Natural Pozzolans a Comparative Study: A Review

Ashish Shukla¹*, Nakul Gupta², Ankur Gupta³, Rajesh Goel¹, Sanjeev Kumar⁵
¹, ², ³ Department of Civil Engineering, GLA University, Mathura 281406, INDIA
⁴ NICMAR, NCR 124507, INDIA
⁵ JC Bose University of Science and Technology, YMCA, Faridabad 121006, INDIA

as302389@gmail.com

Abstract. Exploitation of Natural Pozzolans (Calcined Clay, Calcined Shale & Metakaolin) as Supplementary Cementitious materials (SCMs) for mortar and concrete has attended goodish observance in last decades. In this content the NP used in vast range in partial substitution of cement in concrete and mortar, and due to its pozzolanic behavior, it improves the performance of concrete and mortar strength and durability. The minimization of carbon-dioxide emissions in the cement industry due to the increasing involvement of NP(Natural Pozzolans). The different proportions of NP as partial substitute results in enhancing the comp. strength, water absorption, sorptivity etcetera and it gives the resistance to the structure of mortar and concrete to action of harmful solution.

1. Introduction
Concrete is the vastly used and versatile building material that is used to resist C.S. In construction work like building, roads, dams & other infrastructure, concrete has the main contribution. In every year's production, it is the second most-consumed substance with about 270 MMT. During the goodish monitoring in late years, there has been an increasing demand for reducing carbon dioxide emissions in the cement manufacturing industry[1]–[3]. By using SCMs, cement consumption reduction can be managed by extracting raw materials and emissions of carbon dioxide during cement production[4][5][6]. The natural replacement used in concrete has resulted in natural resources being consumed and depleting the surface of ozone[7].

Various technical experiments and researches are being conducted to enhance the property of concrete. The major term is to enhance the structural properties of concrete. NP has distinctive properties than other SCMs like FA, GGBS, and Marble dust etcetera[8][9]. Natural Pozzolans are of three types as Calcined Clay (CC), Metakaolin (MK) & Calcined Shale (CS). Many industries using NP due to their lower cost and accessibility[10]. NP is efficacious at minimizing the heat of hydration of concrete, which enhances workability and durability[11].

The feasibility and efficiency of using NP as a cement substitute in concrete are examined in this study. This reviews the work carried out by many researchers considering the following test: Comp. S, Water absorption, sorptivity, sulphate attack and (ASR)[12].
Table 1: Natural Pozzolans Properties and Chemical Composition[7]

| CONTENT             | MK   | CC   | CS   |
|---------------------|------|------|------|
| Fe$_2$O$_3$ %       | 0.51 | 4.0  | 8.1  |
| Al$_2$O$_3$ %       |  42  |  30  |  21  |
| SO$_3$ %            |  0.11|  0.50|  0.40|
| CaO %               |  0.10|  1.0 |  8.0 |
| Na$_2$O %           |  0.05|  0.21|  NIL |
| SiO$_2$ %           |  52.5|  57.5|  51  |
| K$_2$O %            |  0.45|   2.1|  NIL |
| Total Na eq. alk. % |  0.30|  1.50|  NIL |
| LOI %               |  0.75|  1.50|  3.5 |
| Blaine Fineness m$^2$/kg | 19.000 | 992 | 735 |
| Relative density    |  2.51|  2.52|  2.64|

2. Review of Literature

2.1. Sabir B.B, (2001)
The resistance of concrete to wounding solutions and groovy enrichment in the pore structure caused by the partial substitution of MK and CC in cement[13]. This study also investigated that MK is an extremely efficient NP, which results in the enhancement of early strength gain and CC is exceedingly effective in some improvement in the LTSG[14]. By the goodish observance for great enhancement in diffusion ions & migration of water leading to barbarization of the matrix[4][15][16][17][18].

2.2. PCA_manual/Chap03.pdf[19]
The researchers show the phenomenon of NP on the freshly mixed concrete. It demonstrates the water requirement, workability, air content, bleeding & segregation, the heat of hydration, setting time etcetera[20]. This study reviews the comparative relation of CC, CS & MK in respect of Long term strength gain (LTSG), Early age strength gain (EASG), Drying shrinkage & Creep (DS & C), Abrasion resistance(AR), Permeability & Absorption (P & A), Corrosion resistance (CR), Sulphate resistance (SR), Alkali silica reactivity (ASR), Freezing & Thawing (F & T) & Deicer scaling resistance (DSR)[21][22][23][24].

Table 2: phenomenon of Natural Pozzolans

|         | Calcined clay[4] | Calcined shale[4] | Metakaolin[25] |
|---------|-------------------|-------------------|----------------|
| EASG    | Diminish          | Diminish          | Enhance        |
| LTSG    | Enhance           | Enhance           | Enhance        |
| AR      | Zero effect       | Zero effect       | Zero effect    |
| DS & C  | Zero effect       | Zero effect       | Zero effect    |
| P & A   | Diminish          | Diminish          | Diminish       |
| C R     | Enhance           | Enhance           | Enhance        |
| ASR     | Diminish          | Diminish          | Diminish       |
| S R     | Enhance           | Enhance           | Enhance        |
| F & T   | Zero effect       | Zero effect       | Zero effect    |
| D S R   | Diminish or have  | Diminish or have  | Diminish or have Zero effect |
|         | Zero effect       | Zero effect       |                 |
2.3. Mayuri A. Chandak (2018)[26]
With the substitution of 25% of MK in cement enhances the chemical properties viz. comp. strength, tensile strength, split strength, flexure strength & durability[27].
- The use of MK improves the water absorption, permeability which leads to enriching the density of concrete[28].
- MK reduces the efflorescence, to make calcium carbonate from the atmosphere, calcium transports water to the surface and it combines with carbon di oxide[29][30].

2.4. An Cheng (2012)[31]
The Calcined Shale at 800°C enumerates the best pozollanic strength. The reduction in CaO content leads to the retardation of the setting time[32][33]. 800°C and 900°C are the range of shale at which calcined.

2.5. Potgieter S.S, (2016)
This research analyses MK and Activated MK (CC) experimental behavior at several 550 ° C-850 ° C temperatures. MK & CC replaces cement by up to 30 percent and lists the comp. Strength. Replacing 30% of MK and CC in concrete would greatly improve the compressive strength and work capacity[28]. [34]–[37].

2.6. Gaston Espinoza-Hijazin (2012)[38]
This study concluded that the substitution of NP gives the difference between the maxim and minim strength was 19.8% as followed the w/c ratio for different proportion[39]–[41].Concrete properties that SCMs affect and their degree of influence shown in the Table -3 given below. Along with other mixture parameters the properties will varies dependant on the dosages and constituents of material[42][43]–[46].

Table 3: Physical Properties of Natural Pozzolans

|                      | CS   | CC   | MK     |
|----------------------|------|------|--------|
| Workability          | Enhance | Enhance | Diminish |
| Water Demand         | Zero effect | Zero effect | Enhance |
| Setting time         | Zero effect | Zero effect | Zero effect |
| Bleeding and         | Zero effect | Zero effect | Diminish |
| Segregation          |       |       |        |
| Air content          | Zero effect | Zero effect | Diminish |
| Heat of Hydration    | Diminish | Diminish | Zero effect |

The Table 4 demonstrates standard oxide examination of different pozzolans, Ground granulated Blast Furnace slag and Portland cement. While acid oxides (alumina and silica) vary greatly between pozzolans and other composants, it appears that silica is a Main Compound in their structure, and the most common characteristic of processed pozzolans and natural[47][48]. For natural pozzolans, the glassy silica forms of rapid cooling of lava formed, and usually consist of transparent spherical parts[49][50]. Ranid cooling also forms a vitreous amorphous structure of pozzolane artificial waste (for example, fly ash and silica fume) and Ground granulated Blast Furnace slag[51].

For Metakaolin, calcination at temp. that are generally lower than necessary to produce a liquid form, and the glass formed during cooling, breaks down crystalline structure[52]. Calcined clay's pozzolanic reactivity is consistent with extracting structural water from crystalline clays, which create an amorphous or semiamorphic hard-surface substance and strong chemical reactivity. Depend on the nature of mineral clay’s and on the thermal energy needed for hydroxyl ions release, the calcinating temperature necessary[53].
### Table 4: Compression between MK & Other Pozzolans

| Pozzolans                | Percent   |
|--------------------------|-----------|
|                          | Al₂O₃     | SiO₂   | Fe₂O₃ | MgO | CaO | SO₃ | Na₂O+K₂O | Loss on ignition |
| Portland Cement[54][55][56] | 4.63     | 21.00 | 2.26  | 1.18 | 65.6 | -   | 0.94      | 0.99            |
| Ground granulated Blast Furnace slag[57][58][59] | 16.00    | 34.00 | 0.32  | 8.83 | 36.92 | 2.67 | 0.87      | 0.00            |
| Fly Ash[8][46][25]     | 26.4      | 49.10 | 9.3   | 1.4  | 1.4  | 0.8  | 5.0       | 4.90            |
| Silica Fume[60][61]    | 0.7       | 92.00 | 1.2   | 0.2  | 0.2  | -    | 2.0       | 3.00            |
| Metakaolin[62][47]     | 41.00     | 52.10 | 4.32  | 0.19 | 0.07 | -    | 0.89      | 0.60            |
| Ground Clay Brick[63]  | 19.05     | 54.83 | 6.00  | 1.77 | 9.39 | 2.9  | 3.65      | 1.48            |

### Table 5: Comparative Study Review of used NP

| Originator                        | REFERENCE                                                                 | POZZOLANS TYPE | RESULT                                                                 |
|-----------------------------------|---------------------------------------------------------------------------|----------------|------------------------------------------------------------------------|
| S. J. Chao, An Cheng, W. T. Lin[31]| Effect of calcination temperature on CS mortar's pozzolanic reaction. (2012) Switzerland, Trans Tech Publications. | Shale of Calcined with a temperature of 500 °C to 900 °C. | The C.S of samples is increased to 7, 28, 56 days. The C.S of samples displays lower absorption of water and ultra-wave velocity, which is similar to compressive test results. |
| J H Potgieter, Potgieter S. S, P Napo[64] | Metakaolin's effect on the development of strength in cement mortars.(2016) ICE Publishing, South Africa. | Up to 30% replacement of metakaolin and calcined clay. | The C.S of metakaolin rises by replacement proportion (10%, 20% and 30%). The C.S of metakaolin increases by 10% and 30% respectively with Calcined clay. C.S of 30NP for 28 & 90 days is 50.75 & 58.4Mpa respectively, while C.S of 40NP for 28 & 90 days is 27.5 & 36.4Mpa respectively. Max C.S reaches 30% for 28 days as compared to other proportions. |
| Walid Deboucha[65]                | Additional influence of natural pozzolana on mortar compressivity. | Substitution of Natural Pozzolans ranging 30% to 40% for obtaining the reduction in C.S. | It demonstrates that MK enhances the early strength gain & CC improves the long-term strength gain. |
| Osei D. Y.[66]                    | Workability and Compressive strength of concrete which substitutes normal Portland cement by pozzolana. 2012. | The C.S of replacement of 30% as compared to 3%, 12%, 24% for 7, 14, 21 & 28 days respectively. | It demonstrates that MK enhances the early strength gain & CC improves the long-term strength gain. |
| B.B. Sabir[4]                     | Calcined Clays and Metakaolin as pozzolans for concrete: a review. Cement & concrete | Metakaolin & Calcined Clay substitute with cement for mortar & | It demonstrates that MK enhances the early strength gain & CC improves the long-term strength gain. |
| Venu Malagavelli[67] | Metakaolin influence in concrete as a partial cement substitution. July 7, 2018 | MK replaced with grade of concrete with w/c ratio 0.3 super plasticizer. VARAPLAST PC 432 plasticizer used. | It enumerated the comp. strength for 7 & 28 days at CTM and results the enhancing target strength in 28 days. |

3. Conclusion

- MK enhances the early age strength gain concerning CC & CS.
- All Natural Pozzolans improve the Long term strength gain.
- Permeability & Absorption decreases as the content of Natural Pozzolans content increases.
- Comp. strength of MK in respect of CC & CS at 28 days on CTM increases and enhance the durability and performance of the concrete structure.
- The inverse relation developed between the ASR & NP.

References

[1] B. Ahmadi and M. Shekarchi, “Use of natural zeolite as a supplementary cementitious material,” *Cem. Concr. Compos.*, vol. 32, no. 2, pp. 134–141, 2010.
[2] A. M. Al-Swaidani and A. Meziab, “Study on the optimum nano-natural pozzolan content in the concrete binder,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 615, no. 1, 2019.
[3] M. Ananthkumar and K. M. Mini, “Effectiveness of corrosion resistance of strontium and barium coated rebars - A preliminary comparative study,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 561, no. 1, pp. 1–7, 2019.
[4] B. Sabir, S. Wild, and J. Bai, “Metakaolin and calcined clays as pozzolans for concrete: A review,” *Cem. Concr. Compos.*, vol. 23, no. 6, pp. 441–454, 2001.
[5] G. W. BRINDLEY and M. NAKAHIRA, “The Kaolinite- Mullite Reaction Series: II, Metakaolin,” *J. Am. Ceram. Soc.*, vol. 42, no. 7, pp. 314–318, 1959.
[6] J. Bai, B. B. Sabir, S. Wild, and J. M. Kinuthia, “Strength development in concrete incorporating PFA and metakaolin,” *Mag. Concr. Res.*, vol. 52, no. 3, pp. 153–162, 2000.
[7] E. Ferraz, S. Andrejkovicova, W. Hajjaji, A. L. Velosa, A. S. Silva, and F. Rocha, “Pozzolanic activity of metakaolin by the French standard of the modified Chapelle test: A direct methodology,” *Acta Geodyn. Geomater.*, vol. 12, no. 3, pp. 289–298, 2015.
[8] R. S. Blissett and N. A. Rowson, “A review of the multi-component utilisation of coal fly ash,” *Fuel*, vol. 97, pp. 1–23, 2012.
[9] Y. S. V. Ganesh, P. Durgaiyya, C. Shivanarayana, and D. S. V. Prasad, “Compressive strength of concrete by partial replacement of cement with metakaolin,” *AIP Conf. Proc.*, vol. 1859, 2017.
[10] K. Celik, C. Meral, M. Mancio, P. K. Mehta, and P. J. M. Monteiro, “A comparative study of self-consolidating concretes incorporating high-volume natural pozzolan or high-volume fly ash,” *Constr. Build. Mater.*, vol. 67, pp. 14–19, 2014.
[11] G. K. Al-Chaar, M. Alkadi, and P. G. Asteris, “Natural Pozzolan as a Partial Substitute for Cement in Concrete,” *Open Constr. Build. Technol. J.*, vol. 7, no. 1, pp. 33–42, 2013.
[12] and J. P. J. Ambroise, S. Martin-Calle, “Pozzolanic behavior of thermally activated kaolin,” *ACI Mater. J.*, vol. 103, no. 1, pp. 45–52, 2006.
[13] A. Chakchouk, L. Trifi, B. Samet, and S. Bouaziz, “Formulation of blended cement: Effect of process variables on clay pozzolanic activity,” *Constr. Build. Mater.*, vol. 23, no. 3, pp. 1365–1373, 2009.
[14] A. E. Lavat, M. A. Trezza, and M. Poggi, “Characterization of ceramic roof tile wastes as pozzolanic admixture,” *Waste Manag.*, vol. 29, no. 5, pp. 1666–1674, 2009.

[15] IS-2386-2-1963, “Methods of test for aggregates for concrete,” *Indian Stand.*, pp. 1–31, 1963.

[16] M. Murat, “Hydration reaction and hardening of calcined clays and related minerals. I. Preliminary investigation on metakaolinite,” *Cem. Concr. Res.*, vol. 13, no. 2, pp. 259–266, 1983.

[17] J. R. P. Donald E. Dixon, “Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91) Donald,” 2002.

[18] E. O. Ajayi and A. J. Babafemi, “Effects of pulverized burnt clay waste fineness on the compressive strength and durability properties of concrete,” *Eng. J.*, vol. 22, no. 2, pp. 83–99, 2018.

[19] Memphis, “Fly ash, Slag, silica fume, and natural Pozzolans,” *Des. Control Concr. Mix.*, no. 54048, pp. 57–72, 1996.

[20] R. Firdous, D. Stephan, and J. N. Y. Djobo, “Natural pozzolan based geopolymers: A review on mechanical, microstructural and durability characteristics,” *Constr. Build. Mater.*, vol. 190, pp. 1251–1263, 2018.

[21] [22] K. Scrivener and A. Favier, “Calcined Clays for Sustainable Concrete,” *RILEM Bookseries*, 2015.

[23] S. Bishnoi, S. Maity, A. Mallik, S. Joseph, and S. Krishnan, “Pilot scale manufacture of limestone calcined clay cement : The Indian experience,” no. April 2017, 2014.

[24] V. S. K. . Dr.K.Srinivasu, M.L.N.Krishna Sai, “A Review on Use of Metakaolin in Cement Mortar and Concrete,” *Int. J. Innov. Res. Sci. Eng. Technol. (An ISO Certif. Organ.,* vol. 3297, no. 2, pp. 17–24, 2007.

[25] M. Lamine Zeggar, N. Azline, and N. Azizi Safiee, “Fly ash as supplementry material in concrete : A review,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 357, no. 1, 2019.

[26] M. A. Chandak and P. Y. Pawade, “Influence of Metakaolin in Concrete Mixture : A Review,” pp. 37–41, 2018.

[27] I. P. Hastuty and I. S. Sembiringand Nursyamsi, “Comparison of compressive strength of paving block with a mixture of Sinabung ash and paving block with a mixture of lime,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 309, no. 1, 2018.

[28] B. Patil and P. Kumbhar, “Strength and Durability Properties of High Performance Concrete incorporating High Reactivity Metakaolin,” *IJmer.Com*, vol. 2, no. 3, pp. 1099–1104, 2012.

[29] A. P. Shelorkar and P. D. Jadhao, “Strength Appraisal of High Grade Concrete by using High Reactive Metakaolin,” *Int. J. Innov. Res. Sci. Eng. Technol. (An ISO Certif. Organ.,* vol. 3, no. 7, pp. 14697–14701, 2014.

[30] B. Gorai, R. K. Jana, and Premchand, “Characteristics and utilisation of copper slag - A review,” *Resour. Conserv. Recycl.*, vol. 39, no. 4, pp. 299–313, 2003.

[31] A. Cheng, S. J. Chao, and W. T. Lin, “Effect of calcination temperature on pozzolanic reaction of calcined shale mortar,” *Appl. Mech. Mater.*, vol. 174–177, pp. 843–846, 2012.

[32] T. Kovářík, L. Kullová, and D. Rieger, “Production of refractory chamotte particle-reinforced geopolymer composite,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 123, no. 1, 2016.

[33] K. M. A. Hossain, “Volcanic ash and pumice as cement additives: Pozzolanic, alkali-silica reaction and autoclave expansion characteristics,” *Cem. Concr. Res.*, vol. 35, no. 6, pp. 1141–1144, 2005.

[34] R. Siddique, “Coal Fly Ash,” *Waste Mater. By-Products Concr.*, pp. 177–234, 2007.

[35] D. D. Vu, P. Stroeven, and V. B. Bui, “Strength and durability aspects of calcined kaolin-blended Portland cement mortar and concrete,” *Cem. Concr. Compos.*, vol. 23, no. 6, pp. 471–478, 2001.

[36] M. Singh and M. Garg, “Reactive pozzolana from Indian clays-their use in cement mortars,”
Cem. Concr. Res., vol. 36, no. 10, pp. 1903–1907, 2006.

[37] K. A. Gruber, T. Ramlochan, A. Boddy, R. D. Hooton, and M. D. A. Thomas, “Increasing concrete durability with high-reactivity metakaolin,” Cem. Concr. Compos., vol. 23, no. 6, pp. 479–484, 2001.

[38] G. Espinoza-Hijazin, Á. Paul, and M. Lopez, “Concrete containing natural pozzolans: New challenges for internal curing,” J. Mater. Civ. Eng., vol. 24, no. 8, pp. 981–988, 2012.

[39] J. S. Lawler, James D. Connolly Paul D. Krauss, and Sharon L. Tracy, Guidelines for Concrete Mixtures Containing Supplementary Cementitious Materials to Enhance Durability of Bridge Decks, no. January. 2007.

[40] J. L. Provis, P. Duxson, and J. S. J. van Deventer, “The role of particle technology in developing sustainable construction materials,” Adv. Powder Technol., vol. 21, no. 1, pp. 2–7, 2010.

[41] IS 10262, “Guidelines for concrete mix design proportioning,” Bur. Indian Stand. Delhi, pp. 1–21, 2009.

[42] K. M. A. Hossain and L. Mol, “Some engineering properties of stabilized clayey soils incorporating natural pozzolans and industrial wastes,” Constr. Build. Mater., vol. 25, no. 8, pp. 3495–3501, 2011.

[43] M. M. Hossain, M. R. Karim, M. K. Hossain, M. N. Islam, and M. F. M. Zain, “Durability of mortar and concrete containing alkali-activated binder with pozzolans: A review,” Constr. Build. Mater., vol. 93, pp. 95–109, 2015.

[44] M. M. Hossain, M. R. Karim, M. Hasan, M. K. Hossain, and M. F. M. Zain, “Durability of mortar and concrete made up of pozzolans as a partial replacement of cement: A review,” Constr. Build. Mater., vol. 116, pp. 128–140, 2016.

[45] D. N. Huntzinger and T. D. Eatmon, “A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies,” J. Clean. Prod., vol. 17, no. 7, pp. 668–675, 2009.

[46] M. Jalal, A. Pouladkhan, O. F. Harandi, and D. Jafari, “Comparative study on effects of Class F fly ash, nano silica and silica fume on properties of high performance self compacting concrete,” Constr. Build. Mater., vol. 94, pp. 90–104, 2015.

[47] M. Omrane, S. Kenai, E. H. Kadri, and A. Ait-Mokhtar, “Performance and durability of self compacting concrete using recycled concrete aggregates and natural pozzolan,” J. Clean. Prod., vol. 165, pp. 415–430, 2017.

[48] M. A. Tambichik, N. Mohamad, A. A. A. Samad, M. Z. M. Bosro, and M. A. Iman, “Utilization of construction and agricultural waste in Malaysia for development of Green Concrete: A Review,” IOP Conf. Ser. Earth Environ. Sci., vol. 140, no. 1, 2018.

[49] M. J. Shannag, “High strength concrete containing natural pozzolan and silica fume,” Cem. Concr. Compos., vol. 22, no. 6, pp. 399–406, 2000.

[50] Z. Zhang, B. Zhang, and P. Yan, “Comparative study of effect of raw and densified silica fume in the paste, mortar and concrete,” Constr. Build. Mater., vol. 105, pp. 82–93, 2016.

[51] J. M. Paris, J. G. Roessler, C. C. Ferraro, H. D. Deford, and T. G. Townsend, “A review of waste products utilized as supplements to Portland cement in concrete,” J. Clean. Prod., vol. 121, pp. 1–18, 2016.

[52] A. Salas, S. Delvasto, R. M. de Gutierrez, and D. Lange, “Comparison of two processes for treating rice husk ash for use in high performance concrete,” Cem. Concr. Res., vol. 39, no. 9, pp. 773–778, 2009.

[53] M. Sinka, G. Sahmenko, A. Korjakins, L. Radina, and D. Bajare, “Hemp thermal insulation concrete with alternative binders, analysis of their thermal and mechanical properties,” IOP Conf. Ser. Mater. Sci. Eng., vol. 96, no. 1, 2015.

[54] S. A. Miller, A. Horvath, and P. J. M. Monteiro, “Readily implementable techniques can cut annual CO2 emissions from the production of concrete by over 20%,” Environ. Res. Lett., vol. 11, no. 7, 2016.
[55] O. A. Qasim, “Comparative study between the Cost of Normal Concrete and Reactive Powder Concrete,” IOP Conf. Ser. Mater. Sci. Eng., vol. 518, no. 2, 2019.
[56] F. Pacheco-Torgal, J. Castro-Gomes, and S. Jalali, “Alkali-activated binders: A review. Part 2. About materials and binders manufacture,” Constr. Build. Mater., vol. 22, no. 7, pp. 1315–1322, 2008.
[57] S. Kumar Karri, G. V. R. Rao, and P. M. Raju, “Strength and Durability Studies on GGBS Concrete,” Int. J. Civ. Eng., vol. 2, no. 10, pp. 34–41, 2015.
[58] P. Saranya, P. Nagarajan, and A. P. Shashikala, “Eco-friendly GGBS Concrete: A State-of-The-Art Review,” IOP Conf. Ser. Mater. Sci. Eng., vol. 330, no. 1, 2018.
[59] H. W. Song and V. Saraswathy, “Studies on the corrosion resistance of reinforced steel in concrete with ground granulated blast-furnace slag-An overview,” J. Hazard. Mater., vol. 138, no. 2, pp. 226–233, 2006.
[60] M. Thomas, “The effect of supplementary cementing materials on alkali-silica reaction: A review,” Cem. Concr. Res., vol. 41, no. 12, pp. 1224–1231, 2011.
[61] M. E. S. I. Saraya, “Study physico-chemical properties of blended cements containing fixed amount of silica fume, blast furnace slag, basalt and limestone, a comparative study,” Constr. Build. Mater., vol. 72, pp. 104–112, 2014.
[62] R. Siddique and J. Klaus, “Influence of metakaolin on the properties of mortar and concrete: A review,” Appl. Clay Sci., vol. 43, no. 3–4, pp. 392–400, 2009.
[63] G. Silva et al., “A Comparative Study of Linen (Flax) Fibers as Reinforcement of Fly Ash and Clay Brick Powder Based Geopolymers,” IOP Conf. Ser. Mater. Sci. Eng., vol. 416, no. 1, 2018.
[64] S. S. Potgieter, J. H. Potgieter, and P. Napo, “the Effect of Metakaolin Additions on Strength Development in Cement Mortars,” Challenges Concr. Constr. Vol. 5, Sustain. Concr. Constr., pp. 263–269, 2002.
[65] W. Deboucha, N. Leklou, A. Khelidj, and M. N. Oudjit, “Natural pozzolana addition effect on compressive strength and capillary water absorption of Mortar,” Energy Procedia, vol. 139, pp. 689–695, 2017.
[66] D. Osei and E. Jackson, “Compressive strength and workability of concrete using natural pozzolana as partial replacement of ordinary Portland cement,” J. Adv. Appl. …, vol. 3, no. 6, pp. 3658–3662, 2012.
[67] S. Joshi, “influence of metakaolin in concrete as partial replacement of cement,” Int. J. Civ. Eng. Technol., vol. 9, no. 7, pp. 105–111, 2018.