STRUCTURAL ANALYSIS ON FLY ASH BASED GEOPOLYMER COLUMNS IN MODERN CONSTRUCTION

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Abstract: This research is on the behavior of Low-Calcium Fly Ash-Based Geopolymer Concrete with and without manufactured sand. Common river sand is expensive due to excessive cost of transportation and scarcity from natural sources. As environmental constraints make the availability and use of river sand less attractive, a substitute or replacement product for concrete industry needs to be found. There are six short columns going to be casted for the optimized compressive strength that will obtain by testing the specimens casted with river sand or manufactured sand as fine aggregate. Among the six columns three for river sand and the remaining three for manufactured sand.

***IndexTerms* – Fly Ash, Geopolymer Concrete, Manufactured sand and River sand.**

I. INTRODUCTION

Geopolymer concrete is produced without the presence of Portland cement as a binder. Instead, the base material such as fly ash, that is rich in Silicon (Si) and Aluminum (Al), is activated by alkaline solution to produce the binder. The Portland cement is used as an important ingredient in the conventional concrete. It is reported that geopolymer concrete possess excellent similar strength and appearance to those from conventional concrete made from the Portland cement. It is estimated the one ton of carbon di oxide is emitted to the atmosphere for the production of one ton of cement. Moreover, cement production also consumes significant amount of natural resources.

On the other hand, already huge volume of fly ash is generated around the world; most of the fly ash is not effectively used, and a large part of it is disposed in landfills. Due to the need of power, high volume of fly ash is produced. It is necessary and significant to use fly ash as material to produce concrete without Portland cement. By using geopolymer concrete we can reduce the emission of carbon dioxide during the cement production, also the manufactured sand can be used in an effective manner to produce the concrete. The fly ash usage will reduce the pollution in the environment.

The source materials and the alkaline liquids are the two main constituents of geopolymers. Geopolymers are adherents of the inorganic polymer family. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, which is in polymeric chain and ring structure.

II. PROPERTIES OF MATERIALS

2.1. Fine Aggregate

The Zone III natural river sand is used as fine aggregate in concrete. The aggregate used was cleaned and rendered free from silt, clay and other impurities. Sand should be as per IS 383-1963. The river sand is used which passes through 4.75mm sieve. Physical properties of aggregates are as per IS 2386-1963.

2.2. Manufactured Sand

Successful manufactured sands are generally 4 mm minus or smaller. All but one sample ranged from 95 to 100% passing the 4.75-mm sieve. An excess of material retained on the 4.75-mm sieve is regularly reported to have a negative impact on concrete slab finishing processes, as well as reducing concrete workability. The grading of fine aggregates shall be so controlled that fineness module of at least nine out of ten sample of fine aggregate delivered to the maximum shall not vary more than 0.20 from the average of ten samples tested.

2.3. Fly ash

The production of energy is essential for industrial growth in the country. Out of total installed generating capacity of 82000 MW at present in India about 53000 MW is generated from coal based thermal units. Fly ash is a waste product from these power stations and is available in the form of fine dust. Seventy-two power plants in India are the source of fly ash. About 220 million tonnes of coal used as fuel annually produces about 80 million tonnes of ash as a byproduct. The figure is likely to cross 100 million tonnes per year by the end of this century. The level utilization of fly ash in India is low. If the utilization of fly ash is not increased by an order of magnetite, the hazards of fly ash will grow and may become alarming in many parts of the country. Fly ash is a versatile material with many applications is in the construction industry. However, over 20% fly ash produced in the world is utilized in variety of application.

2.3.1. Chemical composition of fly ash

The major constituents of ash are Silica (SiO_2), Alumina ($A1_2O_3$) and Iron oxide (FeO) with traces of Calcium (CaO), Magnesium (MgO) Sulphur (SO_3). The chemical composition of all the samples is almost same. The constituents most likely to affect the index and engineering properties of fly ash are Silica, Free lime, Iron and Carbon.

2.3.2.Coarse Aggregate

The size of coarse aggregate used in concrete was 20mm passing and 10mm retaining. The aggregate used must be cleaned and rendered free from silt, clay and other impurities. The coarse aggregate shall conform to relevant specification of latest IS: 515 (for natural and manufactured aggregates) or of IS: 383-1963 (for natural aggregates as revised from time to time). The aggregates shall be composed of clean, hard, durable pieces of stone, regular in shape obtained naturally or by crushing from suitable stone. The coarse aggregate shall be free from objectionable quantity of weeds or other deleterious substances, the preparation of which in any size of coarse aggregates as delivered to the mixture shall not exceed the following values. Permissible deleterious materials in manufacture of coarse aggregates.

2.3.3. Alkaline Solution

Chemical activation using sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) is prepared. The alkaline liquid is prepared by using sodium silicate solution and sodium hydroxide pellets. The NaOH solution is made in different molars. The alkaline liquid is prepared by mixing the two solutions together at least 24 hours prior to use. The sodium silicate solution is commercially available in different grades. The sodium silicate solution with SiO_2-to-Na_2O ratio by mass of approximately, i.e., SiO_2 = 15.89%, Na_2O = 4.37%, and water = 79.74% by mass, is used for the test. The 97% to 98% pure sodium hydroxide in flake or pellet form, is commercially available.

III. MIX PROPORTIONS

3.1. SELECTION OF MIX PROPORTION

To achieve high durability of GPC, the mix design should be based on the following considerations.

1. The water binder ratio should be least as possible.
2. The workability of concrete mix should be enough to obtain good compaction.
3. The transition zone between aggregate and binder should be strengthened.

3.2. MIX DESIGN OF GEOPOLYMER CONCRETE

The mix design in the case of geopolymer concrete is inverse to that of the conventional concrete. The material proportion can be found out for the required strength using the code for conventional concrete, but in the case of geopolymer concrete there is no design methods or codal provisions readily available. Here only by means of trail mixes the concrete is being produced. By testing that concrete produced by trail mixes we will get some strength. Now this trail proportion is the required mix design for that particular strength attained. For e.g. If we got a strength of 30 N/mm^2 for a particular trail mix, then that is the mix proportion for M30 concrete.

Table 4.1: Trial Mix for geo polymer concrete with natural river sand as fine aggregate

Materials	Fly ash	River sand	C.Aggregate	Water	Sodium silicate	Sodium hydroxide solution
Mix 1	374.91	583.35	978.22	48.69	92.05	37.22
Mix 2	364.91	585.35	1049.52	36.50	184.50	52.72
Mix 3	419.65	585.35	1018.03	44.23	171.12	68.45
Mix 4	482.60	567.79	987.50	44.23	171.12	68.45
Mix 5	554.99	550.75	957.87	44.23	171.12	68.45
Mix 6	554.67	534.23	810.40	44.23	171.12	68.45
Mix 7	483.72	567.11	882.15	14.15	224.58	89.83
Mix 8	554.67	535.40	832.82	12.72	257.50	82.19
Mix 9	483.72	567.11	832.82	28.30	205.47	82.19
Mix 10	554.99	535.40	832.82	14.15	224.58	89.83
Mix 11	554.67	554.67	832.82	28.30	205.47	82.19
Mix 12	364.91	364.91	964.32	14.15	207.25	83.83

Mix 13	447.21	576.26	907.46	28.30	224.58	89.19

Table 3.2: Trial Mix for geo polymer concrete with manufactured sand as fine aggregate

Materials	Fly ash	M.sand	C.Aggregate	Water	Sodium silicate	Sodium hydroxide solution
Mix 1	374.91	572.40	978.22	43.79	93.05	37.22
Mix 2	364.91	613.22	1049.52	36.50	184.50	52.72
Mix 3	419.65	608.10	1018.03	44.23	171.12	68.45
Mix 4	482.60	589.86	987.50	44.23	171.12	68.45
Mix 5	554.99	572.16	957.87	44.23	171.12	68.45
Mix 6	554.67	615.61	810.40	44.23	171.12	68.45
Mix 7	483.72	652.07	882.15	14.15	224.58	89.83
Mix 8	554.67	615.61	832.82	12.72	257.50	82.19
Mix 9	483.72	652.07	832.82	28.30	205.47	82.19
Mix 10	554.99	615.61	832.82	14.15	224.58	89.83
Mix 11	483.72	652.07	882.15	28.30	205.47	82.19
Mix 12	554.67	615.61	832.82	14.15	224.58	89.83
Mix 13	554.67	615.61	832.82	28.30	205.47	82.19

The mix design in the geopolymer concrete has certain assumptions.

1. The quantity of combined aggregates may be taken to between 76% and 80% of the quantity of the geopolymer concrete.
2. The alkaline liquid to fly ash ratio by mass values in the range of 0.30and 0.45 are recommended.
3. The ratio of sodium silicate solution to sodium hydroxide solution is by mass the mass of 2.5.

IV. MECHANICAL PROPERTIES

4.1 COMPRESSIVE STRENGTH

The compressive strength test is the most common test conducted because most of the desirable characteristic properties of concrete and the structural design purpose are qualitatively related to compressive strength. The test was conducted in compression testing machine as per the specifications given in IS 516: 1959 under normal room temperature. The test set up is shown in Fig 4.1. The compressive strength of concrete cube is calculated by using equation,

$$\text{Compressive strength} = \frac{\text{Maximum Load}}{\text{C / S Area of the cube}} \quad N/mm^2$$

Fig 4.1 Testing of cubes in CTM

Table 4.1. Specimen Sizes

S.No	Properties Studied	Specimen Shape	Properties Studied	No. of Specimens	Specimens Sizes in mm
1	Concrete Strength Related Properties	Cube	Compressive Strength	26	100 x 100 x 100
2		Cylinder	Spilt Tensile Strength	26	100 x 200

4.2 SPLIT TENSILE STRENGTH

The test was conducted in CTM of capacity 2000 kN. The tensile strength of cylinders is calculated by the formula given below.

$$SplitTensileStrength = \frac{2P}{\pi LD}$$

Where,

P= Compressive Load in kN

L=Length in mm

D=Diameter in mm

The split tensile strength results are listed in Table 5.4 and 5.5. The failure of cylinder specimens is shown in Fig 4.2.

Fig 4.2 Failure of Cylinder Specimen

4.3 RESULTS AND DISCUSSIONS

4.3.1 COMPRESSIVE STRENGTH TEST RESULT

Totally there are 26 cubes casted to determine the compressive strength of GPC, where 13 cubes are casted with river sand as fine aggregate and the remaining 13 are casted with manufactured sand as fine aggregate. Due to the need of high temperature the cubes are placed in heat chamber. After 14 hours the cubes are taken out from the heat chamber and allowed for testing. The compressive strength of test cubes was measured and shown in the table 4.2 and 4.3 below.

Table – 4.2 Compressive strength for GPC with river sand

Days	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix 7**
7	21	20	19	21	22	29
14	24	23	23	24	25	33
28	32	25	25	28	34	35
Days	**Mix 8**	**Mix 9**	**Mix 10**	**Mix 11**	**Mix 12**	**Mix 13**
7	24	24	22	26	20	22
14	28	27	25	30	24	25
28	36	35	37	39	31	36

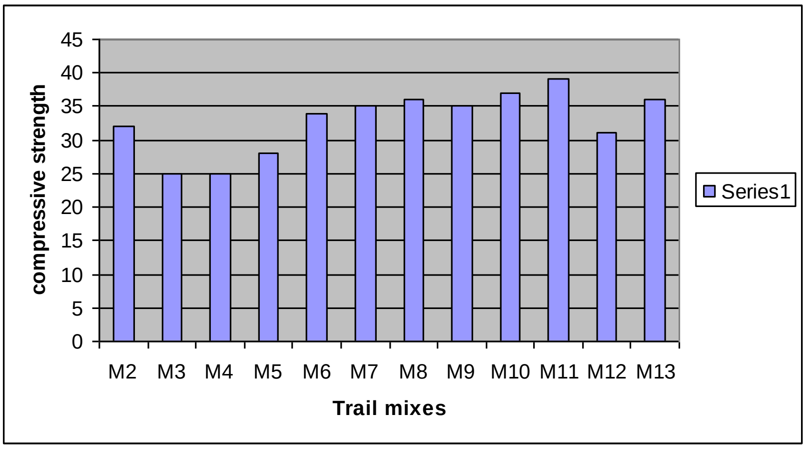

Fig 4.3 Compressive strength test result with river sand

Table – 4.3 Compressive strength for GPC with manufactured sand

Days	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7
7	12	20	19	21	12	17
14	21	25	22	24	21	33
28	27	34	24	25	27	35
Days	**Mix 8**	**Mix 9**	**Mix 10**	**Mix 11**	**Mix 12**	**Mix 13**
7	13	14	13	14	12	17
14	20	22	21	23	20	21
28	23	24	23	25	23	24

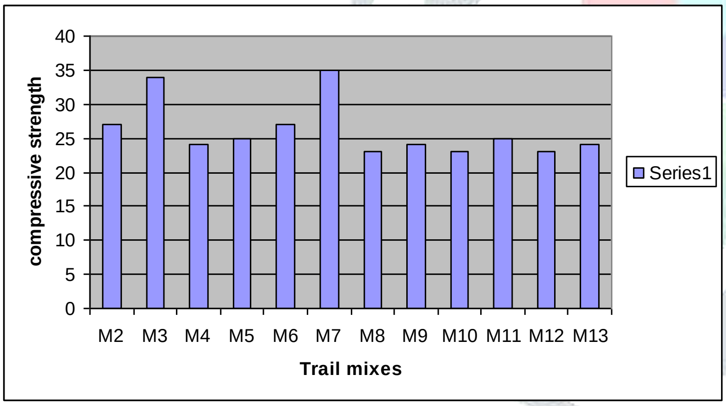

Fig 4.4 Compressive strength test result with manufactured sand

4.4 DESIGN DETAILS OF SHORT COLUMNS

Behaviour of GPC Short Columns Under Axial Compression

Ultimate Load Carrying Capacity of Columns

Gross area of the column,	Ag	= 100 x 100 =10000 mm^2.
Area of steel in compression,	Asc	= 452.39 mm^2. {(π x 12^2) / 4} x 4
Area of concrete,	Ac	= Ag – Asc
		= 10000 – 452.39 = 9547.61 mm^2.
M35 Grade Concrete,	fck	= 35 N/ mm^2.
Fe 415 Grade Steel,	fy	= 415 N/ mm^2.

Strength of Column

Axial load carrying capacity of short columns is determined by,

Pu = 0.4 fck. Ac + 0.67 fy. Asc
= (0.4 x 35 x 9547.61) + (0.67 x 415 x 452.39)
= 193089.893 N

Ultimate strength of column Pu = 193.089 kN

For M35 grade concrete

In this test slenderness ratio of short column is 10

Dimensions of columns =100 mmx100 mm x 1000 mm

4.5 MATERIALS

GPC column specimens were provided with M25, M30 and M35 mixes, alkaline solutions, Natural River sand, manufactured sand and crushed graded aggregate of size 12.5 mm were used. Fe415 grade steel was used as main reinforcement. For short column, the main bar reinforcement was 12 mm in Diameter, lateral ties of 6 mm diameter, Spacing 50 mm @ Both ends & 100 mm @ Middle Portions as per IS 456-2000.

All the reinforced column specimens were cast at the Structural Engineering Laboratory. Plywood moulds are used for casting the columns. Before Casting, oil was applied on all the surfaces of the moulds. Cover blocks were placed inside the mould to give proper cover to the reinforcement. All the materials were taken by weight as per the mix proportions. Concrete was mixed by hand mixing were adopted for making concrete and was poured into the moulds in layers. The concrete was well compacted and after 24 hours of casting, the specimens were demolded from the mould and the columns were kept for 24 hours under hot temperature. To facilitate easy loading of the columns, all the columns were provided with column heads both at top and bottom ends. After drying they were cleaned with a sand paper to remove all grit and dirt. Then all the specimens were prepared by white washing from all sides. White washing was done to facilitate easy detection of crack propagation.

V. EXPERIMENTAL SETUP AND INSTRUMENTATION

The rubber pads are used as the support for the column to provided hinged end condition. The column specimens are adjusted so that the centre line of the axial load coincides with column faces. Proper care was taken to ensure the load was applied as concentrically as possible throughout the test setup. The plumb bob was used to keep the columns perfectly vertical, however some eccentricities are unavoidable. All the short columns were tested for axial compression under a loading frame of capacity of 1000 kN. One 50 mm range Linear Voltage Differential Transducers (LVDT) is placed at the middle of short columns to measure the lateral deflection of the column. A Demountable mechanical strain gauge length of 100 mm with least count of 0.002 mm was used to measure the axial deformation.

5.1 TEST PROCEDURE

In this test axial loading was applied using a hydraulic jack of 500 kN. An Electronic load cell of capacity 500 kN was used to measure the applied axial loads and was monitored by load indicator. Axial load was transmitted to the column through steel plates and neoprene pads are placed over it to provide hinge condition. The column specimens are adjusted so that the centre line of the axial load coincides with column faces.

The loads were applied as axial and the axial deformations were measured at mid span of the specimen on all four faces. The average value was used to plot the load versus axial deformation curves. One number of 50 mm range Linear Voltage Differential Transducer (LVDT) were used to measure the mid-height deflection of the short column specimens, read in electronic monitors.

The load was applied gradually and the deflection was measured at various load stages at regular intervals, at the same time strain values were also measured and observations of initiation of crack and propagation of cracks at different stages of loading, ultimate load to failure and mode of failure were taken. A typical test setup is shown in Fig. 5.1.

Fig 5.1 Experimental Test Setup for Short Columns

Table 5.1 Short Column Testing Results

Specimen Details	First Crack load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
GSCS 1	116	136	8
GSCS 2	142	164	9.5
GSCS 3	215	225	23.78
GSCMS 1	76	103	7.9
GSCMS 2	147	167	9.12
GSCMS 3	175	190	18.81

5.2 LOAD Vs DEFLECTION CURVE

Load Deflection characteristics of the geopolymer concrete short columns are shown below. It is found that the strength of the short column casted with river sand gives more strength when compared to that of the short columns casted with manufactured sand.

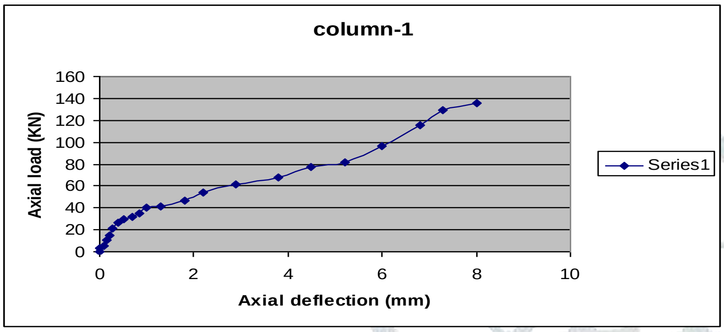

Fig 5.2 Axial Load – Deformation Curves of Short Column -1

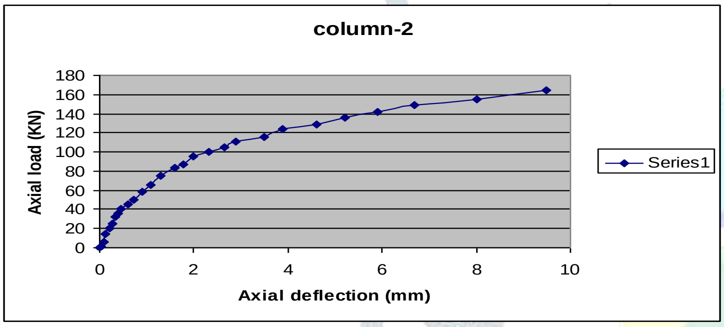

Fig 5.3 Axial Load – Deformation Curves of Short Column -2

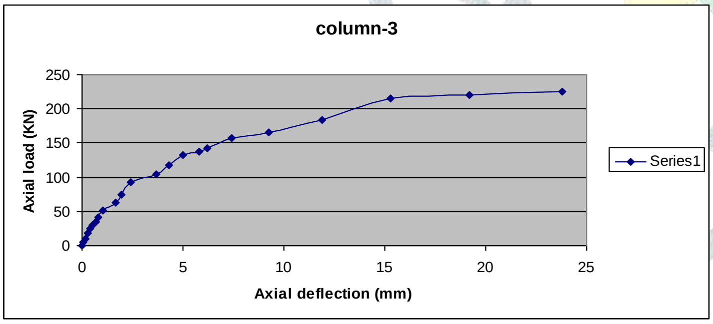

Fig 5.4 Axial Load – Deformation Curves of Short Column -3

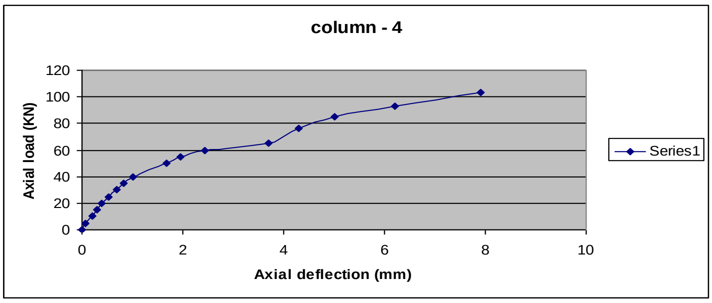

Fig.5.5 Axial Load – Deformation Curves of Short Column -4

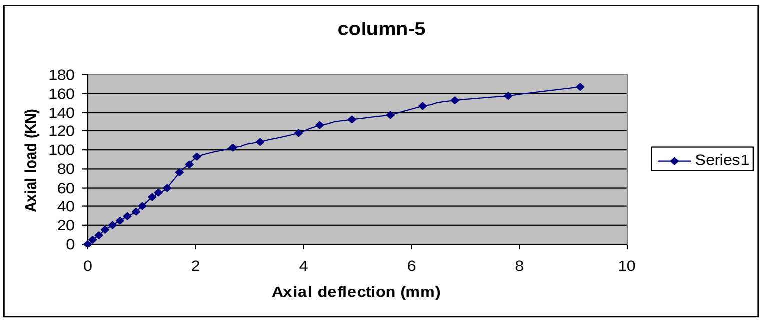

Fig 5.5 Axial Load – Deformation Curves of Short Column -5

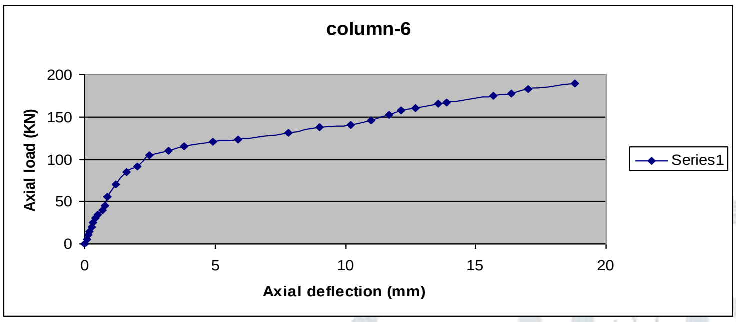

Fig 5.6 Axial Load – Deformation Curves of Short Column -6

5.3 DISCUSSIONS

The first specimen tested was the short column made of river sand as fine aggregate. It is designed for the strength of 153 kN. By testing it withstand up to a load of 136 kN. When the load reached 116 kN, first crack appeared at the column Head. As the load increased, the cracks widened and propagated around the initial crack. The maximum load obtained for control column was 136 kN, at which failure occurred at the column head due to crushing of concrete with an explosive sound. Similarly the other columns are tested and the test results are given above. By testing it is concluded that the strength of the short column casted with river sand gives more strength when compared to that of the short columns casted with manufactured sand, it can be clear by seeing the Fig.5.6.

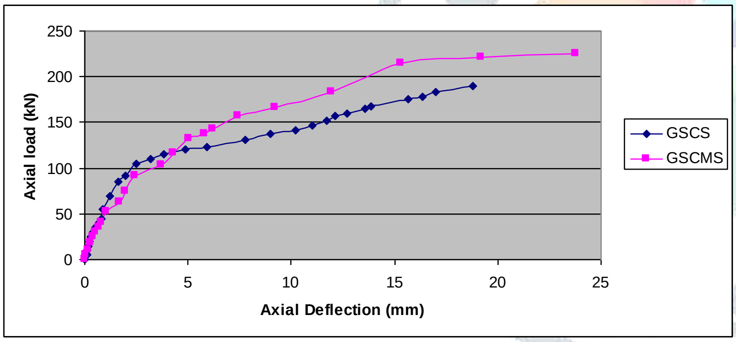

Fig 5.6 Axial Load – Deformation Curves comparing GSCS AND GSCMS

VI. CONCLUSION

Material test is carried out to determine the physical properties of fine aggregate, fly ash, required for the design and casting of specimen. In the case of strength calculation out of 13 trial mixes optimised results obtained for 10 mixes for river sand and only 5 mixes for manufactured sand. The workability of geopolymer concrete is comparatively less due to the use of manufactured sand. But while using the river sand as fine aggregate the workability is good. The slump value increases with the increase of extra water to the fresh fly-ash-based geopolymer concrete. As the ratio of water-to-geopolymer solids by mass increases, the compressive strength of fly ash-based geopolymer concrete with manufactured sand decreases.

Better results are obtained for compressive strength and split tensile strength of cubes and cylinders when heat curing was done. When the short columns subjected to loading, crushing of column takes place with slight axial deflection. The strength of the columns came nearly to the estimated load. It is found that the column casted with river sand as fine aggregate shows better performance than that of the manufactured sand as fine aggregate.

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