Characterization & Durability Properties of Ultrafine Fly Ash based Geopolymer Concrete

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Abstract

Huge scale generation of cement is creating environmental issue on one hand and depletion of natural resources on the other hand. This danger to nature has prompted research being made of industrial byproducts as supplementary cementetious materials in making concrete for more green and durable. Fly ash and silica fume both are pozzolanic materials which have been broadly utilized for improving the properties like strength and durability in concrete. Silica fume demonstrates the greater pozzolanic activity then fly ash because of its finer particle size distribution, the pozzolanic activity of fly ash also can be enhanced by decreasing the particle size distribution. Geopolymer is a class of aluminosilicate binding materials integrated by thermal action of solid aluminosilicate based materials such as metakoaline, GGBFS, fly ash. Geopolymer get activated with the alkaline solution and heat. Sodium hydroxide and sodium silicate were utilized as an alkaline solution with a steady ratio of 2.5 and the mix is designed for molarity 10 for the work carried out. In the present study, an attempt has been made to explore the geopolymer concrete by utilizing ultrafine fly ash (UFFA) produced by air classification and processed GGBFS with varied proportions. Discusses on the properties of geopolymer concrete has also been mentioned. Compressive strength and durability tests like Permeability, Abrasion, Sorptivity, Acid and sulphate attack, Drying shrinkage were conducted. In this work geopolymer concrete was prepared with varying proportions of GGBS and UFFA in the ratio of 92.5:7.5 and 88:12 and 80:20. The maximum strength was achieved for the ratio 92.5:7.5. The obtained compressive strength is in the range of 36.5MPa to 91.6MPa from 1st day to 28th day of hot curing.
Keywords: Geopolymer Concrete, Ultrafine Fly Ash, Metakoaline, GGBFS, Silica Fume

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I. INTRODUCTION

Cement is the primary component of concrete, it is estimated that production of one tone of OPC release around one tone of carbon dioxide to the environment and the global cement release around 1.35 billion tons of gas emission annually, Similarly if the production continuous till 2020, it is estimated that carbon dioxide emission will be rises 50% from the current level [2].

A. Supplementary Cementetious Materials (SCM)

In its most basic form, concrete is a mixture of Portland cement, sand, coarse aggregate and water. The principal cementetious material in concrete is Portland cement. Today, most concrete mixtures contain supplementary cementetious materials that make up a portion of the cementetious component in concrete. These materials are generally by products that are obtained from other processes or by natural means. They may or may not be further processed for use in concrete. Some of these materials are called pozzolans, an essentially siliceous material which while in it possessing little or no cementetious properties but, in finely divided form and in the presence of water, react with calcium hydroxide at ambient temperature to form compounds possessing cementetious properties. Other materials, such as slag, do exhibit cementetious properties. Some examples of these materials are listed as below:

1) Fly Ash (Pulverized Fuel Ash)
2) GGBFS (Ground Granulated Blast Furnace Slag)
3) Metakaoline (An alumino silicate material)
4) Micro Silica (A silica rich product)
5) Ultra-fine Slag

B. Geopolymer Concrete

Davidovits was the first person that introduced the geopolymer concrete in 1988. In the beginning stages alkaline liquids are used to react with silica and aluminum as bi product materials such as fly ash, silica fume. In the polymerization process fast chemical reaction take place under alkali condition on silica and aluminum minerals which resulting three dimensional polymeric chains and consisting of Si-O-Al-O ring like structure. Nowadays GPC is emerging as a good cement binder.

II. MATERIALS AND SAMPLE PREPARATION

The materials along with the geopolymer concrete have been utilized as a part of the experimental work are Ultra fine fly ash (UFFA) JSW origin (0.10%LOI, 0.09%SO_3, 64.68%SiO_2, 23.84%Al_2O_3, 5.02%Fe_2O_3, 1.27%CaO, 0.86%MgO, 1.62%K_2O, 0.33%Na_2O), GGBS: JSW origin (0.35%insoluble residue, 35.28%SiO_2, 16.82%Al_2O_3, 1.48%Fe_2O_3, 35.90%CaO, 8.08%MgO, 0.78%K_2O, 0.34%Na_2O), Fine aggregate: M-sand confirming to Zone-II of IS:383-1970 with a specific gravity 1.93, Coarse aggregate: confirming to IS:383-1970 with a specific gravity 1.93, Alkaline liquids: sodium hydroxide(NaOH) having water content 27.6%, 32.88%SiO_3,17.02%Na_2O, 14.12%K_2O,1.18%Al_2O_3 sodium silicate (Na_2SiO_3) with specific gravity of 1.58.

Test samples were prepared as per IS standard, that is, cubes of (100X100X100) mm for compressive strength, For durability tests the samples of (150X150X150) mm for durability test, for water permeability test moulds of (75X75X75) mm for acid and sulphate attack test, (70x70)mm square specimen for abrasion test, (100mm diaX50mm height) for Rapid chloride penetration test.

III. EXPERIMENTAL METHODS

A. Mix Design for Geopolymer Concrete

In the present design mix of geopolymer concrete, coarse aggregate and fine aggregate were taken as 77% of entire mix, coarse aggregate and fine aggregate ratio were taken as 70%and30% respectively, density of concrete was taken as 2400kg/m^3similar to that of OPC, The ratio of sodium silicate to sodium hydroxide is taken as 2.5. [2], Ratio of Alkaline liquid to Binder taken as 1. Totally 7 different mix proportions are considered for the experimental work, table-2 shows different proportion of mix

Table – 1
Mix Design for Geopolymer Concrete

Material	*GGBS + UFFA*	*Coarse Aggregate*	*Fine Aggregate*	*Alkaline Solution*
Weights in Kg	*276*	*1294*	*555*	*276*

Table - 2
Different proportions of mix

Mix	*% GGBS*	*% UFFA*
GPC1	*92.5*	*7.5*
GPC2	*88*	*12*
GPC3	*80*	*20*
GPC4	*100*	*0*
GPC5	*7.5*	*92.5*
GPC6	*12*	*88*
GPC7	*20*	*80*

B. Preparation, Casting and Curing of GPC

The combination of sodium silicate and sodium hydroxide in ratio 2.5 was used as a alkaline solution for preparing GPC. The concentration of sodium hydroxide as taken as 10M, for the preparation of 10M concentrated sodium hydroxide solution 400 gms of sodium hydroxide flakes were dissolved in one liter of water. The polymerization reaction takes place after mixing sodium hydroxide and sodium silicate solution together which will liberate large amount of heat hence the alkaline solution was used after 24 hours of mixing. To improve the workability of concrete Auromix 400plus was used as superplastisizer with a dosage of 1.5% by mass of binder material. Mixing process can be handling with 5 min for each mix in mixer with proper dosage of alkaline solution and super plasticizer. Normally the heat curing is recommended for the GPC because polymerization takes place around 60°C. Hence one set of specimen was kept for oven curing for three days with a temperature of 60°C and another set of specimens were kept for ambient curing.

Fig. 1: Oven Curing

Fig. 2: Ambient Curing

IV. EXPERIMENTAL RESULT AND DISCUSSION

C. Workability and Compressive Strength

Based on experimental work carried out for different percentage variations of GGBS and UFFA in geopolymer concrete the result are expressed below. In the fresh geopolymer concrete workability was poor, and the mix was stiffer compared to POC because of less amount of water content and also because sodium silicate is cohesive in nature.

Compressive strength test was carried out at the age of 1st, 3rd, 7th and 28th days according to IS 516-1959 using UTM having a capacity of 2000kN testing machine with uniform rate of application of load. The average compressive strength of 3 cubes of all the different proportions of GPC mix of normal (N) and heat (H) Curing are as show below

Table – 3
Average Compressive Strength

Mix	*1st day*	*3rd day*		*7th day*		*28th day*	
	N	*N*	*H*	*N*	*H*	*N*	*H*
GPC1	*9.77*	*20.07*	*33*	*26.57*	*44.33*	*60.7*	*83.1*
GPC2	*18.57*	*25.9*	*43.37*	*37.4*	*53.5*	*62.4*	*86.2*
GPC3	*20.63*	*40.27*	*48.67*	*48.1*	*60.1*	*68.5*	*87.8*
GPC4	*23.77*	*35*	*49.43*	*40.5*	*57.3*	*49.4*	*64.3*
GPC5	*36.5*	*55.6*	*70.2*	*74.4*	*87.5*	*78.9*	*91.6*
GPC6	*27.7*	*50.2*	*67.3*	*68.1*	*79.5*	*72.4*	*84.2*
GPC7	*26.4*	*46.03*	*63.42*	*59*	*67.06*	*65.4*	*73.4*

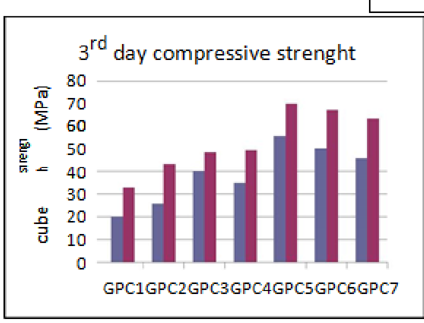

Fig. 3: 3rd day compressive strength

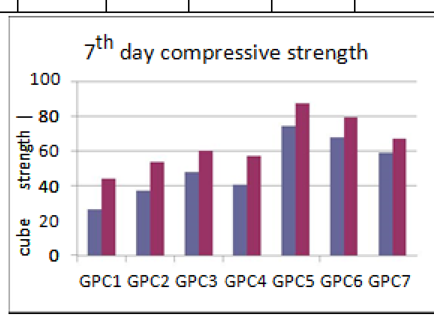

Fig. 4: 7th day compressive strength

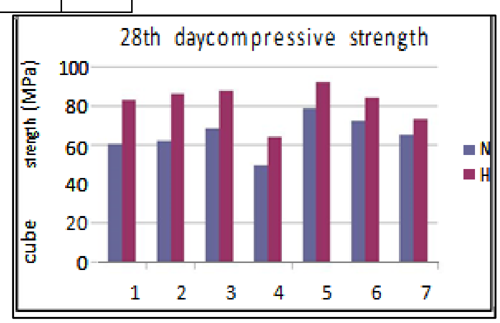

Fig. 5: 28th day compressive strength

The data illustrated in table-3, shows that the effect of ultra fine fly ash in strength development of GPC. With 100% GGBS the strength attained is increasing from 23.77MPa to 64.3MPa for first to 28th days of age, comparing with all the results obtained for different proportion of GGBS and ultrafine fly ash GPC-5 attains a very good strength that is 35.6 MPa to 92.3MPa. It is observed that increasing the percentage of GGBS the strength will decrease; optimum strength was achieved for the ratio 7.5 and 92.5 of GGBS and UFFR respectively. It is observed that GPC will attain early strength almost 30% of strength on in 1st days and around 80% strength on 7th days

D. Water Penetration Test

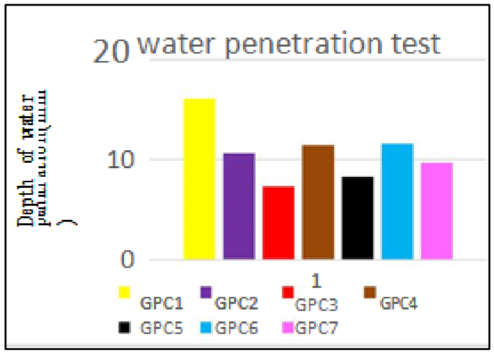

Fig. 6: Water penetration test result

From the result it is observed that GPC with ultrafine material will resist water penetration through the concrete, because of small partial size distribution which helps for good bonding between the particles. Normally the depth of penetration should not be more then 25mm but in GPC all the samples are within 15mm and, hence it can be concluded that less the depth of penetration more is the durability of concrete

E. Abrasion Resistance Results

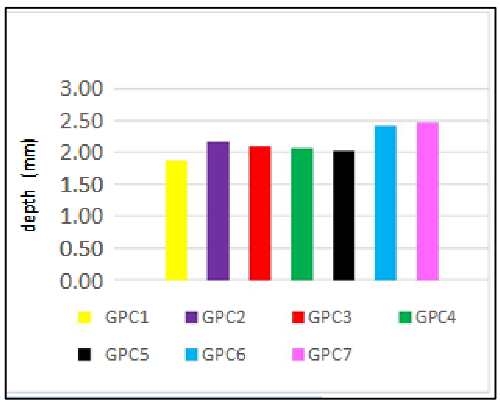

Fig. 7: Abrasion Resistance Results

This test is carried out to determine the abrasive resistance of the materials, as per standard the abrasion value is 2.5mm for the commercial building and 3.5mm for residential buildings. From the result it is clear that all values are within 2.5mm hence GPC is good in abrasion resistance. Less the abrasion value more the durability of material.

F. Drying Shrinkage

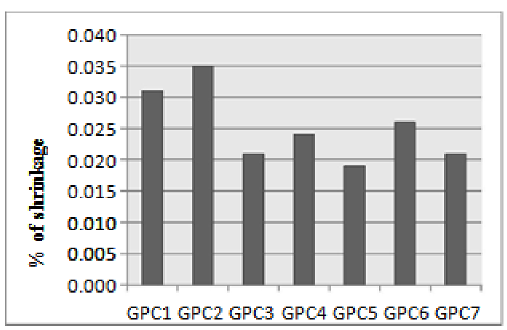

Fig. 8: Drying shrinkage test result

This test is conducted to determine the change in length of concrete specimen due to change in moisture content. Less the change in length the concrete is good, it is observed that in GPC -5 the change length is very less hence it more durable compared to all other proportions.

G. Acid and Sulphate Attack Test

Experimental result is shown in fig-9, percentage of weight loss for different proportion when specimens are immersed in concentrated sulphuric acid and sulphate. It is observed that increasing the percentage of UFFA, acid attack will be comparatively less but in case of sulphate attack increasing the percentage of UFFA and there by weight loss is more.

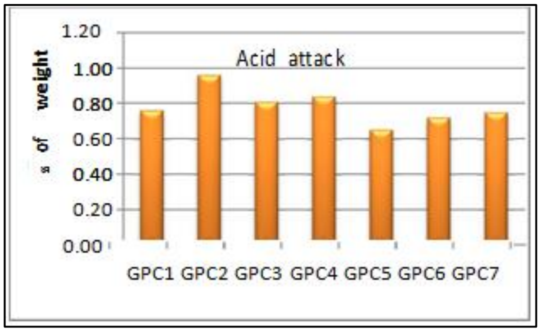

Fig. 9: Acid Attack Test Result

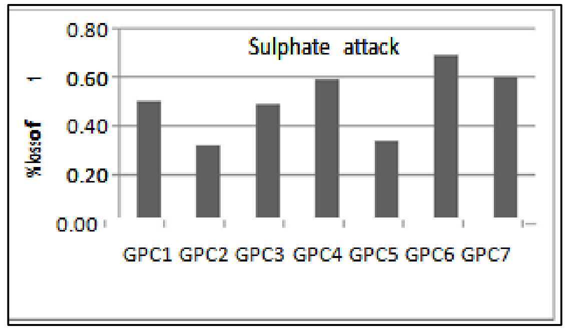

Fig. 10: Sulphate Attack Test Result

Fig 11 and 12 shows the comparison of compressive strength decrement after acid and sulphate attack test , it is observed that in acid test more the GGBS, decrease the strength of concrete. In case of GPC-5 after acid test also strength attain will be 73 MPa and also percentage of strength loss is also less compared with other proportions.

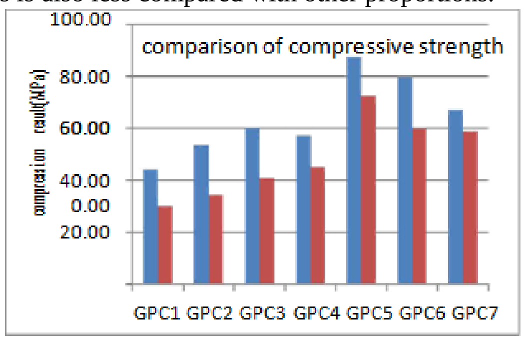

Fig. 11: Comparison of compressive strength with acid test.

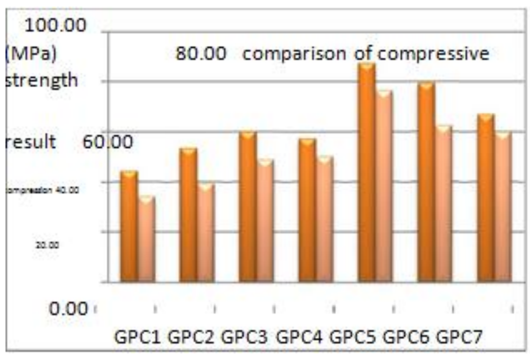

Fig. 12: Comparison of Compressive Strength of Specimens with and without acid

H. Sorptivity Test:

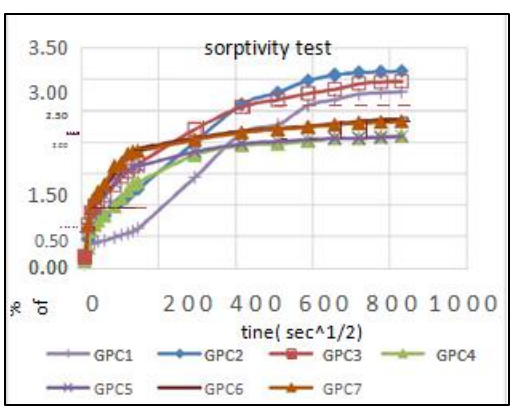

Fig. 13: Sorptivity Test Result

Sorptivity is conducted to determine the amount of water observed by concrete. From the above result it is observed that GPC-5 and GPC 7 will have the less sorptivity value, lesser the Sorptivity value more is the durability of concrete.

V. CONCLUSION

1) From the investigation it is clear that GPC-5 will give high compressive strength from 1st day to 28th day in comparison with other combinations, because in GPC -5 91.6% of UFFA is used, in where in the particle size distribution is small which helpful for strong bonding between particles resulting the reduction of voids which makes the concrete strong and durable.
2) Use of ultrafine material will attain early strength approximately 30% of strength is attained in one day.
3) The 7th day strength of GPC due to heat curing is almost equal to almost equal to the 28th day of normal curing, and it can be concluded that heat curing can achieve earlier strength,
4) In durability aspect it is clear that use of more UFFA in concrete is much more durable in sorptivity, acid attack, sulphate attack, water permeability because of good bonding between the particles.
5) From abrasion test it is clear that abrasion value is very less hence GPC can be used as a pavement material in highways.

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