Indian Journal of Engineering & Materials Sciences
Vol. 27, February 2020, pp. 67-76

GGBFS & M-sand impact on workability and strength properties of fly-ash based geopolymer concrete

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Received: 31 January 2018; Accepted: 22 August 2019

This study involves the application of replacement material to cement which eliminates the carbon-dioxide emissions. Cement production industries alone give out 5 to 8 % of greenhouse gas into the atmosphere globally. Naturally, geopolymer concrete emits very low greenhouse gas compared to ordinary portland cement (OPC). Therefore, geopolymer concrete is greatly ecological and alternative material for OPC. This research has been intended to study the impact on workability and mechanical properties of fly ash based geopolymer concrete using ground granulated blast furnace slag (GGBFS) along with manufactured sand (M-Sand) under ambient curing condition. The work has been executed to explore compressive strength of G30 grade geopolymer concrete along with split tensile, flexural strength and its workability. The result shows that there has been increased strength and decreased workability with higher GGBFS & M-sand. Further, it shows the optimum percentage replacement of 20% of GGBFS & 50% of M-sand has been yielded G30 grade geopolymer concrete easily. Based on the investigation, better strength has been achieved by full replacement of natural sand with M-sand. Statistical analysis such as simple linear & multi variables regression has been carried out and formulas have been anticipated to find relationship between the mechanical properties of geopolymer concrete while increasing percentage of GGBFS.

Keywords: Geopolymer, GGBFS, M-Sand, Ambient curing, Mechanical properties, Statistical analysis

1 Introduction

In construction industry, the production of cement increased as 2.2 billion tons in 2010 which was 1.5 billion tons in 1995[1]. One ton of cement production exhibits one ton of carbon dioxide into the atmosphere[2]. Cement and Ceramic manufacturing plays a vital role in production of greater than 20% CO_2 among world's industry[3]. Waste materials from industries such as fly-ash (450 million ton) and GGBFS (530 million ton) are generated annually[4]. The production of GGBFS emits up to 80% less greenhouse gas[5] and the production of fly ash emits 80-90% less greenhouse gas[6]. Hence it's an urgent need to replace the cement with fly ash and GGBFS to reduce the greenhouse gas emissions. Geopolymers are mainly formed by the reaction of alumino-silicate materials with alkaline activator solutions during geo-polymerization.

Geopolymer is produced from waste materials like fly ash, GGBFS etc., having high aluminum & silicon[7]. Globally about 53 billion tons of sand is mined in every year. Sand is the highest volume of raw material used on earth after water[8]. Now-a-days availability of natural sand is in dwindling nature. There is scarcity of natural sand, which increases the demand and cost of natural sand. This leads to significant requirement of Manufactured-Sand in place of natural sand.

Priyanka *et al.*, showed that the cement mortar exhibits excellent compressive strength while using 50% of M-Sand in-place of river sand[9]. Aleem *et al*. concluded a compound of albite has formed when geopolymer concrete was reacted with M-Sand and it has high compressive strength[10]. Prabu *et al*. observed that strength properties and density increases with high volume of steel fibers in geopolymer concrete[11]. Anuradha *et al.* formulated the new mix design procedure using Indian standard when geopolymer concrete mixed with M-sand[12].

Albitar *et al.* showed that there is zero impact on slump and unfavorable impact on strength while using naphthalene sulphonate polymer based super plasticizer in fly ash based geopolymer concrete[13].

Nagan *et al.*, found that the load carrying capability and ductility index for G30 columns strengthened by GFRP bars increased was by 68.53% when compared with M30 concrete[14]. David *et al.* investigated the strength properties and durability properties of rapid

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chloride permeability, sorptivity, X-ray spectroscopy etc. The results revealed that geopolymer concrete gave good durability parameters while using activator modules of 1.00 & 1.25 compared with OPC but 0.75 activator modulus showed lower durability performance[15]. Rangan *et al.*, have shown that the workability of geopolymer concrete improved by adding super plasticizer (naphthalene sulphonate) up to 4% of binder, but the strength properties of geopolymer concrete is slightly degrades by adding more than 2% of super plasticizer[16].

Madheswaran *et al.*, varied that the molarity of geopolymer concrete and found the concentration of NaOH raises it increases the strength properties and concluded that geopolymer concrete is both economical and environmental benefits of using fly ash and GGBFS[17]. Prakash R Vora considered that the parameters such as concentration of sodium hydroxide, curing temperature, sodium silicate to sodium hydroxide ratio, alkaline liquid to fly-ash ratio, super plasticizer dosage in the mixes. From the above consideration, compressive strength increases with concentration of sodium hydroxide solution, curing temperature, curing time, rest period and strength decreases with the ratio of water to geopolymer solids increases[18]. Mohammd Shojaei *et al.*, found optimal mixture design which provides the maximum compressive strength have identified by the Taguchi design of experimental method and also showed that the alkaline activated slag (AAS) mixture is better than conventional concrete used for railway sleepers[19].

Amol A. Patil *et al.*, studied that the effect on curing conditions of geopolymer concrete using fly ash and showed the parameters of curing temperature and time affects the geopolymer concrete compressive strength[20]. Pattanapang Topark – Ngarm *et al.*, varied the NaOH molarity, and concluded that the modulus of elasticity and compressive strength were comparable with OPC but split tensile strength and bond strength was higher than OPC[21]. Karthiyaini *et al.* arrived the ultimate load carrying capability& deflation pattern in short columns of geopolymer concrete supported by Glass Fiber Reinforced Polymer (GFRP). Load carrying capacity of G30 columns higher than M30 grade of control columns[22].

Benny Joseph *et al.*, taken that the influence of aggregate content in geopolymer concrete. It was concluded that better engineering properties achieved than ordinary cement concrete with right ratio of entire aggregate content and optimum values of other parameters[23]. Sujatha *et al.*, showed that the geopolymer concrete slender circular columns increase the stiffness, load carrying capacity and ductility upto failure[24]. Yeonho park *et al.*, concluded as the replacement of crumb rubber in-place of sand is in strength reduction of geopolymer concrete[25]. Ivana perna *et al.*, by modifying the Clay/Slag ratio, changes the setting time easily, and it was used to quick emergency repairs, prolong the workability and extend setting time [26].

Mahindra *et al.* compared that the strength properties of natural sand fiber reinforced concrete with artificial sand fiber reinforced concrete. By considering the factors of technical, environmental commercial, it was concluded that full replacement of artificial sand is an excellent material compared with natural sand[27]. Adams Joe *et al.* carried that the workability and strength test by replacing the river Sand with M-Sand along with Steel Fiber in high performance concrete. It was concluded that 50% replacement of M-Sand gave maximum results[28]. Okoye *et al.* found that 50% of fly ash and 50% of kaolin combination shows that maximum strength and compared with KOH, NaOH gives more compressive strength[29]. Prabir Kumar Sarker *et al.* concluded that there is no spalling, cracking and higher strength of geopolymer concrete compared with OPC when it is exposed in fire[30]. Deepak Ravikumar *et al.* explained that the differences the reaction products and the micro structure between the fly ash and GGBFS for the pastes & concretes of fly ash shows more porous than GGBFS[31]. Gomathi *et al.* indicated that fly ash–GGBS based aggregate along with 10M NaOH showed highest crusting strength of 22.81 Mpa and reported a highest compressive strength of 31.98 MPa while using 20% fly ash – GGBS based aggregate[32].

Janani *et al.* concluded that based on the experimental investigation, the strength properties of geopolymer concrete is high when using M-sand and it can be an alternative material to OPC[33]. Elavenil *et al.* found that when river sand was fully replaced by M-sand, there is 7.5% higher compressive strength compared with river sand, and M-sand is an alternative solution to river sand[34]. Nagajothi *et al.* reviewed that the geopolymer concrete using fly ash as binder material, M-sand as fine aggregate and GFRP as an alternative to steel reinforcement[35]. Nagajothi *et al.* concluded that when natural sand is fully replaced by manufactured sand it increases the strengths of geopolymer concrete in oven dry curing at 60 °C[36].

In the present paper, GGBFS was added as 0%, 10%, 20% & 30% of the total binder of fly ash and M-Sand was added as 0%, 25%, 50%, 75% & 100% of the natural sand. Based on the above range of mix proportions, indicates the significance of GGBFS, fly ash & M-Sand and their impact on mechanical properties of pollution free geopolymer concrete.

2 Experimental Program

2.1 Materials

Geopolymer concrete are mainly made by the class F fly ash obtained from North Chennai Thermal power plant station, Chennai. Commercially available GGBFS is taken as part replacement material of fly ash for this study. The composition of fly ash and GGBFS are given in Table 1.

The mixture of sodium silicate and sodium hydroxide solution is used as Alkali Activated Solutions (AAS). Sodium hydroxide is mainly available in pellets, flakes and solution form. In this study, 99% purity of NaOH in flakes form is dissolved in one liter of distilled water to achieve 8M concentration of NaOH solution. Sodium silicate solution ratio of SiO_2/Na_2O by mass of 2.0 is used. Locally available crushed granite coarse aggregate is used with nominal maximum sizes of 8mm, 12mm and 20mm. As a fine aggregate, natural sand is fully and partially replaced by manufactured sand in this study. The compositions of manufactured sand are given in Table 2. The properties of materials shown below Table 3. Aggregates are used in saturated surface dry condition (SSD) in geopolymer concrete. Super plasticizer (naphthalene based) is used to achieve the geopolymer concrete workability. Natural sand and M-sand is falls within the limits of Zone II and is represented in the Fig. 1.

2.2 Mixed proportioning of geopolymer concrete

Geopolymer concrete were proportioned to study the effect of GGBFS with the replacement of fly ash in the binder and M-sand with replacement of natural sand in the fine aggregate. The details of twenty geopolymer concrete mixes and five OPC concrete mixes are represented in Table 4.

53 grade ordinary portland cement was used to prepare M30 grade of concrete. In this mix, the binder and the fine aggregate was fully and partially replaced by fly ash and M-Sand. Fly ash was replaced by GGBFS in the range of 0% to 30% of total binder and alternative of river sand with M-sand in range of 0%, 25%, 50% 75% &100% of the fine aggregate to fix the optimum level G30 grade concrete. The concentration of sodium hydroxide was constant (8M) for every mixture. Addition of extra water was not done. To get geopolymer concrete workability, superplasticizer (Conplast SP430) was added. Mix GC1 to GC5 is designed with varying the percentage of M-sand and by keeping the GGBFS as 0%. Similarly GC6 to GC 10 is designed with varying the percentage of M-sand and by keeping the GGBFS as 10%.Similarly GC11 to GC15 for 20% GGBFS and GC16 to GC20 for 30% GGBFS as constant. In these mixes 45% of alkaline activator was used with 2.5 constant ratio of Na_2SiO_3 to NaOH. The geopolymer concrete mixes were designed with variable constituents in the mix. For example, S0M0 represents that Slag as 0% and M-sand as 0%. Similarly S10M25 represents slag as 10% and M-sand as 25%.

Table 1 — Composition of fly ash and GGBFS.

Sample (%)	SiO_2	K_2O	MgO	CaO	Al_2O_3	SO_4	Na_2O	Fe_2O_3	LOI *
Fly ash	63.32	0.0002	0.29	2.49	26.76	0.36	0.0004	5.55	0.97
GGBFS	35.05	0.6	6.34	34.64	12.5	0.38	0.9	0.3	0.26

*-Loss of Ignition

Table 2 — Compositions of manufactured sand.

Sample (%)	CaO	SiO_2	SO_4	MgO	Cl	Al_2O_3	Fe_2O_3	Na_2O	K_2O	PH
M-Sand	6	63.86	0.07	0.7	0.07	22.93	4.25	0.0001	Nil	8.74

Table 3 — Physical properties of materials.

Description	Fly ash	GGBFS	NS[a]	MS[b]	CA[c]
Specific gravity	2.13	2.85	2.66	2.72	2.73
Fineness modulus	-	-	3.04	2.90	-
Water absorption	-	-	1.13	1.52	0.64

a - Natural Sand, b - Manufactured Sand, c - Coarse Aggregate

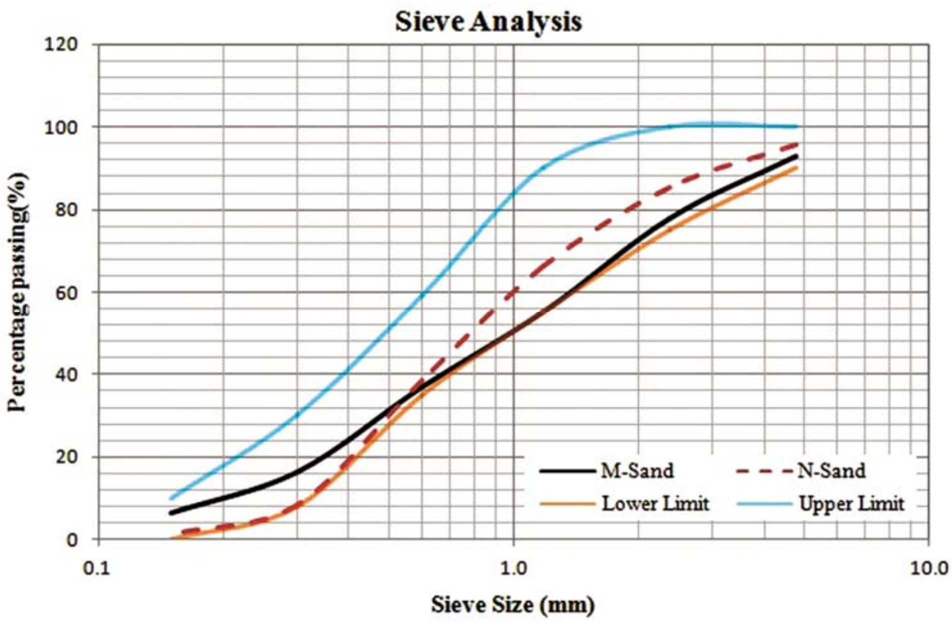


Fig. 1 — Grain size distribution curves of natural sand and M-sand.

Table 4 — Details of concrete mixes (Kg/m^3).

Mix No	Designation	CA[x]	NS[y]	MS[z]	Fly ash	GGBFS	Cement	SS[*]	SH[#]	Water
GC1	S0M0	1189	660	0	380	0	-	122	49	-
GC2	S0M25	1189	495	165	380	0	-	122	49	-
GC3	S0M50	1189	330	330	380	0	-	122	49	-
GC4	S0M75	1189	165	495	380	0	-	122	49	-
GC5	S0M100	1189	0	660	380	0	-	122	49	-
GC6	S10M0	1189	660	0	342	38	-	122	49	-
GC7	S10M25	1189	495	165	342	38	-	122	49	-
GC8	S10M50	1189	330	330	342	38	-	122	49	-
GC9	S10M75	1189	165	495	342	38	-	122	49	-
GC10	S10M100	1189	0	660	342	38	-	122	49	-
GC11	S20M0	1189	660	0	304	76	-	122	49	-
GC12	S20M25	1189	495	165	304	76	-	122	49	-
GC13	S20M50	1189	330	330	304	76	-	122	49	-
GC14	S20M75	1189	165	495	304	76	-	122	49	-
GC15	S20M100	1189	0	660	304	76	-	122	49	-
GC16	S30M0	1189	660	0	266	114	-	122	49	-
GC17	S30M25	1189	495	165	266	114	-	122	49	-
GC18	S30M50	1189	330	330	266	114	-	122	49	-
GC19	S30M75	1189	165	495	266	114	-	122	49	-
GC20	S30M100	1189	0	660	266	114	-	122	49	-
C1	CM0	1189	660	0	-	-	380	-	-	171
C2	CM25	1189	495	165	-	-	380	-	-	171
C3	CM50	1189	330	330	-	-	380	-	-	171
C4	CM75	1189	165	495	-	-	380	-	-	171
C5	CM100	1189	0	660	-	-	380	-	-	171

x - Coarse Aggregate, y- Natural Sand, z- Manufactured Sand, * - Sodium Silicate, #- Sodium Hydroxide

2.3 Mixing, casting and curing of specimens

The NaOH flakes are mixed with distilled water before a day to its use, to lower down with ambient temperature and it is mixed with Na_2SiO_3 solution for making alkaline activator solution to accelerate the reactivity of solution. Before mixing of concrete, the aggregates are taken in saturated surface dry (SSD) condition and mixed with the binders of fly ash and GGBFS in the pan mixture. The AAS are mixed with this. The mixing is continued in 5 more minutes to make geopolymer concrete. In addition to alkaline solutions, 1% of super plasticizer is added with the mixes to achieve the appropriate geopolymer concrete workability. Geopolymer concrete specimens were cured in ambient condition after demoulding the specimens and water curing done for OPC specimens. The geopolymer concrete mixes in fresh state before moulding and standard cube moulds before casting are shown in Fig. 2. The geopolymer and OPC specimens were tested at 7 days and 28 days ages under ambient and water curing. For finding the compressive, flexural and split tensile strength of concrete, the samples were tested in Universal Testing Machine (UTM) as per IS 516-1959 and IS 5816-1999.

3 Results and Discussions

Totally twenty mixtures were designed to understand the impact of the strengths, workability of geopolymer concrete at ambient temperature and it is compared with five mixtures of conventional concrete.

3.1 Work ability of concrete

Workability is a basic property of freshly mixed concrete and it is said to be workable when it should be easily transporting, placing, compacting and finishing without any segregation. To measure the workable of concrete, slump test is mainly used. This test should be mainly conducted after mixing of the geopolymer concrete. Compared with water, the alkaline activated solutions are more cohesive, sticky and viscous than OPC. Geopolymer concrete with higher slump value specifies a higher workability in the mix proportions. Geopolymer concrete and OPC mixtures with various slump values are graphically shown in Fig. 3.

From the Fig. 3, the mix of S0M0 with 0% slag shows 155 mm slump which is higher than the mix of S10M0 with 10% slag having 135mm slump. Similarly the mix of S20M0 with 20% slag shows 130mm slump which is higher than mix of S30M0 with 30% slag having 105mm slump.

Hence the slag content increases in the geopolymer concrete, the workability of mixes are decreasing in trend. The mixture S0M0 with 0% of M-sand shows a higher slump value of 155mm compared to S0M100 with 100% of M-sand and a slump value of 125 mm. Similar trend for S10M0, S10M100, S20M0, S20M100 and S30M0, S30M100. Hence the workability of geopolymer concrete is in decreasing trend with increasing the M-sand Percentage. Mixture S30M100 showed the lowest slump value when compared with mixtures of all geopolymer concrete due to the 30% percentages of slag and 100% of M-Sand. Mixture CM0 shows higher slump value than CM100. Hence in normal cement concrete, the workability values decreases when M-sand percentage increases.

Alkaline activator content (40%) tried with mixture of geopolymer concrete yields poor workability, when

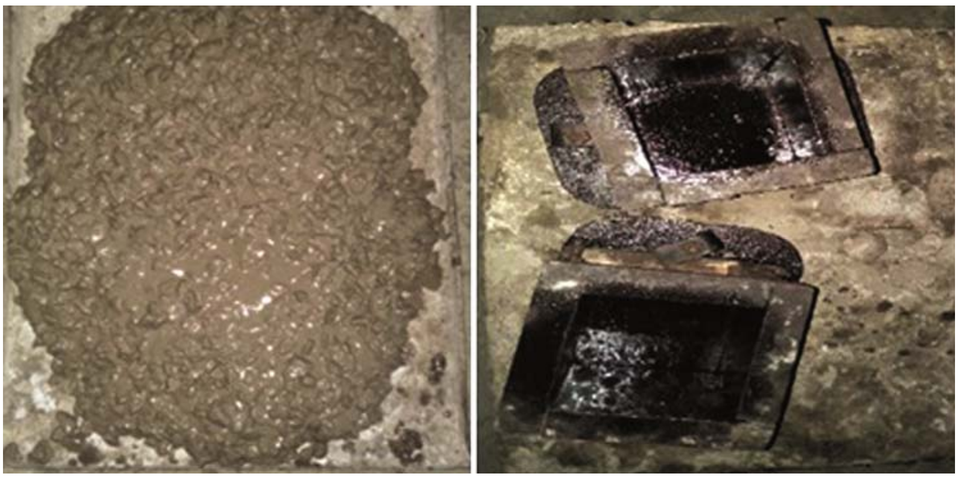


Fig. 2 — Fresh geopolymer concrete mix and standard cube moulds.

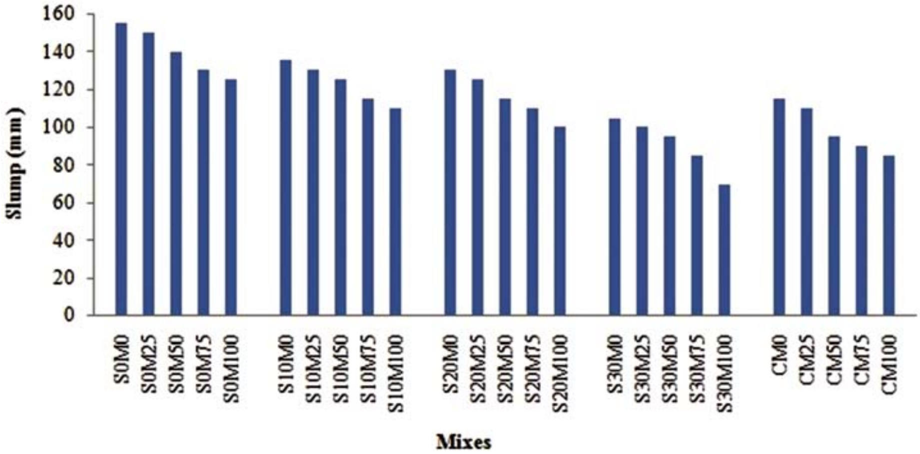
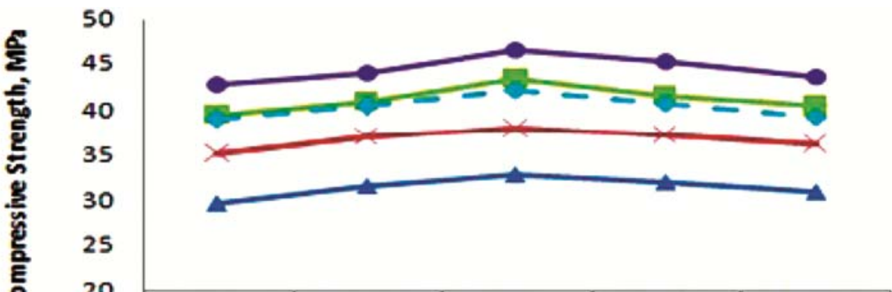


Fig. 3 — Slump of geopolymer and OPC concrete.



	M0	M25	M50	M75	M100
S0	29.67	31.42	32.67	31.95	30.82
S10	35.06	36.94	37.87	37.09	36.13
S20	39.37	40.87	43.28	41.49	40.35
S30	42.62	43.93	46.51	45.07	43.54
C100	38.95	40.33	42.09	40.64	39.24

Fig. 4 — Compressive strength of geopolymer and OPC concrete.

no extra water and more superplasticizer added. Hence to improve the workability of geopolymer concrete the alkaline activator content (45%) is adopted and superplasticizer 1% of binder is added. The slump values of the mixtures CM0 to CM100 is varied from 115mm to 85mm. With the comparison of OPC concrete mixtures, the GC mixtures prove more cohesiveness property. As described by Khale *et al.*, the changes are due to the rheology between both the concretes. No segregation and bleeding are observed in geopolymer concrete[37]. The slump values are in the same trend using fly ash and GGBFS with the other researcher's values.

3.2 Compressive strength

Concrete is a brilliant material to resist compressive loading. Compression or compressive strength is a common strength property of concrete. Compressive strength is a display of other strength properties of concrete. These values are taken from the average values of three specimens. The compressive strength results obtained for GPC and OPC concrete by increase in GGBFS and M-sand are shown in Fig. 4. It can be observed that the increased compressive strength value achieved when there is high GGBFS content in the mixture proportions of S0M0, S10M0, S20M0 and S30M0.

The compressive strength ranges from 29.67 MPa to 46.51 MPa by changing the percentage of GGBFS and M-sand for geopolymer concrete in ambient curing condition where as ranges from 38.95 MPa to 42.09 MPa by changing the percentage of M-sand for ordinary portland cement concrete in water curing condition. S30M50 geopolymer concrete mixture was higher compressive strength than all the mixes. The compressive strength increases while raising the M-sand percentage up to 50% in all the mixes of slag replacing as 0%, 10%, 20% & 30%. For the remaining replacement percentage of M-sand, the compressive strength decreases in nature. Hence the optimum percentage replacement of M-sand is 50% of natural sand. The strength of 50% M-sand increases about 10% higher than the natural sand. From the results, it was observed that the strengths for full replacement of M-sand and natural sand are closing each other. Anuradha concluded from the experimental values, the strengths of river sand and M-sand were nearly equal[38].

In OPC concrete, it was observed that the optimum percentage replacement of M-sand with natural sand is 50%. It was observed by adding the percentage of GGBFS in geopolymer concrete, the compressive strength raises 1.18 times, 1.33 times & 1.44 times at 28 days, and 1.2 times, 1.34 times & 1.48 times at 7 days while comparing with fly ash based Geopolymer concrete. As additives of materials like kaolinite in the geopolymer concrete, increases the microstructure of the concrete[39]. Pradip Nath *et al.*, proved that mixing of small % of additives with fly ash based geopolymer concrete is suitable for low to moderate concrete strength in ambient curing condition[40]. Thus GGBFS plays a vital function to improve the compressive strength of fly ash based geopolymer concrete. Under ambient curing condition, the development of strength in geopolymer concrete is similar as OPC while using slag and also strength increases & workability decreases when GGBS increase in manner as analyzed by Partha Sarathi Deb *et al.*[41]. When compared with OPC concrete, the G30 grade of concrete easily achieved in the range of S20M0 to S20M100 itself.

The correlation analysis between replacement of GGBFS with fly ash and compressive strength of geopolymer concrete are shown in Fig. 5 and the statistical analysis such as simple linear & multi variables regression were carried out to resolve the compressive strength at 28 days in terms of percentage increase in GGBFS is given in Eqs (1 & 2). Using regression analysis, equations were proposed to determine the strength properties of geopolymer concrete along with steel fiber reinforcement[11].

$$f_{cg} = f_{cf} + 0.446\, s_p \quad \ldots (1)$$

$$f_{cg} = f_{cf} + 0.583\, s_p - 0.005 s_p^2 \quad \ldots (2)$$

where, f_{cg} is the compressive strength of fly ash based geopolymer concrete with slag replacement, f_{cf} is the compressive strength of flyash based geopolymer concrete, s_p is the percentage increase in slag with fly ash based geopolymer concrete.

Using multi variables regression Eq. (2), multiple factors 0.583 and -0.005 values are considered along with different s_p value. With the Eq. (2) – correlation coefficient (R^2) value of 1 is achieved which indicates that the 100% accuracy and quality of correlation between percentage of GGBFS and compressive strength in Fig. 5 b.

The strength development of mixes of GC1 to GC10 was attained slightly lower than ordinary Portland cement concrete mixes. At the same time the mixes of GC11 to GC20 was attained equivalent or higher than the OPC. It is observed that, to reach the strength about 38 N/mm^2, the conventional concrete can be replaced by 80% fly ash and 20% GGBFS along with M-sand as full or partial replacement of natural sand.

3.3 Split tensile strength and flexural strength

The split tensile and flexural strength of geopolymer concrete at 28 days is given in

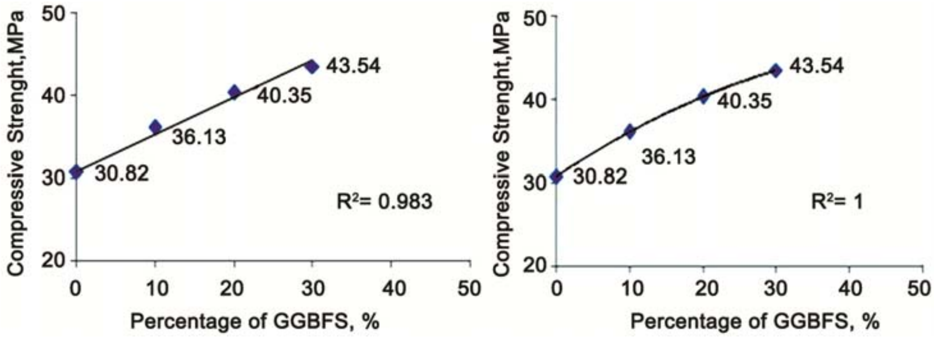


Fig. 5 — Correlation analysis between compressive strength and percentage of GGBFS using (a) Simple linear and (b) Multi variables regression.

Fig. 6 (a & b). From the fig., it is cleared that the split tensile and flexural strength are similar trends to those of compressive strength. The Split tensile strength changes from 2.89 Mpa to 3.67 Mpa. It was observed by addition of GGBFS improved the split tensile strength. The split tensile strength of S10M0, S20M0 & S30M0 increases 1.15 times, 1.33 times, 1.44 times at 28 days when compared with fly ash based geopolymer concrete (S0M0).The split tensile strength of OPC concrete is nearly the same in the range of S20M0 to S20M100 in geopolymer concrete. The split tensile strength of S30M0 to S30M100 is about 11% higher in geopolymer concrete than the OPC concrete.

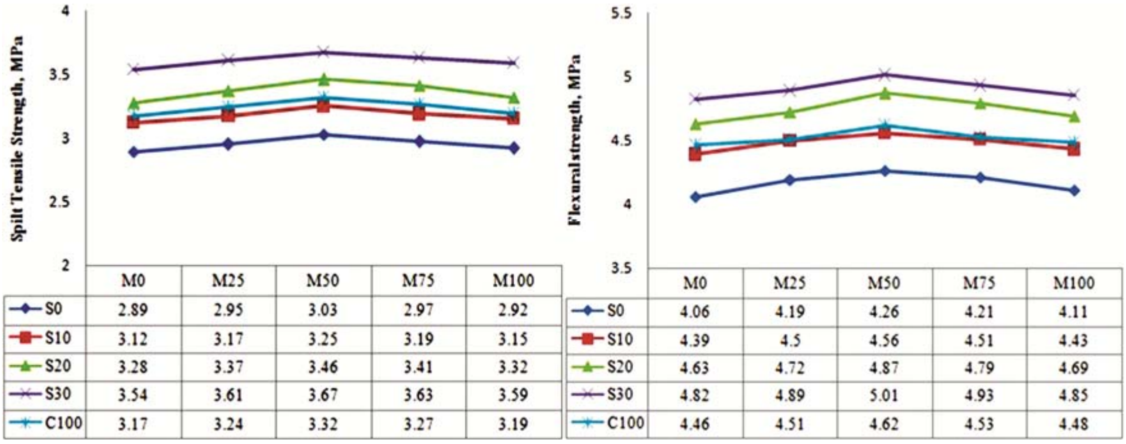
The flexural strength changes from 4.06 MPa to 5.01 MPa. By adding the percentage increase in GGBFS shows improved flexural strength and S30M50 exhibits excellent flexural strength. The flexural strength of S10M0, S20M0 & S30M0 increases 8%, 14% & 19% at 28 days when compared with fly ash based geopolymer concrete. The correlation analysis between split tensile and flexural strength in terms of percentage increase of GGBFS with fly ash are shown in Fig. 7 and Fig. 8. From Fig. 7, the statistical analysis such as simple linear & multi variables regression is carried out to resolve the split tensile strength at 28 days in terms of percentage increase in GGBFS and it is given in Eqs (3 & 4).

$$f_{sg} = f_{sf} + 0.021\, s_p \qquad \ldots (3)$$

$$f_{sg} = f_{sf} + 0.031\, s_p - 0.001 s_p^2 + 3E-05 s_p^3 \qquad \ldots (4)$$

where, f_{sg} is the split tensile strength of fly ash based geopolymer concrete with slag replacement, f_{sf} is the split tensile strength of fly ash based geopolymer concrete, s_p is the percentage increase in slag with fly ash based geopolymer concrete.

Using multi variables regression Eq. (4), multiple factors 0.031, -0.001 and 3E-05 values are considered along with different s_p value. With the Equation 4 –



	M0	M25	M50	M75	M100
S0	2.89	2.95	3.03	2.97	2.92
S10	3.12	3.17	3.25	3.19	3.15
S20	3.28	3.37	3.46	3.41	3.32
S30	3.54	3.61	3.67	3.63	3.59
C100	3.17	3.24	3.32	3.27	3.19

	M0	M25	M50	M75	M100
S0	4.06	4.19	4.26	4.21	4.11
S10	4.39	4.5	4.56	4.51	4.43
S20	4.63	4.72	4.87	4.79	4.69
S30	4.82	4.89	5.01	4.93	4.85
C100	4.46	4.51	4.62	4.53	4.48

Fig. 6 — (a) Spilt tensile strength of geopolymer and OPC concrete and (b) Flexural strength of geopolymer and OPC concrete.

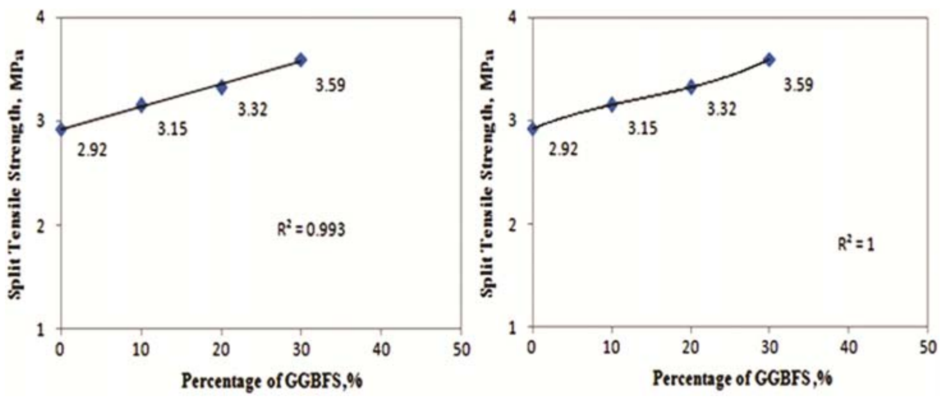


Fig. 7 — Correlation analysis between split tensile strength and percentage of GGBFS using (a) Simple linear and (b) Multi variables regression.

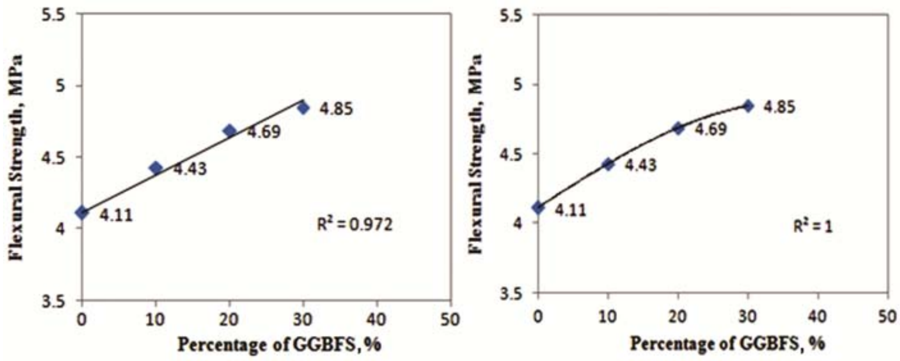


Fig. 8 — Correlation analysis between flexural strength and percentage of GGBFS using (a) Simple linear and (b) Multi variables regression.

correlation coefficient (R^2) value of 1 is achieved which indicates that the 100% accuracy and quality of correlation between percentage of GGBFS and Split tensile strength in Fig. 7 b.

From Fig. 8, the statistical analysis is carried out to resolve the flexural strength at 28 days in terms of percentage increase in GGBFS is given in Eqs (5 & 6).

$$f_{fg} = f_{ff} + 0.026\, s_p \qquad \dots (5)$$

$$f_{fg} = f_{ff} + 0.033\, s_p - 0.000 s_p^2 \qquad \dots (6)$$

where, f_{fg} is the flexural strength of fly ash based geopolymer concrete with slag replacement, f_{ff} is the flexural strength of flyash based geopolymer concrete, s_p is the increase in percentage of slag with fly ash based geopolymer concrete.

Using multi variables regression Eq. (6), multiple factors 0.033 & -0.000 values are considered along with different s_p value. With the Eq. (6) – correlation coefficient (R^2) value of 1 is achieved which indicates that the 100% accuracy and quality of correlation between percentage of GGBFS and Split tensile strength in Fig. 8 b. Based on the experimental results, mechanical properties of geopolymer concrete yields better results by the addition of GGBFS with the fly ash along with full or partial replacement of M-Sand. Hence these materials – fly ash, GGBFS and M-sand are alternative materials for cement and natural sand.

4 Conclusions

Twenty geopolymer concrete mixtures were designed with fly ash & GGBFS as the binder source materials with replacing river sand with M-sand as the fine aggregates. Five OPC concrete mixtures were designed using M-sand for an alternative material of natural sand as the fine aggregate. This paper mainly investigated the impact by adding the GGBFS & M-sand to get G30 grade of concrete with desired workability of geopolymer concrete and it was compared with OPC.

The following were observed from the experimental test results.

(i) By increasing the addition of GGBFS from 10% to 30% in the fly ash based geopolymer concrete, it shows a decrease in the workability about 48% and increases in the compressive, split tensile & flexural strengths about 44%, 44% & 19% respectively.

(ii) By addition of GGBFS in the mixes made to attain early strength under ambient curing condition.

(iii) From the investigations, it is revealed that the 80% fly ash & 20% GGBFS using M-sand as full or partial replacement like mix proportions of S20M0, S20M25, S20M50, S20M75 & S20M100 achieves the strength of G30 grade and it can be used as an alternative material for OPC concrete.

(iv) Variation of M-sand percentage increases, the workability of geopolymer and OPC concrete decreases. It shows similar mechanical properties of natural sand are achieved after the full replacement of natural sand with M-sand. M-sand usage suppresses the cost involved drastically, and it reduces the demand for natural sand.

(v) Based on the experimental values, a statistical analysis (simple linear and multi variables regression) were carried out and formulas were anticipated to resolve the strength properties of geopolymer concrete by increasing the percentage of GGBFS.

(vi) Ambient curing in Geopolymer concrete is very convenient method for practical applications when compared with other curing methods such as oven curing, membrane curing & steam curing.

(vii) The disposal problem relevant to industrial by-products wastes can be minimized by effective utilization on replacement of cement.

Acknowledgements

The author would like to thank Dr. S. Elavenil for her guidance and support for this study. The author would like to gratefully thank the laboratory staffs of Vellore Institute of Technology, Chennai.

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