CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

The purpose of this chapter is to relate what is already known about geopolymer concrete by discussing the theoretical derivations and experimental findings of previous studies. As the present investigation deals with studies on the strength and flexural behavior of plain and fibre reinforced geopolymer concrete composites using fly ash as source material, an attempt has been made to review briefly the available literature on the following topics:

i) Investigations on geopolymer concrete

ii) Investigations on fibre reinforced concrete

iii) Experimental and analytical investigations on the flexural behaviour of reinforced concrete beams with and without fibres

The scope of the present investigation is given at the end of this chapter.

2.2 INVESTIGATIONS ON GEOPOLYMER CONCRETE

Vijaya Rangan (2008) carried out extensive studies on the fly ash-based geopolymer concrete utilizing low calcium fly ash as the source
material. The salient factors that influence the properties of the fresh concrete and the hardened concrete have been identified. From the experimental investigations it has been found that fly ash-based geopolymer concrete has excellent compressive strength and is suitable for structural applications. The elastic properties of hardened concrete and the behaviour and strength of reinforced structural members are similar to those of Portland cement concrete. Hence it is concluded that, the design provisions contained in the current standards and codes can be used to design reinforced fly ash-based geopolymer concrete structural members. The fly ash-based geopolymer concrete also shows excellent resistance to sulfate attack, undergoes low creep, and suffers very little drying shrinkage.

The effect of concentration of NaOH and curing time on fly ash based geopolymer concrete has been studied by Anurag Mishra et al (2008). Totally nine mixes were prepared with NaOH concentration as 8 M, 12 M, 16 M and curing time as 24 hrs, 48 hrs, and 72 hrs. Compressive strength, water absorption and tensile strength tests were conducted on each of the so cast nine mixes. Results of the investigation indicated that with increase in NaOH concentration, there was an increase in compressive strength. With increase in curing time, compressive strength also increased but it was found that the increase in compressive strength after 48 hrs of curing time was not significant. Compressive strength up to 46 MPa was obtained with curing at 60°C. The results of water absorption test indicated that percentage of water absorption decreased with increase in NaOH concentration and curing time.

Geopolymer concrete prepared from low lime based fly-ash and a mixed alkali activator of sodium hydroxide and sodium silicate solution has been investigated by Siva Konda Reddy et al (2010). The workability of geopolymer concrete is reduced with higher concentrations of sodium hydroxide (in the range of 10 M to 16 M) solution which results in a higher
compressive strength. There is a slight increase in the compressive strength with age of the concrete for a defined concentration of NaOH solution. The addition of high-range water reducing admixture with 1.5% of fly-ash (by mass) resulted no much impact on the compressive strength of the hardened concrete, but improved workability of fresh geopolymer concrete.

Experimental investigations on geopolymer concrete incorporating recycled concrete aggregates have been reported by Anuar et al (2011). Waste paper sludge ash and alkaline liquids were used to replace the Portland cement to produce geopolymer concrete. Geopolymer concrete specimens with two different molar concentrations of sodium hydroxide such as 8 M and 14 M were prepared. Thirty cube specimens of size 100 mm x 100 mm x 100 mm were cast and the compressive strength of the geopolymer concrete specimens were tested at the age of 3, 7, 14, 21 and 28 days after curing in local laboratory ambient conditions. The test results showed that the compressive strength of waste paper sludge ash based geopolymer concrete incorporating recycled concrete aggregates increases by increasing the molarities of sodium hydroxide.

Monita Olivia and Hamid R. Nikraz (2011) investigated the strength development, water absorption and water permeability of low calcium fly ash geopolymer concrete with variations of water/binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio. The results indicated that the strength of fly ash geopolymer concrete was increased by reducing the water/binder and aggregate/binder ratios and the water absorption of low calcium fly ash geopolymer was improved by decreasing the water/binder ratio, increasing the fly ash content, and using a well-graded aggregate. It was also observed that there was no significant change in water permeability coefficient for the geopolymer with different parameters. The test data indicates that a good quality of low calcium fly ash
geopolymer concrete can be produced with appropriate parameterisation and mix design.

The effects of various factors such as the age of concrete, curing time, curing temperature, quantity of superplasticizer, the rest period prior to curing, and the water content of the mix on the properties of fly ash based geopolymer concrete, especially the compressive strength have been studied by Djwantoro Hardjito et al (2004). The test results show that the compressive strength of geopolymer concrete does not vary with age, and curing the concrete specimens at higher temperature and longer curing period will result in higher compressive strength. Furthermore, the commercially available Naphthalene-based superplasticizer improves the workability of fresh geopolymer concrete. The start of curing of geopolymer concrete at elevated temperatures can be delayed at least up to 60 minutes without significant effect on the compressive strength. The test data also show that the water content in the concrete mix plays an important role.

Fareed Ahmed (2011) documented the assessment of the compressive strength and workability characteristics of low-calcium fly ash based self compacting geopolymer concrete. The essential workability properties of the freshly prepared self-compacting geopolymer concrete such as filling ability, passing ability and segregation resistance were evaluated by using Slump flow, V-funnel, L-box and J-ring test methods. The fundamental requirements of high flow ability and segregation resistance as specified by EFNARC guidelines on self compacting concrete were satisfied. In addition, compressive strength was determined and the test results were included. The effect of extra water, curing time and curing temperature on the compressive strength of self-compacting geopolymer concrete was also reported. The test results show that extra water in the concrete mix plays a significant role. Longer curing time improves the geopolymerisation process resulting in
higher compressive strength. The compressive strength was highest when the specimens were cured for a period of 96 hours; however, the increase in strength after 48 hours was not significant. Concrete specimens cured at 70°C produced the highest compressive strength as compared to specimens cured at 60°C, 80°C and 90°C.

The mechanical properties of fly ash based geopolymer concrete were studied by Ivan Diaz- Loya et al (2011). Experimentally measured values of the static elastic modulus, Poisson’s ratio, compressive strength and flexural strength of geopolymer concrete specimens made from 25 fly ash stockpiles from different sources were recorded and analyzed. The results were studied using regression analysis to identify tendencies and correlations within the mechanical properties of geopolymer concrete. It was found that the mechanical behavior of geopolymer concrete is similar to that of ordinary Portland cement concrete.

The durability of the fly ash based geopolymer concrete prepared with sodium silicate and sodium hydroxide as activators was studied by Sathia et al (2008). The concretes were prepared with varying fly ash content of 350, 450 & 550 kg/m$^3$ and activator solution to fly ash ratio of 0.4 and 0.5. Compressive strength in the range of 10-60 MPa was obtained. The performance of these concretes in aggressive environments was also studied, using tests on absorption, acid resistance and potential. Results indicated that the water absorption decreased with an increase in the strength of the concrete and the fly ash content. All geopolymer concretes showed excellent resistance to acid attack (3% H$_2$SO$_4$) compared to the normal concrete.

Ravindra N. Thakur and Somnath Ghosh (2009) reported results of an experimental study on development of compressive strength and microstructure of geopolymer paste and mortar specimens prepared by thermal activation of Indian fly ash with sodium hydroxide and sodium
silicate solution. The effect of main synthesis parameters such as alkali content, silica content, water to geopolymer solid ratio and sand to fly ash ratio of geopolymer mixture and processing parameters such as curing time and curing temperature on development of compressive strength and microstructure of fly ash based geopolymer paste and mortar were studied. The compressive strength of 48.20 MPa was obtained for geopolymer mixture cured at 85°C for 48 hours with alkali content (Na₂O/Al₂O₃) of 0.62 and silica content (SiO₂/Al₂O₃) of 4.0. The mineralogical and microstructure studies on hardened geopolymer performed by means Scanning electron microscope and X-ray diffraction, showed formation of a new amorphous alumino-silicate phase such as hydroxysodalite and herschelite, which influenced development of compressive strength.

The effects of various parameters on the properties of geopolymer concrete have been presented by Djwantoro Hardjito et al (2004). Based on the experimental investigations, they found that higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength of geopolymer concrete and higher the ratio of sodium silicate to sodium hydroxide liquid ratio by mass, higher is the compressive strength of geopolymer concrete. It was also reported that, as the curing temperature (in the range of 30 to 90°C) increases, the compressive strength of geopolymer concrete also increases. Longer curing time, in the range of 6 to 96 hours (4 days), produces larger compressive strength of geopolymer concrete. However, the increase in strength beyond 48 hours was not significant. The addition of high range water reducing admixture, up to approximately 2% of fly ash by mass, improved the workability of fresh geopolymer concrete with very little effect on the compressive strength of hardened concrete. The rest period between casting of specimens and the commencement of curing up to 60 minutes has no effect on the compressive strength of geopolymer concrete. It is also reported that the fresh geopolymer
concrete is easily handled up to 120 minutes without any sign of setting and without any degradation in the compressive strength. As the ratio of water to geopolymer solids by mass increases, the compressive strength of the concrete decreases. The compressive strength of geopolymer concrete cured for 24 hours at 60°C does not depend on the age. The geopolymer concrete undergoes very little drying shrinkage and low creep. The resistance of geopolymer concrete against sodium sulfate is excellent. The applications of geopolymer concrete and future research needs are also identified.

Olivia et al (2008) presented a detailed experimental investigation on water penetrability properties, namely water absorption, volume of permeable voids, permeability and sorptivity of low calcium fly ash geopolymer concrete. In this research, geopolymer concrete is made from fly ash with a combination of sodium hydroxide and sodium silicate as alkaline activator. Seven mixes were cast in 100 x 200 mm cylinders and cured for 24 hours at 60°C in the steam curing chamber. After 28 days, the cylinders were cut into slices for permeability, sorptivity and volume of permeable voids tests. In addition, a microstructure characteristic of geopolymer concrete was studied using Scanning Electron Microscopy. Results indicate that geopolymer concrete has low water absorption, volume of permeable voids and sorptivity. It is found that the geopolymer concrete could be classified as a concrete with an average quality according to water permeability value. Moreover, a low water/binder ratio and a well graded aggregate are some important factors to achieve low water penetrability of geopolymer concrete.

The effect of curing conditions on the compressive strength of self compacting geopolymer concrete prepared by using fly ash as base material and combination of sodium hydroxide and sodium silicate as alkaline activator has been studied by Fareed Ahmed Memon et al (2011). The experiments were conducted by varying the curing time and curing
temperature in the range of 24-96 hours and 60-90°C respectively. The essential workability properties of freshly prepared Self compacting geopolymer concrete such as filling ability, passing ability and segregation resistance were evaluated by using Slump flow, V-funnel, L-box and J-ring test methods. The fundamental requirements of high flowability and resistance to segregation as specified by guidelines on Self compacting Concrete by EFNARC were satisfied. Test results indicate that longer curing time and curing the concrete specimens at higher temperatures result in higher compressive strength. There was increase in compressive strength with the increase in curing time. However increase in compressive strength after 48 hours was not significant. Concrete specimens cured at 70°C produced the highest compressive strength as compared to specimens cured at 60°C, 80°C and 90°C.

The results of an experimental investigation on the durability of fly ash based Geopolymer concretes exposed to 10% sulphuric acid solutions for up to 8 weeks have been presented by Song et al (2005). A class F fly ash based Geopolymer concrete was initially cured for 24 hours at either 23°C or 70°C. The compressive strength of 50 mm cubes at an age of 28 days ranged from 53 MPa to 62 MPa. After immersion in a 10% sulphuric acid having a fixed ratio of acid volume to specimen surface area of 8 ml/cm², samples were tested at 7, 28, and 56 days. The mass loss, reduction of compressive strength and the residual alkalinity were determined on the basis of modified ASTM C267 tests. The results confirmed that geopolymer concrete is highly resistant to sulphuric acid in terms of a very low mass loss, less than 3%. It was also observed that, geopolymer cubes were structurally intact and still had substantial load capacity even though the entire section had been neutralized by sulphuric acid.
2.3 INVESTIGATIONS ON FIBRE REINFORCED CONCRETE

Ramadoss and Nagamani (2008) presented investigations towards developing a better understanding of the contribution of steel fibres to the tensile strength of high performance fibre reinforced concrete. For 32 series of concrete mixes, flexural and splitting tensile strengths were determined at 28 days. The variables investigated were fibre volume fraction, silica fume replacement level and matrix composition. The influence of fibre content in terms of fibre reinforcing index on the flexural and splitting tensile strengths of high-performance fibre reinforced concrete is presented. Comparative studies were performed on the tensile behavior of steel fibre reinforced concrete measured by two different loading tests: flexural test and splitting test. Based on the test results, using the least square method, empirical expressions were developed to predict 28-day tensile strength of high performance fibre reinforced concrete in terms of fibre reinforcing index. Durability tests were carried out to examine the performance of the steel fibre reinforced concrete. Relationship between flexural and splitting tensile strengths has been developed using regression analysis. The experimental values of previous researchers were compared with the values predicted by the empirical equations and the absolute variation obtained was within 6% and 5% for flexural and splitting tensile strengths respectively.

An experimental study dealing with the toughness of heavy concrete based on the ASTM C1018 has been presented by Yu-Cheng Kan et al (2003). Mixtures including 0%, 0.5%, 1.0% and 1.5% of steel fibre content by volume are designated, which are all developed according to a mixture used in Kuosheng nuclear power plant in Taiwan. Metallic aggregates of iron shots and iron ore take 48.8% by volume in that mixture. Test results revealed that the tensile strength, rupture modulus and bond strengths appeared increasing with the increase of steel fibre content, while the
compressive strength and modulus of elasticity turned out a bit decreasing. Flexural toughness tests showed that the toughness of heavy concrete grew with the steel fibre fraction.

The effect of alkali resistant glass fibres on the compressive, flexural and split tensile strength of various grades of concrete such as M 20, M 30, M 40 and M 50 has been studied by Chandramouli et al (2010). It was observed that glass fibre reinforced concrete shows less permeability of chlorides for higher grade of concrete. A reduction in bleeding is observed by addition of glass fibres in the glass fibre concrete mixes which improves the surface integrity of concrete, improves its homogeneity and reduces the probability of cracks.

Yeol Choi and Robert L. Yuan (2005) presented an experimental investigation into the relationship between the splitting tensile strength and compressive strength of glass fibre reinforced concrete (GFRC) and polypropylene fibre reinforced concrete (PFRC). The splitting tensile strength and compressive strength of GFRC and PFRC at 7, 28 and 90 days are used. Test results indicate that the addition of glass and polypropylene fibres to concrete increased the splitting tensile strength of concrete by approximately 20–50%, and the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of its compressive strength. Based on this investigation, a simple 0.5 power relationship between the splitting tensile strength and the compressive strength was derived for estimating the tensile strength of GFRC and PFRC.

The impact resistance of polypropylene fibre-reinforced concrete and normal concrete has been investigated by Shin Hwang et al (2003). The impact resistance of polypropylene fibre reinforced concrete and normal concrete was measured by using a drop weight test and analyzed by using statistical procedures. The polypropylene fibre reinforced concrete
outperformed the normal concrete in the impact strength. The polypropylene fibre reinforced concrete was 1.1 and 1.2 times higher in first crack strength and failure strength respectively, than the normal concrete. The polypropylene fibre reinforced concrete performed better than the normal concrete in impact resistance after the first visible crack appeared. The impact resistance models established for polypropylene fibre reinforced concrete and normal concrete provide an estimate for the failure strength and the 95% confidence interval on the mean failure strength.

Sekar (2004) investigated the feasibility of using industrial waste fibres in fibre reinforced concrete. Three types of waste fibres collected from three different industries namely lathe, wire winding and wire drawing industries were used in this investigation. Concrete specimens were cast with and without fibres and were tested under compression, split tension and flexure as per relevant Indian Standard Specifications. Test results indicated that addition of waste fibres from lathe and wire winding industries in plain concrete enhances the strength markedly, whereas the inclusion of waste fibres from wire drawing industry decreases the strength of concrete. Also the percentage increase in strength to weight ratio achieved by adding lathe industry waste fibres in plain concrete is higher than those obtained by adding wire winding industry waste fibres.

Kayali (2004) reported the effects of incorporating high volume fly ash in fibre reinforced concrete. Fly ash was mixed as a partial fine aggregate replacement of approximately one third of the fines volume. The fibres were polypropylene or steel fibres at a maximum proportion of 1% by volume of the concrete. The results showed that fibre reinforced concrete that included high fly ash volume achieved compressive and tensile strength values that are more than double those of concrete without fly ash. Values of other mechanical properties have also achieved significant increase due to fly ash
addition. It is suggested that a large quantity of fly ash is necessary to enhance the efficiency of fibre reinforcement. Polypropylene fibres resulted in gains up to 50% while steel fibres achieved gains up to more than 100%. This enhancement is believed to be due to the microstructural modification and densification in the transition zone between the matrix and the fibres.

A practical rapid method of proportioning steel fibre reinforced concrete (SFRC) mixes is developed and validated by Nataraja et al (2005). The basis for developing this is to use the re-proportioning method, which has already been developed for proportioning normal density cement concrete mixes, for SFRC mixes. Based on the results of the trial mix, two SFRC mixes having 28 day target strength of 30 and 50 MPa are designed using this technique and examined regarding its validation. In addition, the impact resistance of these re-proportioned Plain Concrete (PC) and SFRC is studied at 7 and 28 days. It is observed that the SFRC has developed significant impact resistance even for a small addition of steel fibres. Pulse velocity test is conducted at different ages to assess the quality of concrete. It is found that all concrete specimens could be classified under good quality.

The durability properties of concrete containing polypropylene fibre and fly ash have been studied by Okan Karahan and Cengiz Duran Atis (2011). Properties studied include unit weight and workability of fresh concrete, and compressive strength, modulus of elasticity, porosity, water absorption, sorptivity coefficient, drying shrinkage and freeze–thaw resistance of hardened concrete. Fly ash content used in concrete mixture was 0%, 15% and 30% in mass basis, and fibre volume fraction was 0%, 0.05%, 0.10% and 0.20% in volume basis. The laboratory results showed that inclusion of fly ash improves; however, polypropylene fibre decreases the workability of concrete. Moreover, polypropylene fibre addition, either into Portland cement concrete or fly ash concrete, did not improve the compressive strength and
elastic modulus. The positive interactions between polypropylene fibres and fly ash lead to the lowest drying shrinkage of fibrous concrete with fly ash. Freeze–thaw resistance of polypropylene fibre concrete was found to slightly increase when compared to concrete without fibres. Moreover, fly ash increased the freeze–thaw resistance more than the polypropylene fibres did.

Ali Behnood and Masoud Ghandehari (2009) presented the results of an extensive experimental study on the compressive and split tensile strength of high strength concrete with and without polypropylene fibres after heating to 60°C. Mixtures were prepared with water to cementitous materials ratios of 0.40, 0.35, and 0.30 containing silica fume at 0%, 6%, and 10% cement replacement and polypropylene fibres content of 0, 1, 2, and 3 kg/m³. For all of the concretes, a severe strength loss was observed after exposure to 600°C, particularly the concretes containing silica fume despite their good mechanical properties at room temperature. The range of 300–600°C was more critical for concrete having higher strength. The relative compressive strengths of concretes containing polypropylene fibres were higher than those of concretes without polypropylene fibres. The split tensile strength of concrete was more sensitive to high temperatures than the compressive strength. Furthermore, the presence of polypropylene fibres was more effective for compressive strength than split tensile strength above 200°C. Based on the test results, it is concluded that the addition of 2 kg/m³ polypropylene fibres can significantly promote the residual mechanical properties of high strength concrete during heating.

The impact of polypropylene fibres on the performance of lightweight self compacting concrete at its fresh condition as well as its mechanical properties at the hardened condition has been analyzed by Mazaheripour et al (2011). From the experimental investigations it is found that, applying 0.3% volume fractions of polypropylene fibre to the light
weight self compacting concrete resulted in 40% reduction in the slump flow (from 720 mm to 430 mm). In general, the rate of slump flow over Super Plasticizer volume percentage reduced with the use of polypropylene fibres in the fibre reinforced light weight self compacting concrete. Polypropylene fibres did not influence the compressive strength and elastic modulus of light weight self compacting concrete, however applying these fibres at their maximum percentage volume determined through this study, increased the tensile strength by 14.4% in the splitting tensile strength test, and 10.7% in the flexural strength.

The effects of silica fume and polypropylene fibres on the impact resistance and mechanical properties of concrete have been investigated by Mahmoud Nili and Afroughsabet (2010). Impact resistance and strength performance of concrete mixtures with 0.36 and 0.46 water–cement ratios made with polypropylene fibre and silica fume are examined. Polypropylene fibre with 12-mm length and four volume fractions of 0%, 0.2%, 0.3% and 0.5% are used. In pre-determined mixtures, silica fume is used as cement replacement material at 8% weight of cement. The results show that incorporating polypropylene fibres improves mechanical properties. The addition of silica fume facilitates the dispersion of fibres and improves the strength properties, particularly the impact resistance of concretes. It is shown that using 0.5% polypropylene fibre in the silica fume mixture increases compressive split tensile, and flexural strength, and especially the performance of concrete under impact loading.

The strength properties of nylon and polypropylene fibre-reinforced concretes at a fibre content of 0.6 kg/m³ have been investigated by Song et al (2005). The compressive strength, split tensile strengths and modulus of rupture of the nylon fibre concrete improved by 6.3%, 6.7%, and 4.3% respectively, over those of the polypropylene fibre concrete. On the impact
resistance, the first-crack and failure strengths and the percentage increase in the post first-crack blows improved more for the nylon fibre concrete than for its polypropylene counterpart. In addition, the shrinkage crack reduction potential also improved more for the nylon-fibre-reinforced mortar. The above-listed improvements stemmed from the nylon fibres registering a higher tensile strength and possibly due to its better distribution in concrete.

The effects of polypropylene fibre on the compressive and flexural strength of normal weight concrete have investigated by Rana A. Mtasher et al (2011). Four mixes were used with weight of polypropylene fibre as 0.4, 0.8, 1.0 and 1.5% by weight of cement content. To provide a basis for comparison, reference specimens were cast without polypropylene fibres. The test results showed that due to the addition of polypropylene fibres the increase in compressive and flexural strength was relatively high.

2.4 EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS ON THE FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE BEAMS WITH AND WITHOUT FIBRES

An experimental investigation of the behavior of concrete beams reinforced with conventional steel bars and steel fibres and subjected to flexural loading has been presented by Mukesh Shukla (2011). An experimental program consisting of tests on steel fibre reinforced concrete (SFRC) beams with conventional reinforcement and reinforced concrete (RC) beams was conducted under flexural loading. SFRC beams include two types of beams containing steel fibres in two different volume fractions i.e. one percent and two percent. The cross sectional dimensions and span of beams were fixed same for all types of beams. Tests on conventionally reinforced concrete beam specimens, containing steel fibres in different proportions, have been conducted to establish load–deflection curves. It was observed that SFRC beams showed enhanced properties compared to that of RC beams.
A modified procedure has been suggested to calculate the ultimate strength of the conventionally reinforced beams with steel fibres. The ultimate loads obtained in the experimental investigation were also compared with the theoretical loads for all types of beams.

The flexural behaviour of Self Compacting Concrete (SCC) beams with varying percentage of locally available steel fibres has been explored by Divya et al (2010). Specimens were cast with fibre volume fraction ($V_f$) of 0%, 0.5% and 0.75% and with an aspect ratio of 50. Preliminary experimental investigation was done to study the influence of steel fibres on fresh and hardened properties of SCC. It demonstrated that, increase in fibre volume fraction will affect both the filling ability and hardened properties of SCC. Experimental investigations on SCC beams were done with particular attention to fibre effects on crack spacing, crack width, deflection, first crack load and ultimate load. Results were compared with control beam and it is seen that fibres can improve almost all the properties of SCC beams. Addition of 0.75% fibres has shown notable improvement in the ultimate strength and first crack load.

Destructive test on simply supported beams has been carried out in the laboratory by Saifulla et al (2011) and the load-deflection data of those under-reinforced concrete beams was recorded. After that finite element analysis was carried out by ANSYS, SAS 2005 by using the same material properties. Finally results from both the computer modeling and experimental data were compared. From this comparison it was found that computer based modeling can be an excellent alternative of destructive laboratory test with an acceptable variation of results. In addition, an analytical investigation was carried out for a beam with ANSYS, SAS 2005 with different reinforcement ratio (under, balanced, over). The observation was mainly focused on reinforced concrete beam behavior at different points of interest which were
then tabulated and compared. From this observation it shows that 1st cracking location is 0.43L to 0.45L from the support. Maximum load carrying capacity at 1st cracking was observed for over reinforced beam but on the other hand it was the balanced condition beam at ultimate load.

Chin and Xiao (2009) demonstrated the results of a series of physical testing conducted to evaluate to what extent the ultimate shear strength of reinforced concrete beams are improved by the incorporation of High Performance Polymer (HPP), with regard to fibre volume fraction. The influence of HPP fibres on both ultimate shear strength and failure mode of longitudinally reinforced concrete (RC) beams with and without shear links, subjected to two-point loading has been reported. The experimental findings indicate that HPP fibres have resolved controversial shear failures of reinforced concrete beams and improve remarkably ultimate shear strength. The ductility of the basic concrete matrix can also be enhanced with the inclusion of HPP fibres. Nonlinear finite element analysis has also been performed where the numerical results have shown to provide close agreement to those experimentally obtained.

Three-dimensional nonlinear finite element model of reinforced concrete beam has been developed by Dahmani et al (2010). The general purpose finite element package, ANSYS 8.0, was employed for the numerical analyses. Using SOLID 65 solid elements, the compressive crushing of concrete was facilitated using plasticity algorithm while the concrete cracking in tension zone was accommodated by the nonlinear material model. Smeared reinforcement was used and introduced as a percentage of steel embedded in concrete. Comparison with hand calculated results has been presented for the concrete beam. Convergence of analytical results was also showed. The capability of the model to capture the critical crack regions, loads and
deflections for various types of loadings in reinforced concrete beam has been illustrated.

Experimental and finite element analysis of three SFRC beams has been presented by Mehmet Ozcan et al (2009). For this purpose, three SFRC beams with 250 x 350 x 2000 mm dimensions were produced using a concrete class of C20 with 30 kg/m$^3$ dosage of steel fibres and steel class S420 with shear stirrups. SFRC beams were subjected to bending by a four-point loading setup in certified beam-loading frame, exactly after having been moist cured for 28 days. The beams were loaded until they are broken and the loadings were stopped when the tensile steel bars are broken into two pieces. Applied loads and mid-section deflections were carefully recorded at every 5 kN load increment from the beginning till the ultimate failure. One of the SFRC beams modeled by using nonlinear material properties adopted from experimental study was analyzed till the ultimate failure cracks by ANSYS. Eight noded solid brick elements were used to model the concrete. Internal reinforcement was modeled by using 3D spar elements. A quarter of the full beam was taken into account in the modeling process. The results obtained from the finite element and experimental analyses were compared to each other. It was seen from the results that the finite element failure behavior indicates a good agreement with the experimental failure behavior.

Vasudevan and Kothandaraman (2011) presented the results of the four points bending analysis of RC beams using ANSYS, conducted with respect to concrete constitutive properties, mesh density, use of steel cushion for the supports and loading points. The effect of shear reinforcement on flexural behaviour, convergence criteria, and impact of percentage of reinforcement were also analyzed and discussed. The outcome of this work will provide a wider platform for further usage of ANSYS in the analysis of RC beams.
Anthony J. Wolanski (2004) presented finite element analysis of reinforced concrete and prestressed concrete beams using ANSYS. Characteristic points on the load-deformation response curve predicted using finite element analysis were compared to theoretical (hand-calculated) results. The failure mechanism of a reinforced concrete beam was modeled quite well using finite element analysis, and the failure load predicted was very close to the failure load measured during experimental testing. For the prestressed concrete beam, camber due to the initial prestressing force and after application of the self-weight of the beam compares well to hand computed values. Also, a bursting effect was seen in the FE model. The load applied to cause initial cracking of the prestressed concrete beam compares well with hand calculations. Flexural failure of the prestressed concrete beam was modeled well using a finite element package, and the load applied at failure was very close to hand calculated results.

2.5 COMMENTS ON EARLIER WORKS

The review of literature on earlier works on geopolymer concrete reveals the following:

i) In most of the previous studies, strength of geopolymer concrete cured at elevated temperature was studied. An elevated temperature curing results in development of strength at early ages only. On the other hand, little information is available in the literature about the development of strength of geopolymer concrete when cured under ambient curing at room temperature. Hence there is a lot of scope to carry out investigations on geopolymer concrete under room temperature curing.

ii) Limited research works have been performed on the fibre reinforced geopolymer concrete. Despite the engineering
characteristics of the geopolymer concrete, its performance under impact loading and flexural behavior of fibre added geopolymer composite reinforced concrete beams is not still well known.

2.6 SCOPE OF THE PRESENT INVESTIGATION

The review of literature indicated that the higher concentrations of sodium hydroxide solution resulted in a higher compressive strength of geopolymer concrete. The geopolymer concrete undergoes very little drying shrinkage and low creep. In most of these studies, the effect of various parameters such as concentration of sodium hydroxide, curing time, curing temperature, age of concrete, water content of the mix on the workability, compressive strength, tensile strength, flexural strength, elastic modulus, water absorption, sorptivity, and permeability characteristics only were studied. In addition to that, majority of the studies are limited to geopolymer concrete cured at elevated temperature and this curing method would prevent the geopolymer concrete to be applied in a cast in situ concrete work. Therefore this research is mainly focused on the utilization of ambient temperature to cure the geopolymer concrete.

Also, studies to investigate the effect of addition of fibres on the strength characteristics of geopolymer concrete are limited. Hence, there exists a technical knowledge gap in this area. This gap in the existing knowledge suggests that a research programme to study the effect of addition of fibres on the various engineering properties of geopolymer concrete would be of much relevance and useful. Hence, an attempt has been made through the present investigation to conduct an experimental programme to study the effect of addition of fibres such as steel, polypropylene and glass on the strength and other engineering properties of geopolymer concrete composites.