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EXPERIMENTAL STUDY ON FLEXURAL BEHAVIOR OF GEOPOLYMER RCC BEAMS USING BOTTOM ASH.

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***Abstract**:* Bottom ash is formed in coal furnaces. It is made from agglomerated ash particles that too large to be carried in the flue gases and fall through open grates to an ash hopper at the bottom of the furnace. Bottom ash is mainly comprised of fused coarser particles. These particles are quitep porous and look like volcanic lava. Bottom ash forms up to 25% of the total ash while the fly ash is remaining 75%. The present work deals with flexural behavior of bottom ash geopolymer reinforced concrete beam. A total of six beams were cast, in which three beams were control reinforced concrete beams and thee beams were bottom ash geopolymer reinforced concrete beam. bottom ash geopolymer reinforced concrete beamwas cured at ambient temperature. The load carrying capacity, load deflection behavior and initial stiffness capacity of beams were arrived and compared with control reinforced cement concrete (RCC) specimens.

Key words: Mix Design, alkaline activators, industrial by-products, Geo polymerization

INTRODUCTION

Concrete Various industries produce numerous solid waste materials. The disposal of these solid waste materials is an environment hazard for the surrounding living beings. It is observed that because of increasing environmental concerns and sustainable issues, the utilization of solid waste materials is the need of the hour. The productive use of solid waste materials is the best way to alleviate the problems associated with their disposal. The construction industry has enormous potential for the use of solid waste materials as construction material. Based upon their properties, the solid waste materials can either be used as supplementary cementitious materials or as replacement of fine/coarse aggregate in concrete or mortars. Based on the research reports some solid waste materials such as fly ash, silica fume, grounded blast furnace slag etc. have been put in use in manufacturing of either cement or concrete. In India, about 67% of electricity requirements are fulfilled by the coal fired thermal power plants. Electricity demand in the country is increasing every year. At present, the country is facing average energy shortage of 6.7% at national level but the southern part of the country experience 26.7% energy shortage. To fill up the exiting gap between demand and supply of power and to meet the increasing energy requirements, coal fired thermal power plants are being set up in large number in the country. Coal fired thermal power plants produce large volumes of coal bottom ash. Till now, it is treated as solid waste material and is disposed off on open land. As per Central Electricity Authority, India, report (2014), about 57.63% of coal ash produced by coal fired thermal power plants is used in cement production and in manufacturing of bricks and tiles, construction of ash dykes and reclamation of low-lying areas. Fly ash is used as raw material in manufacturing of cement and bricks. However, coal bottom ash is not used in any form. The enormous quantity of coal bottom ash is getting accumulated near the power plant sites. The dumped coal bottom ash on open Land is posing environmental hazards to the surrounding community and ecosystem. On the other hand, large volumes of high CO_2 emission emitted during normal concreting. Geopolymer concrete is an innovative and eco-friendly construction material and an alternative to Portland cement concrete. Use of geopolymer reduces the demand of Portland cement which is responsible for high CO_2 emission.

1. LITERATURE REVIEW

Flexural Behaviour of Bottom Ash Geopolymer Reinforced Concrete Beams (Kumar & Revathi (2016). Asian Journal of Research in Social Sciences and Humanities),

The present work deals with flexural behavior of bottom ash geopolymer reinforced concrete beam. A total of twelve beams were cast, in which six beams were control reinforced concrete beams and six beams were bottom ash geopolymer reinforced concrete (BAGPRC) beam. BAGPRC beam was cured at ambient temperature. The load carrying capacity, load deflection behavior, initial stiffness, ductility factor and energy absorption capacity of beams were arrived and compared with control reinforced cement concrete (RCC) specimens. The test result reveals that BAGPRC exhibited excellent performance over control RCC beam. However, ductility index and stiffness behavior of BAGPRC beam were comparable with control RCC beam.

Comparison of the Flexural Performance and Behaviour of Fly-Ash-Based Geopolymer Concrete Beams Reinforced with CFRP and GFRP Bars(Hemn Qader Ahmed , Dilshad Kakasor Jaf, and Sinan Abdulkhaleq Yaseen-2019),

A construction system with high sustainability, high durability, and appropriate strength can be supplied by geopolymer concrete (GPC) reinforced with glass fibre-reinforced polymer (GFRP) bars and carbon fibre-reinforced polymer (CFRP) bars. Few studies deal with a combination of GPC and FRP bars, especially CFRP bars. The present investigation presents the flexural capacity and behavior of fly-ash-based GPC beam reinforced with two different types of FRP bars: six reinforced geopolymer concrete (RGPC) beams consisting of three specimens reinforced with GFRP bars and the rest with CFRP bars. The beams were tested under four point bending with a clear span of 2000 mm. The test parameters included the longitudinal-reinforcement ratio and the longitudinal- reinforcement type, including GFRP and CFRP. Ultimate load, first crack load, load-deflection behaviour, load-strain curve, crack width, and the modes of failure were studied. The experimental results were compared with the equations recommended by ACI 440.1R-15 and CSA S806-12 for flexural strength and mid span deflection of the beams. The results show that the reinforcement ratio had a significant effect on the ultimate load capacity and failure mode. The ultimate load capacity of CFRPRGPC beams was higher than that of GFRP-RGPC, more crack formations were observed in the CFRP-RGPC beams than in the GFRP-RGPC beams, and the crack width in the GFRP-RGPC beams was more extensive than that in the CFRP-RGPC beams. Beams with lower reinforcement ratios experienced a fewer number of crack and a higher value of crack width, while numerous cracks and less value of crack width were observed in beams with higher reinforcement ratio. Beams with the lower reinforcement ratios were more affected by the type of FRP bars, and the deflection in GFRP-RGPC beams was higher than that in CFRP-RGPC beams for the same corresponding load level. ACI 440.1R-15 and CSA S806-12 underestimated the flexural strength and mid span deflection of RGPC beams; however, CSA S806-12 predicted more accurately.

Studies on Flexural Behavior of Geopolymer Concrete Beams with GGBS (M. Ratna srinivas, Y. Himath Kumar, B. Sarath Chandra Kumar-2019),

As CO2 emissions are increasing in the atmosphere and causes global warming with the production of cement, the alternative pozzolanic material is needed. The alternative pozzolanic material for cement in the production of concrete is GGBS. Geopolymer Concrete (GPC) is an alternative material for conventional concrete. Geopolymer concrete is made by mixing GGBS, fine aggregate, coarse aggregate and alkaline activator solution. GGBS is a by-product of the iron industry. This paper shows the results on experimental investigation done on reinforced geopolymer concrete beams to know the flexural behavior. The alkaline activator solution is prepared by sodium hydroxide NaOH and sodium silicate Na_2SiO_3 in 1:2.5 ratio. The flexural behavior of the beams is examined with different molars of NaOH solution. The GPC beams are compared with conventional reinforced concrete beam of M40 grade concrete. The type of curing adopted in the experimental study is ambient. The size of beam is 1000 mm × 150 mm × 150 mm. The flexural test is done on the loading frame of capacity 200 tons. The ultimate load, cracking load and the maximum deflection and the crack pattern is determined and the load Vs deflection graphs are plotted. This experimental study gives a clear conclusion on the flexural behavior of conventional reinforced concrete beam and reinforced geopolymer concrete beam made with GGBS.

3. MATERIALS PROPERTIES

3.1 Introduction

The material testing includes the tests on cement, coarse aggregate and fine aggregate. This chapter includes all these tests and its results and observations.

3.2 Details of Specimen & Naming

A total of eight beams were cast, in which four beams were control reinforced concrete beams and four beams were bottom ash geopolymer reinforced concrete beam. Both beams are arranged in two types of reinforcement are shown in Fig. 4.1. A four-lettered designation is given to the specimens; first two letters represent the nature of concrete whether it is conventional or geoploymer, 3rd and 4rth indicate the type of reinforcement. Full details of the specimen's configuration are shown in Table 3.1.

SI. No	Specimen Designation
1	RCM1
2	GPCM1
3	RCM2
4	GPCM2

Table 3.1 Details of the beam specimens tested

3.3 Cement

Ordinary Portland cement of 53 grade [IS: 12269-1987, Specifications for 53 Grade Ordinary Portland cement] has been used in the study. It was procured from a single source and stored as per IS: 4032 – 1977. Care has been taken to ensure that the cement of same company and same grade is used throughout the investigation. The cement thus procured was tested for physical properties in accordance with the IS: 12269 – 1987.

Table 3.2 shows the physical characteristics of cement used, tested in accordance with IS: 4031-1988 [Methods of physical tests for hydraulic cement].

Fig1. Coarse Aggregate

MATERIALS USED

The concrete is a composite mass containing coarse aggregate, fine aggregate, water and cement. The strength and durability of concrete depends mainly on the materials used in it. The behavior of materials would be different based on its nature.

1. FINE AGGREGATE

Manufactured sand (M-Sand) is a substitute of river sand for concrete construction. M- Sand is produced from hard granite stone by crushing. Due to fast growing construction industry, the demand for sand has increased tremendously, causing deficiency of suitable river sand in most part of the word. Due to the depletion of good quality river sand for the use of construction, the use of M-Sand has been increased. M-Sand is used for availability and transportation cost. The properties of sand will affect the strength of concrete in great manner. The fine aggregates should not have high clay and silt content, since clay will affect the behavior of cement and reduces the strength of concrete. The fine aggregate should also be free from any organic contents. Fineness modulus of sand should be between 2.5 to 3.2.

Fig2. Fine Aggregate

2. COARSE AGGREGATE

Aggregates are the most mined materials in the world. Aggregates are a component of composite material such as concrete. The aggregate serves as reinforcement to add strength to the overall composite material. Due to the relatively high hydraulic conductivity value as compared to most soils, aggregates are widely used in drainage applications such as foundation and French drains, septic drain field, retaining wall drains and road side edge drains. Aggregates are also used as base material under foundations, roads and railroad. In other words aggregates are used as a stable foundation or road/rail base with predictable, uniform properties (e.g. to help prevent differential settling under the road or building). The coarse aggregate is collected from local area. The nominal coarse aggregate size is 20 mm. the texture of the aggregate will have significant effect on properties of concrete.

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3.6 Water

Water used for mixing and curing was potable water, which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials or other substances that may be deleterious to concrete or steel confirming to IS : 3025 – 1964 part22, part 23 and IS : 456 – 2000 [Code of practice for plain and reinforced concrete]. The pH value should not be less than 6. The solids present were within the permissible limits as per clause 5.4 of IS: 456 – 2000.

3.7 Bottom Ash

Bottom ash is one of the most extensively used supplementary cementitious materials in the construction field resembling Portland cement. It is an inorganic, noncombustible, finely divided residue collected. Most of the Bottom ash particles are solid spheres and some particles, called cenospheres, are hollow and some are the plerospheres, which are spheres containing smaller spheres inside. The particle sizes in Bottom ash vary from less than 1 µm to more than 100 µm with the typical particle size measuring less than 20 µm. Their surface area is typically 300 to 500 m^2/kg, although some Bottom ashes can have surface areas as low as 200 m^2/kg and as high as 700 m^2/kg. Bottom ash is primarily silicate glass containing silica, alumina, iron and calcium. The relative density or specific gravity of Bottom ash generally ranges between 1.9 and 2.8 and the color is generally grey.

It confirms with grade I of IS: 3812 – 1981 [Specifications for fly ash for use as pozzolana and admixture]. It was tested in accordance with IS: 1727 – 1967 [Methods of test for pozzolana materials]. A typical oxide composition of Indian fly ash is shown in Table 3.5. The chemical composition and physical characteristics of Bottom ash used in the present investigation were given in Tables 3.6.

3.8 Alkaline Solution

In the present investigation, sodium based alkaline activators are used. Single activator either sodium hydroxide or sodium silicate alone is not much effective as clearly seen from past investigation. So, the combination of sodium hydroxide and sodium silicate solutions are used for the activation of bottom ash based geopolymer concrete. It is observed that the compressive strength of geopolymer concrete increases with increase in concentration of sodium hydroxide solution and or sodium silicate solution with increased viscosity of fresh mix. Due to increase in concentration of sodium hydroxide solution in terms of molarities (M) makes the concrete more brittle with increased compressive strength. Secondly, the cost of sodium hydroxide solid is high and preparation is very caustic. Similarly to achieve desired degree of workability, extra water is required which ultimately reduce the concentration of sodium hydroxide solution. So, the concentration of sodium hydroxide was maintained at 13 M while concentration of sodium silicate solution contains Na_2O of16.37 %, SiO2 of 34.35 % and H_2O of 49.72 % is used as alkaline solutions. Similarly, sodium silicate-to-sodium hydroxide ratio by mass was maintained at1 which set cubes within 24 h after casting and gives fairly good results of compressive strength. These solutions were purchased from the local supplier.

Fig 3.1 NaOH

3.9 Super Plasticizer

High range water reducing admixture called as super plasticizers are used for improving the flow or workability for lower water-cement ratios without sacrifice in the compressive strength. These admixtures when they disperse in cement agglomerates significantly decrease the viscosity of the paste by forming a thin film around the cement particles. In the present work, water-reducing admixture Glenium conforming to IS 9103: 1999 [Specification for admixtures for concrete], ASTM C – 494 [Standard Specification for Chemical Admixtures for Concrete] types F, G and BS 5075 part.3 [British Standards Institution] was used. The details of the super plasticizer used are given in Table 3.7.

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3.12 Methodology

it describes about the workflow of the project as follows:

5.0 NUMERICAL INVESTIGATION

General

ANSYS is analysis software across a range of disciples including finite element analysis, structural analysis, computational fluid dynamics, explicit and implicit methods and heat transfer. The ANSYS MECHANICAL is a finite element analysis tool for structural analysis including linear, non-linear and dynamic studies. This computer simulation provides finite elements to model behaviour, and support material models and equation solvers for a wide range of mechanical design problems. ANSYS Mechanical also includes thermal analysis and coupled-physics capabilities involving acoustics, piezoelectric, thermal–structural and thermoelectric analysis. ANSYS workbench (Mechanical) is more graphics focused and geometry focused. There is less direct connection to the FEM. Workbench provides easy to learn, easy to use environment. The ANSYS Workbench environment is an intuitive up-front finite element analysis tool that is used in conjunction with CAD systems and/or design modeler.

ANSYS Modeling Procedure

The analysis focuses on,

- Engineering Data
- Geometric Modeling
- Meshing
- Boundary conditions and Loads
- Solution

5.3.1 Engineering Data & Geometrical Design

In engineering data to fill the properties such as Density, Poisson's Ratio, Young's modulus of concrete and Grade of Steel obtained experimentally has been assigned to the model.

Properties of Outline Row 3: Concrete

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2500	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's Modulus and Poisson...			
8	Young's Modulus	27386	MPa		
9	Poisson's Ratio	0.18			
10	Bulk Modulus	1.4264E+10	Pa		
11	Shear Modulus	1.1604E+10	Pa		
12	Tensile Yield Strength	0	Pa		
13	Compressive Yield Strength	0	Pa		
14	Tensile Ultimate Strength	0	MPa		
15	Compressive Ultimate Strength	30	MPa		

Fig: 5.1 Concrete Properties

5.3.2 Geometric Modeling

Firstly, a solid rectangular path has been taken according to the dimension of the experimental beam and reinforcement has been modeled as in the case of experimental beam as shown in Figure 5.2&5.3.

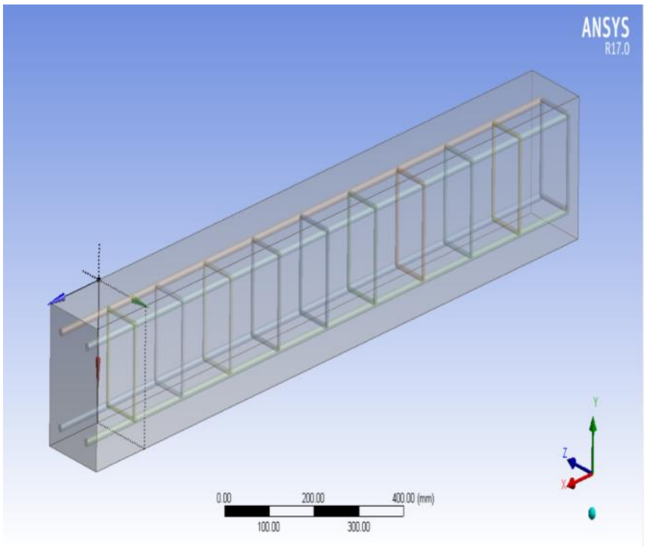

Fig: 5.2 Model-I Reinforcement arrangement

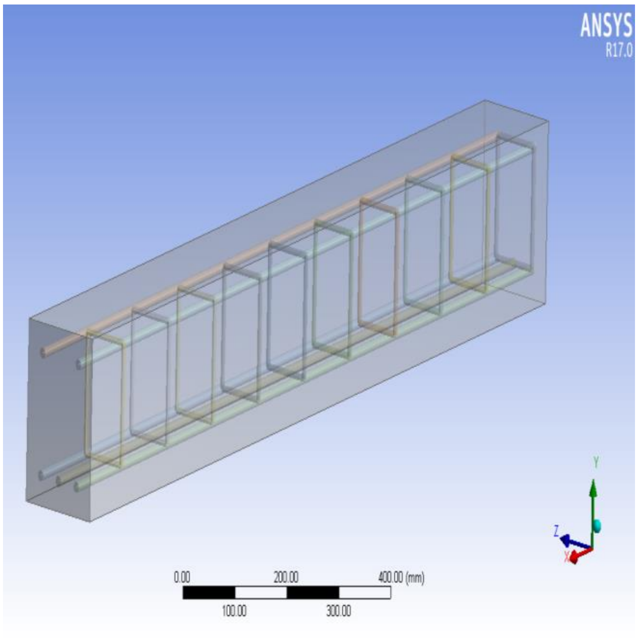

Fig: 5.3 Model-II Reinforcement arrangement

5.3.3 Meshing

The geometrical model is divided into number of elements by using isoperimetric meshing is as shown in Figure 5.4.

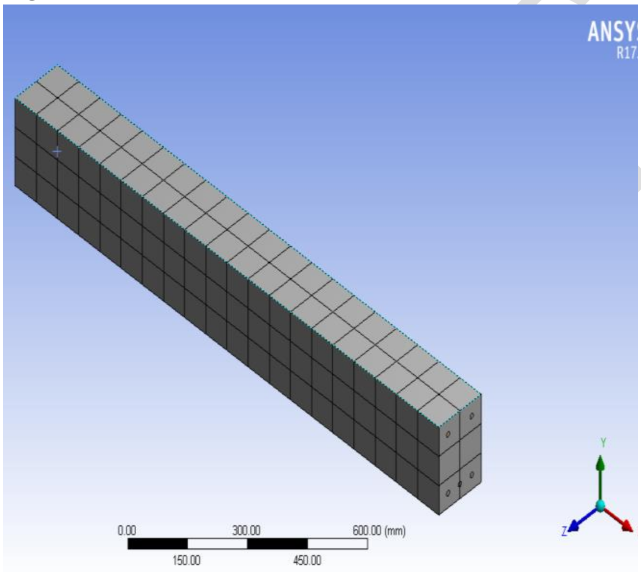

Fig: 5.4 Meshing

5.3.4 Boundary conditions and Loads

The boundary condition as in the case of simply supported beam has been assigned to the model. The RC beam were applied two point load to investigate the failure modes and improvement in strength as shown in fig.5.5

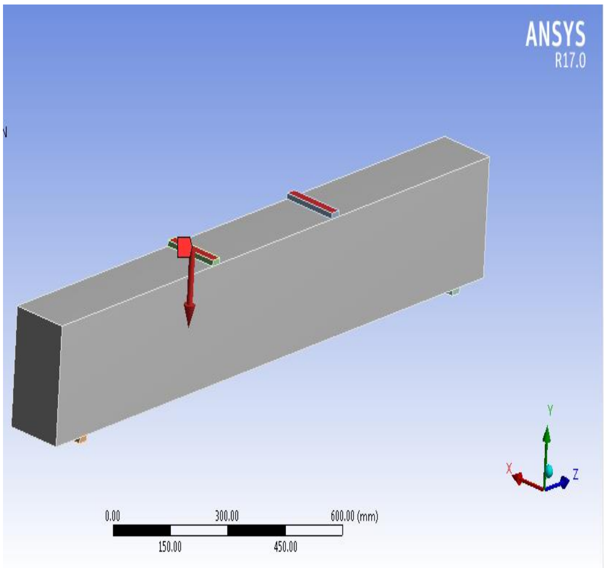

Fig: 5.5 Loading Condition

6.0 EXPERIMENTAL INVESTIGATION

6.1 Tests on Fresh Concrete

Fresh concrete or plastic concrete is freshly mixed material which can be molded into any shape. Strength of concrete primarily depends upon the strength of content paste. In other words, the strength of paste increases with cement content and decreases air and water content. Abrams w/c ratio law states that the strength of concrete is only dependent upon w/c ratio required from the point of view of workability.

6.2 Slump test

The slump test is the most well-known and widely used test method to characterize the workability of fresh concrete. The inexpensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete should be accepted or rejected. The test method is widely standardized throughout the world.

Fig: 6.1 Slump Specimen

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6.3 Preparation of Test Specimen

The preparation of test specimen including sampling of materials, preparation of materials, proportioning, weighting, testing for workability, choice of size of test specimens, compacting, and capping of specimen shall be in accordance with IS: 516-1959*, if test are intended to draw correlation curve between the results from compressive strength tests on specimens cures by normal curing method and accelerated curing. If the test are intended for control purposes, sampling shall be done in accordance with IS: 1199-1959* and choice of the size of the test specimens, compacting ad capping of specimen shall be done the size of the test specimens, compacting and capping of specimen shall be done in accordance with IS: 516-1959*, immediately after molding, each specimen shall be covered with a steel mould thinly coated with oil to prevent adhesion of concrete.

Threat and extent of hydration of cement under a particular curing regime depend mainly upon the chemical composition of cement, water cement ratio and mix proportions, which are considerable to be important parameters in the correlation of results from compressive strength test on specimens cured by normal curing method.

6.4 Tests on Hardened Concrete

For testing concrete in hardened state, it is required to cast various moulds like cubes, cylinders and beams. It is cured for the required period after 24hrs of casting.

6.4.1 Introduction about Hardened Concrete

Compressive strength of hardened concrete is most important parameter and representative of overall quality of concrete. It is mainly depended upon water cement ratio of the mix and curing and age after it is casted. Compressive strength of concrete is determined by testing cubical specimens using compressive strength testing machine at various ages such as 3days, 7days and 28 days.

Modulus of elasticity is yet another very important property of hardened concrete. It is obtained through testing cylindrical specimens. The stress applied and resulting deformation in the specimens are plotted and then stress strain curve, the modulus of elasticity is determined. Modulus of elasticity test on concrete is required for calculating deflection and predicting shrinkage cracking.

6.4.2 Compressive Strength Test:

Out of many tests applied to the concrete, this is the most important test which gives an idea about all the characteristics of concrete. By this single test one can judge that concrete is has done properly or not. For cube tests 2types of specimens are either 15cm*15cm*15cm or 10cm*10cm*10cm depending on the size of aggregate are used. For most of the works cubical moulds of size 15cm*15cm*15cm are commonly used.

These specimens are tests by compression testing machine after 7days or 28 days of curing. Load should be applied gradually at a rate of 14kg/cm² per minute till the specimen fails. Load at failure divided by area of specimen gives the compressive strength of concrete.

Fig 6.2 Compressive Strength Test

6.4.3 Tensile Strength Test of Concrete

The tensile strength of concrete is one of the basic and important properties. Splitting tensile strength test on concrete cylinder is a method to determine the tensile strength of concrete.

The concrete is very weak in tension due to its brittle nature and is not expected to resist the direct tension. The concrete develops cracks when subjected to tensile forces. Thus, it is necessary to determine the tensile strength of concrete to determine the load at which the concrete members may crack.

Horizontal tensile stress = $2P/\Pi D L$

Where,

P = Compressive load on the cylinder.

L = Length of cylinder.

D = Diameter of cylinder.

Fig: 6.3 Tensile Strength Test of Concrete

6.4.4 Flexural Strength Test of Concrete

Standard beam test (Modulus of rupture) was carried out on the beams of size 100 mm x 100 mm x 500 mm as per IS: 516 [Method of test for strength of concrete], by considering that material is homogeneous. The beams were tested on a span of 400 mm for 100 mm specimen by applying two equal loads placed at third points. To get these loads, a central point load has applied on a beam supported on steel rollers placed at third point as shown in Fig.3.9. The rate of loading is 1.8 kN/minute for 100 mm specimens and the load was increased until the beam failed. Depending on the type of failure, appearance of fracture and fracture load, the flexural tensile strength of the sample was estimated.

As explained earlier, in the present investigation, the flexural strength test has been conducted on concretes with different type of coarse aggregate M30 grade of concrete at 7and 28 days.

6.4.5 RC Beam Test

A total of six beams were cast, in which two beams were control reinforced concrete beams and two beams were bottom ash geopolymer reinforced concrete with bottom ash beam. Both beams are two different reinforcement arrangements. The beams were considered as simply supported and two point static loading was applied. The effective span of the beam measurement is 1200 mm. This beam load was tested by hydraulic jack and deviation was measured by load cell. Fig. 2.5 shows the experimental set up of simply supported beams subjected to monotonic loading. The load was increased till the failure of the specimen occurs. Then, the deflections at mid-span by LVDT were noted.

Fig. 6.7 RC Beam Test Setup

7.0 RESULTS AND DISCUSSIONS

7.1 Introduction

Numerical simulation and experimental investigation analysis is carried out considering different concrete property on the beam to determine its structural performance. The results of the parameter study are discussed herein.

7.2 Numerical Results

The parameters which are to be found such as Deflection, Maximum Equivalent stresses (Von-Misses stress) and Maximum Strain can be obtained upon selection. example, the stress contour of conventional and geo polymer concrete with bottom ash RC beam are shown in Figs. 7.1, 7.2,7.3 and 7.4. Table 7.1 shows the load–deflection values obtained using Ansys results.

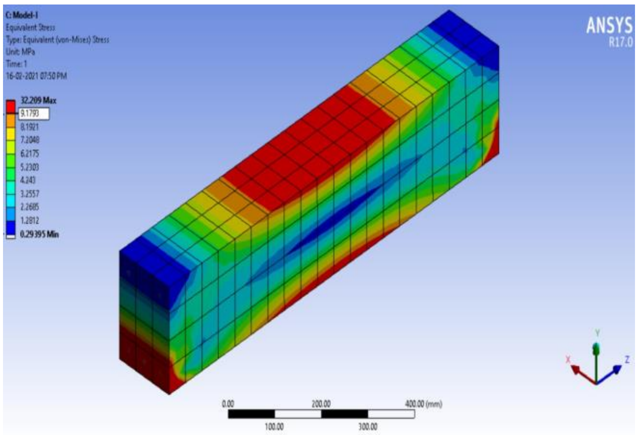

Fig. 7.1 RCM1 – Stress Contour

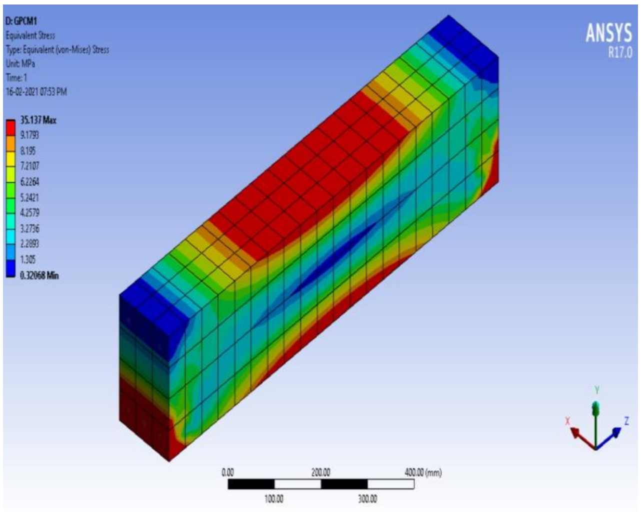

Fig. 7.2 GPCM1 – Stress Contour

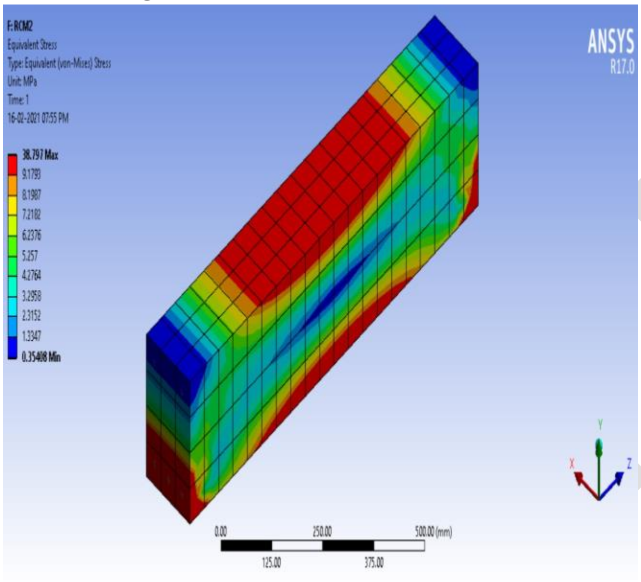

Fig. 7.3 RCM2 – Stress Contour

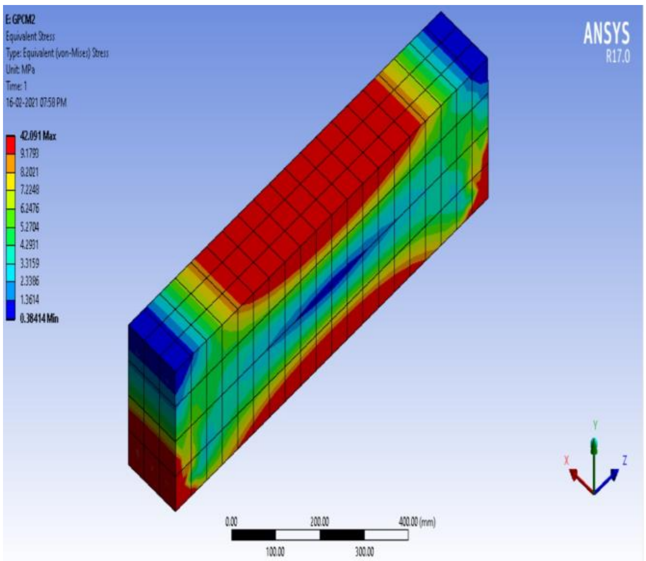

Fig. 7.4 GPCM2 – Stress Contour

SI. No	Specimen Designation	Ultimate Load (KN)	Deflection (mm)
1	RCM1	88	3.2
2	GPCM1	96	4.1
3	RCM2	106	5.4
4	GPCM2	115	6.1

Table: 7.1 Load–Deflection values

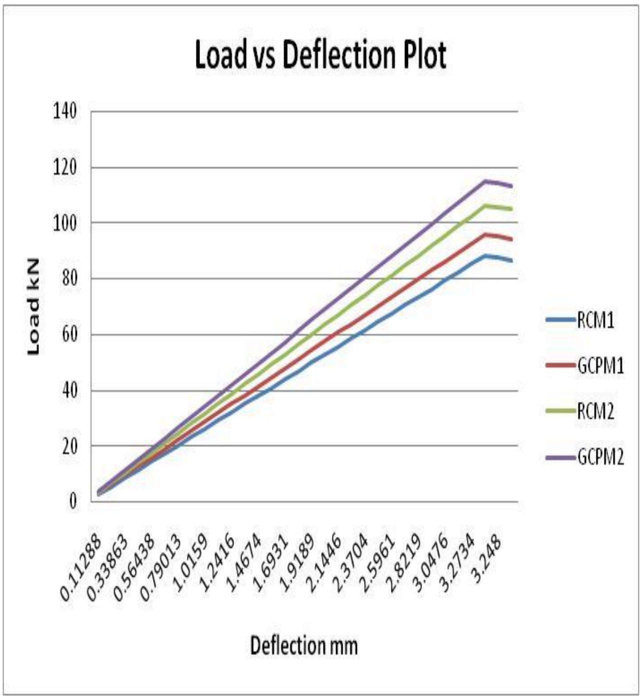

Fig. 7.6 Load Vs Deflection Curve for all Beams (Numerical Result)

7.3 Experimental Results

7.3.1 Compressive strength

The results of the mechanical properties (according to IS: 516) obtained on the basis of the samples tested according to Indian standard testing procedures are discussed. M30 grade conventional and geo polymer concrete with bottom ash are trial variables with their three different age cures. Details of the compressive strengths of the M30 standard are shown in Table 7.2.

From the table it is observed that rate of gain in Compressive strength is more at 28 days compared to 21 days.

7.3.2 Split tensile strength

The splitting tensile strength is presented. For a mix three cylinders were tested for split tensile strength. The results from the tensile test are presented in Table 7.3.

8. CONCLUSIONS

The geopolymer reinforced concrete with bottom ash beam has much greater advantageous than the normal reinforced concrete beam. In this project, various literatures were collected to get an idea about the geopolymer concrete. Numerical and experimental analysis of various concrete property beams was done and its results are obtained.

The beams were analyzed using 2-point load test and a flexural crack has been observed. From the study it shows that use of geopolymer concrete with bottom ash showed an improvement in both the ways and also increases the flexural capacity of the beam and it helps to increase stiffness under service loads. It also helps to reduce the deflection in both ways.

From the results the deflection values of beams are approximately near to the experimental values.

It is clearly seen that the load carrying capacity of geo polymer concrete with bottom ash increased with the increase of reinforcement with bottom ash.

Load carrying capacity of GPCM2 was 9 % higher than that of RCM2 & GPCM1 was 9.1 % higher than RCM1.

GPCM2 has the higher load carrying than GPCM1 due to the additional of reinforcement.

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