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STRENGTH ASSESSMENT OF HEAT CURED GEOPOLYMER CONCRETE SLENDER COLUMN

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ABSTRACT

Geopolymer and geopolymer concretes, being versatile in nature, have been acknowledged by research fraternity around the world. Many researches been undertaken, to date, dealt with the study on basic engineering properties of geopolymer mortars and unreinforced geopolymer concrete. Papers on application of geopolymer concretes as structural elements are found to be countable. This paper describes about the heat-cured geopolymer concrete slender circular columns using ASTM Class F Fly ash. This research focuses on the adaptability of Indian fly ash into geopolymer concrete structural members used primarily to support compressive loads. In this paper, geopolymer concrete slender circular columns of size 100mm diameter and length 1800mm with 2.16 % reinforcement are cast, tested and results are compared with its OPC concrete counterparts . Totally, 12 specimens of M30 and M50 grade slender columns were fabricated. Six specimens each for low calcium fly ash based reinforced Geopolymer concrete as well as for ordinary Portland cement reinforced concrete. The results have shown that the geopolymer concrete columns have exhibited increase in load carrying capacity, stiffness and ductility until failure.

Keywords: Geopolymer concrete; flyash; slender column; load carrying capacity; stiffness; ductility

1. INTRODUCTION

In recent times, construction activities are rocketing throughout the world. This exponential trend of construction has made the requirement of cement shoot up. Subsequently, the upward demand for cement has led the mushrooming of many cement industries all over the world. As predicted by Scientists, the worldwide requirement of cement, in the recent years, would be around 2.2 billion tonnes. Also, production of one tonne of cement leads to the emission of 0.8 tonne of CO_2, the prime green house gas which mostly contributes to global warming. This underlines the need for new technologies to overcome the environmental

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issue. In this scenario, the geopolymer Technology has emerged as the viable alternative to ordinary Portland cement, which was vented by Davdovits [1]. On the other hand, the flyash, the byproduct from coal based thermal power stations, also poses disposable problems requiring large area for its dumping which ultimately leads to environmental hazards. In spite of various technologies developed for fly ash use in concrete, the utilization rate of fly ash in them is still quite low. It is well established and acknowledged that the rate of consumption of fly ash shall be substantially increased in geopolymer concrete than high volume fly ash concrete. This increased usage of fly ash would help to reduce disposable problems and total elimination of cement in concrete and would contribute in a minor way, to a cleaner environment. Davidovits invented that Geopolymers were members of the family of inorganic polymers similar to natural Zeolitic materials, when produced with low Si: Al ratio of 2 would be suitable for Construction industries.

Recently, because of their architectural aesthetics and efficiency in the use of working space, relatively slender columns have been widely used in many building structures in the Metropolitan cities in India. Reinforced concrete structures are most commonly designed to satisfy serviceability and safety. To ensure the serviceability requirements, it is mandatory to observe precisely the crack patterns and failure modes under service loads. To meet out safety against failure, accurate estimation of ultimate load is essential. Therefore, the development and application of "Geopolymer Concrete Technology" to characterize reinforced concrete slender columns under axial concentric compression, under heat-curing mode is focused at, in this research article. The main objective of this research piece is to experimentally investigate the strength and buckling behavior of Reinforced Geopolymer Concrete Circular Slender Columns, based on the previous works done by Rangan, BV [2] on analysis on the behavior and Strength of reinforced Geopolymer Concrete Slender Columns. The experimental work done by Rangan BV involved testing of twelve columns under axial load and uniaxial bending in single curvature mode. He found out that the crack pattern and failure modes observed for Geopolymer Concrete Columns were similar to those reported in the literature for reinforced Portland Cement Concrete slender columns.

Though many literatures are available on Precast Geopolymer Concrete elements like what Angel Palomo et al. [3] tried and demonstrated on small sized pre-stressed Geopolymer Concrete monobloc sleeper for railway tracks; Gourley and Johnson [4] experimented and revealed the methodology to manufacture Geopolymer concrete sewer pipes and wall panels in a precast concrete plant: Siddiqui [5] exhibited the manufacturing process of reinforced geopolymer Concrete box Culverts under a two-stage steam curing regime; Ee Hui Chang [6] cast and investigated the shear strength of Geopolymer Concrete beams only very countable number of experimental works on Geopolymer concrete columns are available, till today.

Geopolymerisation is a geosynthesis reaction that chemically integrates minerals that involves naturally occurring silico-aluminates. Any pozzolanic compound or source of silica and alumina, that is readily dissolved in the alkaline solution, acts as a source of geopolymer precursor species and thus lends itself to geopolymerisation [1]. Mechanism of geopolymers yields Si-O-Al bond.

$$M_n [- (Si - O_2)_z - Al - O]_n \,.\, Wh_2O$$

Where M is the alkaline element, *z* is 1, 2, or 3 and *n* is the degree of polycondensation. Strong alkalis are required to activate the silicon and aluminum, which allows transforming glassy structure partially or totally into a very compacted rock like material.

2. EXPERIMENTAL PROGRAMME

2.1 Materials characterisation

2.1.1 Source materials

Any material rich in silicon and aluminium [7] in glassy powder form is apt for acting as a source material in the synthesis of Geopolymeric binder and consequently, Geopolymer concrete. In the recent past, several naturally available materials like Metakaolin clay, red soil or synthetic waste products from industries like ground granulated blast furnace slag and flyash have been used as source material and investigations are done. Though Metakaolin showed very fast rate of dissolution in the alkaline solution, owing to its high cost, the abundantly available flyash was chosen for this work. Since high calcium Indian flyash contains excess quantity of calcium and sulphate in it, which may disturb the polymerization action [8], ASTM Class F flyash was preferred than ASTM Class C flyash. Indian flyashes are heterogeneous in nature, greyish white in colour, contain moisture less than 3% by weight, bulk density 1047 Kg/m3, specific gravity 2.2 and with some traces of Sulphur trioxide. An X-Ray Fluorescence (XRF) analysis done to determine the chemical composition of low calcium flyash collected from Tuticorin Thermal Power plant used in this experimental program is shown in Table 1. Flyash is obtained from Tuticorin Thermal power plant, Tamilnadu and contained 1.26% of CaO by weight and hence has been designated as Class F fly ash.

2.1.2 Alkaline liquids

The silicates and hydroxides of water soluble high alkaline Sodium is utilized in this investigation. The alkali silicate (Na2SiO3), commonly known as water glass is purchased from a local supplier in bulk with a modulus ratio of 2.15. The alkali hydroxide (NaOH) which is also called lye or caustic soda, in flake form with 97%-98% purity is also purchased from a local supplier in bulk. The hydroxide solution required for complete activation is prepared to a concentration of 12M by adding water i.e. 12 X 40 = 480 grams of NaOH flakes in one litre of solution, where 40 is the molecular weight of NaOH.

2.1.3 Other materials

Hard Blue Granite metal comprising of 20mm, 12mm and 6mm size purchased from local quarry is used as coarse aggregate and sand collected from the Vaigai river is used as fine aggregate. The specific gravity of coarse aggregate and fine aggregate are 2.75 and 2.60 respectively. All the aggregates are in surface dry condition. To improve the workability10 of stiff and fresh concrete, Glenium B233, product of BASF, a PCE polycarboxylic ether based super plasticizer is added. The addition of super plasticizer enhanced the workability considerably and the mean slump for G30 Concrete is 57 mm and the slump noticed for G50 Concrete is very minimal despite adding superplasticiser.

Table 1: Chemical composition of fly ash

Type of Chemicals	% by Weight
Silica	65.43
Alumina	20.67
Iron Oxide	6.18
Calcium Oxide	1.26
Magnesium Oxide	0.82
Sodium Oxide	-
Sulphur Trioxide	Trace
Titanium Dioxide	-
Potassium Oxide	-

2.2 Mixture proportions of concrete

The materials for Geopolymer concrete are mixed as per details provided in Table 2.

Ordinary Portland Cement of 43 grade is used to prepare the Counterparts M30 grade and M50 grade concrete columns. The design mix ratio is 1:1.84:3.61 for M30 grade concrete with water/cement ratio as 0.38 and the mix ratio for M50 grade concrete is 1:0.94:3 with water/cement ratio as 0.34. Pan mixer is used to mix the concrete and effective control on water/cement ratio is maintained to achieve results. The details of pan mixer is shown in Figure 1. For every batch of concrete unloaded from mixer, representative or companion concrete cubes of three numbers are cast for evaluating their compressive strengths.

Table 2: Proportioning of constituent materials

Constituent Materials	G 30	G50
Coarse aggregate 20mm	388	---
12mm	543	841
6mm	363	360
River sand	554	647
Fly ash	378	408
Sodium Hydroxide	50	63
Sodium Silicate	124	138
Super Plasti-cizer	8	8
Water	----	----

Figure 1. Pan mixer

2.3 Specimen details

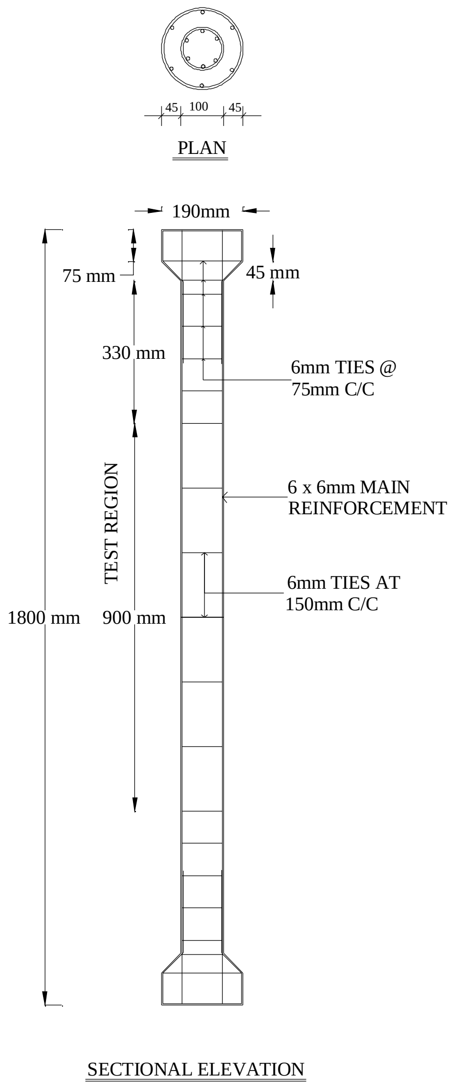

Figure 2. Sketch showing plan and sectional elevation of slender column (typical)

All the slender Columns are 100mm in diameter with enlarged head at the ends, in order to avoid crushing failure. All the columns are provided with six 6mm diameter mild steel rods as longitudinal reinforcement and 6mm diameter mild steel rods at suitable spacing as circular ties. The overall height of column is divided into central test region of height 900 mm and two end regions of height 450 mm each. The circular lateral ties are placed at a spacing of 150 mm centre to centre, uniformly throughout the test region where observation has to be taken. For the end regions, spacing of 75mm centre to centre is provided. Extra rods are provided at both the end regions to suit the configuration of head. The plan view and sectional view of the column (typical) has been shown in Figure 2. The designation for Geopolymer concrete of 30MPa compressive strength is given as G30; for 50MPa grade, M50; for 30MPa grade ordinary Portland cement concrete as M30 and for 50MPa grade ordinary Portland Cement Concrete specimen as M50. Totally, 12 numbers of columns are cast. Three numbers for each G30, G50, M30 and M50 Grade concrete.

2.4 Manufacturing process of specimen

Sodium Silicate and Sodium hydroxide solution are mixed together in a ratio of 2.5, consumed immediately after mixing. Weighed quantity of fly-ash and alkaline solution are first mixed together, to initiate polymerization process, in the 150-kg capacity concrete pan mixer for about 4 minutes. Subsequently fine aggregate and coarse aggregates are added to the Geopolymer paste and the mixing continued for about 3 minutes. Before taking out the mixture from the pan mixer, superplasticiser (2% by weight of flyash) is added to improve the workability. The details of pan mixer is shown in Figure1.The fresh concrete is poured into the column mould made of plywood and companion 150mmx150mmx150mm cube moulds, in three layers. For better and uniform compaction, each layer is vibrated for 2 minutes on a table vibrator. Slump cone test is done to find out the workability of fresh concrete. Keeping actual site procedure in mind, Columns are cast vertically. The specimen kept on the table vibrator is shown in Figure 4.

Figure 3. Heat curing chamber under operation mode

2.4 Curing regime of test specimen

Immediately after casting, all the columns and cubes are kept inside Steel chamber and cured at 70^0C for 24 hours. After heat curing, test specimens are allowed to cool in the moulds for six hours in order to avoid a drastic change due to change in temperature. After demoulding, the specimens are air dried in the room until the date of test. The Heat Curing Chamber which was designed exclusively [9] for manufacturing Geopolymer Concrete Columns is shown in Figure 3.

2.5 Testing of specimens

Slender columns are tested in a compression testing machine of capacity 2000kN. The specimens are tested under monotonically increasing axial compression and three

Figure 4. Specimen (typical) during table vibration

Figure 5. Experimental set up and instrumentation

LVDTs are positioned at selected locations to monitor the lateral deflection and axial deformation of the columns. Extra care is taken to avoid eccentricity caused due to imperfect alignment of column by checking the verticality of column with plump bob and a level. The ends of the column are planed smoothly with the aid of granite polisher in such a manner that the orthogonality of axis is achieved. The orthogonality of horizontal plane is achieved by two spirit levels. Observed cracks are also monitored and marked for further study. Suitable head is provided at both ends with dimension 190 mm diameter. The load is applied gradually in a controlled manner in increments of 2kN by hand pumping the manually operated hydraulic jack.The loading is monitored through a high accuracy load cell with a sensitivity of 1kN. The initial cracking load, ultimate load, failure load and the deflection mode of all the specimens are noted for comparison with that of reference concrete columns. All the readings are recorded in a data logger system. The picture showing experimental test set up at the time of testing is going-on, is shown in Figure 5. The design provisions contained in the current standards and codes are used to design reinforced fly ash-based geopolymer concrete structural members.

3. RESULTS AND DISCUSSION

3.1 Load carrying capacity

All columns are tested under monotonically increasing axial compressive load. As expected, the load carrying capacity of the columns increased with the increase in compressive strength of concrete. The failure loads of reinforced Geopolymer long columns are compared with its counterpart concrete columns' results. Comparison of failure loads of tested Geopolymer Concrete Columns and Ordinary Portland Cement Concrete Columns is tabulated in Table 3. It is established that all the columns according to their corresponding Grade behaved similarly, which is obvious from the test results shown in the Table 3. All the G 30 Grade columns have shown exemplary results in load carrying capacity than M 30 Grade Concrete Columns by around 34.2% and G 50 Grade Columns are stronger than M 50 Grade concrete columns by 27% which might be due to the rigidity of higher grade Geopolymeric materials. This shows the higher concrete strength columns have shown a more sudden drop in load after peak. This observed phenomenon reveals that there may be possibility of stability failure to occur in higher strength concrete columns. The load vs mid-height deflection curves of geopolymer Concrete columns (typical) and OPC Concrete Columns are shown in Figure 6.

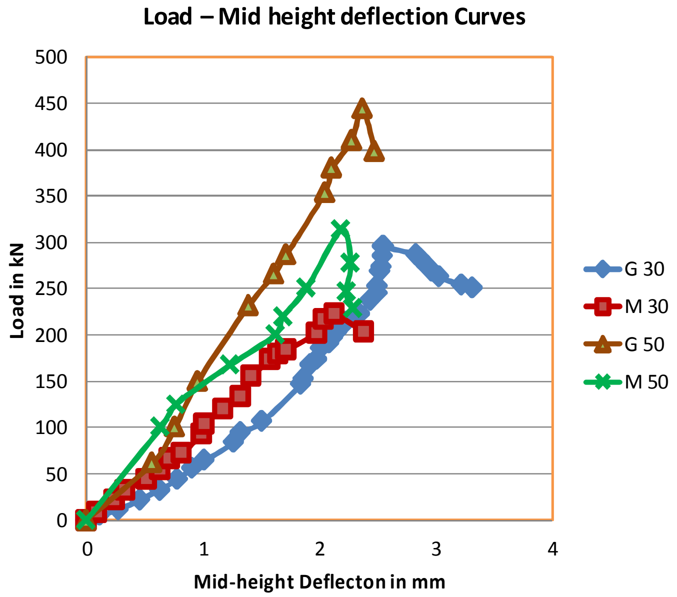

Figure 6. Load – mid height deflection curves of typical geopolymer concrete columns and typical OPC concrete columns

3.2 Ductility

The concept of ductility is related to the ability to sustain inelastic deformations without substantial decrease in the load carrying capacity. From the experimental results, it is inferred that, regardless of material properties, all the 30MPa Grade concrete columns possess high ductilityIndex , which is appreciable for structural elements. All G50 Grade Concrete columns exhibited more ductility than M50 Concrete columns. It is well established that whenever the grade of Concrete increases, the material tends to result in lower ductility. When Geopolymer Concrete columns are used for earthquake resistance structures, a ductile type behavior is recommended and essential to form plastic hinges and to enhance their capacity to absorb and dissipate energy without significant loss in strength. From this point of view also, Geopolymer Concrete column exhibited superior quality.

Table 3: Details of columns and their results

Specimen Id	Details of Companion Concrete elements			Ultimate Load Tested P_{ut} (kN)	Calculated Ultimate Load P_{uc} (kN)	Correlation Ratio P_{ut}/P_{uc}	Compressive Strength of Column (MPa)	Ductility Index (μ)
	No.of cubes Cast	Comp. Strength (MPa)	Split tensile strength (MPa)					
G 30-I	3	34.59	4.42	296	202	1.47	37.77	1.09
G 30-II		35.85	4.58	276	202	1.37	35.16	0.98
G 30-III		36.00	4.89	302	202	1.50	38.47	1.07
M 30-I	3	32.90	4.21	244	202	1.21	31.08	0.94
M 30-I		31.04	4.03	196	202	0.97	24.96	0.80
M 30-III		30.67	4.09	222	202	1.09	28.22	0.92
G 50-I	3	54.20	7.35	393	309	1.02	50.06	0.93
G 50-II		53.35	7.05	444	309	1.43	56.56	1.06
G 50-III		52.95	7.47	348	309	1.12	44.33	0.84
M 50-I	3	52.77	7.03	278	309	0.89	28.19	0.53
M 50-II		56.44	7.11	243	309	0.79	30.86	0.55
M 50-III		57.82	7.24	313	309	1.01	29.72	0.51

3.3 Crack patterns and failure modes

The initiation of cracks is seen at the mid-height of all Columns , invariably of Grade of concrete and materials type. Then, the cracks get propagated in upward directon with increase in applied load, allowing new cracks to form. All the G30 Grade Columns showed buckling of reinforcement, as shall be witnessed from Figure 7, as the load increased until failure. The zone of failure is around 175mm above and below the mid-height of G 30 columns. The mode of failure shall be seen in Figure 7. Invariably, in all M50 grade concrete columns, cracks initiated near the head of the column and the crack propagated at the circumference of column 450mm below the top end of column.

The mode of failure is seen in Figure 8. The reason for such failure may be due to rigidity of concrete with increase in compressive strength.

Figure 7. Failure pattern of G30 concrete column (typical)

Figure 8. Failure pattern of G50 concrete column (typical)

3.4 Ultimate loads

The ultimate loads the concrete can withstand without failure are given in Figure 9. It is inferred from the bar charts that both G30 and G50 grade concrete columns took higher loads when compared to calculated as well as its corresponding counterparts.

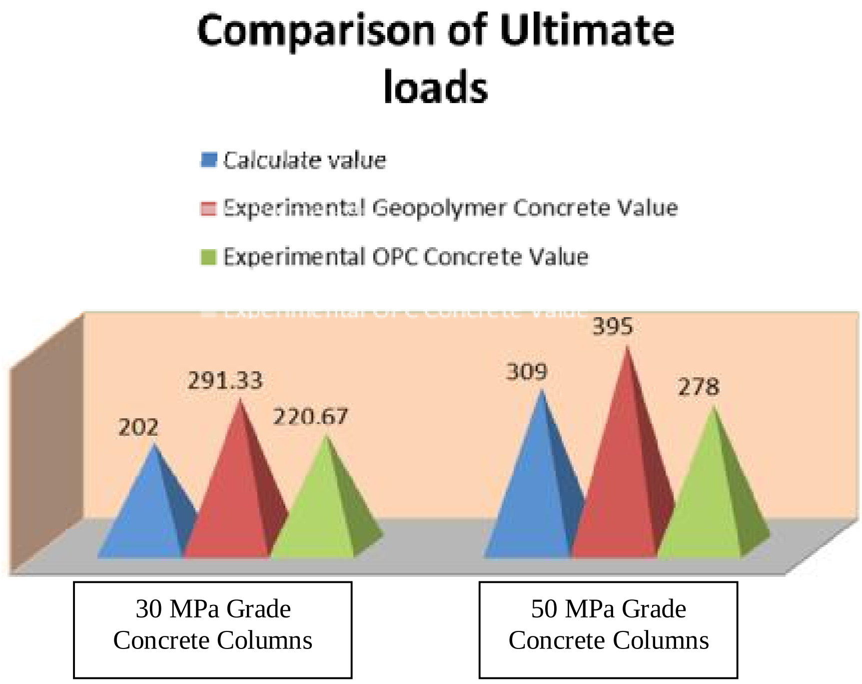

Figure 9. Comparison of ultimate loads for G30 and G50 concrete columns

4. CONCLUSIONS

An investigation is carried out to study the applicability of Geopolymer Concrete into the main important structural element, Columns. This is done on two different grades of concretes and has been compared with its counterpart OPC concrete columns. Based on the results of the study, the following conclusions are drawn.

1. The bonding of Geopolymer paste and aggregates is so strong and cohesive hence the segregation of aggregates from paste while placing the concrete is very minimal.
2. All the Geopolymer concrete columns behave similar to OPC columns regardless of the grade of concrete. Despite having the same steel reinforcement ratio for both reinforced Geopolymer Concrete and RCC Columns, the former Columns exhibited slightly lesser deflection withstanding higher loads.
3. The mean value of experimented/calculated ultimate load of both the M30 Grade Concrete columns is 1.27. The ultimate load capacity of M30 Grade Geopolymer concrete columns is much higher than the control columns and also exhibit ductile behaviour.
4. Although slender columns under axial compression usually do not encounter in real construction field, extra care is taken to maintain its verticality not only at the time of casting but also at the time of testing. All the specimens tested in this study failed showing inelastic buckling.

5. The mean value of experimented/calculated ultimate load of both the M50 Grade Concrete columns is 1.04. The ultimate load capacity of M50 Grade Geopolymer concrete columns is slightly higher than the control columns and also exhibit lesser ductility until failure.
6. Geopolymer concrete columns show less deformation than that of controlColumns for the same percentage of steel.
7. In accordance with the above data, it is pertinent to point out that there is a promising scope in the applicability of Geopolymer concrete as structural elements in the construction field.

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REFERENCES

1. Davidovits J. Soft mineralogy and geopolymers, *Proceedings of Geopolymer 88 International Conference*, the Université de Technologie, Compiegne, France, 1988.
2. Sumajouw DMJ, Hardjito D, Wallah SE, Rangan BV. Fly ash based geopolymer concrete-study of slender reinforced columns, *Journal of Material Sciences*, **43**(2007) 3124-30.
3. Palomo A, Grutzeck MW, Blanco MT. Alkali activated fly ash cement for future, *Cement and Concrete Research*, No. 8, **29**(1999) 1323-29.
4. Gourley JT, Johnson GB. Developments in geopolymer precast concrete, *International Workshop on Geopolymers and Geopolymer Concrete*, Perth, Australia, 2005.
5. Siddiqui KS. Strength and durability of low-calcium fly ash-based geopolymer concrete, University of Western Australia, Perth, 2007.
6. Ee Hui Chang. Shear and bond behaviour of reinforced fly ash-based geopolymer concrete beams, *Research Report*, Curtin University of Technology, Perth, Australia (2009).
7. Hardjito D, Rangan BV. Development and Properties of Low-Calcium Fly Ash-based Geopolymer Concrete, *Research Report GC-1*, Faculty of Engineering, Curtin University of Technology, 2005.
8. Bakharev T. Geopolymeric materials prepared using class F flyash and elevated temperature curing , *Cement and Concrete Research*, No. 6, **35**(2005) 1224-32.
9. Kannapiran K, Nagan S. Durability study on alumino-silicate concrete, synthesized using anthracite coal flyash, *Journal of Structural Engineering*, No.1, **38**(2011) 94-100.
10. IS 456:2000, Indian Standard Code for Plain and Reinforced Concrete – Code of practice, 4th Revision, BIS, New Delhi.