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Study on mix design of fly ash and GGBS based high performance geopolymer concrete

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Abstract:**Geo-polymer concrete (GPC) is nature friendly concrete which has less carbon emitted than that of cement concrete but still not popular. The reason behind it is lack of knowledge and unavailability of standard mix design.Packing density is unique type of mix design method used to design various types of concrete. Trial and error method is adopted to know FA: GGBS proportion and fluid binder ratio to be considered in order to achieve required strength. The mix design of normal cement concrete is developed using both IS 10262-2019 code and packing density method to check the reliability on packing density method. The tests are then conducted to verify the strength properties of concrete. There are list of test like compressive strength test, split tensile test and flexural tensile test for strength check.***

Conclusion:_The results obtained indicate that the strength of HPGPC is increased with increase in GGBS content. The F/B ratio also influences strength properties of HPGPC to larger extent. It is observed that the strength is decreased with increase in F/B ratio. The normal concrete shows lesser values of strength as compared to HPGPC._

Key Word**:**Bulk density, packing density, Geopolymer,HPGPC, HPCC and Mix design

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I. Introduction

Concrete is the basic material needed for construction of any structure. Concrete is the most consumed material globally after water. In 2014 about 2,238,377.14 thousands of kilotons of CO_2 is emitted in India out of which about 8% of total global CO_2 emission was found to be by cement industry.

To produce concrete which is nature friendly, we have to completely replace the cement with some other binders which do not harm environment. The industrial by products can be effectively used as binders. To do so, the new technology GPC is a promising technique. About 80% of CO_2 emission can be reduced by using geo-polymer technology (Davidovits, 1994) [1]. By doing so, the disposing of industrial waste will also be reduced to greater extent.

This work aims at providing complete experimental knowledge on high performance GPC. It will imitate a mix design of SCC for HPGPC and provide successful design for further studies. It checks HPGPC for its strength properties and compares it with HPCC to get thorough idea of pros and cons of using HPGPC. This study plots various graphs indicating effect of different F/B ratios corresponding to various FA: GGBS proportions in systematic manner so that the judgement on selecting these parameters to get required strength can be easily made. By following the present study one can get a clear idea about various parameters to be considered while designing, casting, and testing of HPGPC.

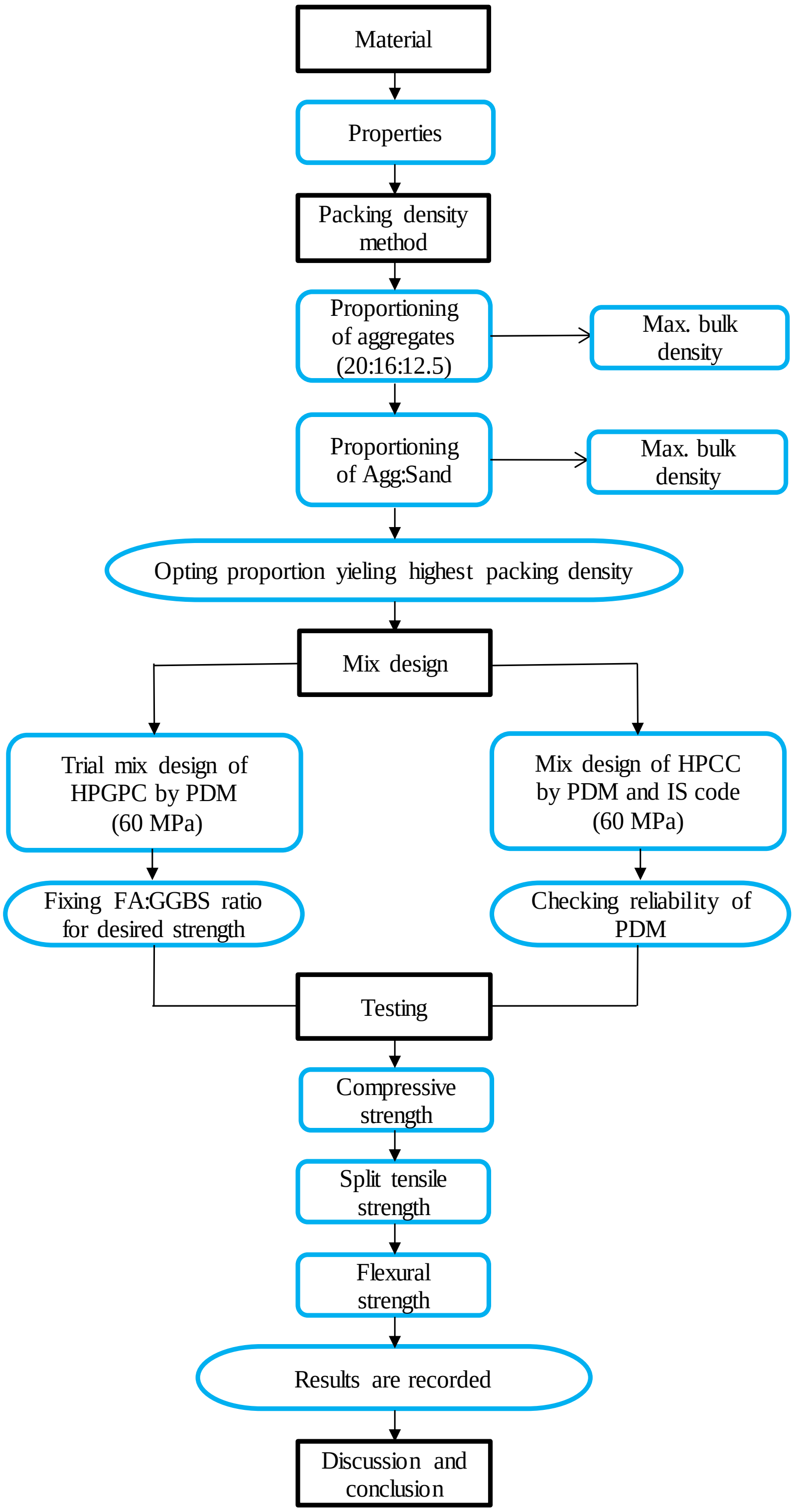
Suresh G Patil.et al. [2] have developed a mix design from packing density method for self-compacting concrete. In this they have clearly explained about the concept packing density and have given detailed explanation on each step need to be followed to achieve mix design of self-compacting concrete. An illustrative example was also provided in paper to help understand better.

P. Pavitra.et al. [3] have developed mix design of geopolymer concrete with fly ash. They have given detailed explanation on each step required to design mix of GPC. The main ingredient of geopolymer concrete is alkaline solution. Steps are given on how to prepare alkaline solution which was not mentioned in previous paper as it was for SCC.

By studying the design of two papers, a mix design of GPC is formed and its reliability is checked.

II. Methodology

This can be explained by using the following flow chart.



Materials

Locally available crushed aggregate of size 12.5 mm, 16mm and 20 mm down size conforming to IS 383-1970 [4] were used in the preparation of concrete. Portable water was used in the present study for both casting and curing of the concrete. The master glenium SKY 8630 is used as super plasticizer. Sodium silicate and sodium hydroxide are used in making alkaline solution. Bulk density and specific gravity test were carried out as per IS 2386(Part III)-1963 [5] and the test results are presented in Table no 1.

Table no 1: Bulk density and specific gravity.

Sl. No.	Material	Bulk density (kg/m^3)	Specific gravity
1	Fine aggregate	1540	2.538
2	Coarse aggregate	1644	2.53

Packing density of aggregates

The solid volume in a unit total volume id defined as packing density of aggregate mixture. This method decreases the porosity of mixture which lessens the demand of binder content. The particles are so selected that they fill up the voids between particles, to make a structure dense. Higher the particle packing, minimum will be the voids, maximum will be the density hence less will the F/B ratio required [2].

Three size fraction course aggregates are selected for mix i.e. 20mm, 16mm and 12.5mm. The bulk density of course aggregate is first determined individually. The coarse aggregate 20mm, 16mm and 12.5mm are mixed in various proportions, such as 65:30:5, 65:25:10, 65:20:15, 65:15:20, 65:10:25, 65:5:30 and 65:0:35. The bulk density of each mixture is determined individually. As the addition of smaller aggregates increases (12.5mm), the bulk density of mixture goes on increasing. But a point comes, when bulk density of course aggregate mixture starts decreasing. The results are plotted in fig. 1. As per records the proportion 65:20:15 has achieved maximum bulk density and is chosen for mixing with sand.

Now the proportioned course aggregates are mixed with fine aggregates (sand) to know the effect of fine aggregates on bulk density of mixture. The sand is mixed with proportioned aggregated (Aggregates proportion yielding higher bulk density i.e. 65:20:15). The proportioned course aggregates are mixed in different proportion by weightsuch as 90:10, 80:20, 70:30, 60:40, 65:45 and 50:50. The bulk density of each mixture is determined and found that addition of fine aggregates increases the bulk density. However a point comes, when bulk density of mixture starts decreasing. The results are plotted in fig. 2. The proportion with highest bulk density is chosen to attain maximum packing density i.e. 65:45.

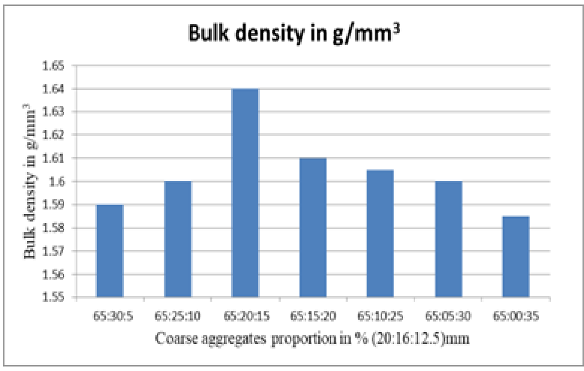


Fig. 1-Graph representing effect of proportioning on bulk density different sized aggregates (20mm: 16mm: 12.5mm)

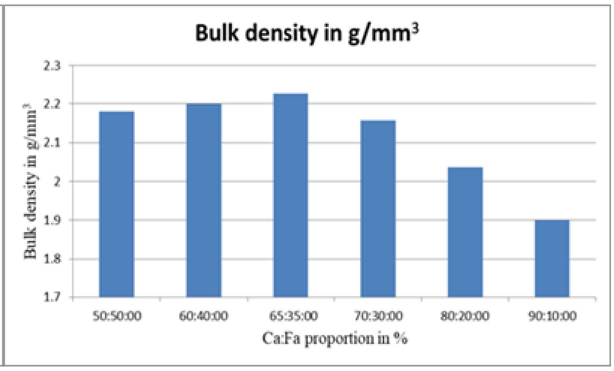


Fig. 2-Graph representing effect of proportioning on bulk density of aggregate and sand mixture (aggregate:sand)

How to convert mix design of SCC to HPGPC?

The ingredients included in self-compacting concrete are as follows,

- Coarse aggregates (Ca)
- Fine aggregates (Fa)
- Cement
- Water cement ratio
- Fly ash (FA)
- Super plasticizer

In packing density method aggregates weight calculated are independent of fluid binder ratio (means water cement ratio). Coarse and fine aggregate weights are determined without any intervention of it. Therefore, there is no problem in adopting this design. The problem arrived while calculating the binder content. When clearly studied, one can easily understand that the water cement ratio used to calculate cement content in SCC can be rightfully taken as fluid binder ratio to calculate binder content in GPC. By doing so the mix design for GPC was derived from the mix design of SCC. Further the fluid content distribution and extra water content needed is calculated by following P. Pavitra.et al. [3] paper where, it is clearly given in step by step. This can be better understood with following illustrative example given in below. FA and GGBS are used as binders. The mix design is developed for different proportions of binders as 80:20, 70:30, 60:40 and 50:50.Such combinations of binders are tried for different fluid/binder ratios as 0.3, 0.35 and 0.4. This range of fluid/binder ratio is set depending upon literature survey. By trying out different possible combinations of binders with different fluid/binder ratios keeping the Molarity of alkaline solution as 16M and ratio of Na_2SiO_3 to NaOH as 2.5 one can understand the effect of FA and GGBS on strength of concrete. The master glenium SKY 8630 is used with dosage of 1%. The target strength is set to be 60MPa as it is a high performance concrete.

The mix design giving the nearest expected result is chosen to be as suitable mix. The binder proportion used in it is decided as optimum proportion for strength of 60MPa with Na_2SiO_3 to NaOH ratio of 2.5 and Molarity of 16M.

After attaining at the mix of HPGPC of strength 60MPa, the same packing density method of mix design is followed for high performance cement concrete (HPCC) and the results are compared with HPGPC of same strength i.e. 60MPa. The mix design of HPCC is also developed using IS 10262-2019 to check the adequacy and efficiency of packing density method. The quantity of materials found for HPCC by both types of mix design are found to be slightly varying in numbers, proving the efficiency of mix design by PDM.

The mix design to be developed are as follows-

A. Mix design for different binder proportions and different fluid/binder ratio for HPGPC of strength 60MPa by packing density method.
B. Mix design of HPCC of strength 60MPa by packing density method and IS 10262-2019 code.

A. Mix design for fluid/binder ratio of 0.3 and FA: GGBS proportion of 80:20 for HPGPC of strength 60MPa by packing density method

<u>Data</u>

1. Target strength = 60 MP
2. Course aggregates (Ca)
   - 20mm = 42.25%
   - 16mm = 13%
   - 12.5mm = 9.75%
3. Fine aggregates (Fa)
   - River sand = 35%
4. SG of:
   - Ca = 2.538
   - Fa = 2.53
   - Fly ash= 2.2
   - GGBS = 2.8
   - SP = 1.02
5. Dosage of SP = 1%
6. F/B ratio = 0.3
7. Na_2SiO_3 to NaOH ratio = 2.5
8. Molarity = 16M
9. Curing Time = 24 Hours

Calculations

Step 1 Bulk density of combined Ca 20mm, 16mm, and 12.5mm in proportion 65:20:15

Bulk density $=W_2-W_1/ V$

$=1.64$ gm/cm^3

Here, W_1= Wt. of empty bucket =12.1kg

W_2= Wt. of bucket + agg =36.31kg

V= Vol. of bucket = $\pi*r^2*h$ = 14728.125 cm^3

Step 2 Bulk density of Ca (20:16:12.5) and Fa in proportion 65:35

Bulk density = W_2-W_1/V

= 2.226 gm/cm^3

Here, W_1= Wt. of empty bucket =12.1 kg

W_2= Wt. of mould + agg =34.502 kg

V= Vol. of bucket = $\pi*r^2*h$ = 10064.21 cm^3

Step 3 Void content

Voids in %=(Avg. SG of Ca and Fa-Bulk density of Ca &Fa*100) /(Avg. SG of Ca &Fa)

=12.22 %

Here, Avg. SG of Ca and Fa = 2.536

Bulk density of Ca &Fa = 2.226 gm/cm^3

Step 4 Packing density (PD)

Packing density = bulk density*weight fraction/specific gravity
Packing density of 20mm agg = 0.371 gm/cm^3
Packing density of 16mm agg = 0.114 gm/cm^3
Packing density of 12.5mm agg = 0.086 gm/cm^3
Packing density of Fa= 0.308 gm/cm^3
Total packing density = 0.878 gm/cm^3

Step 5 Determination of paste content
Void content = 1-PD = 0.122
Paste content excess in % = 10% =0.1
Paste content = Void content+ (excess paste*void content)= 0.134
Volume of agg =1-paste content = 0.866 cc
Total solid vol. = (Wt. fraction of 20/SG) + (Wt. fraction of 16/SG) + (Wt. fraction of 12.5/SG) + (Wt. fraction of Fa/SG) = 0.394 cc

Weight of 20mm agg = 927 kg/cum
Weight of 16mm agg = 285 kg/cum
Weight of 12.5mm agg = 214 kg/cum
Weight of Fa = 768 kg/cum

Step 6 F/B ratio
F/B ratio fixed from trials as = 0.3
F= 0.3 B
Total paste F+B = (B/2.5) + 0.3
B = 0.7 B
Binder content = 192 kg/cum
Fluid content = 58 kg/cum

Step 7 Fluid content distribution
Ratio of Na_2SiO_3 to NaOH (R) = 2.5
Mass of NaOH = Mass of fluid/(R+1)=16 kg/cum
Mass of Na_2SiO_3 = Mass of NaOH *2.5=41 kg/cum

Step 8 Extra water content
Percent share of NaOH: Na_2SiO_3 =45.5: 34.5
Mass of water in,
NaOH= NaOH mass (1-0.455)=9 kg/cum
Na_2SiO_3= Na_2SiO_3 mass (1-0.345)= 27 kg/cum
Total water content in mix= 36 kg/cum

Step 9 Super plasticizer content
Dosage =1 % = 2kg/cum

Table no 2: Mix design of HPGPC with different binder proportions for 0.3 fluid binder ratio.

Sl. No.	Ingredient Kg/cum	Binder ratio FA: GGBS (In percentage)							
		FA	**GGBS**	**FA**	**GGBS**	**FA**	**GGBS**	**FA**	**GGBS**
		80	20	70	30	60	40	50	50
1	20mm agg	927		927		927		927	
2	16mm agg	285		285		285		285	
3	12.5mm agg	214		214		214		214	
4	FA(sand)	768		768		768		768	
5	Binder	153	38	134	58	115	77	96	96
6	NaOH	16		16		16		16	
7	Na_2SiO_3	41		41		41		41	
8	SP	2		2		2		2	
9	Water	36		36		36		36	

Similarly such mix designs are carried out for 0.35 and 0.4 fluid binder ratio.

B. Mix design of HPCC of strength 60MPa by packing density method and IS 10262-2019 code.

Table no 3: Comparison of mix design for HPCC.

Sl. No.	Ingredient	Quantity in kg/cum	
		Packing density method	**IS 10262-2019**
1	20mm aggregate	987	761
2	16mm aggregate	303	234
3	12.5mm aggregate	227	176

4	Fine aggregate	651	657
5	Cement	360	471
6	Water	107	141
7	Fly ash (15%)	54	71
8	GGBS (25%)	90	117
9	Super plasticizer (1%)	3.59	4.71

This proves that the mix proportioning by both the method yield approximately same values. It therefore checks the reliability of packing density method of mix design.

Testing

The 3 strength tests on concrete are as follows-Compressive strength test, Splitting tensile test and flexural strength test.

Table no 4: Trials conducted to finalize mix design for compressive strength.

F/B ratio	FA:GGBS proportioning	Curing period	Number of specimen
	Compressive strength test		
0.3	80:20	7, 28 days	3 + 3 = 6
	70:30	7, 28 days	3 + 3 = 6
	60:40	7, 28 days	3 + 3 = 6
	50:50	7, 28 days	3 + 3 = 6
	Total number of cubes		24
0.35	Similar combinations		24
0.4	Similar combinations		24
Total number of cubes for compressive strength test			72
Similarly, total number of beams for flexural strength test			72
Similarly, total number of cylinders for split tensile strength test			72

III. Result

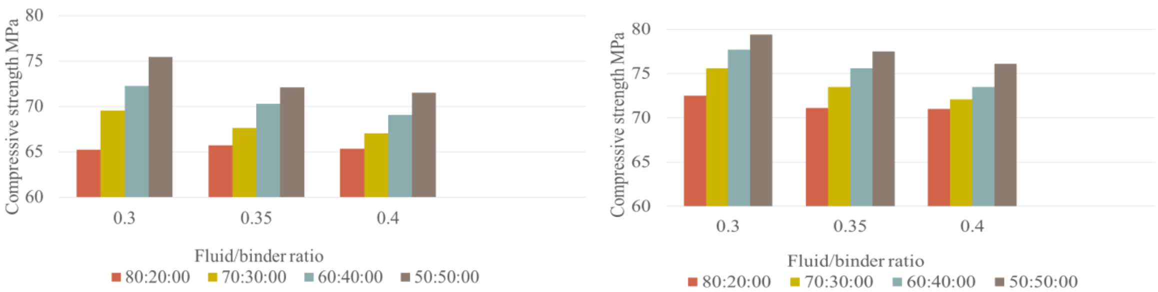


Fig. 3: Effect of F/B ratio with various FA: GGBS combination on compressive Strength of HPGPC for 7 and 28 days respectively

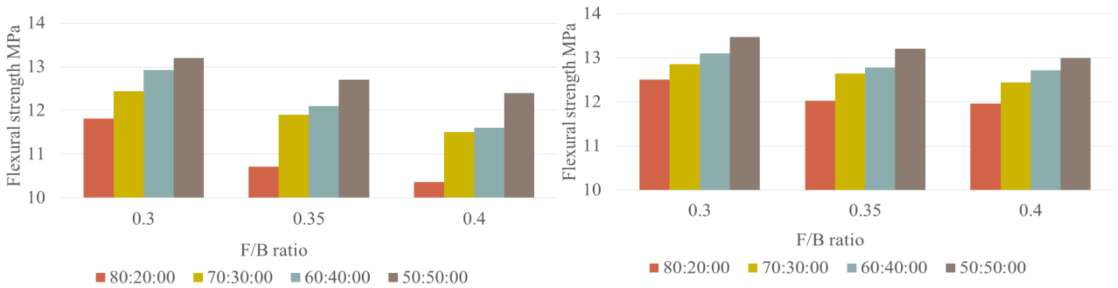


Fig. 4: Effect of F/B ratio with various FA: GGBS combination on flexural strength of HPGPC for 7 and 28 days respectively

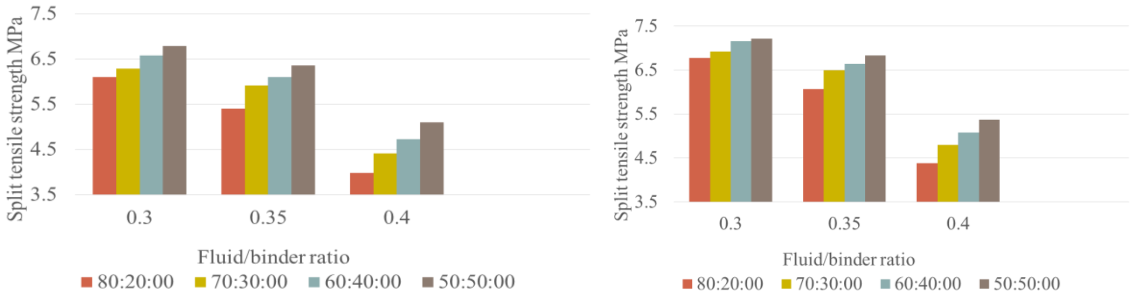


Fig. 5: Effect of F/B ratio with various FA: GGBS combination on split tensile strength of HPGPCfor 7 and 28 days respectively

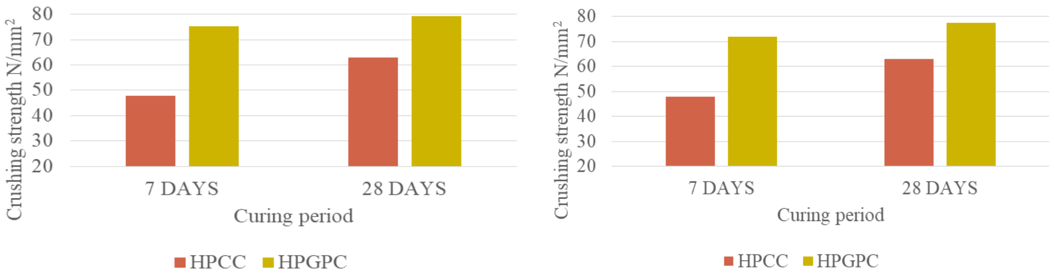


Fig. 6: Comparison of compressive/crushing strength between HPCC and HPGPC for 7 and 28 days curing for 0.3 and 0.35 F/B ratio respectively.

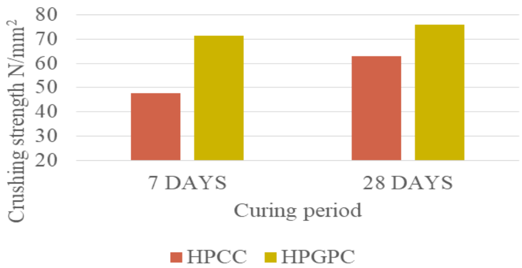


Fig. 6: Comparison of compressive/crushing strength between HPCC and HPGPC for 7 and 28 days curing for 0.4 F/B ratio.

IV. Discussion

The results of table 4 prove that the quantity of material calculated by PDM and IS 10262-2019 code are approximately similar for normal concrete. This implies that the PDM is correct and can be used for designing.

The fig. 3, fig. 4 and fig. 5 clearly implies that the strengths are varying in linear pattern within most reasonable range of strength for all combinations of binders for 0.35 F/B ratio, this means that the strength results of 0.35 are reliable whereas the results of 0.3 and 0.4 F/B ratio are not in accordance with the strength expected and also they are at extreme ends of strength expected with abrupt workability values. The strength results of 80:20 are less varying with increase in F/B ratio which is not reliable and also it doesn't provide workability needed for casting. The 50:50 proportion gives strengths very much higher than expected and this is not needed. Whereas the proportions 70:30 and 60:40 give required strength and workability.This implies that both are better suited but the proportion 70:30 can be adopted for economic reasons (Because GGBS is costlier than fly ash).

The geopolymerization reactions occurs at faster rate in initial days. Therefore from fig. 3, it is seen that a strength of 90-95% of strength is achieved whereas, only 70% of strength is achieved by HPCC within 7 days of curing.

V. Conclusion

The general conclusions of work are as follows-

1. Use of GPC in construction will reduce environmental pollution to greater extent as it uses industrial waste as replacement of cement.
2. Encouraging results are obtained when mix is designed by packing density method.
3. The packing density method of mix design has provided nearly similar quantity of material for mix as provided by IS code which ensures the reliability.
4. By proportioning the aggregates using packing density, strength and uniformity of concrete is enhanced.
5. HPGPC achieves higher strength than required.
6. HPGPC is better suitable for higher strength concretes than HPCC.
7. The strength of HPGPC increases with increase in GGBS content.
8. The strength of HPGPC decreases with increase in F/B ratio.

The experimental conclusions of work are as follows-

9. There is no much variation seen in compressive strength with 80:20 combination of binder content, which implies it cannot be adopted as the strength achieved will be approximately same for various F/B ratios. Like vise the strength by 50:50 combination is much more than required so can't be suggested for use.
10. The required strength is achieved by every mix, but the mix I suggest as suitable for M60 grade will be of F/B ratio 0.35 with binder content of 70:30, 10% of extra water and 1% of super plasticizer by percent of binder with concentration of NaOH as 16M and ratio of Na_2SiO_3 to NaOH as 2.5. By keeping in the economic reasons the 70:30 proportion shall be adopted as the GGBS is costlier than fly ash.
11. For 7 days curing, only 70% of the strength is achieved by HPCC whereas, around 90-95% of strength is achieved by HPGPC.

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