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An Experimental Study on Low Calcium Fly Ash Based Geopolymer Concrete

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Abstract
Geopolymer Concrete (GPC) is the name given to concrete where the binder is entirely replaced by an inorganic polymer formed between a strong alkaline solution and an aluminosilicate source. The source material such as fly ash that are rich in silicon (Si) and aluminium (Al) are activated by alkaline liquid to produce the binder. On the other hand the abundant availability of fly ash worldwide creates opportunity to utilize as substitute for OPC to manufacture concrete. This research report presents the study on the development of strength for various grades of geopolymer concrete for different curing conditions (ambient and oven curing). Trial mix was chosen for low calcium fly ash based geopolymer concrete using mix design reported in the research. The concentration of the sodium hydroxide solution was varied as 8 Molar, 10 Molar, 12 Molar and 14 Molar. The alkaline solution used in the study is a combination of sodium silicate and sodium hydroxide solution with the ratio of 2.5. The 28th day compressive strength of the concrete for the mix GP1, GP2, GP3 and GP4 was observed to be in the range of 29.12 MPa to 36.24 MPa for specimen cured at room temperature, whereas the strength varied between 32.11 MPa to 37.12 MPa for specimen cured at 60^{o}C. Study on water absorption was also carried out for geopolymer specimens. The percentage of water absorption varied in the range 2% to 4.33% and 1.33% to 3.42% for specimen cured at room temperature and at 60^{o}C. The percentage of water absorption is found to be less in case of specimen cured at 60^{o}C temperature than specimen cured at room temperature.

Keyword: - Geopolymer Concrete, water absorption, sulphuric acid, compressive strength, fly ash, tensile strength.

INTRODUCTION

Concrete is the most commonly used construction material in the world due to its high compressive strength, durability and availability. One of the efforts to produce more environment friendly concrete is to partially replace the amount of OPC in concrete with by-product materials such as fly ash. Fly ash is a residue from the combustion of coal which is widely available worldwide and leads to waste disposal proposal problems. Recent research has shown that it is possible to use 100% of fly ash as the binder in mortar by activating it with an alkali component, such as silicate salts and non-silicate salts of weak acids (Bakharev et al (1999a), Talling et al (1989)). In fly ash based geopolymer concrete the silica and the alumina present in the source materials are first induced by alkaline activators to form a gel known as aluminosilicate. This gel binds the loose aggregates materials in the mixture to form the geopolymer concrete (Wallah, 201 Fly ash is a by-product of the combustion of finely ground coal used as fuel in the generation of electric power. A dust collection system removes the fly ash as a fine particulate residue from combustion gases before they are discharged into the atmosphere. The ash content of coal used by thermal power plants in India varies between 25% and 45%. Coal with an ash content of around 40% is mostly used in India for thermal power generation.

As a consequence, a large amount of fly ash is generated in thermal power plants causing several disposal-related problems. In spite of initiatives taken by the government, several non-governmental organizations and research and development organizations, the total utilization of fly ash is only about 75%. India produces 222 million tons of fly ash annually (CEA-Delhi-2020) .This is expected to reach 437 million tons by 2030. Disposal of fly ash is a growing problem as only 25% of fly ash is currently used for applications like concrete and 7.37 % for bricks and tiles (CEA-Delhi Report-2020), the remaining being used for land filling. Globally less than 35% of the total annual fly ash produced in the world is utilized. Fly ash has been successfully used as a mineral admixture component of Portland pozzolana blended cement for nearly 60 years.

2. LITERATURE REVIEW

Abdul Aleem et al. have conducted an experimental investigation to find out an optimum mix for the geopolymer concrete. Concrete cubes of size 150 x 150 x 150 mm were prepared and cured under steam curing for 24 hours. The compressive strength was found out at 7 days and 28 days. The results are compared. The optimum mix is Fly ash: Fine aggregate: Coarse aggregate (1:1.5:3.3) with a solution (NaOH and Na_2SiO_3 combined together) to fly ash ratio of 0.35. The results conclude that high and early strength was obtained in the geopolymer concrete mix and geopolymer concrete was a workable mix. It was also observed that the increase in percentage of fine aggregates and coarse aggregates increased the compressive strength. This may be due to the high bonding between the aggregates and alkaline solution. The compressive strength was found reduced beyond the optimum mix. This may be due to the increase in volume of voids between the aggregates. The optimum mix is- Fly ash: Fine aggregate: Coarse aggregate are 1:1.5:3.3 with a solution (NaOH and Na_2SiO_3 combined together) to fly ash ratio of 0.35.

Hardjito and Rangan. Low-calcium fly ash-based geopolymer concrete has excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulfate attack, and good acid resistance. It can be used in many infrastructure applications. One ton of low-calcium fly ash can be utilised to produce about 2.5 cubic metres of high quality geopolymer concrete, and the bulk cost of chemicals needed to manufacture this concrete is cheaper than the bulk cost of one ton of Portland cement. Given the fact that fly ash is considered as a waste material, the lowcalcium fly ash-based geopolymer concrete is, therefore, cheaper than the Portland cement concrete. The special properties of geopolymer concrete can further enhance the economic benefits. Moreover, reduction of one ton of carbon dioxide yields one carbon credit and, the monetary value of that one credit is approximately 20 Euros. This carbon credit significantly adds to the economy offered by the geopolymer concrete. In all, there is so much to be gained by using geopolymer concrete

Bhikshma et al. Have conducted an experimental investigation on the properties of geopolymer concrete. Test experiments have proved that fly ash based Geopolymer concrete has excellent compressive strength, suffers very low drying shrinkage, low creep, excellent resistant to sulphate attack and good acid resistance. The workability of the concrete in terms of slump and compacting factor are observed to be excellent. The geopolymer concrete in fresh state has been observed to be highly viscous and good in workability.

Raijiwala et al. have reported the progress of the research on making geopolymer concrete using the thermal power plant fly ash, (Ukai) Gujarat, India. The project aims at making and studying the different properties of geopolymer concrete using this fly ash and the other ingredients locally available in Gujarat. Potassium Hydroxide and sodium Hydroxide solution were used as alkali activators in different mix proportions. The effects of various salient parameters on the compressive strength of low-calcium fly ash-based geopolymer concrete are discussed by considering the ratio of alkaline solution to fly ash (by mass) 0.35 constant. The specimens were cured at two different temperature 25^{o}C and 60^{o}C for 24 hours in the oven. The main parameters studied were the compressive strength, curing temperature, effect of wet-mixing time, influence of handling time on compressive strength, effect of super plasticizer on compressive strength, effect of super plasticizer on slump of concrete, effect of water-to-geopolymer solids ratio by mass on compressive strength, stress-strain relation of geopolymer concrete in compression. Experimental results indicate that the compressive strength of GPC increased over controlled concrete by 1.5 times and split tensile strength of GPC increased over controlled concrete by 1.45 times. The flexural strength of GPC increased over controlled concrete by 1.6 times. In pull out test GPC increases over controlled concrete by 1.5 times.

3. EXPERIMENTAL PROGRAMME

Fly ash Fly ash is a fine powder recovered from the gases of burning coal during the generation of electricity. These micron-sized earth elements consist primarily of silica, alumina and iron. Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. Fly ash improves considerably the performance of binder paste and increases the bonding action with aggregate and reinforcement. The properties of fly ash may vary considerably according to several factors such as the geographical origin of the source coal, conditions during combustion and sampling position within the power plant.

Alkaline Activators- The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The NaOH solids were dissolved in water to make the solution. The mass of NaOH solids in a solution depends on the concentration of the solution and is expressed in terms of Molar (M).

Aggregates- In the absence of the usage of proper alternative aggregates becoming possible in the near future, the concrete industry globally will consume 8-12 billion tons annually of natural aggregates after the year 2010 (Tsung et al 2006). Aggregates are inert granular materials such as sand, gravel or crushed stone which, along with water and Portland cement, constitute an essential ingredient in concrete.

4. METHODOLOGY

The testing of concrete plays an important role in controlling and confirming the quality of cement concrete works (Shetty, 2007). Systematic testing of raw materials and fresh concrete are inseparable parts of any control programme for concrete. The main task is that when different materials are used in the concrete, careful steps are to be taken at every stage of work for different tests.

- **Compressive Strength Test**

Compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is implied primarily to resist compressive stress. In this experimental investigation, both geopolymer concrete cubes and hollow blocks were used for testing compressive strength. The load at which the specimen ultimately fails is noted. Compressive strength is calculated by dividing load by area of specimen as shown in equation 1.

$$f_c = \frac{P}{a} \qquad \ldots (1)$$

Where

f_c = Cube compressive strength in N/mm^2

P = Cube compressive load causing failure in N a =

Cross sectional area of cube in mm^2

Figure 1: Compressive Strength Testing.

- **Water Absorption Studies on Geopolymer Concrete**

The durability of concrete has been evaluated in this study through parameters related to permeability. The absorption study was done to know the permeability characteristics of geopolymer concrete and was performed in accordance to ASTM C: 642-2006 at 7, 14 and 28 days. The specimens used for this test were 150 x 150 x 150 mm cubes with different concentration of NaOH ranging from 8M to 14M.

- **Preparation of Test Specimens**

The test specimens such as cube and cylinder block were cast for studying the mechanical and chemical property. Geopolymer concrete block were used to study the behaviour of various heights. Sample specimens of cube

Figure 2: Sample Specimens of Cube.

5. RESULTS AND DISCUSSION

A. Compressive Strength of GPC Solid Block

The ratio of alkaline liquid-to-fly ash, by mass, was not varied. This ratio remained approximately around 0.4 and the concentration of NaOH solutions were varied as 8M, 10M, 12M and 14M. The measure 7th day 14th day and 28th day for two different curing conditions is given in Table 5.2 and 5.3. The difference between the mixtures is the concentration of NaOH in terms of molar and the curing condition. GP4 with higher concentration of NaOH solution yielded higher compressive strength. The 28th day compressive strength of the concrete for the mix GP1, GP2, GP3 and GP4 was observed to be in the range of 29.12 MPa to 36.24 MPa for specimen cured at room temperature, whereas the strength varied between 32.11 MPa to 37.12 MPa for specimen cured at 60^{o}C.

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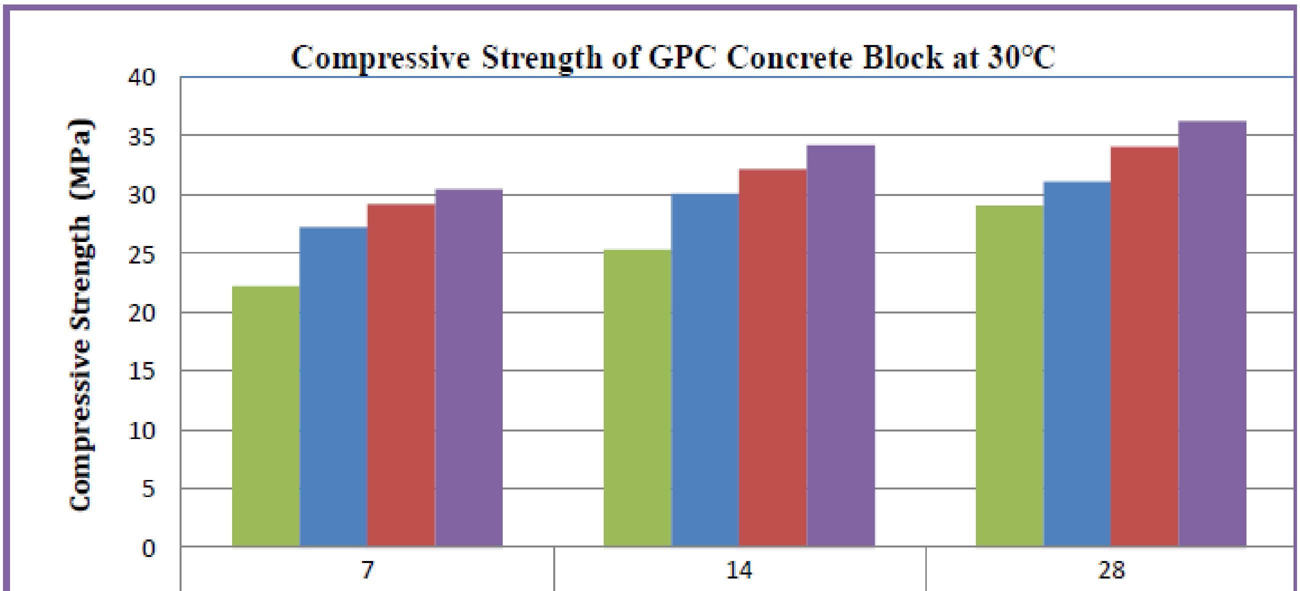
Table 1: Compressive Strength of GPC Concrete Block at 30°C.

Mix Designation	Molarity Of NaOH	Curing Condition	Compressive Strength (MPa) (Days)		
			7	**14**	**28**
GP1	**8M**	**30°C**	**22.25**	**25.37**	**29.12**
GP2	**10M**	**30°C**	**27.22**	**30.14**	**31.12**
GP3	**12M**	**30°C**	**29.23**	**32.14**	**34.12**
GP4	**14M**	**30°C**	**30.45**	**34.22**	**36.24**

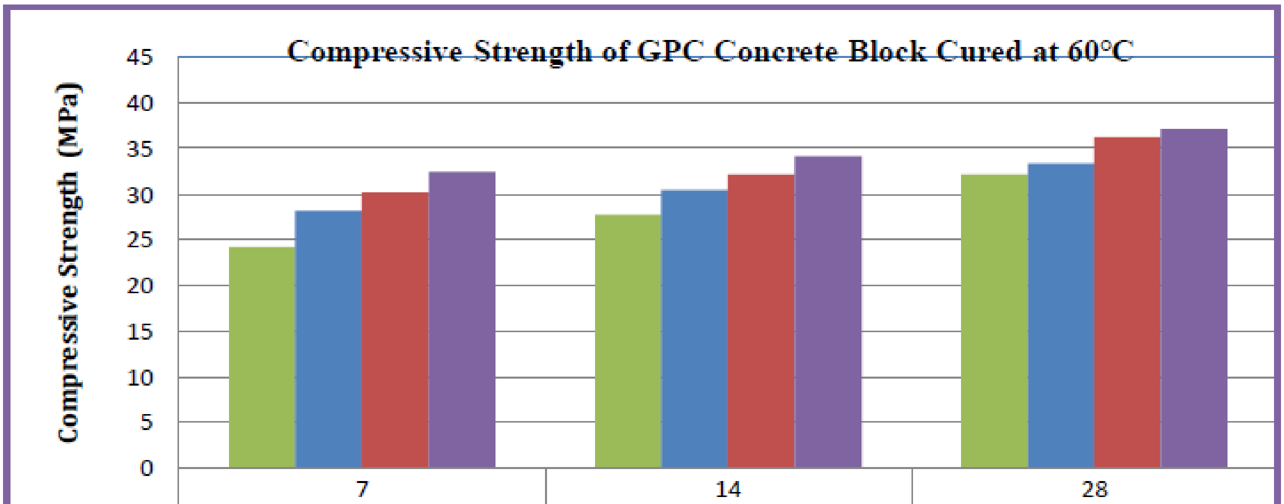
Table 2: Compressive Strength of GPC Concrete Block Cured at 60°C.

Mix Designation	Molarity of NaOH	Curing Condition	Compressive Strength (MPa) (Days)		
			7	**14**	**28**
GP1	**8M**	**60°C**	**24.15**	**27.76**	**32.11**
GP2	**10M**	**60°C**	**28.12**	**30.43**	**33.36**
GP3	**12M**	**60°C**	**30.12**	**32.11**	**36.16**
GP4	**14M**	**60°C**	**32.45**	**34.12**	**37.12**



	7	14	28
GP1 8M	22.25	25.37	29.12
GP2 10M	27.22	30.14	31.12
GP3 12M	29.23	32.14	34.12
GP4 14M	30.45	34.22	36.24

Figure 3: Development of Compressive Strength of GPC Solid Block for Curing at 30°C.



	7	14	28
GP1 8M	24.15	27.76	32.11
GP2 10M	28.12	30.43	33.36
GP3 12M	30.12	32.11	36.16
GP4 14M	32.45	34.12	37.12

Figure 4: Development of Compressive Strength of GPC Solid Block for Curing at 60°C.

B. Water Absorption of Geopolymer Concrete

Water absorption tests were performed for 7, 14 and 28 days on geopolymer concrete cubes of size 150 x 150 x 150 mm. Sample cured at room temperature and at 60^{o}C were tested for water absorption. Figure 5.14 and 5.15 shows the results of water absorption tests. The percentage of water absorption varied in the range 2% to 4.33% and 1.33% to 3.42% for specimen cured at room temperature and at 60^{o}C. The water absorption of fly ash geopolymer normally varies between 3% and 5% (Sathia et al, 2008) and (Song, 2007). Overall, a water absorption value of less than 5% is classified as "low"- according to VIC Road's standard specification (Song, 2007). This low water absorption level is a good indicator of limited open porosity that can inhibit the high flow of water into the concrete.

Table 3: Water Absorption for Specimen Cured at 30^{o}C.

Mix Designation	Weight of Concrete Before Immersion (kg)	Weight of Concrete Cubes (After Immersion) (Days) (kg)			Percentage of Water Absorption of Specimen After Immersion		
		7	14	28	7	14	28
GP1	7.39	7.61	7.68	7.71	2.98	3.92	4.33
GP2	7.45	7.65	7.71	7.74	2.8	3.6	3.9
GP3	7.5	7.68	7.72	7.75	2.5	3	3.4
GP4	7.56	7.71	7.75	7.78	2	2.5	2.9

Table 4: Water Absorption for Specimen Cured at 60^{o}C.

Mix Designation	Weight of Specimen Before Immersion (kg)	Weight of Concrete Cubes (After Immersion) (Days) (kg)			Percentage Weight of Water Absorption of Specimen After Immersion		
		7	14	28	7	14	28
GP1	7.30	7.45	7.52	7.55	2.05	3.01	3.42
GP2	7.41	7.55	7.62	7.66	1.89	2.83	3.37
GP3	7.46	7.58	7.65	7.68	1.61	2.55	2.95
GP4	7.5	7.6	7.67	7.70	1.33	2.40	2.67

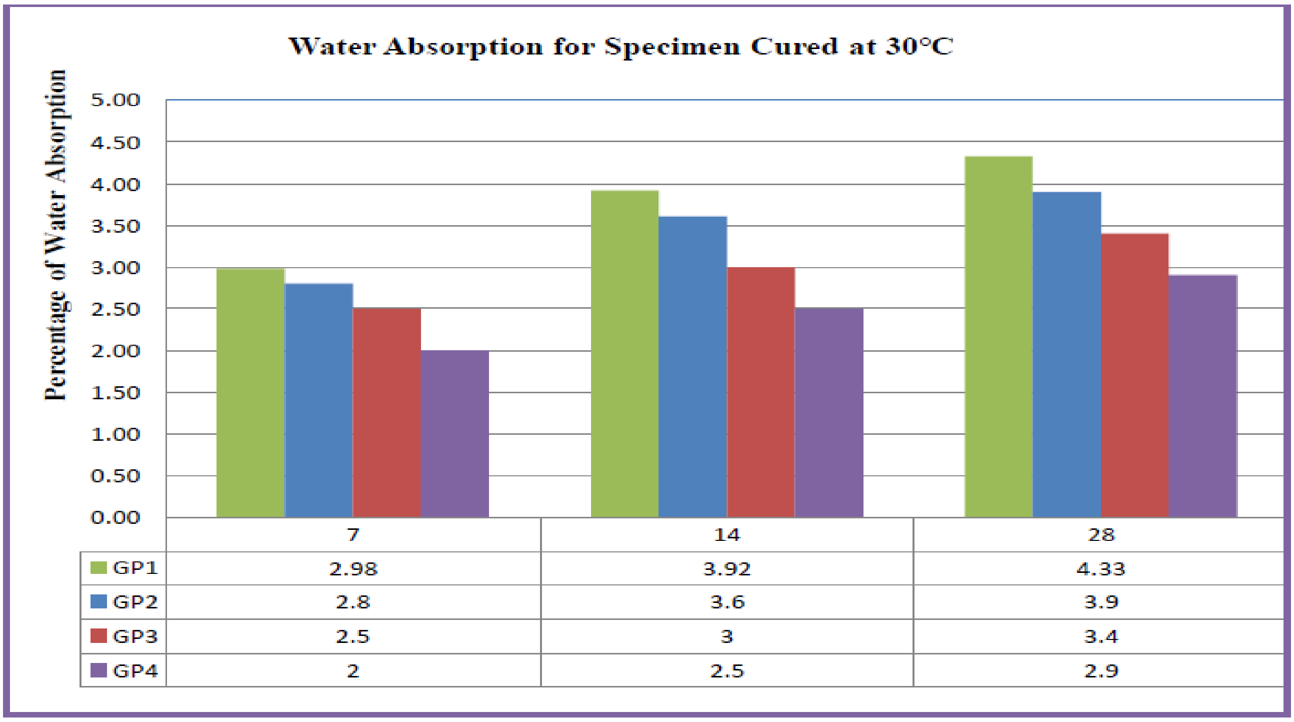


Figure 5: Percentage of Water Absorption for Specimen Cured at 30°C.

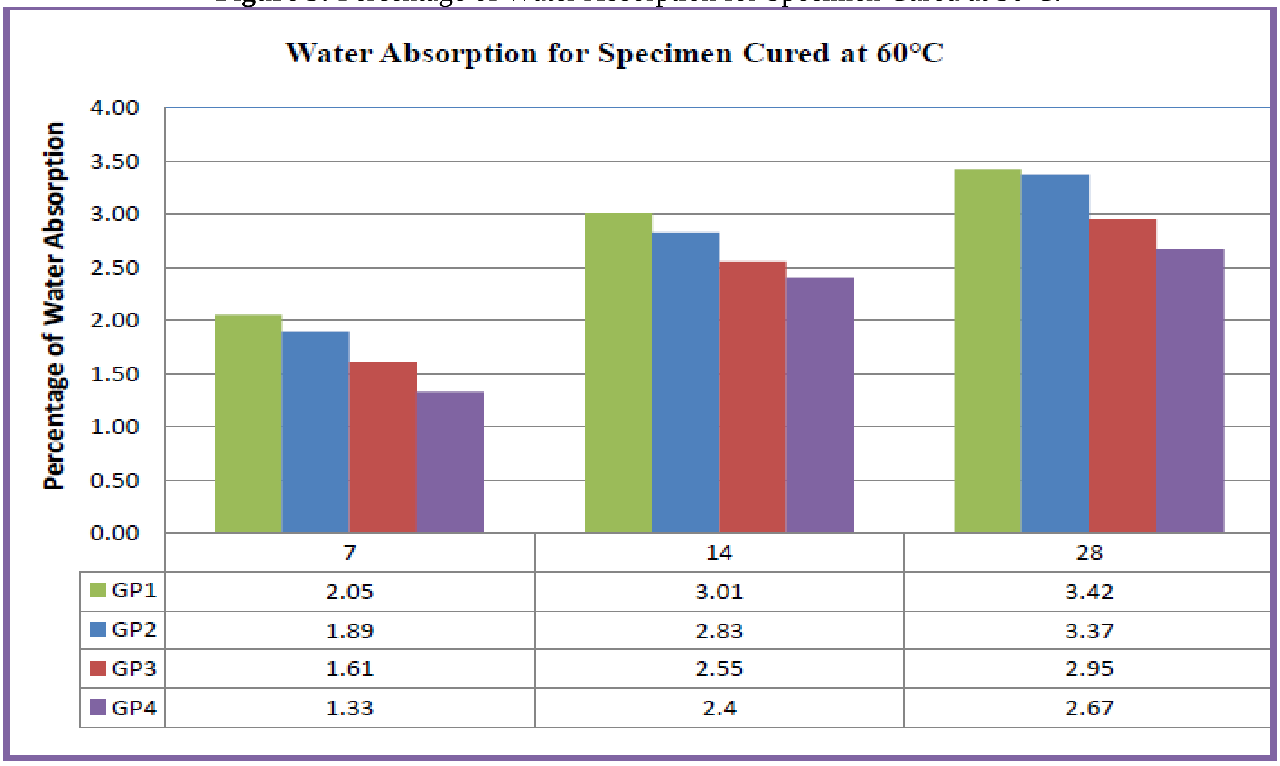


Figure 6: Percentage of Water Absorption for Specimen Cured at 60°C.

6. CONCLUSION

1. Compressive strength increases with increase in concentration of NaOH from 8M to 14M. Increase in compressive strength was also observed with increase in curing time for GPC concrete.

2. Maximum compressive strength achieved for GPC solid block for curing at 60^{o}C was 37.12 MPa.

3. Water absorption decreases with increase in concentration and curing time. The percentage of water absorption was found to decrease with increase in concentration of NaOH from GP1 to GP4.

4. The percentage of water absorption varied in the range from 2% to 4.33% and 1.33% to 3.42% for specimen cured at room temperature at 30^{o}C and 60^{o}C.

5. The percentage of water absorption is found to be less in specimens cured at elevated temperature than specimen cured at room temperature.

6. The reduction in compressive strength observed for GPC specimens for specimen cured at 30^{o}C and 60^{o}C was found to vary between 23.92 MPa to 29.75 MPa and 25.69 MPa to 29.705 Mpa.

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