International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 7 (2018) pp. 292-298

Experimental investigation of Mechanical properties of Geo polymer concrete with GGBS and Hybrid Fibers

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Abstract: Cement manufacturing causes significant pollution. To reduce such pollution, investigation into alternative materials for concrete production is an important research topic. Geo-polymers are potentially effective substitutes for cement in concrete production. Through a polymerisation reaction with Fly Ash and Alkaline solution, the geo-polymer concrete matches that of the conventional concrete in mechanical properties as well as in durability characteristics. Fly ash is one of the bi product which is used in the preparation of the geo polymer concrete by mixing with alkaline solution and cured under 60 deg in hot air oven to undergo polymerisation. In this paper an attempt has made for mechanical properties of geo polymer concrete with GGBS and Hybrid fibers. Ground granulated blast furnace slag is replaced with fly ash in ratios 20%, 40%, 60% and 80%. Hybrid fibers added are the combination of the steel fiber and glass fiber. Three trials are conducted for each mechanical property test. The specimens are cured for 7, 14 and 28 days and the tests are conducted at the corresponding days of the curing. The results are compared with the Geo polymer concrete with GGBS and Hybrid fibers v/s Geo polymer concrete with GGBS and without hybrid fibers.

Keywords: Alkaline solutions, Conplast SP430, Fly ash, Geo polymer concrete, GGBS, Hybrid fibers, Hot air oven, OPC.

I. INTRODUCTION

Construction in the present century is growing very rapidly. Hence the concrete is the second most commonly used material next to the basic human needs. Demand for cement and concrete is goes on increasing as the construction is increasing day by day. So the demand for Ordinary Portland cement also increases. Due manufacturing of OPC around 1.35 billion tons annually or approximately 7% of the total greenhouse gas emissions to the earth's atmosphere [2]. Carbon dioxide is the major source for Greenhouse effect which is liberated from vehicles and by human activities. 65% of global warming is by carbon dioxide among all the greenhouse gases. The cement industries are also one of the responsible bearing batch for the emission of carbon dioxide i.e., 1 tonne of carbon dioxide is liberated to the atmosphere in generation of about 1 ton of Portland cement.

Many researches are now a days being conducted to replace the use of Portland cement in concrete. In order to reduce the global warming issues the utilisation and use of the other cementations materials such as Fly ash, silica fume, Ground granulated blast furnace slag, rice husk, metakaolin etc. are developed and are using as alternative binders to the Portland cement. From the 1998 estimation, the global coal ash production was more than 390 million tonnes annually, but its use was less than 15%.[7]

The geo polymer concrete technology was introduced by DAVIDOVITS and first coined in 1978 as an alternative material for cement. These new binding materials which are used as an alternative material are obtained by the alkaline activation or geo polymerisation of different industrial products. In geopolymer concrete, a by-product material rich

in silicon and aluminium, such as low-calcium (Class F) fly ash, is chemically activated by a high-alkaline solution to form a paste that binds the loose coarse and fine aggregates[1].

High-alkaline solutions are used to induce the silicon and aluminium atoms in the source materials to dissolve and form the geopolymer paste. The polymerization process may be assisted by applied heat, followed by drying. The specimens are cured for 24 hours if the temperature maintained inside the oven is 60 deg. The curing time decreases as the temperature increases. The curing time is around 3 hours if the temperature is around 500 deg. But Van Jaarsveld, van Deventer, and Lukey[10] confirmed the importance of curing at elevated temperature for fly ash based geopolymeric material, they found that curing for a longer period of time at elevated temperature weakened the microstructure.

So in order to improve the performance of the concrete and to improve the mechanical performance of geo polymer concrete GGBS (ground granulated blast furnace slag) is added as a replacement material and hybrid fibres in concrete. The term hybrid fibres refers that the weakness of one fibre is replaced by the other one. Addition of GGBS and these fibres will restrict the development of crack, also it is very known for increase in fracture, toughness provided by fibre bridging on the main crack plane prior to crack extension. The glass fibre and steel fibres are used in this experiment to study the mechanical properties of geo polymer concrete. The 3Ds steel fibres used are of diameter 0.5mm and length is 200mm and aspect ratio 40. These fibres are applied in the 2 % by weight of cementations material. GGBS is replaced with the total fly ash content by 20%, 40%, 60% and 80%.

II. LITERATURE REVIEW

Lot of investigations have been reported on geo polymer concrete with respect to the mechanical properties like compressive, split tensile and flexural strength behaviour by addition of certain replacement material and by adding different fibres. The literature reviewed with respect to different area are used as datum for my work.

B.V.Rangan studied the efficient advantages of low calcium fly ash based geo polymer concrete with respect to the environmental friendly concept. He undergone with the constituents to be used in the preparation of Geo polymer concrete. After the study and result data they concluded that geo polymer concrete requires a basic method of mix design for its preparation. They clearly explained the mix design method in one example. They also mentioned about the mix design required for the specific grade. Though we have separate code of practice for mix design of conventional concrete, it cannot be used for the preparation of the geo polymer concrete. The basic concept of mix design remains same, apart from that water to geo polymer solids ratio, molarity concentration plays a major role in the strength gaining factor. The strength has increased around 10-20% compared to the 7 days testing. And also they given comparison for result with the specimens kept exposed to the sun rays and the specimens kept in the sun shade, in which the maximum strength is gained by the specimens which are kept exposed to sun rays.

3. CONSTITUENTS OF GEO POLYMER CONCRETE USED IN THIS PROJECT

The constituents of geo polymer concrete are.

3.1 Low calcium dry fly ash
3.2 Ground Granulated Blast furnace slag (GGBS)
3.3 Aggregates
- 20 mm size aggregates
- 12.5 mm size aggregates
- 6 mm size aggregates and fine aggregates

3.4 Alkaline solution (Sodium Hydroxide and Sodium Silicate)
3.5 Hybrid Fiber (Crimped steel fiber and Glass fiber)
3.6 Super plasticizer
3.7 Hot air oven
3.8 Water

3.1 Fly ash: Fly ash used in this study is low calcium based fly ash (ASTM Class F) dry fly ash collected from Raichur thermal power plant, which is under the Karnataka Power Corporation Limited. Alumina silicate is the source of fly ash material used in the synthesis of geo polymer binder.

3.2 GGBS is also one of the most commonly replacing material for cement in construction field. Though it is an effective replacing material the optimum replacement varies. In cement GGBS replacement gives maximum strength upto 40 % of replacement. Ground granulated blast furnace slag is also the end product or bi-product obtained from the STEEL manufacturing industry. It is abbreviated as GGBS throughout this paper.

3.3 Aggregates: Aggregates of size 20mm,12.5mm and 6 mm are used in the mix, which forms a well graded mixture of the aggregates and also improves the strength of concrete.

3.4 Alkaline solution: Alkaline solution is the combination of Sodium hydroxide and sodium silicate which plays an important role in attaining strength of geo polymer concrete. The quality of the alkaline solution is very important and also sodium hydroxide and sodium silicate should be purer in the sense that it should not contain more impurities.

3.5 Hybrid fibers: The combination of the fibers which overcomes the negative things of each other which will be combined together to get a better result is hybrid fibers. It is the combination of two or more different types of fibers.

3.6 Super plasticizer: Super plasticizer is added to the concrete mix to get better workability. Conplast SP430 was used for the matrix.

3.7 Hot air oven: Hot air oven is very important in Geo polymer concrete. After demoulding the specimens, it has

to be kept inside the hot air oven. The specimens are to be cured in hot air oven for 24 hours at 60 deg. This is very important because the activation of the alkaline solution with the fly ash and other materials will take place to form a geo polymer concrete. This process helps for getting the bond. After curing in hot air oven, the specimens are ambient cured and tests are conducted for 7, 14 and 28 days of ambient curing.

III MIX DESIGN

A. MATERIALS REQUIRED FOR MIX DESIGN

- Fly ash (Class F)
- Molar concentration of NaOH solution = 16M
- Na_2SiO_3 to NaOH solution ration = 2.5
- Alkaline solution to binder ratio is = 0.45
- Aggregates used = 77% of mass of concrete
- Super plasticizer used = 2 % of fly ash
- Steel fibers 0.6 % and Glass fibers 2 %

B. MIX DESIGN CALCULATION FOR THE PRESENT STUDY.

Step 1: Unit weight of the concrete = 2400 kg/m^3

Step 2: Mass of combined (coarse & fine) aggregates = 77 % of the mass of concrete
= 77 x 2400 = 1848 kg/m^3

Step 3: I.Coarse aggregates

20 mm aggregates =15% = 0.15x1848 =**277.2** kg/m^3
12.5 mm aggregates = 20% = 0.20 x 1848 = **370** kg/m^3
6 mm aggregates = 35% = 0.35 x 1848 = **647** kg/m^3

II.Fine aggregates

Sand used = 30 % = 0.3x1848 kg/m^3 = **554.4** kg/m^3

Step 4: Mass of fly ash and alkaline solution
= 2400 – 1848 = **552** kg/m^3

Let the alkaline solution to the fly ash ratio by mass = 0.35.

Step 5: Mass of the fly ash = $\frac{552}{(1+0.35)}$
= **408.89** kg/m^3

Step 6: Mass of alkaline liquid = 552 – 408.89
= **143.11** kg/m^3

Let the ratio of Na_2SiO_3 to NaOH solution = 2.5

Step 7: Then the mass of Sodium hydroxide solution is calculated as = $\frac{143.11}{(1+2.5)}$ = **40.89** kg/ m^3

Step 8: Then the mass of Sodium silicate solution
= (143.11- 40.89) = **102.22** kg/ m^3

TRIAL MIX / PROPORTION.

- Mass of combined aggregates = 1848 kg/ m^3
- Mass of fly ash = 408.89 kg/ m^3
- NaOH solution = 40.89 kg/ m^3
- Na_2SiO_3 solution = 102.22 kg/ m^3

Step 9: In the Sodium silicate solution;

Let the $\frac{SiO_2}{NaO_2} = 2$

($NaO_2 = 14.5, SiO_2 = 33.905$, Water = 51.535)

a. In the Sodium Silicate solution
Water content = 52.64
Solids = 49.58
b. In sodium hydroxide solution
Solids = 18.15
Water content = 22.74
c. Therefore, the total mass of water = 75.38
d. Therefore, the total mass of geo polymer solids
= 476.62
e. The ratio of water to geo-polymer solids = 0.16

Step 10: Geo polymer concrete mixture for kg/m^3

- Coarse aggregate required
  - 20 mm down size aggregate = 277 kg/ m^3
  - 12 mm down size aggregate = 370 kg/ m^3
  - 6 mm down size aggregate = 647 kg/ m^3
- Sand required = 554.4 kg/m^3
- Fly ash require = 408.89 kg/m^3
- Sodium silicate solution required
  - Solids = 49.58 kg/m^3
  - Water = 52.64 kg/m^3
- Sodium hydroxide solution required
  - Solids = 18.15 kg/m^3
  - Water = 22.74 kg/m^3
- Super plasticizer required = 2 % by mass of the total fly ash + GGBS = 0.2 x (408.89) = 81.78 ml

NOTE:

To prepare 16 Molarity solution:

To prepare the solution of 16 molarity, take 16 x 40 = 640 grams of sodium hydroxide pellets and dissolve it in 1000 ml of distilled water. Once adding water to the sodium hydroxide pellets stir well until pellets gets dissolved. Maintain the molarity for any required quantity of solution by doing the above so.

C. QUANTITY OF THE MATERIALS REQUIRED FOR THE PREPARATION OF THE GEOPOLYMER CONCRETE.

Table 1: ***Mix design specification used in the concrete***

Sl. No	Materials required	Mass, kg/ m^3		
1	Coarse aggregate	15%	20 mm	277
		20%	12.5 mm	370
		35%	6 mm	647
2	Fine aggregate	554.4		
3	Fly ash	408.89		
4	Na_2SiO_3	102.22		
5	NaOH	40.89		
6	Super plasticizer	2%		
7	Hybrid Fibers	3Ds Steel fiber		Glass fiber
		2%		0.6%
8	Extra water	5 % to the total weight of concrete		

i. Parameters in the experimental work are

- Variation of % replacement of GGBS. i.e., Testing of specimens without adding fibers
- Adding Hybrid fibers
- Molarity of the solution.

Table 2: Total no:of specimens prepared and cast for the study.

Test to be conducted With addition of hybrid fibers	Batch 1	Batch 2	Batch 3	Batch 4
	80% FA & 20% GGBS	60% FA & 40% GGBS	40% FA & 60% GGBS	20% FA & 80% GGBS
Compressive strength	9	9	9	9
Split tensile strength	9	9	9	9
Flexural strength	9	9	9	9
Total specimens	27	27	27	27
.'. Totally 108 specimens are cast for 7,14 & 28 days of curing				
Test to be conducted Without addition of hybrid fibers	**Batch 1**	**Batch 2**	**Batch 3**	**Batch 4**
	80% FA & 20% GGBS	60% FA & 40% GGBS	40% FA & 60% GGBS	20% FA & 80% GGBS
Compressive strength	9	9	9	9
Split tensile strength	9	9	9	9
Flexural strength	9	9	9	9
Total specimens	27	27	27	27
.'. Totally 108 specimens were cast for 7,14 & 28 days of curing				

The preparation of geo polymer concrete specimens for studying mechanical properties is similar to that of preparation of conventional concrete. The basic materials required for geo polymer concrete is first sieved, weighed and kept ready for mixing. The aggregates used were saturated surface dry.

The alkaline solution required for the mix is prepared 24 hours prior to the casting.

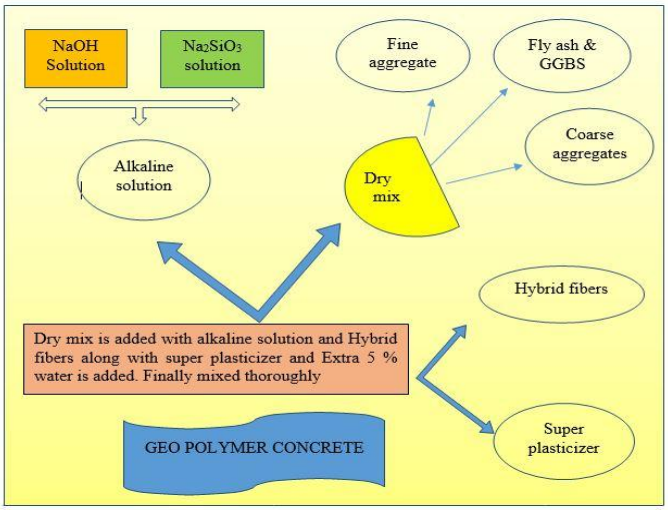

Figure 1: Preparation detail of Geo polymer concrete

Figure 2: Dry mix of materials

Figure 3: Wet mix of materials with fibers added

Figure 4: Test specimens are placed inside the oven

IV. RESULTS AND DISCUSSIONS

Geo polymer concrete with partial replacement of Fly ash by GGBS and with hybrid fibers are done to study the mechanical properties of the concrete. The experimental study was conducted to study the variation in mechanical property of the geo polymer concrete in which GGBS and hybrid fibers are the key variable. The experimental results are compared with the geo polymer concrete having hybrid fibers and the geo polymer concrete without having hybrid fibers.

Compressive strength test are conducted for cubes for size 150 x 150 mm, split tensile strength are conducted with the cylinders of diameter 150mm and height 300mm and the flexural strength is conducted with beam or prism of size 500 x 100 x 100 mm.

Every mechanical property test has its own advantage and shows variations in every percentage of replacement of GGBS. The major line of work in this experimental study is, the fibers percentage is kept constant, only GGBS percentage are varied with the fly ash content.

A. Compressive strength

After the cubes are cast, it is kept for 24 hours in hot air oven maintained 60 deg throughout during hot curing. After 24 hours, the specimens are taken out and kept for ambient curing. Test are conducted for 7, 14 and 28 days of the ambient curing. In this section the comparison of the results for 7, 14 and 28 of curing of Geo polymer concrete with GGBS and hybrid fibers and Geo polymer concrete with GGBS and without hybrid fibers are conducted. After the test is noticed for the optimum mix which has given the maximum strength.

Table 3: Average compressive strength of GPC for 7 days of curing.

7 days Compressive strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	18.93	17.45
F60G40	60	40	24.83	24.80
F40G60	**40**	**60**	**40.65**	**40.7**
F20G80	20	80	31	31.65

Table 4: Average compressive strength of GPC for 14 days of curing.

14 days Compressive strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	18.72	21.77
F60G40	60	40	37.37	32.34
F40G60	**40**	**60**	**40.34**	**42.8**
F20G80	20	80	38.7	38.26

Table 5: Average compressive strength of GPC for 28 days of curing.

28 days Compressive strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	27.18	21.34
F60G40	60	40	36.42	41.29
F40G60	**40**	**60**	**60.62**	**44.14**
F20G80	20	80	42.28	43.15

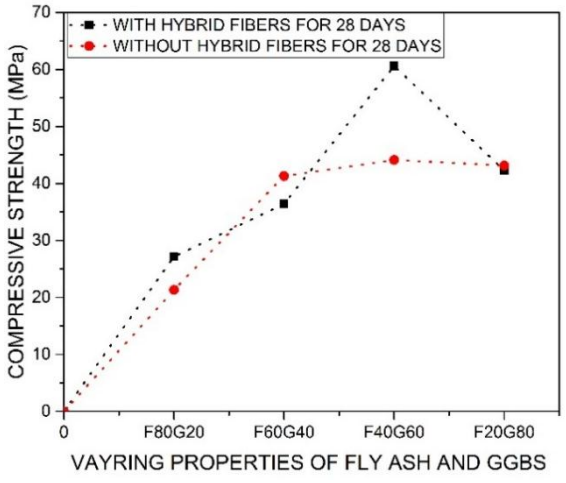

Figure 5: Compressive strength test results for 28 days curing of GPC with GGBS with hybrid fibers v/s without hybrid fibers in graph.

B. Compressive strength

Table 6: Split tensile strength of GPC for 7 days of curing.

7 days Split tensile strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	2.55	1.67
F60G40	60	40	2.42	2.68
F40G60	**40**	**60**	**3.17**	**2.96**
F20G80	20	80	3.03	2.87

Table 7: Split tensile strength of GPC for 14 days of curing.

7 days Split tensile strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	2.3	2.01
F60G40	60	40	2.58	2.78
F40G60	**40**	**60**	**3.38**	**3.06**
F20G80	20	80	3.24	2.63

Table 8: Split tensile strength of GPC for 28 days of curing.

7 days Split tensile strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	2.45	2.15
F60G40	60	40	2.44	2.33
F40G60	**40**	**60**	**3.67**	**3.24**
F20G80	20	80	3.29	2.55

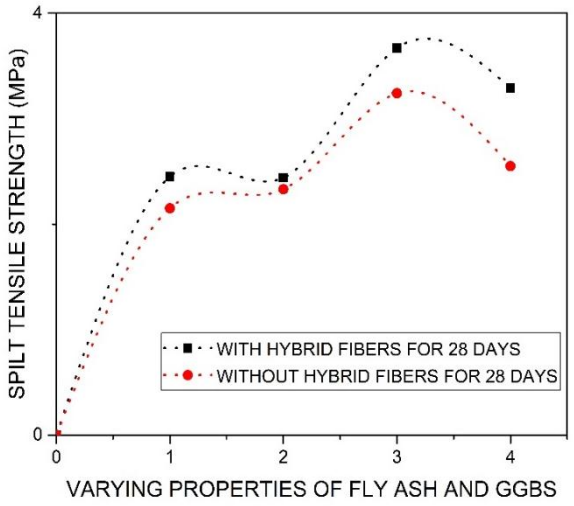

Figure 7: Split tensile strength test results for 28 days curing of GPC with GGBS with hybrid fibers v/s without hybrid fibers in graph.

From the above table [8,9,10] it is observed that the split tensile strength of the GPC with GGBS and hybrid fibers found to be increase from 7 days to 28 days and the GPC with GGBS and hybrid fibers has achieved the strength more than without hybrid fibers.

And, the maximum strength is got for the mix of batch 3 which contains fly ash 40% and 60% GGBS. And it is confirmed that the batch 4 mix has achieved more strength when compared to batch 2 mix. On the other hand the strength decreases after certain range of replacement of fly ash with GGBS.

Figure 6 : Failed cylinder specimen under split tensile test

C. Flexural strength

Table 9: Flexural strength of GPC for 7 days of curing.

7 days flexural strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	1.45	1.42
F60G40	60	40	2.67	1.75
F40G60	**40**	**60**	**3.33**	**3.08**
F20G80	20	80	3	2.25

Table10: Flexural strength of GPC for 14 days of curing.

7 days flexural strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	2.33	1.5
F60G40	60	40	3.23	2.08
F40G60	**40**	**60**	**4.1**	**3.25**
F20G80	20	80	3.58	3.17

Table11: Flexural strength of GPC for 28 days of curing.

7 days flexural strength (N/mm^2)				
Mix	**Fly ash %**	**GGBS %**	**With hybrid fibers**	**Without hybrid fibers**
F80G20	80	20	2.33	1.5
F60G40	60	40	3.23	2.08
F40G60	**40**	**60**	**4.1**	**3.25**
F20G80	20	80	3.58	3.17

From the table [9,10,11], the flexural strength of the GPC with GGBS was found to be increased with the increase in curing days. The maximum strength is achieved for the batch 3 mix which has 40% fly ash and 60% GGBS with hybrid fibers. On the other hand the GPC without hybrid fibers has also the maximum strength for batch 3 mix which is giving less strength than the GPC with fibers.

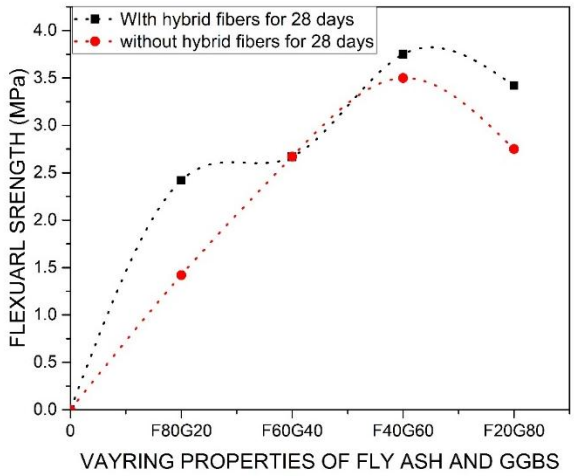

Figure 8 : Flexural strength test result for 28 days curing of GPC with GGBS and hybrid fibers v/s without fibers.

V. CONCLUSION

1. The compressive strength of GPC with GGBS and Hybrid shows increasing in its strength from Batch 1 mix (80% Fly ash & 20% GGBS) to Batch 3 mix (60%GGBS and 40% Fly ash) shows in decrease of result in Batch 4. It means the maximum can be achieved for Batch 3 mix which has 60% GGBS and 40% fly ash.

2. The test is conducted by preparing 16 molar concentration of the alkaline solution for which we have obtained maximum compressive strength of 60.12 MPa. This agrees with the design table suggested by B.V.Rangan to obtain the compressive strength of 60 MPa.

3. In split tensile strength, the strength of the mix is maximum for Batch 3 i.e., 3.67 MPa (60% GGBS and 40% Fly ash) and also it is observed that without fibers has initially given more strength and the strength is maximum for Batch 4 (80% GGBS and 20% Fly ash) when compared to Batch 1(20% GGBS to 80% Fly ash) and Batch 2 mix (60% Fly ash & 40% GGBS). It means 2nd maximum strength is achieved for Batch 4 mix.

4. Finally for flexural strength test the result is maximum for 60% of GGBS. Max Flexural strength is 3.75Mpa
5. Hence it is concluded that to obtain maximum strength in 16 molar concentration use of GGBS along with hybrid fibers is suggested.

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