ranges in between 60 and 89 mm and these mixes are regarded as medium workable mixes. The accumulation of only fly ash as binder in AAC mix shows optimum enhancement in workability. At the same time, the accumulation of GGBS in AAC mix as replacement to fly ash diminishes the workability. The mix AAC10 contains 320 kg of GGBS and 80 kg of lime shows 33% decrease in the workability of concrete as compared to the mix AAC0 containing 400 kg of fly ash as binder. This is due to the faster calcium reaction and the angular form of slag [31].

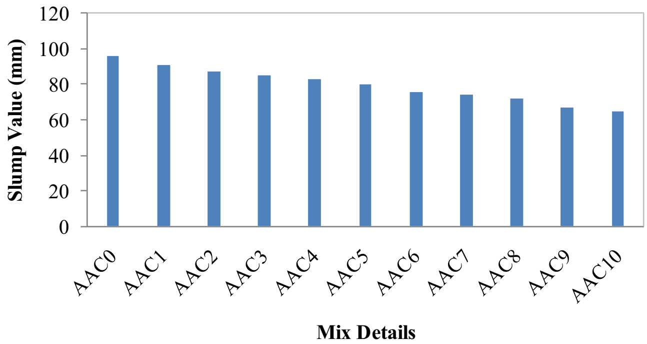

Fig. 1. Slump cone test results

3.2. Compressive strength

The utmost essential mechanical quality of concrete is its compressive strength. According to ACI 318 M-05 [32], concrete 28-day compressive strength must reach 28 MPa for basic industrial implementations. Concrete must have a minimum compressive strength of 35 MPa in order to prevent concrete reinforcing against corrosion. Using these parameters, the best AAC mixes for compressive strength was identified in this research. Figure 2 depicts the strength results of all mixes. From Fig. 2 it is recognized that the 28 days strength results of mixes AAC0, AAC1, AAC2, and AAC3 are below the 28 MPa and are not suitable for engineering applications. Also, the strength results of mixes AAC0 to AAC5 are below 35 MPa, for these mixes have less corrosion protection. The addition of only lime and GGBS shows optimal development in the compressive strength in comparison with the mixes containing fly ash. Similar pattern of results has been noticed in both 7- and 28-day samples. The increasing in the quantity of GGBS enhances the strength. This is due to the development of C-A-S-H

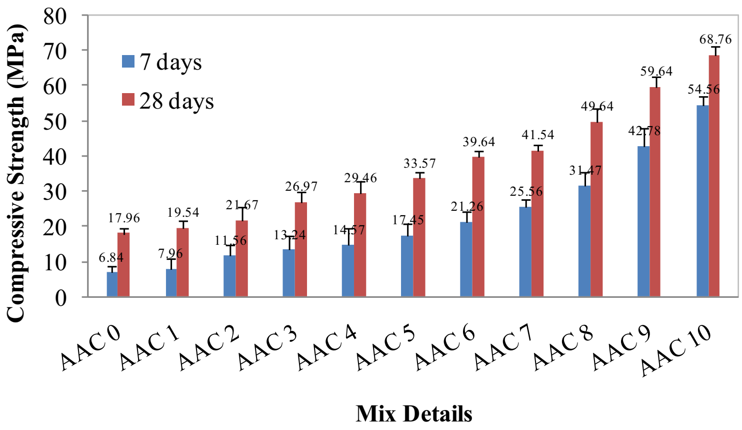

Fig. 2. Compressive strength test results

gels, which lower the porosity of the AAC matrix and improves the microstructure [33].

3.3. Flexural strength

The test has been conducted to all mixes in triplicate as per IS: 516-2006 [29]. The test results are represented in Fig. 3. From Fig. 3 it is recognised that the addition of GGBS and lime without fly ash indicate optimum augmentation in flexural strength in comparison to concrete mixes containing fly ash. The alternative of fly ash with GGBS also increases the flexural strength. The interaction of alkali activators with the SiO_2 and Al_2O_3 in the GGBS aids in the development of C-A-S-H, C-S-H, and N-A-S-H, gels in AAC [34]. The development of these gels is responsible for the increase in strength. The inclusion of GGBS results in greater early strength, for the reason that the nucleation impact of Ca^{2+} accelerates the hydration process of AAC [35]. Furthermore, the release of Ca^{2+} from lime and its topographical features may contribute to the development of strength and pore structure modification by providing additional surface binding inside the particles, thereby enhancing the overall structure [36].

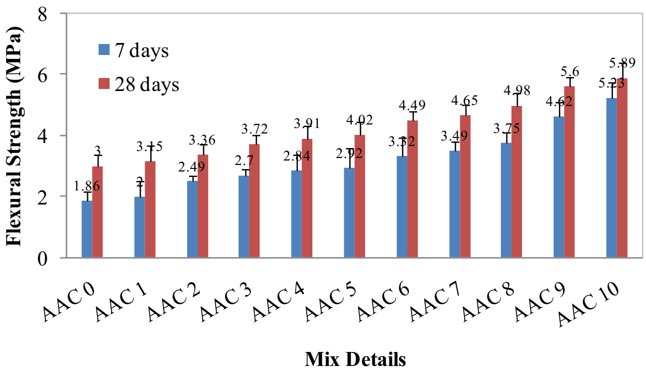

Fig. 3. Flexural strength test results

3.4. Acid attack

Figures 4 and 5 illustrate the test results of acid attack in terms of weight loss and strength loss. From Figs 4 and 5 it is noticed that the strength loss and weight loss are following the same trend for all concrete mixes. The mix AAC10 shows better acid attack resistance as compared to all other mixes. The mix AAC10 contains only GGBS and lime as binder. The accumulation of GGBS as substitute to fly ash along with lime shows dense structure that enhances the resistance towards acid attack.

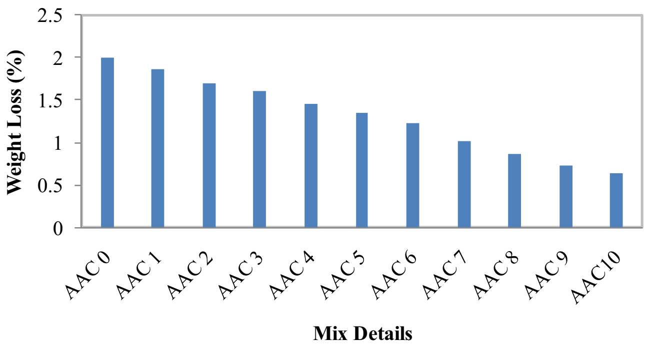

Fig. 4. Weight loss of mixes due to acid attack

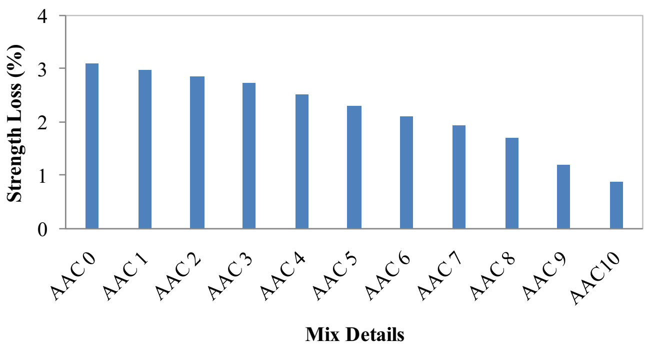

Fig. 5. Strength loss of mixes due to acid attack

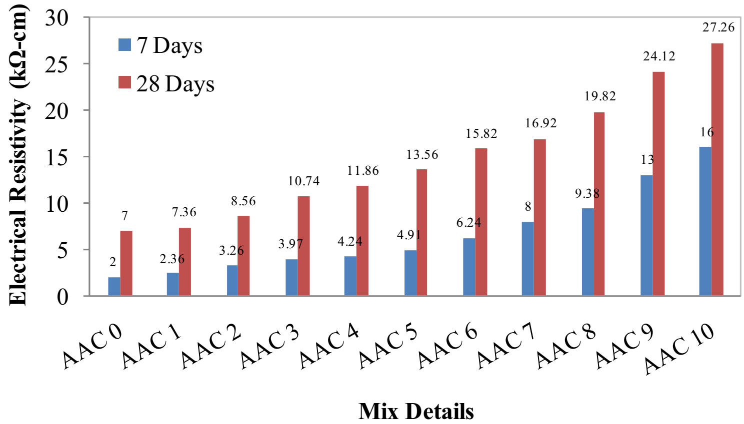

Fig. 6. Electrical resistivity test results

3.5. Electrical resistivity

Electrical resistivity testing was done on concrete to assess the quality of the material in terms of pores and micro-cracks. The bulk electrical resistivity test was conducted as per ASTM C 1202. The electrical resistivity of AAC was measured utilizing Eq. (1) [37].

$$\rho = \frac{A}{L} \times z \quad (1)$$

Where, (ρ) is the resistivity of AAC ($k\Omega$-cm),

(A) is the cross-sectional area of the specimen (cm^2),
(L) is the length of the specimen (cm) and
(Z) denotes the impedance measured by the device ($k\Omega$).

The test was conducted to all mixes in triplicate respectively. Figure 6 denotes the electrical resistivity test results of AAC mixes. From Fig. 6 it is noticed that the electrical resistivity results followed the similar pattern as of strength results. The mix AAC1 shows 5% improvement in electrical resistivity in comparison to the mix AAC0. The mix AAC5 shows 93% enhancement in electrical resistivity as compared to the mix AACO. Similarly, the mix AAC6 shows 123% enhancement in electrical resistivity of concrete in comparison with the mix AACO. As the proportion of GGBS increases as alternative to fly ash, the electrical resistivity of AAC also increases. The addition of only GGBS along with lime shows optimum results in electrical resistivity test results. The GGBS and lime content as binder gives dense structure to AAC by minimizing the voids and pores in micro-structure. Thus, the electrical resistivity of concrete enhances.

4. REGRESSION ANALYSIS

Regression analysis is a sophisticated arithmetical method for examining the correlation between two or more variables of interest. In this study regression analysis has been performed to predict the compressive strength of concrete considering the dosage of fly ash, dosage of GGBS and age of sample as input variables. The regression analysis yielded the following regression Eq. (2).

$$\text{Compressive Strength} = -13.14 + 0.053x + 0.175y + 0.722z \quad (2)$$

Where,

x = Dosage of fly ash (kg)
y = Dosage of GGBS (kg)
z = Age of sample (Days)

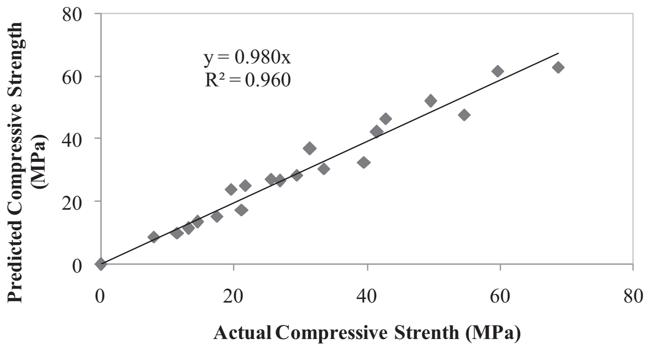

Fig. 7. Actual and predicted compressive strength results

The experimental and predicted compressive strength results are depicted in Fig. 7. From Fig. 7 the disparity in total variance is just 0.04 percent, the created model's co-efficient of determination (R^2 = 0.960) demonstrates that it falls within a permissible error range. Considering the R^2 value of the developed model it is a good fit model.

5. CONCLUSIONS

The effect of different proportions of fly ash and GGBS along with lime on properties of AAC was studied. The accumulation of only fly ash in AAC is optimum for enhancing the workability. The increasing the proportion of GGBS as replacement to fly ash diminishes the workability.

The strength results confirm that addition of GGBS along with lime shows optimum results as compared to the mixes containing fly ash. Further the acid attack and electrical resistivity test results also confirm that the addition of GGBS along with lime as binder in AAC provides dense structure to the concrete by minimizing voids and micro-cracks in concrete. The utilization of calcium based activators along with lime enhances the performance of concrete. Further, regression analysis has been used to build up a model for predicting the compressive strength of AAC. The coefficient of determination (R^2) value confirms that the developed model is a good fit model and predicts the compressive strength accurately. From the results it was suggested that the addition GGBS and lime in AAC mixes enhances the properties of AAC.

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REFERENCES

[1] C. R. Gagg, "Cement and concrete as an engineering material : an historic appraisal and case study analysis," *Eng. Fail. Anal.*, vol. 40, pp. 114–40, 2014.

[2] J. Gale, Y. K. Eds, N. Mahasenan, S. Smith, and K. Humphreys, "The cement industry and global climate change : current and potential future cement industry co2 emissions," *Greenh. Gas Control Technol.*, vol. II, no. 1, pp. 995–1000, 2010.

[3] P. Nath and P. K. Sarker, "Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition," *Constr. Build. Mater.*, vol. 66, pp. 163–71, 2014.

[4] X. Fan and M. Zhang, "Experimental study on flexural behaviour of inorganic polymer concrete beams reinforced with basalt rebar," *Compos. Part B*, vol. 93, pp. 174–83, 2016.

[5] K. Yang, J. Song, and K. Song, "Assessment of CO_2 reduction of alkali-activated concrete," *J. Clean. Prod.*, vol. 39, pp. 265–72, 2013.

[6] A. Mehta, R. Siddique, T. Ozbakkaloglu, F. Uddin, A. Shaikh, and R. Belarbi, "Fly ash and ground granulated blast furnace slag-based alkali-activated concrete : mechanical, transport and microstructural properties," *Constr. Build. Mater.*, vol. 257, pp. 1–10, 2020.

[7] A. F. Abdalqader, F. Jin, and A. Al-tabbaa, "Development of greener alkali-activated cement: utilization of sodium carbonate for activating slag and fly ash mixtures," *J. Clean. Prod.*, vol. 113, pp. 66–75, 2016.

[8] J. S. J. Van Deventer, J. L. Provis, and P. Duxson, "Technical and commercial progress in the adoption of geopolymer cement," *Miner. Eng.*, vol. 29, pp. 89–104, 2012.

[9] G. L. Thankam, T. R. Neelakantan, and S. C. Gnanaraj, "GGBS based alkali activated fine aggregate in concrete - properties at fresh and hardened state," *Int. Rev. Appl. Sci. Eng.*, vol. 13, no. 2, pp. 239–45, 2022.

[10] F. Puertas, G. B. Fonteboa, G. I. Taboada, M. M. Alonso, F. Puertas, and B. Gonz, "Alkali-activated slag concrete : fresh and hardened behaviour," *Cem. Concr. Compos.*, vol. 85, pp. 22–31, 2018.

[11] C. Shi, A. F. Jiménez, and A. Palomo, "Cement and Concrete Research New cements for the 21st century : the pursuit of an alternative to Portland cement," *Cem. Concr. Res.*, vol. 41, no. 7, pp. 750–63, 2011.

[12] W. D. A. Rickard, J. Temuujin, and A. Van Riessen, "Thermal analysis of geopolymer pastes synthesised from five fly ashes of variable composition," *J. Non. Cryst. Sol.*, vol. 358, no. 15, pp. 1830–9, 2012.

[13] A. F. Æ. I. Garcı and A. Palomo, "Durability of alkali-activated fly ash cementitious materials," *J. Mater. Sci.*, vol. 42, pp. 3055–65, 2007.

[14] M. Talha, A. Khennane, O. Kayali, A. Sadaoui, D. Picard, and M. Fafard, "Aspects of the deformational behaviour of alkali activated fly ash concrete at elevated temperatures," *Cem. Concr. Res.*, vol. 60, pp. 24–9, 2014.

[15] X. Guo, H. Shi, and W. A. Dick, "Compressive strength and microstructural characteristics of class C fly ash geopolymer," *Cem. Concr. Compos.*, vol. 32, no. 2, pp. 142–7, 2010.

[16] M. Ibrahim, M. Azmi, M. Johari, M. Kalimur, M. Maslehuddin, and H. Dafalla, "Enhancing the engineering properties and microstructure of room temperature cured alkali activated natural pozzolan based concrete utilizing nanosilica," *Constr. Build. Mater.*, vol. 189, pp. 352–65, 2018.

[17] K. Somna, C. Jaturapitakkul, P. Kajitvichyanukul, and P. Chindaprasirt, "NaOH-activated ground fly ash geopolymer cured at ambient temperature," *Fuel*, vol. 90, no. 6, pp. 2118–24, 2011.

[18] S. Alonso, T. Va, F. Puertas, and S. Martõ, "Alkali-activated fly ash/slag cement Strength behaviour and hydration products," *Cem. Concr. Res.*, vol. 30, pp. 1625–32, 2000.

[19] A. M. Rashad, "A comprehensive overview about the influence of different admixtures and additives on the properties of alkali-activated fly ash," *Mater. Des.*, vol. 53, pp. 1005–25, 2014.

[20] S. Puligilla and P. Mondal, "Role of slag in microstructural development and hardening of fly ash-slag geopolymer," *Cem. Concr. Res.*, vol. 43, pp. 70–80, 2013.

[21] P. Nath and P. K. Sarker, "Flexural strength and elastic modulus of ambient-cured blended low-calcium fly ash geopolymer concrete," *Constr. Build. Mater.*, vol. 130, pp. 22–31, 2017.

[22] G. L. Thankam, T. R. Neelakantan, and S. C. Gnanaraj, "GGBS based alkali activated fi ne aggregate in concrete - properties at fresh and hardened state," *Int. Rev. Appl. Sci. Eng.*, vol. 13, no. 1, pp. 47–53, 2022.

[23] B. Yilmaz and A. Olgun, "Studies on cement and mortar containing low-calcium fly ash, limestone, and dolomitic limestone," *Cem. Concr. Compos.*, vol. 30, pp. 194–201, 2008.

[24] M. Antoni, J. Rossen, F. Martirena, and K. Scrivener, "Cement substitution by a combination of metakaolin and limestone," *Cem. Concr. Res.*, vol. 42, no. 12, pp. 1579–89, 2012.

[25] A. J. Moseson, D. E. Moseson, and M. W. Barsoum, “High volume limestone alkali-activated cement developed by design of experiment,” *Cem. Concr. Compos.*, vol. 34, no. 3, pp. 328–36, 2012.
[26] IS 383: 2016, “Coarse and fine aggregate for concrete - specification,” *Bur. Indian Stand.*, no. 3, pp. 1–21, 2016.
[27] M. T. Junaid, O. Kayali, A. Khennane, and J. Black, “A mix design procedure for low calcium alkali activated fly ash-based concretes,” *Constr. Build. Mater.*, vol. 79, pp. 301–10, 2015.
[28] IS: 1199-1959, “Methods of sampling and analysis of concrete,” *Bur. Indian Stand.*, no. 11, pp. 1–49, 2004.
[29] IS: 516-1959, “Methods of test for strength of concrete,” *Bur. Indian Stand.*, no. 18, pp. 1–30, 1959.
[30] ASTM C1202, “Standard test method for electrical indication of concretet’s ability to resist chloride ion penetration,” Am. Soc. Test. Mater., no. C, pp. 1–8, 2012.
[31] P. Sarathi, P. Nath, and P. Kumar, “The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature,” *Mater. Des.*, vol. 62, pp. 32–9, 2014.
[32] A. M318-05, “Building Code Requirements for Structural Concrete and Commentary, American Concrete Institude,” 2005.
[33] X. Wan, D. Hou, T. Zhao, and L. Wang, “Insights on molecular structure and micro-properties of alkali-activated slag materials : a reactive molecular dynamics study highlights,” *Constr. Build. Mater.*, vol. 139, pp. 430–7, 2017.
[34] A. Rafeet, R. Vinai, M. Soutsos, and W. Sha, “Guidelines for mix proportioning of fly ash/GGBS based alkali activated concretes concretes,” *Constr. Build. Mater.*, vol. 147, pp. 130–42, 2017.
[35] W. Hai-long, W. Jun-jie, S. U. N. Xiao-yan, and J. I. N. Wei-liang, “Improving performance of recycled aggregate concrete with superfine pozzolanic powders,” *J. Cent. South Univ.*, vol. 20, pp. 3715–22, 2013.
[36] A. Cwirzen, J. L. Provis, V. Penttala, and K. Habermehl-cwirzen, “The effect of limestone on sodium hydroxide-activated metakaolin-based geopolymers,” *Constr. Build. Mater.*, vol. 66, pp. 53–62, 2014.
[37] V. N. Kanthe, S. V Deo, and M. Murmu, “Effect of fly ash and rice husk ash on strength and durability of binary and ternary blend cement mortar,” *Asian J. Civ. Eng.*, vol. 6, pp. 1–8, 2018.