Catalyst Research Volume 23, Issue 2, September 2023 Pp. 1005-1015

MECHANICAL PROPERTIES AND DURABILITY CHARACTERISTICS INVESTIGATION OF HIGH VOLUME PULVERIZED FUEL ASH (PFA) BASED GEO-POLYMER CONCRETE (GPC)

Vishal Gajghate[1, a *], Dr. Abhijeet Nardey[2, b)]

[1] *GHRU, Saikheda,* [2] *GHRCE, Nagpur*

[a)] vishal.gajghate@ghru.edu.in, [b)] abhijeet.nardey@raisoni.net

Abstract

Geo-Polymer Concrete (GPC) attains low early strength and sustains against freeze – thaw, chemical attacks and corrosions which enables the durable concrete. GPC is durable to resists fire, alkali aggregate reaction, chemical attacks, weathering and acid rains. Especially GPC is designed to resist chemical reactions involving sea water. On Plain Concrete, sea water effects of sulfates, chlorides, magnesium can easily observed along with precipitation of insoluble composites. Later forms crystallization of salts may further corrodes reinforcement.

Durability Property along with mechanical properties as split tensile strength and elasticity modulus has been evaluated for grade of GPC and the results are tabulated. From the results of split tensile strength, as the percentage of PFA increases for designated replacement, the split tensile strength shows decrement. And decrement varies more or less 10 % with variational % replacement of PFA. In modulus of elasticity, the decrement varies about 5 % for various percentage replacement of PFA as designated in TABLE 3. For durability aspect, in acid attack test, more % of scale formation and salt deposition observed on surfaces of ordinary concrete. As % PFA content increasing in GPC, the scale formation and salt deposition reduce respectively. pH of the acid solution recorded 4.74 and maintained before submerging the concrete sample in it. During and after acid attack test, pH of acid solution recorded and observed that the solution turning towards alkalinity with recorded pH 11.12.

Keywords: Mechanical Properties, Durability, Pulverized Fuel Ash (PFA), Geo-Polymer Concrete (GPC)

Introduction

Class – F Fly Ash may attained the cementitious property by adding percentages of activators and variational curing. The particles size of Class – F Fly Ash varies from 0.5 µm to 100 µm. And fineness less than 45 µm. Class - F Fly Ash particles are of Spherical, creates ball-bearing effect in concrete at plastic state resulting higher structural strength when mixed with free lime, decreases the permeability and increases durability. And provide more resistance to acid rain, sea water. Also reduce water content, efflorescence, shrinkage, heat of hydration, alkali-silica reaction, bleeding, and segregation and improves workability and finishing [1]. Pertaining to mentioned characteristics of Fly Ash, it supports the GPC manufacturing.

Previous studies focuses evaluation of mechanical properties of class – C Fly Ash. The prime focus of current study to evaluate the elasticity modulus, split tensile strength and acid attack resistance on Low Calcium GPC for Tropical Environment. GPC is manufactured on material basis using Fly Ash, GGBS, RHA's, Bagasse Ash (BA's) percentage replacements of cement. In tropical environment, GPC plays vital role to withstand against dry weather, heavy rain, sever humidity, acidic, sulfate, chlorides attacks and high temperature variations from shivering cold winter to extreme hot summer to prove its durability service for its designed lifespan.

Past Reviews

In most of the past reviews low calcium Fly Ash (Class – F) based Geo-Polymer concrete manufactured with alkaline activators, water reducers in batches thermally cured in oven. And tested for characteristics performance and durability on drying shrinkage, creep and sulfate resistance. Durability evaluated using sodium sulfate solution. some findings shows excellent against sulfate solution and compressive strength were unchanged [2]. A little change observed on characteristics strength for parametric study of acid attack using sulfate solution [3]. Sulfate resistance has experimented on GGBS based Geo-Polymer concrete and found less mass extinction with changes in characteristics strength [4]. Sulfate, acid and creep resistance evaluated for low calcium fly ash based geo-polymer precast heat cured concrete shows better results but suffers in drying shrinkage [5]. FA based GPC acts superior against acid attack using 5 % Sulfuric and Acetic acid and formation of zeolite takes place. Effect of Sodium Sulfate seen on early and later age flexural strength and least deterioration observed due to 5 % Sodium and Magnesium Sulfate for later aging. Changes were observed visually and in compressive strength [6].

Class – F Fly Ashed GPC is studied in comparison with recycled coarse aggregate and using alkali activators. The mechanical and durability properties viz. compressive strength, indirect tensile strength, sorptivity (rate of absorption) and volume of permeable voids of GPC are measured. Durability aspect is focused in respect of voids, absorption and chemical attack on GPC [7]. Durability of Class – F Fly Ashed GPC is studied when immersed in solution of chloride and sulfate of sodium, magnesium sulfate and sulfuric acid of 5 % each for 9 months and compressive strength, split tensile strength, sorptivity, absorption and porosity evaluated. Concluded that sodium sulfate has great impact on GPC [8]. Acid resistance is studied on one year aged GPC by microstructural analysis and compressive strength is evaluated [9]. Comparative chloride attack on Reinforced OPC and GPC concrete is studied. Especially focuses on corrosion aspect in reinforced OPC & GPC concrete and proved that Reinforced GPC is superior [10,11].

Materials and Proportions

Low Calcium ASTM Class – F PFA from Local Thermal Power Station (KTPS, Koradi), OPC 53 Grade, river sand and Local Quarry Crushed Aggregate (20 mm) made available for this study. Binary blended Cement Concrete was used with replacement of Pulverized Fuel Ash. PFA was used in replacement of cement by the proportion of 50 to 100 % in additive interval of 10 % by

Catalyst Research Volume 23, Issue 2, September 2023 Pp. 1005-1015

weight. The water – binder ratio considered as 0.48 for moderate exposure. The experimented permissible physical characteristics of cement, PFA, sand and quarry crushed aggregate is summarized in Table 1 and Mechanical Characteristics of crushed Aggregate is in Table 2. The Mix Design for Ordinary & GP Concrete is summarized in Table 3. And observed that the total weight of the Designed Standard Concrete for 30 MPa gets reduced with percentage increase of PFA and may produce the light weight concrete. Alkali activator used in combination of Sodium Hydroxide and Sulfuric Acid from (Research Institutional Laboratory) to form Sodium Sulfate solution of pH 3.5 to 5.6.

TABLE 1. Physical Characteristics of Materials

Physical Characteristics	OPC conforming to IS:12269-1987	FA Confirming to IS:2386-1963	CA Confirming to IS:2386-1963	PFA Confirming to IS:3812-2013
Specific Gravity	3.15	2.66	2.82	2.2
Standard Consistency	31 %	--	--	--
Fineness Modulus	2.8	--	--	--
Initial Setting Time	88 Min	--	--	--
Final Setting Time	310 Min	--	--	--
Silt Content	--	2.7 %	--	--
Flakiness	--	--	19.75 %	--
Elongation	--	--	19.75 %	--
Water Absorption	--	--	1.98 %	--
Initial Water	--	--	--	22.84 %

TABLE 2. Mechanical Characteristics of Coarse Aggregate confirming to IS: 2386-1963

Mechanical Strength	**Observed Values**
Impact	15.86 %
Crushing	39.08 %
Abrasion	16.9 %

TABLE 3. Mix Design for Ordinary & GP Concrete

Design Compositions	**Cement**		**Pulverized Fuel Ash (PFA)**		**River Sand**	**Crushed Aggregate**	**Weight of Concrete**
	% Content	**By Weight (Kg/m^3)**	**% Content**	**By Weight (Kg/m^3)**	**By Weight (Kg/m^3)**	**By Weight (Kg/m^3)**	**By Weight (Kg/m^3)**
C-100:PFA-0	100	348	0	0	725	1275	2500
C-50:PFA-50	50	174	50	174	701	1233	2434
C-40:PFA-60	40	139	60	209	696	1225	2421
C-30:PFA-70	30	104	70	244	692	1216	2408
C-20:PFA-80	20	70	80	278	687	1208	2395

Catalyst Research Volume 23, Issue 2, September 2023 Pp. 1005-1015

C-10:PFA-90	10	35	90	313	682	1200	2382
C-0:PFA-100	0	0	100	348	677	1191	2368

Casting of Test Specimen

Ordinary and GP Concrete casted in cube of size 150 mm for evaluation of compressive strength and in beams of 100 mm x 100 mm x 300 mm for flexural strength. Casting molds, cleaned prepared and greased surfaces internally. Fresh concrete poured in to molds casted in three layers and tampered using tamping bar for 25 blows per layer and vibrated for 20 – 30 Seconds on vibrating table and kept in mold for a day [3]. After demolding, the specimens were kept for curing for 3, 7, 28, 90 and 365 days and then tested in temperature controlled laboratory on Automatic Compression Testing Machine (ACTM).

FIGURE 1. Concrete Casting

FIGURE 2. Concrete Testing

Catalyst Research Volume 23, Issue 2, September 2023 Pp. 1005-1015

FIGURE 3. Automatic Compression Testing Machine (ACTM)

Preparation of Acid

Sulfuric Acid is added using eye dropper in water filled container and stirred till to maintain the pH in between 3.5 to 5.6. The solution for acid attack prepared and pH recorded. The solution is prepared for pH of 4.74, which is used for acid attack on ordinary and GP Concrete. The reaction takes place to form Sodium Sulfate and free water.

$$NaOH + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$$

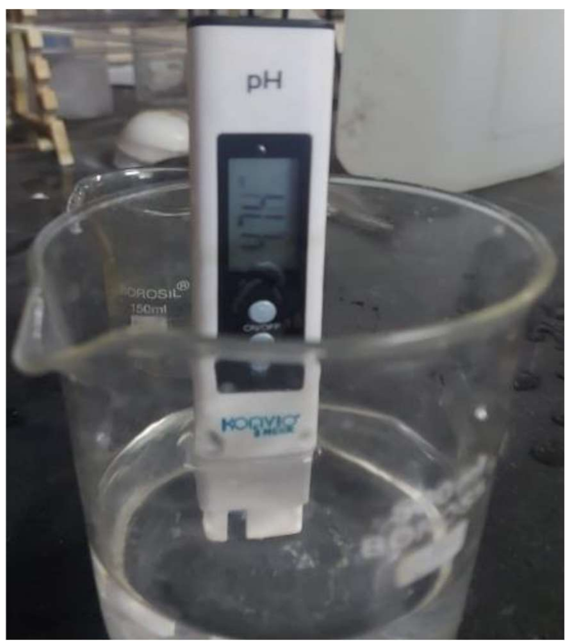

FIGURE 4. Acid Attack Solution

Acid Attack Test: Preliminary Study

Solution of 4.74 pH is prepared and used for acid attack on ordinary and GPC for 7th day compressive strength tests. As the test cube specimens tested on ACTM for 7 day strength test.

FIGURE 5. Samples submerged in Acidic Solution

Samples of cementitious mortar cover with aggregate collected after strength test on ACTM. The test samples collected for different percentage replacement of cement with PFA referring **TABLE 3**. The samples submerged in freshly prepared acid solution for pH of 4.74. Samples submerged in acid solution for 2 days period. Then after samples removed and kept in sunlight exposure for atmospheric drying. Acid solution and submerged samples were kept for observation.

FIGURE 6. Samples exposed for Atmospheric Drying

Results and Discussions

TABLE 4. Split Tensile Strength (MPa) of Ordinary and PFA based GPC Concrete.

Design Compositions	7 Days	28 Days	90 Days	365 Days
C-100:PFA-0	2.54	5.73	7.43	9.26
C-50:PFA-50	1.19	2.43	3.56	4.19
C-40:PFA-60	1.07	2.14	3.29	3.96
C-30:PFA-70	0.86	1.96	2.94	3.63
C-20:PFA-80	NA	1.53	2.72	3.44
C-10:PFA-90	NA	1.23	2.41	3.21
C-0:PFA-100	NA	NA	NA	NA

TABLE 5. Modulus of Elasticity (GPa) of Ordinary and PFA based GPC Concrete.

Design Compositions	7 Days	28 Days	90 Days	365 Days
C-100:PFA-0	7.41	12.42	14.96	18.41
C-50:PFA-50	4.25	6.78	7.78	10.22
C-40:PFA-60	4.22	6.69	7.64	10.07
C-30:PFA-70	4.09	6.50	7.57	9.86
C-20:PFA-80	3.98	6.31	7.51	9.60
C-10:PFA-90	3.67	5.96	7.33	9.32
C-0:PFA-100	NA	NA	NA	NA

TABLE 4 and FIGURE 7 shows tabular and graphical representation of Split Tensile Strength, for no replacement of cement and percentage replacements from 50 % to 100 %. For no replacement of cement and 50 % replacement with PFA, the split tensile strength shows major variations. And for 50 % to 90 % replacements strength shows more or less 10 % variations for same days of tests. And as the percentage replacement of PFA is increasing the split strength decreasing. Though the PFA is a cementitious material, it is partially contributing to the split strength. NA is Not Achieved Values of strength and modulus of elasticity in TABLE 4 and TABLE 5.

TABLE 5 and FIGURE 8 shows tabular and graphical representation of Modulus of Elasticity, for zero replacement of cement and percentage replacement of cement from 50 % to 100 %. For zero replacement and 50 % replacement of cement, elasticity modulus shows major variations. And from 50 % to 90 % replacement, elasticity modulus shows more or less 5 % variations for respective days of tests. Same as split tensile strength, in modulus of elasticity, though the PFA is cementitious material but it contributes less to elastic modulus.

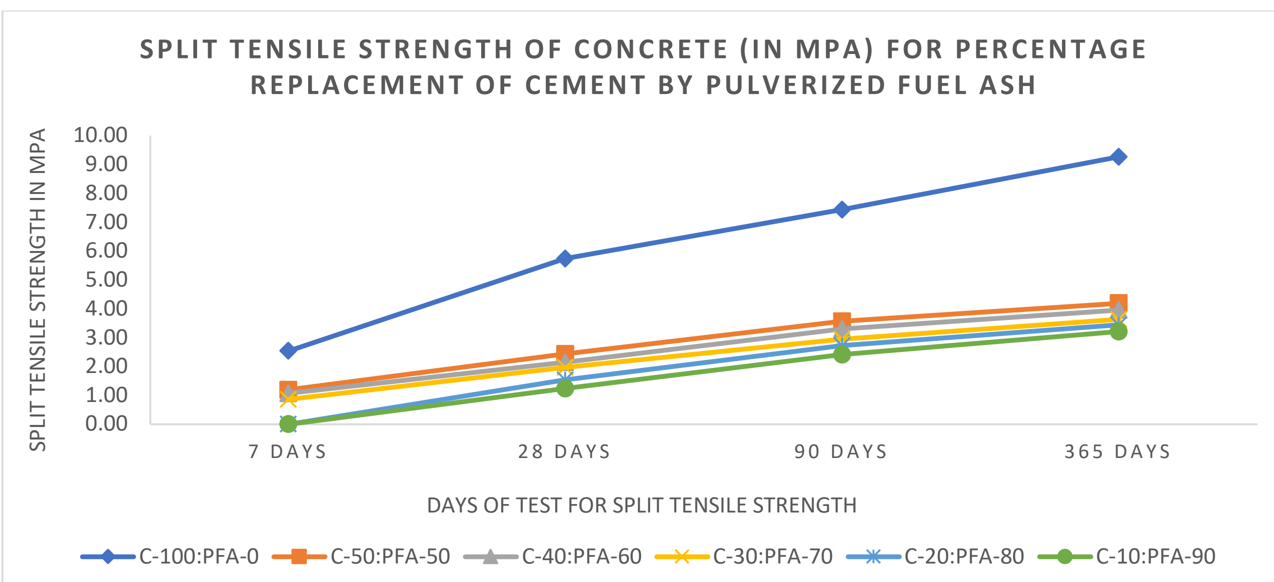

FIGURE 7. Split Tensile Strength (in MPa) of Standard Concrete and Pulverized Fuel Ash (PFA) based GPC Concrete

Catalyst Research Volume 23, Issue 2, September 2023 Pp. 1005-1015

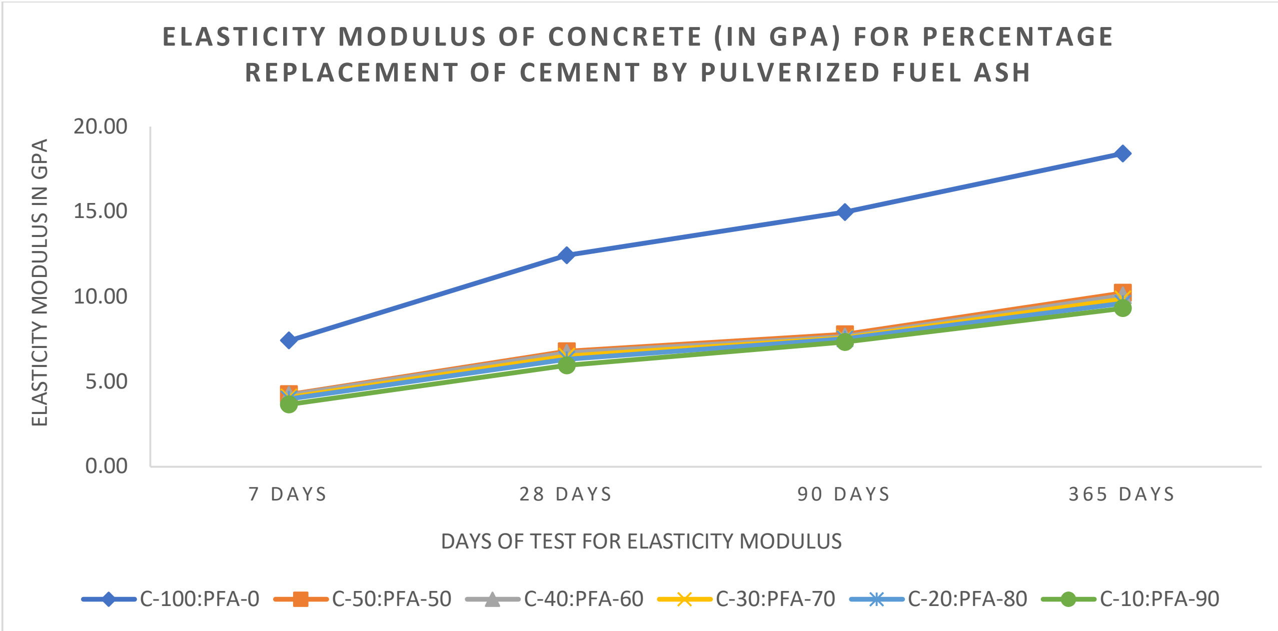

FIGURE 8. Elasticity Modulus (in GPa) of Standard Concrete and Pulverized Fuel Ash (PFA) based GPC Concrete

The study concentrates on mechanical and durability study of PFA based Geo-Polymer Concrete. Preliminary durability study performed and measured on acid attack test on crushed sample from ACTM for different percentage replacement of cement with PFA. Acidic solution prepared and crushed sample for 7 days compressive strength from ACTM submerged in solution for 2 days. Then after sample removed and kept for atmospheric drying. And both crushed sample and solution kept in observation. And on surface of sample of ordinary concrete, scale formation and salt deposition is observed. And as the solution may be reacting with minerals deposition in aggregate and cement content, bubble formation on surface of aggregates of crushed sample is observed. And therefore the scale formation and salt deposition on the surface of crushed sample may takes place.

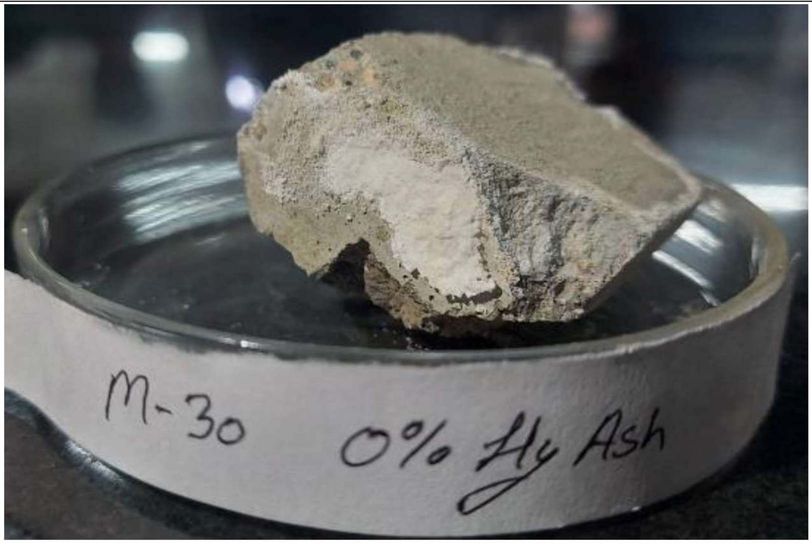

FIGURE 9. Scale Formation and Salt Deposition on Ordinary Concrete sample in Acid Attack Test.

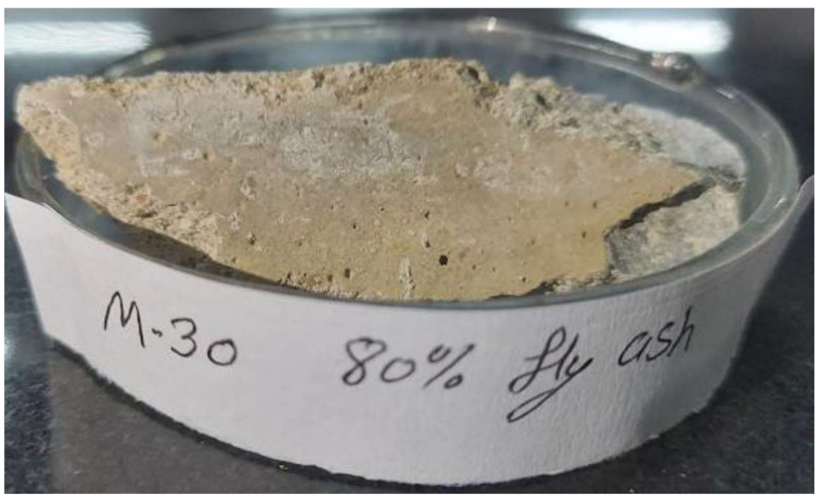

FIGURE 10. Scale Formation and Salt Deposition on 80 % replacement of Cement with PFA in Geo-Polymer Concrete sample in Acid Attack Test.

The crushed samples for designated percentage replacement of cement with PFA in Geo-Polymer concrete submerged in acidic solution for 2 days and then after kept for atmospheric drying. As the cement content decreasing for designated percentage replacement of cement with PFA in GPC, the scale formation and salt deposition on surfaces of GPC also deceases. Acid solution reacting with % cement content and minerals in aggregate. More percentage of cement content in GPC, the scale formation and salt deposition on surfaces will be more and vice-versa. Increasing percentage of PFA also plays vital role against the acid attack. As the particle size of PFA is less as compare to that of cement, it restrains the entry of solution in pours of test sample. And may be therefore, the scale formation and salt deposition on crushed sample of Geo-Polymer concrete is less as comparison to that of ordinary concrete. FIGURE 9 and FIGURE 10 shows the scale formation and salt deposition on surfaces of crushed sample of ordinary concrete and 80 % replacement of cement with PFA in Geo-Polymer concrete respectively.

Apart from the crushed sample for non-replacement and with replacement of cement by PFA for designated percentage replacement in Geo-Polymer concrete is observed for acid attack test. The acid solution in which the concrete sample submerged, observed on pH parameter before and after removing the concrete sample from it. And it is observed that the pH of acid solution rises to alkaline after 24 hours of sample submergence.

FIGURE 11. pH of Acid Solution rises towards Alkaline.

Acknowledgement

I would like to thank the Vice Chancellor, G. H. Raisoni University, Saikheda (M. P.) for constant support in progressive research of Ph. D. Program and to make available the facilities of experimentation. And also thank to Supervisor for constant motivation and guiding support towards conceptual, experimental knowledge sharing.

References

[1] Behera, R. K., 2010, “CHARACTERIZATION OF FLY ASH FOR THEIR EFFECTIVE MANAGEMENT AND UTILIZATION.”

[2] Hardjito, D., Wallah, S. E., Sumajouw, D. M. J., and Rangan, B. V., 2004, “On the Development of Fly Ash-Based Geopolymer Concrete,” ACI Mater. J., **101**(6), pp. 467–472.

[3] Long-term, G. C., Wallah, S. E., and Rangan, B. V, 2006, “LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE: LONG-TERM PROPERTIES.”

[4] Das, S. K., Mishra, J., and Mustakim, S. M., 2008, “An Overview of Current Research Trends in Geopolymer Concrete,” Int. Res. J. Eng. Technol., p. 376.

[5] Lloyd, N. A., and Rangan, B. V., 2010, “Geopolymer Concrete with Fly Ash,” 2nd Int. Conf. Sustain. Constr. Mater. Technol., **7**, pp. 1493–1504.

[6] Singh, B., Ishwarya, G., Gupta, M., and Bhattacharyya, S. K., 2015, “Geopolymer Concrete: A Review of Some Recent Developments,” Constr. Build. Mater., **85**, pp. 78–90.

[7] Shaikh, F. U. A., 2016, “Mechanical and Durability Properties of Fly Ash Geopolymer Concrete Containing Recycled Coarse Aggregates,” Int. J. Sustain. Built Environ., **5**(2), pp. 277–287.

[8] Albitar, M., Mohamed Ali, M. S., Visintin, P., and Drechsler, M., 2017, “Durability Evaluation of Geopolymer and Conventional Concretes,” Constr. Build. Mater., **136**, pp. 374–385.

[9] Mehta, A., and Siddique, R., 2017, “Sulfuric Acid Resistance of Fly Ash Based Geopolymer Concrete,” Constr. Build. Mater., **146**, pp. 136–143.

[10] Tennakoon, C., Shayan, A., Sanjayan, J. G., and Xu, A., 2017, “Chloride Ingress and Steel Corrosion in Geopolymer Concrete Based on Long Term Tests,” Mater. Des., **116**, pp. 287–299.

[11] Abbas, R., Khereby, M. A., Ghorab, H. Y., and Elkhoshkhany, N., 2020, “Preparation of Geopolymer Concrete Using Egyptian Kaolin Clay and the Study of Its Environmental Effects and Economic Cost,” Clean Technol. Environ. Policy, **22**(3), pp. 669–687.