Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Flexural Strength Study on Geopolymer Concrete Beams Exposed to Elevated Temperature

A PROJECT REPORT

submitted by

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Reg No: IGW24CESC01

to

The APJ Abdul Kalam Technological University

in partial fulfilment of the requirements for the award of the Degree

of

MASTER OF TECHNOLOGY

In

STRUCTURAL ENGINEERING AND CONSTRUCTION MANAGEMENT

(CIVIL ENGINEERING)

DEPARTMENT OF CIVIL ENGINEERING INDIRA GANDHI INSTITUTE OF ENGINEERING &

TECHNOLOGY, KOTHAMANGALAM

APRIL 2026

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

DECLARATION

I undersigned hereby declare that the project report "Flexural Strength study on Geopolymer concrete Beams exposed to elevated Temperature", submitted for partial fulfilment of the requirements for the award degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a Bonafide work done by me under supervision of Asst Prof. Geethika G Pillai. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Place: Kothamangalam

AFSA KASSIM

Date: 05 /04/2026

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

DEPARTMENT OF CIVIL ENGINEERING

INDIRA GANDHI INSTITUTE OF ENGINEERING AND TECHNOLOGY, KOTHAMANGALAM

CERTIFICATE

This is to certify that the report entitled, **"FLEXURAL STRENGTH STUDY ON GEOPOLYMER CONCRETE BEAMS EXPOSED TO ELEVATED TEMPERATURE"** submitted by **AFSA KASSIM (IGW24CESC01)** to the APJ Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Structural Engineering and Construction Management (Civil Engineering) is a Bonafide record of the project work carried out by her under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

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ACKNOWLEDGEMENT

First, I would like to thank the almighty for the divine grace bestowed on me to complete this Project.

I Express my heartful thanks to Dr. S Senthilkumar, Principal, Indira Gandhi Institute of Engineering and Technology for granting me the permission to do the project and also I express my sincere gratitude to Asst Prof. Geethika G Pillai, Department of Civil Engineering, Indira Gandhi Institute of Engineering and Technology, Kothamangalam for her timely guidance and support for taking up this project work and Asst Prof. Geethika G Pillai, Head of Civil Engineering Department, Indira Gandhi Institute of Engineering and Technology, Kothamangalam for their cooperation and constant encouragement. The help and support rendered by all the staff, teachers and students of M.Tech section of Civil Engineering Department of Indira Gandhi Engineering and Technology was also valuable in making this report.

AFSA KASSIM

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ABSTRACT

The development of fly ash-based geopolymer concrete is in response for the need of a 'greener' concrete in order to reduce the carbon dioxide emission from the cement production. Geopolymer concrete is manufactured from predominantly silica and alumina containing source material. It offers a significant opportunity to materialise 'green' concrete as it is possible to utilise an industrial by-product such as fly ash, to totally replace the use of ordinary Portland cement. The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates, and other un-reacted materials together to form the geopolymer concrete. Geopolymer concrete shows better resistance to chemical condition and durability in the use of aggressive environment were the durability of ordinary Portland cement is of concern. The bond characteristics of reinforcing bar in geopolymer concrete have been researched and determined to be comparable or superior to normal Portland cement concrete. The durability properties of geopolymer concrete and its better temperature resistance nature suggests its use in structural application. In the study, the flexural strength of geopolymer concrete after exposed to elevated temperature was accessed. The effect of cover in load bearing capacity after heat treatment and the loss in the residual strength, the colour variation, the crack formation after exposed to elevated temperature were also accessed. In the work Geopolymer beam specimens were cast providing with different cover (20mm,30mm and 40mm) and are exposed to an elevated temperature of 200°C, 400°C, 600°C and 800°C. Two point loading was carried out to study the flexural properties.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete usage around the world is second only to water. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilise this by-product of burning coal, as a substitute for OPC to manufacture concrete.

The amount of carbon dioxide released during the manufacturing process of OPC is approximately one ton for every ton of OPC produced. Globally, the OPC production contributes about 7% of the world's carbon dioxide (Sarkar, 2008). Since it is important to control warming by reducing the carbon dioxide emissions, it is appropriate to search for alternative low emission binding agents for concrete. The manufacturing of OPC requires the burning of large quantities of fuel, and decomposition of limestone. Both, burning of fuel and decomposition of limestone, result in significant emissions of carbon dioxide. Cement plants are reported to emit up to 1.5 billion tons of carbon di oxide into the atmosphere annually (Daniel L Y Kong, Jay G. Sanjayan 2008). Hence, environmental preservation has become a driving force behind the search for new sustainable and environmentally friendly composites to replace conventional concrete produced from OPC.

In 1978, Davidovits introduced the word 'geopolymer' to describe an alternative cementitious material which has ceramic-like properties. As opposed to OPC, the manufacture of fly ash-based geopolymer does not consume high levels of energy, as fly ash is already an industrial by-product. This geopolymer technology has the potential to reduce emissions by 80% because high temperature calcining is not required. It also exhibits ceramic-like properties with superior resistance to fire at elevated temperatures (Sanjayan 2008). In the geopolymer concrete cement was fully replaced with low calcium class F fly ash. A solution made of sodium silicate and

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sodium hydroxide solution was used as the activator. The main constituent of flyash is aluminium oxides and silica.

The primary difference between geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminium oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates, and other un-reacted materials together to form the geopolymer concrete. As in the case of Portland cement concrete, the coarse and fine aggregates occupy about 75 to 80% of the mass of geopolymer concrete. The influence of aggregates, such as grading, angularity and strength, are considered to be the same as in the case of Portland cement concrete (Lloyd and Rangan, 2009).

In geopolymers, the polymerisation process involves a chemical reaction under highly alkaline conditions on Al-Si minerals, yielding polymeric Si-O-Al-O bonds. The chemical composition of geopolymers is similar to zeolites, but shows an amorphous microstructure. The mechanism of geopolymerisation may consist of dissolution, transportation or orientation, and polycondensation and takes place through an exothermic process (Rangan 2005). (i) Dissolution of Si and Al from the solid alumino-silicate materials in the strongly alkaline aqueous solution, (ii) Formation of oligomers species (geopolymeric precursors) consisting of polymeric bonds of Si-O-Si and/or Si-O-Al type, (iii) Polycondensation of the oligomers to form a three-dimensional alumino-silicate framework (Geopolymeric framework) and (iv) bonding of the unreacted solid particles and filler materials into the geopolymeric framework and hardening of the whole system into a final solid polymeric structure. According to Davidovits these structures can be of three types: poly(sialate) (–Si–O–Al–O–), poly(sialate–siloxo) (Si–O–Al–O–Si–O) and poly(sialate–disiloxo) (Si–O–Al–O–Si–O–Si–O) and the formation of these three forms of geopolymer depending upon the Si/Al ratio of geopolymer. The exothermic Geopolymerisation reaction takes place under atmospheric pressure at temperatures around 100°C. The strength of geopolymer depends on the nature of source materials. Geopolymers made from calcined source materials, such as metakaolin (calcined kaolin), fly ash, slag etc., yield higher compressive strength when compared to those synthesised from non-calcined materials, such as kaolin clay. The source material used for geopolymerisation can be a single material or a combination of several types of materials. A combination of sodium or potassium. silicate and sodium or potassium hydroxide has been widely used as the alkaline activator.

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1.2 LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE

In this work, low-calcium (ASTM Class F) fly ash-based geopolymer is used as the binder, instead of Portland cement to produce concrete. The main constituents includes fly ash and alkaline liquid (a combination of sodium silicate and sodium hydroxide solution) . The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete with the presence of admixtures. The geopolymer concrete is made using the usual concrete technology methods. The silicon and the aluminium in the low-calcium (ASTM Class F) fly ash react with an alkaline liquid that is a combination of sodium silicate and sodium hydroxide solutions to form the geopolymer paste that binds the aggregates.

1.3 GEOPOLYMER CONCRETE PROPERTIES

Geopolymer concrete shows better resistance to chemical attack and better durability in the use of aggressive environment were the durability of ordinary Portland cement is of concern. Geopolymer concrete is also applicable in marine conditions, acidic and sulphate rich environments. Similarly in highly acidic environment, geopolymer concrete has shown to have superior acid resistance and may be suitable for applications such as mining, some manufacturing industries, and sewer systems. The deterioration rate of plain geopolymer concrete specimens when exposed to aggressive environment was low and the specimens were stable when compared to plain ordinary Portland cement concrete (Kannipiran.*et al* , 2012). The bond characteristics of reinforcing bar in geopolymer concrete have been investigated and determined to be comparable or superior to normal portland cement concrete Geopolymer concrete shows high bond strength than ordinary Portland cement (Sarkar, 2010). Geopolymer concrete shows a gain in the residual strength after exposed to elevates temperature about 800°C (Raghu, 2011). Its high strength gain at elevated temperature reveals its application in precast structural members and in pre stressed members. The durability properties of geopolymer concrete and its better temperature resistance nature suggests its use in structural application (Hardjitho, 2005).

1.4 GEOPOLYMER CONCRETE UNDER ELEVATED TEMPERATURE

The compressive strength of normal concrete will decrease with increase in temperature. The bond strength also gets reduce due to the high temperature. In the case of ordinary Portland cement when exposed to elevated temperature, the rebars are more sensitive to high

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temperature than concrete, it will affect the bond between the rebar and the concrete and it degrades (Xiao *et al*, 2003). The bond characteristics of geopolymer concrete with reinforcing bars is superior to normal ordinary Portland cement, geopolymer concrete can be adopted for structural members (sarkar, 2010). The durability properties of geopolymer concrete and its better temperature resistance nature suggests its use in structural application. The previous studies on geopolymer concrete beam reveals that the load carrying capacity of GPC was more than that of conventional Ordinary Portland Cement concrete (Dattatraya *et al*, 2011). The shear behaviour of reinforced geopolymer concrete beams shows similar to that of reinforced Portland cement concrete. The studies shows that the strength and behaviour of beam with fly ash based geopolymer reinforced concrete was comparable to that of ordinary Portland concrete and they shows better strength properties after exposed to elevated temperature.

1.5 ORGANISATION OF THESIS WORK.

The thesis is presented in five chapters

Chapter 1 includes an introduction to geopolymer concrete and its environmental influences, its properties and its behaviour under elevated temperature.

Chapter 2 gives the review of literature of the work related to presented study. The objective and scope of the present study is also presented.

Chapter 3 explains the details of preliminary investigation conducted. The results were analysed and discussed.

Chapter 4 includes the details of present experimental investigation conducted. The results obtained were discussed and analysed.

Chapter 5 summarizes the conclusions drawn from the present investigation.

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CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Geopolymer concrete offers a solution for the need of 'greener' construction material in the midst of the environmental concern on the production of ordinary Portland cement (OPC). Fly ash based Geopolymer are one branch in the Geopolymer family and these have attracted more attention since the 1990's. In the last some years, a significant progress has been made in the development of fly ash-based geopolymer concrete, understanding its properties, and application of geopolymer concrete in Reinforced structural members. This chapter discusses about the studies carried about the formation of geopolymer, mechanical and thermal properties of geopolymer concrete.

2.2 LITERATURE REVIEW

Davidiovits (1991) introduced development of new materials such as Geopolymer. The new state of art material was designed with the help of Geopolymerisation reaction. These materials are polycondensed inorganic compounds formed around 100˚C. He illustrated the Geopolymerisation reaction as chemical reaction of alumino-silicate oxides with alkali poly silicates yielding polymerised Si-O-Al bonds. The resulting compound is amorphous to semi crystalline three dimensional silico-aluminate structure of polysialate type (-Si-O-Al-O-). The polysialate siloxo type (-Si-O-Al-O-Si-O-) and the polysialate di sioloxo (-Si-O-Al-O-Si-O-Si-O-) group. He also stated the field of application of Geopolymer such as in the automobile and aerospace industries, non-ferrous foundries and metallurgy industries, civil engineering plastic etc.

Lloyd and Rangan (2010) conducted studies on fly ash-based geopolymer concrete to identify the effects of salient factors that influence the properties of the geopolymer concrete and proposed a simple method for the design of geopolymer concrete mixtures. Test data of various short-term and long-term properties of the geopolymer concrete and the results of the tests conducted on large-scale reinforced geopolymer concrete members show that geopolymer concrete is well-suited to manufacture precast concrete products that can be used in infrastructure developments.

Sarkar et al (2010) studied the effects of the geopolymer binder on the behaviour of concrete. In their study, the effect of the geopolymer binder on fracture mechanics of concrete has been

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investigated by three point bending test of RILEM TC 50 – FMC type notched beam specimens. The peak load was generally higher in the GPC specimens than the OPC concrete specimens of similar compressive strength. The failure modes of the GPC specimens were found to be more brittle with relatively smooth fracture plane as compared to the OPC concrete specimens. Fracture energy calculated by the work of fracture method was found to be similar in both types of concrete. The critical stress intensity factor of GPC was found to be higher than that of OPC concrete. The different fracture behaviour of GPC is mainly because of its higher tensile strength and bond strength than OPC concrete of the same compressive strength.

Daniel and Sanjayan (2008) studied on geopolymers and geopolymer aggregate composites made with class F fly ash. Samples were heated up to 800°C to evaluate strength loss due to thermal damage. The geopolymers exhibited strength increases of about 53% after temperature exposure. Geopolymer aggregate composites with identical geopolymer binder formulations decreased in strength by up to 65% after the same exposure. Test data from dilatometry measurements of geopolymers and aggregates provides an explanation for this behavior. The tests show that the aggregates steadily expanded with temperature, reaching about 1.5–2.5% expansion at 800°C. Correspondingly, the geopolymer matrix undergoes contraction of about 1% between 200°C and 300 °C and a further 0.6% between 700 °C and 800 °C. This apparent incompatibility is concluded to be the cause of the observed strength loss.

Bakharev (2006) This article reports a study of thermal stability of properties upon firing at 800–1200 °C of geopolymer materials prepared using class F fly ash and Na and K alkaline activators. Compressive strength and shrinkage measurements, XRD, SEM (BEI), TGA and MIP were utilised in these studies. The materials were prepared at water/binder ratios in a range of 0.09–0.35, using compaction pressures up to 10 MPa and curing temperatures 80 and 100 °C. Thermal stability of the studied geopolymer materials was rather low. In the samples prepared using sodium-containing activators rapid deterioration of strength at 800 °C was observed, which was connected to a dramatic increase of the average pore size. In materials prepared using fly ash and potassium silicate compressive strength was significantly increased on heating, deterioration of strength started at 1000 °C. After firing these materials remained amorphous with reduced average pore size and significantly increased compressive strength. Compaction at 1–10 MPa reduced shrinkage on firing in all materials. Geopolymer materials prepared using class F fly ash and alkaline activators showed high shrinkage as well as large changes in compressive strength with increasing fired temperature in the range of 800–1200°C.

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Dattatreya et al (2011) conducted studies carried out on the behaviour of room temperature cured reinforced GPC flexural members. A total of eighteen beams were tested in flexure. Three conventional concrete mixes and six GPC mixes of target strength ranging from 17 to 63 MPa and having varying combinations of fly ash and slag in the binder phase were considered. All the specimens were tested under two-point static loading. His studies demonstrated that the load carrying capacity of most of the GPC beams was in most cases marginally more than that of the corresponding conventional OPCC beams. The deflections at different stages including service load and peak load stage were higher for GPC beams. The ductility factor was comparable to that of OPCC beams. The studies showed that the conventional RC theory could be used for reinforced GPCC flexural beams for the computation of moment capacity, deflection, and crack width within reasonable limits.

Pan and Sanjayan (2010) reported stress versus strain curves of geopolymer tested while the specimens were kept at elevated temperatures, with the aim to study the fire resistance of geopolymer. Tests were performed at temperatures from 23 to 680 °C and after cooling. Hot strengths of geopolymer increased when the temperature increased from 290 to 520 °C, reaching the highest strength at 520°C, which is almost double that of its initial strength at room temperature. However, glass transition behaviour was observed to occur between 520 and 575 °C, which was characterised by abrupt loss of stiffness and significant viscoelastic behaviour. The glass transition temperature is determined to be 560 °C. Further, the strength reductions occurred during cooling to room temperature. This is attributed to the damage due to brittle nature of the material making it difficult to accommodate thermal strain differentials during cooling phase.

Xudong et al (2004) conducted study on six specimens having different cover thickness(10-30mm) to investigate the properties of cover on reinforced concrete flexural members exposed to fire. The specimens were heated on their bottom and the two lateral surfaces. From the test results he obtained that the bottom cover has significant influence on the specimens ultimate load bearing capacity but the extent of the influence will decrease with increase in the concrete cover thickness. Thus it is excessively improper to increase the bottom concrete cover to improve the specimen fire resistance. The lateral cover has a less beneficial effect on the specimens fire compared to the bottom cover. A concept on an equivalent concrete cover was proposed to reinforced concrete flexural members exposed to high temperature.

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Kannapiran (2012) The deterioration rate of plain geopolymer concrete specimens when exposed to aggressive environment was low and the specimens were stable when compared to plain ordinary Portland cement concrete. Attention was paid upon the durability and flexural behaviour of reinforced geopolymer concrete beams, manufactured using low calcium class F Indian fly ash, exposed to 10% concentration of sulfuric acid attack and chloride attack for a period of 180 days. 100mm × 100mm cross-section and 500mm long beams with 1% tensile reinforcement were cast. Concentration of sodium hydroxide was taken as 8M for a cube compressive strength of 30N/mm2. Test results showed very little surface erosion, 3.26% and 1% weight loss, 10.64% and 4.47% decrease in ultimate moment for specimens exposed to chloride and acid attacks, respectively. This has revealed better performance of reinforced geopolymer concrete beams subjected to aggressive situation and is in line with earlier studies on plain geopolymer concretes. The erosion of surface of specimens had not led to corrosion of steel bars which underlines the geopolymer concrete as an an impermeable one.

Kalyan et al (2011) conducted studies on the performance of fly ash based geopolymer pastes at elevated temperature. Three series of geopolymer pastes differing in Na_2O content (8.5%, 10% and 11.5%) were manufactured by activating low calcium fly ash with a mixture of sodium hydroxide and sodium silicate solution. The paste specimens were subjected to temperatures as high as 900°C and the behaviour at elevated temperatures were investigated on the basis of physical appearance, weight losses, residual strength, shrinkage measurements and absorptivity tests at different temperatures. Specimens which were initially grey turned reddish accompanied by appearance of small cracks as the temperature increased to 900°C. Loss of weight was more inspecimens manufactured with highest Na_2O content. Geopolymer paste specimen containing minimum Na_2O performed better than those with higher Na_2O content in terms of residual compressive strength.

Irshad (2011) conducted studies on geopolymer concrete and developed a mix proportion for high strength geopolymer concrete by optimising several parameters of the geopolymer concrete. Based on his study he optimised the parameters for the geopolymer mix. The optimum curing temperature was found to be 100˚C and curing period was 24 hours. The molarity of NaOH solution used was 10M. The ratio of alkaline liquid to flyash ratio was 0.55. Sodium silicate to sodium hydroxide ratio was 2.5. The ratio of fine aggregate to total aggregate was 0.3. Water to geopolymer solids ratio was adopted as 2.5. Based on these several parameters the he compared the geopolymer concrete properties to that of ordinary Portland

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cement concrete. He also studied on the interface shear properties of the geopolymer specimens.

Raghu (2012) conducted studies of residual strength of ordinary Portland concrete and geopolymer concrete after elevated temperature exposure. The specimens were treated upto a temperature of 800°C. The effect of rapid cooling on residual strength was studies by changing the cooling conditions. The weight loss, crack formation and colour change of both geopolymer and ordinary Portland concrete after exposed to elevated temperature was assessed and revealed that the compressive strength, flexural strength, split tensile strength, modulus of elasticity reduced for both GP and OP and concrete up to 600˚C. After 800˚C exposure these properties showed an increase in GP concrete while it continued decreasing for OP concrete. He also conducted a study on the microstructure of geopolymer concrete.

SUMMARY

The ideas regarding the design of geopolymer mixes were obtained through literature review. Geopolymer concrete shows good thermal resistance property than OPC and also shows better flexural strength than ordinary Portland concrete due to its high bond strength. Its good thermal resisting capacity reveals its application in environments subjected to high temperature. The study on literature helps to get good ideas regarding the behaviour of geopolymer concrete under elevated temperature. Based on literature review objectives of the study and methodology of the work were finalized.

2.3 OBJECTIVE AND SCOPE OF THE STUDY

2.3.1 Objective of the study

The main objective of the study includes

1. To study the flexural strength properties of Geopolymer Concrete beams exposed to different elevated temperature.
2. To identify the effect of cover on load bearing capacity of geopolymer concrete beam after heat treatment.

2.3.2 Scope of study

Experimental investigations are to be done on geopolymer concrete beams after exposed to elevated temperature for studying the ultimate load, moment resisting capacity and development of cracks. Specimens with different cover are to be prepared for conducting experiment and study the effect of cover on ultimate load moment resistance and deformation.

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2.4 METHODOLOGY FOR THE THESIS WORK

- The material properties of all the constituent materials used for the study was obtained from the experiments conducted in the laboratory.
- Casting of geopolymer beams having required dimension.
- Curing of the specimens was done at 100°C in hot air oven.
- Temperature exposure of specimens to about 200˚C, 400˚C, 600˚C and 800˚C using a muffle furnace.
- Testing of the specimens for flexural strength by two point loading test.
- Analysis and discussion of the results to arrive at the conclusions.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

3.1 GENERAL

This chapter presents the details of tests conducted in the laboratory to evaluate the required properties of the individual materials. The mechanical properties of Geopolymer concrete depends on the materials used. So the workability studies in terms of compacting factor was conducted. The cube compressive strength of the mixes was also determined.

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3.2 PROPERTIES OF THE MATERIALS USED

The materials used for making the geopolymer concrete were alkaline solution, river sand, coarse aggregate, water and super plasticizer.

3.2.1 Fly ash

Flyash used for the work was more fine low calcium fly ash that conforms to ASTM Class-F having a particle size of 12 micron which obtained from Hi-Tech Fly ash Pvt Ltd, Tuticorin, Tamil Nadu. The specific gravity of flyash was determined by the laboratory test and it is 1.88. Table 3.1 shows the chemical composition of flyash. The main constituents of fly ash are SiO_2 and Al_2O_3.

Table 3.1: The chemical composition of fly ash

Chemical components	% By Mass
SiO_2	60.28
Al_2O_3	31.76
Na_2O	2.1
P_2O_5	1.42
SO_3	0.97
Fe_2O_3	0.89
CaO	0.72
K_2O	0.69
TiO_2	0.64
MgO	0.52

3.2.2 Fine Aggregate

Locally available good quality river sand was used as fine aggregate. Laboratory tests were conducted on fine aggregates to determine the different physical properties as per IS 383 (Part III)-1970. Table.3.2 shows the properties of fine aggregate. The sieve analysis details of fine aggregate are presented in Table 3.4 which conforms to IS 383:1970 specification Zone II. The gradation cure of fine aggregate is shown in Fig 3.1.

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Table. 3.2: Properties of Fine Aggregate

Particulars	Values
fineness modulus	2.38
Specific gravity	2.58
gradation	Zone II

Table 3.3: Sieve analysis details of fine aggregate

Sieve Size (mm)	Mass Retained (kg)	Cumulative Mass retained (kg)	% mass Retained	Cumulative % mass retained
40	0	0	0	0
20	0.269	0.269	8.97	8.97
10	2.409	2.678	80.33	89.3
4.75	0.321	2.999	10.7	100
2.36	0	2.999	0	100
1.18	0	2.999	0	100
0.60	0	2.999	0	100
0.30	0	2.999	0	100
0.15	0	2.999	0	100

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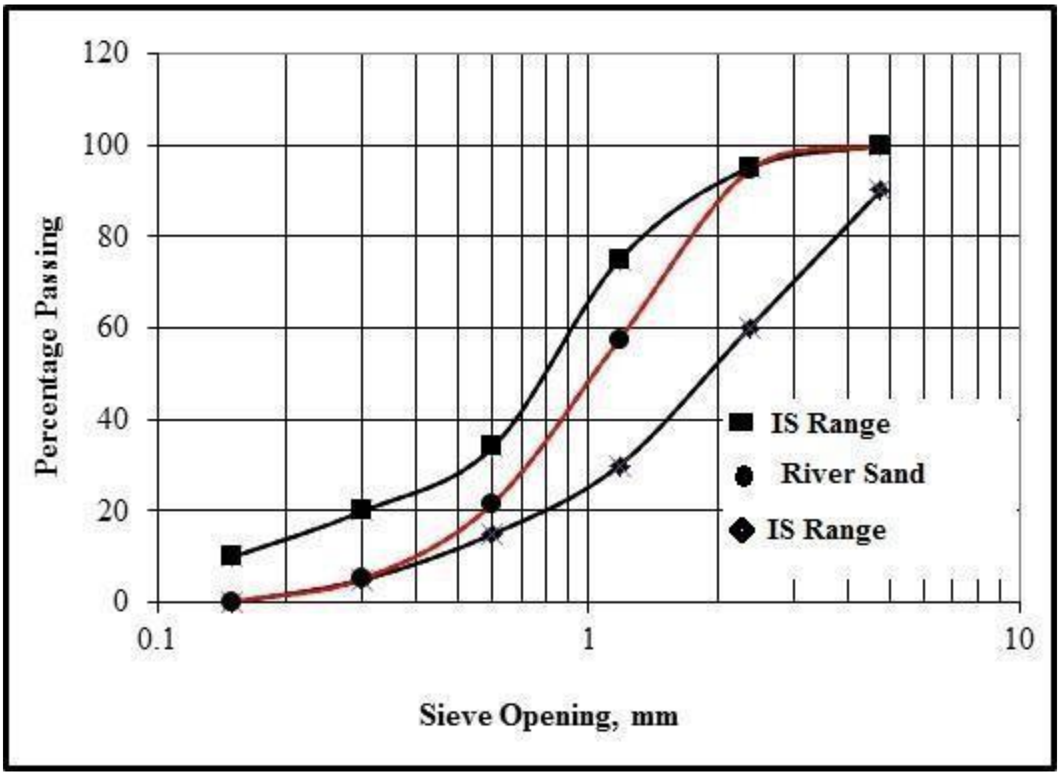

Fig. 3.1: Gradation curve of fine aggregate

3.2.3 Coarse aggregate

The size of aggregate between 20mm and 4.75mm is considered as coarse aggregate. Laboratory tests as per IS 383 (Part III)-1970 were conducted on coarse aggregates to determine the different physical properties. Fineness modulus is the index of coarseness or fineness of material. It is an empirical factor obtained by adding cumulative percentage of aggregate retained on each of the standard sieves and dividing this by 100. This method is useful for finding the particle size distribution of aggregates. The properties and sieve analysis details of coarse aggregate are shown in Table 3.4 and Table 3.5 respectively.

Table 3.4 Properties of coarse aggregate

SI No.	Particulars	Values
1	Specific gravity	2.7
2	Fineness modulus	6.98

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Table 3.5: Sieve analysis details of Coarse aggregate

Sieve size (mm)	Mass retained (g)	Cumulative mass retained (g)	Cumulative % mass retained	Cumulative % finer	IS Range for zone II
4.75	0	0	0	100	90-100
2.36	11	11	1.1	98.8	75-100
1.18	207	215	21.5	78.2	55-90
0.06	363	281	28.1	41.9	35-59
0.30	284	865	86.5	13.5	8-30
0.15	125	990	99.0	1	0-10

3.2.4 Alkaline Liquid

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution was purchased from Minar Chemicals Edayar, Ernakulam. The specific gravity of sodium silicate solution was found at laboratory as 1.53. The details of chemical composition are given in Table 3.6 which was obtained from the manufacturer itself. Silica-to-Sodium oxide ratio by mass should be almost equal to 2 for better results. The sodium hydroxide (NaOH) in pellets form with 97%-98% purity was purchased from a local supplier. The NaOH solution was prepared by dissolving the solids in water. The pH value of sodium silicate solution was obtained as 14 which shows the high alkaline character. Alkaline liquid was prepared by mixing sodium silicate and sodium hydroxide solutions together at 24 hours prior to use. Table 3.6 shows the details of chemical composition of sodium Silicate.

Table. 3.6: Chemical Composition of Sodium Silicate.

Chemical Composition	% by mass
Silica	34.64
Sodium Oxide	16.27
Water	49.09

3.2.5 Super plasticizer

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The super plasticizer used was Ceraplast-300. Ceraplast-300 is a high performance new generation super plasticizer cum retarding admixture which lowers the surface tension of water and makes cement particles hydrophilic, resulting in excellent dispersion as well as controls the setting of concrete, depending on dosage. This increases the workability of concrete drastically and also facilitates excellent retention of workability. The workability offered at a lower water-cement ratio eliminates chances of bleeding and increased workability retention which allows increased travel time. Reduced water-cement ratio reduces capillary porosity and improves water tightness. The use of superplasticizer helps in good compaction, resulting in production of dense, impermeable concrete. The properties of Ceraplast-300 are listed in table 3.7.

Table 3.7: Details of Ceraplast 300

Supply form	Liquid
Colour	Brown
Specific gravity	1.24
Solids content	40%
Recommended dosage	0.3% to 1.2% by weight of cement

Advantages of super plasticizer Ceraplast-300 (Cement Concrete) are:

- Reduction in water-cement ratio of the order of 20-25%
- Flowing, pumpable concrete
- Excellent workability and workability retention even in extreme temperatures
- High quality concrete of improved durability, reduces heat of hydration even with very high strength cements
- Compatible with mineral admixtures
- Waterproofing effect by drastic reduction in permeability of concrete

3.2.6 Water

Very small quantity of water used for making sodium hydroxide solution.

3.3 MIX PROPORTION

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The silicon and aluminium oxides in the low calcium fly ash is the main constituents of geopolymer binder and it reacts with the alkaline liquid to form the geopolymer paste which binds the loose aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete. The mix proportion of geopolymer concrete was arrived on volume basis (Benny Joseph, 2012). The total volume of Geopolymer concrete was constituted by volumes of coarse aggregate, fine aggregate, fly ash, alkaline liquid and water needed in geopolymer concrete. The geopolymer is considered as a two part material. The first part constitutes volume of coarse aggregate and fine aggregate. The second part contains the volume of fly ash, alkaline liquid and water considered. The volume of entrapped air should also be considered and it was assumed as 2 %. The final mix was fixed from the optimum value of cube compressive strength to find out the volume of aggregates and binders.

For designing low calcium fly ash based Geopolymer concrete mixtures, a single parameter called ‘Water to Geopolymer solids ratio’ by mass was devised. In this parameter, the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of water used in the making of the sodium hydroxide solution, and the mass of extra water present in the mixture. The mass of Geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids used to make the sodium hydroxide solution, and the mass of solids in the sodium silicate solution (i.e. the mass of silica and sodium oxide).

- For arriving the mix proportion of Geopolymer concrete the optimum values of the important parameters were finalized based on a previous research work (Irshad 2011) as shown in table 3.8

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Table 3.8 Optimum Values of Parameters for Geopolymer Mix Design (Irshad 2011)

Parameter	**Value**
Curing temperature	100°C
Curing period	24 hrs
Molarity of Sodium Hydroxide	10 M
Ratio of alkaline liquid to fly ash	0.55
Ratio of Sodium Silicate solution to Sodium Hydroxide solution	2.5
Ratio of fine aggregate to total aggregate	0.35
Volume of aggregates	70 %
Volume of binders	28 %
Volume of air voids	2 %
Water to Geopolymer solid ratio	0.25

Based on these optimum values the mix proportion was obtained for Geopolymer concrete which is shown in table 3.9.

Table 3.9 Mix Proportion Geo polymer Concrete (Irshad 2011)

Material		**Weight (kg/m^3)**
Coarse aggregate	20 mm	481.596
	12 mm	601.995
	6 mm	120.4
Sand		648.35
Fly ash		309.85
NaOH solution (10 M)		48.69
Sodium silicate		121.72
Super plasticizer		6.197
Extra water		3.80

To study the compressive strength of geopolymer mix, initially cubes were casted. The compaction factor and compressive strength obtained were compared with the results of Irshad

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(2011) and Reghu (2012). Table 3.10 and 3.11 shows the values of compaction and compressive strength.

Table 3.10 Compaction Factor of the Mixes

Thesis work	Compaction factor
Irshad (2011)	0.91
Reghu (2012)	0.89
Current Work	0.88

Table 3.11 Average Compressive Strength of the Mixes

Thesis work	Compressive strength (N/mm^2)
Irshad (2011)	56
Reghu (2012)	57
Present work	58

3.4 PREPARATION OF GPC TEST SPECIMENS

Mixing was done in a laboratory type pan mixer. Pan mixers with revolving star of blades were used. While preparation of GPC aggregates, cement and mineral admixtures were mixed in the revolving pan. After the proper mixing of ingredients, superplasticizer was added. The mixing was continued until a uniform mix was obtained. The concrete was then placed into the properly oiled beam moulds. After placing of concrete in moulds proper compaction was given using the needle vibrator. Specimens were demoulded after 24 hours of heat curing using hot air oven.

3.4.1 Test specimens

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For casting beams steel mould having dimensions of 1.1 × 0.2 × 0.15 m was used. The dimensions of mould were mainly based on the space available in the furnace for the heat treatment.

Fig 3.2: Mould for Beam casting

Based on the variation in the cover (20mm, 30mm, and 40 mm), total three sets of beam specimens were casted. Each set includes 5 numbers of beams. The temperature given for curing using hot air oven is 100°C. Each of these specimens was heated to 200°C, 400°C, 600°C and 800°C respectively. Fig 3.2 shows the steel mould used for the casting. Fig 3.3 shows the detailing of reinforcement provided in the GPC beam specimen. In the tension zone 2 number of 10mm diameter bar are provided and in the compression zone 2 number of 8mm diameter bar was provided. Stirrups are of 6mm diameter bar with 80mm spacing.

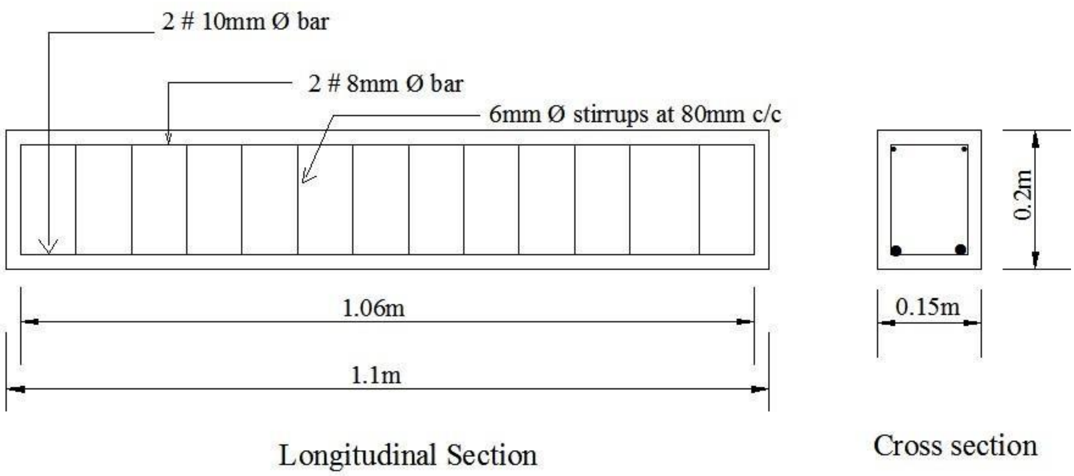

Fig. 3.3: Detailing of Beam specimens

The properties of reinforcement bars used are given in table 3.12.

Table 3.12 Properties of reinforcement bars

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Diameter of bar	Number of bars used	Yield strength (N/mm^2)	Percentage elongation
10mm	2	453	14.40%
8mm	2	419	20.02%
6mm		720	23.33%

The reinforcement on the longitudinal direction comprises of 2 number of 10mm dia bars in the tension zone and 2 number of 8mm dia bar in the compression zone with stirrups of 6mm dia bars at required spacing. While placing in the beam mould cover blocks (20mm, 30mm and 40mm) are provided. Compaction was done using needle vibrator.

3.5 SPECIMEN DESIGNATION

Total fifteen specimens were casted in three sets with different covers. Each set comprises of five beams. Specimens from each mix were allowed to expose different temperature (200°C, 400°C, 600°C and 800°C). Table 3.13 shows the specimen designations given to specimen. Geopolymer concrete was noted as GPC.

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Table 3.13: Details of Specimens

<table>
<tr><th>MIX</th><th>Cover provided</th><th>Temperature</th><th>Beam Designation</th><th>Number</th><th>Total Beam for each Cover</th><th>Total Beams</th></tr>
<tr><td rowspan="5">GPC</td><td rowspan="5">20 mm</td><td>Ambient Temperature</td><td>GPCA 20mm</td><td>1</td><td rowspan="5">5</td><td rowspan="15">15</td></tr>
<tr><td>200 °C</td><td>GPCA 20mm 200°C</td><td>1</td></tr>
<tr><td>400°C</td><td>GPCA 20mm 400°C</td><td>1</td></tr>
<tr><td>600°C</td><td>GPCA 20mm 600°C</td><td>1</td></tr>
<tr><td>800°C</td><td>GPCA 20mm 800°C</td><td>1</td></tr>
<tr><td rowspan="5">GPC</td><td rowspan="5">30 mm</td><td>Ambient Temperature</td><td>GPCA 30mm</td><td>1</td><td rowspan="5">5</td></tr>
<tr><td>200°C</td><td>GPCA 30mm 200°C</td><td>1</td></tr>
<tr><td>400°C</td><td>GPCA 30mm 400°C</td><td>1</td></tr>
<tr><td>600°C</td><td>GPCA 30mm 600°C</td><td>1</td></tr>
<tr><td>800°C</td><td>GPCA 30mm 800°C</td><td>1</td></tr>
<tr><td rowspan="5">GPC</td><td rowspan="5">40 mm</td><td>Ambient Temperature</td><td>GPCA 40mm</td><td>1</td><td rowspan="5">5</td></tr>
<tr><td>200°C</td><td>GPCA 40mm 200°C</td><td>1</td></tr>
<tr><td>400°C</td><td>GPCA 40mm 400°C</td><td>1</td></tr>
<tr><td>600°C</td><td>GPCA 40mm 600°C</td><td>1</td></tr>
<tr><td>800°C</td><td>GPCA 40mm 800°C</td><td>1</td></tr>
</table>

3.6 CASTING AND CURING OF SPECIMENS

Heat curing was given to all the specimens for 24 hours at 100°C using laboratory hot air oven immediately after the casting itself. Fig. 3.4, 3.5, 3.6, 3.7 and 3.8 shows the casting of specimens.

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Fig. 3.4: Geopolymer concrete after mixing

Fig. 3.5: Casting of GPC 20mm beam specimen

Fig. 3.6: Casting of GPC 30mm beam specimen

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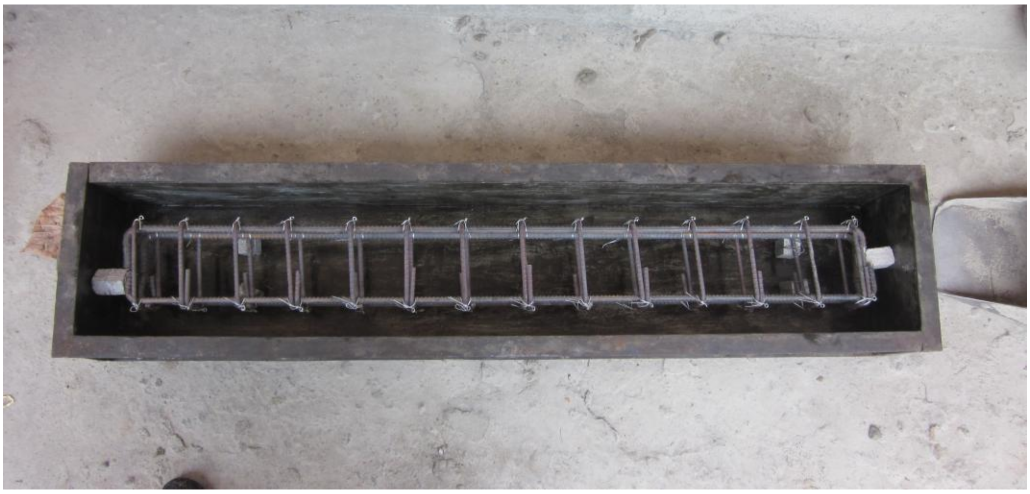

Fig. 3.7: Casting of 40mm beam specimen

Fig. 3.8: After casting of GPC beam specimen

The mould should be oiled properly by using a combinatioin of diluted acetic acid and oil or grease to avoid the sticking of geopolymer matrix in the mould. Within one hour after casting, the specimen including the mould was placed in the hot air oven for 24hrs curing at 100°C, which is the optimum condition. After the curing the specimens were taken for heat treatment using the furnace. Fig. 3.9 shows the specimen placed in the hot air oven for curing and fig. 3.10 shows the cured specimens.

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Fig. 3.9: Casted specimen placed in hot air oven for curing.

Fig. 3.10: Specimens after curing

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3.7 ELEVATED TEMPERATURE TREATMENT OF SPECIMENS

Fig. 3.11: Cured beam placed in the furnace

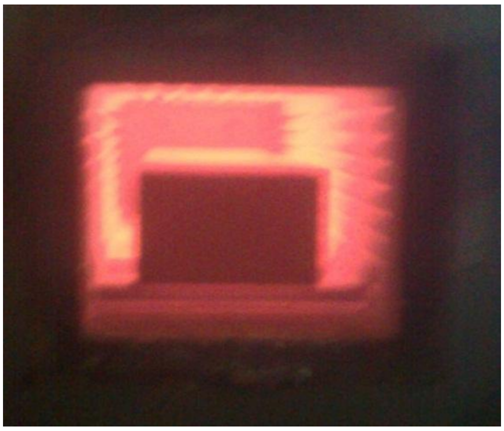

Fig. 3.11 (a)

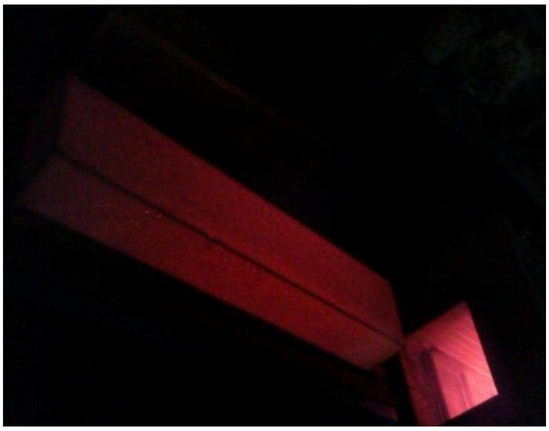

Fig. 3.11 (b)

Fig. 3.11 (c)

Fig. 3.12: Heat treatment of GPC specimens

(a) Placing of specimen inside the furnace at 800°C.
(b) Taking out of specimen from the furnace.
(c) Specimen exposed to 800°C.

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Fig 3.11 and 3.12 shows the process of heating the specimens to elevated temperature. After curing the specimens were exposed to elevated temperature using furnace of internal dimensions 29×29×1400 mm. Exposure temperatures selected was 200˚C, 400˚C, 600˚C, 800˚C respectively for an exposure period of 1 hour by giving an increment of about 8˚C/min to each of them.

3.8 OBSERVATIONS AFTER HEAT TREAMENT

Visible changes in the colour and appearance were observed in beams after the heat treatment. Fig 3.13 shows formation of white precipitation on the surface of the beam after exposed to 200°C.

Fig. 3.13: White precipitation on the surface of heated specimen

The colour variation from light grey to light red was observed in GPC beams after exposed to 800°C. Micro cracks were seen after 600°C heat exposure and the cracks get closed when the beam get cooled. Fig. 3.14 shows the colour variation in the geopolymer specimens after the heat treatment. The specimen became more brittle when the temperature increases.

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Fig. 3.14: Colour variation in the specimens after heat treatment

Fig. 3.15: Cracks formed in the specimens after treated to 600°C

The crack pattern of the beam after heated to 800°C was shown in the figure given below. After the cooling of beam in room temperature, some of the cracks remained but the width get reduced. Fig 3.15 shows the micro cracks formed after exposed to 600°C.

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Fig. 3.16: Cracks formed in the specimen after treated to 800°C

Fig. 3.16 shows the crack formation after exposed to 800°C. The main change noticed after the heat treatment was the increase in the brittleness of the beam. The beams exposed to 800°C showed a brittle nature and no thermal cracks get predominant during the flexure test.

3.9 TESTS ON HARDENED GEOPOLYMER CONCRETE AFTER ELEVATED TEMPERATURE EXPOSURE

3.9.1. Cube Compressive Strength

The compression test was carried out for the Geopolymer concrete specimens. Three cube specimens each of size 150mm×150mm×150mm were tested in a compression testing machine of capacity 200kN, at a loading rate of 14N/mm^{2}per minute. The compressive strength obtained was 58N/mm^2. Details are shown in Fig. 3.17 according to the IS 516:1959 specifications.

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Fig. 3.17: Compressive strength test on GPC cube

3.9.2. Flexural Strength Study

Beam specimens were tested as simply supported at two ends, with one end as fixed roller support and other end as a free roller support. Steel roller of 40 mm diameter was used in both roller supports.

One layer of white wash was applied on the surface of the beam in order to make the cracks more visible. The positions of the supports, load points and the midpoint were marked on the beam. Then the beam was placed carefully over the supports in the loading frame along the marking by giving 150mm beyond the support and a clear distance of 800mm between the supports. Level of the beam was checked by a level tube.

Load was applied to GPC beams of dimension of 1.1×0.2×0.15 m using a hydraulic jack of 200 kN capacity. Jack was fixed to the loading frame using a C-clamp. The position of the beam was adjusted such that the plumb line through the centre of the jack and the centre line of the beam coincided exactly. A dial gauge of 200 kN capacity was placed in between the jack and

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the beam to maintain the loading rate. Two point loading was adopted for this study and this was applied at one third distance.

The loading was transferred to the beam by using a rectangular steel section. The centre of the spreader beam was made to coincide with the plumb line through the jack. Spreader beam and proving ring were loosely tied to the frame using ropes, to avoid any accidents.

Three dial gauges of 0.01mm accuracy were placed in both load points and midpoint of the bottom portion of the beam to measure the deflection at each load increment. A small piece of glass plate was fixed in the bottom portion of the beam, at both load points and mid point. This was to avoid any undulations in the bottom surface of beam, while taking the dial gauge readings. The plunger portion of the dial gauge was made to touch with the bottom surface of the glass plate and initial dial reading was set to zero. To measure the strain, the damec buttons were placed at levels corresponding to the reinforcing bars mainly in the extreme tension, tension, compression and extreme compression zones using spacer having 20cm.The measurement was carried out using strain measuring Demec of 0.01 mm accuracy at each load increment.

Fig. 3.18 shows the flexural strength test set up diagram. Load was applied manual pumping of the hydraulic jack. A seating load was given to the beam and the readings of both dial gauges and demec were taken corresponding to the zero load. Load was incremented to 3kN, dial gauge readings were taken and strain was measured at each increment. Load at first crack was noted. The cracks were marked according to their chronological order. Crack propagation corresponding to different loading were also measured. Dial gauges were removed when the cracks widened. The loading was continued upto failure of the beam and the load at failure was noted. Fig. 3.20 shows the testing of GPCA 20mm normal specimen

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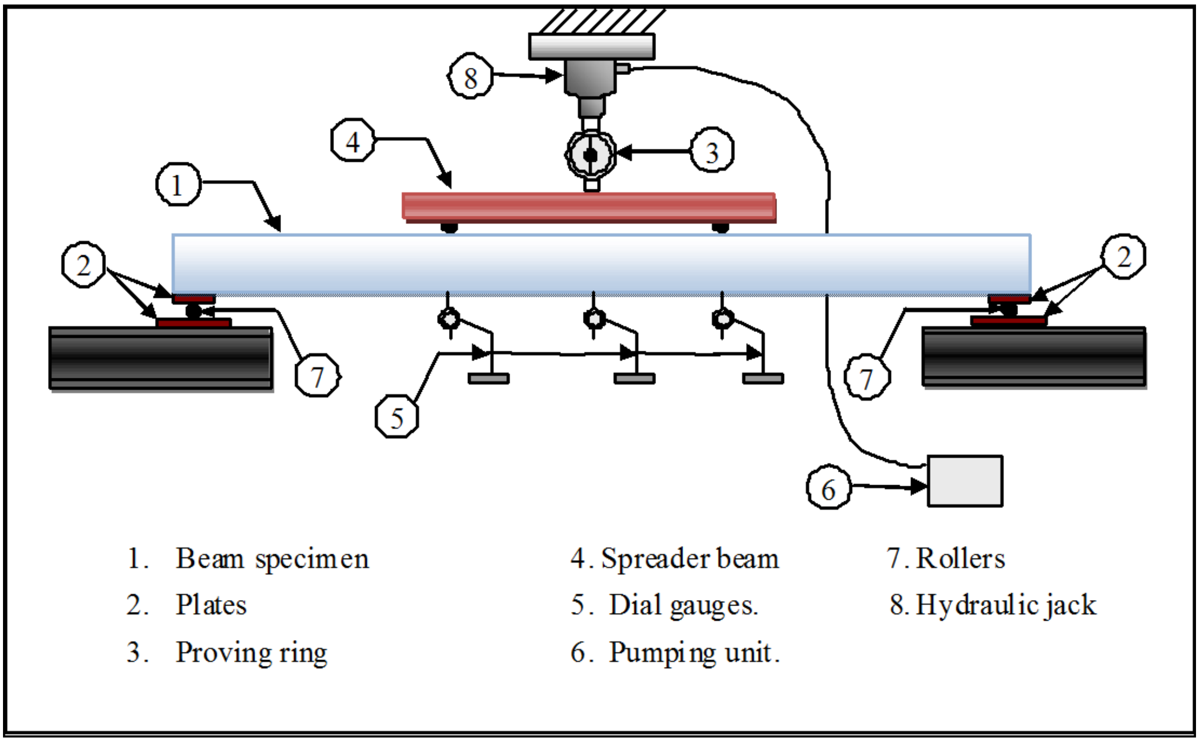

Fig. 3.18: Flexural strength test setup

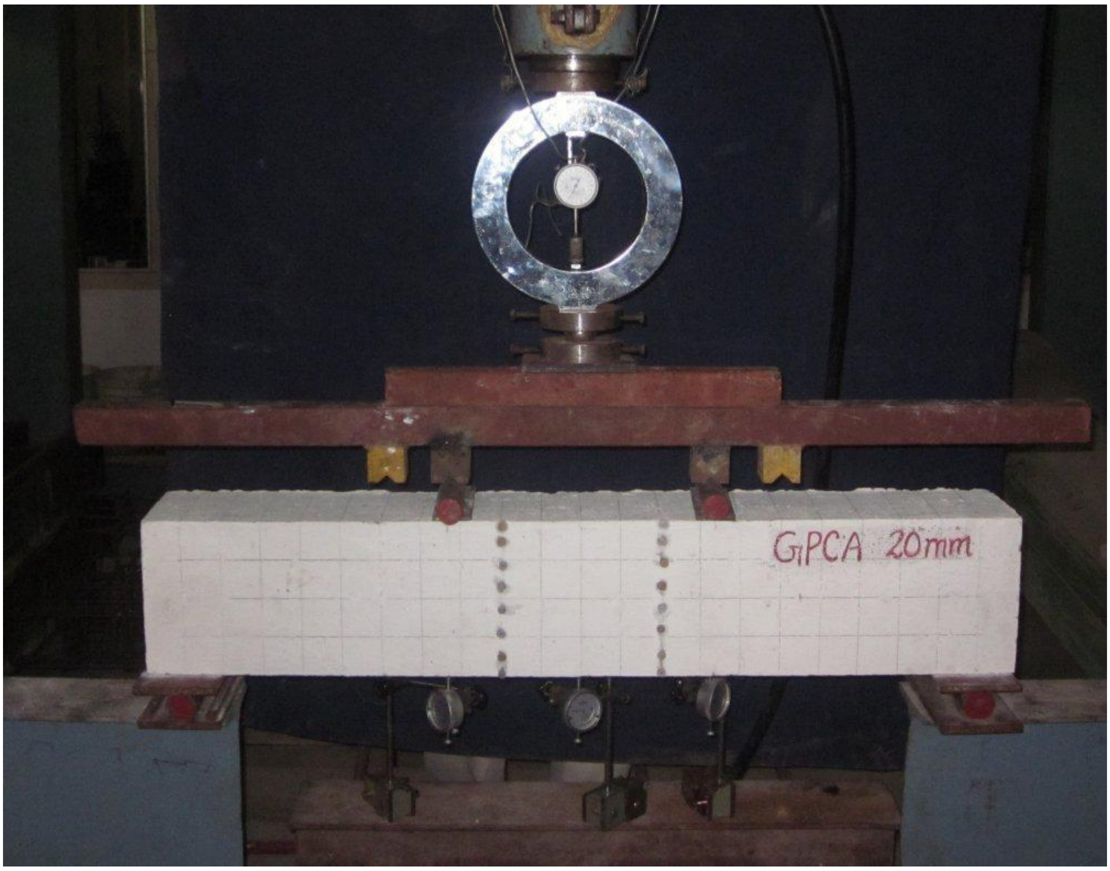

Fig. 3.19: Flexural Strength testing of geopolymer beam specimen.

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3.10 SUMMARY

Total 15 numbers of GPC beam specimens were cast to study the flexural behaviour. All the beams were exposed to different elevated temperature of 200°C, 400°C, 600°C and 800°C. Two point loading was carried out and deflections, strains, load at first crack and ultimate load were found out.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 GENERAL

The results from the experimental investigation carried out based on the tests mentioned in the previous section are analysed in this chapter. The test result covers the flexural strength of geopolymer concrete in ambient temperature (28°) exposed to different temperature. The effect of elevated temperature on geopolymer concrete beam with varying cover was also studied.

4.2 FLEXURAL STRENGTH OF GPC BEAM EXPOSED TO ELEVATED TEMPERATURE.

4.2.1 Ultimate Load Capacity

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Fig. 4.1 shows the details of ultimate load for GPC beams having 20mm cover. From the fig 4.1 it could be seen that ultimate load carrying capacity of beams at ambient temperature is comparatively higher than that of beams after exposed to 200°C, 400°C, 600°C and 800°C. Fig 4.2 shows the comparison of ultimate load obtained for GPC beams with different covers. The ultimate load obtained for GPC beams at ambient temperature, GPCA 20mm, GPCA 30mm, GPCA 40mm are respectively 101kN, 99kN and 98kN . The percentage loss in ultimate load for GPCA 20mm, 30mm and 40mm with respect to ambient temperature curing (28°C) is shown in figure 4.3.

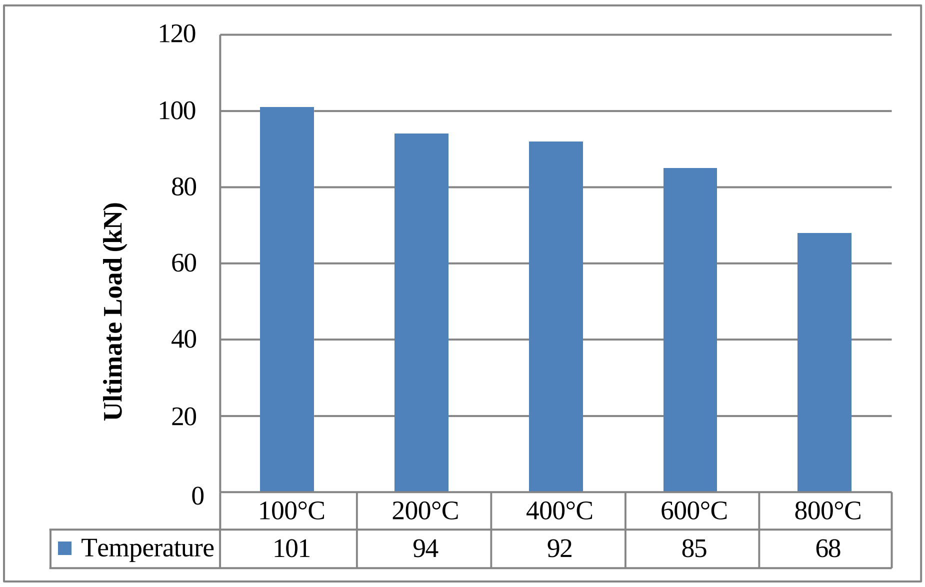

Fig 4.1 Ultimate Load for GPC 20mm Beams

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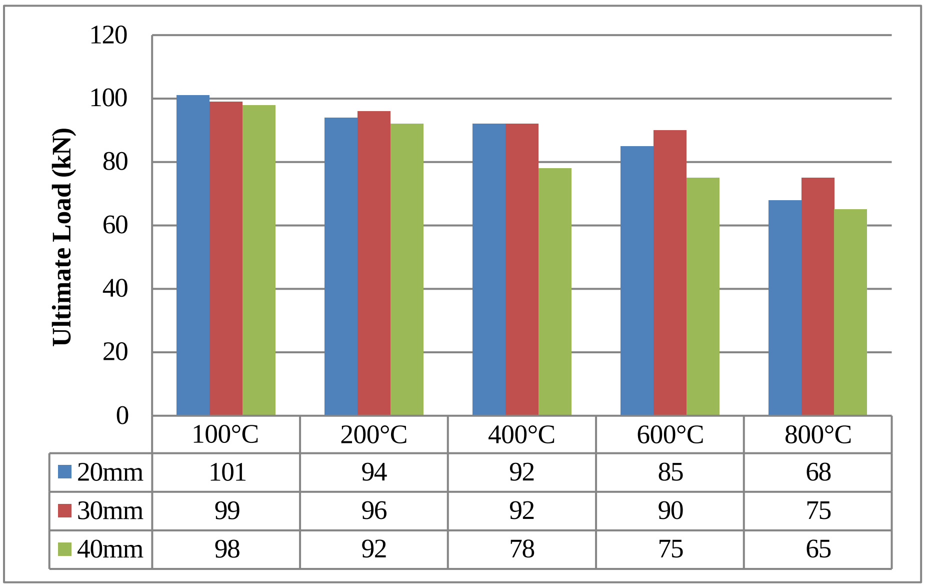
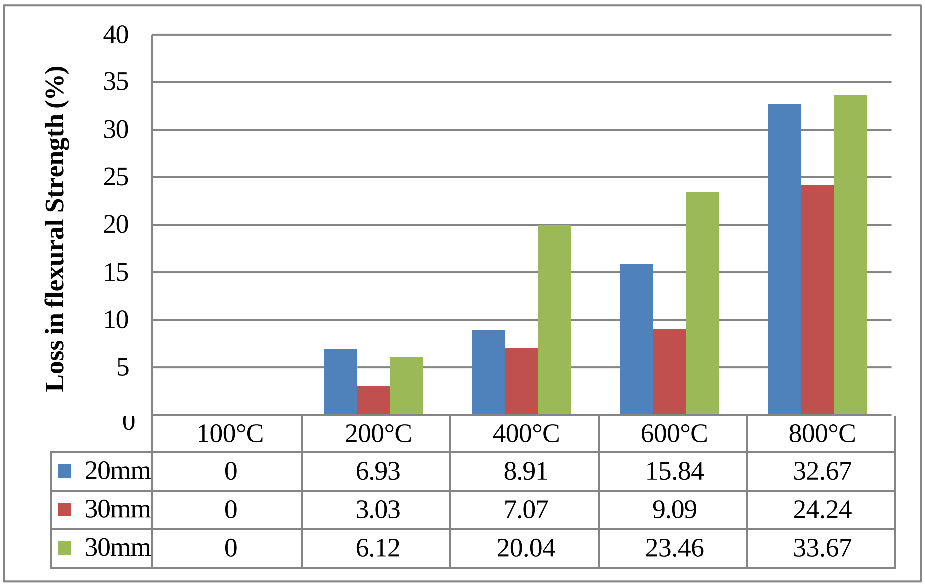


	100°C	200°C	400°C	600°C	800°C
20mm	101	94	92	85	68
30mm	99	96	92	90	75
40mm	98	92	78	75	65

Fig 4.2 Comparison of Ultimate Load of GPC Beams



	100°C	200°C	400°C	600°C	800°C
20mm	0	6.93	8.91	15.84	32.67
30mm	0	3.03	7.07	9.09	24.24
30mm	0	6.12	20.04	23.46	33.67

Fig 4.3 Percentage Loss in Flexural Strength for GPC Beams

The reduction in ultimate load of beams having same cover with increase in temperature exposure is due to the reduction in the compressive strength and modification of yield strength of reinforcing steel (Raghu, 2012). Fig. 4.3 shows a comparison of ultimate load of GPCA 20mm, GPCA 30mm and GPCA 40mm specimens at ambient temperature, 200°C, 400°C,

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600°C and 800°C temperature exposure. A similar result was also noticed elsewhere (Xudong, etal., 2004).

4.2.2 Cracking Load

First crack load and ultimate load for GPCA 20mm, 30mm and 40mm beams are shown in table.4.7 through 4.9

Table 4.1 First Crack and Ultimate Load of GPC 20mm Beams

	Load at First Crack, P_{cra} (kN)	**Ultimate Load, P_u (kN)**	P_u / P_{cra}
Ambient	45	101	2.24
200°C	42	94	2.23
400°C	36	92	2.55
600°C	33	85	2.57
800°C	30	68	2.26

Table. 4.2 First Crack and Ultimate Load of GPC 30mm Beams

Temperature	**Load at First Crack, P_{cra} (kN)**	**Ultimate Load, P_u (kN)**	P_u / P_{cra}
Ambient	43	99	2.30
200°C	42	96	2.28

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400°C	39	92	2.35
600°C	36	90	2.50
800°C	33	75	2.27

Table 4.3 First Crack and Ultimate load of GPC 40mm beams

Temperature	**Load at First Crack, P_{cra} (kN)**	**Ultimate Load P_u (kN)**	P_u / P_{cra}
Ambient	40	98	2.45
200°C	36	92	2.56
400°C	33	78	2.36
600°C	33	75	2.27
800°C	30	65	2.17

For all GPCA beams having same cover, the first crack load decreases with increase in temperature. The decreasing nature of first crack load is due to reduction in tensile strength of geopolymer concrete beam. It is reported that OPC concrete beams subjected to various temperature exposures have significant effect on tensile strength of reinforced concrete flexural members (Sarkar, 2010).

4.2.3 Load - Deflection Characteristics

The load - deflection curves for GPC beams is shown in figure 4.4 to figure 4.8. It is found that the beams exposed to various temperatures have lower stiffness than the control specimens. The pre-cracking and post-cracking stiffness of GPC beams were found from the slopes of load-deflection graph obtained for each beam. Pre-cracking and post-cracking stiffness of different series of beams are presented in table 4.4 to 4.6. comparing the stiffness obtained for GPC beams, GPCA 20mm beams shows more stiffness than GPCA 30mma and GPCA 40mm beams after same temperature exposure. The stiffness of GPC beam was compared with result reported in a published paper of OPC beam (Dattatreya, 2011) OC beam. The results show that

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GPC has comparatively higher stiffness than OC beam. Figure 4.10 comparison of stiffness of GPC and OPC at ambient temperature. Beam having different cover do not shows significant deflection variation, when exposed to particular elevated temperature. However the deflection increases when the temperature increases.

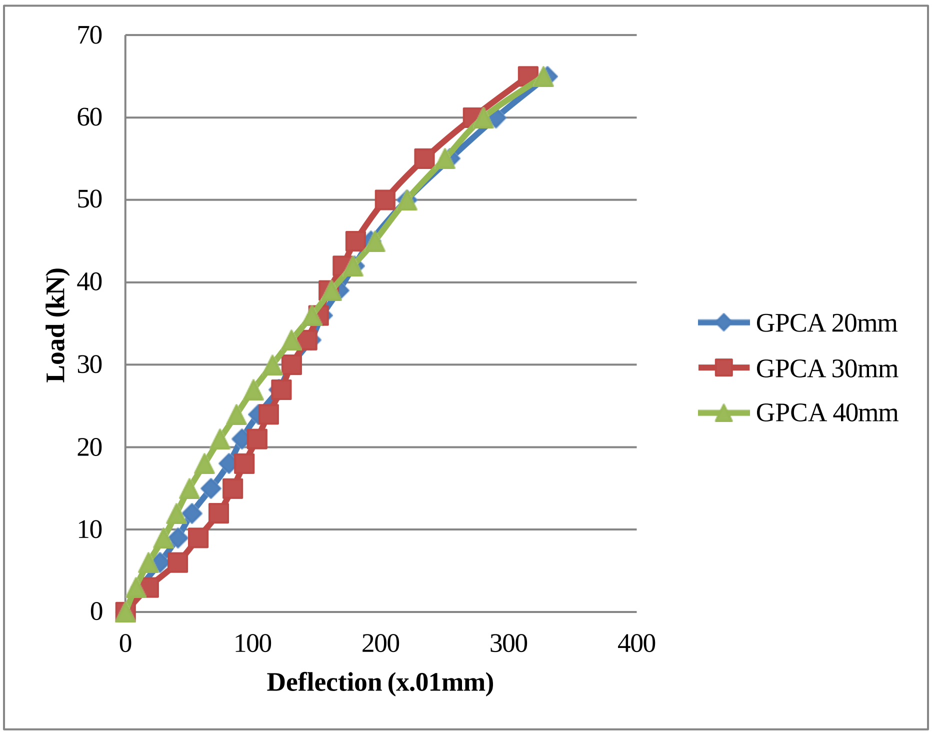

Fig. 4.4 Load - Deflection Curve of GPC beams at ambient temperature

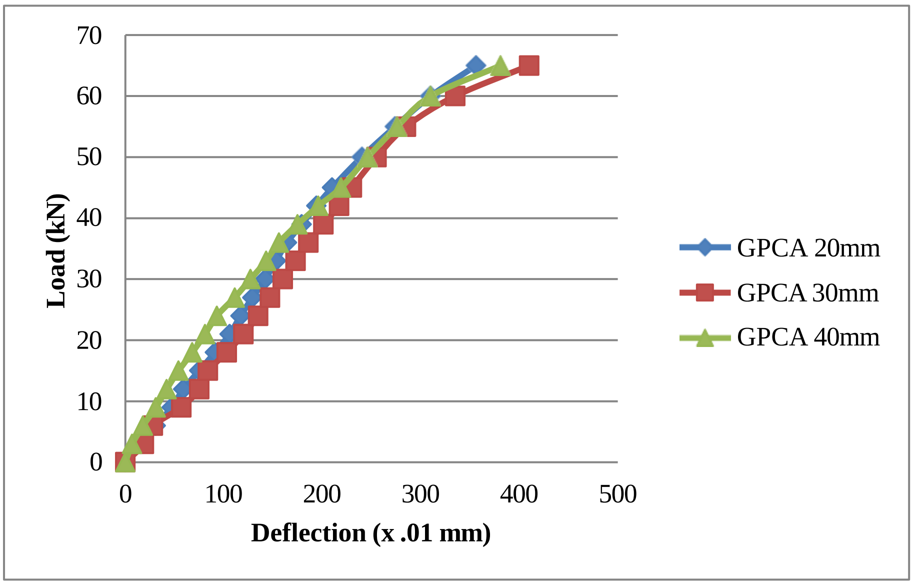

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Fig. 4.5 Load - Deflection Curve of GPC beams after exposed to 200°C

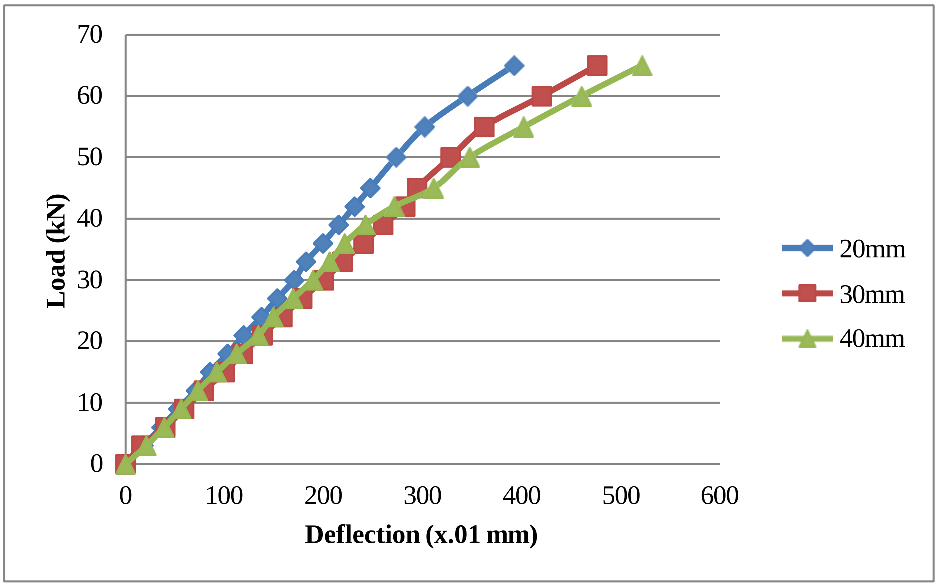

Fig. 4.6 Load - Deflection Curve of GPC beams after exposed to 400°C

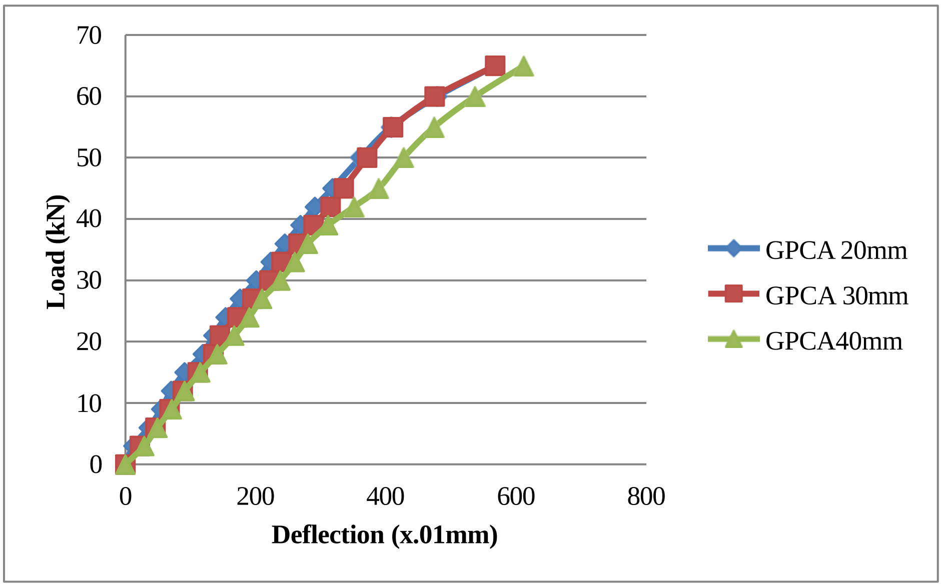

Fig. 4.7 Load - Deflection Curve of GPC beams after exposed to 600°C

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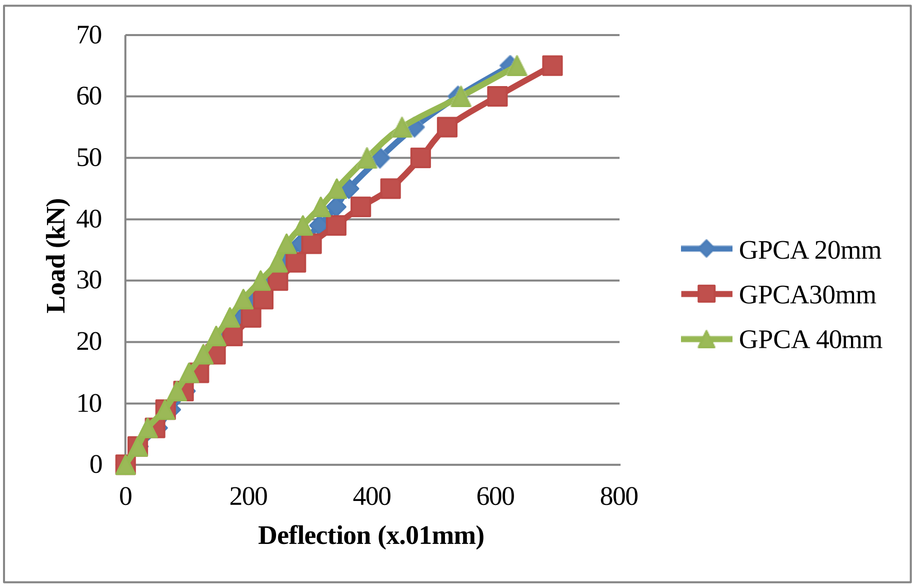

Fig. 4.8 Load - Deflection Curve of GPC beams after exposed to 800°C

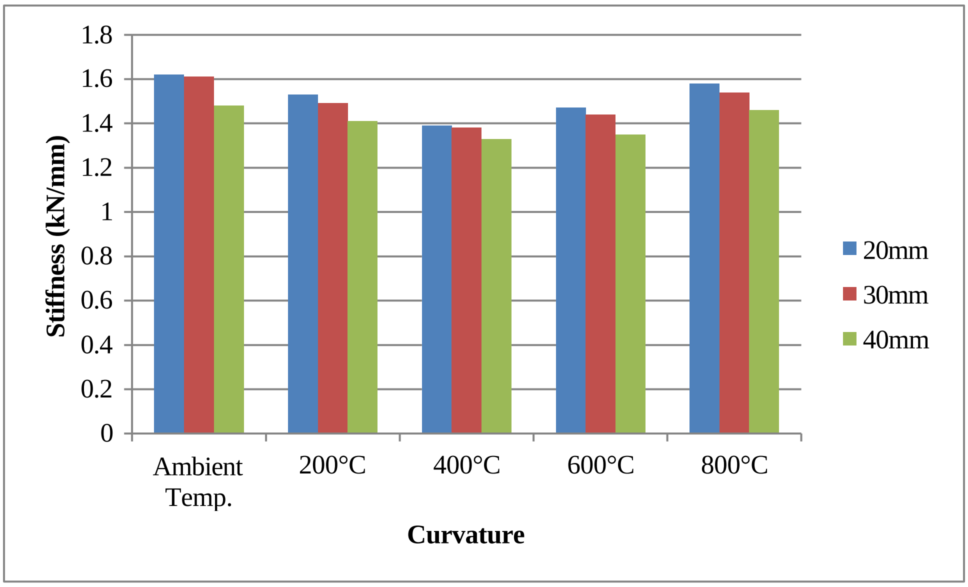

Fig. 4.9 Comparison of Stiffness at Each Temperature

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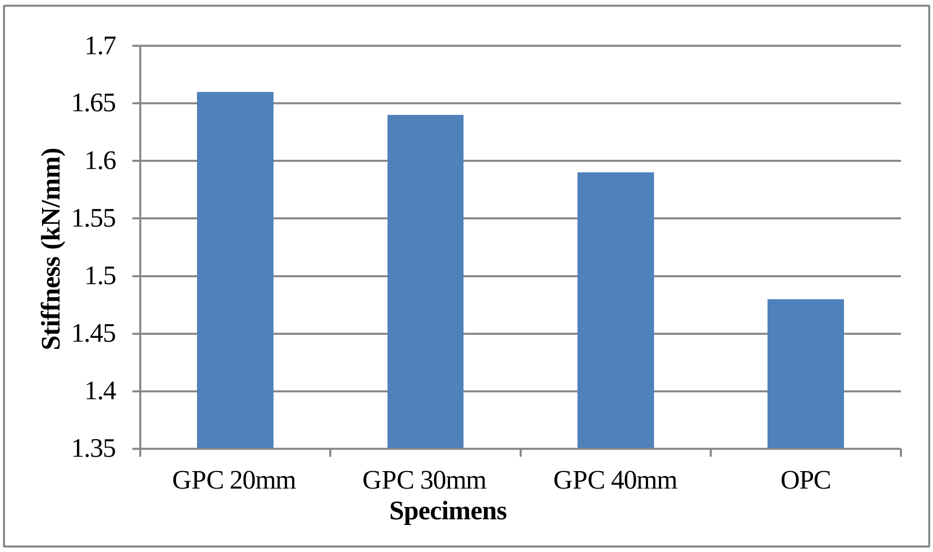

Fig. 4.10 Comparison of Stiffness of GPC and OPC

Table 4.4 Pre-cracking and Post-cracking Stiffness of GPC 20mm beams

Temperature	**Pre-Cracking Stiffness K_{pre}**	**Post-Cracking Stiffness K_{post}**	K_{pre}/K_{post}
Ambient	23.46	14.50	1.62
200°C	21.61	14.124	1.53
400°C	18.09	15.027	1.20
600°C	14.80	10.07	1.47
800°C	12.89	5.11	2.52

Table 4.5 Pre cracking and Post cracking of GPC 30mm beams

Temperature	**Pre-Cracking stiffness K_{pre}**	**Post-Cracking Stiffness K_{post}**	K_{pre}/K_{post}
Ambient	23.80	14.88	1.60
200°C	19.30	11.91	1.62
400°C	15.00	11.03	1.36
600°C	13.80	9.58	1.44
800°C	13.40	7.77	1.74

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Table 4.6 Pre cracking and Post cracking of GPC 40mm beams

Temperature	Pre-Cracking stiffness K_{pre}	Post-Cracking Stiffness K_{post}	K_{pre}/K_{post}
Ambient	22.40	15.13	1.48
200°C	23.00	12.56	1.83
400°C	16.01	11.12	1.44
600°C	12.69	9.40	1.35
800°C	13.69	8.39	1.63

The differential thermal expansion between aggregate and geopolymer might be one of the causes of increase in deformation. Similar observations were reported previously by Daniel and Sanjayan, 2008.

4.2.4 LOAD - STRAIN CURVE

Load Vs strain (at the level of tension steel) graph after exposed to different temperature is shown in figure 4.11 to 4.13.

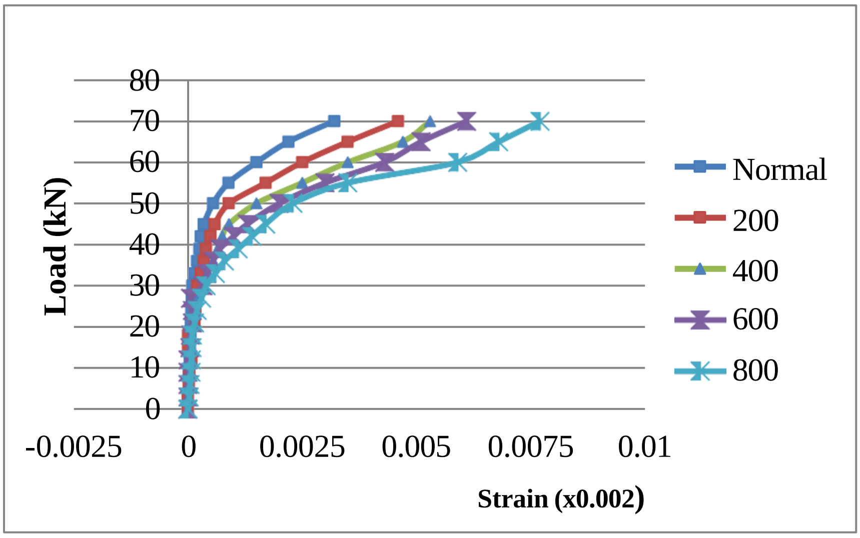

Fig. 4.11 Load Vs Strain at Tension Zone of GPC 20mm Exposed to Different Temperature

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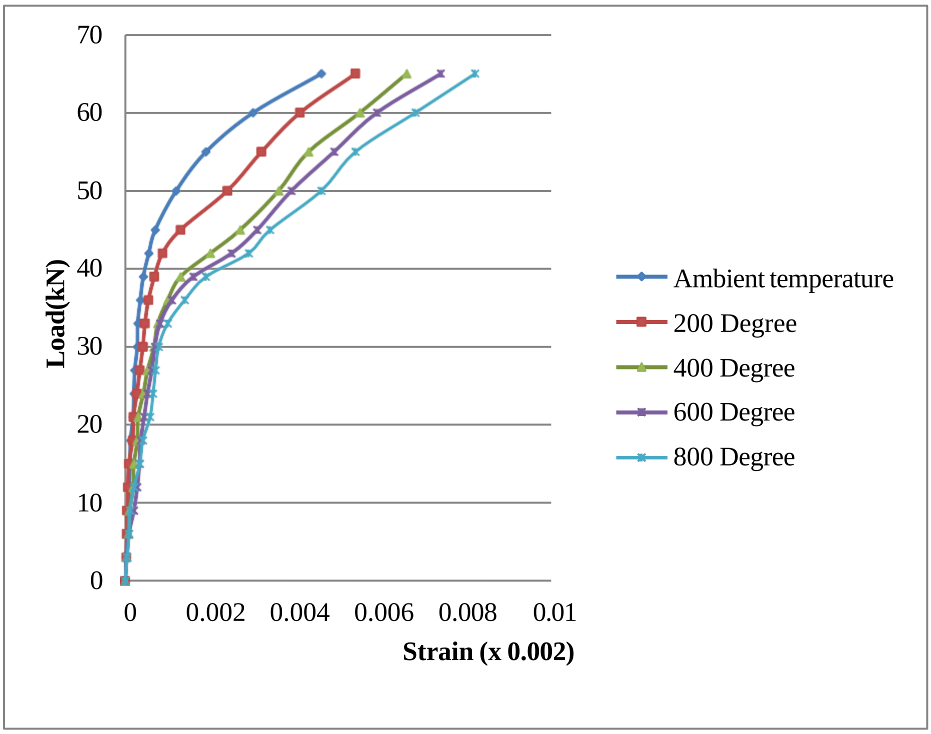

Fig 4.12 Load Vs Strain at Tension Zone of GPC 30mm Exposed to Different Temperature

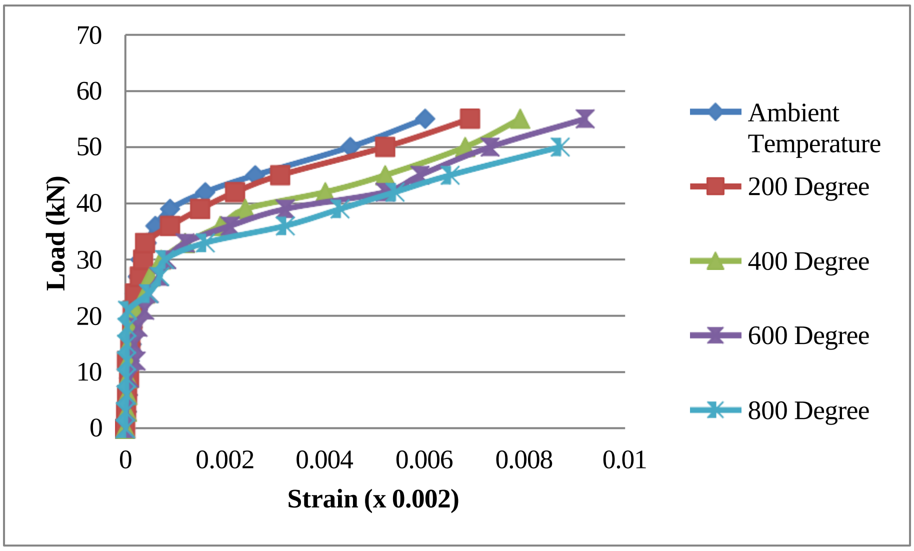

Fig 4.13 Load Vs Strain at Tension Zone of GPC 40mm Exposed to Different Temperature

It is seen that in all the GPC beams there is no significant change in strain (at level of steel) at different temperature exposure before first crack load. However beyond the first crack load ,strain in beam having same cover changes slightly with change in exposure temperature. After the first crack, there is a marginal increase in strain of GPC specimen having different cover at same temperature exposure.

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4.2.5 MOMENT CURVATURE COMPARISON

The curvature for different beam specimen was calculated using the strain profile, while moment values were calculated based on the loading condition (*wl/6*).

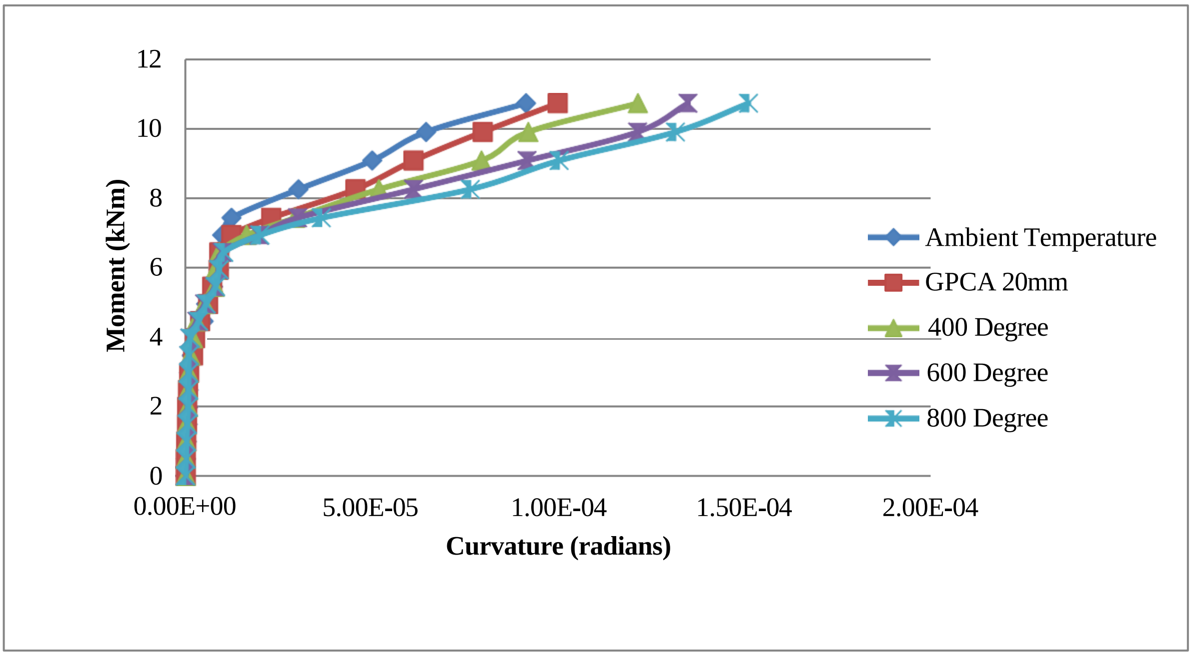

Fig 4.14 Moment Curvature of GPC 20mm Beams Exposed to Different Temperature

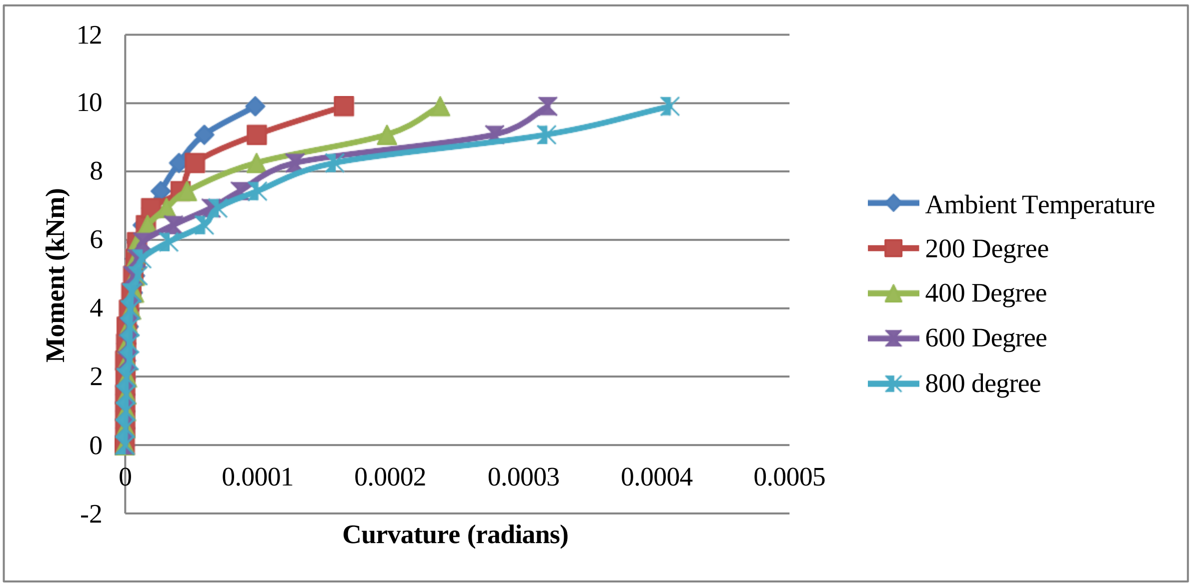

Fig. 4.15: Moment Curvature of GPC 30mm Beams Exposed to Different Temperature

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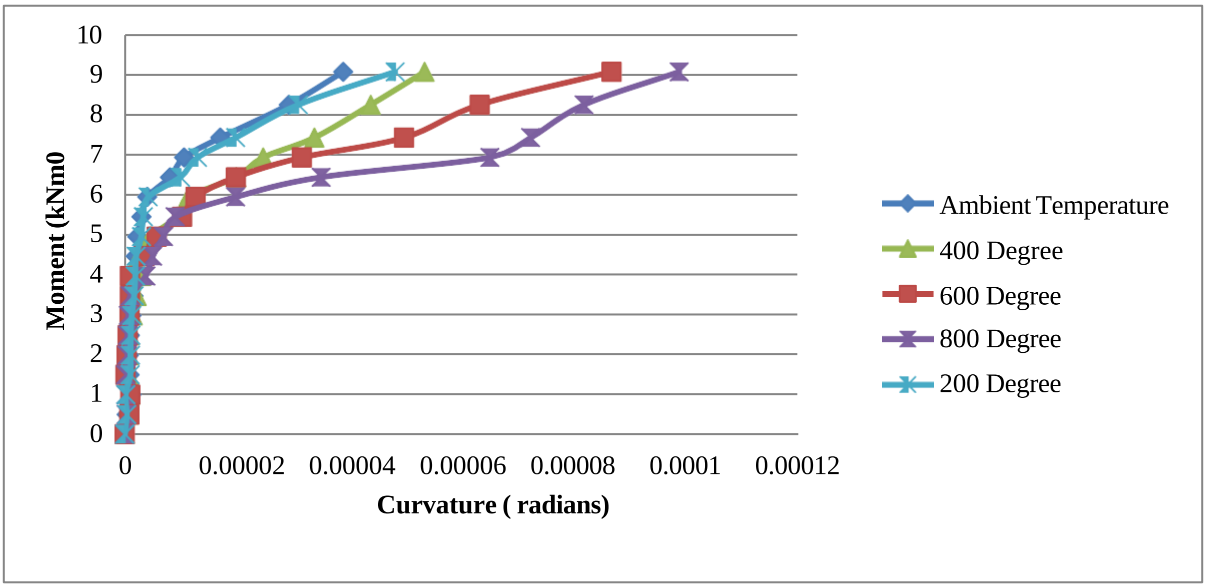

Fig. 4.16: Moment Curvature of GPC 40mm Beams Exposed to Different Temperature

It is reported that strength of geopolymer concrete reduces when exposed to elevated temperature (Raghu, 2012). Curvature ductility was reduced gradually as the concrete strength decreases from 0 to 40MPa. Similar observations were also noticed by Olivia and Mandal, 2005.

4.2.6 Crack pattern and Crack width

Minute cracks were seen in beam specimen cooled down to room temperature after exposed to 600°C and 800°C.This cracks have not extended or widened during the loading. For all GPC beams the first crack was initiated approximately at the midspan. As the load increased the crack formed at the middle portion extended towards compression side. On further increase of load, more cracks were formed at the tension zone below the point load and extended toward compression zone. For beams exposed to temperature beyond 400°C, the number of cracks remains the same while the crack width increase with increase in temperature exposure. It was noticed that crack width increased with increase in temperature exposure.

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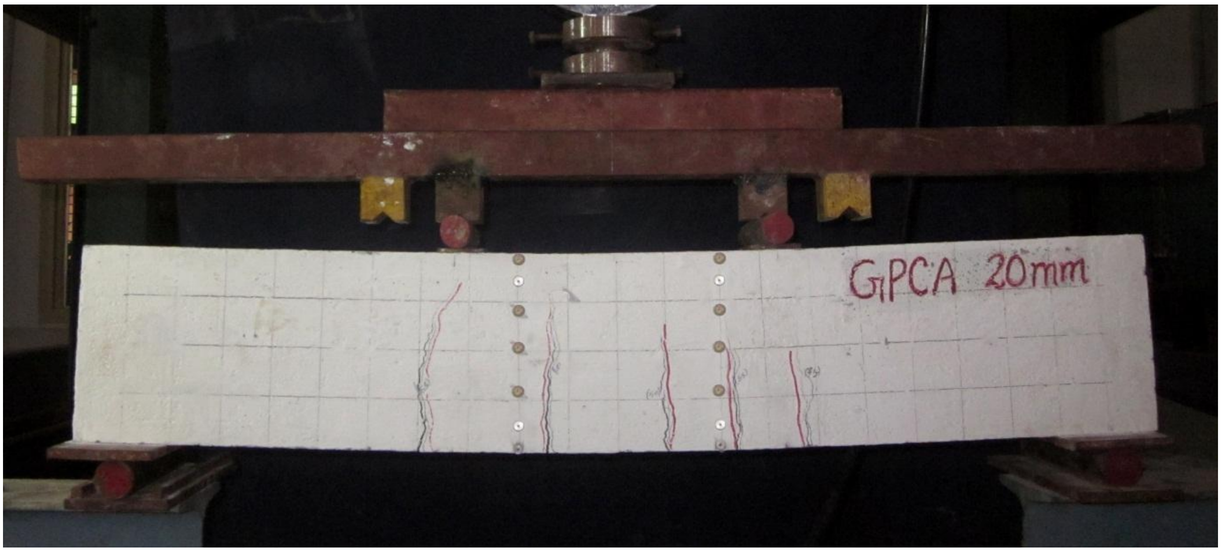

Fig. 4.17: Crack pattern of GPCA 20mm specimen

Fig. 4.18: Crack pattern of GPCA 20mm 200°C

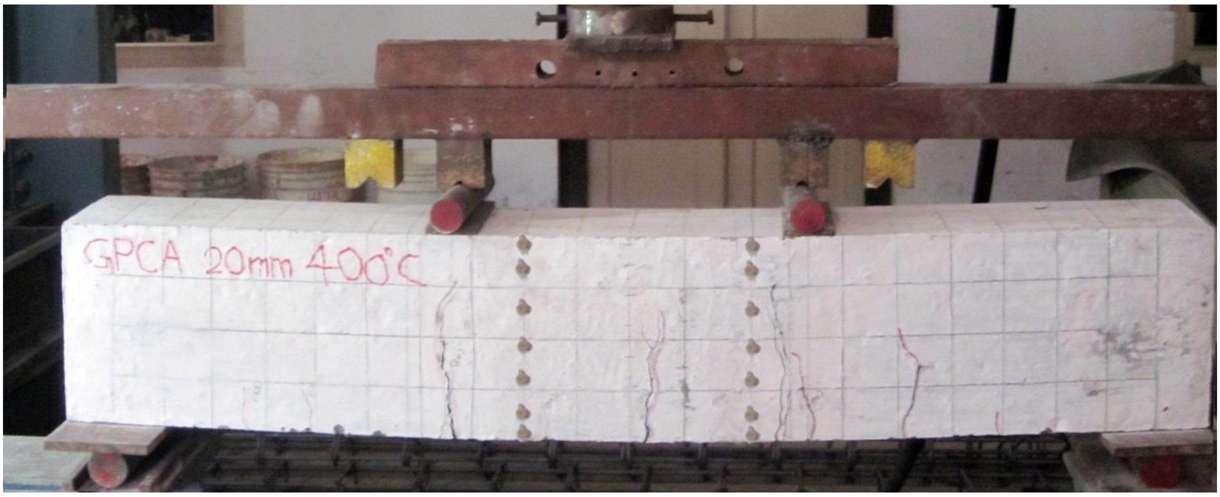

Fig. 4.19: Crack pattern of GPCA 20mm 400°C

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Fig. 4.20: Crack pattern of GPCA 20mm 600°C

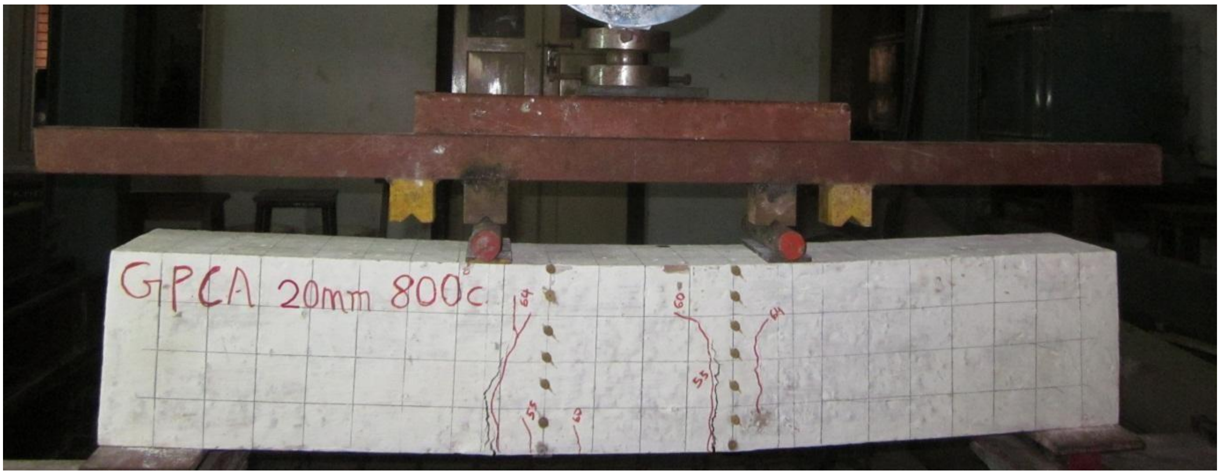

Fig. 4.21: Crack pattern of GPCA 20mm 800°C

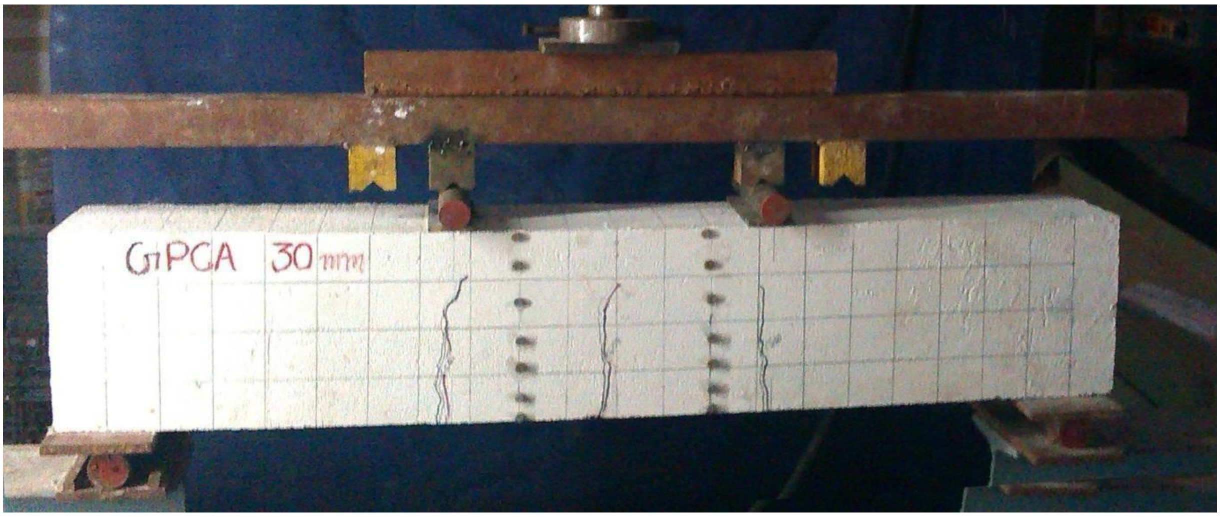

Fig. 4.22: Crack pattern of GPCA 30mm specimen

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Fig. 4.23: Crack pattern of GPCA 30mm 200°C

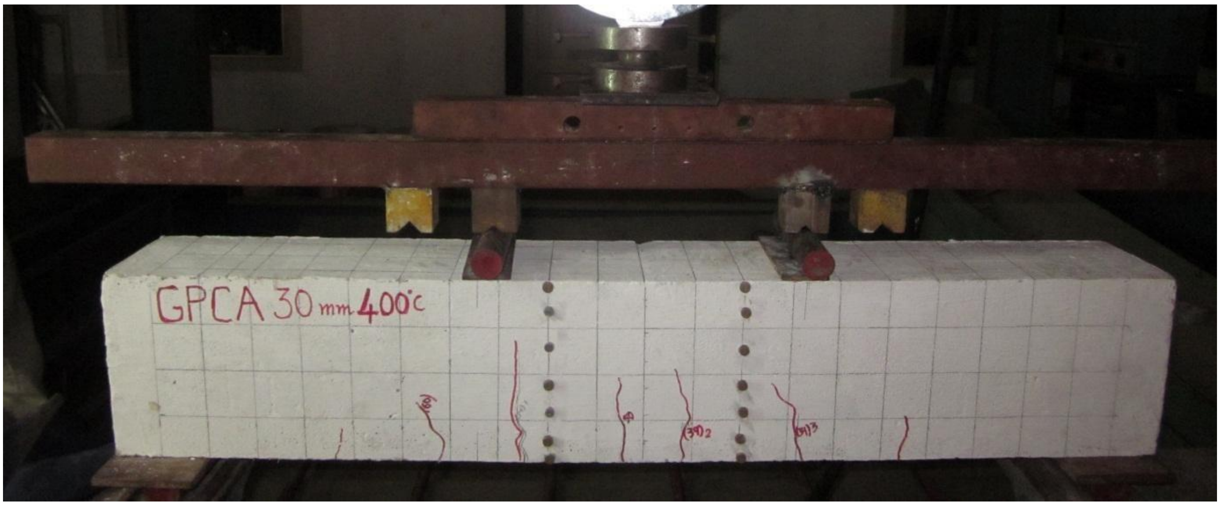

Fig. 4.24: Crack pattern of GPCA 30mm 400°C

Fig. 4.25: Crack pattern of GPCA 30mm 600°C

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Fig. 4.26: Crack pattern of GPCA 30mm 800°C

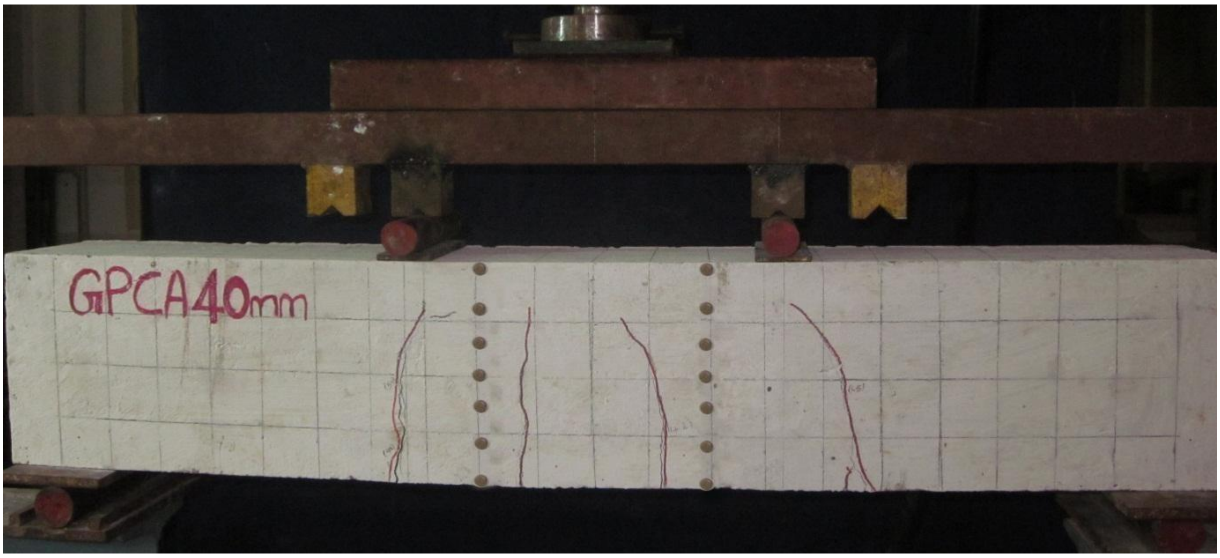

Fig. 4.27: Crack pattern of GPCA 40mm spacimen

Fig 4.28: Crack pattern of GPCA 40mm 200°C

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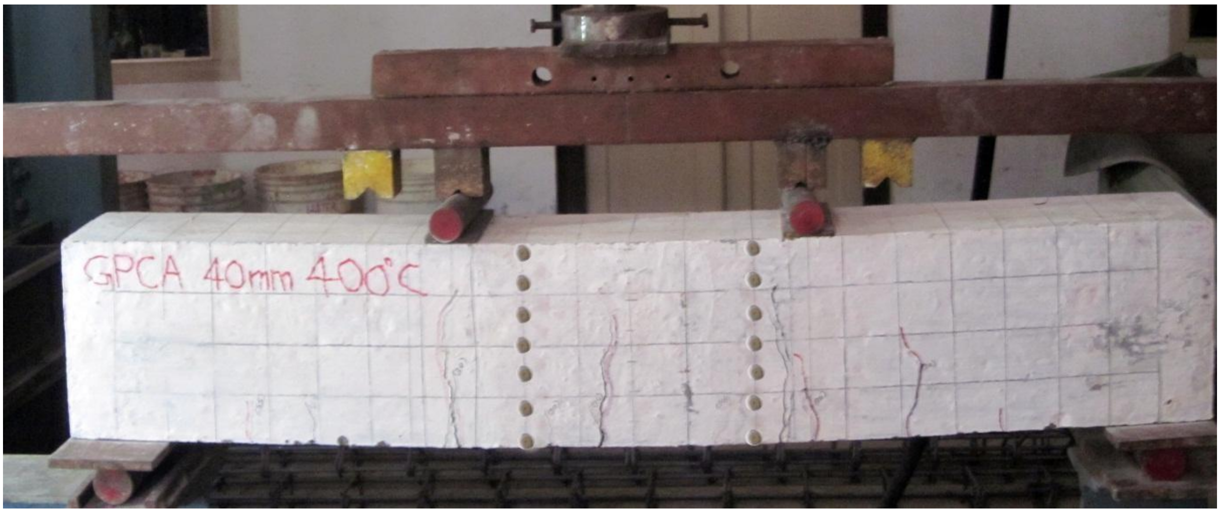

Fig. 4.29: Crack pattern of GPCA 40mm 400°C

Fig 4.30: Crack pattern of GPCA 40mm 600°C

Fig 4.31: Crack pattern of GPCA 40mm 800°C

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CHAPTER 5

CONCLUSION

5.1 GENERAL

The main objective of this study was to compare the flexural strength of reinforced geopolymer concrete (GPC) beams with different cover after elevated temperature exposure. The effect of temperature on the ultimate load of geopolymer beams was also studied.

5.2. CONCLUSIONS

From the present investigation the following conclusions are arrived at:

- At same cover, flexural strength of geopolymer concrete beam reduced with the increase in temperature exposure.
- The beams with 20mm cover after 600°C exposure and 40mm cover after 400°C exposure showed a large reduction in the ultimate load carrying capacity than 30mm beam.
- After being exposed to 800°C geopolymer concrete beam specimens shows strength reduction of about 25% for GPC 30mm cover and for 20mm and 40mm cover, it was 31% and 33% respectively. 30mm cover beam shows less reduction in ultimate strength.
- Colour change was noticed in geopolymer specimens and the variation was visible after 400°C exposure. After exposed to 800°C and cooling down to room temperature the colour became light red.
- Beam having different cover do not shows significant deflection variation, when exposed to particular elevated temperature.
- For beams having same cover shows no significant change in strain after exposed to different temperature.
- No significant change in curvature was noticed for beams of different cover after exposed to different temperature.
- Beam having 20mm cover shows more stiffness after same temperature exposure.

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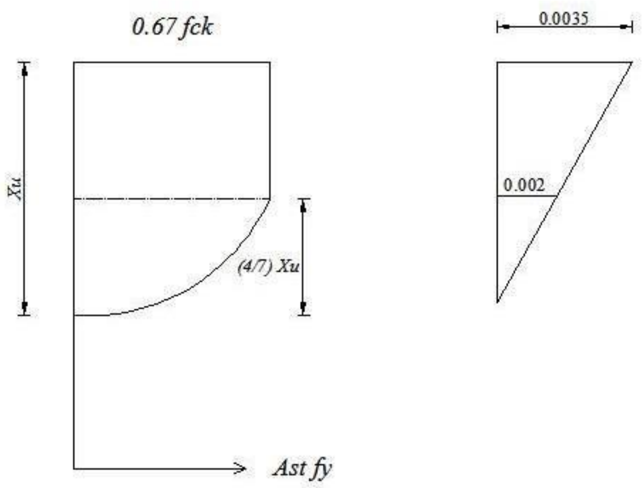
APPENDIX

CALCULATION OF MOMENT OF RESISTANCE



Compressive Force, $C = 0.67\, f_{ck}\, b\, [\,{}^{3}/_{7}\, X_u + {}^{2}/_{3} \times {}^{4}/_{7}\, X_u\,]$

$$= f_{ck} \times b \times {}^{17}/_{21}\, X_u = 0.54\, b\, X_u\, f_{ck}$$

$$\bar{Y} = \frac{{}^{3}/_{7}\, x_u \times {}^{3}/_{4} X_u + {}^{2}/_{3} X_u \times {}^{4}/_{7} X_u\, ({}^{3}/_{7} X_u + {}^{3}/_{8} \times {}^{4}/_{8} X_u)}{[\,{}^{3}/_{7} X_u + {}^{2}/_{3} + {}^{4}/_{7}\; X_u\,]} = {}^{3}/_{7}\, X_u$$

$$0.54\, f_{ck}\; b\, X_u = A_{st}\, f_y$$

$$\frac{X_u}{d} = \frac{A_{st}\, f_y}{0.54\, f_{ck}\; bd}$$

$$\frac{\varepsilon_u}{\varepsilon_s} = \frac{X_u}{d - X_u}$$

$$\frac{X_u}{d} = \frac{c}{s_{cu} + s_s} = \frac{0.0035}{0.0035 + (0.002 + \frac{f_y}{s_s})} = \frac{0.0035}{0.0035 + 0.002 + {}^{415}/_{(2 \times 10^{6})}}$$

$$= 0.613$$

$$\frac{X_{u\,max}}{d} = 0.613$$

$$moment\ of\ resistance = 0.54\, f_{ck}\, b\, X_u (\, d - 0.42\, X_u)$$

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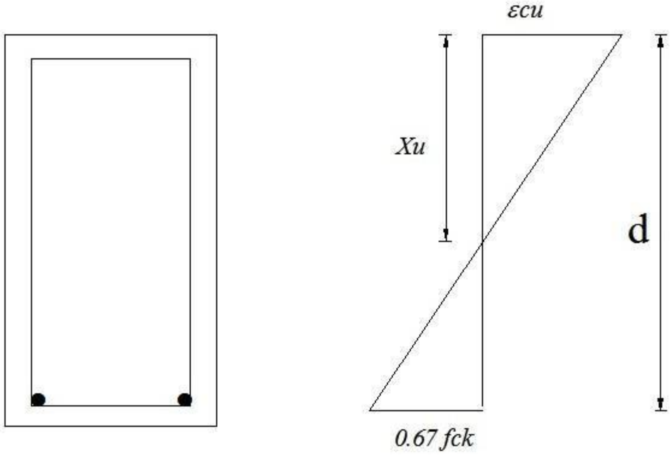

$$\frac{X_u}{d} = \frac{A_{st}\ f_y}{0.54\ f_{ck}\ bd}$$

$$= \frac{157 \times 415}{0.54 \times 57 \times 150 \times 175}$$

$$= 0.0806$$

$$x_u = 0.0806 \times 175 = 14.1$$

Moment of Resistance $= 0.54 \times f_{ck}\ b\ X_u\ (d - 0.42\ x_u)$

$= 0.54 \times 57 \times 150 \times 14.1\ [\ 175 - (14.1 \times 0.42)\ ]$

$= 11 \times 10^6$ Nmm = 11 kNm

Calculation of Ultimate Load

Width = 150mm

Effective depth, d = 175mm

f_{ck} = 57 MPa

f_y = 415

$$M = \frac{WL}{6}$$

$$11 = \frac{W \times 0.8}{6}$$

W = 73.33 kN

$$V_u = \frac{W}{2} = \frac{41.25}{2} = 20.6\text{kN}$$

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$$\tau_u = \frac{V_u}{bd} = \frac{20.6 \times 10^3}{150 \times 175} = 0.78$$

$$\tau_v = \frac{0.8\sqrt{0.8\, f_{ck}}\;(\sqrt{1+5\beta}-1)}{6\beta}$$

$$ß = \frac{0.8\, f_{ck}}{6.89\, P_t}$$

$$P_t = \frac{100\, A_{st}}{bd} = 0.598$$

$$ß = \frac{0.8 \times 57}{6.89 \times 0.598} = 11.06$$

$$\tau_u = \frac{0.8 \times \sqrt{0.8 \times 57}\;[\sqrt{1+(5 \times 11.06)}-1]}{6 \times 11.06}$$

= 0.48

0.78 – 0.48 = 0.30

Shear Force = 0.3 bd

= 0.3 × 175 × 150 = 7.87 kN

$$S_v = \frac{f_y\, A_{sv}\, d}{V_{us}}$$

$$= \frac{415 \times (28.2 \times 2) \times 175}{(7.87 \times 10^3)}$$

= 520mm

0.7 d = 0.75 ×11

= 131.2mm

$$\frac{0.4}{0.87\, f_y} = \frac{0.4}{0.87 \times 415} = 0.0011$$

$$\frac{A_{sv}}{b\, S_v} = \frac{(28.2 \times 2)}{150 \times 131.6}$$

= 0.0029

Minimum spacing is 131mm c/c, take 6mm dia stirrups and 10mm dia main bar.

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ii) Strain Calculation:

For GPCA 40mm beams.

Load	Ambient Temperature	200 °C	400°C	600°C	800°
0	1162	1163	1164	1165	1166
3	1165	1165	1167	1166	1167
6	1167	1167	1168.2	1167	1168
9	1169	1171	1169.1	1173	1169
12	1171	1166	1170	1187	1172
15	1174	1175	1176	1177	1178
18	1177	1177	1173	1191	1180
21	1179	1178	1184	1204	1182
24	1181	1182	1183	1184	1185
27	1187	1192	1214	1232	1235
30	1192	1199	1236	1248	1245
33	1205	1203	1284	1285	1326
36	1222	1253	1354	1375	1486
39	1252	1313	1404	1485	1596
42	1322	1383	1564	1685	1706
45	1422	1473	1684	1755	1816
50	1612	1683	1844	1895	2036

Strain for 3kN = [(1165-1162)/1162]*.002/200

= .000025478

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iii) Curvature Calculation:

For calculation curvature damec readings in the extreme compression zone and tension zone was needed.

Load (kN)	Strain at Tension zone	Strain at extreme compression zone
0	0	0
3	0.00002	0.00003
6	0.00013	0.00005
9	0.00006	0.00007
12	0.00002	0.00009
15	0.00001	0.000129
18	0.00003	0.00015
21	0.00007	0.00017
24	0.00007	0.000194
27	0.00005	0.00025
30	0.00004	0.0003
33	0.00003	0.00043
36	0.00002	0.0006
39	0.00005	0.0012

Curvature = (Strain at tension zone +Strain at extreme compression zone)/d

Where d= effective depth.

For GPCA 40mm

Curvature at 3kN = (0.00003+0.00002) / (200-40-5)

= 3.225x10^-07 radians.