Sustainable laboratory arrangements for dry curing & conducting study on curing process of some large size geopolymer specimens

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ABSTRACT

In case of geopolymer concrete it is observed that the curing temperature significantly affected the mechanical strength, together with the curing time. Higher curing temperature (starting from 27°C to 100°C) and longer curing duration (in the range of 24 to 96 hours) were proved to result in higher compressive strength. Curing is nothing but drying of specimens at slow speed. During curing process the moisture from specimens is accommodated by the atmospheric air. Thus humidity of the available air for drying is also one of the affecting factors. For production of any precast concrete component from the particular fly ash based geopolymer concrete, it is required to optimize not only the design mix but also the curing process as per the major seasons in India.
For this purpose, there exists a need for study of curing process with reference to environmental conditions on real specimens with the precast industry potential. Some of such specimens are railway sleepers, roof- planks & joists, beams, precast floors, wall panels, drains, fencing polls etc. Dry curing is found more effective than steam curing. The efforts have been made for development of dry curing arrangement for some of such large size specimens with data logging facility for temperature & humidity, in laboratory. This curing chamber is named as DCCA (Dry curing chamber for AMPRI). The strength of the geopolymer concrete specimens was cross checked with conventional oven cured specimens and there is no significant variations found in results. The data logging system records the inside & outside temperature & humidity during curing process at an interval of 05 minutes, in a memory card.

Key words: Geopolymer concrete, Data logging system, Heat control system

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INTRODUCTION

The curing process of geopolymer concrete is the most crucial aspect and plays an important role in geopolymerization reaction. Researchers concluded the curing regime as one of the main parameter to be considered during the synthesis of geopolymers. During curing process, the geopolymer concrete experience polymerization process. Due to the increasing of temperature, polymerization become more rapid and the concrete can gain strength.

Curing of geopolymer products can be done in two methods that are dry curing and steam curing. In dry curing specimens are heated in oven at an elevated temperature for particular duration. Curing process can be in single stage or multi stages & every time the temperature & time parameters chosen might be same or different. In steam curing the specimens are heated by steam of specified temperature supplied from boiler.

In India potential items for precast industries are roof-plank & joist, broad gauge railway sleeper, wall panel, fencing poll etc. For production of such items deep study of their curing process is needed. It is evident from the literature that for curing of such large size specimens who cannot be adjusted in oven, the steam chamber is designed as per requirement & usage. The design of steam curing chamber is a cost effective alternative solution to large size laboratory oven. But steam generation facility is not available in all laboratories and operation of boiler is licensed & high skill work. Under such circumstances it becomes almost impossible to conduct experiments with these specimens Nevertheless DCCA provides significant & reliable results. It is cost effective & appropriate arrangement for laboratories.

Size considerations

While deciding for the size of curing chamber CSIR-AMPRI has taken consideration for railway sleepers, which are most commonly used precast concrete component in India. As per Indian railway standard specification for pre-tensioned pre stressed concrete sleepers for broad gauge, the length of a railway sleeper is always kept 2440 mm or more. In Normal Broad Gauge the sleeper has a trapezoidal cross section having a width of 154 mm at the top and 250 mm at the bottom and a height of 210 mm at rail seat. Thus, the size of a broad gauge railway sleeper can be generalized as 300cm X 30cm X 25cm.

It is always essential to leave sufficient spacing not only between the walls of the chamber and specimens but also among the specimens kept inside the chamber, in order to ensure effective & homogeneous curing. For research purpose it is needed to prepare at least three specimens at a time (called 01 set) under same environmental conditions, to draw any conclusion about the strength gain in concrete component, because the code directs for average value of three specimens. Thus it became mandatory to provide the width of chamber suitable for accommodation of at least three no of specimens.

While deciding the height of chamber the energy consumption, enough space for hot air circulation, size wise & weight wise ease in handling, time of construction & cost effectiveness were major considerations The volume & nature (alkaline) of Vapor / fumes resulting from drying process of geopolymer specimens & space required for its safe accumulation till exit, were also some important factors in the decision of height. After considering all the above discussed aspects, we arrived to the shape of a box of size of **360cm X 150cm X 75cm** for proposed **DCCA**.

Requirements associated with proposed curing chamber

After several round of discussions, the requirements related to development of curing chamber were finalized as listed below:-
(1) Dimension :- 360cm X 150cm X 75cm
(2) Energy consumption (maximum):- 04 Kilowatt
(3) Should be easy in operation & must posses' proper insulation.

(4) Should be equipped with:-
- a Microcontroller based fully automatic temperature control panel system
- b Pre settable temperature selection system as per user requirement (Ranging from 30°C to 100°C).
- c Live temperature display board.
- d Two channel temperature monitoring with electronic switching unit (situated at equal distance from both end along the length)
- e Two point temperature data logging system
- f Two point humidity data logging system.

(5) Should be portable with partial dismantling facility

Precast items are needed to be cured in both positions i.e. with mould & after demouding. The items considered for experiment like: - broad gauge concrete sleeper, roof-plank & joist etc. are very heavy in nature. Due to lack of man power & other resources in laboratory it is very troublesome to transport: - (1) compacted moulds of the specimens from work floor to curing chamber (2) Partially cured specimens for demouding from the chamber to work floor, after substantial hrs curing, when the specimens attain size stability (3) Demoulded specimens from work floor to curing chamber for optimized hrs curing. Moreover, efforts should be towards ensuring the optimum use of expensive electric energy by curing of as many as possible items, at a time. Thus it is needed that the curing chamber must be such which:-
(I) Can be installed where the specimens will be casted.
(II) Can be dismantled partially for: - (a) Demoulding process. (b) Addition of other newly prepared specimens for curing. (c) Visual inspection during curing.
(III) Can be adjusted easily during installation over casted specimens, for ensuring the proper position.
(IV) Can be shifted to other place after completion of curing in easy way, by few unskilled labours.

Construction of DCCA

DCCA is prepared as a hallow box of size 360cm X 150cm X 75cm without base, so that it can be placed or installed over the specimens, casted on work floor. Simultaneously, dismantling facility with one wall (360cm X 75cm) is provided.

[A]Walls & roof

Initially a structure like pond was fabricated by using iron pipes of size 05cm X 2.5cm [Rectangular] and 2.5cm X 2.5cm [Square].This iron cage is provided for extra durability & robustness. Later on the side walls and roof of the chamber were prepared by properly screwing the 12mm. thick good quality, high strength plywood inside the iron skeleton. Inside walls of the chamber were covered with reflective G.I. sheet (thickness 20 gauges) lining for minimizing the temperature losses due to absorption of heat. For giving final finish to the chamber, a layer of 08mm plywood, covered outside with powder coated G.I. sheet (thickness 20 gauges) is wrapped all around its walls & roof. This not only imparts attractive look but also adds to heat effectiveness including durability. The space between 12mm & 08mm plywood were filled with glasswool as a low thermal conductivity material to avoid temperature losses. Thickness of the glasswool layer is kept around 2.5cm. This three layer insulation including glasswool sandwich was provided for preventing heat losses & maintaining the maximum temperature generated from the heaters on particular energy consumption, inside the chamber. Adjoining portion of different walls & roof are tightly fastened by aluminum angle 0f size 25mm X 25mm.

Table 1 provides information about the thermal conductivity & autoignition temperature of different material used for construction of curing chamber. Wall cross section is shown in fig.1.

Table 1 Thermal characteristics of materials

Materials	**Thermal conductivity in W/(m.K)**	**Auto ignition temperature in ˚C**
G. I. sheet	55	-
Glasswool	0.038	-
Plywood	0.13	280

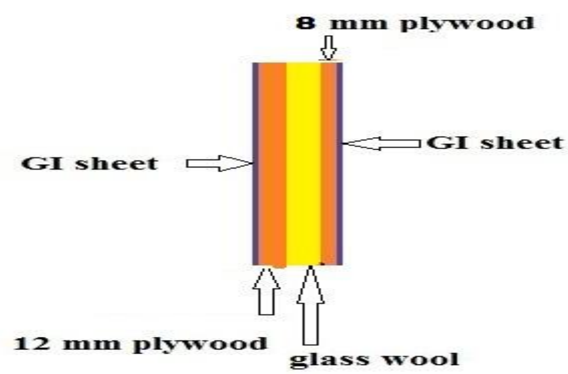

Fig1 Cross section of chamber wall

The chamber has removable side wall (360cm X 75cm) for access & operation purpose, which is shown in fig 2.

Roller guides are provided on the base of chamber for ease in installation & adjustment of position while application over casted specimens. Roller guides create gap between the work floor & base of chamber. Roller guide & skirt arrangement is shown in fig.3.

For covering up this gap, skirt of length about 05cm is provided below the chamber walls, all around the base for ensuring proper insulation during curing process. For providing skirt, 12cm wide pieces (for rigid & firm screwing) of 8mm thick plywood sheet are used.

For smooth movement of curing chamber a gap of 03 to 04mm is left between the skirt & floor. It is considered that this much gap will not result into temperature loss & is necessary for proper air circulation inside the chamber. Handles are provided on side walls of the chamber for lifting & carrying purposes.

	
Fig. 2 Removable side wall	**Fig.3 Roller guide & Skirt**

[B]Electrical & electronic installations

(i)Heat control system

Four number of equi spaced electrically operated tube industrial heaters each of 1000Watts were used as the heating source. The heaters were installed serially on inner roof wall along the length. The chamber was designed to maintain temperature in the range of 30 ˚C to 100˚C.Since the curing process of geopolymer specimens may remain continue as long as 72 hrs, a rectangular piece of 06mm thick asbestos sheet [size 60cm X 30cm] is provided in two folds, below each heater for avoiding any chance of damage to the roof of the chamber, due to such a long heating. 1.5mm Teflon wire was used for connections between the control system & heaters, for ensuring proper safety & no damage to wire during long curing processes.

A dedicated blower is installed exactly in middle position of one of the side wall (150cm X 75cm) of chamber for circulating the heated air inside. Separate electric supply is given to this blower & it is controlled by a 1500Watt regulator. For space economy & safety purpose, the regulator of the blower is provided on the electrical cabinet installed for temperature display.

Two semiconductor based temperature sensors (range 0-150 ˚C) are provided at equal distance from both ends of chamber along the length, for measuring the temperature T1 & T2 and knowing the temperature difference existing between two points of curing chamber against the set temperature T. The important feature about the semiconductor based temperature sensors is that they generate 0.1 volt per 1˚C temperature & don't require any calibration. This two channel temperature monitoring is very important feature which gives idea about the homogeneity of temperature existing inside the large volume of curing chamber. These temperature sensors are installed in corresponding middle position of each set (02 no) of heaters. These sensors were attached with a 16X2 LCD Temperature Display Unit, which digitally displays the temperature T1, T2 & T.

Three phase industrial power supply is given to Heat Control System which contains two Relays (RL1 & RL2), each attached with one set of heaters for controlling the temperature, according to the set temperature T. A control switch attached to Heat Control System is provided separately which is meant for setting the desired temperature for curing. This contains 03 switches namely UP, DN & SET for digitally setting the temperature. By these switches temperature in the range of 10 ˚C to 100˚C can be set & when we try to set the temperature beyond this it automatically attains the temperature 60˚C, which is recorded in its memory. A beep system is also provided with control switch. Beep indicates that the process of temperature setting is successfully completed & system has recorded the set temperature in memory. Even in case of power failure / break the system will automatically start functioning on set temperature as soon as the power supply is again restored.

An electrical Cabinet (metallic, Size :- 15$_{1/2}$ inch X 11 $_{1/2}$ inch with closing door) containing complete Heat Control System comprised of setting switches & temperature display is fixed on outer face of the chamber. 2.5 square mm, 03 core electrical cables were used for providing outer connections.

The heating system of curing chamber is designed with variable rate of increase of temperature & can be set at once, as per suitability and need. The rate of increase of temperature can be such that the time required for attaining the set temperature may vary within the range of 10 minutes to 140 minutes, depending upon the atmospheric temperature, the temperature chosen for set & speed of the blower. Installations of heating system are shown in fig.4.

Installation of 04 no heaters on roof	**Installation of fan on side wall (inside)**	**Installation of control unit on outer face**

Fig. 4 Installation of heating system of Curing Chamber

(ii) Data logging System

Separate electric supply arrangement is made for Data logging system which contains: - (1) two point temperature data logging system & (2) two point humidity data logging system. This system is provided with a memory card which is placed over the display box of data logger & records data of temperature & humidity of every 5minute interval. This card can be taken out & the data stored in it can be transferred & analyzed by any software processing unit.

For recording the data of temperature & humidity one sensor is placed inside the chamber while the other is placed open to the environment, in which the chamber is situated. This logger records & displays the readings of temperature & humidity inside the curing chamber as T3 (in display indicated by T1) & RH1 respectively & outside the chamber as T4 (in display indicated by T2) & RH2 respectively. In this way the curing process can be compared & analyzed in terms of change in environment. Moreover, the effect on optimum curing temperature, curing duration & strength gain of geopolymer concrete with respect to change in environment can also be studied.

An electrical Cabinet (metallic, Size:- 09 inch X 7 1/2 inch) with temperature and humidity display containing complete Data Logging System is installed nearby to temperature monitoring unit, which is shown in fig. 5. The position of memory card is shown in fig. 6.

The display unit of data logging system at a time displays the Date, Time & RH2. Time is displayed with a fixed interval of 05 minutes like 14.20, 14.25, 14.30 etc. Every time when change in display occurs (at an interval of 05 minute), the readings of T1, T2 & RH1.are also displayed on the screen for 10 seconds & later on the screen returns back to its previous position of displaying the date, time & RH2.

	
Fig.5 Data logging display unit (right with red indicator)	**Fig.6 The Box (black) containing detachable memory card**

[C]Electrical Connections

Three separate power connections were given for (1) The heating system (2) The blower & (3) The data logging system .These connections were made as shown in circuit diagram fig.7.

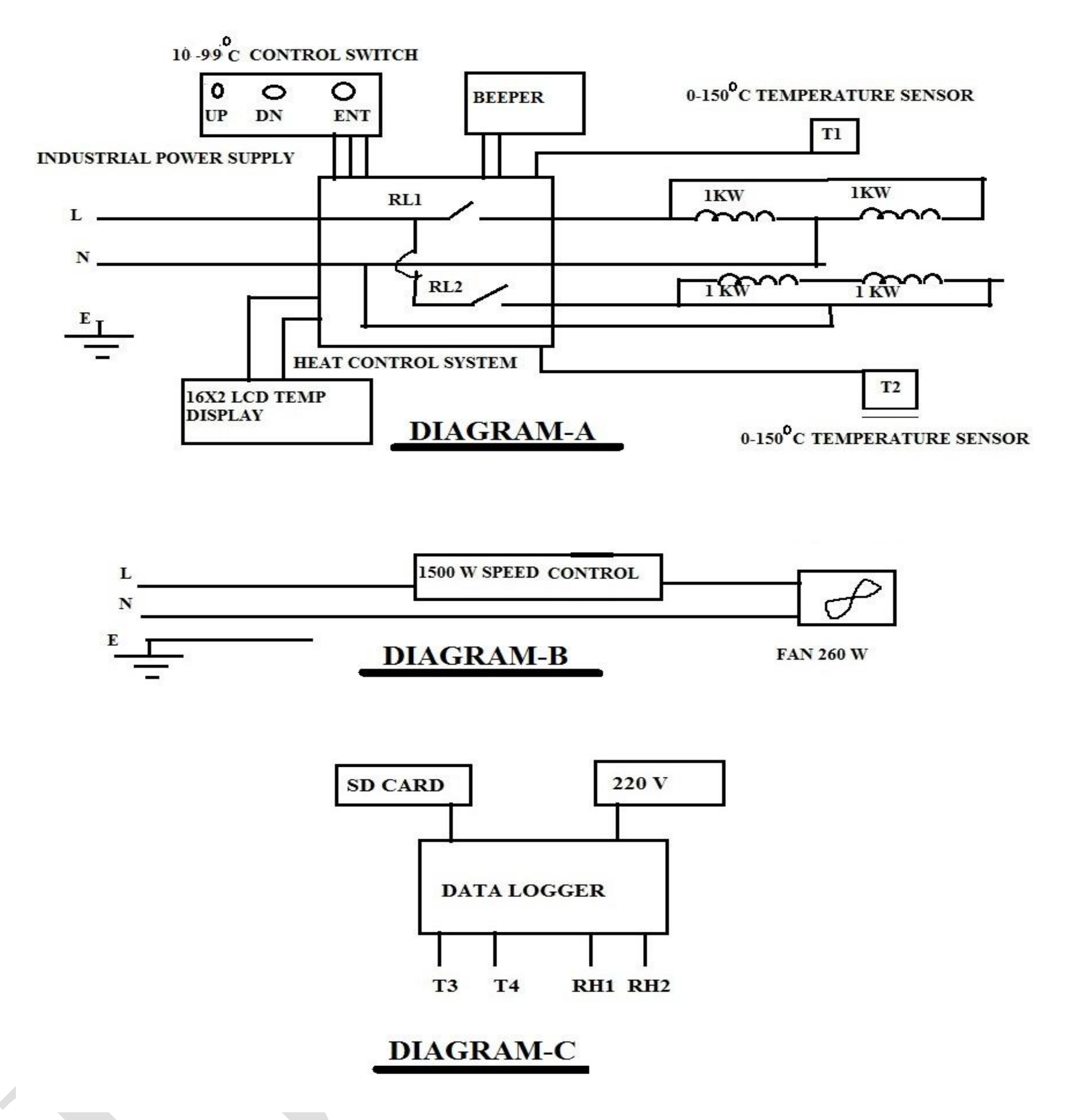

Fig 7. Circuit diagram for (1) Heating System (Diagram A) (2) Blower (Diagram B) & (3) Data Logging System (Diagram (C)

Operation of DCCA

Chamber is planned for placing over the specimens after the casting. For installation of this chamber about 13ft X6ft size floor area (work floor for casting of bigger size specimens) in one corner of laboratory was constructed. The floor area was made especially strong & smooth, so that its free & smooth movement on rollers can be ensured, for long time.

It is mandatory that samples should be properly organized to suit the inside chamber dimensions. During idle period the chamber (approximate weight -280 Kg) can be organized on the platform in two parts i.e. the removable long side wall (approximate weight -70 Kg) kept supported by laboratory wall & the remaining portion in standing position based on side walls of the chamber. This will result into space economy. Most appropriate operational position of the chamber can be marked by paint on the platform for guidance in arranging specimens for curing purpose.

For installation purpose the chamber will be put over the specimens and then cover it by exactly keeping in marked position on ground. The roller guides are provided on the base of the chamber by which the position of chamber can be adjusted, very easily. While handling chamber it should be ensured that the power supply should be disconnected.

Arrangements for three separate electrical connections were made nearby to the platform. After installation of chamber on specimens, power supply should be given from three separate connections to heating system, blower & data logging system respectively.

Readings of two channel temperature monitoring system T1 & T2 are to be watched closely for ensuring the homogeneous temperature inside & noting the start time of curing on set temperature T. The variations among the temperatures T1 & T2 should be within 0 to 2 ˚C and both the readings should be either equal or higher than the set temperature T by margin of 1to 2 ˚C, then only the system is said to become operative for experimental purposes. More variations in temperature can be adjusted by adjusting the speed of the blower. The complete curing chamber is shown in fig.8.

Front view	**Left side view**

Fig.8 complete curing chamber

Temperature consistency in DCCA

For checking the temperature consistency of DCCA the readings of temperatures T1 & T2 were recorded at an interval of 10 minutes, after setting the temperature on maximum i.e. 99˚C. Here it is important to point out that the sensors limit was kept at 150˚C and the temperature functioning / checking were limited up to 99˚C. The variation between the temperatures T1& T2 was tabulated in table 2. The data was analyzed for increase in temperature with respect to time &

shown in fig.9. Total time taken by the chamber for attaining maximum temperature was 130 minute.

Table 2:- Tabulation of data for Temperature consistency in curing chamber

S.No.	Time in Minute	Temperature readings in °C		Average Temperature °C
		Left sensor T1	Right sensor T2	
1	10	37.6	38.8	38.20
2	20	44.1	45.2	44.65
3	30	51,3	53.7	52.50
4	40	59.3	62,1	60.70
5	50	65.2	66.9	66.05
6	60	71,6	73.1	72.35
7	70	78.1	80.1	79.10
8	80	82,8	83,9	83.35
9	90	86.2	88.2	87.20
10	100	89.3	90.9	90.10
11	110	92.4	94.2	93.30
12	120	95.8	96.1	95.95
13	130	98.9	99.1	99.00

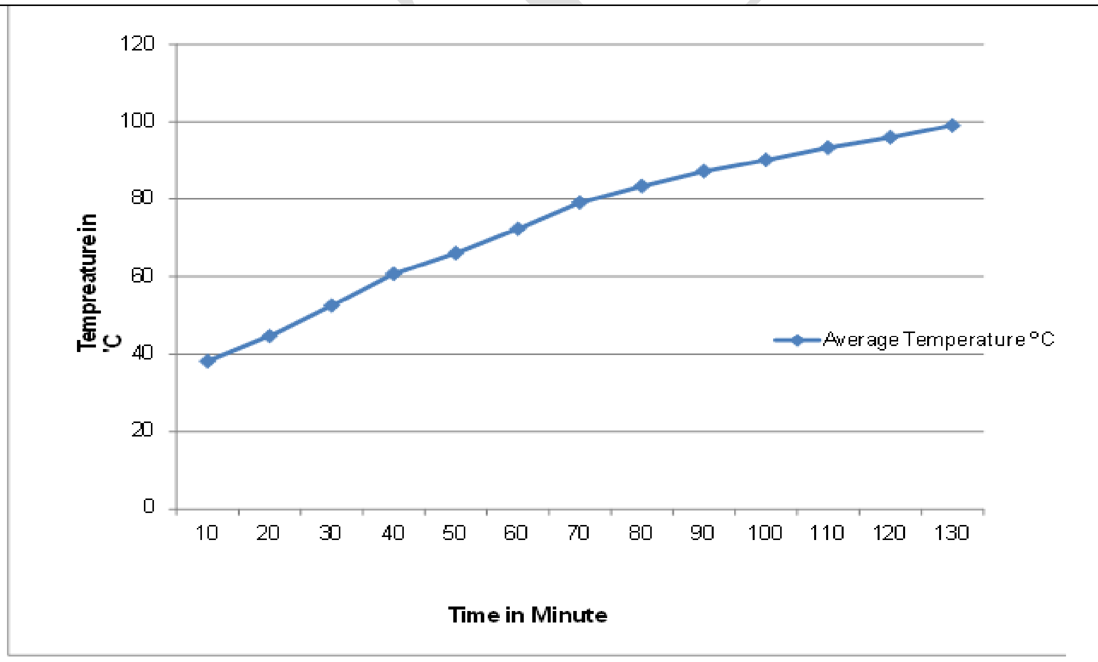

Fig. 9 Increase in temperature inside the developed curing chamber (DCCA) with respect to time

Performance of DCCA

DCCA performance was checked by placing 15cm compression test cube samples made from the three different design mixes as shown in table 3. For each mix six samples were casted and three samples were kept in hot air in laboratory oven and three were kept in DCCA at the same time. The temperature was set to 60˚C for both DCCA and oven. The samples were cured up to 48hrs duration. The samples were taken out at the same time from DCCA and oven and kept in the room temperature until the date of testing. The samples were tested at third day in compression testing machine by applying uniform increasing load. The efficiency of developed curing chamber which was found more than 98% is depicted in table 4.

Table 3. Details of different mixes tried for cross check of curing chamber

Mix	Fly Ash (Kg) & type	Coarse aggregate (Kg)			Sand (Kg)	Alkaline solution	
		20mm - 10mm	10mm-6.75mm	06mm down		Chemical Activators(1 + 2)	Water (Lit.)
GC 1	9.00 R3	-	-	30.0	15.0	2.16 Kg.	2.70
GC 2	9.00 R3	12.0	18.0	-	15.0	1.90 Kg.	2.55
GC 3	18.0 F2	12.0	18.0	-	6.0	3.15 Kg.	4.20
Curing at 60˚C for 48 hrs							

Table 4:- Tabulation of data for Compressive strength testing of Geopolymer concrete cubes manufactured from 03 different design mix & cured at constant temperature 60º C for 48hrs in oven & curing chamber for determining the efficiency of developed curing chamber.

S.No.	Design Mix	Compressive Strength (MPa)		Efficiency over oven [B/A] X 100%
		Average strength from oven [A] (MPa)	Average strength from curing chamber [B] (MPa)	
1.	GC 1	35.94	35.42	98.55 %
2	GC 2	50.31	49.43	98.25 %
3	GC 3	23.67	23.87	100.84 %

Specifications and cost of DCCA

The specifications of material and cost analysis for manufacturing of the DCCA of size 360cm X 150cm X 75cm are shown in table 5.

Table 5. Specifications and costing of DCCA

No.	Material and equipments	Specifications	Qty	Unit	Rate per unit (Rs)	Amount (Rs)
1	Plywood (1)	12mm thick good quality	17.50	m^2	1000/-	17500.00
2	Plywood (2)	08mm thick good quality	17.50	m^2	835/-	14613.00
3	Fiberglass wool blanket	25mm thick (Reaction to fire Euro class A1)	24.0	m^2	300/-	7200.00
4	Iron Pipe (1)	2inch X 1inch (Rectangular)	24.00	M	225/-	5400.00
5	Iron Pipe (2)	1inch X 1inch (Square)	12.00	M	135/-	1620.00
6	Aluminum angle	1 inch X 1inch	11.0	M	56/-	616.00
7	Roller guides	2 inch length	06	No	90/-	540.00
8	G. I. Sheet (1)	20gauge (Reflective & non-corrosive)	54	M	170/-	9180.00
9	G.I. Sheet (2)	20gauge (Powder coated)	54	M	220/-	11880.00
10	Steel Handle	Normal size	04	No	50/-	200.00
11	Asbestos Sheet	6mm thick , 2 feet X 1 feet (two layers)	04	No	200/-	800.00
12	Industrial Heater	18” length, 1000watt, 220V.	04	No	850/-	3400.00
13	Blower with 1500W regulator	15”Φ,1400 rpm, 260Watt	01	No	2800/-	2800.00
14	Electrical Cabinet (metallic) with Temperature display containing complete Heat Control System.	151/2 inch X 11 1/2 inch Relay (1) – 2 no - 220Volt, 36 Amp Relay (2) – 4no - 12Volt, 07Amp [Designed from market]	01	No	20000/-	20000.00
15	Temperature sensor	05Volt, DC (Range -30˚C. to 150 ˚C)	04	No	280/-	1120.00
16	Humidity sensor	05Volt, DC (Range 10%. to 90%)	02	No	1850/-	3700.00
17	Electrical Cabinet (metallic) with Temperature and Humidity display containing complete Data Logging System	09 inch X 7 1/2 inch [Designed from market]	01	No	14000/-	14000.00
18	Cable	2.5 square .mm , 03 core	08	M	65/-	520.00
19	Teflon wire	1.5mm thickness	10	M	60/-	600.00
20	Other					3000.00

	miscellaneous	Lump sum	
21	Labour Charges	Lump sum	15000.00
		Total Rs	133689.00
(Rupees one lakh & thirty five thousand only)		**Total Amount (Rs)**	**135000.00**

Note: - Costing sheet prepared as per current market rates.

CONCLUSION

It is evident from the literature that many countries are producing precast items from geopolymer concrete & these items are in public use there. In India very little progress is made in this field. For promoting the application of geopolymer concrete in precast industry proper study of curing process of geopolymer concrete is urgently needed. This can be carried out by DCCA. The DCCA is a alternate arrangement made for heat curing of large size geopolymer concrete test specimen in laboratory. It is found quite economical as compared to the cost of oven with such a huge volume available for keeping samples. This chamber prepared from good quality material is durable & its maintenance cost is also very less.

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