Geopolymer Concrete with FlyAsh and GGBS at Ambient Temperature – A State of the Art Review

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Abstract— Geopolymer is an alkali aluminosilicate binder formed by the alkali silicate activation of aluminosilicate materials. This fabric has been examined extensively over the past several decades and shows promise as a greener option to Ordinary Portland Cement (OPC) concrete. It has been found that geopolymer has good engineering properties with a reduced carbon footprint resulting from the zero-cement content. Since 1970's many research projects have been carried out to investigate the strength, durability and microstructure of Geopolymer concrete. Trials have been done to study the effects of water solids ratio, binder content, the molar concentration of alkaline solution, curing conditions and aggregate to solids ratio. The present report surveys the research carried out on GeoPolymer Concrete (GPC) with fly ash (FA) and Ground Granulated Blast funace Slag (GGBS) for ambient conditions. The review also includes the work that has been carried out, to date, accounting for the effects of various ingredients, ratios and structural aspects on the behaviour of geopolymer concrete and present applications in construction industry.

Key words: Geopolymer Concrete, Fly Ash, GGBS

I. INTRODUCTION

Geopolymer concrete utilizes fly ash and GGBS as a binder system to produce concrete eliminating cement. Geopolymer is a type of amorphous alumino-hydroxide product that exhibits the ideal properties of rock-forming elements, i.e., hardness, chemical stability and longevity. Geopolymer binders are used together with aggregates to produce geopolymer concretes which are ideal for building and repairing infrastructures and for precasting units, because they have very high early strength, their setting times can be controlled and they remain intact for very long time without any need for repair. The properties of geopolymer include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance and corrosion resistance. These high alkali binders do not generate any alkali aggregate reaction. The geopolymer binder is a low CO2 cementitious material. It does not depend on the calcinations of limestone that generates CO_2. This technology can save up to 80% of CO_2 emissions caused by the cement and aggregate industries.[1]

In 1979, Joseph Davidovits created and applied the term geopolymer because polymerization process takes place, in which Silica (Si) and Alumina (Al) present in the source material (Fly Ash/Silica Fume), reacts with the alkaline liquid to produce binders.[2, 3]

Numerous researches have been conducted to produce quality geopolymer concrete that is comparable to OPC concrete. However the curing method has generated some limitations to the geopolymer concrete applications. Therefore the current research should focus on the geopolymer concrete at ambient conditions which is suitable for cast in situ application.[4]

II. PREVIOUS RESEARCH

Many research works have been carried out since 1979 to investigate the properties of geopolymer concrete and to suit the present construction industry needs. Tests have been performed to examine strength parameters, workability and durability aspects of geopolymer concrete. These works consists of experimental studies on different binding materials, alkaline solutions, curing conditions, mixing procedures etc. Some of the major research works are discussed here.

Most of the studies are aimed to evaluate strength parameters, workability and durability of geopolymer concrete with traditional material like flyash, GGBS and additives as fibres. Principal factors on which the strength and workability depends are percentage of replacement of fly ash by GGBS, molarity of alkaline solution, flyash to alkaline activator ratio, water to geopolymer solids ratio, aggregate to geopolymer solids ratio, percentage of volume of fibre content etc. Wide ranges of experiments are carried out to examine the various factors as mentioned above. Summary of few such studies are presented here.

III. GEOPOLYMER CONCRETE WITH FLYASH AND GGBS

Ganapati Naidu. P et al experimented to study strength properties of geopolymer concrete using low calcium flyash replacing with slag in 5 different percentages. Sodium silicate (103 kg/m^3) and sodium hydroxide of 8 molarity (41kg/m3) solutions were used as alkalis in all 5 different mixes. With maximum (28.57%) replacement of flyash with slag, achieved a maximum compressive strength of 57 MPa, maximum tensile strength of 11.4 MPa, and maximum flexural strength of 7.06 MPa for 28 days. [5]

N P Rajamane et al conducted experiments with 100% GGBS based geopolymer concrete and compared with 28% Fly ash + 72% OPC concrete. The results showed that compressive strength of GPC at 28 days are 31.25 % of more than that of OPC mix. The GPC is found to be more acid resistance, since the specimens even after 90 days of immersion in both 2% and 10% sulphuric acid solutions, remained almost intact.[6]

More Pratap Kishanrao investigated the behaviour of fly ash, blast furnace slag and catalytic liquids based Geopolymer concrete under high temperatures ranging from 1000C to 5000C. The parameter studied includes compressive strength and weight loss after expose to elevated temperature. Further, it is also established that high elevated temperature curing is not required in all cases of GPC.[7]

Madheswaran C. K et al studied the influence of ground granulated blast furnace slag on geopolymer concrete. The types of geopolymer concrete mixes taken with different molarities of sodium hydroxide solution and GGBS. The measured compressive strength of geoploymer mix is in the range from 24 MPa to 60 MPa and maximum of 60 MPa for 100% GGBS and 7M sodium hydroxide solution at 28 days.[8]

K. Parthiban et al observed the influence of the various proportions of GGBS (0-100%) on Fly Ash based GPC; the effect of the amount of Alkaline Activated Solution (AAS) in the mixture of GPC on their compressive strength is studied under ambient temperature conditions. The results showed that 28 days compressive strength shows higher strength 53.87 MPa for 100% replacement of GGBS compared with OPC.[9]

B. Rajini et al studied the effect of class fly ash and GGBS on the mechanical properties of geopolymer concrete (GPC) at different replacement levels (FA0-GGBS100, FA25-GGBS75, FA50-GGBS50; FA75-GGBS25, FA100, GGBS0). The outcome of experiments illustrate that compressive strength and split tensile strength of geopolymer concrete are maximum of 60.23 MPa and 3.56 MPa for the FA0-GGBS100 at 28 days irrespective of curing period. The compressive strength and split tensile strength of geopolymer concrete decrease with increasing FA content in the mix in all cases of curing periods.[10]

A.R.Krishnaraja et al studied mix proportions with fly ash partially replaced in the range of 10% to 50% by GGBS of total binder content and tests are carried on the density, compressive strength and split tensile strength of geopolymer concrete. Based on the study carried out, replacement of GGBS in fly ash upto 50% produced better compressive strength and tensile strength of 39.23MPa and 4.94 MPa respectively.[11]

Saifuddin.K.P et al studied the variation of workability of flyash and GGBS based geopolymer concrete with the variation of polycarboxylic based,Sulfonated naphthalene based and lignine based superplasticizer. GGBS has been included in the fly ash based geopolymer concrete. The effect of superplasticizer on workability and compressive strength were studied under ambient temperature condition. Up to 6% of superplasticizer dosage and 12M of NaOH concentration have given satisfactorily result in compressive strength of 51.52 MPa and workability.[12]

V Hariharan et al carried out experiments on Geopolymer Concrete with different molarities of sodium hydroxide solution i.e. 8 M , 12 M &16 M and combinations of fly ash and GGBS were used such as 90% fly ash and 10% GGBS, 80% fly ash and 20% GGBS, 70% fly ash and 30% GGBS and 60% fly ash and 40% GGBS. The result shows that the strength of geopolymer concrete is increasing with the increase of the molarity of sodium hydroxide. Also, it was noted that with the increase in content of GGBS, the strength increases. The maximum compressive strength of 82.28 MPa, tensile strength of 4.2 MPa and flexural strength of 11.08 MPa for the mix of 60% fly ash and 40% GGBS were reported.[13]

S. Aravindan et al investigated the long term strength and durability properties of Alkali-Activated and flyash based Geopolymer Concrete comparing with the conventional concrete of M40 grade. The investigation resulted that there is an increase in strength characteristics with increase in concentration of sodium hydroxide solution and open air cured specimens gained more strength than dry cured specimens. The highest values of compressive, tensile and flexural strength is observed for 12 M NaoH and Open air Curing.[14]

Apoorva. S et al experimented Geopolymer Concrete mix with different proportions of Flyash and GGBS i.e., 100% FA + 0% GGBS, 90% FA + 10% GGBS, 80% FA + 20% GGBS, 70% FA + 30% GGBS and 60% FA + 40% GGBS. Geopolymer concrete members are cured at ambient temperature and also at 80°C in oven for 24hours with varying proportions of fly ash and GGBS for 12M concentration. After the experimental investigation, it was found that the strength of geopolymer concrete increased with increase in higher percentage of GGBS and also the strength increased with age of the concrete in case of ambient curing. The highest compressive strength of 51.7 MPa, tensile strength of 10.35 MPa and flexural strength of 10.62 MPa were obtained for the mix 60% FA + 40% GGBS at ambient curing.[15]

IV. Fiber Reinforced Geopolymer Concrete

Sundar Kumar. S et al conducted experiments on geopolymer concrete with different proportion of GGBS such as 0%, 10%, 25% and 50% as replacement of fly ash and 0.75% of crimped steel fibres with aspect ratio 100. From experiments it was found that, tensile and flexural strength of fibre reinforced geopolymer concrete is more than geopolymer concrete without fibres. It was observed that spilt tensile strength is 4.33 MPa and flexural strength is 6.35 MPa.[16]

H. Gokulram et al conducted experimental investigation on the mechanical properties of different binder composition of Geopolymer Concrete Composites (GPCC). The study analyses effect of polypropylene fibre on the mechanical properties such as compressive strength, split tensile strength and flexural strength of hardened GPCC. Polypropylene fibres were added to the mix in the volume fraction of 0.25% volume of concrete. Two kinds of systems were consider in this study using 100% replacement of cement by ASTM class F Fly ash and ground granulated blast furnace slag and 100% replacement of natural sand by Manufactured sand. The mix with 100% GGBS and 0% FA has given the highest mechanical properties i.e. compressive strength as 34 N/mm2, split tensile strength as 4.74 N/mm2 and flexural strength as 5.1 N/mm2.[17]

Nisha Khamar et al conducted experiments on GPC with different molarities of sodium hydroxide solution i.e. 8M, 10M and 12M and the compressive strength is calculated for each of the mix. From that optimum molarity was obtained and which is used for further studies. The steel fibres are added in this mix at varying percentages of 0, 0.25, 0.5, 0.75 and 1. After getting the optimum percentage of steel fibres, while the polypropylene fibre are varied at 0, 10, 20, 30 and 40 percentages of steel fibre with optimum steel fibre remains constant. For curing, temperature was fixed at room temperature for 24 hours. The optimum mix found by addition of 0.5% steel fibre and polypropylene fibre of 30% of steel fibre.[18]

G.Ramkumar et al studied properties of three GPC mixes with fly ash (50%) and GGBS(50%) in the binder stage, stainless steel fibre(0.75%) and mild steel fibres(0.75%). The results concluded that GPC mixes with added steel fibres are approximately 20% more than GPC mix without steel fibres in compression behavior, GPC mix with added stainless steel fibres is 57% more than control mix and GPC mix with added mild steel fibres is 75% more than GPC mix without steel fibres in split tensile strength behavior and Flexural strength of GPC with added fibres is approximately 24% more than GPC mix without steel fibres.[19]

V. Steel Reinforced Geopolymer Concrete

Dattatreya J K et al carried out experiments on the behaviour of room temperature cured reinforced GPC flexural members and are reported. A total of eighteen beams were tested in flexure. Three conventional concrete mixes and six GPC mixes of target strength ranging from 17 to 63 MPa and having varying combinations of fly ash and slag in the binder phase were considered. The reinforcement was designed considering a balanced section for the expected characteristic strength. All the specimens were tested under two point static loading. The studies demonstrated that the load carrying capacity of most of the GPC beams marginally more than that of the corresponding conventional OPC beams.[20]

Ruby Abraham et al carried investigations to determine and to compare the flexural behavior of geopolymer concrete (GPC) beams with conventional concrete beams of same grade. A total of twenty beams consisting of twelve GPC beam specimens and eight OPC beam specimens were considered in this study. The beams were designed as under reinforced with tensile reinforcement ratios 0.55%, 0.83%, 1.02% and 1.3%. The beams were tested under two point monotonic loading. The test results showed that the geopolymer concrete exhibits better performance compared to conventional concrete of same grade.[21]

M. K. Thangamanibindhu et al conducted tests on flexural members to understand the behaviour of ambient cured Reinforced GPC (RGPC). A total of 9 beams were tested in flexure, out of which three were conventional concrete mixes and six GPC mixes having varying combinations of flyash, GGBS and recycled coarse aggregates. The reinforcement was designed considering a balanced section and all the specimens were tested under two point loading The studies showed that the load carrying capacity of the RGPC beams was more than that of the corresponding conventional OPC beams.[22]

Aslam Hutagi et al investigated the flexural behavior of GPC beams cured under ambient temperature. Twelve reinforced concrete beams of size 175mmx 250 mm x 1500 mm were tested. The beams were tested under four point bending over an effective span of 1200mm. The percentage of tensile reinforcement and compressive strength of concrete were taken as the variables while maintaining the same cross section. The behavior was studied with reference to first crack load, service load and ultimate load. The results were found to be similar for GPC beams to that of conventional cement concrete reinforced beams.[23]

VI. Conclusions

Considerable progress has been made during the last two decades in the investigation of geopolymer concrete with Fly ash & GGBS and information available is summarized in this paper. Fundamental knowledge on compressive strength, split tensile strength, flexural strength and Durability of GPC, fibre reinforced GPC and steel reinforced GPC beam has already been obtained by the research carried out so far. However, intensive research is required on mix design with Fly ash, GGBS, different fibres, steel reinforcement and durability of geopolymer concrete at ambient temperature.

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