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Effect of Water to Binder Ratio on Strength Properties of GGBS Based Powder Activated Geopolymer Concrete

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ABSTRACT
The geopolymer concrete is usually produced using laboratory grade alkaline activators. In the present work, the laboratory grade alkaline activators were replaced by relatively cheaper industrial grade alkaline activators and its effect on compressive strength of GPC was studied. Powder activated Geopolymer concrete of M40 grade using GGBS was produced and water to binder ratio was varied from 0.22 to 0.24 using sodium hydroxide and sodium silicate. Slump of 50mm was maintained. Three cubes and beams, each of size 150x150x150mm and 100x100x500mm respectively were cast and were cured at ambient temperature and tested for compressive strength at 3 and 7 days and flexural strength at 7 days. For different water to binder ratio, there was a significant increase in compressive strength and flexural strength. And the compressive strength and flexural strength were reported.
***Keywords*: Geo Polymer Concrete, alkaline activators, GGBS, M40 grade, compressive strength, flexural strength.**

INTRODUCTION

About 5-8% of world’s greenhouse gases are emitted due to the manufacture of Ordinary Portland Cement (OPC), which requires large amount of heat energy. Geopolymer concrete is an alternate innovative material developed to that of conventional concrete. The term “Geopolymer” was introduced by Davidovits in 1978. This concrete is produced by using a source material like flyash, which is a by-product of obtained from the warm power plant is bounty accessible around the world. And flyash is rich in silica and alumina, which results in the formation of strong bond and thus forms aluminosilicate gel. So the flyash based geopolymer concrete sets very slowly at ambient temperature and thus there is a necessity of heat curing, which can be eliminated by the addition of GGBS as replacement of flyash.

The geopolymers rely on thermally activated natural materials, for example kaolinite clay or industrial by products like flyash, GGBS to provide a source of silica and alumina, which is dissolved in an alkaline activating solution and subsequently polymerized into molecular chains and networks to form the hardened binder. Such systems are often referred to as alkali- activated cements or inorganic polymer cements. The geopolymer is in the form of chain and ring structure. The geopolymer is formed when source material (aluminosilicate) is activated by the alkalis such as NaOH and Na_2SiO_3.

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The previous studies on the geopolymer concrete were limited to the use of laboratory grade liquid activators which are expensive. In previous researches, geopolymer binder made from activation of source material by highly concentrated NaOH and Na_2SiO_3 solutions known as liquid activated geopolymer. This method of producing GPC has limitation in mixing and handling process because alkali solution can cause severe burns to human body on contact. They are also corrosive to materials like tin, zinc, copper, aluminium and their alloys. They should be stored very securely in air tight vessels made of non-reactive material. But the present study is mainly focused on powder activated geopolymer concrete. Since laboratory grade sodium hydroxide is highly concentrated in nature, more heat is generated during mixing. And also cost of laboratory grade chemicals are more, hence concrete produced become uneconomical. To overcome these problems, industrial grade NaOH (powdered form) is used and due to this handling of concrete becomes easier and which is cheaper too. In this study an attempt is made to carry out the experimental study on effect of water to binder ratio on strength properties of powder activated geo polymer concrete. The powder activated geopolymer binder which is prepared by blending sodium hydroxide powder with GGBS can overcome the limitations of liquid activated geopolymer binder. And sodium silicate solution is mixed thoroughly with water. This binder can be used as similar to OPC. The mixing procedure of this binder is similar to conventional concrete. In conventional concrete, strength is developed due to C-S-H bond present in concrete where as in GPC geopolymeric reaction forms aluminosilicate gel. For this reaction to happen the alkaline environment and silicates are very important. The ultimate strength and ultimate structure of the geopolymer binders largely depends upon the richness of source material in “silica” and “alumina” also the ratio of Si to Al. The geopolymerisation process involves the activation of source material by NaOH and an additional source of silica Na_2SiO_3. So the quantity of Na_2SiO_3 and NaOH to be added to produce a good quality of GP binder has major importance. Hence in the present study, the arrived optimum ratios of (Na_2SiO_3/NaOH) ratio and (NaOH+Na_2SiO_3)/(GGBS) ratio values were used for the material calculations (Na_2SiO_3 and NaOH) as per mix design of GPC.

EXPERIMENTAL PROGRAMME

Materials:

The materials used to produce powder activated geopolymer concrete are Sodium Hydroxide, Sodium Silicate, GGBS, Coarse aggregates, Fine aggregates, Water and Superplasticizer.

Sodium Hydroxide (NaOH): The industrial grade NaOH pellets having purity of 70-75% was purchased from Megha Chemicals Hubballi.

Sodium Silicate (Na_2SiO_3): Sodium silicate solution was purchased from Megha Chemicals Hubballi.

Ground Granulated Blast Furnace Slag (GGBS):

Ground granulated blast furnace slag is a non-metallic product consisting essentially of silicates and aluminates of calcium and it is a by-product of iron industries. The ground granulated blast furnace slag used for this work was obtained from Jindal Steel Industry, Bellary. The chemical composition of GGBS is shown in the Table 1.

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Table 1: Chemical composition of GGBS

PARAMETER	JSW GGBS	As per IS 12089-1987(Reaffirmed)
CaO	37.34%	-
Al_2O_3	14.42%	-
Fe_2O_3	1.11%	-
SiO_3	37.73%	-
MgO	8.71%	< 17 %
MnO	0.02%	< 5.5 %
Sulphide	0.39%	< 2 %
Loss of Ignition	1.41%	-
Insoluble residue	1.59%	-
Glass content		-

Fine aggregates: River sand confirming to IS 383: 1970 and passing through 4.75mm sieve and retains on 600 micron sieve was used. The specific gravity of the fine aggregate determined was 2.6.

Coarse aggregates: The coarse aggregates of 20 mm down size with specific gravity and water absorption being 2.65 and 0.25% respectively were used in the study.

Water: Water present in geopolymer concrete is of two types namely, water present in alkaline solution and extra water. Water present in alkaline solution is of very small quantity; hence geopolymer concrete mixes are usually very stiff. In order to improve the workability and to make geopolymer mix as a homogeneous mix extra water is added to the mix, but this water directly affects the strength of geopolymer concrete.

Super plasticizer: In order to achieve the desired workability, super plasticizer was used as the water reducer. This belongs to sika brands, Sulphonated Napthalene Formaldehyde.

WORKING PROCEDURE:

Procurement and testing of materials that was for sand and coarse aggregate. Procuring NaOH and Na_2SiO_3 of desired industrial grade alkaline activators and pulverize them. Preparing a powdered dry mix of NaOH with GGBS and Na_2SiO_3 solution with water and stirred it properly. And the ratios of Na_2SiO_3 /NaOH as 2.5 and (NaOH+Na2sSiO3):GGBS as

0.3 were adopted for the mix design of GPC. And water to binder ratio was varied as 0.22, 0.23, and 0.24. Based on these W/B ratios, the quantities of water were calculated respectively for each ratios by keeping all other parameters constant. In order to achieve the desired workability of 50mm slump, a super plasticizer was used as the water reducer. Super plasticizer of 0.3%, 0.25% and 0.2% of GGBS content for each water to binder ratios were used respectively. Three cubes each of size 150x150x150 mm and 3 beams each of size 100x100x500 were cast for each W/B ratio. And were cured at ambient temperature and tested for compressive strength and flexural strength for 3 and 7 days respectively.

MIX CALCULATIONS:

For GPC there were no IS code for mix design. Hence trial mix design was to be calculated. Assuming the density of GPC to be 2400 Kg/m^3. Arrived optimum ratios of sodium silicate to sodium hydroxide and alkaline activators to GGBS were 2.5 and 0.3 respectively. Weight of GGBS was based on the alkaline activators to GGBS ratio of 0.3. And weight of sodium hydroxide and sodium silicate were calculated by considering the ratio of sodium silicate to sodium hydroxide ratio as 2.5. The water content required for each W/B ratios were calculated. Since GPC is very stiff in nature, to maintain a workability of 50mm slump, an extra water of 61 kg/m^3 (206 gm) added for all W/B ratios remains constant. And only water content is varied by keeping all other parameters constant. And details of mixtures for all W/B ratios were shown in table below.

Table 2: Details of mixtures of all ingredients

W/B	Water kg/m^3	GGBS kg/m^3	NaOH kg/m^3	Na_2SiO_3 kg/m^3	Coarse Aggregates kg/m^3	Fine Aggregates kg/m^3	Super plasticizer kg/m^3
0.22	93.225	325.96	39.11	58.67	1391.25	585	0.978
0.23	97.463	325.96	39.11	58.67	1391.25	585	0.815
0.24	101.700	325.96	39.11	58.67	1391.25	585	0.652

PREPARATION OF MIX:

Quantities of ingredients were calculated as per mix design of GPC. Industrial grade sodium hydroxide pellets were blended with the GGBS. And sodium silicate was stirred thoroughly with the calculated quantity of water for each W/B ratios. And blended GGBS with sodium hydroxide has to be mixed with the calculated quantity of fine aggregates and coarse aggregates. And quantity of super plasticizer calculated for each W/B ratios were mixed with the calculated quantity of water. Preparation of GPC mix was similar to that of OPC. Mixing of all the ingredients properly so that homogeneous mix was formed. And checked for workability of geopolymer concrete by slump cone test and maintain a constant slump of 50mm for all W/B ratios. And place the concrete in moulds of size 150x150x150mm for cubes and 100x100x500mm for beams, which were placed on table vibrator for few seconds for proper compaction. Then level the top surface of each mould and cover with steel plate. And after 24hr of casting, all the cubes were demoulded. All the cubes were air cured for 3 and 7 days at an ambient temperature. All the cubes were tested for compressive strength at 3 and 7 days.

Fig 1: Vibration Process

Fig 2: Failure of Cube.

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RESULT AND DISCUSSIONS

Compressive strength obtained at 3 and 7 days for the each W/B ratios were reported. The average compressive strength of 3 cubes at 3 days for water to binder (W/B) ratios of 0.24, 0.23 and 0.22 were 39.15 N/mm², 44.38 N/mm² and 47.25 N/mm² respectively as shown in table 4 given below. And there is a significant increase in strength from 3 days to 7 days. And thus average compressive strength at 7 days for W/B ratio of 0.24, 0.23 and 0.22 were 45.91 N/mm², 51.94 N/mm² and 60.25 N/mm² respectively. The average flexural strength for W/B ratios of 0.24, 0.23 and 0.22 were 3.13 N/mm², 3.54 N/mm², and 4.21 N/mm² respectively at 7 days as shown in table 4 given below.

Table 3: Average compressive strength at 3 and 7 days

W/B ratio	Load (kN)	Compressive strength at 3 days (N/mm²)	Load (kN)	Compressive strength at 7 days (N/mm²)
0.22	1063	47.25	1356	60.25
0.23	998.5	44.38	1169	51.94
0.24	880.85	39.15	1033	45.95

Table 4: Average flexural strength at 7days

W/B ratio	Load (kN)	Compressive strength (N/mm²)
0.22	10.53	4.21
0.23	8.86	3.54
0.24	7.84	3.13

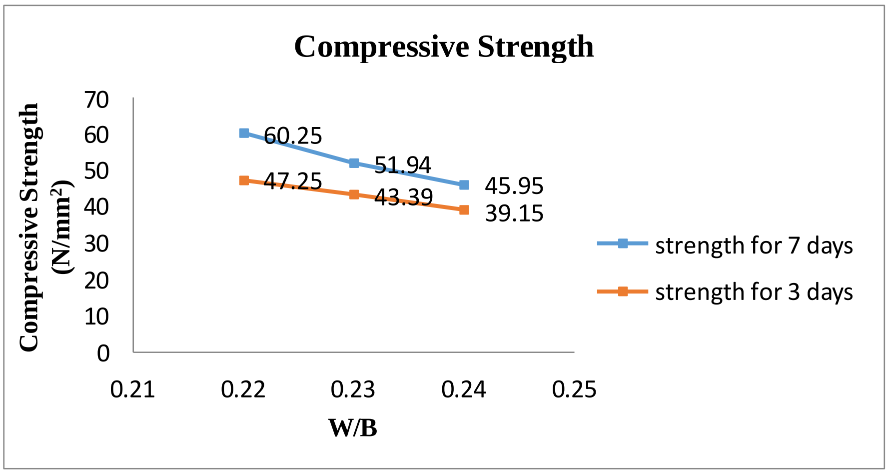

Fig 3: Compressive strength at different W/B ratio

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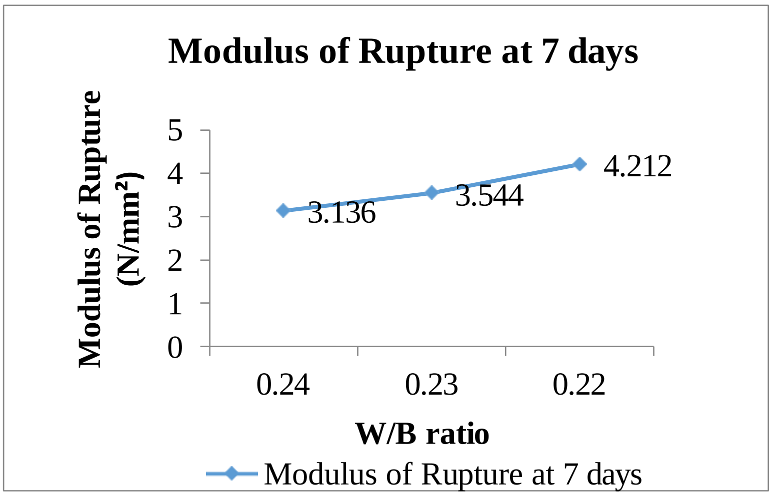

Fig 4: Modulus of rupture at different W/B ratio

From the above graph in above fig 3 and 4, it clearly mentions that the compressive strength increased with decrease in water to binder ratio. And flexural strength also decreases with increase in W/B ratio. Thus the compressive strength and flexural strength are inversely proportional to the water to binder ratio of powder activated geopolymer concrete. Since maximum compressive strength obtained at lower W/B ratio, the concrete was very stiff. And thus dosage of super plasticizer required was more. Therefore quantity of water plays vital role in compressive strength of concrete and more the amount of water increases workability of concrete but it affects inversely with strength.

COST ANALYSIS

Cost comparison made on both laboratory grade and industrial grade alkaline activators. Since laboratory grade activators are costly, industrial grade alkaline activators were used to make concrete economical. Cost of the materials considered as per dealers in larger quantities.

Materials	Laboratory grade (kg/m^3)	Cost per kg (Rs)	Industrial grade (kg/m^3)	Cost per kg (Rs)
GGBS	325.96	3	325.96	3
NaOH	39.11	100	39.11	60
Na_2SiO_3	58.67	40	58.67	25

- Total cost per m^3 for laboratory grade is 7235 Rs.
- Total cost per m^3 for industrial grade is 4792 Rs.
- Cost of industrial grade is 51% lesser than laboratory grade.

CONCLUSION

- Lower the W/B ratio gives the maximum strength of concrete but lowers the workability.
- Industrial grade alkaline activators can be replaced by the laboratory grade alkaline activators in powder activated geopolymer concrete.
- The cost of industrial grade alkaline activators were lesser compared to laboratory grade, hence production of geopolymer concrete with industrial grade alkaline activators becomes economical.

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