Micro-behavioral Study of Bagasse Ash based Geopolymer Concrete

Savitha T M, Y M Manjunath, Dilip Srinivas

***Abstract:** Cement manufacturing industries which emits about 7% of CO_2 to the environment causing pollution. So, in order to avoid pollution problems there is a need to find an alternative binding material. Wastes like agricultural or industrial in the form of ash can be utilized as a substitute for cement. In this research work, Ground Granulated Blast-furnace Slag(GGBS) and Sugarcane Bagasse ash(SCBA) is used as a complete replacement to cement so as to form Geopolymer concrete(GPC). Two different SCBA sources which has high amount of silica content is considered for the partial replacement of GGBS in varying percentages like 5%, 10%, 15%, 20%, 25%, 30% to determine mechanical and microstructure properties. A 5M alkaline solutions of Sodium hydroxide and Sodium silicate is used. In this work, mechanical properties of GGBS-SCBA based GPC which includes compressive strength, split tensile strength, flexural strength and microstructure properties of SCBA samples by X-ray Fluorescence(XRF), Energy Dispersive spectroscopy(EDS), X-ray Diffractometer(XRD), Scanning Electronic Microscope(SEM) techniques are determined and analyzed on different GPC mix proportions.*

***Index terms**: Geopolymer concrete, Ground Granulated Blast-furnace Slag, Strength, Sugarcane Bagasse ash.*

I. INTRODUCTION

At present, India faces waste management problem in every field, which is one of the major issues for the developing country [1]. India is an agricultural country & its main economy is depending on agriculture[1]. Brazil is in the first place to produce more sugarcane, next to Brazil; India is the second largest sugarcane producing country[1]. Today in India there are 453 sugar mills which consists of 252 mills of co-operative sector and 134 mills of private sector. It is estimated that in India sugarcane production during the period of 2017-18 is reached to 32.25million tonnes. In India top sugarcane producing states are Uttar Pradesh, Maharashtra, Karnataka and Tamil Nadu. Table 1 shows the sugarcane production in various states of India during the year 2017-18.

Table 1. Production of sugarcane in various states of India during 2017-18

Sugarcane producing states in India	Production of sugarcane in the year 2017-18(lakh tonnes)
Uttar Pradesh	120.5
Maharashtra	107.15
Karnataka	36.54
Tamil Nadu	6.0

Geopolymer concrete is one of the best solutions. It was first introduced by Prof. T. Davidovits to characterize mineral polymers described by networks of inorganic molecules[2]. Geopolymer is resulting from the reaction between alumina-silicates and alkaline solution of Sodium hydroxide(NaOH) and Sodium silicate(Na_2SiO_3)[3]. Waste by-products of industries like fly-ash, GGBS, silica fume can be utilized to produce Geopolymer concrete[4]. For nation's economy, construction industry plays an important role. In the construction, utilization of agricultural or industrial by-products could become an important route for large scale safe disposal of wastes & there is a reduction of construction costs[5].

The objective of this work is to find the optimal replacement level of GGBS by SCBA sources and to analyze the microstructure of SCBA samples and GPC.

II. MATERIALS AND METHODOLOGY

A. Materials

The ingredients of GPC are GGBS, SCBA, fine and coarse aggregates, NaOH and Na_2SiO_3. GGBS and SCBA were the supplementary cementitious materials in GPC. GGBS is a by-product from thermal steel plants. It is collected from JSW cements, Mysore with loss of ignition 0.08, with specific gravity 2.92 and fineness 6%. SCBA is an agricultural waste material obtained by burning the bagasse, where bagasse is a fibrous residue after extracting juice from sugarcane during the production of sugar. The sources which are considered for the study are named as GGBS, SCBA-1 and SCBA-2.

Revised Manuscript Received on July 05, 2019.

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Fig 1. Appearance of GGBS, SCBA-1, SCBA-2

Figure 1 shows the physical appearance of GGBS, SCBA-1 and SCBA-2. 10mm and 20mm downsize coarse aggregates and fine aggregates were used. Manufactured sand is used as fine aggregate instead of natural sand because natural sand has become expensive and scarce. NaOH and Na_2SiO_3 are used as alkaline activator. NaOH is purchased in the form of pellets and dissolved in distilled water for 5M concentration. Na_2SiO_3 is in semi liquid form.

B. Methodology

a) Preliminary tests on aggregates being carried out for M-sand, 10 mm and 20 mm downsize aggregates. Table 2 shows the physical properties of coarse aggregates and fine aggregates. These tests results are confirming to IS:383-1970.

Table 2. Physical properties of aggregates

Physical properties	20 mm size	10mm size	M-sand
Specific Gravity	2.60	2.62	2.51
Fineness modulus	7.6	7.301	3.50
Bulk density			
Loose sand (Kg/m^3)	1264.19	1353.31	1317.53
Compacted sand (Kg/m^3)	1479.19	1534.16	1572.96
Water absorption	1.6 %	1.4 %	1.25 %

b) Preliminary tests on source materials [SCBA and GGBS] is being carried out such as specific gravity and fineness of the sample. Table 3 shows the physical properties of GGBS, SCBA-1 and SCBA-2. Fineness of SCBA-1 and SCBA-2 is found to be 62% and 54% respectively. Fineness of SCBA is more because of the presence of coarser particle in it.

Table 3. Physical properties of GGBS, SCBA-1 & SCBA-2 as per IS 1727-1967

Test onducted	pecific Gravity	ineness of SCBA
GGBS	2.92	6%
SCBA-1	0.32	0.41
SCBA-2	62%	54%

c) Design mix for the GPC for the grade of M30 mix is adopted as per **B.V. Rangan** method.

d) NaOH solutions is prepared for 5M concentration.

e) Alkaline solution is prepared by adding Na_2SiO_3 solution to the NaOH solutions before 30 minutes of casting.

f) Test specimens are prepared for various GPC mixes.

g) The trial mixes are carried out for 5%SCBA-1 +95%GGBS and 5% SCBA-2+95% GGBS.

h) The test specimens like cubes, cylinders and beams with different SCBA sources for 5M concentration are casted for various mixes like
- M1 - 5%SCBA+95%GGBS
- M2 - 10%SCBA+90%GGBS
- M3 - 15%SCBA+85%GGBS
- M4 - 20%SCBA+80%GGBS
- M5 - 25%SCBA+75%GGBS
- M6 - 30%SCBA+70%GGBS

i) The test specimens were exposed to the sunlight for the sunlight curing.

j) The results such as compressive strength, split tensile strength and flexural strength are tabulated for cubes, cylinders and beams respectively.

k) The economic replacement is being carried forward to analyse the microstructure of GPC with SCBA-1 and GPC with SCBA-2. Then by using SEM, microstructure analysis is carried out.

l) XRF, XRD, SEM, EDS analysis is carried out to study the microstructure of SCBA-1 and SCBA-2 samples.

C. Preparation of Alkaline solution

Alkaline solution is prepared by using NaOH and Na_2SiO_3 in the ratio of 1:2.5. A 5M of NaOH solution is prepared by dissolving 200gms of NaOH pellets in distilled water. It is prepared one day before casting and after 24 hours, Na_2SiO_3 solution is added to the NaOH solution to form alkaline solution. Figure 2 shows the preparation of alkaline solution.

Fig 2. Preparation of alkaline solutions

D. Mixing Procedure and Curing

For M30 grade, GPC mix is prepared**.** Mix design is followed as per **B.V. Rangan** paper. There are 6 GPC mixes developed by varying the percentage replacement of GGBS by different sources of bagasse ash. Mix proportions are shown in table 4a and 4b.

Table 4a. Mix proportions

Material	Mix proportion (kg/m^3)		
	M1	M2	M3
GGBS	411.82	390.15	368.47
SCBA	21.67	43.35	65.02

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M-sand	760.32	760.32	760.32
20mm aggregate	483.84	483.84	483.84
10mm aggregate	483.84	483.84	483.84
NaOH molarity	5M	5M	5M
NaOH	68.12	68.12	68.12
Na_2SiO_3	170.32	170.32	170.32
Water	75.00	75.00	75.00

Table 4b. Mix proportions

Material	Mix proportion (kg/m^3)		
	M4	**M5**	**M6**
GGBS	346.80	325.12	303.45
SCBA	86.70	108.37	130.05
M-sand	760.32	760.32	760.32
20mm aggregate	483.84	483.84	483.84
10mm aggregate	483.84	483.84	483.84
NaOH molarity	5M	5M	5M
NaOH	68.12	68.12	68.12
Na_2SiO_3	170.32	170.32	170.32
Water	75.00	75.00	75.00

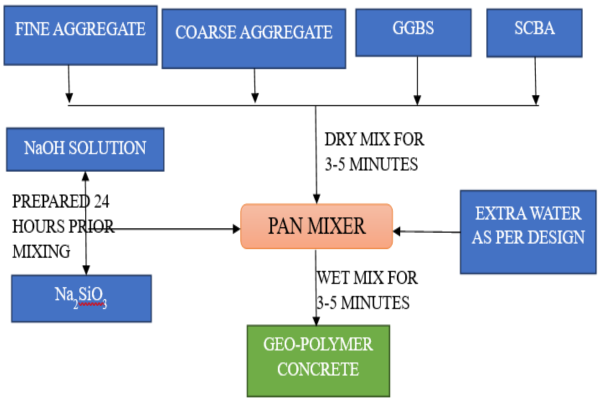

Fig 3. Flowchart of mixing process of GPC

Figure 3 shows the mixing procedure of GPC. First batching of materials like GGBS, SCBA, fine aggregate and coarse aggregate is done. These materials poured into pan mixer and dry mixed for about 3-5 minutes as shown in figure 4.

Fig 4. Dry mixing of ingredients

Then for this mixture alkaline solution and water is added and mixed for about 3-5 minutes as shown in figure 5.

Fig 5. Addition of alkaline solution and water

After proper mixing, the GPC is filled into appropriate moulds of cubes, beams and cylinders shown in figure 6. Figure 7 shows the casted specimens kept outside the lab for sun light curing.

Fig 6. casted specimens

Fig 7. sunlight curing of casted specimens

E. Experimental execution

The compressive, split tensile and flexural strength is determined for all 6 GPC mixes. XRF, XRD, EDS and SEM analysis were carried out for SCBA-1 and SCBA-2 source samples. For GPC mix with highest strength is considered for SEM analysis of GPC. The cube of size 150mmX150mmX150mm, cylindrical specimen of 150mm diameter and 300mm height, beam of 100mmX100mmX500mm is used.

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Cubes are cured for a period of 7 and 28 days. Cylinders and beams are cured for 28 days. Cubes and cylinders were tested by 2000kN capacity compression testing machine as per IS:516-1959 and IS:5816-1999. Beams are tested by Universal testing machine as per IS:516-1959.

III. RESULTS AND DISCUSSIONS

A. XRF Analysis

Chemical composition of GGBS and SCBA is determined by XRF analysis. These results confirm as per IS:16714-2018 specifications. Table 5 shows the chemical composition of GGBS and it is observed that GGBS consists of 88.7% of glass content.

Table 5. chemical composition of GGBS

Test Conducted	Results (%)
Manganese oxide (MnO)	0.07
Magnesium oxide (MgO)	7.07
Sulfide sulphur (S)	0.47
Sulphate (SO_3)	0.18
Insoluble residue (Max)	0.78
Chloride content	0.02
Loss on ignition	0.08
Glass content	88.70

Table 6 shows 9 different SCBA samples collected from different places in Karnataka with varying silica content. It is seen that SCBA-1 and SCBA-2 contains highest silica content. So, these two sources of SCBA is considered for the further study.

Table 6. chemical composition of different SCBA sources

SCBA samples	Location	Silica content(%)
SCBA-1	**Shamboonalli Aalemane 1**	76.06
SCBA-2	**Shamboonalli Aalemane 2**	72.89
SCBA-3	**Bannur Aalemane**	64.35
SCBA-4	**Srirangapattana Sugar factory**	60.78
SCBA-5	**K.R. Nagara Aalemane 1**	49.73
SCBA-6	**K.R. Nagara Aalemane 2**	67.78
SCBA-7	**K.R. Nagara Aalemane 3**	53.81

Table 7. chemical composition of SCBA-1 & SCBA-2

Test	SCBA-1(%)	SCBA-2 (%)
Silicon as SiO_2	72.89	76.06
Iron as Fe_2O_3	2.34	5.60
Aluminium as Al_2O_3	3.65	4.94
Calcium as CaO	4.55	1.86
Magnesium as MgO	2.55	1.48
Sodium as Na_2O	0.76	0.55
Potassium as K_2O	5.05	1.77
LOI	0.52	0.71

Table 7 shows the chemical composition of SCBA-1 and SCBA-2. As per ASTM C 618, LOI <10% and SiO_2+ Al_2O_3 +Fe_2O_3 > 70%. It is observed from the Table 7 that LOI is within the limits and for SCBA-1, sum of SiO_2+ Al_2O_3 +Fe_2O_3= 78.88% > 70% and for SCBA-2, sum of SiO_2+ Al_2O_3 +Fe_2O_3= 86.61% > 70%.

B. XRD analysis

Mineralogical examination of SCBA is completed by XRD analysis**.** From XRD graphs it is observed that intensity changes continuously and 2θ also gradual changes. In order to conduct XRD analysis, the SCBA is sieved through 90µm sieve and then the samples are tested in the laboratory by using XRD equipment. In the present study, SCBA is scanned from 10˚ to 70˚. The results obtained are then plotted to graphs by using Origin Pro-2018 software. This software is mainly used for graphing and analysis.

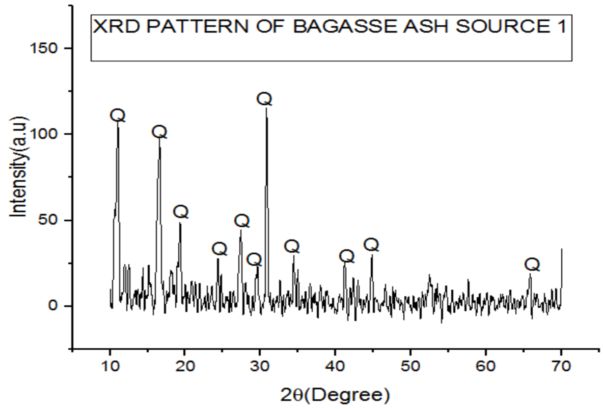

Fig 8. XRD pattern of SCBA-1

Figure 8 and 9 shows the XRD pattern of SCBA-1 and SCBA-2 respectively. It is said that pozzolanic activity depends on the presence of amorphous silica rather than crystalline silica. It can be detected from the graph in figure 8 that the SCBA-1 contains silica in the form of Quartz. Highest peaks are observed at the diffraction angle of 11˚, 16˚ and 31˚.

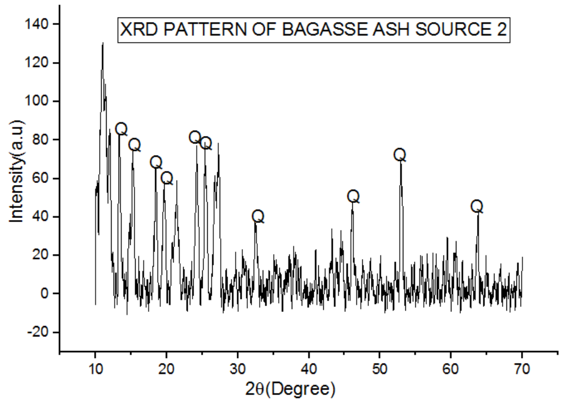

Fig 9. XRD pattern of SCBA-2

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From the graph in figure 9 it can be witnessed that multiple peaks shows the presence of Quartz. Highest peaks are observed at the diffraction angle between 10˚ and 30˚. But after 30˚ also peaks of Quartz are observed. Some peaks are deviated from the baseline in SCBA-2 which represents the presence of amorphous constituents that seen as broad peaks between 10˚ and 15˚ and also between 20˚ and 25˚ these represent the presence of reactive silica.

C. SEM and EDS Analysis

By using SEM, the morphology of SCBA is determined. Elemental composition is determined by EDS analysis. In order to know the characterization and identification of minerals present in SCBA and morphology of SCBA, SEM with EDS analysis is carried out.

(a) SCBA-1 **(b) SCBA-2**

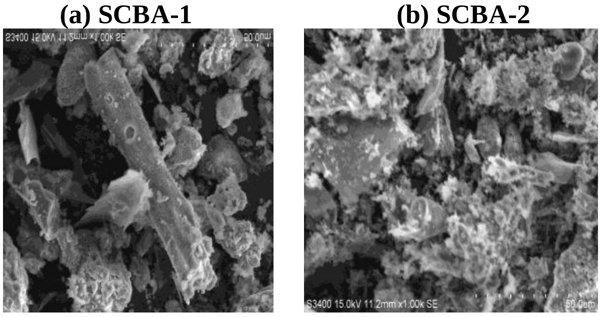

Fig 10. SEM images of SCBA-1 and SCBA-2

In figure 10 (a), the morphology of SCBA-1 is seen which shows that the particles are less dense, it contains crystalline and prismatic particles. In figure 10(b), the morphology of SCBA-2 is seen which shows that the particles are denser.

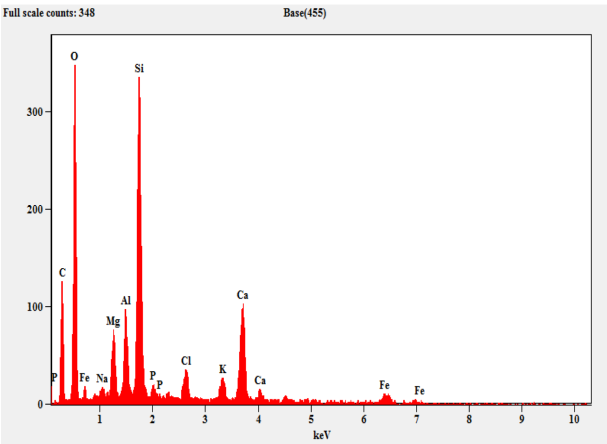

Fig 11. EDS analysis of SCBA-1

Figure 11 shows the EDS analysis results, from which it is observed that SCBA-1 contains large amount of Silica (Si), oxygen(O), Aluminum(Al), Magnesium(Mg), Carbon(C), Calcium(Ca) and lesser amount of Potassium(K), Sodium(Na), Chloride(Cl), Titanium(Ti), Iron(Fe), Phosphorus(P). The Elemental composition of SCBA-1 is shown in table 8 which shows similar composition but there is some variation in the proportions.

Table 8. Elemental composition of SCBA-1

Element	BA-1 (weight %)
Si	7.83
O	45.32
Mg	1.36
Al	1.85
P	0.43
Cl	1.28
K	1.10
Ca	4.70
Fe	1.56
C	34.56

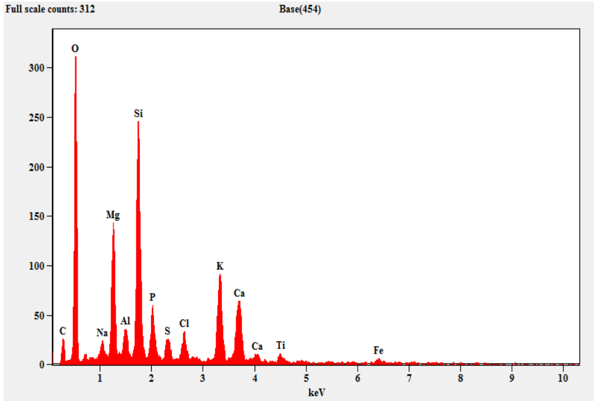

Fig 12 EDS analysis of SCBA-2

Figure 12 shows the EDS analysis results, from which it can be observed that SCBA-2 contains large amount of Silica(Si), oxygen(O), Magnesium(Mg), Calcium(Ca), Potassium(K) and lesser amount of Sodium(Na), Aluminum(Al), Sulphur, Chloride(Cl), Titanium(Ti) and Iron(Fe), Phosphorus(P) and carbon. . The Elemental composition of SCBA-2 is shown in table 9.

Table 9. Elemental composition of SCBA-2

Element	BA-2 (weight %)
Si	14.73
O	1.385
Na	0.91
Mg	7.05
Al	1.82
P	5.14
S	2.58
Cl	2.67
K	9.52
Ca	8.82
Ti	2.07
Fe	2.84
C	40.45

D. Workability of GPC

On fresh concrete in order to know the effect of inclusion of SCBA in GPC, it is tested for slump. The workability for GPC is tested as per IS 1199-195.

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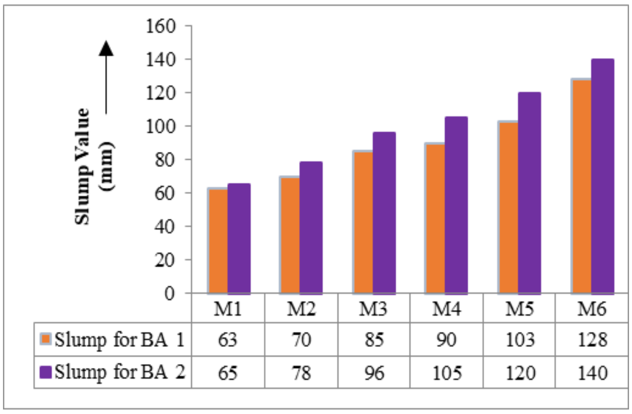

Fig 13. workability of GPC mix

From the figure 13 it is detected that the workability of GPC decreased as the percentage inclusion of SCBA is increased in the mix because when SCBA is added to the mix it absorbs water.

E. Compressive strength test

Compressive strength test for GGBS with SCBA-1 based GPC cubes is conducted at 7th and 28th days and the results are tabulated in table 10.

Table 10. Compressive strength test results in MPa

Mix ID	7days	28days
M1	30.45	43.00
M2	28.75	41.04
M3	28.62	40.90
M4	27.93	40.11
M5	25.15	35.2
M6	23.06	32.92

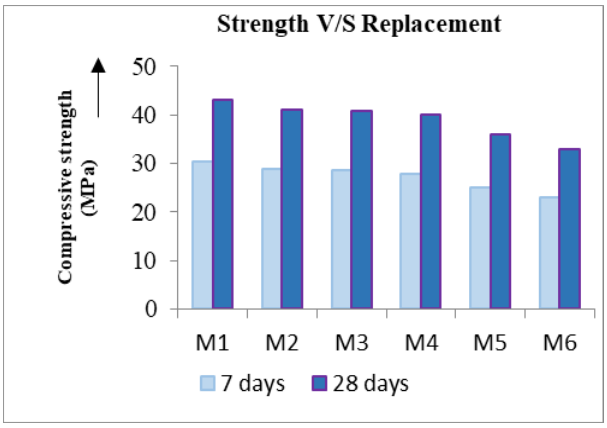

Fig 14. Compressive strength of SCBA-1

Figure 14 shows the variation in the compressive strength for SCBA-1. The results show that the strength of GPC decreased as the percentage of SCBA-1 increased in the rate of 5%, 10%, 15%, 20%, 25%, 30%. The target strength of specimen for 7 days is 26 MPa but for GPC with 5%, 10%, 15%, 20% SCBA-1 it was increased by 17.11%, 10.57%, 10.15%, 7.42% respectively. For 25% and 30% it was decreased by 3.26% and 11.30% respectively. For 5% replacement of GGBS by SCBA-1 gives highest compressive strength of about 43MPa. The target strength of specimen for 28 days is 38.25 MPa but for GPC with 5%, 10%, 15%, 20% SCBA-1 it was increased by 12.41%, 7.29%, 6.92%, 4.86% respectively. For 25% and 30% it was decreased by 6.09% and 13.93% respectively. It shows that up to 20 %, GGBS can be optimally replaced with SCBA-1.

Compressive strength test for GGBS with SCBA-2 based GPC cubes is conducted at 7th and 28th days and the results are tabulated in table 11.

Table 11. Compressive strength test results

Mix ID	7days	28days
M1	30.66	44.02
M2	29.62	42.29
M3	28.76	41.07
M4	28.12	40.15
M5	27.74	39.85
M6	25.55	36.33

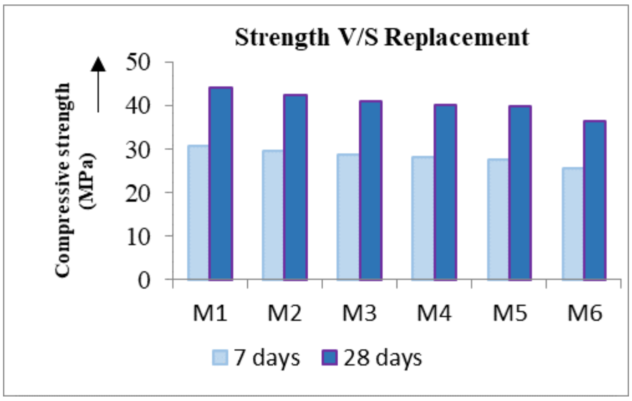

Fig 15. Compressive strength of SCBA-2

Figure 15 shows the variation in the compressive strength for the age of 7th and 28th days for SCBA-2. The target strength of specimen for 7th day is 26 MPa but for GPC with 5%, 10%, 15%, 20%, 25% SCBA-2 it was increased by 17.92%, 13.92%, 10.61%, 8.15%, 6.69% respectively. For 30% it was decreased by 2.11%. For 5% GGBS replacement by SCBA-2 gives the highest compressive strength of 44.02 MPa. The target strength of specimen for 28th day is 38.25 MPa but for GPC with 5%, 10%, 15%, 20%, 25% SCBA-2 it was increased by 15.08%, 10.56%, 7.37%, 4.96%, 4.18% respectively. For 30% it was decreased by 5.01%. It is seen that up to 25%, GGBS can be optimally replaced with SCBA-2.

F. Split tensile strength test

Split tensile strength test for GGBS with SCBA-1and SCBA-2 based GPC cylinders is conducted at 28th days and the results are tabulated in table 12.

Table 11. Split tensile strength test results

Mix ID	GGBS with SCBA-1 based GPC	GGBS with SCBA-2 based GPC
M1	3.33	3.48
M2	3.25	3.36
M3	3.2	3.27
M4	3.18	3.2
M5	3.02	3.14
M6	2.82	2.89

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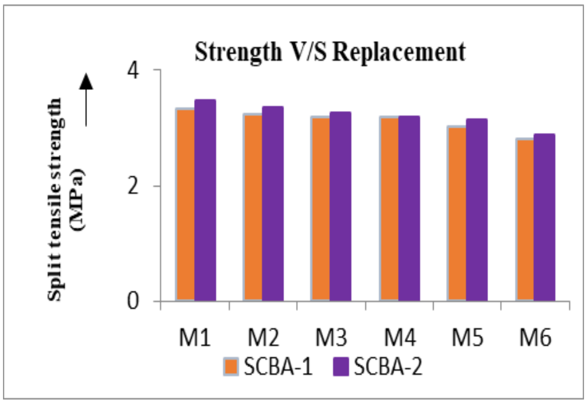


Fig 16. Split tensile strength SCBA-1 and SCBA-2

From figure 16 it can be witnessed that strength of GPC decreased as the replacement of SCBA increased in the rate of 5%, 10%, 15%, 20%, 25%, 30% for both sources of SCBA. Comparing the results of both SCBA sources, SCBA- 2 gives better result than SCBA-1. The target strength of specimen for 28th days is 3.06 MPa but for GPC with 5%, 10%, 15%, 20% SCBA-1 it was increased by 8.82%,6.20%, 4.57%, 3.92% respectively. For 25% and 30% it was decreased by 1.3% and 7.84% respectively. For 5% partial replacement of GGBS by SCBA-2 gives highest split tensile strength of 3.48 MPa. The target strength of specimen for 28th days is 3.06 MPa but for GPC with 5%, 10%, 15%, 20%, 25% SCBA-2 it was increased by 13.72%, 9.80%, 6.86%, 4.57%, 2.61% respectively. For 30% it was decreased by 5.55%. For varying replacement, the increase in the strength from SCBA-1 to SCBA-2 is 4.5%, 3.38%, 2.18%, 0.62%, 3.28%, 2.48% for 5%, 10%, 15%, 20%, 25% and 30% respectively.

G. Flexural strength test

Flexural strength test for GGBS with SCBA-1and SCBA-2 based GPC beams is conducted at 28th days and the results are tabulated in table 13.

Table 13. Split tensile strength test results

Mix ID	GGBS with SCBA-1 based GPC	GGBS with SCBA-2 based GPC
M1	5.73	6.02
M2	5.25	5.57
M3	4.88	5.06
M4	4.26	4.33
M5	3.66	3.92
M6	2.62	2.72

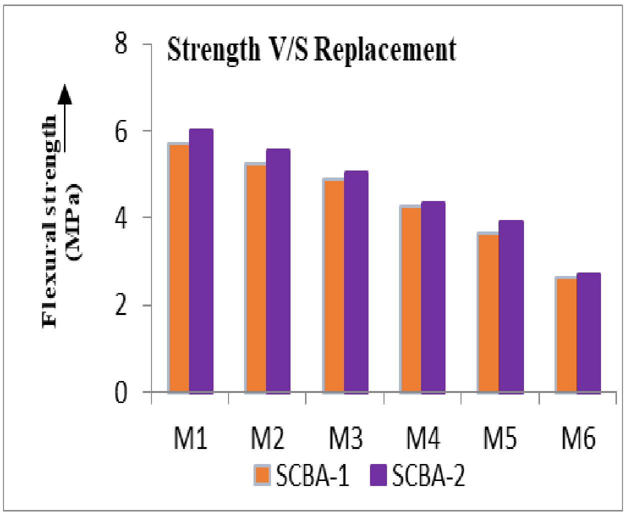
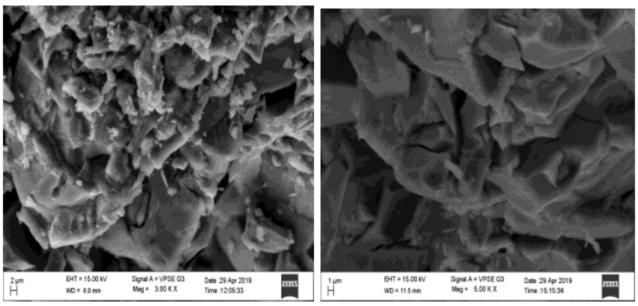


Fig 17. Flexural strength of SCBA-1 and SCBA-2 for 28 days

Figure 17 shows the variation in the flexural strength for both SCBA-1 and SCBA-2 sources. It can be detected that as the percentage replacement of GGBS by SCBA increases the flexural strength decreases gradually. For SCBA-2 the flexural strength obtained is more when compared to SCBA-1. For 5% replacement of GGBS by SCBA-1 gives highest flexural strength of 5.73 MPa. The target strength of specimen for 28th days is 3.80 MPa but for GPC with 5%, 10%, 15%, 20% SCBA-1 it was increased by 50.78%, 38.15%, 28.42%, 12.10% respectively. For 25% and 30% it was decreased by 3.68% and 31.05% respectively. For 5% replacement of GGBS by SCBA-2 gives highest flexural strength of 6.02 MPa. The target strength of specimen for 28th days is 3.80 MPa but for GPC with 5%, 10%, 15%, 20%, 25% SCBA-2 it was increased by 58.42%, 46.57%, 33.15%, 13.94%, 3.15% respectively. For 30% it was decreased by 28.45%. For various replacement, the increase in the strength from SCBA-1 to SCBA-2 is 7.10%, 2.67%, 3.47%, 2.92%, 6.95%, 5.34% for 5%, 10%, 15%, 20%, 25% and 30% respectively. Strength of GGBS with SCBA-2 GPC is more when compared to GGBS with SCBA-1 GPC.

H. SEM analysis of Geopolymer concrete

a. ***SEM analysis of GGBS based SCBA-1 GPC***



(a)7 days **(b)28 days**

Fig 18. SEM images GGBS based SCBA-1 GPC

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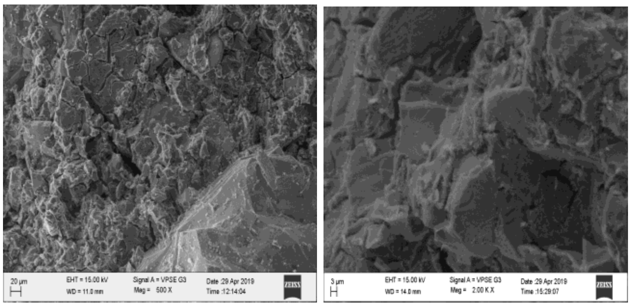
Figure 18 shows the micrographs of 5%SCBA-1+ 95%GGBS for 7th and 28th days taken by SEM technique. In figure 18(a) the micrographs of 5%SCBA-1+ 95%GGBS shows heterogeneous matrix. At 28th day as in figure 18(b) the concrete is observed to be denser and seen like crystalline structure. It is seen that ITZ thickness reduced for 28 days.

b. ***SEM analysis of GGBS based SCBA-2 GPC***



(a)7 days (b)28 days

Fig 19. SEM images GGBS based SCBA-2 GPC

Figure 19 shows the micrographs of 5%SCBA-2+ 95%GGBS for 7th and 28th days taken by SEM technique. In figure 19(a) the micrographs of 5%SCBA-2+95%GGBS shows discontinuous in the interphase between aggregate and the pozzolanic materials like GGBS and BA. At 28 days as in figure 19(b) the concrete is observed to be denser. And ITZ thickness reduced for 28 days.

IV. CONCLUSION

1. GGBS based SCBA geopolymer concrete are less workable. As the inclusion of SCBA increased, the workability of the concrete decreased.
2. From different sources of SCBA, the sources of SCBA which has highest silica content is considered by XRF technique. It is found that SCBA-2 contains the highest silica content than SCBA-1.
3. For both sources of SCBA, micro structural analysis is carried out by XRF, XRD, SEM, EDS and from these tests, the chemical composition of SCBA samples, mineralogical examination of SCBA, morphology of SCBA and elemental composition is determined and studied. The morphology of SCBA-2 sample shows particles are denser and contains amorphous silica as compared to SCBA-1 sample.
4. It is observed that the strength for SCBA-2 based GPC is more when compared to SCBA-1 based GPC, this is because SCBA-2 contains high silica content than SCBA-1.
5. It is observed that for 5% replacement of GGBS by SCBA gives highest compressive strength for both SCBA sources. SCBA-1 at 20% replacement has shown the optimum percentage for best results for GPC. SCBA-2 at 25% replacement has shown the optimum percentage for best results for GPC.
6. It is concluded that SCBA can be used to replace GGBS in order to produce eco-friendly concrete. Because both GGBS and SCBA are waste materials from steel plants and sugar factories respectively.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. N. Suresh for giving his valuable guidance for the research work and the company L & T CTEA for providing the lab facilities to conduct the experimental work. Also thanking to JSW cements for supplying GGBS which is very necessary for the experimental work.

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