Effect of Sugarcane Bagasse Ash as Partial Cement Replacement on the Compressive Strength of Concrete

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Abstract

The disposal of solid waste in open environment is a serious alarming concern that needs immediate attention from the researchers. The hazardous solid agro-industrial wastes which include: wheat straw ash, rice husk ash, corn cob ash and sugarcane bagasse ash (SCBA), having pozzolanic properties, have a versatile use in concrete. The solid pozzolana enhances the various concrete properties by the reaction of silicates with calcium hydroxide in the presence of water, which in result generate a saturated zone of calcium silicate hydrate (CSH) gel. This C-S-H gel reduces the amount of calcium hydroxide $C(OH)_2$ during the hydration process of cement. Very limited research works have been done on concrete by partially replacing cement with SCBA. This research work was focused on evaluating the properties of concrete by partially replacing cement with SCBA at 0, 5, 10, and 15 percentages. Compressive strength, Strength activity index, and water absorption of all mixes were examined. And it was observed that all SCBA mixes showed an increase in compressive strength and at 10% replacement the strength activity index was at a peak of 115.67%, but all the SCBA mixes showed a strength activity index greater than 75% which satisfied the standard specification. The water absorption test for all SCBA mixes showed a slight increase in water absorption.

Keywords—Pozzolanic material, Sugarcane bagasse ash, compressive strength, cement replacement, Strength activity index

1 Introduction

IN the production of concrete, various materials and re-sources are utilized. The process in cement production, pyro-processing (heating raw materials above 1000°C to bring physical and chemical changes to the parent material), emits various amounts of gases and utilizes a huge quantity of resources as fuel [1]. In the contemporary world, there are two requirements of an engineer during any construction project: protecting the environment, and fulfilling the infrastructural requirements of the occupants. To fulfil the occupant's requirements, many resources are being utilized by the construction industry, which result in creating environmental dangers and hazards [2]. Researchers of many developing countries have worked on these wastes including fly ash [3], sugarcane bagasse ash [4][5], rice husk ash [6][7], bamboo leave ash [8], wheat straw ash, groundnut shells [9], corn cob [10], and

produced metakaolin [11][12]. These materials enhance the behaviour of concrete and contribute to an eco-friendly environment [13][14].

With the addition of pozzolanic materials, different properties of concrete like flow-ability, strength, quality, durability and crack resistance can be improved [15]. Several advanced cement blends are produced by adding admixtures, which by pozzolanic reactions, ameliorate the micro-structure by minimising the concentration of calcium hydroxide [16]. The changes in the micro-structure of concrete composites improve mechanical behaviour and extend the service life. At the point when fine pozzolanic particles are scattered in the cement paste, they create an enormous number of nucleation places for the precipitation of hydration items and make the cement paste further homogeneous [17]. This is because of the reaction between silica (SiO_2) of pozzolana and calcium hydroxide (which is not favourable for cement hydration), delivered during the cement hydration reaction and produce additional calcium silicate hydrate CSH gel. In addition to the dense packing, this will reduce the wall effect between

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the paste and aggregate [18]. Janjaturaphan et. al. [4] studied the pozzolanic activity of SCBA and concluded that the improvement in the properties of concrete is due to filling ability and pozzolanic reactions of SiO_2 present in SCBA and $C(OH)_2$ in cement hydration. The filling ability is governed by the shape, size, and texture of SCBA particles and the pozzolanic reactions depend upon the percentage of SiO_2 in the parent SCBA particles. Cordiero et. al. [19] observed that the pozzolanic reactivity of SCBA depends on the burning temperature; the suitable temperature being up to 500°C producing amorphous SiO_2 which is highly reactive.

López et. al. [20] studied the effect of natural pozzolana on porosity and pore connectivity of concrete and found that the pozzolanic activity in the produced concrete had a great impact on durability of concrete. With a replacement of 33% of cement with natural pozzolana, the permeability of concrete reduced up to 200% and greatly reduced the water absorption and as well as chloride ion penetration at 84 days curing. Lathamaheswari et. al. [14] deduced that by replacing cement with SCBA, workability of the concrete mix is reduced due to the water absorption of SCBA particles, and the compressive and tensile strength increased due to extra C-S-H gel, which were maximum at 10% replacement with 35.23 N/mm² and 3.59 N/mm² respectively at 28 days curing and a w/b ratio of 0.5. But modulus of rupture increased on all replacement levels up to 12.5%. Mohd et. al. [21] utilized SCBA and sawdust ash in concrete and examined fresh and hard-ened properties. Cement was partially replaced with SCBA and SDA in varying percentages of 0, 5, and 10. The proportion of SCBA and SDA were kept the same (1:1) in all percentages. Fresh properties of concrete were checked by performing slump cone and compaction factor tests, and it was noted that with the increase of SCBA and SDA amount in the mix, there was a great decrease in workability due to the water absorption by SCMs. Compressive strength of SCBA and SDA made concrete at 7 days of curing indicated a reduction in strength. At 28 days of curing compressive strength of blended concrete enhanced by 5.79% at a replacement level of 5%. Furthermore, Minnu et. al. [22] reviewed the effectiveness of SCBA as a pozzolanic material in comparison with fly ash and ground granulated blast furnace slag in terms of various properties of concrete. SCBA being lighter in weight reduced the density of concrete as compared to FA and GGBFS. The fineness of all SCMs had a great impact on the rate of reaction with $C(OH)_2$. The incorporation of SCBA retarded the setting of concrete mixes by more than 40% as compared to FA and

GGBFS. The optimum percentages of SCBA, FA, and GGBFS in terms of strength were reported as 20, 30, and 40. In addition to strength, all the SCMs increased durability due to the reduction of permeability and alkali-silica reaction.

In tropical countries, sugarcane is the main source used for the production of sugar in sugar mills. Bagasse is left behind as trash after the extraction of juices in the sugarcane, which is used for fuel purposes in the containers to generate energy by the co-generation process, and sugarcane bagasse ash is produced which is a solid waste and nuisance to the environment [15]. Sugar industries play a major role in the economy of Pakistan. According to a report published by the Pakistan sugar mills association in 2015-2016, countrywide sugarcane production was 65.4 million tonnes and was continuously growing on yearly bases [23]. Very limited research work has been done on the sugarcane bagasse ash (SCBA) of matiari region as pozzolana in cement.

The study presented in this paper aims to check the effectiveness of SCBA as supplementary cementitious material on conventional concrete with 0%, 5%, 10%, and 15% replacement of cement.

2 Materials & Methodology

To check the influence of sugarcane bagasse ash on the compressive strength and water absorption in conventional concrete, sugarcane bagasse ash (SCBA) was collected from matiari sugar mill in Sindh Pakistan, and the chemical composition of SCBA was checked according to the ASTM standard [24]. The collected SCBA, shown in Figure 2, is sieved from a $45\mu\text{m}$ (325 No.) sieve. OPC of DG cement factory conforming to ASTM Standard C150 [25] is used. Locally available Bholari sand was used which has a specific gravity of 2.69. Coarse aggregates were collected from Nooriabad crush factory having a specific gravity of 2.605. The aggregates were made to pass from a 20 mm sieve and retained on 4.75mm. The passed aggregates were then washed properly to remove the dusty particles. Physical and chemical properties of the materials used are shown in Table 1-2. Four cement blends were prepared by partially replacing OPC at 0, 5, 10, and 15 percentages with SCBA. Total 24 cylinders of standard size of $100\text{mm} \times 200\text{mm}$ for compressive strength and 12 cubes of standard size $100\text{mm} \times 100\text{mm}$ for water absorption were casted. For each mix, 6 cylinders and 3 cubes were casted with 3 cylinders for 7 days strength and 3 cylinders for 28 days strength. Water absorption tests were performed on the cubes after 28 days of curing. All the mix proportions were mixed by using a mechanical mixer machine, (Figure 1) and the mix

Fig. 1: Mixer machine

Fig. 2: Sugarcane bagasse ash after sieving from No. 325

ratio was kept at 1:1.5:3 at a water/binder ratio of 0.52. The specific mix proportion is selected from the nominal mix of M20. Different mix proportions obtained by partially replacing cement with different percentages of SCBA are shown in Table 3.

3 Results & Discussion

The following sections describe the results of this study.

3.1 Compressive Strength

The compressive strengths of all mixes were determined by cylindrical specimens of $100\text{mm} \times 200\text{mm}$ according to ASTM C39 [32]. The average compressive strength was determined by testing three samples of each concrete mix using the Universal Testing Machine (UTM) shown in photograph 3. Values of average compressive strengths of each mix are given in Table 4 and Fig. 3, 4, and 5.

Compressive strengths of all concrete mixes are shown in the above figures. The results in Figure 3-4 show that there is no such development in the early age

Fig. 3: Compressive strength of CM and SCBA concrete

strength of blended cement concrete, and the strength of the concrete mix without SCBA (19.05 N/mm^2) was greater than the strengths SCBA made concrete at 7 days curing period. The strengths of SCBA made concrete were 17.93 N/mm^2 , 16.98 N/mm^2 , and 14.92 N/mm^2 at 5%, 10% and 15% replacement of cement with SCBA, respectively. But after 28 days of curing, the compressive strength of blended concrete showed much greater strength than the control mix. Compressive strength of all the mixes after 28 days were 30.17 N/mm^2 , 30.8 N/mm^2 , 34.9 N/mm^2 and 32.72 N/mm^2 at 0, 5, 10 and 15 percent replacement of cement with SCBA, respectively. Strength enhancement started at a replacement level of 5% and was optimum at 10% replacement of cement with SCBA, and showed a reduced value at 15%.

In the chart of strength activity index shown in Figure 5, it can be seen that all SCBA blended mixes showed greater values than 75% which satisfies ASTM C618 [24]. The peak value of SAI was 115.67% and reported at a 10% replacement level. The SAI of all mixes were 100%, 102.08%, 115.67% and 108.45% at 0%, 5%, 10% and 15% replacement of cement with SCBA, respectively.

$$\text{Strength activity index} = \frac{A}{B} \times 100 \quad (1)$$

Where A is the strength of concrete with blended cement, and B is the strength of concrete with OPC. The failure patterns were same for all the replacement levels, as shown in Figure 7-8. The patterns for 0, 5, 10 and 15% were same as type 2 in ASTM C39 [32]. Cracks started to generate from the top on the cylinders and travelled down forming a well-formed cone at the bottom side.

Chemical Constituents %	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LoI	$SiO_2 + Al_2O_3 + Fe_2O_3$
SCBA (class N)	67.3	5.34	4.27	1.9	1.23	0.29	4.26	0.95	10.48	76.91
OPC	23.6	4.71	2.32	62.7	2.05	2.15	0.46	0.49	1.5	-

TABLE 1: Chemical constituents of SCBA and OPC

Material	Property	Value	Relevant Standard
OPC	Specific Gravity	3.15	ASTM C188 [26]
	Fineness	4	ASTM C786 [27]
	Consistency	32	ASTM C187 [28]
	In. Setting time	45	ASTM C191 [29]
	Fi. Setting time	250	ASTM C191
Fine aggregate	Specific gravity	2.69	ASTM C128 [30]
	Water absorption	1.3	ASTM C128
Coarse Aggregate	Specific gravity	2.605	ASTM C127 [31]
	Water absorption	0.7	ASTM C127

TABLE 2: Properties of materials

Mix Proportion	Binder content in %		F. & C. Aggregate %	W/B Ratio	Amount of quantities in Kg				
	SCBA	OPC			SCBA	OPC	F. Aggregate	C. Aggregate	Water
CM	0	100	100	0.52	0	340	510	1020	176.8
S5%	5	95	100	0.52	17	323	510	1020	176.8
S10%	10	90	100	0.52	34	306	510	1020	176.8
S15%	15	85	100	0.52	51	289	510	1020	176.8

TABLE 3: Mix proportion required for 1 m^3 of concrete

No.	Mix	Average Compressive Strength (N/mm ²)	
		7 days	28 days
1	CM	19.05	30.17
2	S5%	17.93	30.8
3	S10%	16.98	34.9
4	S15%	14.92	32.72

TABLE 4: Compressive strengths of all cylindrical concrete mixes

Fig. 5: Strength activity strength of SCBA with CM

Fig. 4: 7 and 28 days compressive strength

Fig. 6: Compression test of Cylinders

Fig. 7: Type 2 well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end (Failure pattern in ASTM C39 [32])

Fig. 8: Failure patterns of cylinders

Fig. 9: Water absorption of concrete mixes after 28 days curing

Sr. No	Mix	Water absorption (%)
1	CM	3.01
2	S5%	3.20
3	S10%	3.31
4	S15%	3.35

TABLE 5: Water absorption of hardened concrete

3.2 Water Absorption

Water absorption tests were carried out according to BS 1881-122:1983 [33]. After 28 days of curing, weights of three cubical specimens for each mix were noted and placed in oven for 24 hours at a temperature of 105°C. After 24 hours, weights of specimens were again noted and the values of water absorption for different mixes were determined. The calculated water absorption was 3.01%, 3.2%, 3.31% and 3.35% at 0%, 5%, 10% and 15% replacement of cement with SCBA, respectively. Different values of water absorption in percentages are shown in Table 5. With increase in the amount of SCBA, water absorption of the concrete specimen also increased. Maximum value of water absorption was at 15% SCBA mix. As shown in Table 5 and Figure 9, water absorption of SCBA blended concrete gradually varied in increasing order at all replacement percentages of cement with SCBA. In comparison with the control mix, 5% replacement showed 6.31% increase in water absorption, 10% replacement showed 9.9% increase in water absorption, and 15% replacement showed 11.29% increase in water absorption respectively.

4 Conclusion

From the experimental results of cement partially replaced with SCBA in conventional concrete, the following points were concluded.

- SCBA blended concrete showed great improvement in compressive strength. Maximum compressive strength of 34.9N/mm² was achieved at 10% SCBA. All the SCBA made concrete mixes showed increase in compressive strength of concrete.
- However, all mix proportions showed a value of SAI greater than 75%. Maximum SAI value was calculated at 10% SCBA which is 115.67%. The maximum SAI of 108.45% was achieved at 15% replacement of cement with SCBA.
- The optimum percentage of SCBA is concluded to be at 10% replacement of cement with SCBA.
- SCBA blended concrete at all replacement percentages gave more water absorption than the control mix. The increase in the water absorption is due to the high water demand of SCBA.

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