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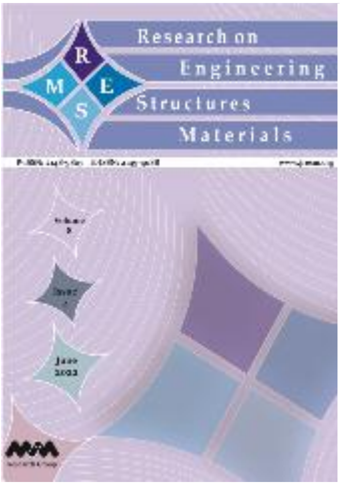

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Research Article

Effect of SCBA and GGBFS on the performance of binary and ternary blended concrete

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Abstract

The present studies focus on the characteristics of binary and ternary concrete in plastic and hardened stage for a mix of grade M25. Two mineral admixtures were used, sugarcane bagasse ash (SCBA) and ground granulated blast furnace slag (GGBFS). In preparing binary and ternary blended concrete, these admixtures partially substituted cement. Cement was replaced with SCBA and GGBFS, with the substitution percentage being 15%, 20%, 25%, and 30% by mass. Fresh properties were evaluated in terms of slump cone and setting time. Moreover, the mechanical characteristics were assessed concerning the strength of concrete in compression, split, and flexure. The microstructural properties were investigated in terms of scanning electron microscope (SEM) images. The experimental result indicated that the inclusion of SCBA and GGBFS improves workability and strength in compression while strength in the split and flexural hampered in binary as well as ternary concrete.

1. Introduction

Ordinary Portland cement (OPC) is the world's leading cement. According to statistics from the U.S. government, approximately 4.1 billion tonnes of OPC were generated globally in 2015 alone. Since the creation of concrete, OPC has been integrated as the primary binder material [1]. OPC's financial and environmental issues have motivated scientists to find other product to replace OPC. Supplementary cement products are helpful for concrete properties and play a role in some extra production of calcium silicate hydrate (C-S-H) gel. The concept of partly substituting OPC with supplementary products may be backed by the reality that's there a considerable quantity of unwanted material generated by different sectors with appropriate characteristics for use in concrete. These waste materials generally require a lot of effort and energy for disposal. Among the most widely used industrial waste in concrete are fly ash and GGBFS. Along with industrial waste, certain farming waste has revealed excellent performance when utilized in concrete, such as rice husk ash (farming waste of the rice milling sector) [2].

Sugarcane crops are cultivated all over the world to produce sugar, ethanol, and much more. The bagasse, waste material after drying in the sugar sector, is generally used as fuel for boilers. Sugarcane bagasse ash is commonly found in boilers under non-controlled burning situations. When the bagasse is heated under controlled circumstances, it can generate ash with more excellent amorphous silica[3]. GGBFS is a waste generated in iron-making blast furnaces. Iron-ore, coke, and limestone melt in blast

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furnaces, producing molten iron and slag. Mostly silicates and alumina are included in the molten slag. The slag granulation method includes refrigerating molten slag with water jets with high pressure. This quickly quenches the formation of slag as well as granular particles. The granulated slag is further dried and ground to an extremely fine particle in a revolving ball mill called "GGBFS." The variables determining a slag's cementitious characteristics are the slag's chemical composition and the fineness of the slag[4].

The employment of supplementary cementitious material considerably improves the concrete microstructure. Reactive silica in these materials reacts with calcium hydroxide when using pozzolanic materials and produces extra C-S-H gel. Due to pore enhancement and extra C-S-H formation, concrete permeability is significantly reduced. Grinding of the burnt sample of SCBA at 700°C presented maximum pozzolanic activity. SCBA in concrete significantly enhance durability [5]. It has been shown to have greater strength in compression at 20% substitution of cement with SCBA[6]. Besides the increase in strength, there are cost savings of 35.62%, as noted by Tayyab Akram et al. [7]. Workability is seen to be increased up to 25% cement replacement, as noted by R. Srinivasan et al. also, strength in compression, split and flexural increases up to 10% replacement [8]. There will significantly enhance workability, compressive strength, and tensile strength by using GGBFS and rice husk ash [9]. Moulshree Dubey et al. found the addition of GGBFS and metakaolin in binary concrete enhances the concrete performance [10]. G. C. Cordeiro et al. found significant pozzolanic activity corresponding to be mechanical as well as a chemical method of evolution [11]. Noorul Amin et al. showed activation of bagasse ash in which mechanical activation was done using grinding and chemical by different alkalis. Strength increases with fineness and decreases by chemical activation [12]. Chemical test outcomes indicate SCBA has pozzolanic characteristics when burned at 700°C and sieved through a 45-micron sieve [13]. Setting time is slightly affected by use of SCBA at 50% and strength in compression is up to 90% of reference concrete for 50% replacement. There is an increase in durability properties especially chloride ion penetration [14]. Strength in compression is higher for 10% substitution of cement by SCBA while flexural strength is lower when revealed to temperature from 300˚C to 500˚C for two hours [15]. The influence of residual rice husk ash and SCBA in binary and ternary blended concrete permitted attainment of high intensity of cement substitution and retained steady or improved strength in compression [16]. Ashhad Imam et al. developed several synergic equations using micro silica, marble dust, and rice husk ash. These equations could explain the early and long-term strength [17]. Mateusz Radlinski and Jan Olek used fly ash and silica fume in ternary concrete. They found improved compressive strength and resistance to chloride ion penetration with a reduced water adsorption rate [18]. G.C. Isaia et al. found increased pozzolanic and physical effects when fly ash, rice husk ash, and limestone filler are increased in concrete. These effects are higher at 91 days compared to 28 days [19]. Shweta Goyal et al. used silica fume and fly ash with different water-cement ratios, along with water cured to continuously air-cooled regime, and found the economic combination of silica fume and fly ash [20]. There will be an increase in compressive and flexure strength when silica fume and fly ash are used in concrete at a different water-cement ratio, as noted by Muhannad Ismeik. At a later age, fly ash incorporation showed better results [21]. OPC was substituted by ground fly ash and ground bagasse ash. Compressive strength at 20% replacement by both ashes is similar to reference concrete; water permeability is reduced, and resistance to chloride penetration is improved [22]. Microstructural studies revealed that fly ash and bagasse ash fiber equally dispersed throughout the matrix. Both strengths in compression and flexure decrease. Bagasse fiber exhibits better tensile strength and decreased density [23]. Calcium carbide residue and bagasse ash mixture in concrete reduce cement consumption up to 70% with similar mechanical properties [24]. SCBA produces more viscous and plastic binary paste when used in the binary and ternary systems, along with cement and fly ash [25]. There is a decrease in strength for compression, flexure, and split at three days of curing but at 7, 28, and 90 days it increases when GGBFS partially replaces cement. Abrasion resistance also increases with curing age [26]. The flowability of ultra-high-performance concrete increases steadily with GGBFS and fly ash content. Under standard curing, there is limited influence on compressive strength by incorporating fly ash [27]. Workability decreases for 10% micro silica and 30% GGBFS, while compressive strength is maximum for 5% microsilica and 30% GGBFS when used as a cementitious material in concrete [28]. The incorporation of fly ash and GGBFS decrease permeability and improve sulfate attack resistance under any curing condition [29]. It was found that compressive strength is maximum when manufactured sand is used in concrete containing GGBFS. Abrasion resistance was influenced by strength irrespective of GGBFS and manufactured sand content [30]. The consistency of cement decreases with increases in GGBFS amount while workability and setting time increases. GGBFS speeds up the hydration of OPC at the initial time of hydration. Sulfate resistance is superior as compared with normal concrete [4]. Compressive strength is seen to be maximum for 90 days of curing for cement replacement by slag [31]. Zheng et al. used a fly ash and silica fume combination and found a significantly higher strength retention ratio [32]. The mixture of calcium carbide residue and fly ash was used by Kittiphong Amnadnua et al., who found improved compressive strength with lower water permeability [33]. Liwa Mo et al. used ground granulated blast furnace slag, fly ash, and magnesia and found the same or higher mechanical strength at 28 days and 90 days [34]. The chloride permeability was low to moderate when quarry dust powder, silica fume, and fly ash were used in concrete by H.A.F Dehwah et al. [35].

2. Research Significance

The construction industry is currently concentrating on replacing cement with locally available environmental friendly products. The main emphasis is on reducing the quantity of consumption of cement content in the production of concrete, which in turn decreases the release of greenhouse gases into the atmosphere. The utilization of these products also assists in preventing the difficulties of disposal and landfill that cause significant environmental problems. The use of these products in a lucrative manner as an alternative to cement is essential for preserving sustainability. Many investigators concentrated on alternative cemented materials and concluded that the usage of these materials revealed improved strength along with durability properties. A comprehensive analysis of the literature suggested that fly ash is a significant material used to replace cement in mixed concrete partially. Only a few emphasized using SCBA as one of the complementary cement components in producing cement concrete mixture together with GGBFS. The application of these products is a significant benefit in environmental and economic terms. It also answers the problems of landfill and global warming and their applicability in the construction sector. It is planned to consider the above aspects to address the following issues. Whether the use of SCBA, a sugar industry by-product, along with GGBFS, may or may not be used in the preparation of blended concrete mix? How does this substitute affect the strength and microstructural properties?

3. Objectives and Methodology

The goal of the current research is to find out blended cementitious concrete via two materials. The materials are SCBA and GGBFS. The mechanical and microstructural characteristics are evaluated concerning the reference mix. To accomplish the research goals, a comprehensive experimental program was scheduled. The research aims to identify the optimal amounts of SCBA and GGBGS that can be substituted in cement. The concrete blend of target strength in compression of 25MPa was designed with no mineral admixtures. Initially, sugarcane bagasse ash was optimized from 0 to 30% cement. Ternary blended cement concrete mix proportion was established utilizing SCBA and GGBFS as partial substitution of cement from 0 and 30%. This optimization method substantially improves the volume of cement use and can decrease at least some quantity of carbon dioxide released due to cement production. The mechanical and microstructural properties were assessed and correlated with the reference mix. An assessment of binary and ternary blended composite with reference mix was conducted by evaluating mechanical performance by preparing cubes, cylinders, and standard-size beams.

4. Materials and Mix Proportion

The materials utilized in this investigation are cement, aggregate, SCBA, GGBFS, and water. OPC affirming IS12269-1987 [36] was used in the investigation. The grade was 55, and specific gravity was 3.15 having a setting time of 200 min as initial and 312 min as final. The fine aggregate affirming Zone-II of IS: 383-1970 [37] was utilized. The fine aggregate so employed was obtained from the local river source. Well-graded crushed granite having size confirming to IS: 383-1970 [37] was used, which was obtained from the local crushing unit. The physical properties of fine and coarse aggregate are shown in Table. 1. For this investigation, SCBA was collected from Prasad Sugar and allied Agro-Products limited, Maharashtra (India). SCBA is burnt at 700˚C for two hours in a muffle furnace, and then ground to make it fine. The chemical properties of SCBA are presented in Table 2.

Table 1. Physical properties of aggregate

Property	Fine Aggregate	Coarse Aggregate	Coarse Aggregate
Particle Shape, Size	Round,< 4.75 mm	Crushed angular, 20 mm	Crushed angular, 10 mm
Fineness modulus	6.63	6.79	6.57
Silt content (%)	1.0	Nil	Nil
Specific Gravity	2.81	2.82	2.79
Surface moisture	Nil	Nil	Nil
Water absorption (%)	1	1.33	1.45

GGBFS was collected from Guru Corporation Ahmedabad, Gujarat (India). The chemical properties of GGBFS are presented in Table 2. Portable water affirming to IS 456-2000 [38], was utilized for mixing and curing. Concrete mix design is done concerning the Indian standard code [39] for M25 grade. A water-cement ratio of 0.5 was used. Mix proportions for binary and ternary blended concrete are presented in Table 3.

Table 2. Chemical properties of SCBA and GGBFS

Content	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
SCBA	85.23	12.62	0.60	2.34	1.04	0.001
GGBFS	34.12	18.95	0.23	35.46	8.2	0.45

Table 3. Concrete mix proportion for binary and ternary blended concrete

Mix Designation	Cement (kg/m^3)	SCBA %	GGBFS %	SCBA (kg/m^3)	GGBFS (kg/m^3)
P	394.32	0	0	0	0
B15	368.69	15	0	65.06	0
B20	347.00	20	0	86.75	0
B25	325.31	25	0	108.44	0
B30	303.62	30	0	130.13	0
G15	368.69	0	15	0	65.06
G20	347.00	0	20	0	86.75
G25	325.31	0	25	0	108.44
G30	303.62	0	30	0	130.13
B10G05	368.69	10	05	43.38	21.69
B10G10	347.00	10	10	43.38	43.37
B10G15	325.31	10	15	43.38	65.06
B10G20	303.62	10	20	43.38	86.75
B15G05	347.00	15	05	65.06	21.69
B15G10	325.31	15	10	65.06	43.38
B15G15	303.62	15	15	65.06	65.06
B20G05	325.31	20	05	86.75	21.69
B20G10	303.62	20	10	86.75	43.38
B25G05	303.62	25	05	108.45	21.69

5. Result and Discussion

5.1. Workability and Setting Time

The workability of concrete was obtained concerning IS 1199-1959 [40]. As shown in Fig. 1, the test result noticed that concrete without SCBA and GGBFS i.e. [P], had the lowest slump of 140 mm compared with binary concrete. At the same time, a lower slump of 145 mm and 140 mm was noticed in binary composite with substitution of cement at 15% and 30% by SCBA & GGBFS, respectively. In ternary composite, the lowest and highest slump value was noticed at B10G20 (cement replaced by 10% SCBA and 20% GGBFS) and B15G10 (cement replaced by 15% SCBA and 10% GGBFS), which are 100 mm and 160 mm, respectively. It was also noticed that the slump increases as SCBA content increases and decreases as GGBFS content increases. The initial and final setting times are found concerning IS 4031-1988 [41]. As shown in Fig. 2 Initial setting time (191 min) was noticed to be less against the 15% substitution of cement with SCBA, but the final setting time (380 min) will be more for concrete without any replacement. However, incorporating GGBFS resulted in a lower setting time at 30% and a higher one at 15%. Ternary blended concrete exhibited lower initial setting times at B15G10 and B25G05 while final setting times were higher at all replacement levels. The increase in setting time may be due to carbon content and crystalline particles. As SCBA was a burnt material, the carbon content was found to be reduced, producing amorphous silica content that may be active. This can be attributed to the slowing down of the initial hydration process due to excess water. Genesan et al. 2007 reported a rise in setting time with an increase in bagasse ash because of the dilution effect [42]. The water requirement of the SCBA blended mix was more than the control mix due to the presence of large fibrous particles [5].

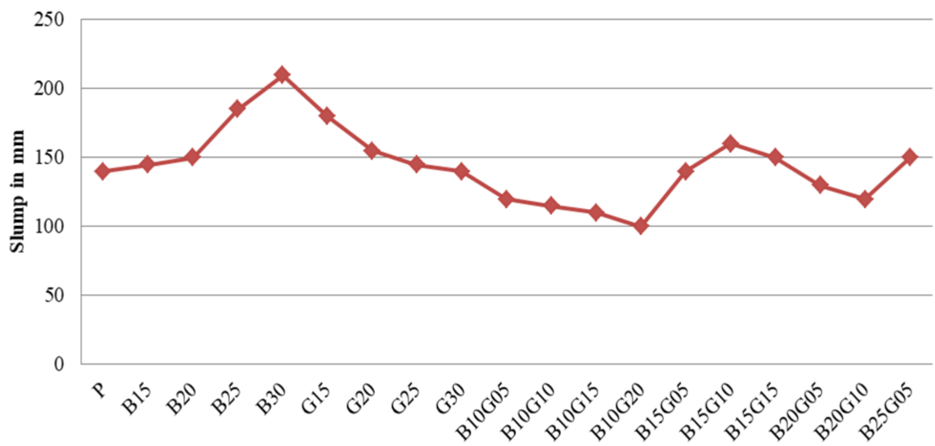

Fig. 1 Slump for various binary and ternary mixes of SCBA & GGBFS

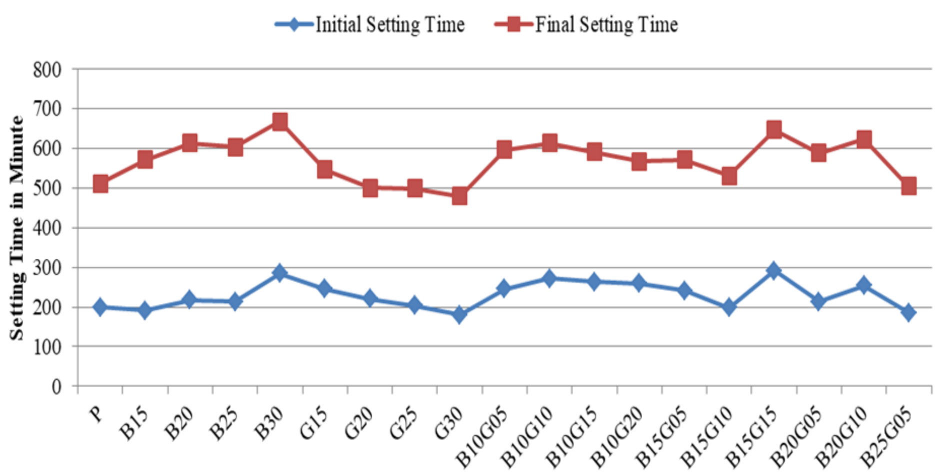

Fig. 2 Setting time for various binary and ternary mixes of SCBA & GGBFS

5.2. Compressive Strength

Concrete is well known for its strength in compression, as, in most places, it is used due to this property only. Concrete properties influence the structures' service life in harden stage. The strength of concrete in compression was measured at 7 and 28 days as per the procedure of IS 516-1959 [43]. The addition of SCBA increases the strength in compression at 15% substitution whereas addition of GGBFS increases the strength in compression at 15% and 20%. For all other substitutions, there is a reduction in strength in compression. Ternary blended concrete exhibit higher strength in compression at 20%

(B15G05) substitution. These results showed a substantial effect of SCBA and GGBFS on seven days of compressive strength which is lower for all replacement levels. Improvement in strength results with SCBA and GGBFS may have been caused by the filler effect and the pozzolanic reaction between $Ca(OH)_2$ from cement hydration and reactive SiO_2 from SCBA. The dilution effect may cause a decrease in strength in compression. Govindarajan and Jayalakshmi 2011 also observed an increase in strength at 5, 10, and 15% replacement.

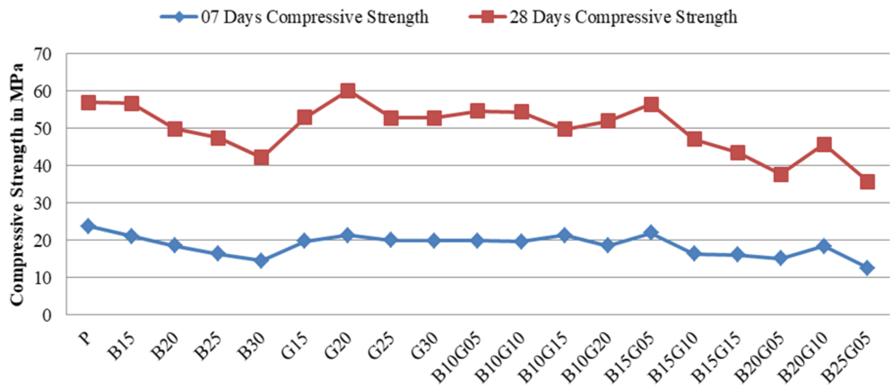

Fig. 3 Strength in compression of concrete for various binary and ternary mixes of SCBA & GGBFS

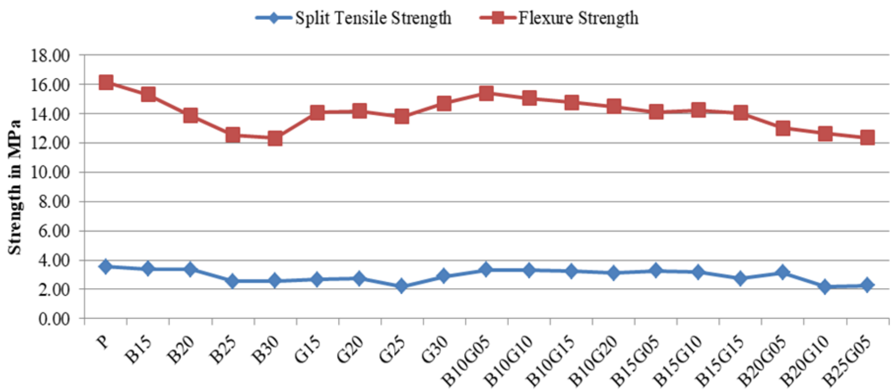

Fig. 4 Strength in flexural and split tensile of concrete for various binary and ternary mixes of SCBA & GGBFS

A sample of SCBA showed that when C-S-H increased (strength improved), peaks of $Ca(OH)_2$ diminished, indicating that a pozzolanic reaction occurred between $Ca(OH)_2$ & amorphous silica present in SCBA [44]. The reason for the improvement in the strength of SCBA may be attributed to silica content, fineness, and pozzolanic reaction between calcium hydroxide and reactive silica in SCBA. Similar behaviour was reported in previous work [45-46].

Flexural strength is measured following IS 516-1959 [43] on a 100 X 100 X 500 mm beam, and split tensile strength is carried out as per IS 5816-1999 [47] on 150 mm dia. X 300 mm height Cylinders. The result illustrated in Fig. 4 shows that adding SCBA and GGBFS causes a decrease in the average value of flexure and split tensile strength.

5.3. Microstructural Properties

To observe the microstructure of binary and ternary blended concrete specimens with SCBA and GGBFS, SEM and Energy Dispersive Spectroscopy (EDS) analysis were performed in the field emission scanning electron microscope laboratory of the College of Engineering Pune. Fig.5-13 shows the SEM/EDS micrographs. For the specimen with 20% and 30% of SCBA, unreacted bagasse ash particle was observed, leading to lesser compressive strength. Moreover, voids were also detected, representing permeable concrete. With the rise in the replacement amount, the unreacted particle of SCBA will rise and decrease the compressive strength. Binary concrete containing GGBFS have less voids than binary concrete containing SCBA, indicating a compacted and dense matrix. Crystalline particles were observed at high magnification as coated by a rough layer pertaining to the additional C-S-H product. The internal structure of reference concrete and concrete containing SCBA and GGBFS is dense at B20, G20, and B10G20 mixes, and C-S-H gel exists in the form of continuous block [48]; this results in higher compressive strength. Chemical compound analysis by EDS was investigated and shown in Fig. 5-13. The ratio of Si/Al was calculated from the EDS analysis. The ratio of Si/Al for ternary concrete with 10% SCBA and 10% GGBFS was observed to be higher, making it more rigid in terms of its microstructure. Similar behaviour in the cementitious medium is clearly defined by P. C. Hewlett (2004) [49]. The Ca/Si ratio represents the overall cementitious medium properties. Ca/Si ratio was found to be decreasing with an increase in replacement level for both binary and ternary blended concrete. Ca content decreased with an increase in SCBA and GGBFS in binary and ternary concrete. Fe content was found to be increased up to 20% SCBA replacement, and then it started decreasing. The pozzolanic nature of SCBA with C-H can be confirmed with an increase in the concentration of ferrous content with the inclusion of SCBA and GGBFS content [50].

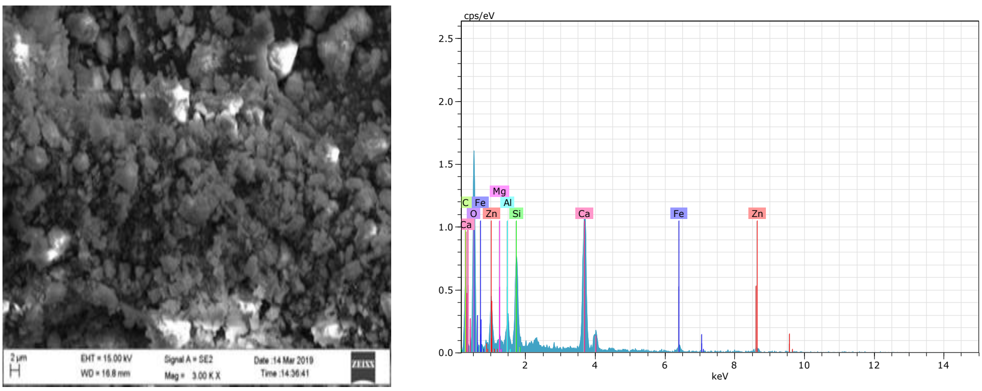

Fig. 5 SEM evaluation of concrete specimen using OPC

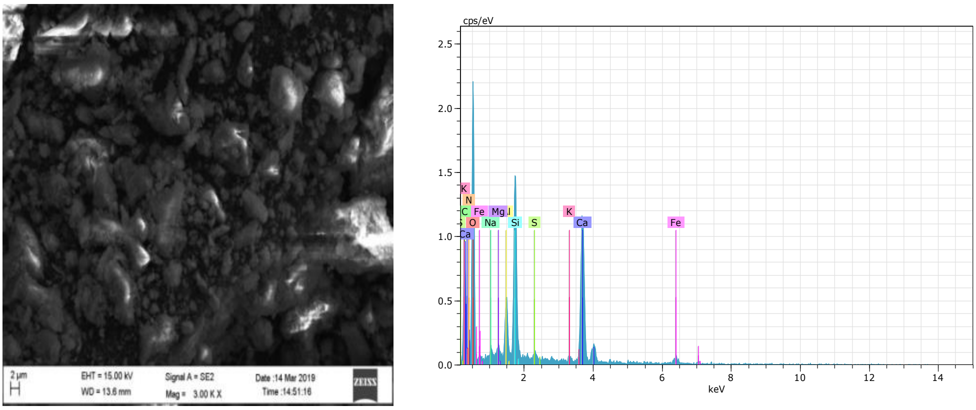

Fig. 6 SEM evaluation of concrete specimen using OPC by 20% SCBA

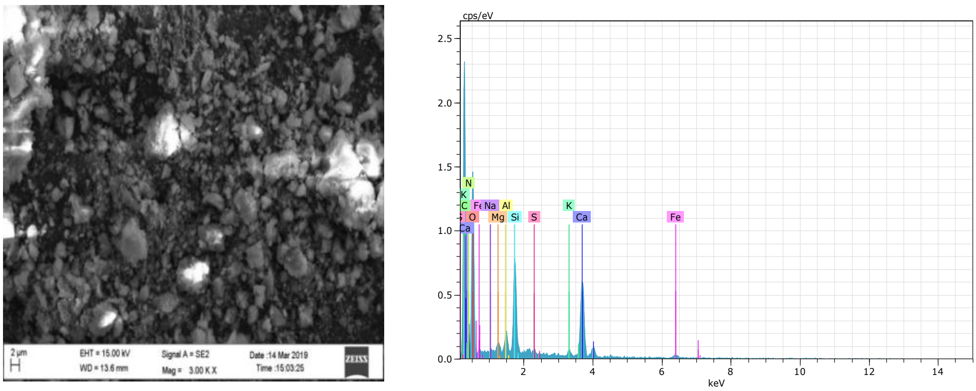

Fig. 7 SEM evaluation of concrete specimen using OPC by 30% SCBA

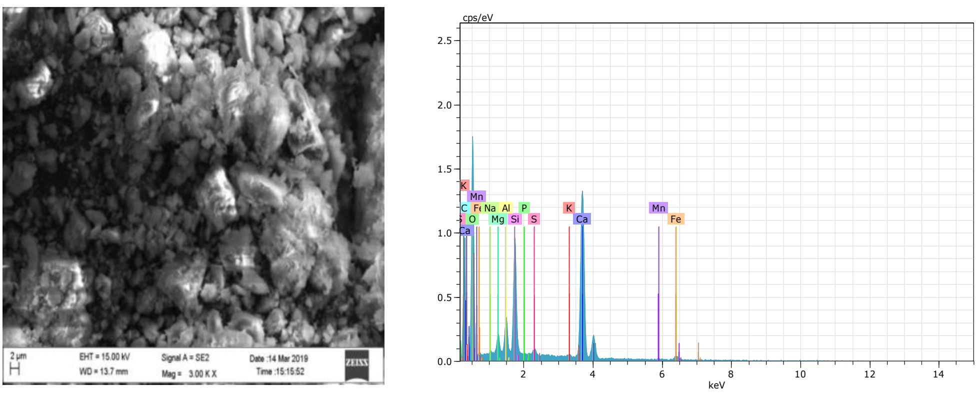

Fig. 8 SEM evaluation of concrete specimen using OPC by 20% GGBFS

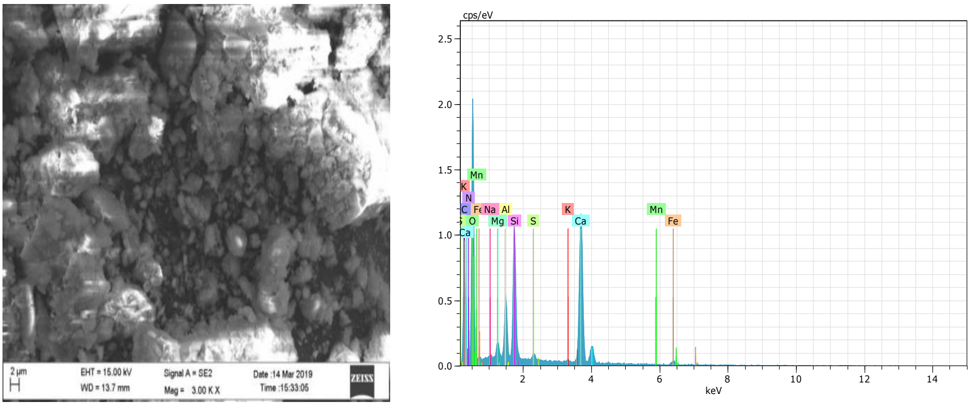

Fig. 9 SEM evaluation of concrete specimen using OPC by 30% GGBFS

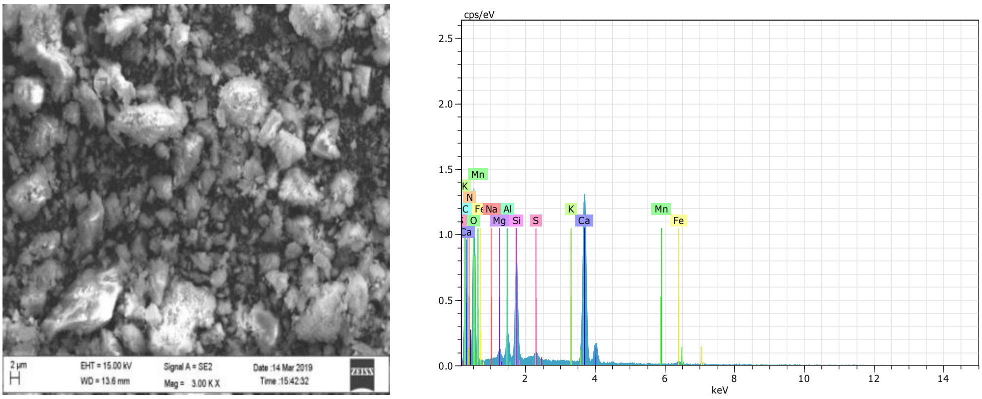

Fig. 10 SEM evaluation of concrete specimen using OPC by 10% SCBA & 10%GGBFS

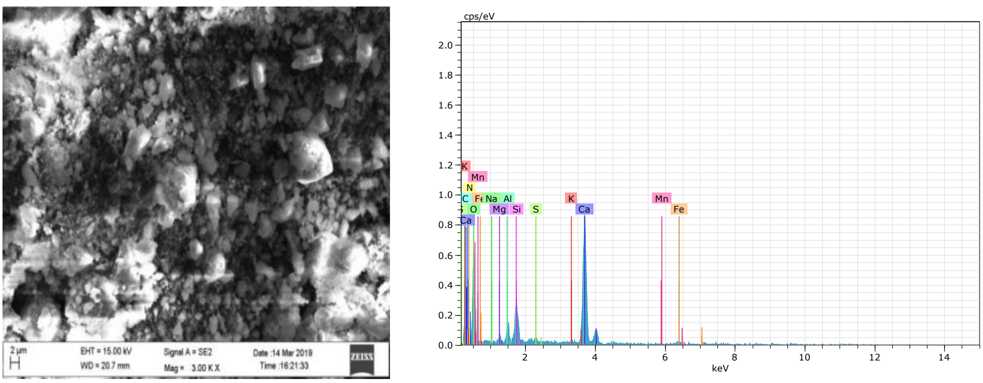

Fig. 11 SEM evaluation of concrete specimen using OPC by 10% SCBA & 20% GGBFS

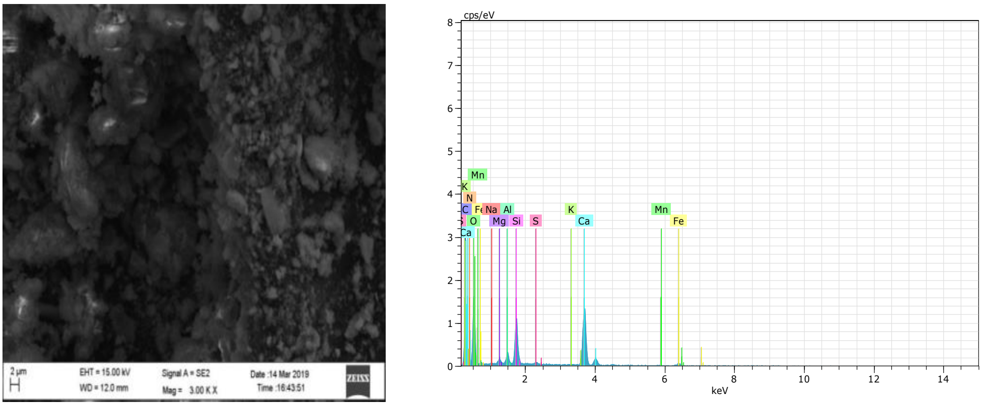

Fig. 12 SEM evaluation of concrete specimen using OPC by 15% SCBA & 15% GGBFS

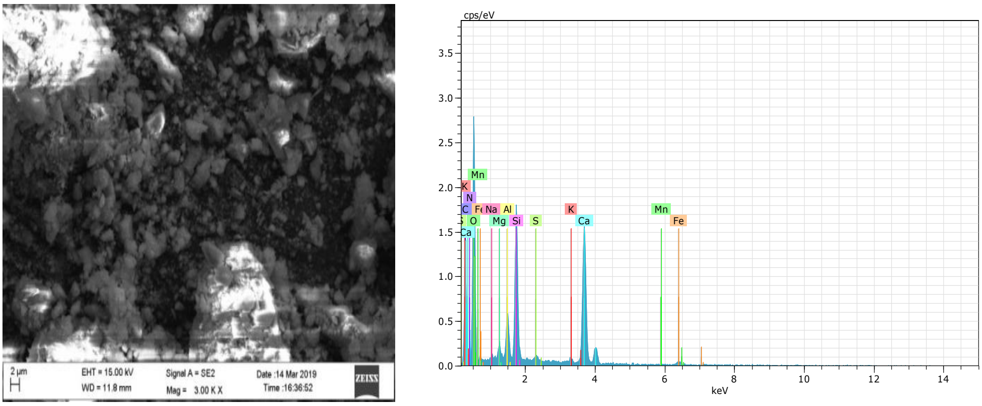

Fig. 13 SEM evaluation of concrete specimen using OPC by 20% SCBA & 10% GGBFS

Fe content in the present study was found more for the B20 mix than the B30 blend; also, for ternary concrete, it was found more for the B10G20 combination. This investigation supports explaining and relating the strength enhancement due to SCBA and GGBFS inclusion.

6. Conclusions

This research focussed on the effect of different pozzolanic materials on the properties of binary and ternary blended concrete in fresh and hardened stages. Pozzolanic materials are agriculture and industrial waste. Sugarcane bagasse ash was heated and ground before using it. The chemical properties of SCBA were determined, and for GGBFS, they were obtained from the supplier. Concrete mixes were cast using % variation up to 30% replacement in binary and ternary concrete. Experimental data were also analysed by using microstructural studies.

- The workability of binary concrete mixes follows an increasing trend with a rising percentage of SCBA and a decreasing trend with a rising percentage of GGBFS. A maximum slump was obtained for 30% replacement of cement. However, for the optimum replacement percentage, the slump obtained was 145 mm and 155 mm in binary concrete, whereas 140 mm in ternary concrete.

- The setting time of binary concrete mixes follows an increasing trend with a rising percentage of SCBA and a decreasing trend with a rising percentage of GGBFS. The value of both setting times is more for all binary and ternary mixes than concrete without any cement replacement.
- The optimum value for compressive strength was obtained at 15% SCBA and 20% GGBFS in binary concrete and 15%SCBA + 5%GGBFS in ternary concrete. At this replacement, the compressive strength value at 28 days was observed as 35.6MPa, 38.7MPa, and 34.5MPa. Similarly, for flexure and split tensile strength, the value obtained are 11.93MPa, 11.45MPa, 10.85MPa, 3.38MPa, 2.72MPa, and 3.26MPa, respectively.
- Microstructural studies indicate that extra calcium-silicate-hydrate gel, which is responsible for compressive strength development, was found in concrete containing SCBA and GGBFS, due to which compressive strength increases for 15% SCBA and 20%GGBFS use in concrete.

Considering the excess amount of sugarcane bagasse ash and ground granulated blast furnace slag, the amount of cement in concrete can be lowered. The partial substitution of cement by SCBA and GGBFS has an economic and environmental benefits. Concrete properties are improved using these materials; therefore, both are better in binary and ternary concrete. Studies on using these agricultural and industrial wastes open the path for creating sustainable construction materials. This research work can be extended using sodium hydroxide and sodium silicate solution while manufacturing concrete.

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