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Geopolymer Concrete for Sustainable Future Development

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Abstract

This paper showed the result of experimental study carried out to study the mechanical properties of Geopolymer concrete in the presence of blast furnace slag (BFS). Three different geopolymer mixes were designed. Two mix designs were prepared by replacing fly ash with blast furnace slag in the ratios of 10% and 20%, and another mix was prepared with 100% fly ash to compare with the blended fly ash. The specimens were cubes of 100mmx100mm x100mm which were cured in oven at 100°C for 48 hours and left at room temperature until the day of testing. Mechanical properties of geopolymer concrete were evaluated such as workability, compressive strength, flexural and tensile strengths.. Portland cement concrete with the same mix proportions was designed as control. Sodium hydroxide and sodium silicate were used as alkali activators with molarity of 14M concentration. The result showed that the workability of OPC concrete is higher than geopolymer concrete. As the percentage replacement of fly ash in geopolymer concrete increased, workability decreased. The compressive strength of geopolymer concrete with 100% fly ash was higher than the control. Moreover, blending fly ash with blast furnace slag gave very high compressive strength more than the control. Tensile and flexural strengths increased as the percentage replacement of fly ash increased. From the results, it is seen that OPC is not required in the production of geopolymer concrete. Consequently, the global problem of greenhouse gases are drastically reduced. It can be concluded that geopolymer concrete is a veritable alternative to OPC concrete and essential for sustainable future development.

Keywords: Geopolymer, Blast furnace slag, fly ash, compressive strength, flexural and tensile strengths.

Introduction

The need to conserve energy and protect our environment has necessitated the search for alternative building materials that are eco-friendly. The major aim of these of research is to minimise the greenhouse emissions which cause Ozone layer depletion and reduce the energy required for material production. Cement production consumes a lot of energy and releases a large volume of CO_2 into the atmosphere. The energy consumption of cement industries are comparable to energy consumed by steel industries. Every year, the concrete industry produces approximately 12 billion tonnes of concrete and uses about 1.6 billion tones of Portland cement (PC) worldwide [Malhotra V.M et. al 2005]. This prompted the search for alternative construction material that is environmentally friendly. However, various attempts have been made to replace OPC with supplementary cementitious materials(SCMs) such as fly ash, blast furnace slag , silica fume etc.[N.B Singh et. al 2008, N.B Singh et. al 2009]. F.N Okoye et.al [2016] used bone ash to replace cement , all in attempt to reduce CO_2 emissions. The maximum replacement reported was 20%. Regrettably, these attempts has not yielded positive result since a lot of CO_2 emissions still persist. Incidentally, a new type of binder called Geopolymer was developed by Davidovits in [1978]. Geopolymer binder uses low energy in its production unlike OPC and has excellent mechanical and durability properties coupled with early strength development[F.N Okoye et. al 2016]. It is an inorganic aluminosilicate polymer, synthesised from materials of geological origin such bas fly ash, silica fume, rice husk ash etc which are rich in silicon and aluminium[Okoye F.N et. al 2016, Saeed et. al 2012 and PhairJ.W 2000]. However, this paper presents the result of investigation into the mechanical properties of geopolymer concrete in the presence of blast furnace slag

Materials and Methods

Low calcium Fly ash was used which conformed to the requirements of ASTM C618 (Class F). It was obtained from National Power Station, Dadri, Uttar Pradesh, India while blast furnace slag was obtained from Jindal Vijayanagar steel ltd, Toranagalla, Bellary-Hospect, Kanataka, India. Grade 43 OPC was used as reference. The chemical composition of the binders are given in table 1.

Table 1. Chemical composition of binders

Chemical composition (%)	OPC	Fly ash	BFS
Loss of ignition	2.48	3.79	0.31
Silicon Oxide (SiO_2)	19.01	50.7	35.5
Calcium Oxide (CaO)	66.89	2.38	41.41
Magnesium Oxide (MgO)	0.81	1.39	0.82
Phosphate (P_30_5)	0.08	-	-

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Sodium Oxide (Na_2O)	0.09	0.84	-
Potassium Oxide (K_2O)	1.17	2.40	-
Manganese Oxide (MnO)	0.19	-	-
Aluminium Oxide (Al_2O_3)	4.68	28.80	14
Iron Oxide (Fe_2O_3)	3.20	8.80	0.30
Sulphur trioxide (SO_3)	3.0	0.3	0.16

Coarse aggregates used was 20mm and 10mm while river sand was used as fine aggregate. The particle size distribution is given fig.1 as per BS 812, Part 1, 1975.

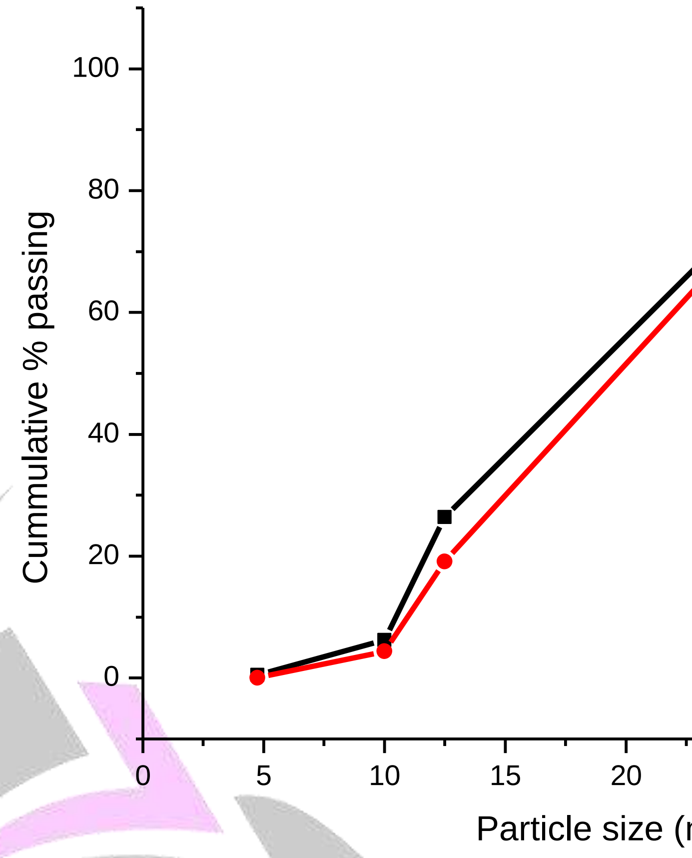

Fig. 1. Grading curve of 20mm and 10mm coarse aggregates

Physical properties of aggregates are given in table 2. Distilled water was used to prepare alkali solution while Naphthalene sulfonate was used as super plasticisers. Solutions of Sodium hydroxide and Sodium silicate were used as alkali activators.

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Table 2. Physical properties of gravels and sand

Sample	Specific Gravity	Water absorption (%)	Fineness modulus
20 mm aggregate	2.5	0.17	2.7
10 mm aggregate	2.4	0.87	2.8
Sand	2.6	-	2.1

Preparation of alkali

Solution of sodium hydroxide (14M) was prepared and left for 24 hours and then mixed with sodium silicate. The mixtures of sodium hydroxide and sodium silicate solutions were left for one day to enhance geopolymerisation.

Mix proportion

The geopolymer concrete was designed by conventional method as OPC concrete. The density of geopolymer concrete is 23.8Kg/m^3 in which aggregates occupy 75-80% by mass in geopolymer concretes[Hardjit D. et. al 2005]. Hence, coarse and fine aggregates were taken as 77% by mass of the entire mixture. Fine aggregates were 30% by mass of the total aggregates. The ratio of sodium silicate to sodium hydroxide solution was kept 2.5 and the concentration of NaOH solution was 14M. To improve the workability of fresh geopolymer mix, Naphthalene sulfonate based superplasticizer was used in all the mixes. The detailed mix design of geopolymer concrete mixes are given in table 3. Four different mix designs were developed for compressive strength, four each were developed for flexural and tensile strengths. In mixtures GP2 and GP3, fly ash was replaced with blast furnace slag in the ratios of 10% and 20% respectively as illustrated in table 3. Aggregates were kept constant together with superplasticicer and alkali. A control mix was cast as M40 with Portland cement concrete to determine the performance of geopolymer concrete over the control.

Table 3. Mix proportion of geopolymer concrete

MIX NO	Quantity of ingredients (Kg/m^3)										
	Coarse Aggregate		Fine Sand	Fly Ash	BFS	OPC	SS	NaOH (14M)	SP	ALK/FA	W/S
	20 mm	10 mm									
GP1	862	431	554	400	0	0	113	45	4.0	0.4	0.2
GP2	862	431	554	390	10	0	113	45	4.0	0.4	0.2
GP3	862	431	554	380	20	0	113	45	4.0	0.4	0.2

M40	862	431	554	0	0	400	N.A	N.A	4.0	N.A	0.3

FA-Fly ash, SS-Sodium silicate, SP-Superplasticisers, ALK-Alkaline, W/S-Water/Solid ratio, BFS-Blast furnace slag

Casting of geopolymer concrete

The casting of geopolymer concrete was similar to that of OPC concrete which was carried out in the laboratory under room temperature. Aggregates were mixed together in 600 mm x 900 mm mixing pan for about 3 minutes. The alkali solution was mixed with superplasticizer and then added to the dry materials and mixing continued for 2 minutes. The whole mixture was then transferred into a tilting type drum concrete mixer and mixing continued for 3 to 5 minutes. The fresh geopolymer concrete formed pellets when homogeneously mixed in a drum concrete mixer and were very stiff in consistency as far as workability was concerned; however, adequate compaction was achieved. The mixture was cast in a 100mm x100 mmx100mm steel mould in three layers, and each layer given 60 strokes with 20 mm compacting rod. The fresh samples were left in the laboratory at room temperature for 48 hours before demoulding.

Workability test

The workability of the fresh geopolymer concrete was investigated by using slump cone test in compliance with BS EN 12350-2:2000 standard

Curing of geopolymer concrete

The curing of geopolymer concrete required elevated temperature, hence after demoulding, all the samples were transferred in the oven for heat curing at 100^{o}C for 72 hours since according to F.N. Okoye et. al [2015], strength was found to be maximum. The samples were then left at room temperature after curing until the day of testing.

Results and discussion

Workability

Workability of geopolymer concrete was studied using slump cone test. The workability of geopolymer was low compared to the control as shown in Fig.2. The fresh geopolymer concrete formed pellets when mixed properly in a drum concrete mixer and were very stiff in consistency as far as workability was concerned, however, adequate compaction was achieved. To improve the workability of fresh geopolymer mix, Naphthalene sulphate based superplasticiser was used. The slump of OPC concrete was higher than those of geopolymer concretes

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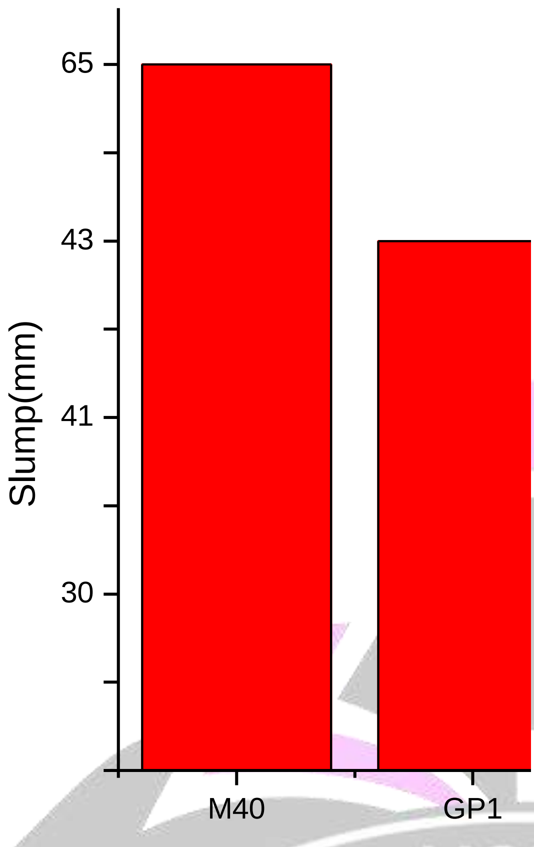

Fig 2. Slump of fly ash based geopolymer concrete blended BFS with in relation to control.

From the fig. 2, It was found that the slump of geopolymer concretes decreased with the increase of BFS. The poor workability of geopolymer concretes could be attributed to high viscosity of the mixtures. The GPC mixtures were stiffer than the OPC concrete mixtures due absence of water , and also due to the sticky sodium silicate solution used in geopolymer as activators. Similar observation was reported by other researchers [Rangan B.V 2008, Chindaprasirt P 2007]. When sodium silicate solution was added in concrete, the binding of the fine and coarse aggregate particles occurred making the composite, sticky thereby reducing the slump.

Compressive strength

Fig. 3 showed the variation of compressive strengths of various geopolymer mixtures in relation to control. The result shows that the compressive strength of GP3 with 20% replacement is higher than 10% and 100% replacement respectively and much higher than the control. It was also observed that as the blast furnace slag increased, the strength also increased. The variation in the compressive strength was due to differences in the composition, structure, particle size and dissolution rates of fly ash and blast furnace slag[Duxon P.et. al 2007].

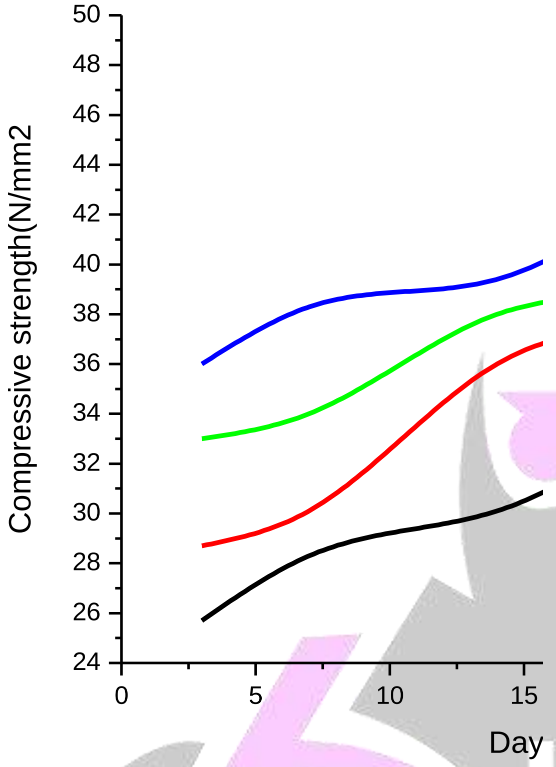

Fig. 3 Compressive strength of fly ash based geopolymer concrete blended with BFS in relation to control

BFS is a pozzolanic material with high content of amorphous silicon dioxide with very fine spherical particles and has great potential of enhancing the mechanical properties of concrete, while fly ash contains higher aluminium oxide in its chemical composition. Therefore, blending FA and BFS increased the alumino- silicate content of the mixture, which increased geopolymerisation reaction and subsequent increase in the mechanical properties and increased in the geopolymer matrix. Thus both the effects may generate dense geopolymer structure. As a result the compressive strength is increased.

Flexural strength

Figure 4 shows the flexural strength of FA-based geopolymer concrete blended with BFS. The mixture GP1 was made with 100% fly ash while GP2 and GP3 were prepared by blending FA with 10% and 20% BFS respectively. The flexural strengths of the blended samples were compared with GP1 mixture prepared with 100% fly ash and their overall performance over the control(M40).

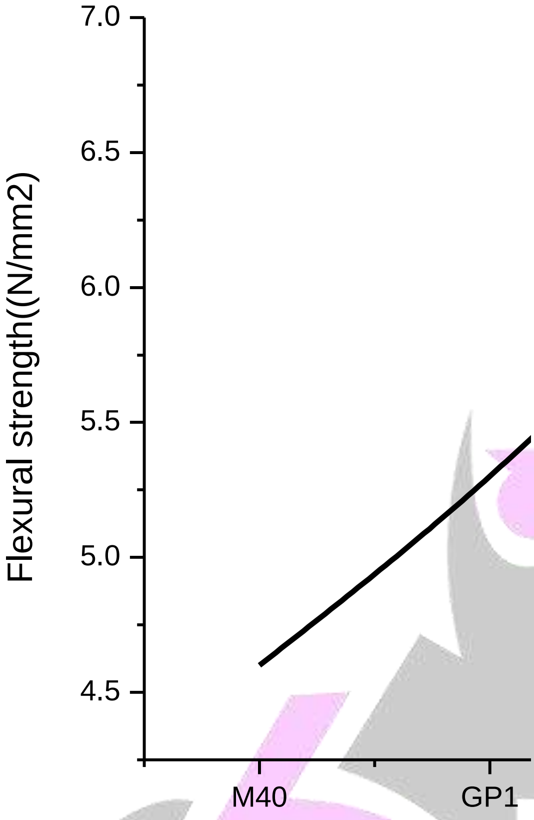

Fig.4 Flexural strength of fly ash-based geopolymer concrete with different proportions of BFS

The flexural strength of fly ash based geopolymer concrete containing silica fume followed the same progressive increment pattern as compressive strength. The flexural strength increases as the percentage replacement of fly ash with BFS increased. It is observed from the figure that the flexural strengths of GP2 and GP3 samples gave higher flexural strengths than the strength of corresponding control mix. The percentage increase showed that GP1, GP2 and GP3 increased 26.5%, 41% and 73% more than the control.

Tensile strength of geopolymer concrete

Fig. 5 shows the effect of BFS on tensile strength of fly ash based geopolymer concrete. Fly ash was replaced with different proportions of BFS in the ratio of 1:2 and their effects on the tensile strength noted as shown below.

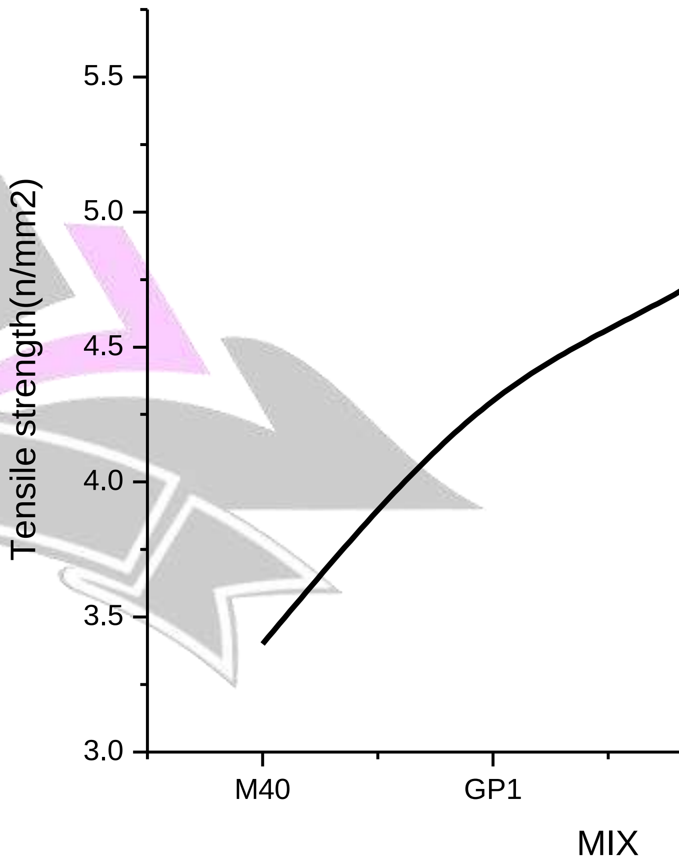

Fig. 5 Tensile strength of fly ash-based geopolymer concrete with different proportions of BFS

As noted in compressive and flexural strengths, the strength development of tensile strength followed the same pattern. As the percentage replacement of fly ash increased, the tensile strength also increased. The tensile of geopolymer concrete increased more than the control. Comparatively, the percentage increase shows that GP1, GP2 and GP3 increased 11%, 22% and 29% more than the control.

Conclusions

The result of this study shows that the workability test of fly ash based geopolymer concrete containing BFS were generally low as noticed from the slump test when compared with control. This may be as a result of high viscosity and cohesiveness of the mixtures. The compressive strength of geopolymer concrete containing BFS perform better than the strength of the corresponding control. The compressive strength increased with the percentage increase of BFS. The flexural and tensile strengths of geopolymer concrete containing BFS show better performance over the control. The flexural and tensile strengths increased as the percentage replacement of fly ash increased. The maximum flexural and tensile strengths were obtained at 20% replacement. OPC is not required in the production of geopolymer concrete, consequently, the global problem of greenhouse gases are drastically reduced. It can be concluded that geopolymer concrete is a veritable alternative to OPC concrete and essential for sustainable development.

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