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Influence of Ambient Curing on Reinforced Geopolymer Concrete Structural Elements

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***Abstract*— Investigations on geopolymer reinforced concrete structural elements are gaining momentum. The present study is focused on influence of *hand mixing and ambient curing on* flexural behavior of reinforced rectangular geopolymer slabs. Seven reinforced geopolymer concrete slabs are casted *using hand mixing and cured at room temperature*. All slabs were tested in 50MTon loading frame and load v/s deflection is noted. Measured deflections are compared with calculated deflections as per IS 456-2000.**

***Keywords*— Flyash, GGBS, Geopolymer slabs, Alkaline liquid, M-sand, workability, flexural strength, load vs. deflections.**

1.0 Introduction.

With the ever increasing demand of urbanization, the utilization of ordinary cement concrete has become second to water. Production of one ton of cement gives out one ton of Co_2 resulting into 6% of global Co_2 emmissions and by the year 2020 this is expected increase by 50%. Investigations around the world are being continuously done to find an alternate binder replacing cement in reinforced structural applications. The fly ash based investigations to replace cement are gaining momentum and are the promise of future concrete structural elements.

2.0 Constituents of Geopolymer Concrete

Fly ash : Fly ash utilized for this investigation is of low calcium grade of F class collected from Raichur thermal power station Karnataka having sp.gravity of 2.15

Ground granulated blast furnace slag (GGBS): used is procured from Jindal steel factory Bellary, having Sp.Gr 2.84.

Alkaline solution: consists of sodium hydroxide (NaoH 97% purity) and sodium silicate (Na_2Sio_3) at a ratio of **2.5**. Sodium hydroxide flakes of **314gms** are dissolved in potable clean drinking water of **686gms** to produce one litre of NaOH solution of **10Molarity.** After 24 hours NaoH solution is mixed with Na_2Sio_3 solution of A53grade with $Si0_2$-to-Na_20 ratio ***2*** by mass, i.e., $Si0_2$ = 29.4%, Na_2O = 14.7%& water = 55.9%.

Coarse Aggregates:
Three sizes of coarse aggregates are used i.e., 20mm, 12.5mm and 4.75mm sizes of granite origin available from the local source confirming to having specific gravity 2.67 and fineness modulus 7.572 .

Fine Aggregates:
Manufactured sand and river sand at 25% and & 75% are used as fine aggregates. Fineness Modulus of M-sand and River sand is 2.901 and 4.637 respectively and Sp.Gravity of M-sand and River sand is 2.7 and 2.68 respectively.

Water:
Clean potable water used for drinking purpose is used for preparing NaoH solution and concrete mixing concrete purposes. It is observed that water has Ph Value of **7**

Super plasticizer:
Locally available sulphonated naphthalene based super plasticizer i.e., ***CONPLAST - SP430*** distributed by FOSROC chemicals is used to increase the workability of fresh geopolymer concrete.


Sodium Siliate factory


Sodium Hydroxide pallets


Ingradients for Gepolymer concrete & Plasticizer

3.0 Mix Design of Geopolymer Concrete

The geopolymer concrete density is assumed as 2400 Kg/m^3 and trial mixes using 10Molar NaoH solution are tested and following mix design used.

The target strength fixed is at 45Mpa. The trials were done with NaoH/Na_2Sio_3 at 2.50 using 10Molar NaoH Solution. Several trail mixes were tried using hand mixing and ***curing was done at ambient room temperature***. All cube were tested after 7 days of casting.The coarse aggregates were stored at room temperature and thus surface absorption of water content was observed to be less than 0.5% .The alkaline solution was prepared 24 hours prior to mixing. Following mix design was used for preparation of reinforced geopolymer concrete slabs.

Table 1: Ingredients for 1 m^3 of concrete

Sl NO	Material	Kg/m^3	Specifications
01	Fly Ash	286.22	70% of total FlyAsh
02	GGBS	122.67	30% of total Fly Ash
03	River sand	137.22	25% of total FA
04	M-Sand	411.66	75% of total FA
05	20mm to 12.5mm	448.25	35% of total CA
06	12.5mm to 4.75mm	448.25	35% of total CA
07	4.75mm to down sizes	384.22	30% of total CA
08	(NaoH) 10M	40.9	97%purity (26.20%)
09	(Na_2Sio_3)	102.22	
10	Super plasticizer	10.222	SP430 DIS (2.5%)
11	Extra water	8.17	potable water

Notations: F.A-Fine aggregates, C.A-Coarse aggregates

4.0 Preparation and Mixing of Geopolymer Concrete

Alkaline Activator:
Alkaline liquid is prepared **24** hours prior to mixing of concrete. This solution consists of **NaoH/Na_2Sio_3 ratio 2.50** with **10Molar NaoH solution**.

Slab size:
The size of the slab specimen selected is **975mm x 650mm x 75mm overall thickness,** having aspect ratio **1.5**. Cover blocks of size 10mm x10mm are used at 0.3m spacing

Reinforcement for GPC slabs:

Fe500 grade HYSD steel bars of 8mm diameter 6 number parallel to 975 mm side and 8mm diameter bars of 4 bars parallel to shorter sides are placed and joints are tied using ordinary binding wires.

Mixing of concrete:

Looking into general housing industry in ***INDIA***, concrete for slab is prepared using *hand mixing tools like wooden handled spades and related tools*. First calculated quantities of ingredients are spread over nonabsorbent concrete floor and thoroughly mixed by adding successive ingredient one after the other and the last ingradient being alkaline solution. To get good workability, superplasticizer and extra water are added to suit the desired slump (100 to 150mm).It is observed that the workability of concrete increases as *hand mixing time increases 20 minutes after addition of alkaline liquid*. Compaction of concrete is done by using ordinary hand held rammers.Total water to geopolymer solids is kept below 0.35.

After casting concrete, the peripheral form work is removed after 24 hours and *slabs were kept for curing at room temperature. The room temperature during the time of ambient curing was observed to* ***be 28.2ºc at day time and 20ºC at night.***

Compressive strength & split tensile strength of concrete:

Three cubes of 150mm x150mm x 150mm and three cylinders of 150mm dia and 300mm length are cast during slab concreting. These are tested on the day of testing of slabs to know the compressive strength and split tensile strength of slab concrete.

Table2: Test results for compressive strength concrete

SN	Wt in kg	Load at failure in KN	Cube strength in Mpa	DOC	DOT
1	7.930	1022	45.4	1-7-2015	27-7-2015
2	7.870	1260.2	56	1-7-2015	27-7-2015
3	7.865	821.1	36.4	1-7-2015	27-7-2015

Table3: Test results of split tensile strength of slab concrete

SN	Failure load(KN)	Split tensile strength(Mpa)	DOC	DOT
1	204.7	2.899	1-7-2015	27-7-2015

5.0 Load testing of slabs

Loading Frame

50Mton self straining loading frame with one displacement transducer (LVDT) transmitting central deflections is used for testing .The load Vs displacement out puts are directly interfaced with compatible software.

End Conditions

Simply supported and free ends of slabs are tested. For creating simply supported ends 50mm x 50mm solid steel sections are used along the periphery of slab.

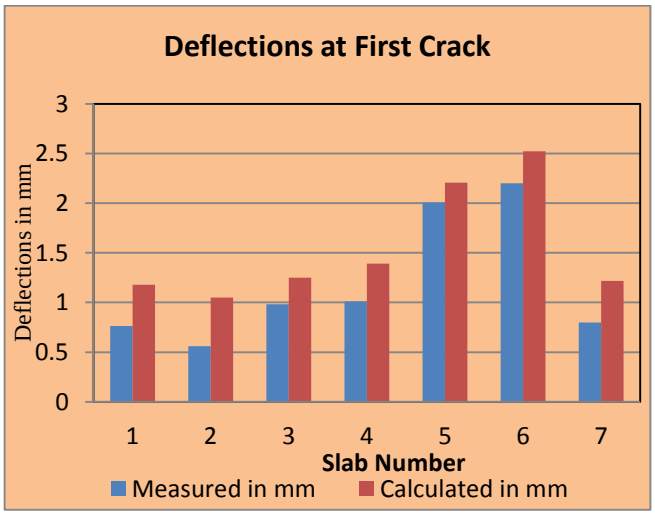
Testing of Slabs:

On the day of testing of slabs, specimen cubes and cylinders were tested to know the compressive strength and tensile strength of concrete used for casting the slabs .**Table 2** and **Table 2** indicate the average compressive strength of ***45.93 Mpa*** and Split Tensile strength of ***2.899 Mpa***

Load testing of slabs were conducted using different end conditions and loading.The test results of slab for load vs central deflections are noted in Table 4.

Table 4: Test results of slabs at First crack

Slab	Slab Size mm×mm× mm	Loading	End cond.	Load Mton	Δex (mm)	Δcal mm
S1	975 ×650 ×75	U D L	2SS,2LF	1.7	0.764	1.178
S2	975 ×650 ×75	U D L	2SS,2LF	1.6	0.56	1.049
S3	975 ×650 ×75	U D L	2LS,2SF	5.2	0.982	1.248
S4	975 ×650 ×75	U D L	2LS,2SF	5.6	1.012	1.39
S5	975 ×650 ×75	U D L	2LS,2SS	6.9	2.006	2.206
S6	975 ×650 ×75	C –Pt Load	2SS,2LF	3.7	2.2	2.524
S7	975 ×650 ×75	C –Pt Load	2LS,2SF	1.6	0.8	1.216

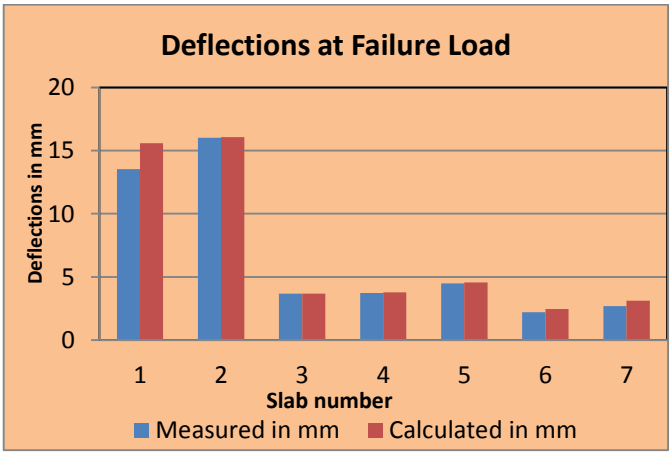


Notations: SS: short sides simply supported,**LS**: Long sides simply supported, **LF**: Long side free, **SF**: Short sides free : C-pt central point load, UDL- uniformly distributed load

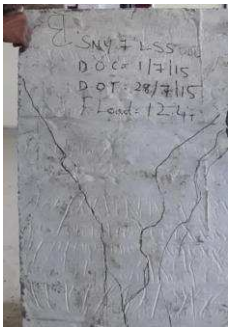
Further loading on slab continued and failure load Vs deflections are noted in ***Table 5***

Table 5: Test results of slabs at Failure Load

Slab	Slab Size mm×mm×mm	Loading	End cond	Load Mton	Δex (mm)	Δcal mm
S1	975× 650×75	UDL	2SS,2LF	13.1	13.53	15.586
S2	975× 650×75	UDL	2SS,2LF	13.5	16.01	16.08
S3	975× 650×75	UDL	2LS,2SF	12.1	3.675	3.681
S4	975× 650×75	UDL	2LS,2SF	12.4	3.724	3.787
S5	975× 650×75	UDL	2LS,2SS	12.8	4.493	4.563
S6	975× 650×75	C –Pt Load	2SS,2LF	3.7	2.2	2.45
S7	975× 650×75	C –Pt Load	2LS,2SF	2.4	2.7	3.12



Crack pattern for S1 and S2 slabs

Crack pattern for S3and S4 slabs


Crack pattern for S5 and S6 slabs

6.0 Results and Discussions:

In these test results **NaoH** used is of **10 Molar** concentration and **Na_2Sio_3/NaoH** ratio is **2.50**.

The tensile strength of geopolymer concrete is comparatively less than the ordinary cement concrete. Measured Split tensile strength of this geopolymer concrete is 2.899 Mpa as against 4.74Mpa arrived using IS 456-2000 relation 0.7√fck.

Workability of concrete improves with rigorous hand mixing up to **20minutes**.

The reinforced geopolymer slabs undergo deformations as tabulated in Table 4 and Table 5. For all the slabs it is observed that the measured deflections at first crack formations are comparatively less than the calculated deformations based on RCC procedures of IS 456-2000. At failure point these deflections tend to converge.

7.0 Conclusions:

Here in this investigation reinforced geopolymer concrete (fly ash and GGBS as source material) is prepared by using hand mixing and cured at ambient room temperature. The following conclusions are made from the above observations.

- Workability of concrete increases with increase in hand mixing time and preferably recommended up to 20 to 30 minutes.
- Reinforced Geopolymer concrete elements have flexural behavior similar with reinforced cement concrete elements.
- *Reinforced cement concrete (RCC) provisions can be used to predict deflections, crack width and other structural parameters using IS 456-2000 with slight modifications*
- The reinforced geopolymer concrete slabs subjected to udl have more resistance than slabs subjected to central point loads.
- Geopolymer concrete prepared by using hand mixing and cured at ambient temperature behave in a similar way with RCC and hence can used as replacement for ordinary cement concrete in civil engineering applications especially housing industry.
- The cost of production of GPC is in line with OPC but for higher grades GPC will be competitive.

8.0 References

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