

Application of agriculture and an industrial by-product as a supplementary cementitious material in binary and ternary blended concrete

S. M. Palaskar^{1,2*}, G.R. Vesmawala³

¹Department of Civil Engineering, Assistant Professor, SCSMCoE, Ahmednagar 414 005, India

²Department of Civil Engineering, Research Scholar, SVNIT, Surat, 395 007, India

³Department of Civil Engineering, Associate Professor, SVNIT, Surat, 395 007, India

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Abstract

The production of ordinary Portland cement [OPC] causes an environmental imbalance of nature by consuming the natural resources and releasing a very high amount of atmospheric carbon dioxide. Therefore it is necessary to find the substitute to cement. Bagasse ash from sugar industries and slag from steel industries are the waste product which is utilized as the supplementary cementitious materials. In this study, sugarcane bagasse ash (SCBA) and ground granulated blast furnace slag (GGBFS) are used to replace cement partially. The fresh and hardened properties find out for the M25 grade of concrete. The experimental outcome reveals that binary concrete with 15% bagasse ash and ternary concrete with 20% bagasse ash and 5% slag had maximum strength.

Keywords: Bagasse ash, Slag, Fresh properties, Harden properties

1. Introduction

Sugarcane is a cash crop cultivated throughout the globe in many nations. The amount of sugarcane cultivation in separate countries are acquired to undergo a detailed assessment of bagasse ash. As per the Food and Agriculture Organization of the United Nations Statistics Division, the sugarcane produced in various countries is as shown in Table 1. Juice extraction by sugarcane crushing yields approximately 25 to 30% of moist bagasse. Sugarcane bagasse is used as fuel for steam generation in factories and cogeneration plants. Bagasse burning yields about 3% to 5% of ash, which is a waste material dumped on open lands that cause pollution[1].

Ground granulated blast furnace slag, which is a by-product of iron-making blast furnaces. The average production of one tone of steel outcomes in a by-product of 200 to 400 kg, including slags, dust, sludges, and other materials. The amount of steel production in distinct nations was acquired for the detailed assessment of blast furnace slag. According to the steel organization of the globe, steel generated in different countries is shown in Table 2[2].

This indicates a greater waste outcome after sugar and steel production. Production of a greater amount of waste highlights a scope to researchers for waste management.

Fly ash, ground granulated blast furnace slag, and silica fume are used as supplementary cementitious material (SCM), and ground granulated blast furnace slag was ranked as the most sustainable among these three SCM's[3].

Mohammed S. M. et al. noted that using both silica fume and metakaolin as a partial substitute of cement in binary concrete significantly enhances the strength and durability properties [4]. The mechanical performance and durability of the mortar mixture using aggregate, which is recycled from concrete, were studied. Mineral admixture comprising of silica fume, metakaolin, and class C fly ash is used in the binary and ternary system and noted that beyond 28 days, there would be gradual gain in strength while a reduction in initial shrinkage value[5].

Mohammed S. M. et al. noted that when limestone is used in the binary, ternary, and quaternary system, there is the less environmental impact and also improvement in durability performance[6]. Engineering properties of concrete containing oil palm shell, rice husk ash, and fly ash were studied and proved the possibility of the use of agriculture waste and industrial waste material in lightweight concrete[7].

S. S. Vivek and G. Dhinakaran used ground granulated blast furnace slag, silica fume metakaolin as a mineral admixture to replace cement partially to study fresh and hardened properties and found that optimum values as 50% for GGBFS, 10% for SF, and 20% for metakaolin[8]. Fly ash and limestone filler were used in binary concrete to study the porosity and microstructure. Durability properties are seriously affected, while the use of ternary mixes is highly beneficial[9].

*Corresponding author. Tel: +919922955937; E-mail address: satishpalaskar@gmail.com

Table-1. Main sugarcane producing countries as per FAOSTAT for the year 2014

Ranking	Country	Sugarcane Production (Tones)
1	Brazil	736108487
2	India	352142000
3	China	126153469
4	Thailand	103697005
5	Pakistan	62826458
6	Mexico	56672829
7	Colombia	36508450
8	Australia	30517650
9	USA	27600190
10	Philippines	25029880
11	Argentina	24502741
12	Cuba	18000000
	Others	410640563
	Total	2010399722

Table-2. Main steel-manufacturing countries as per World steel association for the year 2016

Ranking	Country	Steel Manufacturing (Tones)
1	China	80.84x10 ⁷
2	Japan	10.48 x10 ⁷
3	India	95.6 x10 ⁶
4	United States	78.5 x10 ⁶
5	Russia	70.8 x10 ⁶
6	South Korea	68.6 x10 ⁶
7	Germany	42.1 x10 ⁶
8	Turkey	33.2 x10 ⁶
9	Brazil	31.3 x10 ⁶
10	Ukraine	24.2 x10 ⁶
11	Italy	23.4 x10 ⁶
12	Taiwan	21.8 x10 ⁶
	Others	22.69 x10 ⁷
	Total	16.296 x10 ⁸

Ternary concrete containing untreated sugarcane bagasse ash, fly ash, and ordinary Portland cement was prepared to study the microstructure and mechanical properties. The result shows that at an early age, due to the high level of carbon in SCBA, influence compressive strength, but at a later age, it is beneficial due to pozzolanic reaction. Comparable results were obtained at 90 days of curing[10]. Victor A. F. B. et al. used untreated sugarcane bagasse ash and fly ash to study chloride-induced steel corrosion and found unaffected compressive strength and decreased the chloride ion diffusion[11].

Ali Reza Bagheri et al. incorporated silica fume and low reactivity blast furnace slag in ternary concrete to study strength and durability properties and found considerable improvement in durability while the slow gain in strength[12]. Brabha Hari Nagaratnam et al. produced self-compacting concrete containing fly ash and palm oil fuel ash to study the strength and microstructural properties. The result shows adequate strength while lower Ca(OH)₂ content and ettringite at 90 days[13].

2. Objective

So far, many researchers have been working on the use of fly ash, silica fume, ground granulated blast furnace slag, metakaolin, rice husk ash, and untreated sugarcane bagasse ash in binary and ternary concrete, but no research is performed on the use of treated sugarcane bagasse ash along with other cementitious material to produce ternary concrete blended with OPC, SCBA, and GGBFS. Study of setting time, workability, and strength characteristics are performed. The goal is to preserve natural resources by utilizing industrial and agriculture waste to produce green binders.

3. Material used

In the research at hand, ordinary Portland cement of 53 grade confirming to IS 12269-1987 was used. The specific gravity of cement was 3.15, with fineness at 6.8%. Sugarcane bagasse ash was obtained from a nearby area, Ahmednagar, Maharashtra, India. Obtained sugarcane bagasse ash was treated. The treatment given is, first the obtained ash is heated in a muffle furnace for 700°C. The heated ash is then cooled at room temperature. The ash so obtained is then grinded to make it fine. It is then sieved through a 90-micron sieve. Slag was obtained from Guru corporation Ahmedabad, Gujrat, India. The chemical properties of treated ash and slag are shown in Table 3. Locally available fine aggregate, which is confirming to Zone II as per IS 383-1970 with specific gravity as 2.62 are utilized. The coarse aggregate used is well-graded crushed granite as per IS 383-1970 with specific gravity as 2.90 are being used. The water confirming to IS 456-2000 was used for mixing and curing.

4. Mix design

For the M25 grade of concrete, a mix design is done concerning IS10262-2009. The replacement percentage is, as shown in Table 4.

Table-3. Chemical Properties of SCBA and GGBFS

Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃
SCBA	82.53	12.62	0.60	2.34	1.04	0.001
GGBFS	34.12	18.95	0.23	35.46	8.2	0.45

Table-4. Replacement percentage of SCBA and GGBFS

Mix ID	Cement (%)	SCBA (%)	GGBFS (%)
P	100	0	0
B15	85	15	0
B20	80	20	0
B25	75	25	0
B30	70	30	0
B10G05	85	10	05
B10G10	80	10	10
B10G15	75	10	15
B10G20	70	10	20
B15G05	80	15	05
B15G10	75	15	10
B15G15	70	15	15
B20G05	75	20	05
B20G10	70	20	10
B25G05	70	25	05

5. Workability test

As per the IS 1199-1959 slump test, was performed to find workability. For this test, a standard slump cone along with a tamping rod has been used. It can be noted that the slump value was found to be decreasing as bagasse content will go on increasing in binary concrete. At 30%, the replacement slump value reduces by 17.24%. In the case of ternary concrete at a constant replacement percentage of bagasse ash, slump value was found to be decreasing with an increase in ground granulated blast furnace slag. The lowest slump value was found for the B10G20 mix, which was 34.48% lower as compared with the reference mix: table 5 and Figure 1.

6. Setting time

As per IS 4031-1988, a setting time test was conducted to discover the initial setting time and final setting time. For this test, the Vicat apparatus, as per IS 5513-1976, was used.

Table-5. Slump for various mixes of SCBA and GGBFS

Mix ID	Slump in mm	% Variation from control specimen P
P	145	0.00
B15	130	-10.34
B20	135	-6.90
B25	125	-13.79
B30	120	-17.24
B10G05	115	-20.69
B10G10	120	-17.24
B10G15	110	-24.14
B10G20	95	-34.48
B15G05	130	-10.34
B15G10	125	-13.79
B15G15	125	-13.79
B20G05	110	-24.14
B20G10	105	-27.59
B25G05	100	-31.03

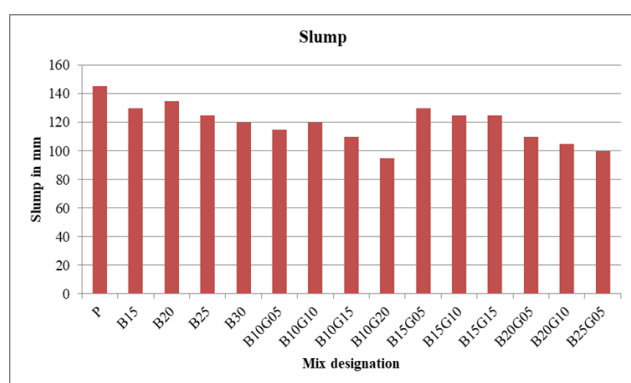


Fig. 1 Slump for various mixes of SCBA and GGBFS

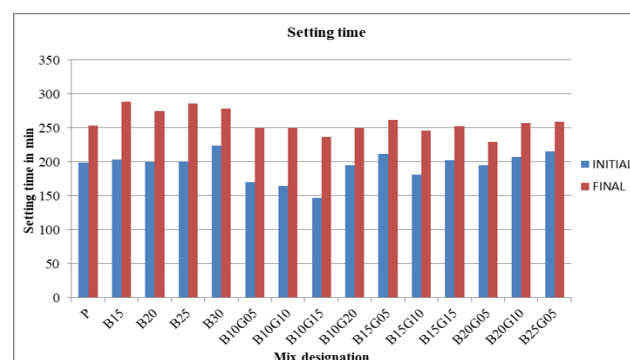


Fig. 2. Setting time for various mixes of SCBA and GGBFS

It can be noted that initial setting time rises with an increase in bagasse ash content. For the B30 mix, it was found to be 12.56% more as compared with the reference mix. The final setting time was found to be 9.84% more as compared with the reference mix. In the case of ternary concrete at a constant replacement percentage of bagasse ash, initial setting time decreases with an increase in ground granulated blast furnace slag. B10G20 mix exhibits the lowest initial setting time, which was 2.01% lower as compared with the reference mix. The final setting time also decreases with an increase in slag content, and it was 6.69% lower for the B10G15 mix: table 6 and Figure 2.

Table-6. Setting time for various mixes of SCBA and GGBFS

Mix ID	Setting Time in min		% Variation from control specimen P	
	Initial	Final	Initial	Final
P	199	254	0.00	0.00
B15	204	289	2.51	13.78
B20	200	275	0.50	8.27
B25	201	286	1.01	12.60
B30	224	279	12.56	9.84
B10G05	170	250	-14.57	-1.57
B10G10	165	250	-17.09	-1.57
B10G15	147	237	-26.13	-6.69
B10G20	195	250	-2.01	-1.57
B15G05	212	262	6.53	3.15
B15G10	181	246	-9.05	-3.15
B15G15	203	253	2.01	-0.39
B20G05	195	230	-2.01	-9.45
B20G10	207	257	4.02	1.18
B25G05	216	259	8.54	1.97

7. Compressive strength

Compressive strength was executed on a concrete cube having a size (150×150×150) mm.

Table-7. Compressive strength for various mixes of SCBA and GGBFS

Mix ID	Compressive Strength in MPa		% Variation from control specimen P	
	07 Days	28 Days	07 Days	28 Days
P	22.16	33.18	0.00	0.00
B15	20.38	34.00	-8.03	2.47
B20	16.96	29.09	-23.47	-12.33
B25	17.56	27.8	-20.76	-16.21
B30	15.96	25.6	-27.98	-22.85
B10G05	20.53	30.78	-7.36	-7.23
B10G10	22.09	35.04	-0.32	5.61
B10G15	21.36	34.98	-3.61	5.42
B10G20	19.56	31.68	-11.73	-4.52
B15G05	23.22	33.69	4.78	1.54
B15G10	19.78	32.38	-10.74	-2.41
B15G15	17.22	31.07	-22.29	-6.36
B20G05	20.8	34.36	-6.14	3.56
B20G10	20.27	30.67	-8.53	-7.56
B25G05	18.93	28.31	-14.58	-14.68

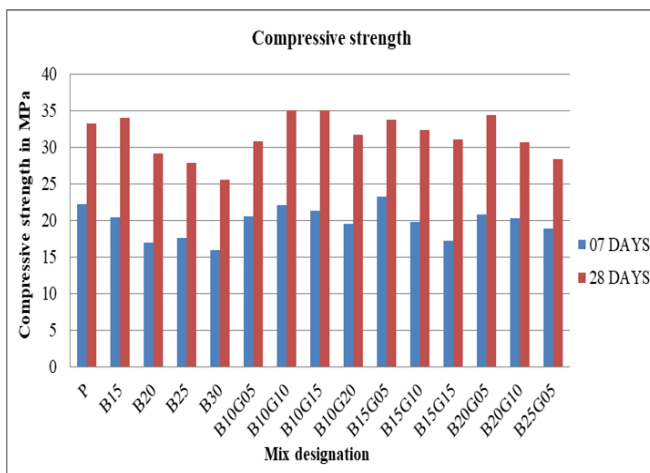


Fig. 3. Compressive strength for various mixes of SCBA and GGBFS

As per IS 516-1959 compression testing machine was used. The strength has been found for seven days and 28 days of water cured specimens. It can be noted that on the 7th day, the compressive strength of concrete with treated bagasse ash decreases. Up to 30% replacement shortfall in strength was found to be 27.98% concerning the reference mix. Compressive strength on the 28th day was more by 2.47% for the B15 blend; for other mixes, it goes on decreasing as replacement percentage goes on increasing. Up to 30% replacement decrease in strength was observed to be 22.85%, which was less as compared with seven days' strength. It indicates that the increase in strength rate is slow in bagasse ash concrete. Ternary concrete exhibits 3.56% more compressive strength for the B20G05 mix. For all other mixes, 28 days' strength was less but having comparable results. Table 7 and Figure 3

8. Flexure strength

To obtain the flexure strength of concrete, a beam having a size (100×100×500) mm was used.

Table-8. Flexure and split tensile strength for various mixes of SCBA and GGBFS

Mix ID	Flexure Strength in MPa	Split Tensile Strength in MPa	% Variation From Control Specimen P	
			Flexure Strength	Split Tensile Strength
P	12.6	3.55	0.00	0.00
B15	12.93	2.25	2.62	-36.62
B20	11.4	2.52	-9.52	-29.01
B25	10.73	2.66	-14.84	-25.07
B30	11.43	2.79	-9.29	-21.41
B10G05	11.3	3.14	-10.32	-11.55
B10G10	11.55	3.52	-8.33	-0.85
B10G15	11.95	2.83	-5.16	-20.28
B10G20	11.33	2.76	-10.08	-22.25
B15G05	11.55	3.18	-8.33	-10.42
B15G10	12.2	2.28	-3.17	-35.77
B15G15	11.2	2.97	-11.11	-16.34
B20G05	11.15	2.79	-11.51	-21.41
B20G10	11.35	2.68	-9.92	-24.51
B25G05	10.58	2.19	-16.03	-38.31

The beam specimen at 28 days of water curing is tested using a universal testing machine under two-point loading. At 28 days of curing beam produced under two-point exhibited a reduction in flexure strength except for the B15 mix, where an increase in flexure strength by 2.62% was observed. The maximum decrease in flexure strength was 14.84% for the B25 mix in binary concrete and 16.03% for the B25G05 mix in ternary concrete. Table 8.

9. Split strength

To obtain the split tensile strength of concrete, a cylinder whose diameter is 150 mm and height 300 mm was used. The cylindrical specimen at 28 days of water curing is tested using a compression testing machine. It can be noted that there is a reduction in split tensile strength at 28 days curing for all mixes of binary and ternary concrete. The minimum reduction in strength was 21.41% in binary concrete for the B30 blend, while 0.85% for B10G10 mix in ternary concrete. It was also noted that as the replacement percentage of bagasse ash in binary concrete increases, a shortfall in strength decreases. Table 8.

10. Conclusions

Based on the above research following conclusion may be made

1. Ternary concrete may be made by using a constant variation of bagasse ash and ground granulated blast furnace slag.
2. The workability of concrete containing SCBA and GGBFS reduces with an increase in bagasse ash content.
3. Initial setting time and final setting time prolonged when bagasse ash is used in binary concrete, but along with GGBFS in ternary concrete, both the times were reduced.

4. The compressive strength reduces at seven days with an increase in SCBA, which is due to reduced hydration of bagasse ash at an early age, but the higher strength at 28 days was obtained. Overall up to 15% substitution of cement by SCBA can be made in binary concrete. For ternary concrete, a 25% substitution of cement can be made.
5. The strength of the split tensile and flexural was reduced at 28 days.

Disclosures

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