Flexural Behaviour of Carbonated Lightly Reinforced Geopolymer Concrete Beams using Manufactured Sand

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Abstract:- **The emission of CO_2 in the atmosphere is the biggest contributor on global warming. The necessary action to minimize the impact on the sustainability of our living environment is required. The carbonation of concrete is one such problem. The non-availability of natural sand is another environmental issue. An attempt is made to use the materials which might otherwise be a burden on the environment. The reduction in the consumption of cement will have a positive impact on the environment. The carbonation of concrete is one more critical issue. The investigation was carried out to study the strength and durability of lightly reinforced concrete beams after they were exposed to different durations of accelerated carbonation. The concrete mix (of target strength of M40) included Fly Ash & GGBS, Manufactured Sand, Coarse aggregate, alkaline solutions and water. The beams specimens of size 1000 x 100 x 150 mm were cast and were kept for 48, 96 and 144 hours of carbonation durations inside carbonation chamber before the flexure test. Surface strains at various depths under the loading points were measured. The deflections at different stages of loading were recorded. The depth of carbonation in each case was recorded from the cut samples. The flexure strength, crack pattern, and deflections are compared with those of control specimen.**

Key Words: Sustainability, Carbonation, Flyash & GGBS, Manufactured Sand

1. INTRODUCTION:

The emission of CO_2 in the atmosphere is the biggest contributor on global warming. The necessary action to minimize the impact on the sustainability of our living environment is required. The carbonation of concrete is one such problem. The non-availability of natural sand is another environmental issue. An attempt is made to use the materials which might otherwise be a burden on the environment. The reduction in the consumption of cement will have a positive impact on the environment. The carbonation of concrete is one more critical issue. There is a significant expectation on the industry to reduce carbon dioxide (CO_2) emissions to the atmosphere. In view of this, one of the efforts to produce environmentally friendly concrete is to reduce the use of Portland cement by using by-product materials, such as fly ash and Ground granulated blast furnace slag (GGBS).

In 1978, Davidovits proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, Davidovits (1994, 1999) coined the term `Geopolymer' to represent these binders. In this work, Class F fly ash and GGBS mix geopolymer is used as the binder to produce concrete. The fly ash and GGBS mix based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. There are several test on durability of Geopolymer concrete just to make sure that this new material really can replaced Portland cement in the future such as carbonation of Geopolymer concrete, resistance to carbonic acid and sulphate resistance. The carbonation test is one of indication of the quality of durability for concrete.

Carbonation is defined as the process whereby carbon dioxide in air diffuses into concrete, dissolved in the pore solution, and then react with the hydroxides, converting them to carbonates with a consequent drop in pH to a value less than 9. Depassivation of steel can occurs as pH of the pore solution approaches 11. The rate of carbonation is very much moisture dependent such as the macro and micro-climatic conditions of the exposed concrete element. Concrete exposed to temperate climate are expected to have higher carbonation rates. The Durability is a major concern for concrete structures exposed to aggressive environments. Carbonation is one of the major factors to cause structure deterioration. Carbonation is the reaction of the hydration products dissolved in the pore water with the carbon dioxide in the air which reduces the pH of concrete pore solution. Carbonation reduces pH value and destroys the passive film around the steel, but it seems to densify concrete surface and reduce chloride ion permeability, reduce surface porosity. Carbonation could have both positive and negative effects on concrete durability.

Ganapati Naidu et al., (2012) studied the strength properties of Geopolymer concrete that containing fly ash and GGBS. Higher concentrations of GGBS (Slag) result in higher compressive strength of geopolymer concrete.

Compressive strength of geopolymer concrete increases with increase in percentage of replacement of fly ash with GGBS. Abdul Aleem and Arumairaj (2012) reviewed the constituents of Geopolymer concrete, its strength and potential applications. Azhar Badaoui, et al (2012) presented the randomness effect of the pressure of carbonic gas on the carbonation phenomenon of the reinforced concrete. This analysis concentrates on the evaluation of carbonation depth and the carbonation time which is the time necessary so that the face of carbonation arrives until the reinforcement from a probabilistic analysis. Jack M. Chi et al (2002) studied the effect of carbonation on mechanical properties and durability of concrete. It was observed that deformed bars corroded more than the plain bar. Formation of gaps under horizontal steels causes significant corrosion. Water cement ratio has a significant influence on corrosion of steel in concrete.

The present study dealt with the effects of carbonation in geopolymer concrete beam with light renforcement. The study is related to determination of the depth of carbonation reaction to Geopolymer concrete beams and the performance of these beams under flexure with the mix proportion 50% of Fly ash and 50% GGBS subjected to different exposure conditions during carbonation. M-sand or Manufactured sand was used as the fine aggregates.

2. MATERIALS USED

FLY ASH: Fly ash is removed from the combustion gases by the dust collection system, either mechanically or by using electrostatic precipitators, before they are discharged to the atmosphere. Fly ash particles are typically spherical, finer than Portland cement and lime, ranging in diameter from less than 1 µm to no more than 150 µm. The types and relative amounts of incombustible matter in the coal determine the chemical composition of fly ash. The chemical composition is mainly composed of the oxides of silicon (SiO_2), aluminum ($A1_2O_3$), iron (Fe_2O_3), and calcium (CaO), whereas magnesium, potassium, sodium, titanium, and sulphur are also present in a lesser amount. The major influence on the fly ash chemical composition comes from the type of coal. In this experimental work, low calcium, Class F dry fly ash from the silos of Jindal thermal power station of Bellary district, Karnataka state was used.

GGBS: For an environmental friendly concrete, the cement was replaced with the industrial by products such as fly-ash, GGBS (Ground granulated blast furnace slag) etc. GGBS is used to make durable concrete structures in combination with ordinary Portland cement and/or other pozzolanic materials. Impermeability is the foremost mechanism for making the concrete more durable and is best achieved by using GGBS. Reduction in heat of hydration and minimization of thermal cracks.

M-SAND: In this experimental work, M-sand or Manufactured sand is used as the fine aggregates. Now-a-days good sand is not readily available; it is transported from a long distance. Those resources are also exhausting very rapidly. So the best alternative found for this is M sand.

SUPERPLASTICIZER: Super plasticizer is one of the important materials in the concrete mix. Besides it function is to improve workability of mix design, it is also functional as substantial water-reducing agent to enhance the early and ultimate strength of the concrete. Master Glenium SKY 8233 is an admixture of a new generation based on modified Polycarboxylic ether. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. Master Glenium SKY 8233 is free of chloride and low alkali, and the product is supplied by the BASF Chemical Company, Bangalore.

ALKALINE SOLUTIONS: In Geopolymerisation process alkaline solutions plays an important role. There are two types of alkaline solution that being used in this study. A combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solution was chosen as the alkaline liquid; because sodium based geopolymer have a stronger zeolitic property than the potassium based geopolymer [potassium hydroxide (KOH) and potassium silicate (K_2SiO_3)]. Before mixing the concrete, the both alkaline will be mix together at least a day before casting process.

LIGHTLY REINFORCED BEAMS: In a lightly reinforced section the cracking capacity of the concrete is larger than the ultimate tensile capacity of the reinforcement. In these lightly reinforced members the ultimate moment capacity may be less than the bending moment required to crack the member. In these circumstances only one crack may open at the highly stressed part of the member, and strains in the reinforcing will be concentrated at that location. If the steel yielding is concentrated at one location rather than distributed over a plastic hinge length, as in a normally reinforced member, the strains are much higher and, with low-cycle fatigue effects, could lead to fracture of the reinforcing steel. Less than the specified minimum reinforcement for beam, Mild Steel reinforcement of 2 bars of 6mm diameter with yield strength 250 N/mm^2 at the top and 2 bars of 8mm diameter with yield strength $415N/mm^2$ were used at the bottom. Spacing of stirrup bars was 150 mm $c/_c$ at the ends and 190mm $c/_c$ at the centre.

After conducting series of trial mixes, the best mix design was selected for the study. The mix consists of 25 percent from geopolymer mass which is 50:50 of fly ash and GGBS. The mix proportion includes 75 percent geopolymer mass of 10mm of aggregate, M-sand. The usage of super plasticizer is 2 percent of sample mass. Sodium Silicate and Sodium Hydroxide with the molarity of 14M each were chosen. The ratio of Sodium Silicate solution to Sodium Hydroxide solution by mass was approximately as 2.5.

Table 1 Mix Proportions of Materials

Mix Ratios of Flyash: GGBS	100% Fly Ash			70:30			60:40			50:50		
Fly Ash (kg)	1.60			1.12			0.96			0.80		
GGBS (kg)	-----			0.56			0.75			0.93		
Coarse Aggregates (kg)	2.8			2.8			2.8			2.8		
Fine Aggregates (kg)	2.6			2.6			2.6			2.6		
Alkali solution: NaOH (kg)	0.27			0.27			0.27			0.27		
Alkali solution: Na_2SiO_3 (kg)	0.40			0.40			0.40			0.40		
Water	0.35			0.35			0.35			0.35		
Super Plasticizer	0.026			0.026			0.026			0.026		
Cube No	Gp1	Gp2	Gp3	Gp4	Gp5	Gp6	Gp7	Gp8	Gp9	Gp10	Gp11	Gp12
Load (kN)	268	316	242	512	522	536	700	685	628	882	840	876
Compressive Strength, N/mm^2	12	14.5	10.5	22.4	22.7	23.4	30.4	29.8	27.3	39.24	37.36	38.2

Table 2: Mix proportions for $1m^3$ of concrete for 14M

Mixes	GGBS	Fly ash	Coarse Agg	Fine Agg	Sodium Hydroxide		Sodium Silicate	Super plasticizer		Extra Water	
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	Kg/m^3	Mol	Kg/m^3	Kg/m^3	%	Kg/m^3	%
50% GGBS & 50% Fly ash	269	227	794	728	76	14	114	7.44	1.5	99.2	0

Table 3 Quantities of materials required for Beam

Fly Ash	GGBS	Coarse Agg	Fine Agg	Alkaline Solution		Water	Superplastisizers
				NaOH	Na_2SiO_3		
3.4	4.0	11.91	10.92	1.14	1.71	225ml	110ml

Three Beams were cast at a time in a timber mould. A thin layer of oil was applied to the surface of the vertical timber formwork. All the ingredients, as calculated, were mixed by hand mixing. Initially all the ingredients such as Fly ash, GGBS, coarse aggregate, and fine aggregate were mixed for three minutes, after which, the alkaline solutions are added (which is prepared one day prior with the 14M concentration) and then all the above ingredients were mixed thoroughly for five minutes. Finally calculated water and super plasticizer were added in order to pass workability.

Four test series were performed. Series I consisted of three beams which were kept as Control Specimens. Series II, Series III and Series IV consisted of beams subjected to accelerated carbonation durations of 48 hours, 96 hours and 144 hours respectively. Each beam is of span 1.0m and 0.1m width. The overall depth of the beam is 150 mm. 2#6mm @ top and 2# 8mm @ bottom were placed and 7 rings of 6mm were tied. For each series of beams, two specimens were cast with 20mm and 30mm cover each.

3. CARBONATION TEST SET UP

The concrete beam specimens were exposed to carbon dioxide in the carbonation chamber for different durations. The carbonation chamber with suitable housing arrangements for concrete beams is shown in Fig. 1. The carbon dioxide is supplied to the carbonation chamber by burning saw dust and other waste materials. Concrete beams were exposed to carbon dioxide for known duration in the carbonation chamber.

Fig 1. Beams inside carbonation chamber

The depth of carbonation is established by removing the samples at the center and corners of the carbonated beams. All the specimens expect control specimens were tested using the suitable indicator for the detection of carbonation depth. Phenolphthalein is the indicator favourite, by RILEM and the same is used in this study. When there is a carbonated area the colour of phenolphthalein will change from pink to colourless. The solution is sprayed onto freshly broken surface which has been cleaned from the dust and loose particles. Depth of carbonation is only considered for the cement paste. The measurement was carried out immediately after the broken surface was exposed and the second reading should be taken after 24 hours. The transition areas, which lose their colour after 24 hours, are to be judged as carbonated. Hand microscope is used to measure the depth of carbonation on each specimen. It is necessary to record the average depth and maximum depth of penetration. The depth of carbonation is measured from the surface of the sample.

3. Experimental set up observation and discussions:

All beams were simply supported and tested with two symmetrically placed point loads. A single hydraulic jack was used to apply load. The load was distributed to the beam through a spreader beam system, which resulted in two point loads being applied to the specimen. The dial gauges were used to measure deflection. Deflection at the mid-span was registered for one point.

At every interval of 2.5kN the behaviour of beam in flexure was enumerated till the ultimate load. The first crack load and ultimate loads were treated as important parameter with central maximum deflection for the comparative study of the behaviour. The crack patterns for all beams were carefully observed to discuss modes of failure. These results are used to make a comparison between control specimens with beams subjected to different durations of carbonation by plotting load-deflection relationship and depth of Carbonation.

Fig 2. Test setup

Fig 3. Strain measurement using demec gauge

Fig 4. Strain measurement using demec gauge

Fig 5. Carbonation test

For beams with 20mm cover, the carbonation depth was found to be in the range of 1.5mm to 1.6mm and with 30mm cover, it was observed that the variation is from 1.8mm to 2.0mm.

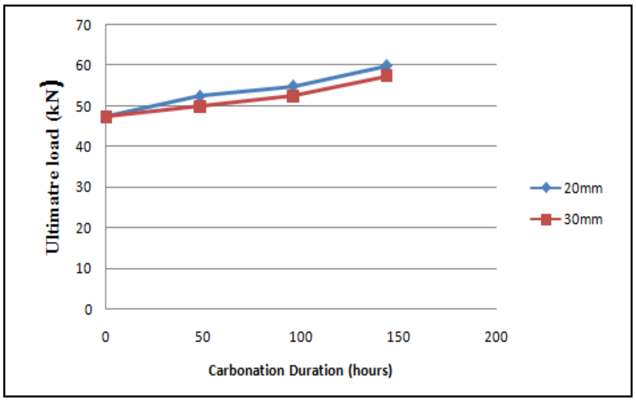


Fig 6. Ultimate Load- Carbonation duration

The relationship between the Ultimate Load to carbonation durations is shown in **Fig 6.**

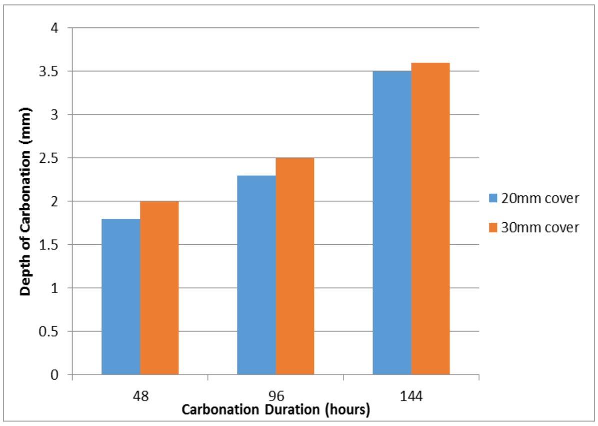


Fig 7. Depth of Carbonation- Carbonation duration

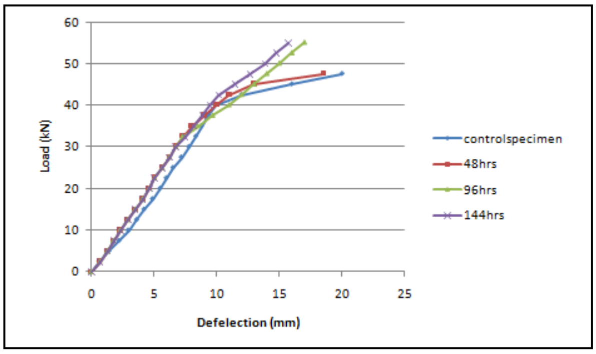


Fig 8. Load Vs Carbonation Period

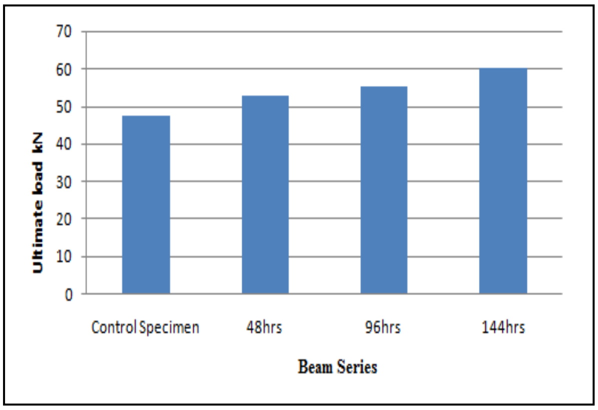


Fig 9. Load Vs Carbonation Period

It was noticed that the phenolphthalein solution sprayed over coarse aggregate does not show any colour variation which indicated no carbonation action. Also at certain places, the depth of carbonation was observed on the higher side which might be due to the honey combed areas in the beam.

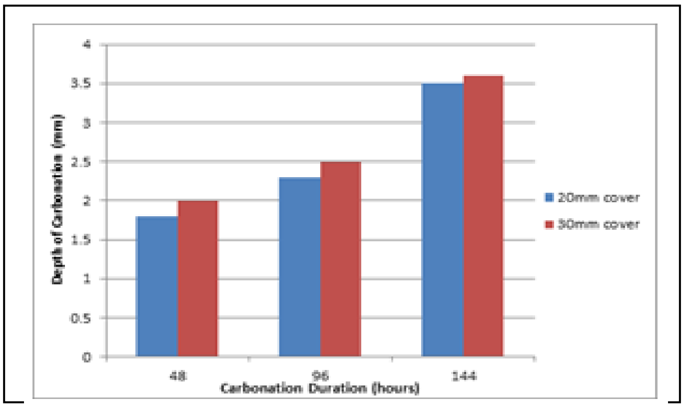
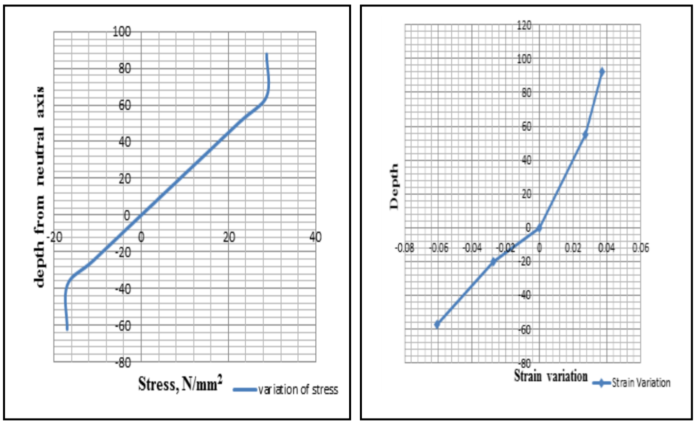


Fig 10. Depth of Carbonation Period Vs Cover thickness



a) Stress Variation; b) strain variation

Fig 11. Typical stress and strain along the depth

Fig. 12. Typical multiple flexural cracks at the bottom

It was observed that the depth of carbonation was more on the bottom portion of the beam compared to the top portion.

There were no signs of corrosion to reinforcement observed in the carbonated specimens might be because the duration of exposure to carbonation was small.

Table 4 Summary of average depth of carbonation

Beams	Cover to reinforcement, mm	Sample Area	Average Depth of Carbonation
Series II	20	Center and corner	1.5
	30		1.8
Series III	20	Center and corner	2.1
	30		2.3
Series IV	20	Center and corner	3.0
	30		3.5

5. CONCLUSIONS

- ✓ The density of concrete increases with carbonation.
- ✓ Increase in the ultimate load carrying capacity of beams with the increase in carbonation duration.
- ✓ The depth of carbonation increases with the increase in duration of carbonation process.
- ✓ The beam with 20mm cover to reinforcement shows 11% increase in penetration of carbon than with 30mm cover for 48 hours of carbonation, whereas it increased by 9% for 96 hours Carbonation and 2.8% for 144 hours.

6. REFERENCES

[1]. Abdul Aleem, M.I. and P.D. Arumairaj (2012), "Geopolymer Concrete- A Review", International Journal of Engineering Sciences and Emerging Technologies, Vol. 1, Issue 2, pp. 118-122.

[2]. Azhar Badaoui, M'hammed Badaoui, Fattoum Kharchi, (2012). "*Carbonic Gas Randomness Effect on Reinforced Concrete Carbonation*", *Engineering*, Vol. 4, 6-10. http://dx.doi.org/10.4236/eng.2012.41002, Published online January 2012 (http://www.SciRP.org/journal/eng).

[3]. Chandrasekaraiah, T., Manjunatha, K.V., Anantharam, H., Dr. M. N. Hegde, Dr. K. Shantharaju (2011). *"Carbonation Studies on Concrete"*. National Conference, AMAS -2011, PEC, Punducherry.

[4]. Ganapati Naidu. P, A.S.S.N. Prasad, S. Adiseshu, P.V.V. Satayanarayana (2012). "A Study on Strength Properties of Geopolymer Concrete with Addition of GGBS" *International Journal of Engineering Research and Development, eISSN: 2278-067X, p-ISSN: 2278-800X*, Volume 2, Issue 4 (July 2012), pp. 19-28.

[5]. Hardjito D. and B. V. Rangan, "*Development and Properties of low-Calcium Fly Ash-Based geopolymer Concrete*" Research Report, GC Faculty of Engineering Curtin University of Technology Perth, Australia.

[6]. Jack M. Chi, Ran Huang, and C.C. Yang. (2002). "*Effects of Carbonation on Mechanical Properties and Durability of Concrete using Accelerated Testing Method", Journal of Marine Science and Technology*, Vol. 10, No. 1, pp. 14-20.

[7]. Supraja, V. and Kanta Rao M (2012) "*Experimental study on Geo-Polymer concrete incorporating GGBS*", International Journal of Electronics, Communication & Soft Computing Science and Engg, ISSN: 2277-9477, Vol.2, Issue 2.

7. BIOGRAPHIES

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