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Study of Compressive Strength of 8M Geopolymer Mortar for Different Combinations of C-Ash with GGBS at 100 degrees Celsius (45µ)

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***Abstract*: Concrete is the material which is abundantly used in the construction industry and the production of cement is one among the reason for global warming due to release of carbon dioxide, to minimize its effect on nature we must use industrial by-product as an alternative material. Among industrial by-product, usage of fly ash is more. The geopolymer mortar made by the using fly-ash set slowly in ambient temperature and needs heat curing. To overcome this limitation, Ground Granulated Blast Furnace Slag (GGBS) powder is used as a cementious material which shows considerable gain in strength. In this paper, we investigated the properties of geopolymeric binder prepared using the Ground "Granulated Blast Furnace Slag" (GGBS) and coal ash without using conventional cement. The individual properties of the GM for 1:3 ratio, such as compressive strength test was determined as per relevant Indian standards. Cubes of size (70.6 x 70.6 x 70.6) mm were casted and cured in ambient condition for molarity 8M with different ratios and different temperatures. After the experiments, compressive strength is increased for increasing number of days of curing. Also, compressive strength decreased for increasing Na2SiO3/NaOH ratios and increasing oven curing temperatures.**

***Keywords*: geopolymer mortar, GGBS, coal ash, 8M (Molarity).**

1. Introduction

The use of cement in the construction industry has long been associated with significant environmental impact, primarily due to the emissions of harmful greenhouse gases like carbon dioxide (CO_2) and carbon monoxide (CO). Cement production is responsible for approximately 6.99% of global greenhouse gas emissions. This is largely because the production of one tonne of cement requires a substantial amount of energy, about 4.01 GJ, which results in the release of nearly the same weight (one tonne) of CO_2 into the atmosphere [1].

However, there has been growing interest in finding more sustainable alternatives to reduce the carbon footprint of cement production. One such alternative is fly ash, a by-product of burning coal. Fly ash is abundantly available and has proven to be an effective substitute for cement.

When fly ash is used in combination with water and slaked lime (calcium hydroxide), it undergoes a chemical reaction known as hydration. In this process, fly ash reacts with slaked lime to form a gel-like compound, typically referred to as H_2CaO_4Si gel, which has binding properties similar to that of cement. This reaction contributes to the hardening and setting of the material, making it suitable as a replacement for traditional Portland cement.

Geopolymerization [2] is indeed a fascinating process that involves the formation of a polymeric structure from alumino-silicate materials, such as fly ash, slag, or natural minerals. The reaction typically occurs in an alkaline environment where the solid materials, rich in alumina (Al_2O_3) and silica (SiO_2), are dissolved in an alkaline solution like sodium hydroxide (NaOH) or sodium silicate (Na_2SiO_3).

2. Material and Methodology

A. Ground Granulated Blast Furnace Slag (GGBS)

GGB (Ground Granulated Blast Furnace Slag) is recyclable material used as a supplementary cementitious material (SCM) in concrete production. It's made by rapidly cooling molten iron slag (a byproduct of steel manufacturing) through a process called "granulation." This material is then ground into a fine powder, which, due to its cementitious properties [3], can replace a portion of cement in concrete mixes, contributing to a more sustainable construction material over 100 years. GGBS is purchased from a vendor, QUALITY POLYTECH, Mangalore.

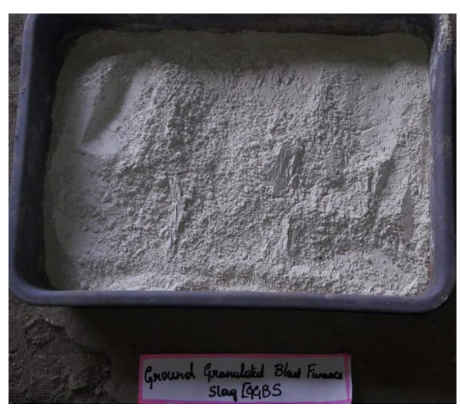

Fig. 1. Ground Granulated Blast Furnace slag (GGBS)

The Physical and Chemical properties of GGBS is as

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tabulated below. There is no Indian Standard on GGBS. The test results are compared with BS Specification. The GGBS confirms to IS: 12089:1987.

B. Physical properties of GGBS

Table 1
Physical properties of GGBS

Properties	Test Result
Colour	Off White
Specific gravity	2.94
Consistency	33%
% particles retained on 90µ sieve	Nil

C. Chemical properties of GGBS

The table 2 shows the chemical properties of GGBS.

D. Fine Aggregates

The locally available river sand is used as fine aggregate. The sand should be free from all organic and inorganic matters. As per IS 383-1976, the particle size distribution of sand shows that it is in zone-II.

Fig. 2. Fine aggregate

1) Physical Properties of River Sand

Table 3
Physical properties of river sand

S.No.	Properties	Test Result
1	Specific gravity	2.8
2	Fineness modulus	5.16
3	Grading zone	Zone-II
4	Bulk density	1685

E. Coal Ash

It is taken from brick industry, Bangalore.

Fig. 3. Coal ash

Table 2
Chemical properties of GGBS

S.No.	Chemical Component	Test Result	Requirement as per IS:12089 1987
1	CaO	37.34%	-
2	Al_2O_3	14.42%	-
3	Fe_2O_3	1.11%	-
4	SiO_2	37.73%	-
5	Magnesium Oxide (MgO)	8.71%	Max 17.0%
6	Manganese Oxide (MnO)	0.02%	Max 5.5%
7	Sulphide Sulphur	0.39%	Max 2.0%
8	Loss On Ignition	1.41%	-
9	Insoluble Residue	1.59%	Max 5%
10	Glass Content	92%	Min 85%
11	Chemical Moduli	-	-
A	$(CaO+MgO+1/3Al_2O_3)/(SiO_2+2/3Al_2O_3)$	1.07	>1.0
B	$(CaO+MgO+Al_2O_3)/SiO_2$	1.60	>1.0

Source: JSW CEMENT Ltd, Test Certificate, GGBFS. Week no (03) 22-08-2016 to 29-08-2016

Table 4
Sieve analysis of River sand

Weight of River sand taken=500grams					
S.No.	**IS-Sieve (mm)**	**Weight Retained (g)**	**% Retained**	**% Passed**	**Cumulative % Retained**
1	4.75	06	1.2	98.8	1.2
2	2.36	33	6.6	92.2	7.8
3	1.18	42	8.4	83.8	16.2
4	600µ	178	35.6	48.2	51.8
5	300 µ	183	36.6	11.6	88.4
6	150 µ	36	7.2	4.4	95.6
7	Pan	22	4.4	0	100
	Total	500		SUM	360.4
				FM	3.60

The Physical and Chemical properties of coal ash are as tabulated.

Table 5
Physical properties of coal ash

S.No.	Characteristics	C-ash
1	Specific gravity	2.59
2	Standard consistency (%)	38.0
3	Setting time	
	• Initial setting time (min)	205
	• Final setting time (min)	340
4	Fineness	
	• Wet sieving (75µ) in (%)	9.0
	• Dry sieving (150µ) in (%)	4.0
5	Lime reactivity (N/mm^2)	1.37
6	Compressive strength of cement mortar (N/mm^2)	
	3 days	6.8
	28 days	11.26
	56 days	13.23

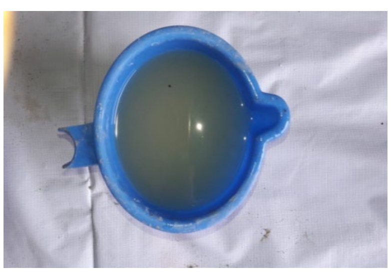
1) Chemical properties of coal ash

Table 6
Chemical properties of coal ash

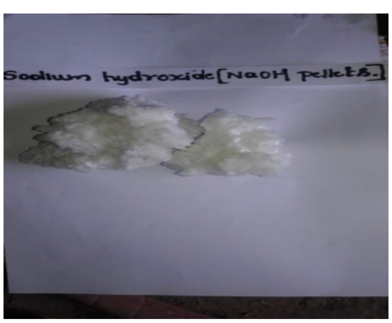
S.No.	Chemical constituents (as oxides) S%	C-Ash
1	SiO_2	57.73
2	Al_2O_3	26.38
3	CaO	4.49
4	MgO	0.20
5	Fe_2O_3	3.79
6	SO_3	2.34
7	Na_2O	0.31
8	K_2O	0.77
9	Cl	0.051
10	L.O.I	3.01
11	Insoluble residue	80.98
12	Moisture	0.24
13	Free Lime	0.11

F. Alkanine Activator

It is a mixture of sodium hydroxide and sodium silicate solution. The sodium hydroxide in flakes form was used is a colour less substance with a purity of 98%. Sodium silicate in liquid form was used, colour of the liquid is white.



a) Na_2SiO_3 solution



b) NaOH pellets

c) Dissolving NaOH pellets

Fig. 4. Solution prepared for casting mortar cubes

G. Methodology

1) Mix design of GPM

The mix design of GPM are given below

a. Ratio of (GB+ CA): Fine aggregate used = 1:3
- (GB+ CA) used = 200g (for 100% GB)
- (GB+ CA) used = 160g + 40g (for 80% GB and 20% Coal ash)
- (GB+ CA) = 120g + 80g (for 60% GB and 40% Coal ash)
- (GB+ CA) = 80g + 120g (for 40% GB and 60% Coal ash)
- (GB+ CA) = 40g + 120g (for 20% GB and 80% Coal ash)
- (GB+ CA) = 160g + 40g (for 0% GB and 100% Coal ash)
- Fine aggregate = 600g

b. Alkaline liquid / (GB+ CA) ratio = 0.5
- Alkaline liquid= 0.5 x (GB+ CA) = 0.5 x 200gm =100 g

c. Molarity of the solution = 8M

d. Na_2SiO_3/NaOH = 1.5

e. Alkaline liquid = Na_2SiO_3+NaOH solutions
- Na_2SiO_3 + NaOH =100
- Na_2SiO_3 solution = 60g
- NaOH solution = 40g

f. For NaOH solution of 8M,

Quantity of NaOH solids = 8x40 =s320g of solids in 1000ml of water.

Hence for 40gm of NaOH solution
- Quantity of NaOH solids = 9.7g
- Quantity of water = 30.3 ml

g. Oven curing period = 24hrs

h. Curing temperature = 100^0C

The mix design procedure is same for 10M and 12M.

For 8M,

Table 7
Mix design values for 8M

$\frac{Na_2SiO_3}{NaOH}$	1.5	2.0	2.5
NaOH pellets (g)	9.70	8.08	6.92
Water (ml)	30.30	25.25	21.64
Na_2SiO_3 (g)	60.00	66.67	71.43
NaOH solution (g)	40.00	33.33	28.57

2) Preparation alkaline solution

- Take water of required quantity
- Add a required or calculated amount of NaOH pellets
- Stir well until it get complete dissolution
- After dissolution, add calculated amount of Na_2SiO_3 and stirr well
- Keep aside for 24 hours for the preparation of the solution

3) Preparation of GPM cubes

- Take a binder of calculated amount and dry mix it well
- Add a sand of calculated amount and dry mix it well
- Add a solution of required amount and mix it well immediately after adding solution
- The mortar is filled in 70.6mm X 70.6mm X 70.6mm moulds in three equal layers and compacted
- Demould the cubes after 24 hours
- Keep the cubes in oven at different temperatures (60^{o}C and 100^{0}C) for 24 hours
- Remove the cubes from the oven after 24 hours and keep the cubes for ambient curing for the different curing periods of 3days, 28days and 56 days.

a) Weighed binder


b) Dry mixing of binders


c) Binders with sand


d) Dry mix of binders with sand


e) After mixing with solution


f) Mortar cubes

g) After demould
Fig. 5. Steps to prepare GPM cubes

4) *Curing*

- Oven curing
- Ambient curing

After 24 hours of casting, all the cubes were demould from the moulds and place the cubes in oven at different temperatures i.e., 60^0C and 100^0C for a period of 24 hours. After oven curing, cubes were kept for ambient curing for different curing periods of 3days, 28days and 56days.

a) Oven curing

b) Ambient curing
Fig. 6. Curing of mortar cubes

H. Test Carried Out on Mortar Cubes

1) Compressive strength test

For compressive strength test, the specimen of a size 70.6mm x 70.6mm x 70.6mm are commonly used. These specimens are tested for a period of 3days, 28days and 56days.

To determine the compressive strength, place the specimen in the machine in such a manner that the load shall be applied to the opposite side of the cube cast. Apply the load gradually without shock till the specimen the fails and record the maximum load.

$$\text{Compressive strength} = \frac{\text{Load in N}}{\text{Area in mm}^2}$$

a) Placing of cubes in CTM

b) Applying load
Fig. 7. Compression testing

Fig. 8. Failure patterns

For 1.5, 8M, 100^{0}C

Table 8
Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different curing periods

S. No.	Combinations	Compressive strength in N/mm^2 for different curing periods in days		
		3	28	56
1	GB100%+0%CA	50.02	53.47	55.06
2	GB80%+20%CA	22.82	24.06	27.01
3	GB60%+40%CA	16.88	17.01	19.26
4	GB40%+60%CA	10.12	10.98	12.14
5	GB20%+80%CA	7.92	8.18	8.98
6	GB0%+100%CA	0.96	1.24	1.47

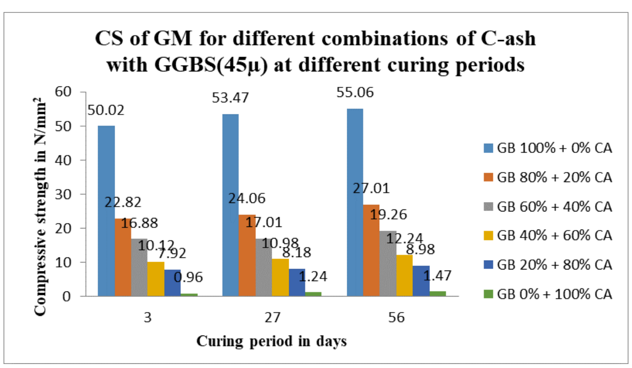


Fig. 9. Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different curing periods

For 2, 8M, 100^{0}C

Table 9
Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different curing periods

S. No.	Combinations	Compressive strength in N/mm^2 for different curing periods in days		
		3	28	56
1	GB100%+0%CA	47.92	49.38	51.81
2	GB80%+20%CA	20.14	22.06	22.98
3	GB60%+40%CA	13.72	15.46	16.34
4	GB40%+60%CA	5.14	6.49	7.26
5	GB20%+80%CA	3.14	4.46	5.92
6	GB0%+100%CA	0.46	0.98	1.14

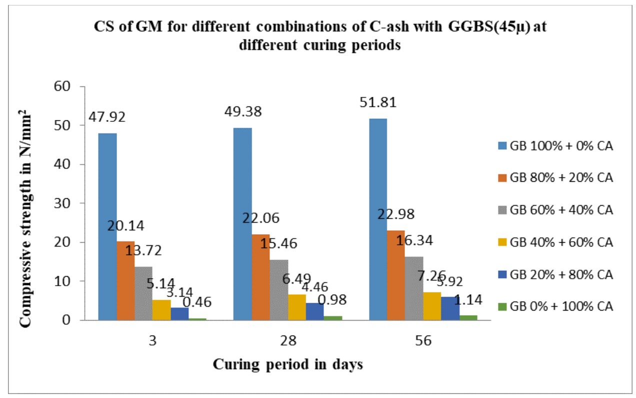


Fig. 10. Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different curing periods

For 2.5, 8M, 100^{0}C

Table 10
Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different curing periods

S. No.	Combinations	Compressive strength in N/mm^2 for different curing periods in days		
		3	28	56
1	GB100%+0%CA	44.27	48.98	51.06
2	GB80%+20%CA	18.14	21.26	23.98
3	GB60%+40%CA	10.36	10.98	12.16
4	GB40%+60%CA	7.47	8.01	8.46
5	GB20%+80%CA	2.14	3.98	4.12
6	GB0%+100%CA	0.88	0.92	1.11

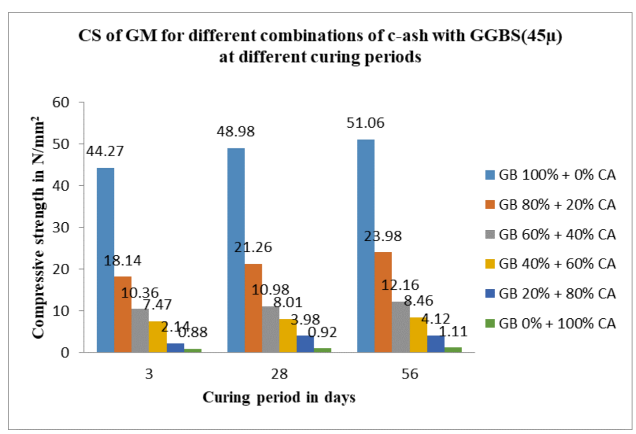


Fig. 11. Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different curing periods

Table 11
Comparison of Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different ratios

S. No.	Combinations	Compressive strength in N/mm² for different curing periods in days		
		3	28	56
1	GB100%+0%CA	50.02	53.47	55.06
2	GB80%+20%CA	22.82	24.06	27.01
3	GB60%+40%CA	16.88	17.01	19.26
4	GB40%+60%CA	10.12	10.98	12.14
5	GB20%+80%CA	7.92	8.18	8.98
6	GB0%+100%CA	0.96	1.24	1.47
1	GB100%+0%CA	47.92	49.38	51.81
2	GB80%+20%CA	20.14	22.06	22.98
3	GB60%+40%CA	13.72	15.46	16.34
4	GB40%+60%CA	5.14	6.49	7.26
5	GB20%+80%CA	3.14	4.46	5.92
6	GB0%+100%CA	0.92	0.98	1.14
1	GB100%+0%CA	44.27	48.98	51.06
2	GB80%+20%CA	18.14	21.26	23.98
3	GB60%+40%CA	10.36	10.98	12.16
4	GB40%+60%CA	7.47	8.01	8.46
5	GB20%+80%CA	2.14	3.98	4.12
6	GB0%+100%CA	0.88	0.92	1.11

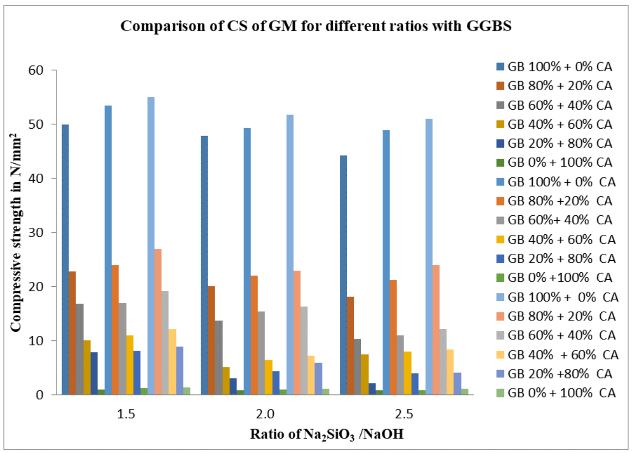


Fig. 12. Comparison of Compressive strength of GM for different combinations of C-ash with GGBS (45µ) at different ratios

3. Results

- The compressive strength decreases from 27.01 N/mm² to 24.14 N/mm² i.e., 10.62% as compared to 1,5, 8M,100⁰C.
- The compressive strength decreases from 24.14 N/mm² to 23.98 N/mm² i.e., 0.66% as compared to 2,100⁰C.

4. Conclusion

This paper presented a study of compressive strength of 8m geopolymer mortar for different combinations of C-Ash with GGBS at 100 degrees Celsius (45µ).

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