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Mix Design and Mechanical Performance of Geo-Polymer Binder for Sustainable Construction and Building Material

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Abstract- Portland cement is the most widely used binder material for concrete. However, it is an energy-intensive material that causes the production and release of CO2 from greenhouse gases from global warming, as well as causing soil degradation due to limestone mining. This requires the development of ecological binding material and geopolymer concrete is one of those potential materials. This study is mainly focused on use of fly-ash based geo-polymer concrete used as a paver block and compares the mechanical properties of GPC with conventional concrete of same grade (M30). Test samples were taken in cubes and stored at room temperature for melting and curing. A hybrid solution to GPC design based on low-calcium fly ash for usability and strength. Alcofin was then used to generate the necessary compressive force at room temperature. 'The combined amount of ash and alkaline activation was determined from the assumed density by deducting the average aggregate weight of 2400 kg/m^3. The mass relation between sodium silicate and sodium hydroxide was held at 1:2.5, fixing the cube within 24 hours of melting. The main purpose of performing this procedure is to achieve the desired compression strength. The mixer is a mixture of fine additives, coarse aggregate and fly ash. Sod-hydroxide granules are combined with filtered water in order to produce alkaline activator solutions (AAS). AAS was developed using a mixture of sodium hydroxide and sodium hydroxide solution. Addition of thin aggregate, coarse aggregate and fly ash AAS results in the formation of Geo-Polymer Concrete. The strength of GPC at 28 days is less than conventional concrete and it is because of water that comes out in Polymerization gives required compressive strength.

Keywords- Portland cement, Geo-Polymer Concrete, Alkaline Activator Solutions, Fly-Ash.

I. INTRODUCTION

“The cement industry accounts for about 7% of total CO2 emissions. This is because producing 1 ton of Portland cement emits about 1 ton of CO2 into the atmosphere, and heating limestone emits CO2 directly.” Calcinations develop as calcium carbonate calcine is heated to calcium oxide and carbonate. This process accounts for 50% of all carbon of fly ash and the problem of fly ash processing are the main issues. Fly ash is a by-product of coal-fired power plants. Traditionally, it has been used as a mechanism for many chemical and environmentally damaging waste and recycled materials.”

1. Fly Ash Based Geo-Polymer Concrete

Fly ash is the primary solid waste generated by coal-fired power plants. “Waste generated by a 500

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megawatt traditional coal plant produces more than 125,000 tons of smoke stack ash and 193,000 tons of sludge each year." As a matter of truth, just 20-30% of Fly Ash is used on asphalt, houses, concrete, blocks and bricks, and some are disposed of in deposits and reservoirs, as the Indian Ministry of Environment and Forestry claims. More than 75% of this pollution is untreated, causing many environmental problems linked to climate, soil and nutrient pollution and groundwater contamination. Consequently, the effective disposal and use of such ash is necessary to protect the ecosystem from illegal disposal of waste from coal-fired installations.

II. LITERATURE SURVEY

Kumaravel et al (2018) specifically, since the tension is weak, steel fibers are added to the concrete to increase the tension. Fiber reinforced concrete can improve the strength properties of hardened geoflyer concrete. GPC is produced by completely destroying ordinary Portland cement using an innovative method, and uses GGBS as a raw material as a low fly ash by-product to react with an alkaline solution of sodium silicate and sodium hydroxide. Then crimp tip steel fibers are added to the GPC mixture at a volume fraction of 1.0%.

Daniel, et AL (2017) Geo-polymer is the newest phase toward complementing cement with an eco-friendly Pozzolanic material. Aluminosilicate gel, which acts as a binder in concrete, is activated in highly alkaline solutions. In this study, the ground granulated lacquer (GGBFS) can be completely replaced. Specifically, it is a fragile fiber of steel and glass, which improves the quality of concrete. These hybrid fibers are sorted by optical test and split tensile test. About the corresponding custom ratio of hybrid fiber The bending behavior of standard concrete and geopolymer concrete is regulated by static circulation manufacturing. Experimental tests have shown significant improvements in bending strength, lack of stiffness, combined energy consumption, expandable displacement and the load of its deflectors.

Karthi, Lathi & E, Aswani. (2017). "The market for concrete as construction material is increasing increasingly and thus the requirement for OPC supply is growing. We are well informed of the environmental issues involved with the manufacture of cement. When 1 ton of cement is produced, calcification of limestone and combustion of fossil fuels release about 1 ton of carbon dioxide into the atmosphere, which promotes global warming. Cement production is also very energy intensive and uses large amounts of natural resources. In order to minimise these problems, substitute material for cement must be found. A variety of tests have been carried out to find a cement solution. Partial substitution and large-volume substitution of OPCs with binding property materials were investigated. In 1978, Davidov its proposed that polymeric reactors, such as fly ash, rice husk ash, slag blast furnace and others could be constructed of alkaline fluid with aluminum silicate materials called geopolymers."

Neupane et al (2018) Geopolymers are noble substances constructed by the reaction of alumino silicates with good alkaline bond solutions. In the last few decades, geopolymers have been studied and developed worldwide to determine the engineering, environmental, microstructure and durability properties of geopolymers as a viable alternative to Portland cement. According to the results of the previous task, the functional efficiency and longevity of geopolymer concrete is greater than the general efficiency of Portland cement (OPC).

Today, large construction companies such as high altitude buildings and bridges have technical and economic advantages over common strength concrete, and high strength concrete is used more often. This work documents experimental results on the engineering properties of high-speed geopolymer concrete. Waiting for the use of geopolymer binders For medical applications, 65 or 80 MPa. The high-strength concrete produced in this study can be easily placed in ambient conditions, not only to obtain sufficient initial strength, but also to improve tensile and bending strength.

III. METHODOLOGY AND EXPERIMENT PLAN

Material Used

In this experimental work, there are various materials used like…

- Fine aggregate
- Coarse aggregate
- Alccofine
- Fly ash
- Sodium hydroxide

- Sodium silicate

Fine Aggregate

The sand used in this study was locally collected in the 4.75 mm layer with an accurate gravity value of 2.80. The following table lists the fine aggregation attributes.

Table 1: Properties of Fine Aggregate

Property	**Value**
Bulk density	1.49 g/cm^3
% of voids ratio	34.23 %
Voids Ratio	0.58
Specific Gravity	2.258

Fig. 1 Fine Aggregate.

Coarse Aggregate

This analysis uses rigorous aggregates up to 20 mm and minimum 10 mm. The value specified is 2.85. "According to IS 383: 1970, the properties of fine aggregates are tested. Topography represents the table below attributes.

Table 2: Properties of Coarse Aggregate"

S. No.	Property	Test Results
1	Specific Gravity	2.74
2	Bulk density (Kg/m^3)	1468 (loose state) 1611 (dry rodded)

Fig 2: Coarse Aggregate

Sodium Hydroxide (NaOH)

This is brought from SCIENCE SALES SONIPAT. It available in pellets form. "To dissolve either flakes or pellents in water, sodium hydroxide (NaOH) solution was prepared. The mass of NaOH in a solution ranges according to the molar concentration of the solution, M. For eg, a 12-m NaOH solution consisted of 12x40 = 480 grammes per litre of the NaOH solids (in the form of a flake or a pellet)."

Fig 3: NaOH pallets

Fly Ash

"Class F Fly Ash is used in this study. Fly ash was procured from Jhajjar, Haryana."

Sodium Silicate NA_2SiO_3

Brought from Rajpura Soap Factory. The sodium silicate solution is the byproduct of soap industry. It is available in dense solution form.

Fig. 4: Sodium silicate NA_2SiO_3

Alcco fine

It is a fine material available in powdered form. It affects strength workability and durability of slag based geopolymer concrete.

Experimental Plan

The experimental project studied a variety of mechanical properties, including compressive strength, split tensile strength and bending strength of concrete using common M30 concrete. Create and control 20 standard 150mm x 150mm x 150mm cubes.

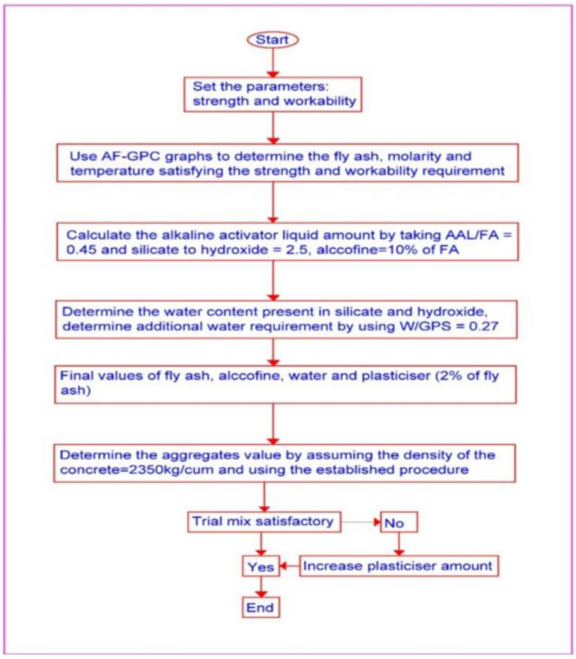

Fig. 5 Flow chart of the proposed mix design process for GPC

Mixing

Hand mixing technique was used for mixing various ingredients. The mixture was carefully Mixed throughout dry condition, then applied sand to both the mixture. Once again, the mixture was gently mixed out over coarse aggregate. After which, water has been added slowly during mixing to chemical admixture. Mixing has been done on a regular basis upon obtaining a workable mixture stopped.

(a)

(b)

(c)

Fig. 6: Casting of cubes

Casting

For casting moulds were used and it was occupied throughout three strata. The concrete cubes are casted 20 times respectively. Vibration became set with table vibrator also on cube moulds. Vibrations that validate uniform compaction are continuous for one minute. Since the specimen was carried out 24 hours from mold and placed in an ambient curing at room temperature for 7, 14 and 28 days. 20 cubes each of conventional concrete and Geo-polymer concrete was casted.

(d)

Fig. 7: Casting

Curing Process

Curing is a method in which a particular organism or concrete component becomes cured under water for drinking purposes no. of days for different specimen.

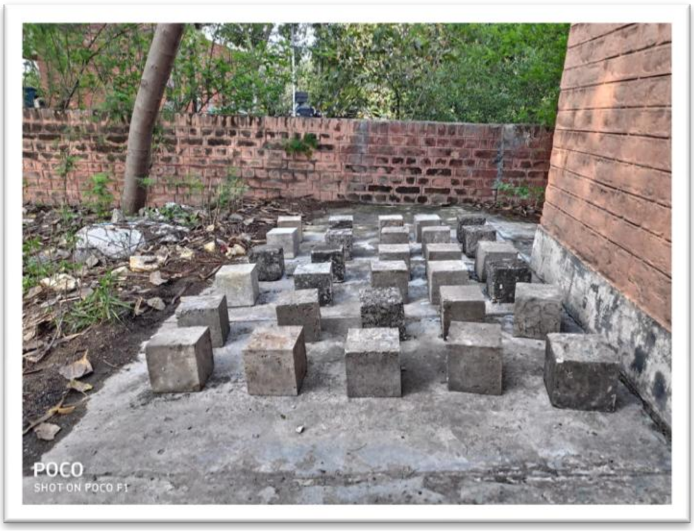

Fig. 8: Curing

Compressive Strength Test

The sample was placed in the M30 concrete stage with a measurement of the compressive strength of a 150mm x 150mm x 150mm cube.

Fig . 9 Specimen loading for compressive strength test

Mix Design for Geo polymer Concrete Grade M30 according to the proposed method:

Analysis leading to a variety mix proportions for M30 grade with geo polymer concrete is conducted utilizing proposed methodology based mostly on mix design measures mentioned in the subsequent segment. That mix design can be considered according to preliminary data:

- Characteristic compressive strength of Geo polymer Concrete (fck) = 30 MPa.
- Workability in terms of flow: 25–50 % (Degree of workability—Medium)
- Fly ash: Fineness in terms of specific surface: 384 m^2/kg
- Alkaline activators (Na_2SiO_3 and NaOH) Concentration of Sodium hydroxide in terms of molarity: 12 M
- Solution-to-fly ash ratio by mass: 0.45

6. Sodium silicate-to-sodium hydroxide ratio by mass: 1:2.5

Design Steps

1. Target mean strength

Fck =fck + 1.65*S

Fck = 30 +1.65 * 5

Fck = 38.25 MPa

Or

Fck = fck + X

Fck = 30 + 6.5

Fck = 36.5 Mpa

The higher value to be adopted, therefore target strength will be = 38.25 Mpa

1. Its quantities for fly ash used in the GPC development is to choose correct alkaline activator liquid (AAL) and fly ash (FA) ratio. It has already been observed that even a value of 0.3 and 0.6 is appropriate with realistic use (Hardjitoet al.2005, Junaidet al., 2015), but this research have required a value of 0.45 and ready that AF-GPC-Graphs.

2. Calculation of the quantity of alkaline activators liquid

Compute the amount of liquid alkaline activators:

Solution/Fly ash ratio by mass = 0.45

Mass of (Na2SiO3 + NaOH)/Fly ash = 0.45

Mass of (Na2SiO3 + NaOH)/384 = 0.45

Mass of (Na2SiO3 + NaOH) = 172.8 kg/m^3

Take the sodium silicate to sodium hydroxide ratio by mass 1

Mass of sodium hydroxide solution (NaOH) =AAL/3.5

= 172.8/3.5

= 49.37 kg/m^3

Mass of sodium silicate solution (Na_2SiO_3) = solution=2.5× sodium hydroxide solution water= 2.5 x 49.37 = 123.42 kg/m^3

3.Calculation of total solid content in alkaline solution

The concentration of solid content in NaOH or Na2SiO3 be based on weight and the composition of NaOH (44.4 percent of solids by weight for 12 M) and Na2SiO3 (40.6 percent of solids by weight as defined mostly by supplier), is shown below.

Mass of solids in NaOH = (44.4/100) × 49.37 = 21.92kg

Mass of water in NaOH = 49.37 -21.92 =27.45 kg

Mass of solids in Na_2SiO_3 = (40.6/100)×123.42 = 50.10kg

Mass of water in Na_2SiO_3 =123.42– 54.42 = 73.32 kg

4. Calculation of additional quantity of water (W_{extra})

Water (sum of masses of additional free water and water used during the preparation of Na2SiO3 and NaOH) to geopolymer binder (sum of masses of fly ash, alccofine, NaOH solids and Na2SiO3 solids) ratio (W / GPB) was kept at 0.27, Pavithraet al.2016).
W/GPB = (WHO + WSI + W extra) / (AF + FA + Solids NaOH + Solid Na_2SiO_3) = 0.27…..

Moreover, the AF-GPC-Graphs have been developed for W/GPB equals to 0.27. So, extra water quantity can be calculated using the Eq
$(W_{extra}+27.45+73.32)/(38.4+384+21.92+50.10) = 0.27$ from which W_{extra} = 51.62 kg.
Total solid content = Mass of solids in NaOH + Mass of solids in Na_2SiO_3= 21.92+ 50.10 = 72.02 kg/m^3

5. Selection of water content
For medium degree of workability and fineness of fly ash of 384 m^2/kg, water content per cubic meter of geopolymer concrete.

Water content = 110 kg/m^3

6. Adjustment in water content
For sand conforming to grading-3, correction in water content Adjustment in water content = -1.5%
Total quantity of water required = 110- (1.5/100) x 110 =108.35 kg/m^3

7. Calculation of fine and coarse aggregate content
Total aggregate content = (Wet density of GPC) - (Quantity of fly ash + Quantity of both solutions + extra water) = 2400 – (384 + 172.8 + 51.62) = 1791.58 kg/m^3
Sand content = (Fine – to - total aggregate content in %) x (Total quantity of all-in-aggregate) = (35/100) x 1791.58 = 627.053 kg/m^3 Coarse aggregate content = (Total quantity of all-in-aggregate) - (Sand content) = 1791.58 – 627.053 kg/m^3 = 1164.52 kg/m^3
Quantity of materials required per cubic meter for M30 grade of geopolymer concrete.

Table 1: Materials required for M30 grade geopolymer concrete"

Ingredients of geopolymer concrete	Fly Ash	NaOH	Na2 SiO3	Sand	Coarse Aggregate	Alccofine (AF)	Extra water
Quantity (kg/m3)	384	49.37	123.42	627.052	1164.52	38.4	51.62

Mix design of Geo-polymer concrete is according to Parveen and Dhirendra Singhala (2017) "Development of mix design method for geopolymer concrete".

IV. RESULTS AND ANALYSIS

1. Workability Test
It is the sum of the functions performed to achieve the overall concrete compression with excellent concrete workability. The workability of concrete is also damaged by the maximum warp aggregate used in the mixture. The commonly used slump test is used to measure the workability of concrete. The slump of the test mixture is shown in Figure 10.

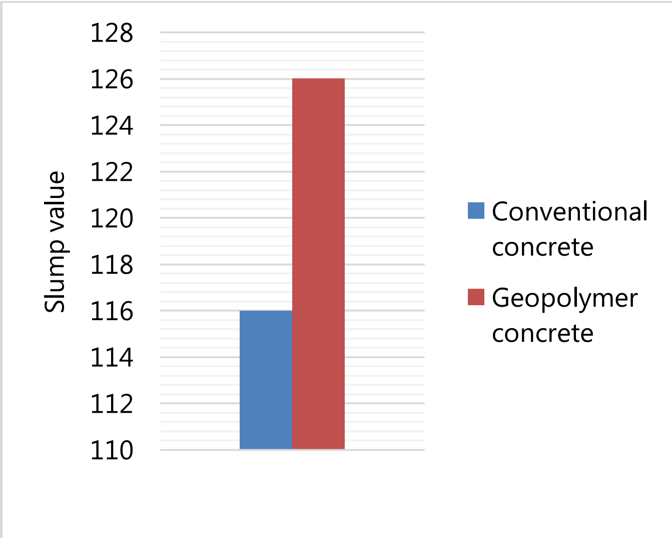

Fig. 10 Variation of slump for conventional and geopolymer concrete

Existing concrete has a slit value of 116 mm, and geopolymer concrete has a slit value of 126 mm.

2. Compressive Strength Test Result
Compressive strength testing provides insight into concrete consistency as there is a direct correlation between performance and the structure of the hydrated cement paste. The compressive strength of

the cube specimens was investigated on days 7, 14, and 28.

Table 4 Compressive strength of conventional strength

Grade of concrete	Water-Cement Ratio	7 days compressive strength(N/mm²)	14 days compressive strength (N/mm²)	28 days compressive strength (N/mm²)
M30	0.45	26.93	34.93	43.2

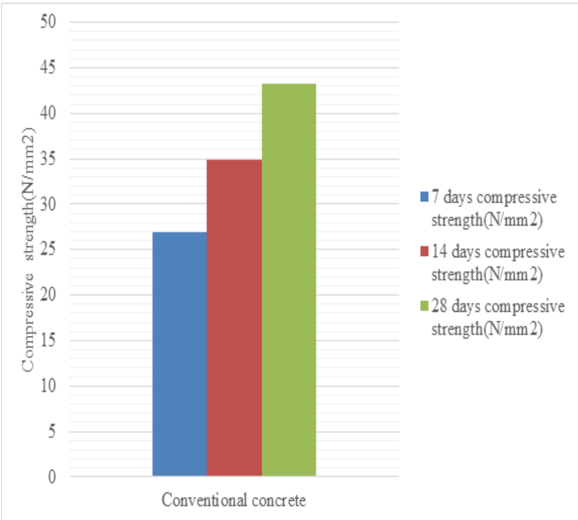

Fig 11: Variation of compressive strength for conventional concrete

Table 5: Compressive strength of geopolymer concrete

Grade of concrete	Water-Cement Ratio	7 days compressive strength(N/mm²)	14 days compressive strength (N/mm²)	28 days compressive strength (N/mm²)
M30	0.45	27.54	36.51	40.9

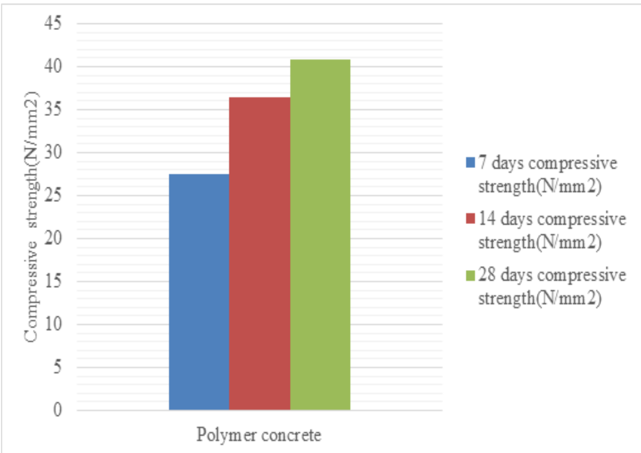

Fig 11: "Variation of compressive strength for geopolymer concrete"

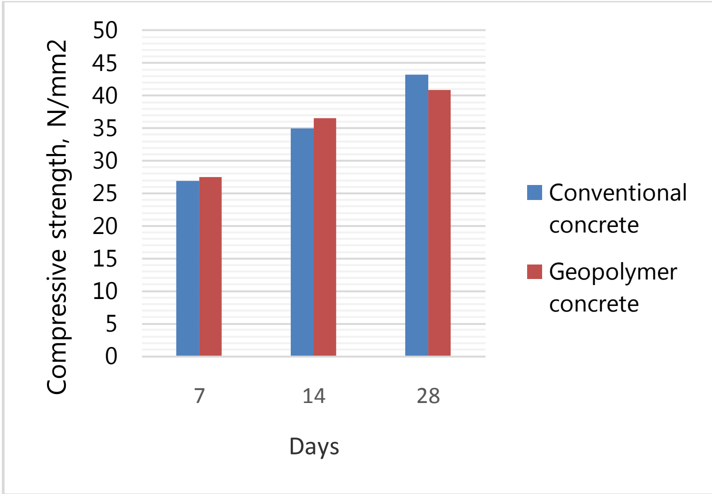

Fig 12: Comparison of compressive strength for conventional and geopolymer concrete

Note that the strength of geopolymer concrete is higher than that of conventional concrete on the 7th and 14th. The increase in the initial strength of geopolymer concrete is due to the very fine Pojollana content contained in the fly ash, which is the binding attribute of the concrete. However, at the age of 28 days, the strength of GPC is lower than that of conventional concrete. GPC has a polymerization process in which water comes out and the strength of GPC decreases, and in ordinary concrete, there is a hydration process that consumes water, and the increase in strength is that 28 days of concrete is considerably completed due to sign language. A little over 99% of OPC is achieved. Therefore, we have come to the conclusion that GPC is a good option for traditional concrete.

2. Split Tensile Strength Test

Tensile tensile strength is one of the most important characteristics of concrete. The average tensile strengths of geopolymer concrete heated at 80 ° C for 24 hours are as follows, and the tensile tensile strengths of GPC and CC concrete are compared using a graph as shown in Fig. 5.4. The increase in split tensile strength was about 26.9% relative to GPC, respectively, for the mixture of GPC.

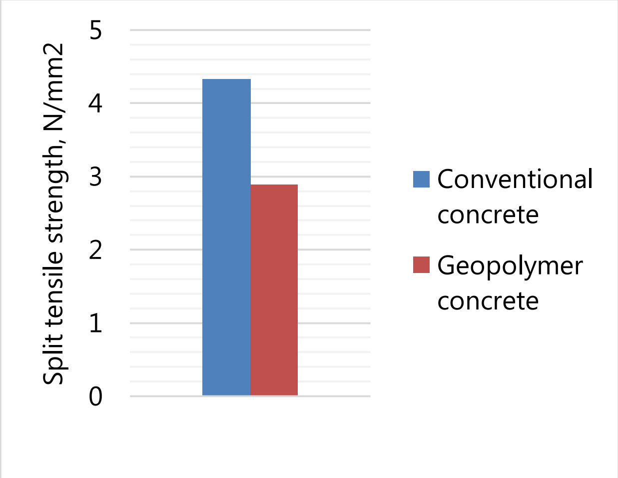

Fig 14: Comparison of split tensile strength for conventional and geopolymer concrete

V. CONCLUSION

- "It is found that Geopolymer Concrete is a promising construction material due to its low carbon dioxide emission and higher early strength & fire resistance (due to their low levels of chemically bound water) make it better than conventional concrete.
- The strength of GPC at 28 days (40.9 N/mm^2) is less than conventional concrete (43.2N/mm^2) and it is because of water that comes out in Polymerization gives required compressive strength. There is chemical reaction due to the speedy polymerization process and aging of the alkaline liquid.
- As GPC gives desired strength, product like Fly ash which is produced abundantly can be managed properly by using it in manufacturing concrete.
- GPC has wide spread application in precast industries.
- Low calcium Fly ash-based GPC has desired compressive strength and is usable for structural applications."

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