EXPERIMENTAL STUDIES ON AMBIENT CURED SELF-COMPACTING GEOPOLYMER CONCRETE MADE WITH GGBS AND BOTTOM ASH

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Professor Davidovits fathered the idea that geopolymer binder is a viable alternative to Portland cement. Geopolymer can be synthesized by alkali activation of alumina silica rich inorganic materials of industrial by products and natural materials. An exhaustive study carried out on geopolymer concrete by the researchers establishes a strong pathway in the construction field. Furthermore, Self-Compacting Geopolymer Concrete (SCGPC) has been promoted using fly ash, GGBS, rice husk ash, silica fume, etc. In this respect, the present study proposes to carry out experimental studies on self-compacting geopolymer concrete, incorporating bottom ash and GGBS, under ambient curing condition. Bottom ash and GGBS were added in the proportion of 100:0, 75:25, 50:50, 25:75, 0:100. The fresh and hardened properties of the SCGPC were analysed for all the mixes. The test result of fresh concrete properties indicates that it satisfies the limits specified by EFNARC standards. The maximum compressive strength of self-compacting geopolymer concrete was ascribed as 38.5MPa and 54.8 MPa at 3 and 28 days by the mix containing only GGBS. An excellent strength achieved at early age is observed in the GGBS mix. Also, the strength results reveal that increase in the content of GGBS achieved greater strength.

Keywords: *Alumina silica, Bottom ash, GGBS, self-compacting geopolymer concrete, EFNARC*

1. Introduction

Since the 20th century, Self-Compacting Concrete (SCC) has received great welcome in the construction industry due to vast industrialization and shortage of labour. SCC is a special high-performance concrete which does not require any vibration or compaction to fill in the places under its own self weight SCC ensures the performance requirements in fresh and in hardened state [1]. In fresh state, high flowabilty and stability of the paste must be established to avoid segregation of coarse aggregates. Also, the structural performance of SCC must be satisfied in the hardened state. EFNARC has set guidelines and specifications for the constituent materials used, testing methods and other technical aspects in SCC. The primary characteristics of SCC are filling ability, passing ability, and segregation resistance. To achieve this, the ingredients must be selected systematically. The amount of powder content has to be up to 600 kg/m^3 while the amount of maximum coarse aggregate content, 1000 kg/m^3. The fine aggregate content is in the range of 48-55% of the total aggregate weight. The content of water is 150 to 210 kg/m^3. Further, super plasticizer and viscosity modifying admixture in option are added to fulfil the requirement of SCC [2]

Ordinary Portland cement and fly ash are the standard powder binding materials used in SCC. However, cement production consumes a massive amount of natural resources and releases huge emission of CO_2 during its production, which leads to severe environmental issues. In order to reduce the use of cement in concrete, a lot many substitutes are entertained by the researchers. Among many other substitutes, geopolymer technology was proposed by professor Davidovits in the year 1970 [3-5]. While other alternatives replace cement partially, geopolymer eliminates completely the use of cement in concrete. Geopolymer is a solid and stable alumina silicate inorganic material formed by combining alkali hydroxide and or alkali silicate activators with reactive alumina silicate solid powder such as fly ash or metakaolin [6]. The reaction of alumina silica solid material with alkaline activators results in an alkali alumina silicate gel known as the geopolymeric gel binder phase. Geopolymer concrete could encouragingly be used extensively as it has low greenhouse gas emissions in production and has similar applications like Portland cement concrete in the construction field [7,8]. Plentiful studies have been carried out using different industrial by products and natural alumina silica rich materials in geopolymer concrete. In the constant exploration of GPC, Self-Compacting Geopolymer Concrete (SCGPC) has been attempted by several investigators. Studies have been reported on the development of self-compacting geopolymer concrete, using fly ash, GGBS, silica fume, rice husk ash, etc.[9-12].

In fact, self-compacting geopolymer concrete is an extremely viscous material. As self compactabilty plays a vital role, attention should be paid for the selection and dosage of super plasticizer in SCGPC [13] Poly carboxylic ether-based superplasticizer is generally recommended in order

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to obtain the desired self-compacting characteristics in SCGPC [14 -17]. Nevertheless, extra water is suggested to improve the workability of GPC, without compromising the required strength properties. In fly ash based CGPC, superplasticizer content is recommended as 3% to 7% and extra water content in the range of 10% to 20%. However, excess water increases bleeding and segregation and decreases the remarkable compressive strength. The addition of extra water does not play any part in any reaction in SCGPC [18]. It was also said that increasing the GGBS concentration with less activator reduces flowability and setting time [19-23].

The higher molarity of NaOH tends to increase the viscosity and decreases the flowabilty characteristics of SCGPC [24,25]. Even so, the higher molarity of NaOH decreases the self-compacting characteristics; the compressive strength was found to increase in fly ash and GGBS based SCGPC [18].Higher concentration of NaOH causes rapid dissolution of alumina silicate glasses and thus higher strength is witnessed [26]. Ajay Kumar et al have recommended higher concentration of 14 M NaOH to obtain the promising compressive strength in SCGPC [27].

Geopolymer concrete can accomplish the strength either by ambient curing or by oven curing. Oven curing at 70°C triggers the polymerization reaction rapidly and achieves greater strength than at ambient curing. It can be seen that use of GGBS achieves excellent compressive strength under ambient curing in SCGPC [15, 18]. Indeed, GGBS perks up the geopolymeric reaction and showcases the co-existence of alumina silicate geopolymer gel and Ca-rich Al-substituted silicate hydrate (C-(A)-S-H) [28]. It is stated that source material with less crystalline phases, finer particle size, high Si/Al ratio and higher concentration of alkaline solution are responsible for better strength of the geopolymer [29].

Yamini and Niraj Shah studied the effect of heat curing and ambient curing on mechanical properties of SCGPC using GGBS and rice husk ash [16]. All the fresh properties of SCGPC made with GGBS and 5% RHA satisfied the desired limits well. Also, the mix with GGBS accomplished a compressive strength of 42.6 MPa at ambient temperature. This higher strength is due to the formation of C-S-H and calcium alumina silicate hydrate (C-A-S-H) in addition to the N-A-S-H gel [30].

Yamini and Niraj Shah found that GGBS based self-compacting geopolymer concrete achieved two times higher compressive strength than that of fly ash based with higher sodium hydroxide molarity 12 at ambient temperature [16]. Further, Srishaila et al reported that compressive strength of GGBS based SCGPC was 40 MPa, while FA based SCGC was 16 MPa at ambient temperature, at 56 days [31]. Notable studies demonstrated that maximum compressive strength was achieved with the inclusion of GGBS in fly ash-based geopolymer at ambient curing conditions [32].

Even so, fly ash and bottom ash are generated as waste material during coal burning process from thermal power plants; fly ash is a common source material in geopolymer concrete. However, the use of bottom ash is found to be restricted due to its coarser particle size. Besides, a huge demand on the availability of fly ash is experienced everywhere as it finds a lot applications in the construction filed. Therefore, larger use of bottom ash is to be promoted. As a trial, several works have been undertaken using bottom ash as coarse aggregate by [33]. Many researches have revealed the potential use of bottom ash in geopolymer concrete [34-38].For further research, the present work advocates bottom ash as one of the source materials in self compacting concrete.

The traditional geopolymer concrete employs fly ash that gives better strength characteristics upon heat curing. The heat curing process for geopolymer concrete, on the other hand, limits its application in cast-in-situ construction and site use of self-compacting concrete. Also, the potential of early age strength development of geopolymer concrete with self-compatibility might be a desirable technique for speeding up and filling congested reinforcement in bridge construction. Furthermore, a detailed examination of previously published work reveals that the use of bottom ash and GGBS in self-compacting geopolymer concrete has not yet been attempted. Self-compacting geopolymer concrete made from bottom ash and GGBS with low sodium hydroxide molarity is a new development that ensures a low embodied energy and low carbon dioxide binder. Hence, the present study aims to endorse bottom ash and GGBS in self-compacting geopolymer concrete. The research significance of this work is to develop mix design for self-compacting geopolymer concrete through the use of GGBS and bottom ash. Further, it proposes to assess the fresh and hardened properties of SCGPC to find its viability in the construction industry.

2. Materials and methods

2.1 Materials

Bottom Ash

In this study, bottom ash was collected from Mettur Thermal Power Plant, Salem. The collected coarser bottom ash was made finer using ball mill to increase its surface area. The specific surface area of ground bottom ash was found to be 335 m^2/kg. It is light grey in colour. The specific gravity of bottom ash was found to be 2.50. Bottom ash has 0.50% of CaO. The chemical properties of bottom

Table 1

Chemical Properties of Bottom Ash

S.No	Properties	Test Result	Requirement as per IS 3812 – 2003
1.	Silica (SiO_2) (%)	52.3	35% min
2.	Alumina (Al_2O_3) (%)	33.4	---
3.	Sulphate (SO_3) (%)	4.94	3% max
4.	Calcium Oxide (CaO) (%)	0.51	---
5.	Magnesium Oxide (MgO) (%)	0.23	5% max
6.	Sodium Oxide (Na_2O) (%)	1.41	1.5% max
7.	Potassium Oxide (K_2O) (%)	0.62	---
8.	Loss of Ignition (LOI)	1.5	5% max

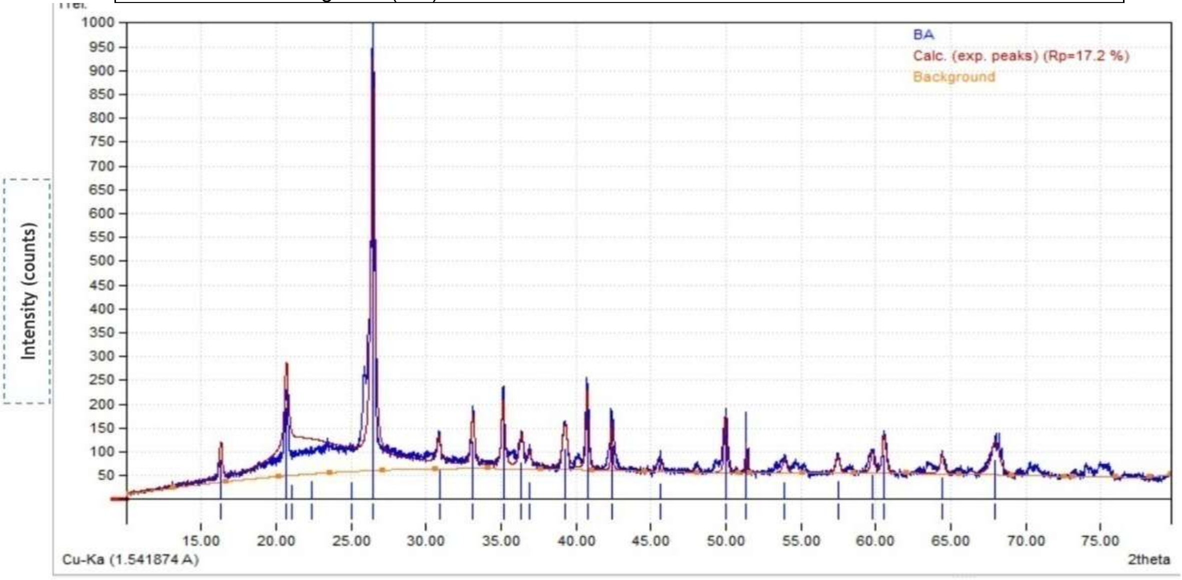

Fig. 1 - X - Ray Diffraction of Bottom Ash

Table 2

Chemical properties of GGBS

S.No	Properties	Test Result	Requirement as per BS EN 15167-1:2006
1.	Fineness (m²/kg)	410	275(min)
2.	Insoluble Residue (%)	0.18	1.5(max)
3.	Magnesia Content (%)	6.27	14.0(max)
4.	Sulphide Sulphur (%)	0.61	2.00(max)
5.	Sulphate content as SO_3 (%)	0.66	2.50(max)
6.	Loss on Ignition (%)	0.30	3.00(max)
7.	Manganese content (%)	0.39	2.00(max)
8.	Chloride content (%)	0.009	0.10(max)
9.	Glass content (%)	97.05	67(min)
10.	Moisture content (%)	0.06	1.00(max)
11.	Chemical Modulus		
i.	$CaO + MgO + SiO_2$	77.01	66.66(min)
ii.	$CaO + MgO / SiO_2$	1.26	>1.0
iii.	CaO / SiO_2	1.07	<1.40

ash are shown in Table 1. Figure 1 represents an XRD analysis of bottom ash, which exhibits many peaks showing crystalline structure in the 2 theta scale extending from 15° to 68°. The presence of crystalline phases confirms the existence of mullite, magnetite, and quartz.

GGBS

Ground Granulated Blast Furnace Slag (GGBS) was purchased from JSW Cement Company. The specific surface area of GGBS was found to be 410 m²/kg. It is light grey in colour. The specific gravity of GGBS was 2.7. GGBS has 36.46% CaO. The chemical properties are presented in Table 2. Figure 2 depicts the XRD pattern of GGBS that exhibits amorphous humps in the 20° to 40° range and no crystalline phases. It demonstrates the existence of calcite and quartz in the GGBS.

Alkaline Activators

Sodium hydroxide and sodium silicate were used as alkaline activators in this work. NaOH concentration of 8M was used. The alkaline solution was prepared by dissolving NaOH pellets in water and mixed with sodium silicate solution, together.

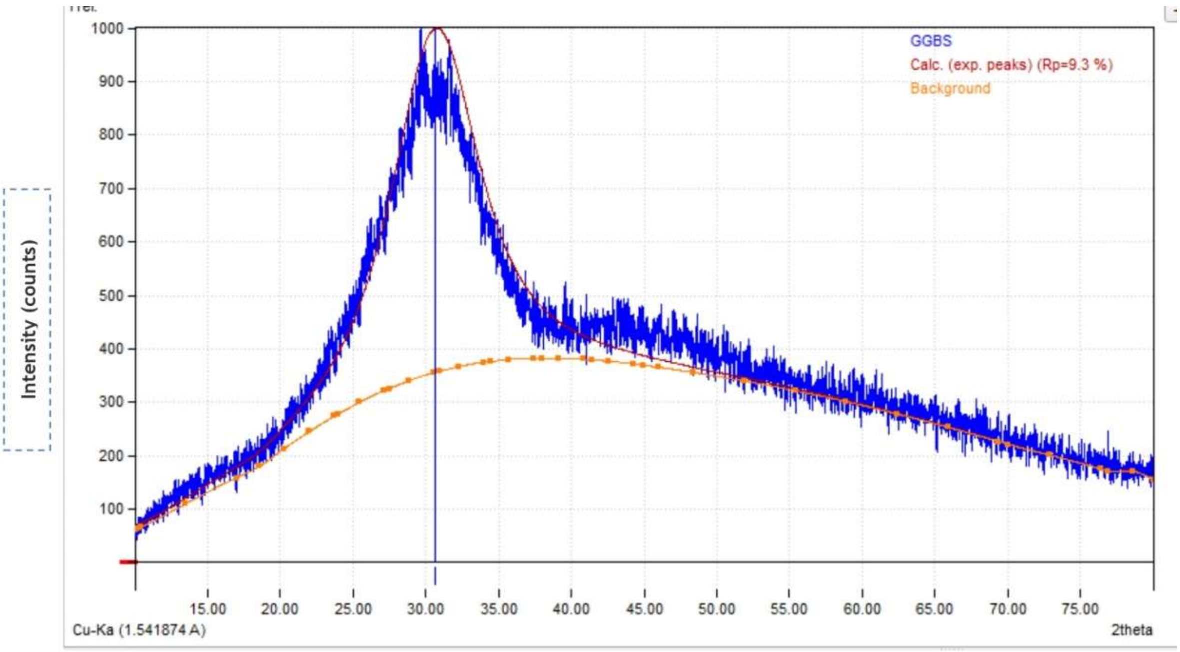

Fig. 2 - X - Ray Diffraction of GGBS

Table 3

Mix Proportions of SCGPC mixes

Parameters	**CM**	**G$_{100}$B$_0$**	**G$_{75}$B$_{25}$**	**G$_{50}$B$_{50}$**	**G$_{25}$B$_{75}$**	**G$_0$B$_{100}$**
Cement	442.7	-	-	-	-	-
Fly ash	135.2	-	-	-	-	-
GGBS (kg/m^3)	-	480	360	240	120	-
Bottom Ash(kg/m^3)	-	-	120	240	360	480
NaOH(kg/m^3)	-	19.7	19.7	19.7	19.7	19.7
Na$_2$SiO$_3$(kg/m^3)	-	160	160	160	160	160
Fine aggregate(kg/m^3)	824.8	859	859	859	859	859
Coarse aggregate(kg/m^3)	762.1	823	823	823	823	823
Super-plasticizer (kg/m^3)	4.04	24	24	24	24	24
Water(kg/m^3)	178.8	67	67	67	67	67

Aggregates

Locally available river sand was used as fine aggregate. It has a specific gravity of 2.69 and a fineness modulus of 2.26. It confirms to aggregate grading zone III as per [39]. Natural crushed granite of size 12 mm of size was used as coarse aggregate in this work. It was collected from nearby sources. The specific gravity of coarse aggregate is 2.73.

Super-plasticizer

Super-plasticizer of Glenium SKY 8233 poly carboxylic-ether was used in this present study. It was used to enhance the workability of Self Compacting Geopolymer Concrete (SCGPC) and added at a dosage of 5% of the binder content.

2.2. Mix design for Self-Compacting geopolymer concrete

The mix design for SCGPC was arrived at as per the guidelines of EFNARC standards [2]. The ingredients such as cement, fly ash, fine aggregate, coarse aggregate, super-plasticizer and water were used in the regular control mix. In geopolymer concrete mixes, bottom ash, GGBS, sodium hydroxide and sodium silicate as alkaline activators, fine aggregate, coarse aggregate, super-plasticizer and water were used. A total of five mixes were made with the combination of bottom ash and GGBS. The bottom ash was replaced by GGBS at the percentage of 0%, 25%, 50%, 75% and 100%. The alkaline liquid to binder ratio was kept at 0.5. The ratio of sodium silicate to sodium hydroxide is kept at 2. The molarity of sodium hydroxide was selected as 8M. In order to improve the self compactabilty, 5% super plasticizer and 14% extra water was added in SCGPC mixes. Control mix is designated as CM. In the SCGPC mix ID, G represents GGBS and B represent s bottom ash. The suffix numeral denotes the percentage of GGBS and bottom ash. The details of mix proportions are given in Table 3.

2.3. Preparation of mixes and Curing

The fresh concrete was methodically prepared using pan mixer to obtain a homogeneous mix. The fine ingredients bottom ash, GGBS and fine aggregate were put in a pan mixer and thoroughly mixed together in dry condition for three minutes.

Coarse aggregate was added then for about two minutes. The meticulously prepared alkaline liquid, super plasticizer and extra water were added in sequence to the dry materials and the mixing was continued for another three minutes. The prepared fresh concrete was examined for the filling ability, passing ability, and segregation resistance to ensure the self compactabilty. Then the fresh concrete was cast in the required moulds. The moulds were demoulded after 24 hours and kept for curing. CM specimens were cured in water and SCGPC specimens cured in room temperature.

2.4. Fresh Properties

The fresh properties of SCGPC mixes are determined to observe the filling ability, passing ability, and segregation resistance using EFNARC, standard methods [2]. The filling ability of SCGPC mixes was determined by conducting slump flow, T_{50cm} slump flow and V-funnel tests. Figure 3 shows the slump and T_{50cm} slump flow test set up and Figure 4 illustrates the measurement of slump flow. Figure 5 presents a V-funnel test. The passing ability of SCGPC mixes was assessed using J-Ring test and L-box test. Figure 6 depicts the J-Ring testing performed in this investigation. L-box testing is shown in Figure 7. GTM Screen Stability test was conducted to check the segregation resistance of SCGCC mixes.

2.5. Hardened Properties

The compressive strength of all the mixes was determined using 150 x 150 x 150 mm size cube specimen. The compressive strength was determined at the age of age of 3, 7 and 28 days. Three specimens were tested at each age for each mix. A total of 54 cube specimens were made for the compressive strength. The split tensile strength was determined using 150 x 300 mm size cylinder. Three specimens from each mix combination were evaluated at 7 and 28 days. For the split tensile strength test, 36 cylindrical specimens were produced. The flexural strength was measured using 500 x 100 x 100 mm size prism. Three samples from each mix combination were examined at the age of 7 and 28 days. For the test, 36 prism specimens in total were prepared. The specimens were cast and tested for compressive strength, split tensile strength, flexural strength, and modulus of elasticity as per [40] and [41].

Fig. 3 - Slump and T_{50cm} slump flow test set up

Fig. 4 - Slump flow measurement

Fig. 5 - V-Funnel test

Fig. 6 - J-Ring test

Fig. 7 L-Box test

Table 4

Fresh Concrete Workability of SCGPC

S. No	**Name of the Test**	**CM**	**$G_{100}B_0$**	**$G_{75}B_{25}$**	**$G_{50}B_{50}$**	**$G_{25}B_{75}$**	**G_0B_{100}**	**Acceptance criteria**	
								Min	**Max**
1.	Slump flow (mm)	700	673	659	665	682	662	650	750
2.	T_{50cm} slump flow (sec)	3	4	5	5	5	4	2	5
3.	'V' Funnel (sec)	10	9	10	8	9	8	6	12
4.	'J' Ring (mm)	7	6	5	4	5	4	0	10
5.	'L' Box (H_2/H_1)	0.81	0.85	0.82	0.82	0.83	0.87	0.8	1

3. Results and discussion

3.1 Fresh properties of SCGPC

The fresh properties of SCGPC made with bottom ash and GGBS as source materials were studied and the results are presented in Table 4. The results indicate that the slump flow values for the different concrete mixes varied from 662-700 mm as shown in figure 3 and 4. Therefore, these mixes are suitable for many normal applications such as walls, columns per EFNARC. The slump flow of SCGPC mixes was found to be 2.57% to 5.86% less workable than that of CM (SCC). The spherical glassy shape of fly ash particles in CM SCC contributes to the greater spread of flow [42]. However, the crystalline particle shape of bottom ash does not contribute to better workability like that of fly ash. Also, the increased fineness of GGBS has resulted in less flowabilty, compared to CM [17]. From the test results, it can be seen that the T50cm slump flow ranged from 3 sec to 5 sec for different mixes as shown in figure 3 and 4. The T50 cm slump flow time indicates that SCGPC mixes took 1to 2 sec extra times to get the acceptance criteria compared to the time taken by CM.

The test results reveal that the 'V' Funnel time for the different mixes varied from 8 to 10 sec as shown in figure 5. 'V' Funnel test recorded an additional 0 to 2 sec more than the CM SCC to allow the concrete to flow out under gravity. The 'J' Ring test value ranged from 4 to 7 mm as shown in figure 6. With respect to the ability to pass the 'J' Ring test, SCGPC mixes showed 1 to 3 mm lesser compared to that of CM SCC. From the 'L' Box test, it was observed that the blocking ratio varied from 0.81 to 0.87 as shown in figure 7. 'L' Box test revealed that SCGPC mixes showed 1.23 to 8.64% higher interruption to the flow than CM SCC. These observations are attributed to the increased weight of SCGPC mixes and particle morphology of binder materials [43]

The overall outcome of the experimental test results indicates that all the SCGPC mixes satisfied the recommendations of EFNARC standard for the passing ability, filling ability and segregation resistance.

3.2 Compressive Strength of SCGPC

Table 5 summarizes the compressive strength of CM and SCGPC mixes. The compressive strength of $G_{100}B_0$ mix made only with GGBS exhibited 38.5 MPa at the age of 3 days while CM produced 18.2 MPa at the age of 3 days. It is evident that the compressive strength of $G_{100}B_0$ mix increased two fold compared to that of control mix. Besides, G_0B_{100} mix made only with bottom ash demonstrated minimum compressive strength of 13.7 MPa at the age of 3 days. This is 0.75 times lower than control mix.

At the age of 28 days, the compressive strength of SCGPC mixes varies from 30.9 MPa to 54.8 MPa with the increase in GGBS content. The maximum compressive strength of 54.8 MPa is achieved by $G_{100}B_0$ mix. The mix $G_{100}B_0$ has attained 21% gain in compressive strength when compared to CM. The mix $G_{75}B_{25}$ has exhibited 16.1% gain in compressive strength while the $G_{50}B_{50}$ mix has shown 5.3% increase in compressive strength compared to that of CM. It can be seen that the compressive strength of SCGPC has portrayed tremendous improvement with the increase in GGBS content at all ages. Beyond 50% GGBS, greater enhancement has been observed in compressive strength compared with CM. $G_{100}B_0$ exhibited superior performance compared to that of other mixes at all ages. This enhancement in compressive strength is mainly attributed to higher specific surface area and the substantial amount of CaO present in GGBS [44]. The higher compressive strength in $G_{100}B_0$ indicates the faster and complete dissolution of alumina and silica of GGBS with alkaline liquid causing formation

Table 5

Compressive strength of SCGPC

Mix ID	Days at Testing	Compressive Strength (MPa)		
		Mean	SD	COV
CM	3	18.2	0.33	1.72
	7	37.4	0.53	1.40
	28	45.3	0.50	1.13
$G_{100}B_0$	3	38.5	1.17	3.03
	7	49.4	0.56	1.13
	28	54.8	0.77	1.40
$G_{75}B_{25}$	3	38.2	0.56	1.46
	7	45.1	0.52	1.15
	28	52.6	0.57	1.08
$G_{50}B_{50}$	3	24.9	0.47	1.88
	7	39.2	0.42	1.07
	28	47.7	0.88	1.84
$G_{25}B_{75}$	3	17.6	0.63	3.57
	7	29.1	0.57	1.95
	28	34.8	0.28	0.80
G_0B_{100}	3	13.7	0.35	2.55
	7	27.6	0.20	0.72
	28	30.9	0.42	1.35

Table 6

Split tensile strength of SCGPC

Mix ID	Days at Testing	Split Tensile Strength (MPa)		
		Mean	SD	COV
CM	7	2.26	0.05	2.21
	28	2.78	0.05	1.80
$G_{100}B_0$	7	2.49	0.05	2.00
	28	2.90	0.04	1.37
$G_{75}B_{25}$	7	2.40	0.03	1.30
	28	2.83	0.04	1.41
$G_{50}B_{50}$	7	2.66	0.04	1.50
	28	2.82	0.03	1.06
$G_{25}B_{75}$	7	2.34	0.08	3.41
	28	2.71	0.04	1.47
G_0B_{100}	7	2.10	0.20	9.52
	28	2.50	0.04	1.60

of C-S-H and calcium alumina silicate hydrate (C-A-S-H) in addition to the N-A-S-H gel [45]. The, coexistence of geopolymeric gel and C-S-H gel compounds depends on the amount of calcium present in the source material [46]. Further, the geopolymeric reaction is much active in fine solid particles having higher specific surface area than in coarser ones [47].

Besides, it is noticed that the strength rate decreases with the increase of bottom ash in SCGPC. The mixes $G_{75}B_{25}$ and G_0B_{100} have demonstrated 23.2% and 31.8% lower strength than CM. The minimum compressive strength of bottom ash mix G_0B_{100} is found to be 30.9 MPa. It is understood that the compressive strength of bottom ash mix, G_0B_{100} is 43.6% lesser compared to the compressive strength of GGBS mixes. The very low percentage of CaO and lesser specific surface area of bottom ash compared to GGBS have imparted minimum strength in SCGPC. Further, the addition of extra water dilutes the concentration of alkaline solution, and thereby causes leaching of silica and alumina. As a result, slower rate of polymerisation process in bottom ash leads to lower compressive strength [34]. Even if extra water is added in all SCGPC mixes to enhance the self compactabilty, the increased specific surface area of GGBS does not affect the geopolymeric reaction in higher amount GGBS content mixes.

3.3 Split Tensile Strength of SCGPC

The split tensile strength of SCGPC is displayed in Table 6 and in Figure 2. Test results reveal that it follows the trend of compressive strength of SCGPC made with bottom ash and GGBS. It can be seen that the maximum tensile strength of 2.90 MPa was attained in $G_{100}B_0$ mix containing only GGBS at 28 days. The lowest split tensile strength of 2.50 MPa was obtained for G_0B_{100} mix containing only bottom ash. $G_{100}B_0$, $G_{75}B_{25}$and $G_{50}B_{50}$with GGBS achieved 4.32%, 1.8% and 1.44% increases in tensile strength, respectively, while compared to CM. The other mixes $G_{25}B_{75}$and G_0B_{100} were found to have 2.52% and 10.07% decrement in tensile strength compared to that of CM.

3.4 Flexural Strength of SCGPC

The flexural strength of SCGPC made with bottom ash and GGBS is presented in Table 7 and in Figure 3. The test results appear to exhibit similar trends in compressive and tensile strength. The

Table 7

Flexural strength of SCGPC

Mix ID	**Days at Testing**	**Flexural Strength (MPa)**		
		Mean	**SD**	**COV**
CM	7	2.65	0.05	1.89
	28	5.63	0.03	0.53
$G_{100}B_0$	7	3.75	0.06	1.60
	28	6.25	0.04	0.64
$G_{75}B_{25}$	7	3.40	0.03	0.88
	28	6.00	0.26	4.33
$G_{50}B_{50}$	7	2.90	0.04	1.37
	28	5.60	0.04	0.71
$G_{25}B_{75}$	7	2.60	0.03	1.15
	28	5.40	0.05	0.93
G_0B_{100}	7	2.30	0.04	1.74
	28	5.00	0.17	3.40

maximum flexural strength of 6.25MPa was achieved by $G_{100}B_0$ mix containing only GGBS at 28 days. Similar to compressive and tensile strength, G_0B_{100} mix containing only bottom ash recorded a lower flexural strength of 5 MPa. $G_{100}B_0$, and $G_{75}B_{25}$ mixes achieved 11.01% and 6.57% improvement in tensile strength while compared to that of CM. The other mixes $G_{50}B_{50}$, $G_{25}B_{75}$and G_0B_{100} were found to have 0.53%, 4.09% and 11.19% lower tensile strength than that of CM.

4. Conclusion

The present study conducted experimental work on self-compacting geopolymer concrete containing GGBS and bottom ash under ambient curing mode. The alkaline liquid to binder ratio was chosen as 0.5. The ratio of sodium silicate to sodium hydroxide was taken as 2. The concentration of sodium hydroxide was 8 Molar. In order to improve self compactabilty, 5% super plasticizer and 14% extra water was added in SCGPC mixes. The fresh and hardened strength properties of SCGPC were studied. Based on the results of this study, the following conclusions can be drawn:

The fresh self-compacting properties of filling ability, passing ability, and segregation resistance of all SCGPC mixes made with bottom ash and GGBS are in conformity with EFNARC standards.

The compressive strength of SCGPC mixes varies from 30.9 MPa to 54.8 MPa at the age of 28 days. The SCGPC mixes containing 50%, 75%, 100% GGBS achieved notably higher compressive strength, from early 3 days, than control mix. Because of larger amount of GGBS, the strength development of SCGPC is much more rapid from early days than the strength development of CM. However, the increase in bottom ash content has yielded lower compressive strength. The mix $G_{100}B_0$ gives 21% higher strength compared to CM and mix $G_{75}B_{25}$ gives 16.1% of higher compressive strength compared to CM at 28 days under ambient curing. The rise in compressive strength implies a higher amount of dissolution of alumino silicate compounds, due to incorporation of GGBS.

As the compressive strength, the split tensile and flexural strength for the mix $G_{100}B_0$ exhibited greater strength compared to control concrete. The maximum split tensile strength of 2.90 MPa was attained by $G_{100}B_0$ mix. Similarly, the highest flexural strength of 6.25 MPa was achieved by mix $G_{100}B_0$.

Therefore, it can be concluded that mix $G_{100}B_0$ is taken as the optimum mix and suggested for further study of durability properties. The ambient cured SCGPC made with GGBS shows excellent strength development and is suitable for many applications.

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