CHAPTER 2: REVIEW OF LITERATURE

2.1 General
This chapter discusses the need for the development of alternate concrete material by diminishing the emission of carbon dioxide gas into the atmosphere. The major part of concrete is contributed by cement. The production of ordinary Portland cement leads to the emission of greenhouse gas is about 1.35 billion tons every year [34]. The usage of cement in the construction industry is unavoidable, since it is one of the most important ingredients which are responsible for the strength development in the concrete. Therefore, it is very much essential to produce a concrete without cement by adopting alternative binders. In turn the abundant availability of byproduct materials such as fly ash, silica fume(SF), ground granulated blast furnace slag (GGBFS) can be used as a substitute for cement which not only reduces the emission of carbon dioxide into the atmosphere but also minimizes the environmental issues such as global warming, greenhouse gas emission etc.

2.2 Application of geopolymer
Geopolymer concrete produced from alkali activated alumina silicate materials is a new type of concrete which can be very well used in applications such as precast concrete, mass concrete in dam construction and roller compacted geopolymer concrete in construction of roads. It can also be used as railway traverse, waste water pipe line, hydraulic structures and pre-tension concrete structures. A typical light pavement can be made using geopolymer of grades 25 MPa and 40 MPa target strengths by adopting variety of construction techniques. The main difference with ordinary concrete is that the geopolymer concrete had no available bleeding rising to the surface. It can be used to construct a precast panel which is used as a retaining wall to retain earth pressure of 3m.
The main characteristics of geopolymer concrete is that high early strength gain when subjected to steam curing, therefore it has been used as a precast product in railway sleepers, sewer pipes, and other precast concrete components [35]. Geopolymer can show excellent resistance against fire, chemical attack and it is particularly used in the aggressive marine environment [36]. It has been widely used for concrete paving and specifically used in kerb and channel, footpath; drive way and joint user path. Geopolymer concrete is used to produce steel reinforced concrete pipes, underground storm water drains, wire rope safety barriers, anchor blocks, post footings. It is also used in the construction of precast and cast in situ drainage pits [37, 38].

Some of the applications of geopolymer were formulated which was based on the Si/Al ratio. If Si/Al =1, it can be applied for in manufacturing bricks, ceramics, fire protection works, Si/Al =2 for low carbon dioxide cements, concrete, radioactive & toxic waste encapsulation, Si/Al = 3 for heat resistance composites, foundry equipment’s and fiberglass composites, Si/Al >3 for sealants for industry and 20<Si/Al <35 for Fire resistance, heat resistance and fiber composites [39].

The effect of thermal curing on chemical composition, microstructure and strength development of class F flyash based geopolymer concrete activated using sodium silicate and sodium hydroxide solutions was studied. Geopolymers kept under rest period gains in strength development. X- Ray diffraction (XRD) analysis, fourier transform infrared spectroscopy (FTIR) and scanning electron microscope (SEM) analysis images are also used in the study. During the process of geopolymerization, alumino silicate gel was formed and this gel was mainly responsible for the strength development [40].
Usage of inorganic polymers as a concrete element in construction industry was examined. This type of concrete has much less CO₂ footprint when compared to OPC due to its properties include good bond strength, chemical resistance etc. This concrete needs complete understanding of chemistry behind the geopolymerization technology which has been successfully applied. Research work was carried out on upcoming issues based on its durability testing. This technology was effectively applied for ceramic applications like geopolymeric adhesives in ceramics [41].

The physical, mechanical and durability characteristics of alkali activated slag concrete with varying concentration of sodium oxide of 4%, 5% and 6% by mass of slag along with sodium silicate modulus ratio kept as 0.8 was investigated. It was concluded that increase in concentration of Na₂O decreases the slump value of slag concrete. In hardened concrete the strength and durability properties such as compressive strength, split tensile strength test, drying and shrinkage test, total charge passed, temperature resistance and sulphate resistance was found to be higher than that of OPC. Durability characteristics improved the performance of slag concrete with increase in dosage of Na₂O at 60 °C which has better performance by air curing and saturated lime water curing [42].

Workability and strength properties of high calcium flyash geopolymer mortar was studied by varying concentration of NaOH solution from 10 M to 20 M and taking Na₂SiO₃ to NaOH ratio from 0.67 to 3.00. The increase in concentration of NaOH and sodium silicate solution reduces the flow of mortar. To produce high strength geopolymer concrete the optimum range of sodium silicate to NaOH ratio was 0.67 to 1.00 which attains the compressive strength of 65 MPa [43].
The effect of modulus and content of alkali activator of NaOH and Na$_2$SiO$_3$ on compressive strength using class C fly ash geopolymer was investigated. It was suggested that the higher compressive strength is obtained when the modular ratio of activator solution was kept at 1.5. The content of mixed activator solution was 10% by mass of the proportions of Na$_2$O to fly ash. The strength obtained was found to be 63.4 MPa. He also suggested that the utilization of fly ash as geopolymer materials acts as an energy saving process and indirectly reduces the emission of greenhouse gas CO$_2$ released from cement manufacturing [44].

The possibility of leaching of fly ash mixes with activator solution to prepare geopolymer was studied. He also investigated the reaction of silica and alumina materials in fly ash with sodium hydroxide for different time intervals. The microstructure of geopolymer paste along with compressive strength was also studied. The results revealed that solubility of fly ash depends upon NaOH concentration and duration of mixing. The high strength up to 70 MPa was obtained with concentration 10M NaOH solution and SiO$_2$/OH ratio was kept at 1.0 along with separate mixing process yields better strength than normal mixing [45].

Parameters namely SiO$_2$/Al$_2$O$_3$, M$_2$O/Al$_2$O$_3$, H$_2$O/M$_2$O with the synthesis of kaolin based geopolymer were examined. He prepared nine different combination using three molar ratios SiO$_2$/Al$_2$O$_3$, Na$_2$O/Al$_2$O$_3$, H$_2$O/Na$_2$O to study the effect on compressive strength and microstructure. The results shows that Na$_2$O/Al$_2$O$_3$ and H$_2$O/Na$_2$O has greater influence on compressive strength and he also noticed that the maximum compressive strength of 34.9 MPa was obtained for the ratio of SiO$_2$/Al$_2$O$_3$ as 5.5, Na$_2$O/Al$_2$O$_3$ as 1.0 and H$_2$O/Na$_2$O as 7.0. This combination involves completely reacted geopolymer concrete. The microstructure study reveals that fully reacted
sodium based a poly-sialate-disiloxo possesses structural characteristic which is similar to gel formation formed by SiO$_4$ and AlO$_4$ tetrahedra [46].

The effect of compressive strength using fly ash geopolymer concrete on various parametric study includes ratio of alkali activator solution, concentration of alkaline liquid, curing temperature and type of alkaline solution was presented. It was observed that the compressive strength of geopolymer concrete increases over controlled concrete by 1.5 times i.e. M25 grade achieves M45 grade strength. The split tensile strength also increases 1.45 times greater than controlled concrete. Flexural strength increased by 1.6 times than that of controlled specimens. It was also observed that use of 12M KOH solution resulted gain in strength due to thermal curing with a temperature of 60° C for 24 hrs and it has completed the poly-condensation reaction [47].

The effect of calcium silicates on polymerization was examined and it was concluded that silicates mainly depend upon two factors they are the crystalline structure of source material and the alkaline nature of activator solution. Seven different materials were prepared which were rich in silica and calcium are used in his study. These materials are synthesis with three different concentration of NaOH solution such as 2M, 5M and 7.5M concentration at 1 hr and 24 hrs. He concluded that at low alkalinity calcium dissolution from source material form C-S-H gel which in conjunction with geopolymer gel improves mechanical strength. Less calcium dissolves from natural source material which results in little formation of calcium silicate hydrate gel. The material which remains unreacted disturbs the geopolymer gel formation which results in less strength. At high alkaline solutions, the geopolymer gel formation is a dominant product. Calcium plays a lesser role in
extent of dissolution. Therefore compressive strength at high alkaline solution is found to be similar to the different calcium silicate materials used [48].

The usage of alternative cementitious binders to OPC in concrete was investigated. Usage of calcium aluminate cement, calcium sulfo aluminate cement; alkali activated binders and super sulfated cement materials were also investigated and compared with Portland cement with their history, composition, hydration process, chemical reaction. Each one has its own merits and demerits. Alkali activated binders’ shows much advantageous when compared with all other cementitious binders [49].

The mechanical and durability characteristic of high strength of alkali activated fly ash geopolymer concrete was examined. The effect of ratio SiO$_2$/Al$_2$O$_3$ (3.5, 4, and 4.5) and Na$_2$O/Al$_2$O$_3$ (0.5, 0.75 and 1.00) on composition nature and mechanical properties of the end properties of the end products were presented. The strength results reveal that the SiO$_2$/Al$_2$O$_3$ ratio increases from 4 to 4.5 the mechanical strength decreases. The optimum ratio is found to be 4.0. Similarly the Na$_2$O/Al$_2$O$_3$ ratio of 1.00 attains compressive strength of over 80 MPa [50].

The durability study of class F fly ash with alkaline activators exposed at 5% of acidic and sulfuric acid solution was investigated. The parameters investigated were weight loss, compressive strength, degradation and microstructure changes. The deterioration of concrete was due to depolymerisation of alumino silicate polymers with the liberation of silicic acid, which caused the ion replacement and alters the polymeric structure which leads to loss of strength. In acidic reaction the deterioration takes place in the polymer matrix. High performance geopolymer results in formation of cracks in amorphous form where as low performance geopolymer deteriorate through crystallization which results in formation of grains. Sodium
Hydroxide solution is more stable than potassium hydroxide solution which results in less porous structure [51].

Many research works were carried out/being carried out on environmental issues related to concrete production and good number of findings was available to mitigate carbon footprint. Some of the literatures related to carbon footprint analysis are briefed in the following paragraphs:

Emissions of carbon dioxide (CO₂) resulting from materials, subsequent activities and operation during life span of a building, ultimately demolition at the end of its designated life named as carbon footprint. Sometimes it will be called as carbon dioxide equivalent (CO₂e) and was a measure of greenhouse gases responsible for global warming. Estimation of carbon footprint will be highly helpful to assess the quantum of damage caused to the society through harmful CO₂ emissions. Reduction of CO₂ emissions became mandatory to have sustainable environment. Many research works were done all over the world to mitigate the CO₂ emissions with available technologies.

Malhotra [52] assessed that finding substitute to cement makes good sense and they also suggested that cement can be replaced to an extent of 30% by wastes obtained from thermal and silicon industries such as fly ash and ground granulated blast furnace slag. It was also realized that large of amount of exploitation of water was done to produce concrete and hence concrete manufacturer can think of making use of washing water after due recycling process. Madlool et al. [53] critically analyzed the energy use and savings in cement industries. They found that in the cement manufacturing process grinding alone consumes around 60% of total energy consumption of cement industry. They concluded that use of alternative fuel could be a good solution and that could be an area for future research and development.
It was estimated that materials which are used for construction itself responsible for the CO₂ emission to an extent of 75 to 83% of the total CO₂ emission during the entire process of construction. Among the different construction materials used, Ordinary Portland Cement contributes around 5% of annual production of CO₂ emission at global level (Flower & Sanjayan, [54], Holcim, [55]). In Netherlands, out of total production only 48% of cement has clinker as ingredient whereas remaining quantity with blending of other materials such as fly ash and ground granulated blast furnace slag (GGBFS). However the properties of concrete were enhanced with substitution of other aggregates (Bremmer & Eng, [56]).

It was indicated that higher cement content to be used in concrete when recycled aggregate used as coarse aggregate either fully or as partial substitute in turn affects GHG emissions. The reason highlighted was, use of recycled aggregate in concrete could reduce the concrete strength and hence more quantity of cement. They also suggested using fly ash as replacement material for cement in concrete, which may reduce water and GHG emission embodied in concrete.

Aldridge [57] highlighted that use of supplementary cementitious materials as a replacement to cement not only reduces carbon foot print but also offers better durability characteristics for a sustainable infrastructure. Turner and Collins [58] claimed that cement was replaced with alkali activators to activate supplementary cementitious materials in geopolymer concrete and hence produce lesser quantity of carbon foot print. Provis and Deventer [59] mentioned that Australia played a vital role in developing geopolymer concrete. White et al. [60-61] have found from their research on structure of kaolin and meta-kaolin that the possibility of achieving new techniques in arriving the structure of amorphous cementitious materials.
Many researchers have done good quantity of research work on quantification of direct and indirect emissions produced from cement industry related on and off site activities like construction, prefabrication, transportation and administration (Dixit et al. [62]). They also found that contribution of direct emissions in building sector was found to be twice the indirect emissions from domestic of total carbon emission (Nässén et al. [63]). Since the contribution of indirect emission was very much higher than the contribution of direct emission in construction materials like cement and steel reinforcement, estimation of direct emission only will not give a reasonable result for any infrastructure project with prefabricated panel systems (Dixit et al. [64], Crawford et al. [65-66], Aye et al. [67], Monahan and Powell, [68], Peng and Pheng, [69]).

It was understood from the available literature that energy consumption of industrial sector ranges from 30 to 70% of total energy consumed in some selected countries [Al-Ghandoor A, et al. [70], Al-Mansour et al. [71], Onut and Soner, [72], Saidur et al. [73-76], Steenhof [77], Subhes and Ussanarassamee, [78]]. It was also assessed that sizeable magnitude of energy was consumed during process of manufacturing cement. Hence there was a compelling necessity to focus on mitigation of energy and energy related environmental emissions at local level and global level [Sheinbaum and Ozawa, [79], Soares and Tolmasquim, [80], Worrell et al. [81]]. There was another assessment on consumption of energy by the industrial sector in which it was estimated that Malaysia consumes about 12% and Iran consumes about 15% of total energy consumption in respective countries [Avami and Sattari, [82]].
2.3 **Objectives of the present research work**

Based on the above said literatures the following objectives were made

1. To produce GGBFS and SF based geopolymer concretes and to study its effect on compressive strength at different ages.
2. To study the durability characteristics of GGBFS and SF based geopolymer concretes against sorption and porosity.
3. To examine the effect of thermal curing (magnitude) and effect of alkaline liquid (AL) solution on geopolymer concrete.
4. To compare and suggest an optimum percentage of alkaline solution concentration to characterize the strength and durability characteristics.
5. To study the flexural behaviour of GGBFS and SF based GPC beams.