CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 GENERAL

This chapter presents a summary of the present study, the major conclusions of the investigations done and recommendations for future research. Exploration on the possibilities of manufacturing Geopolymer Concrete in India with Indian Fly ash and applicability of Geopolymer concrete as structural compression member under concentric load as well as axial load with moments were investigated. The experimental results of Geopolymer concrete were compared with that of Ordinary Portland cement concrete structural members.

Initially, mortar cubes were prepared and cured in oven. But later, utilizing plenty of solar heat available in India, concrete cubes were cured at ambient temperature. Though the curing of Geopolymer concrete could be done in ambient temperature, it took days to attain its ultimate strength. Also the space and volume of oven available permitted curing only few concrete cubes. This absolutely forced to look for an alternative to cure large sized specimens and ultimately arrived at fabrication and installation of heat-curing chamber with thermostats having control over temperature between $60^\circ$C and $90^\circ$C. This chamber, in particular, was designed to accommodate and cure large size structural elements.

Though failures were encountered in the beginning, numerous trials were done to achieve the required compressive strength of concrete. Upon
achieving the compressive strength, further works related to the short term properties of this no-cement concrete were done in a swift pace.

Based on these extensive investigations, the following sets of conclusions are drawn:

- The alkaline solution made of silicates and hydroxides of potassium has rendered a compressive strength marginally higher by 3.69% than the alkaline solution made of silicates and hydroxides of sodium. Considering the economical aspects and dense microstructure the latter was utilized throughout this research work.

- The average compressive strength of G30 concrete made of 14M concentration of NaOH exceeded G30 concrete made of 12M by 11.46%. Whereas the same for G40 concrete, G50 and G60 concrete were higher by 3.52%, 9.19% and 4.9% respectively. Therefore it is evident from the test results that higher the concentration of NaOH, higher the compressive strength of Geopolymer concrete will be.

- The average compressive strength of Geopolymer (G30) manufactured with 14 M concentration of NaOH, exceeded the compressive strength of its counterpart OPC concrete (M30) by 28.7% and the same for G50 was 4.92%.

- Whereas this was not observed in G40 and G60 Concretes. The average compressive strength of G40 Concrete manufactured with 14M concentration of NaOH, was slightly lower than its counterpart OPC concrete(M40) by 2.25%.
The average compressive strength of G60 Geopolymer concrete manufactured with 14M concentration of NaOH solution exceeded OPC Concrete by 0.67%.

From the test result, the tensile strength of Geopolymer concrete G30 specimens manufactured with 14M Concentration of NaOH was 18.27% greater than the OPC concrete specimens and the same is 3.37% for G30, 12M concentration.

G50 14M specimens recorded higher tensile strength than M50 specimens by 5.71% and it was 3.34% for G50 12M specimens.

Split tensile strength of G30(14M), G30(12M) and M30 specimens was 12.3%, 11.9% and 13.4% of their corresponding compressive strength and the same for G50(14M), G50(12M) and M50 was 12.99%, 13.87% and 12.89% respectively.

The average flexural strength of G30(14M) concrete was 13.59% of its average compressive strength whereas the same for G30(12M), G50(14M) and G50(12M) were 14.25%, 10.28% and 10.97% respectively.

From the test result, the impermeability of Geopolymer concrete G30 specimens had increased by 6.5% when compared with OPC concrete M30 specimens. The same for G50 concrete was 24% more than M50 concrete.

From the outcome of the results of pull-out test, the bond between TMT bar and G30 Geopolymer concrete was excellent due to the roughness of steel and the average bond
strength of G30(14M) concrete with TMT bar was 23.71% of its average compressive strength whereas it was 14.61% for CTD bar.

- It is observed that Geopolymer concrete specimens exposed to 500°C yielded a compressive strength of 42.5MPa for G30 and 62MPa for G50 concrete.

- G30 and G50 concretes, when exposed to 500°C, have shown an increase in strength by 28.78% and 22.77% respectively which is almost similar to the established value of Geopolymer paste of 50MPa strength exhibiting strength gain of 27.27%.

- In G30 grade Geopolymer concrete, the ratio of alkaline liquid to fly ash is increased by 1%, the gain in compressive strength noted was 5.17 MPa. Increasing the ratio further by 2% had boosted up the strength by 13.21MPa.

- Compressive strength of Geopolymer concrete increased with increase in concentration of sodium hydroxide solution in terms of molarity. Keeping the ratio of Na₂SiO₃ to NaOH at 2.5 and increasing the NaOH concentration from 8M to 14M, the strength increased from 52.24MPa to 58.42MPa which was closer to the established result increasing from 57MPa to 67MPa.

- When the temperature got increased from 60°C to 90°C, G30 concrete showed an increase in strength by 8.16% whereas G50 concrete showed higher strength by 20.67% which is due to acceleration of Pozzolanic reactions when temperature increased from 60°C to 90°C.
From the results observed, target strength was achieved in 16 hours of curing. When it was prolonged to 36 hours, the strength gain noticed was 15.76% and 13.9% for G30 and G50 concrete.

It was observed from the results that Geopolymer concrete could be handled upto 210 minutes after removal from Pan mixer without any indication of setting and degradation in strength. This result indicates delayed handling of Geopolymer concrete upto 210 minutes as against the established result of 120 minutes.

As the mixing time increased, the viscosity of the mixture increased and hence compressive strength. From the observed results of the test, there was a marked improvement of strength by 40% when the mixing time was increased from 3 minutes to 20 minutes which well correlated with the established result of 37% when the time of mixing increased from 2 minutes to 16 minutes.

Alkaline solution prepared could be used upto 7 days without degradation in the target strength. Alkaline solution prepared and used in 10 minutes before mixing gave the highest strength of 58.65MPa whereas alkaline solution used after 7 days gave a strength of 49.67MPa.

Hardened G50 concrete exhibited an increase in compressive strength from 48.22MPa to 55.33MPa at the age of 90 days which well correlated with the established result varying from 48MPa to 52MPa. At the age of 365 days, the strength of G50 concrete increased further to 58.34MPa.
In the ambient temperature curing the target strength of concrete could be achieved only after 45 days as against the established result of 28 days. G50 concrete at the age of 7 days gave a compressive strength of 32.43MPa and at 28 days yielded 43.11MPa as against the established value of 42MPa at 7 days and 55MPa at 28 days.

The observed results in this research work yielded Modulus of elasticity as 24.29 GPa for G30 concrete and 36.57GPa for G50 concrete. The results are higher than the published data due to size of coarse aggregate used, mode of compaction and mode of curing. Also the Modulus of Elasticities of Geopolymer Concretes were marginally lower than that of Ordinary Cement Concretes due to lesser density of Geopolymer concrete, at similar strength levels.

G30 grade Series-A columns exhibited an average ultimate load of 905kN whereas GCI-1 columns of Research report GC-3 yielded 940 kN.

G30 grade Series-B columns showed an average ultimate load capacity of 567kN whereas M30 grade columns showed only 408kN against the calculated ultimate load of 307.85kN.

G30 specimens tested in this study showed some ductility with an average ductility index of 1.027 though short columns under axial compression behaved in a brittle manner.

G50 grade Series-B columns showed an average ultimate load capacity of 533kN whereas M50 grade columns showed only 511kN against the calculated ultimate load of 489.93kN.
For the same percentage of steel, G50 grade Geopolymer concrete columns have shown less deformation than that of reference cement concrete columns before failure with an average ductility index of 0.66.

The ductility index of Series-C, G30 grade Set-A columns was 1.24 whereas it was 0.86 for M30 grade columns. Similar results were encountered in the case of Set-B columns resulting 1.10 and 0.90 for G30 and M30 grade columns respectively.

All the G30 and G50 Grade Series-D columns have shown exemplary results in load carrying capacity than their counterparts with a ductility index of 1.04 and 0.94 respectively. While the ductility index for Geopolymer concretes was near unity, it was well below unity for M30 and M50 Grade concretes resulting only 0.88 and 0.53 respectively.

The mean value of experimented / calculated ultimate load of G30 Grade, Series-D Geopolymer Concrete columns was 1.44 whereas it was 1.19 for G50 Grade columns. These results were well above the values exhibited by M30 and M50 Grade concretes which read 1.09 and 0.89 respectively.

As envisaged from the test results, all the G30 and G50 Grade series-E columns have shown exemplary results in load carrying capacity than M30 Grade Concrete Columns by around 20.1% and 23.87 % respectively.

All the Geopolymer Series-E columns buckled before failure showing more ductility. The ductility indices of G30 and G50
series-E Geopolymer columns were more or less around unity. But the same for M30 and M50 columns were lesser than unity, exhibiting lesser ductility.

- From EDAX spectrum of Geopolymer concretes, it shall be noted that iron oxide content was 3.7%. The iron oxide content originally presented in Source material has not increased. This shows that the metal did not undergo any chemical reaction.

- From XRD spectrum of G30 and G50 samples, a large part of the structure was amorphous to x-rays and the presence of quartz, mullite and anorthite was revealed. These factors were associated with the strength enhancement region of the Geopolymer matrix.

### 8.2 RECOMMENDATIONS FOR FUTURE WORKS

From the available literatures on Geopolymer concrete and based on the findings in this research, following works are recommended for further research.

- Investigations on the effect of varying percentage of reinforcement and study on buckling and load carrying capacity of slender column.

- Strengthening the top and bottom ends reinforced Geopolymer concrete columns with wrapping, avoiding heads.

- The effect of different type of arrangements of transverse reinforcements on ductility of columns shall be studied.
- Effect of varying the grade, diameter and spacing of confining steel may be studied.
- Impact strength, Fatigue strength and Fracture strength of short and slender columns may be studied.