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Effect of Partial Replacement of Ground Granulated Blast Furnace Slag with Sugarcane Bagasse Ash as Source Material in the Production of Geopolymer Concrete

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The study on the characteristics of geopolymer concrete (GPC) is of ultimate significance to instill assurance in builders and engineers. Abundant available literatures point towards the utilization of fly ash and ground granulated blast furnace slag (GGBFS) as source material in the production of GPC with little on other materials. India produces nearly 350 MMT of sugarcane for the production of sugar, which lies second only to Brazil in the annual production, the disposal of the bagasse creates an environmental issue needs to be effectively utilized. Hence, this work was intended to investigate the effect of utilizing sugarcane bagasse ash (SCBA) as a source material in the production of geopolymer mixes. The fresh (consistency, setting time, soundness and flow), hardened (density, compressive strength, expansion and pH) and microstructural properties (X-ray diffraction) of the tested mixes were asessed. The results infer that 20 % replacement level of GGBFS with SCBA produces superior compressive strength and all other results were within the permissible limits even at 40 % replacement level.

Keywords: geopolymer concrete, alkali activated slag, sugarcane bagasse ash, microstructural behaviour, mechanical properties, alkalinity.

1. INTRODUCTION

Cement is the key ingredient utilized as a part of the concrete production, which has been considered as the majority of the essential substance on the planet. Concrete appears the premise of the structural business nowadays, yet it discharges CO_2 at a rate of approximately 1 ton for each ton of concrete manufactured [1]. To decrease the measure of CO_2 discharge from the cement business, the process of manufacturing must be enhanced to diminish its discharges of air contamination [2]. To meet the needs of sustainable development and environment preservation, new materials which are environment friendly were required to replace the conventional concrete manufactured from OPC and are termed as geopolymers. Geopolymers are a fairly innovative group of building materials that do not need C-S-H gel but make use of the polycondensation of Si and Al from source material to attain a greater strength [3]. Alkali activated binders are typically produced with an aluminosilicate precursor and an activator which is primarily consists of alkalis of Na or K and waterglass. Few investigations have inspected the impact of variables (silica fume [2], fly ash [4] and metakaolin [5]) that persuades the development of alkali activated slag (AAS) activated with common activators.

The sugar which has been extracted from sugarcane leaves behind the sugarcane bagasse which when powdered to ash termed as Sugarcane bagasse ash (SCBA), which erstwhile acknowledged as a pozzolanic material recently and to be utilized as a supplementary cementitious material [6]. The yearly production of sugarcane globally augmented from 1910.88 Mt in 2011 to 2013.72 Mt in 2016. In India, the production rate increases from 342.38 Mt in 2011 to 348.45 Mt in 2016 as shown in Table 1 which accounts about 18 % of the global sugarcane production annually second only to Brazil, which produces about 38 % of the global production.

From every ton of harvested sugarcane, 104 kg of sugar has been produced which yields about 13 % of the harvested sugarcane leaving behind 231 kg of bagasse (28 % of planted sugarcane) [7, 8]. Due to its high BOD, this should not be disposed in water bodies or other sensitive ecosystems [9]. As well as, the industries are facing issues in disposing the waste from production due to its environmental issues, developing an appropriate solution to handle this waste from the sugar industry [8]. Beside these backdrop concerns, this paper deals with the utilization of incinerated SCBA as a geopolymer source material (GSM) in the production of GPC. The development in the strength and the reaction products involved in the reaction mechanism has not been addressed elsewhere, hence this work was intend to investigate the microstructural characterization of geopolymer mixes, when GGBFS has been partially substituted by SCBA. In this regard, the effect of replacing GGBFS with SCBA was investigated with the aid of physical and mechanical characteristics of the mixes and the microstructural analysis in the form of XRD analysis at various curing age.

2. MATERIALS AND METHODS

GGBFS of specific gravity 2.90 obtained from the local steel manufacturing plant satisfying the requirements

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of basicity coefficient, CaO/SiO_2 and Al_2O_3/SiO_2 was utilized as GSM in the production of GPC.

SCBA acquired from the local Sugar Mill was whitish grey in colour with specific gravity of 2.65 was utilized as a substitution for GGBFS in the production of GPC. The chemical composition of GGBFS and SCBA were assesed using X-ray fluorescenece (XRF) study and their results are shown in Table 2. For preparing mortar specimens, sand was used with a specific gravity 2.58, fineness modulus 2.56 and water absorption of 1.37 %. GSMs were activated with the mixture of 99 % pure NaOH in flakes form and Na_2SiO_3 in liquid form with 28 % SiO_2, 11.2 % Na_2O and 60.8 % H_2O by mass with a modulus of silica 2.5.

Five different proportions of GGBFS replacement with SCBA were assessed in the study: 0 % (control), 10 %, 20 %, 30 % and 40 % by mass. For preparing the mixes, NaOH concentration was kept constant at 12 M and ratio of Na_2SiO_3:NaOH was taken as 2.0; whereas, the sand/GSM ratio was fixed as 2.5 (the GSM being the sum of GGBFS and SCBA). The consistency and setting time of the mixes were assessed using Vicat apparatus and soundness with Le-Chateliar method. The specimens were cured under ambient temperature condition of 24 ± 2 °C at a relative humidity of 64 ± 3 %. The compressive strength of the mortar mixes was assessed after 3, 7 and 28 days of air curing on 70 mm cube specimens using 3000 kN capacity compressive testing machine. The expansion of the mortar mixes were tested with a 20 mm × 20 mm × 100 mm specimens. X-ray diffraction (XRD) patterns were obtained for the paste samples after 3, 7 and 28 days using Bruker, D_8 Focus under an accelerating voltage of 40 kV with an alternating current of 40 mA subjected to CuKα radiation with 2ϴ step size ranges from 20° to 80°. The alkaline nature of the tested samples was measured with the help of pH instrument for the powdered samples diluted in distilled water for 72 hrs.

3. RESULTS AND DISCUSSION

3.1. Fresh properties

The properties of the mixes at fresh state were analyzed with the aid of consistency, setting time and soundness of the mixes and their results are detailed in Table 3. It has been observed that the consistency of the paste increases with the increase in the replacement level of GGBFS with SCBA. For example, the paste consistency augmented from 30 % for the control mix to 37 % at 60 % replacement level of GGBFS with SCBA. The increased consistency at higher replacement level is mainly owing to the hygroscopic temperament and higher surface area of SCBA which tends to increased water demand [6, 11]. As the setting time is directly persuaded by the consistency of the paste, the setting time was also examined to increase with the increasing replacement level of GGBFS with SCBA. For instance, the paste setting time at room temperature has increased from 40 min for the control mix to115 min, when replacing GGBFS with 40 % SCBA. This is primarily owing to the moisture grasping properties of SCBA and loss of C_3A owing to the increasing hydration products results in increased duration of setting. Besides, SCBA consists of less CaO as GGBFS, which may as well quicken the increased setting time with the addition of SCBA. There has been a reduction in the soundness results with the increasing percentage of SCBA. For instance, it can be observed that the mixes replacing GGBFS with 40 % SCBA resulted in a soundness of 1.7 mm comparing to 2.5 mm for the control mix. This is mainly due to the reduction in the amount of free CaO and MgO on inclusion of SCBA with GGBFS. Similarly, the behaviour of the concrete in the fresh condition is principally depends on the flowability of the cement paste. For which, the workability results of the mixes in the form of mortar flow for varying replacement level of GGBFS with SCBA are detailed in Table 3. It has been observed that the flow reduces with the increasing SCBA volume. For instance, the flow of the control mortar mix is 90 mm comparing to 71 mm for mixes replaced with 40 % SCBA. On the whole, the size and shape of the particle as well as the filling effect plays a significant part in the workability. The resistance to flow at higher replacement level increases due to the filling capability of SCBA in the pores of GGBFS matrix resulting in increased particle contact because of the higher surface area. Also, at higher replacement level due to its porous [5, 11] and hydrophilic nature [12] of SCBA which attracts more water than GGBFS resulting in reduced flow at higher replacement levels.

Table 1. Production of sugarcane (in Mt) in the world and top countries [10]

Year	World	Brazil	India	China	Thailand	Mexico	Pakistan
2011	**1910.88**	734.01	**342.38**	115.12	95.95	49.74	55.31
2012	**1960.48**	721.08	**361.04**	124.04	98.40	50.95	58.40
2013	**2031.76**	768.09	**341.20**	128.73	100.10	61.18	67.46
2014	**2010.40**	736.11	**352.14**	126.15	103.70	56.67	62.83
2015	**2004.51**	750.29	**362.33**	117.63	94.14	55.40	65.48
2016	**2013.72**	768.68	**348.45**	123.06	87.47	56.45	65.45
2017	**1946.32**	758.55	**306.07**	104.79	102.95	56.95	73.40

Table 2. Chemical composition of the source materials used

Oxides	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	K_2O
GGBFS, %	36.77	30.97	17.41	9.01	1.03	1.82	0.69	0.46
SCBA, %	5.33	71.05	4.84	4.81	3.20	0.76	0.90	2.01

Table 3. Fresh properties of the tested mixes

Mix No.	Consistency, %	Setting time, min	Soundness, mm	Flow, mm
SCBA0	30	40	2.5	90
SCBA10	30	50	2.4	84
SCBA20	32	75	2.1	81
SCBA30	34	90	1.9	77
SCBA40	37	115	1.7	71

3.2. Density

The flowability of the cement paste can also be influenced by the density of the cementitious material principally at reduced water-binder ratio [13]. The densities of the hardened samples were measured at the age of 3, 7 and 28 days curing and their variations in the results are shown in Fig. 1. The density was observed to increase at 20 % replacement level of GGBFS with SCBA and later reduced, whereas 30 % replacement level shows improved density than the control mix. The increased density of the mixes is mainly due to the lesser particle dimension and superior surface area of SCBA.

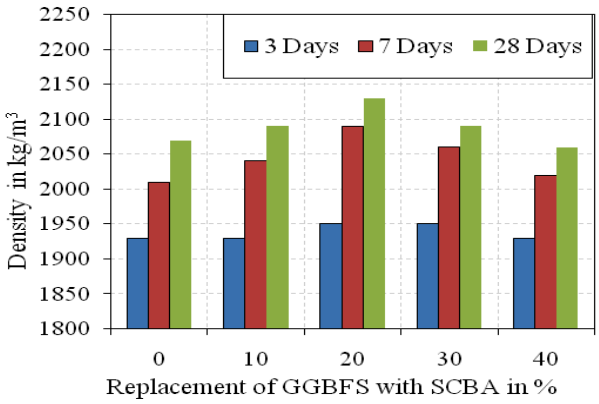

Fig. 1. Density results of the mortar mixes

It was also observed that the increased density of the mixes with the increasing curing age irrespective of the replacement level. This is primarily because of the formation of higher concentration reaction products at later ages. The behaviour is close to the cement mortar blends. The demand for water gets reduced at higher density consequently more water is discharged in the wake of packing the pores so as to cover the solid constituents resulting in lubricated cement paste [14]. In addition, large surface area of the filler material tends to increase the surface area of the solids when mixed with water resulting in higher density of the mixes [15, 16].

3.3. Compressive strength

The compressive strength results of the mortar mixes with partial inclusion of SCBA for GGBFS at the age of 3, 7 and 28 days of air curing respectively are shown in Fig. 2. The strength was estimated to enhance with the mounting age of curing and diminish with the addition of SCBA content at premature ages, whereas at higher curing age, the strength was found to enhance with the increasing SCBA content up to 10 % replacement level. This is primarily as a result of the superior amount of hydration products developed at 10 % SCBA volume. The development in the strength at later ages is mainly accredited to the high amount of silica, fineness and amorphous nature of SCBA [6] and its pozzolanic reactivity [17] utilized in the investigation.

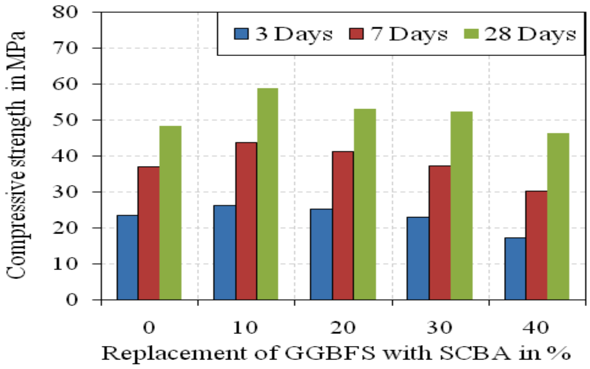

Fig. 2. Compressive strength results

The compressive strength was found to be high at 10 % replacement level, whereas, 20 % and 30 % replacement level were comparable with the conventional mix and minor reduction after 10 % replacement level may be attributed to higher water demand of the material resulting from the reduction in the flow property of the mixes [18]. The reduction may also owing to the utilization of pozzolans which leads to dilution effect.

3.4. Expansion

Fig. 3 demonstrates the variation in the expansion of the mixes at different curing age.

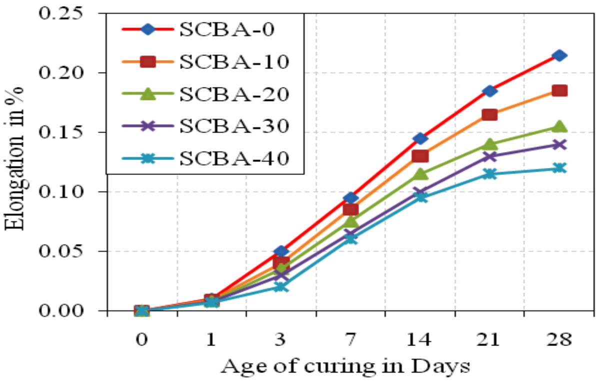

Fig. 3. Expansion results

The control specimens shows a linear increase in the expansion with the age of curing, whereas, there has been a drop in the linearity of the curves with the increasing SCBA quantity. Also, there is a reduction in the expansion results with SCBA replacement for GGBFS compared to the control specimens. For instance, there has been a reduction in the expansion of 10 % and 14 % for the mixes with 10 % replacement at 14 and 28 days curing compared to control mixes. Similarly, 21 % and 28 % for 20 % replacement, 31 % and 35 % for 30 % replacement, 34 % and 44 % for 40 % replacement was observed respectively. The reduction in the expansion with the increasing SCBA volume is principally owing to the development of the hydration product that controls the reaction rate by taking the alkalies due to negative charge [19]. Similar observations were made by Abbas et. al [20] when cement is partially replaced with the pozzolanic materials. The control mix showed a signs of minor surface cracks whereas the mixes with the incorporation of SCBA didn't show any signs of deterioration on the surface. This results show that the mixes with SCBA incorporation can effectively overcome the distress because of the alkali silica reaction contrast to the controlled mix without SCBA incorporation [21].

3.5. X-ray diffraction (XRD)

The XRD results of the samples at 3, 7 and 28 days curing for variation in the SCBA volume were studied and their results are projected in Fig. 4. The major hydration products observed in the mixes were a) Calcium Silicate Hydrate (C* – $Ca_2SiO_4.H_2O$); b) Calcite (C – $CaCO_3$); c) Larnite (L – Ca_2SiO_4); d) Portlandite (P – $Ca(OH)_2$).

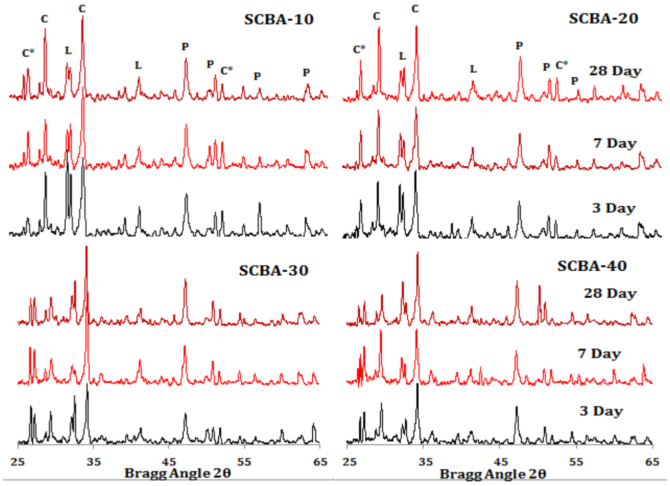

Fig. 4. XRD diffractograms for the mixes with varying replacement level

From the X-ray diffractograms, it was observed that the number and the intensity of calcium silicate hydrate and calcite increase with the increase in the quantity of SCBA as a result of the increased amount of SiO_2 content in SCBA. This may lead to the increase in the compressive strength of the mixes with the increasing volume of SCBA, whereas the formation of calcite and larnite were found to be high at 10 % replacement level of GGBFS with SCBA. This has led to the maximum increased compressive strength at 10 % replacement level. The reduction in the strength of the mixes with the increasing level of SCBA above 10 % is mainly due to the increased formation of calcite, which may leads to the formation of monocarbonates resulting in the dilution of the other hydrates by increasing the porosity of the hydrated pastes. Even with the increase in the SCBA volume, there was only a marginal reduction in the compressive strength values, which may attributed to the filler effect of Calcite at higher replacement level [22]. But, the increase in the intensity of calcite may leads to the reduction in the pH value resulting in the formation of carbonation. Whereas, the pH was maintained due to the comparable formation of Portlandite with the increasing SCBA volume and becomes more crystalline with the increase in the time of hydration which has led to the marginal increase in the pH value.

3.6. pH measurement

Fig. 5 shows the variation in the pH value of the mixes at 28 days of curing for different replacement level of GGBFS with SCBA. It has been observed that the pH values were found to be in the range of 12.38 to 12.88 and found to increase marginally with the increase in the SCBA quantity because of the reduced formation of calcite at higher replacement level which may tend to increase the pH value. In addition to this, due to the increased formation of Portlandite [23] may tend to increase the pH value. Even with no such appreciable variation, the pH values of the mixes were found to be within the acceptable limit which may not induce corrosion to initiate with the increasing SCBA content which enables the formation of passive layer on the top of steel bars [24] thereby reducing the effect of corrosion.

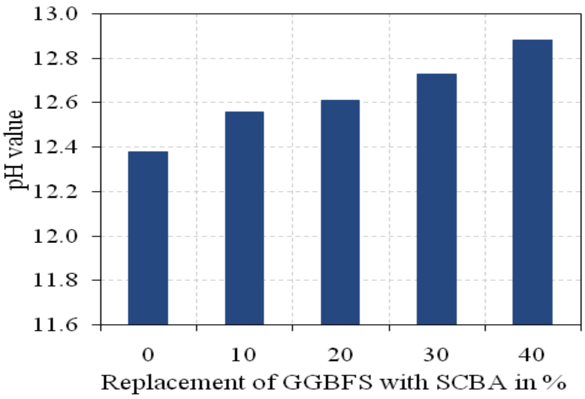

Fig. 5. pH measurement of the tested mixes

4. CONCLUSIONS

Based on the investigation carried out for replacing the GGBFS with SCBA in the production of geopolymer mortar at the rate of 0, 10, 20, 30 and 40 % for varying age of curing, the subsequent conclusions can be made:

1. The water requirement for consistency of the control mix increases with the increase in the SCBA content which leads to the increased setting time at higher replacement level.
2. Reduction in the rate of expansion of the mortar bars was examined when GGBFS is replaced with SCBA. A distress in the alkali silica reaction was controlled at higher replacement levels.
3. The compressive strength was found to increase up to 22 % compared to the control mix at 10 % replacement; still up to 20 % replacement gives higher compressive strength than control mix.
4. The pH value was found to increase with the increase in the SCBA volume due to the increased amount of Portlandite. The results were found to be within the permissible limit.
5. For up to 40 % replacing GGBFS by SCBA in the production of geopolymer mixes shows advantageous results and can produce an environmentally effective cementitious mixes.

The work can further be extended to evaluate the application of SCBA in geopolymer concrete strength and durability properties.

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