# GEOPOLYMER CONCRETE OF NEXT GENERATION

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***Abstract:*** Lessening the ozone depleting substance outflows is the need of great importance. The ozone harming substance emanations are decreased by 80 percentages in Geopolymer concrete opposite the OPC assembling, as it doesn't include carbonate consumes and so on. In 2016, world cement production generated around 2200 million tonnes of $CO_2$ equivalent to 8% of the global total. Unconventional binder system with flyash (FA) to produce concrete eliminating cement is called Geopolymer Concrete (GPC). GPC is a kind of inorganic polymer composite, which has as of late developed as an imminent binding material dependent on novel usage of designing materials. For the preparation of GPC blends FA, blast furnace slag (GGBS) and alkaline solution were used in this analysis. The alkaline mixture was prepared 24 hrs before the production of GPC as the reaction is very exothermic and produce huge amount of heat. This research continues to investigate the behavior of these GPC's of M50 grade concrete under environmental temperatures without water curing the cubes. Replacing 50% of flyash and GGBS each by volume of cement makes two designs namely B and C. 3 different molar NaOH solution i.e. 10M, 12M and 14M is added to each design mixes B and C. The study of workability, compressive strength (CS), and durability tests are done in this study to get the idea of GPC and M50 grade control mix concrete is also casted to compare the results and at last rate analysis is conducted to ensure the feasibility of GPC.

**Keywords:** Geopolymer concrete, Flyash, GGBS, Molarity, NaOH, Compressive Strength.

## 1. Introduction

Once quenched and grounded to cement powderiness, iron blast furnace slag has been used as a primal or supplementary binder in the manufacture of concrete in Europe for more than a centaury. Utilization of slag as an admixture in quality cement has extended quickly since the 1950's. The serious issues related with the Portland concrete are its creation, which is energy consuming and all the more essentially it discharges high volume of $CO_2$ in to the air. Simultaneously the removal of mechanical Squanders for example, FA, GGBS, mine squander, red mud and so on, has become a major issue, it requires huge territories of valuable land and furthermore has immense effect on the earth. At the beginning of the twentieth century, about 10% of the global inhabitants lived in cities; in 2001, nearly 50% of the world's 6 billion inhabitants lived in and around cities. [8]. Populace increase and urban sprawl have added to tremendous extension of the energy, production, and transportation areas of the economy during the 20$^{th}$ century. For instance, according to Hawken et al. [7] only 6% of the total global flow of materials, some 500 billion tons (450 billion tonnes) a year, is actually ending up in consumer products, while a significant number of the virgin materials are dumped into nature as injurious solids, fluid, and vaporous squanders.

Concrete is the most generally utilized man-made material in presence. It is 2$^{nd}$ just to water as the most-expended asset on earth. Be that as it may, while concrete - the key fixing in concrete - has molded quite a bit of our fabricated environment, it additionally has a huge carbon impression. In the event that the concrete business were a nation, it would be the 3$^{rd}$ biggest producer on the planet - behind China and the US. It contributes more $CO_2$ than avionics fuel (2.5%) and isn't a long ways behind the worldwide agribusiness business (12%). In 2016, world concrete creation produced around 2200 million tons of $CO_2$ - equal to 8% of the worldwide sum. The greater part of that originated from the calcination procedure. The creation of 100 kg of OPC legitimately produces 55 kg of $CO_2$ and requires the burning of carbon-fuel to yield an extra 40 kg of $CO_2$ [9]. Figure 1 shows the Production of $CO_2$ at different stages for making Cement. According to Davidovits's [3] study, the creation of 100 kg of geopolymer (GP) produced just 18.4 kg of CO2, from ignition carbon-fuel. From Figure 2 we can see the quantity of cement produced and $CO_2$ emissions by the different countries. [9]

Concrete industry pioneers were in Poland for the UN's environmental change Conference - COP24 [2] to examine methods for meeting the necessities of the Paris Agreement on environmental change. To do this, yearly emanations from concrete should fall minimum of 16% by 2030. Figure 3 shows the global increase in the production of cement from year 1970 to 2018.

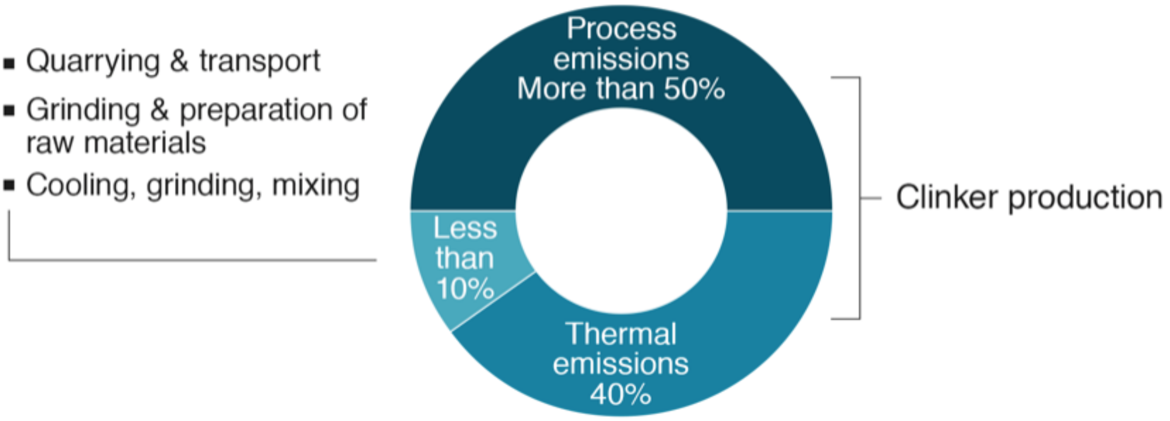


Figure 1: Production of $CO_2$ at different stages for making Cement [1]

Alternative binder system with fly ash to produce concrete eliminating cement is called Geopolymer Concrete (GPC). GPC is a sort of inorganic polymer composite, which has as of late rose as a forthcoming binding material dependent on novel usage of building materials. It can possibly shape a considerable component of an ecologically bearable construction industry by supplanting/enhancing the ordinary concretes [10]. GPC can be structured as high quality concrete with great protection from chloride infiltration, acid assault, sulfate assault, and so forth.

The geo-polymeric cements are usually framed by alkali initiation of industrial alumino silicate squander materials, for example, FA and GGBS, and have extremely little impressions of ozone harming substances when contrasted with conventional concretes. Palomo and Grutzeck [11] reported that sort of alkaline fluid influences the mechanical properties of GPC. Palomo and Femandez-Jimenez [12] concluded that both relieving temperature and curing period influences the CS of GPC blends. Gourley [5] stated that low calcium class F FA is more ideal than high calcium class C FA in the assembling of GPC. Guru Jawahar and Mounika [6] concluded that GGBS and FA mixed GPC blends achieved improved mechanical properties at encompassing room temperature itself.

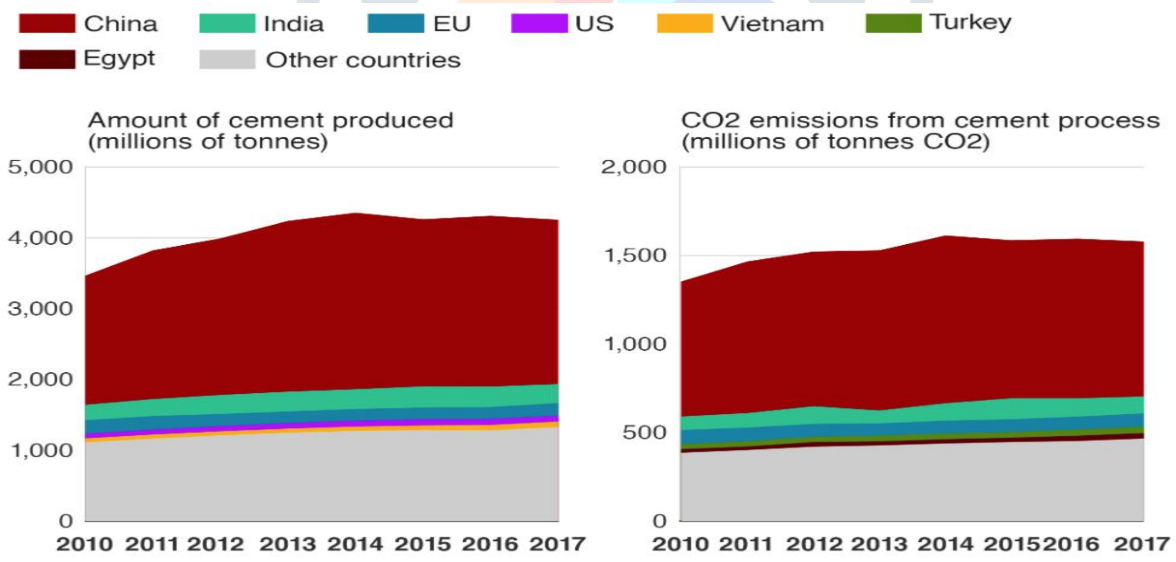


Figure 2: Amount of cement produced and $CO_2$ emissions by the different countries [13]

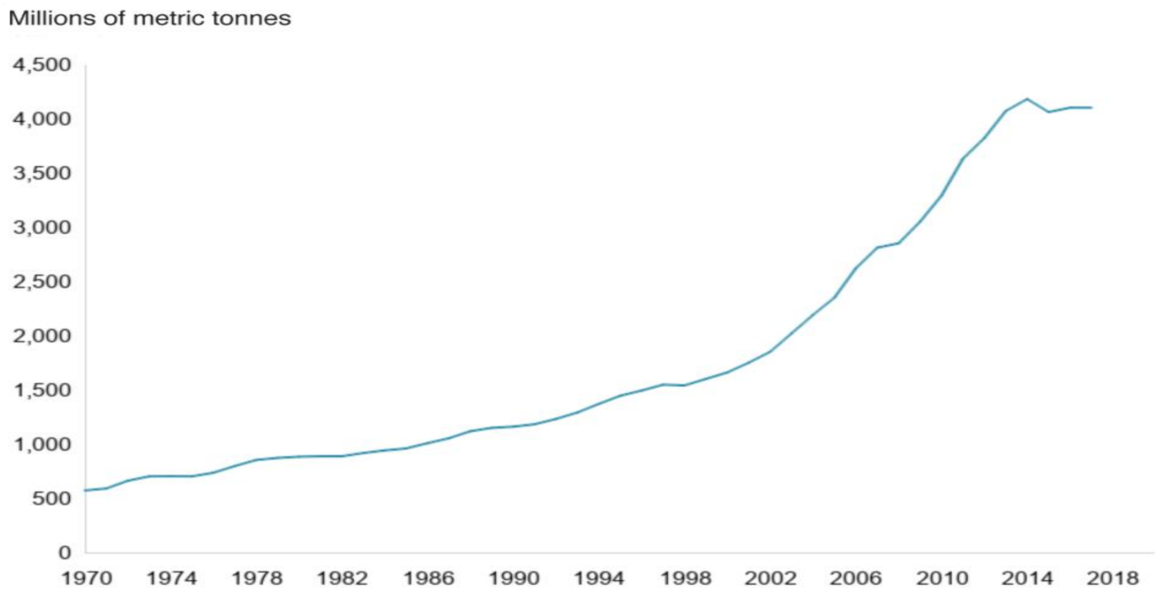


Figure 3: Global Cement Production [14]

## 2. Experimental Work

Right now, calcium (ASTM Class C) FA based GP is utilized as the binder, rather than OPC or other pressure driven concrete paste, to deliver concrete. The FA based GP paste ties the free coarse aggregates, fine aggregates and other unreacted materials together to shape the GPC, with the existence of admixtures.

**Materials:** In the current examination, Class-C FA and GGBS are utilized in equivalent extent (half each) as cementitious materials for the arrangement of GPC blends. A blend of systematic grade Sodium hydroxide (97-100% virtue) and Sodium silicate arrangement ($Na_2O$– 14.7%, $SiO_2$-29.4% and $H_2O$-55.9%) is utilized in the current examination as the catalytic fluid. OPC is not at all used in these mixes. Table 1 shows the chemical composition of cement and its replacement Flyash and GGBS. Table 2 shows the Nomenclature for GPC mixes.

Table 1: Details of Mix Proportions of GPC Mixes for 1m$^3$

| Component | Chemical Composition (%) | | |
|---|---|---|---|
| | Cement (Grade 53) | Flyash (Class C) | GGBS |
| $SiO_2$ | 20.63 | 46.38 | 31.23 |
| $Fe_2O_3$ | 3.41 | 8.26 | 1.88 |
| $Al_2O_3$ | 4.71 | 13.9 | 17.16 |
| CaO | 63.64 | 15.1 | 38.66 |
| MgO | 1.24 | 6.68 | 8.6 |
| $SO_3$ | 2.98 | 4.26 | - |
| Free- CaO | 1.1 | 0.15 | - |

Table 2: Nomenclature for GPC mixes

| Meaning | M = Molarity of NaOH mixture |
|---|---|
| A0 | M50 Control Mix Design |
| B1 | 10M NaOH Solution with G50-F50-S2.5-A0.5 in Concrete |
| B2 | 12M NaOH Solution with G50-F50-S2.5-A0.5 in Concrete |
| B3 | 14M NaOH Solution with G50-F50-S2.5-A0.5 in Concrete |
| C1 | 10M NaOH Solution with G50-F50-S2.5-A0.4 in Concrete |
| C2 | 12M NaOH Solution with G50-F50-S2.5-A0.4 in Concrete |
| C3 | 14M NaOH Solution with G50-F50-S2.5-A0.4 in Concrete |
| G50 | 50% GGBS as a replacement of cement |

| | |
|---|---|
| **F50** | 50% Flyash as a replacement of cement |
| **S2.5** | $Na_2SiO_3$ to NaOH ratio |
| **A0.4** | Alkaline Activator content to Binder Solid ration |

**Mix Design:** Right now no institutionalized strategies for blend structure for GPC blends are accessible. So blends are basically structured by trail and error at now. 7 trial mixes (including control mix M50), whose performance had been discovered good as both ease in mixing and quality perspectives, were considered as candidate blends in this.

**Mixture Proportion:** This ratio of both the liquids was fixed at two and half for the mixtures **[4].** This extent is kept in light of the fact that the sodium silicate mixture is impressively less expensive than the sodium hydroxide mixture. Molarity of NaOH mixture is taken as 10M, 12M and 14M for both B and C design. Ratio of activator solution-to-fly ash, by mass, is taken 0.5 for B design mix and 0.4 for C design mix. Coarse and fine aggregates for mix design are in ratio of 63% and 37% of total volume of aggregates. In coarse aggregate 80% are 20mm down and 20% are 10mm down aggregates. Refer Table 3 for details of Mix Proportions of GPC Mixes for $1m^3$.

Table 3: Details of Mix Proportions of GPC Mixes for $1m^3$

| Mix Design | Cement (Kg) | Flyash (Kg) | GGBS (Kg) | NaOH (Kg) | $Na_2SiO_3$ (Kg) | Coarse Agg. (Kg) | Fine Agg. (Kg) | Water (Litre) |
|---|---|---|---|---|---|---|---|---|
| **A0** | 412 | - | - | - | - | 1284 | 621 | 196.00 |
| **B1** | - | 180 | 248.5 | 17.48 | 67.48 | 1151.0 | 630.8 | 129.24 |
| **B2** | - | 180 | 248.5 | 19.85 | 67.48 | 1153.0 | 632.0 | 126.87 |
| **B3** | - | 180 | 248.5 | 21.97 | 67.48 | 1155.0 | 633.0 | 124.75 |
| **C1** | - | 180 | 248.5 | 14.00 | 54.00 | 1216.0 | 666.4 | 103.41 |
| **C2** | - | 180 | 248.5 | 15.88 | 54.00 | 1218.0 | 667.4 | 101.53 |
| **C3** | - | 180 | 248.5 | 17.58 | 54.00 | 1219.5 | 668.3 | 99.83 |

**Preparation of Alkaline Liquid:** The alkaline mixture was prepared a day before the casting as the reaction is very exothermic and produce huge amount of heat. NaOH mixture is produced by mixing NaOH flakes in water as per the molarity of solution. In the current examination 10M, 12M and 14M molar solutions will be used therefore solution is prepared accordingly. Sodium hydroxide flakes when mixed in water generate heat, as it is an exothermic reaction. So, proper care should be taken while mixing of flakes. The NaOH flakes were kept in a plastic container. The plastic container was closed with the lid immediately to avoid the irritation caused by inhaling hot fumes of gases liberated.

### 3. Mixing and Curing

Blending of the all of materials were done physically in the Concrete lab at room temperature. The FA and aggregates were first blended homogeneously as appeared in Figure 4 and afterward the alkaline mixture, which was made 24 hrs prior, was added to the blend of FA and aggregates.


Figure 4: Raw Materials

Curing of control mix A0 was done by standard procedure by immersing concrete cubes into the water tank for their respective curing period. While for all the GPC mix design i.e. B1, B2, B3 and C1, C2, C3 ambient curing was done i.e. they very exposed to simple environment without water curing.

**Test Methods:** Compressive strength (CS) test was conducted on the cubical specimens for all the blends following 7, 28 and 56 days of curing according to IS 516. 3 cubes of size 15 cm x 15 cm x 15 cm were cast and tested for each age and each mix. All the test cubes were kept at ambient room temperature for all curing periods except control mix A0.

## 4. Discussion

Rheological properties of the freshly mixed GPC are reliant on the type and the contents of the materials utilized in the blend. GPC blends display an alternate rheological conduct. Due to this high viscosity and cohesiveness, though the mixes were comfortable to work with, very low compaction factor value were recorded which in turn demanded longer vibration. Again the initial setting time and final setting times of all GPC mixes used in the study are found to be more than 30 minutes and within 600 minutes, respectively.

**Residual Compressive Strength:** The GPC obtains around 60-70% of the total CS within 7 days. The behaviour of residual CS of GPC cubes at various molarities of NaOH mixtures in the concrete is appeared in Figure 6. From these figures, it very well may be seen that, the residual coefficient of CS of 7 days, 28 days and 56 days cubes presented to ambient curing is somewhat higher at the higher molarity of NaOH solution and also at the same molarity C1, C2, C3 design mix shows higher CS as compared to B1, B2, B3 design mixes. Table 4 shows the avg. CS and % change in CS as compared to A0.


Figure 5: Experimental Methodology for GPC

Table 4: Compressive Strength Test and % Change of GPC mix design at different ages of concrete

| Concrete Mixes | Average Ultimate Compressive Strength (N/mm$^2$) at | | | % Change in Compressive Strength at | | |
|---|---|---|---|---|---|---|
| | 7 Days | 28 Day | 56 Days | 7 Days | 28 Days | 56 Days |
| **A0** | 37.63 | 58.52 | 58.67 | - | - | - |
| **B1** | 46.37 | 59.85 | 59.85 | (+) 23.22 | (+) 2.27 | (+) 2.01 |
| **B2** | 48.44 | 62.81 | 63.56 | (+) 28.73 | (+) 7.33 | (+) 8.33 |
| **B3** | 54.67 | 69.48 | 71.85 | (+) 45.28 | (+) 18.73 | (+) 28.46 |
| **C1** | 46.81 | 59.56 | 60.30 | (+) 24.4 | (+) 1.78 | (+) 2.78 |
| **C2** | 52.59 | 67.85 | 69.33 | (+) 39.76 | (+) 15.94 | (+) 18.17 |
| **C3** | 58.07 | 76.59 | 77.63 | (+) 54.32 | (+) 30.88 | (+) 32.32 |

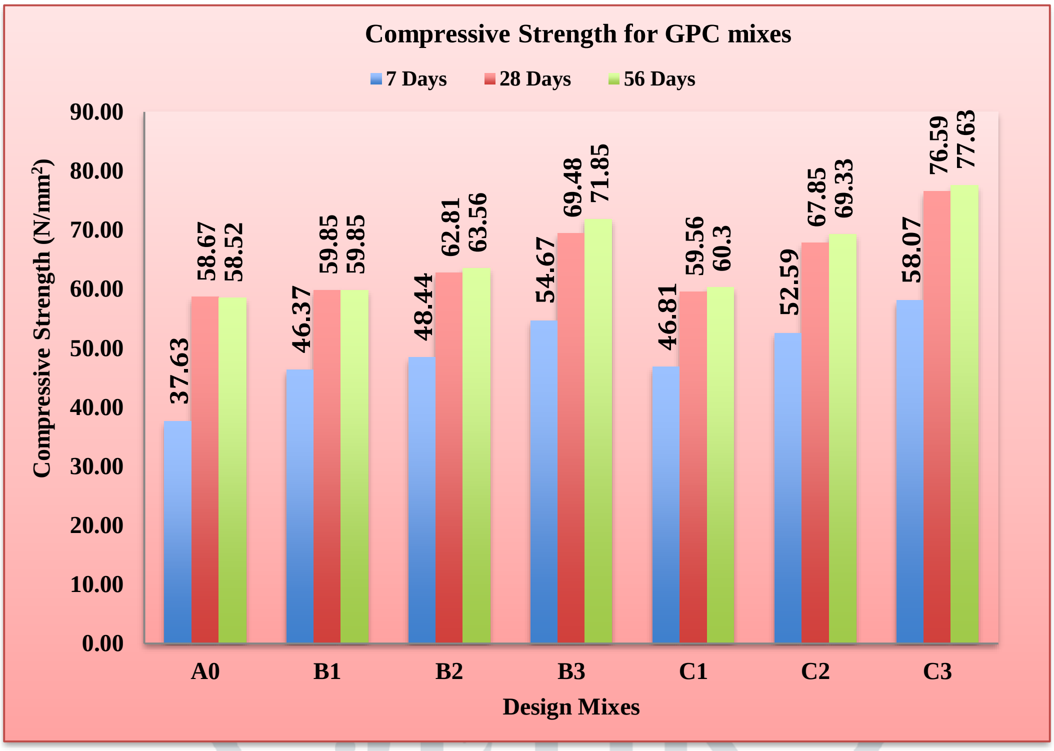


Figure 6: Compressive Strength Results for M50 Concrete Mix: Standard Concrete and GPC (B1, B2, B3 & C1, C2, C3) with Replacement of Flyash and GGBS Waste Powder at 7, 28 and 56 days

**Water Absorption:** The water absorption is mainly depending upon the dense packing of the concrete structure and the porosity. As the Molarity of concrete increases there more hydration rate and produces more heat. So there is increase in the water demand hence there is increase in the water absorption in the concrete up to M14 as compared to control mix A0. It becomes similar to that of control mix A0 at 14M molar solution i.e. B3. Table 5 shows the % Water absorption and by different concrete mixes and % change in water absorption as compared to A0. The behavior of water absorption can be found in the Figure 8 for conventional and GPC mixes

Table 5: Water Absorption Test for GPC

| Concrete Mixes | % Water Absorption | % Change in Water Absorption |
|---|---|---|
| **A0** | 1.55 | - |
| **B1** | 1.74 | (+) 12.26 |
| **B2** | 1.64 | (+) 5.81 |
| **B3** | 1.56 | (+) 0.65 |
| **C1** | 1.78 | (+) 14.84 |
| **C2** | 1.56 | (+) 0.65 |
| **C3** | 1.42 | (-) 8.39 |

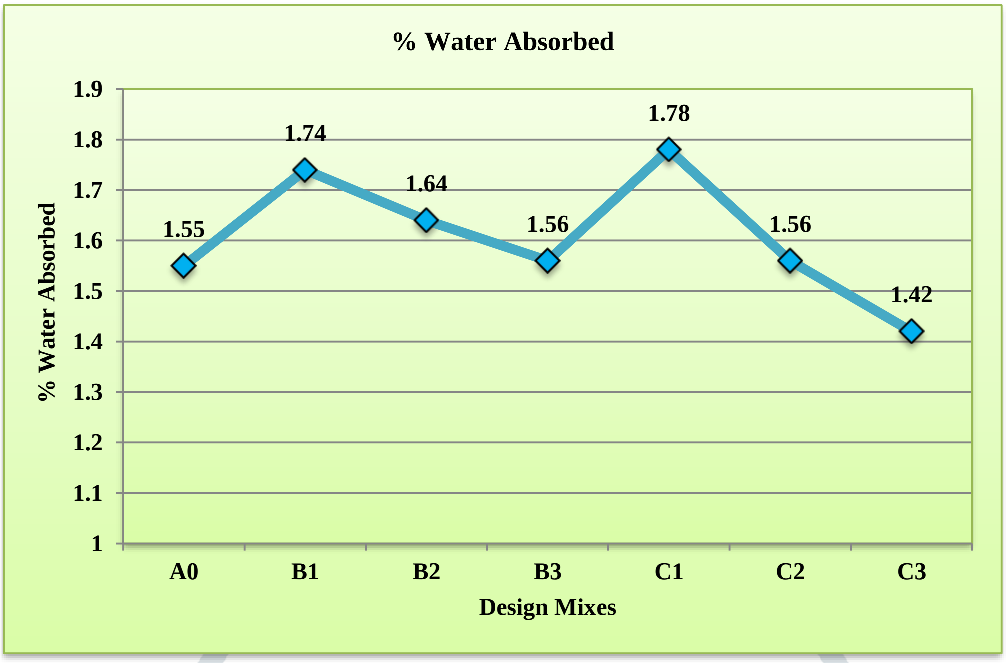


Figure 8: Percentage Water Absorbed for Control Mix and GPC (B & C) with Replacement of Flyash and GGBS Waste Powder at 28 Days for M50 grade Concrete

**Rate Analysis:** Rate analysis is been done for the all-different mixes for the M50 grade of concrete and the cost is gradually increasing at constant rate with the increasing in the molarity of NaOH added to the concrete. From the below table 7 we can clearly see that C1 is most cost effective GPC mix as compared to control mix A0. The control mix is having the rate for 1 $m^3$ of concrete is Rs. 3483.05 and it is decreasing further at the cost saving percentage of 7.72% saving in cost at the C1 design mix. Further increase in the molarity of NaOH will increase the cost very negligible but the CS and durability properties are showing good results. At C1 the cost is Rs. 3214.35 and adopting this proportion of mix design in M50 grade concrete making concrete more economical and cost beneficial is saved the significant amount. Table 6 shows the cost of Raw material per kg.

Table 6: Raw Material Costing per Kg

| Materials | Cost per Kg (Rs.) |
|---|---|
| **Cement** | 6.4 |
| **Fine Aggregate** | 0.45 |
| **Coarse Aggregate** | 0.45 |
| **Flyash** | 1.9 |
| **GGBS** | 2.5 |
| **NaOH** | 27 |
| **$Na_2SiO_3$** | 19 |

Table 7: Cost of Control Mix and GPC (B & C)

| Design Mixes | Cost per $1m^3$ (Rs.) | % Change in Cost |
|---|---|---|
| **A0** | 3484.05 | - |
| **B1** | 3519.14 | (+) 1.007 |
| **B2** | 3584.57 | (+) 2.885 |
| **B3** | 3643.16 | (+) 4.567 |
| **C1** | 3214.35 | (-) 7.741 |
| **C2** | 3266.45 | (-) 6.245 |
| **C3** | 3313.42 | (-) 4.897 |

## 5. Conclusion

In view of limited experimental investigation concerning the Compressive Strength & Water Absorption of GPC, the accompanying ends are drawn:

1. Out of all GPC mixes C1 design mix shows optimum result for all the test result and also rate analysis when compared to control mix A0.
2. Workability of the concrete decreases with increase in the molarity of concrete due to less amount of water in the concrete
3. CS increases with increase in the molarity of the NaOH solution in the concrete mix.
4. C1 design mix shows 24.4%, 1.78% and 2.78% higher CS as compared to control mix A0 at 7, 28 and 56 days respectively.
5. From the above result we can clearly state that GPC mixes gains early high strength hence can be used as rapid hardening concrete having early setting time.
6. Minimum 23.22% high early CS is obtained for B1 and it goes all the way up to 54.32% for C3.
7. Water Absorption decreases with increase in the molarity of the concrete
8. Water absorption is 1.78% for C1, which is higher than 1.55% for A0.
9. And also GPC mix C1 saves approximately 8% of total cost and costs around Rs. 3214 per $1m^3$ where control mix costs Rs. 3494 per $1m^3$.

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