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Characteristics Evaluation of High Volume Pulverized Fuel Ash (PFA) based GPC

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Abstract. Pulverized Fuel Ash (PFA) or 'FA' production exceeded 220 million tons in India by the year 2020 and it would exceeds 400 million tons by the year 2025. This creates huge problems for storage of PFA. It requires thousands of hectors of land for storage. By the chemical composition, PFA is classified in Class – C and Class – F. Class – C has Pozzolanic properties and self-cementing properties rather to Class – F which attains the same properties after adding activator. Alkali and Sulfate content in Class – C PFA are higher. Use of High Volume Pulverized Fuel Ash (HVPFA) in addition to lime and admixtures may be permitted to act as Pozzolanic Binder in ordinary concrete to form Geo-Polymer Concrete (GPC). Basically GPC, a Green Concrete (Eco-Friendly Concrete) also made in another way by adding Pulverized Fuel Ash (PFA), Rice Husk Ash (RHA), Steel Furnace Slag (SFS) and Alkali Activators (AA) following the same process as that of OPC. The main objective of this study to evaluate the comparative characteristics of High Volume PFA with Low Calcium GPC subjected to the Tropical Environment with OPC.

Keywords: Characteristics Evaluation, Pulverized Fuel Ash (PFA), Geo-Polymer Concrete (GPC)

Introduction

Mainly, the Construction Industries and Energy Production Industries (based on Coal Combustions) hugely contributes to the Global Warming Effect by production of oxides of Carbon. Especially the construction industry contributes more, as the rate of construction increasing day – by – day which enhance the rate of cement use. From the coal based Energy Production Industry, greenhouse gasses emits in large quantities contributing to the Global Warming Effect. On another side these coal based Energy Production Industry produces Ashes as FA and Bottom Ash. FA is collected from Energy Production Industry (i.e. Power Plant) after burning the coal. This coal is of Pulverized type. Therefore FA collected is also known as Pulverized Fuel Ash (PFA). According to ASTM C618 and percentage of silicates, iron and calcium oxides, ashes are of two classes, Class – C and Class – F. Class – C FA is rich in silicates, iron and calcium oxides. And therefore, it is Pozzolanic, self – Cementitious whereas Class – F attains same after adding activators. Besides these, the ash particles are of spherical ranges from 0.5 µm to 100 µm with fineness less than 45 µm. In presence of designed percentage of water content, Class – C FA attains strength. As FA particles are of Spherical, creates ball-bearing effect in concrete at plastic state resulting higher structural strength when mixed with free lime. Also decreases permeability and increases durability, as it densify the concrete 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 improve workability and finishing[1]. Pertaining to mentioned characteristics of FA (FA), supports the GPC manufacturing.

Classical way, the ordinary concrete is blend of ordinary cement, sand, aggregates with water for designed strength. Nowadays, the concept of concrete manufacturing has changed on material basis i.e. use of PFA, Steel Furnace Slag, RHA, Sugarcane Bagasse Ash (SBA) as alternatives or percentage replacements of cement to form Green Concrete named as GPC. In tropical environment, ordinary concrete structure 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. The above attacking agents not only attacks the concrete but also inside reinforcements, which effects heavy corrosion and rusting resulting weakening its tie strength of reinforced concrete structures.

As the FA Particles of less than 45 µm in size, which occupies voids that not occupied by cement spheres, results dens concrete than ordinary one. And also blocks passages towards reinforcement inside and saves bars from rusting. Ultimately increases the durability services of structures. On a hand to make use of FA in manufacturing of GPC by various percentage replacements reduces the burdens on Global Warming Environment and helps to make eco-friendly concrete. This study helps to discuss about the various percentage replacements of cement by FA to form Geo-Polymer (eco-friendly) concrete, their physical, mechanical and chemical requirements to meet the satisfactory level of strengths and durability in Tropical Environments.

In the recent development of the GPC, Djwantoro Hardjito et.al. (2004), developed the Class – F, High Volume Low Calcium FA based GPC rich in Silicon and Aluminum with alkaline activators prepared by using Sodium Flakes and Sodium Silicate Solutions with variable molarity and water reducing admixture used. In the experimental work, FA as natural material replaces the OPC 40 % by weight to produce the GPC which casts in five cylinder for a batch and cured in oven at a temperature of 60^0 to 90^0 for 30 minutes to an hour [2]. Wallah and Rangan (2006), presented the study on Class – F Low Calcium FA based GPC to study the effects of mechanical characteristics, creep and drying shrinkage. In this study authors developed the FA based GPC with alkaline activator, water reducing agent, and cylindrical sample cures at elevated temperatures and tested [3].

Lloyd and Rangan (2010), presented the study on Class – F FA based GPC with high Silicon, Alumina, alkaline activator and water reducing agent to cast in cylinders and Precast Box Culvert molds steam cured and tested. Cylinders tested to evaluate the mechanical properties and Box Culverts for flexural strength on loading frame and results validated with previous observations of properties of GPC [4]. W. Wongkeo et. al. (2011) presented work on Geo-Polymer Binder replacing FA and Silica Fumes with Portland cement in 50, 60 and 70 % and 5 and 10 % respectively. The cubical specimen of mortar for 50 mm size autoclaved cured at 20 psi for 9 hours and tested for compressive strength, apparent density, voids and water absorptions. And founds that replacement of SF shows better resistance in compressive nature than in FA [5]. Nath and Sarkar (2014), presented the comparative study on OPC and Geo-Polymer binder and concrete for strength criteria. Also investigates the effects of replacement of cement by 5, 8, 10 and 12 % FA in binder for various mixes and 6 % replacement of OPC by FA for GPC with addition of alkali activator cured at controlled room temperature and humidity. In later study investigates the other characteristics strength parameters and elastic modulus cured in ambient curing. [6,7].

Naskar and Chakraborty (2016) presented the study about GPC with up to 6 % colloidal Nano – Silica by weight of FA in alkaline solution to examine the strength effects. Study presents the mechanical properties of FA based GPC with colloidal Nano-Silica on cubical specimen of concrete cured at elevated temperature and also tested for Non-Destructive parameters. The GPC also tested for pH criteria by passing crushed concrete powder through 600 μ IS Sieve and also add of 1% of TiO_2 to test the pH too. [8]. Faiz Uddin Ahmed Shaikh (2016), examined the behaviour of GPC with replacement of Class – F FA with OPC and mainly focuses on the coarse aggregates from construction and demolition waste which replaces the natural coarse aggregates by Recycled Coarse Aggregates in 15, 30 and 50 % replacement which further evaluate the compressive strength, indirect tensile strength of GPC by preparing the cylindrical specimens and also evaluate the durability properties [9].

Huiskes et. al. (2016), investigated the compressive strength, thermal conductivity of GPC constituted by 70 % Class – F FA and 30 % Steel Furnace Slag with alkali activator, super plasticizer, alkaline solutions with variable molarity and glass light weighted aggregate to form Ultralight Weight Concrete as GPC. Also develops new type of super plasticizer to enhance the workability of concrete [10]. Muhammad N.S. Hadi (2017) developed the Class – F GPC by replacing OPC with GGBS to evaluate the mechanical properties of GPC. Also investigate the other parameters by replacing OPC with FA, Metakaolin, and Silica Fumes in ambient curing. Authors incorporates Taguchi Method for combinations of percentage mixes. Used river sand as fine aggregate and silicates of sodium and hydroxide used together as alkali activators [11]. Kamal Neupane (2018) developed Geo-Polymer GP and Geo-Polymer HE binders and high strength GPC of M_{65} and M_{80} by replacing Portland cement with class – F FA, SFS to evaluate the mechanical characteristics, workability. Also used a special high range water retarding agent to lower the water binder ratio. GPC developed in two batches of percentage replacement of FA (70 %) – GGBS (40 %) and FA (70 %) – GGBS (60 %). Cylindrical specimens and beam specimens were casted, wrapped in impervious plastic to prevent water binder ratios and cured at 23^0 C till tests and results were discussed [12].

Mahya Askarian (2018) developed the F – Class FA with mullite and quartz based GPC by replacing OPC and SFS with gypsum in percentage range FA to SFS as 10 to 60 % to evaluate the characteristics strength of GPC and other parameters like slump, setting time and GPC microstructure by using alkali and carbonates of potassium as activator with citric acid as retarders. Casted in cylindrical specimens and demolded after 24 hours and wrapped in plastic sheet to prevent loss of water and cured normally by maintaining the curing temperature of 20^0 to 23^0 C, and tested for 1d, 7d, 28d and 56d to evaluate the characteristics of GPC. Also evaluate the effect of hydroxide of calcium and silicate of sodium on strength criteria [13]. Abdulkadir Çevik (2018) studied the effect of nano-silica on GPC in characteristics approach and serviceability in short and long term performance. Study takes privilege to use GPC with hydroxides and silicates of sodium admixture and alkaline activator. Cylindrical, cubical and prismatic specimens were casted and wrapped in plastic to retain the effect of alkali activator cured at different environments like firstly oven cured for 2 days to activate the geo-polymerization process and then after placed in controlled room temperature of 20^0 to 23^0 C for 28 days and then pond cured for 28 days to evaluate the compressive strength, flexural strength and split cylinder tensile strength and a linear variable transducer device applied to evaluate the displacements in specimes [14]. Wei-Hao Lee (2019) evaluated the characteristics and durability performance of GPC made by replacement of OPC with FA and GGBS to produce M_{53} and M_{67} grade GPC for 9 months of indoor and outdoor curing and also investigate the effect of chlorine permeability, weathering resistance and mechanical properties of GPC. Cylindrical specimens were casted and cured in indoor and outdoor environmental curing to study the durability effect. Alkali activator with variable molarity were mixed during dry mixes. For indoor curing, samples wrapped in plastic and kept in 90 % humidity and for outdoor curing samples kept on the roof of five storied building to expose the GPC in uncontrolled environment and then tested for 14d, 28d, 56d, 90d, 180d and 270 days. Mechanical properties and rapid chloride permeability test for prolonged curing in durability approach were evaluated [15].

Aissa Bouaissi (2019) investigate the mechanical characteristics of GPC replacing OPC by Class – F FA, granulated blast furnace and high magnesium nickel slag and evaluated the microstructural properties by performing SEM, XRD and FTIR. Consistency, workability and setting time evaluated for binder pest. Also mechanical properties like compressive strength, split cylinder tensile strength were performed under uniform loading rate. Rather to evaluate the characteristics of GPC sample, author evaluate the compressive strength along with mentioned properties on material ingredients [16]. Thanh T. Nguyen (2020) investigates the parameters of GPC with Class – N and Class – S FA with different percentage replacements, also for slag replacements with binder ratios, their fineness, curing conditions like elevated and steam curing for 40^0 to 100^0 C, activators, later on evaluate the parameters of GPC like workability, setting time and mechanical characteristics. Casted cubical specimens and waxed the specimen at the time of casting to prevent loss of water. Cured in controlled temperature about 20^0 to 22^0 C with relative humidity of 65 to 70 %. Also cured specimen in controlled chamber of 10^0 C with 65 to 70 % relative humidity and then tested for prescribed criteria of strength [17,18]. Kishore and Gupta (2021) evaluate the GPC for mechanical characteristics and few other parameters like workability, setting time for percentage replacements of GGBS and Metakaolin up to 50 %. Also use sodium hydroxide, potassium hydroxide admixture, activators and super plasticizers. The cubical specimens were casted by filling of GPC in three layers and vibrated. Consistency, initial setting time, final setting time, microstructural behaviour of pozzolans were checked. Also GPC were evaluated for slump and other mechanical characteristics like compressive strength, flexural strength. Specimens were cured in ambient curing modes till tested and discussed the study [19].

Abhinav Bagde et. al. (2022) presented review on GPC worldwide with its properties of ingredients like consistent materials, initial setting time, final setting time, fineness index and area of sphere per gram, test on ingredients and as on GPC to evaluate the characteristics parameters, advantages and limitations. Also suggested the methodology to adopt in design and use [20]. Gajghate and Patil (2021) suggested and outlined the uses of FA as retarding agenet to improve the characteristics of soil properties like permeability and investigates the effect of FA as retarding agent in black cotton soil and also investigates the permeability effect of black cotton soil with and without FA as retarding agent by conducting various tests on FA and FA mixed black cotton soil and evaluated the combined properties of black cotton soil with and without FA and outlined the results [21]. Nandkishor Aglawe et. al. (2022) suggested the study of Ready – mix GPC its application in various aspects and advantages. Also suggested the design approach and their advancements by studying the various characteristics of ingredient materials like fineness, particle size distribution according to the various size, consistency, setting times. And suggested a modernize design approach of ready mixed concrete using GPC [22]. Gajghate and Gupta (2022) investigates the study on various curing aspects of GPC. And compares the curing methods on their advancements and results oriented aspects. Discussed various modes of curing of GPC like in indoor and outdoor environment, ambient curing, oven curing, accelerated curing, steam curing and outlined the importance of curing in various stages of GPC and explained the modified approach in essence of curing [23]. Abhijeet Chandewar et. al. (2022) investigates the different methods of testing on self-compacting concrete. Especially focuses on characteristics of GPC and their testing methods. Specially focuses on the self-compacting concrete made in essence of GPC, and suggested the different methods of testing of Self-compacting GPC. Also outlined the various parameters to be precautioned during the testing procedure [24].

FIGURE 1: Structure of Class – C PFA (Source: Department of Transportation, United States)

FIGURE 2: Structure of Class – F FA (Source: Department of Transportation, United States)

TABLE 1. Chemical Composition of Low Calcium Class – C PFA (by weight) [1]

Chemical Compositions	Percentage
SiO_2	46 to 59
Al_2O_3	14 to 22
Fe_2O_3	5 to 13
CaO	8 to 16
MgO	3.2 to 4.9
K_2O	0.6 to 1.1
Na_2O	1.3 to 4.2
Loss on Ignition (LOI)	0.1 to 2.3
TiO_2	Less than 1

Materials and Methodology

Ordinary Portland Cement (OPC) of 53 Grade, Pulverized Fuel Ash (Class – C), river sand and coarse aggregate made available for this study. In 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 %, 60 %, 70 %, 80 %, 90 % and 100 % by weight. The water – binder ratio considered as 0.48 for moderate exposure. The physical characteristics of cement is summarized in Table 2 and that of Fine Aggregate and Coarse Aggregate is summarized in Table 3 and Table 4 respectively. The Mechanical Characteristics of Coarse Aggregate is summarized in Table 5. The Design Mixes for Percentage Replacement of Cement in Standard Concrete is summarized in Table 6. The mixes were casted in cubes of 150 mm for compressive strength evaluation and in beams of 100 mm x 100 mm x 300 mm for evaluation of flexural strength. Concrete Molds were compacted using vibration table and kept in mold for a day (24 Hours). After demolding, the specimens were kept in pond curing for 3, 7, 28, 90 and 365 days and then after tested.

TABLE 2. Physical Characteristics of Ordinary Portland Cement (53 Grade) conforming to IS:12269-1987

Physical Characteristics	Observed Values
Specific Gravity	3.15
Standard Consistency	31 %
Fineness Modulus of Cement	2.8
Setting Time (Initial)	88 Min
Setting Time (Final)	310 Min

TABLE 3. Physical Characteristics of Fine Aggregate – River Sand confirming to IS:2386-1963

Physical Characteristics	Observed Values
Specific Gravity	2.6
Silt Content	2.7 %

TABLE 4. Physical Characteristics of Coarse Aggregate confirming to IS:2386-1963

Physical Characteristics	Observed Values
Flakiness	19.75 %
Elongation	19.75 %
Specific Gravity	2.88
Water Absorption	1.98 %

TABLE 5. Mechanical Characteristics of Coarse Aggregate confirming to IS:2386-1963

Mechanical Characteristics	Observed Values
Impact Strength	15.86 % (Strong)
Crushing Strength	39.08 %
Abrasion Strength	16.9 %

TABLE 6. Design Mixes for Percentage Replacement of Cement in Standard Concrete

Design Compositions	Cement	Pulverized Fuel Ash (PFA)	Fine Aggregate River Sand	Coarse Aggregate	Weight of Concrete

	% Replacement	**Weight (Kg/m^3)**	**% Replacement**	**Weight (Kg/m^3)**	**Weight (Kg/m^3)**	**Weight (Kg/m^3)**	**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
C-10:PFA-90	10	35	90	313	682	1200	2382
C-0:PFA-100	0	0	100	348	677	1191	2368

Table 6 shows the Design Compositions of percentage replacement of cement in Standard Concrete by percentage of Pulverized Fuel Ash (PFA). From Design Compositions of percentage replacement of cement in Standard Concrete by percentage of Pulverized Fuel Ash (PFA) in Table 6, it is observed that the total weight per cubic meter of the Designed Standard Concrete for characteristics strength of 30 MPa gets reduced with percentage increase of Pulverized Fuel Ash (PFA) and may generates the curiosity to produce the light weight concrete. Below FIGURE 3. shows the graphical representation of constitutes materials of binary concrete by weight replacement of PFA.

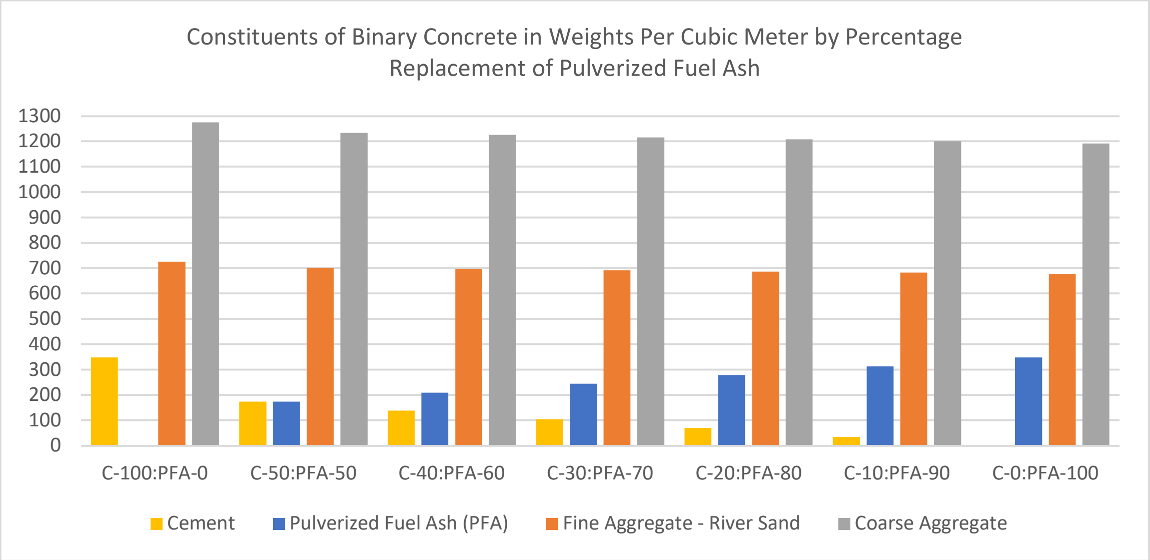

FIGURE 3. Constituents of Binary Concrete in Weights per Cubic Meter by Percentage Replacement of Pulverized Fuel Ash

As the PFA used in replacement of cement by the proportion of 50 %, 60 %, 70 %, 80 %, 90 % and 100 % by weight, produces mixes and need to check the consistency of binary binder, Table 6 shows the consistency of binary binder.

TABLE 7. Consistency for Percentage Replacement of Cement in binary binder material

Design Compositions	Weight of Cement (gm)	Weight of PFA (gm)	Observed Value
C-100:PFA-0	400	0	31 %
C-50:PFA-50	200	200	37 %
C-40:PFA-60	160	240	40 %
C-30:PFA-70	120	280	43 %
C-20:PFA-80	80	320	45 %
C-10:PFA-90	40	360	42 %
C-0:PFA-100	0	400	Undefined

Table 7 shows the consistency for percentage replacement of cement in binary binder material. From the observed value of consistency, Design Compositions from C-100: PFA-0 to C-20: PFA-80 shows progressive value but for C-10: PFA-90 and C-0: PFA-100 shows decline in nature and undefined value of consistency. And therefore to improve the consistency of Design Compositions, percentage replacement of Pulverized Fuel Ash (PFA) by percentage of Lime to make Binary Design Compositions as Ternary Design Compositions. Table 8 shows the consistency for Ternary Design Compositions for percentage replacement of Pulverized Fuel Ash (PFA) by percentage of Dry Lime.

TABLE 8. Consistency for Percentage Replacement of Cement, Pulverized Fuel Ash (PFA) and Dry Lime in Ternary binder material

Design Compositions	Weight of Cement (gm)	Weight of PFA (gm)	Weight of Lime (gm)	Observed Value
C-100:PFA-0:Lime-0	400	0	0	31 %
C-50:PFA-47.5:Lime-2.5	200	190	10	33 %
C-40:PFA-57.0:Lime-3.0	160	228	12	34 %
C-30:PFA-66.5:Lime-3.5	120	266	14	35 %
C-20:PFA-76.0:Lime-4.0	80	304	16	36 %
C-10:PFA-85.5:Lime-4.5	40	342	18	39 %
C-0:PFA-95.0:Lime-5.0	0	380	20	Undefined

Table 8 shows Consistency for Percentage Replacement of Cement, Pulverized Fuel Ash (PFA) and Dry Lime in Ternary binder material. From the observed value of consistency of Ternary binder material in Table 8, consistency from Design Composition of C-100:PFA-0:Lime-0 to C-10:PFA-85.5:Lime-4.5 shows progressive in nature but for Design Composition of C-0:PFA-95.0:Lime-5.0 the observed consistency shows undefined. Which create research need to improve the consistency for Design Combination of C-0:PFA-95.0:Lime-5.0. Furthermore quantity of dry lime is increased for Design Combination of C-0:PFA-95.0:Lime-5.0 again by 5 %, and Design Combinations for increased percentage of lime is altered as C-0:PFA-90.0:Lime-10 and C-0:PFA-85.0:Lime-15. In absence of the percentage of Cement in the Design Combinations C-0:PFA-90.0:Lime-10 and C-0:PFA-85.0:Lime-15, itself be the binary binder and also known as Low Calcium based Geo-polymer Binder. Table 9 shows the Consistency of Low Calcium based Geo-polymer Binder materials.

TABLE 9. Consistency of Low Calcium based Geo-polymer Binder materials

Design Compositions	Weight of Cement (gm)	Weight of PFA (gm)	Weight of Lime (gm)	Observed Value
C-0:PFA-95.0:Lime-5.0	0	380	20	Undefined
C-0:PFA-90.0:Lime-10	0	360	40	42 %
C-0:PFA-85.0:Lime-15	0	340	60	40 %

Above Table 9 shows the Consistency of Low Calcium based Geo-polymer Binder materials for which the characteristics evaluation of High Volume Pulverized Fuel Ash (PFA) based GPC is studied.

Results and Discussions

Table 10 shows the Compressive Strength (in MPa) of Standard Concrete and Compressive Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Designed Compositions under Normal Curing.

TABLE 10. Compressive Strength (in MPa) of Standard Concrete and Compressive Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA)

Design Compositions	3 Days	7 Days	28 Days	90 Days	365 Days
C-100:PFA-0	16.1	22.5	41.7	44.9	59.8
C-50:PFA-50	14.9	21.8	39.5	41.6	56.4
C-40:PFA-60	13.7	19.2	35.3	40.2	51.9
C-30:PFA-70	11.9	17.3	31.4	38.9	46.7
C-20:PFA-80	7.6	12.4	24.9	35.3	41.4
C-10:PFA-90	1.1	1.9	4.4	11.3	12.8
C-0:PFA-100	Undefined	Undefined	Undefined	Undefined	Undefined

And FIGURE 4 shows the graphical representation of Compressive Strength (in MPa) of Standard Concrete and Compressive Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Designed Compositions under Normal Curing.

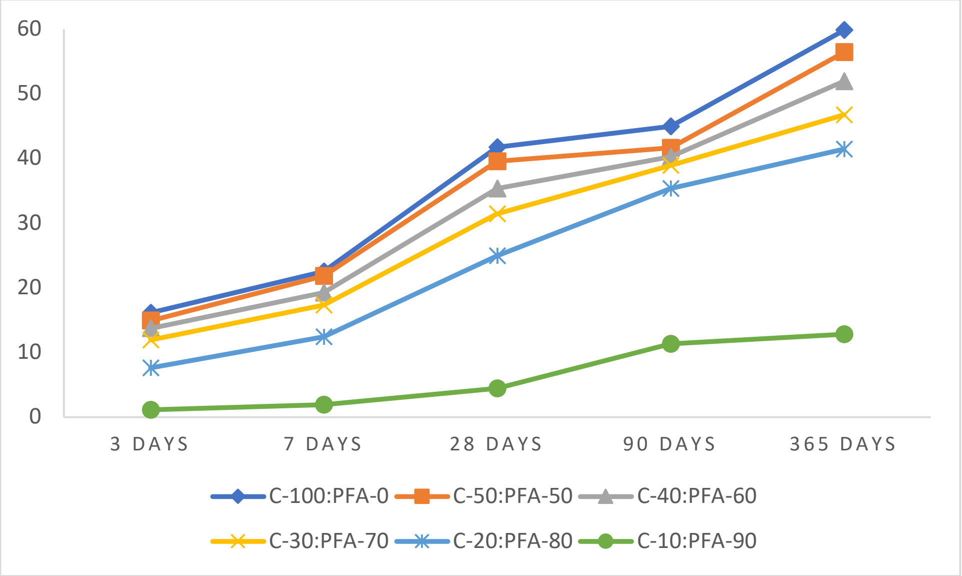

FIGURE 4. Compressive Strength (in MPa) of Standard Concrete and Compressive Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA)

Table 9 shows the Compressive Strength (in MPa) of Standard Concrete and Compressive Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Designed Compositions under Normal Curing and its graphical representation in FIGURE 2, it is observed that the nature of the graphical representation for Design Combinations for C-100: PFA-0 to C-20: PFA-80 is polynomial in nature but for Design Combination of C-10:PFA-90 it shows linear. And the intra-variation in percentage difference for C-100: PFA-0 to C-20: PFA-80 is less than 5 % by average but in between C-100: PFA-0 to C-20: PFA-80 and C-10:PFA-90 is more than 10 % by average. The results for Design Combination of C-0:PFA-100 is ‘Undefined’, and it creates the need of research. As looking to the observed values of Consistencies for Design Combinations of C-0:PFA-90.0:Lime-10 and C-0:PFA-85.0:Lime-15 may provide the solutions for Compressive Strength for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Design Combination of C-0:PFA-100.

Table 10 shows the Flexural Strength (in MPa) of Standard Concrete and Flexural Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Designed Compositions under Normal Curing.

TABLE 10. Flexural Strength (in MPa) of Standard Concrete and Flexural Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA)

Design Compositions	3 Days	7 Days	28 Days	90 Days	365 Days
C-100:PFA-0	2.9	3.5	5.3	6.9	8.2
C-50:PFA-50	2.7	3.3	5.1	6.3	7.6
C-40:PFA-60	2.6	3.1	4.7	5.8	6.9
C-30:PFA-70	2.4	2.9	3.5	4.4	5.2
C-20:PFA-80	1.9	2.5	3.3	3.7	4.2
C-10:PFA-90	0.7	1.0	1.5	2.4	2.9
C-0:PFA-100	Undefined	Undefined	Undefined	Undefined	Undefined

And FIGURE 5 shows the graphical representation of Flexural Strength (in MPa) of Standard Concrete and Flexural Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Designed Compositions under Normal Curing.

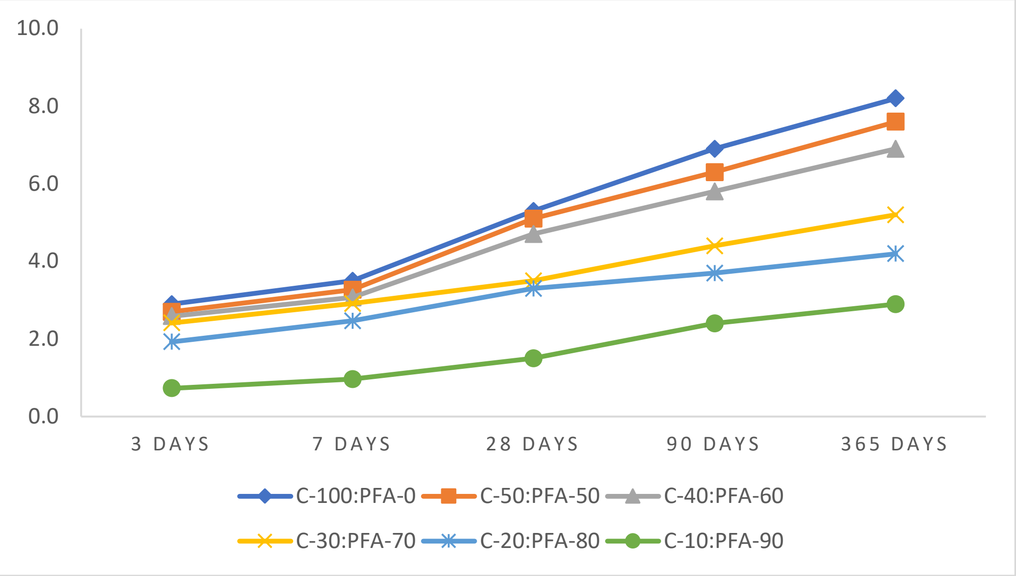

FIGURE 5. Flexural Strength (in MPa) of Standard Concrete and Flexural Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA)

Table 10 shows the Flexural Strength (in MPa) of Standard Concrete and Flexural Strength (in MPa) for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Designed Compositions under Normal Curing and its graphical representation in FIGURE 3, it is observed that the nature of the graphical representation for Design Combinations for C-100: PFA-0 to C-20: PFA-80 is polynomial in nature but for Design Combination of C-10:PFA-90 it shows linear. And the intra-variation in percentage difference for C-100: PFA-0 to C-20: PFA-80 is less than 5 % by average but in between C-100: PFA-0 to C-20: PFA-80 and C-10:PFA-90 is more than 10 % by average. The results for Design Combination of C-0:PFA-100 is 'Undefined', and it also creates the need of research. As looking towards the observed values of Consistencies for Design

Combinations of C-0:PFA-90.0:Lime-10 and C-0:PFA-85.0:Lime-15 may also provide the solutions for Flexural Strength for percentage replacement of Cement by Pulverized Fuel Ash (PFA) for Design Combination of C-0:PFA-100.

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