Development of Self Compacting Concrete Using Sugarcane Bagasse Ash

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Abstract

Sugarcane Bagasse Ash (SCBA) is one kind of waste which can be termed as the residue left over from burning sugarcane bagasse. Chemical test of SCBA shows that bagasse ash contains significant amount of silica which can be used as pozzolanic materials in concrete.
Self Compacting Concrete (SCC) was developed in this paper using SCBA as a partial replacement of cement. Upto 20% cement was partially replaced by SCBA to check the effect on workability and compressive strength of SCC. The experimental results show that the SCC produced using SCBA fulfills the required qualities such as filling ability, passing ability and segregation resistance of fresh SCC and also no water bleeding was occurred. Compressive strength test result of 28 days shows that when cement was partially replaced with SCBA upto 5% in SCC, concrete gain compressive strength close to 90% of target strength and also 5% cement replaced with SCBA in SCC, concrete gain more than 66% of target strength at 7 days.

Keywords: *Sugarcane Bagasse Ash; Self Compacting Concrete; Workability; Compressive Strength.*

1 Introduction

In today's world utilization of the waste product is one of the major focuses. There are several types of industrial wastes which can be utilized in the concrete either as a replacement of cement or as an additive material. It has been identified that utilization of these wastes enhances some properties of the concrete (Ganesan et al., 2007). There are several sugar mills in Bangladesh which produce 0.8 million ton Sugarcane Bagasse Ash (SCBA) approximately per year. Sugarcane bagasse (SCB) is a byproduct from the sugar mills when juices are extracted from the canes. Then SCB is burned under controlled condition in high temperature which contains large amount of silica which has pozzolanic properties (Srinivasan and Sathiya, 2010).
Self Compacting Concrete (SCC) has become more popular in building industry in recent years, due to its superior performance over conventional concrete mix. SCC is an innovative concrete that does not requires vibration for placing and compaction. It is able to flow under its own weight, completely filling the formwork and achieving full compaction, even in the presence of congested reinforcement (Indu and Elangovan, 2016). The use of SCC in place of conventional concrete in big projects increasing day by day, because it superior performance in casting heavily reinforced sections, complex shapes of formwork and places where no access to vibrators for compaction (Gurjar, 2004).
In this paper depending on highest workability of concrete using SCBA on conventional concrete, SCC will be developed using SCBA as a partial replacement of cement and the effect of SCBA in SCC will also be analyzed. This paper describes a procedure specifically developed to achieve Self Compacting Concrete. In addition, the test results for acceptance characteristics for SCC are presented and compressive strength of SCC also determined by partially replaced cement with SCBA.

2 Methodologies

As per ASTM maximum percentage of total cementitious materials is 25% which can be replaced by fly ash, silica fume, slag and other natural pozzolans by weight. To know the maximum percentage at which cement can be replaced by SCBA in SCC, first cement was partially replaced by SCBA upto 25% in conventional concrete

with a mix proportion of 1:2:4. When cement replaced by SCBA in conventional concrete workability increased gradually and at 15% workability of the concrete reached highest level. SCC is also known as high workability concrete. So in this SCC cement can be replaced by SCBA at this highest workability percentage or more than this, here cement was replaced by SCBA in SCC upto 20%.
In this present study, determination of chemical composition of SCBA was done. Test related to workability requirements of SCC and mix design of SCC were discussed in this section.

2.1 Determination of Properties of SCBA

The chemical test for the determination of different constituents in the SCBA sample was performed using EDXRF (Energy Dispersive X-ray Fluorescence) spectrometer in Central Science Lab, University of Rajshahi.

Table 1. Chemical composition of Portland cement, Fly Ash and SCBA

Materials	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	Na_2O_3	TiO_2	K_2O	SO_3	LOI
Portland Cement Type II	22.4	3.3	2.9	52.2	2.3	0.1	0.4	0.3	1	13.5	1.5
Fly Ash C class	48-68	18-34	2-8	15-39	3-6	-	-	-	-	1-5	0.1-12
SCBA (Rajshahi)	86.93	2.52	2.53	-	-	7.54	-	0.23	-	-	0.25

The chemical composition of baggase ash was compared with type II Portland cement and class C fly ash. Data of Portland cement and fly ash were collected from Abbasi and Zargar's (2013) research work. It was observed that SCBA mainly content silica (SiO_2) which is larger in compare with Portland cement and fly ash. Cement and fly ash content a fair amount of calcium oxide (CaO), where SCBA was not content any calcium oxide.

2.2 Workability Requirements of SCC

SCC must possess following three characteristics to meet the workability requirements (Gurjar, 2004).

- **Filling Ability:** It is the ability of SCC to flow into and fill completely all spaces in the formwork and encapsulate reinforcement while maintaining homogeneity.
- **Passing Ability:** It is the ability of concrete mix to pass through obstacles like narrow sections in form work, closely spaced reinforcement bars without getting blocked by interlocking of aggregate particles.
- **Resistance to segregation:** Segregation resistance of SCC is its capability to retain homogeneity in the distribution of ingredient in fresh state during both static and moving condition.

A concrete mix is called SCC if it fulfills the requirement of filling ability, passing ability and resistance to segregation. Slump flow, T50cm Slump flow and V-funnel flow tests are done to check filling ability. Whereas L-box test is done for passing ability and V-funnel at T5 minutes is done for segregation resistance test. A discussion of Slump flow, V−funnel and L-box tests are given below -

2.2.1 Slump flow test and T50cm test

First base plate was placed on level ground and the slump cone centrally on the base plate. Then the cone was filled with concrete. After that the cone was vertically raised and allows the concrete to flow out freely. Simultaneously, the stopwatch was stared and the time taken for the concrete to reach the 500mm spread circle was recorded. The final diameter of the concrete in two perpendicular directions also measured. Average of the two measured diameters was calculated.

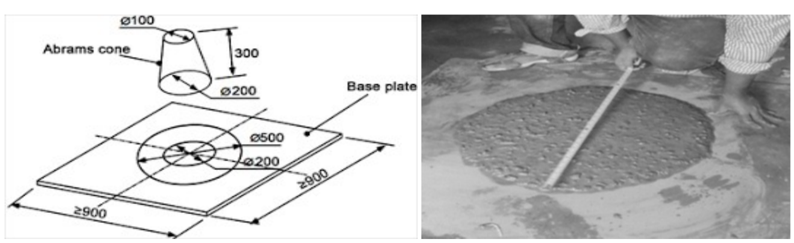

Figure 1. Slump flow test

2.2.2 V-funnel test and V-funnel test at T 5minutes

The V-funnel was completely filled with concrete without compacting. The door was open within 10 sec after filling and allows the concrete to flow out under gravity. Stopwatch was started when the trap door was opened and the time for the discharge to complete was recorded. The whole test was performed within 5 minutes.

The inside surface of the funnel was not clean again and the trap door was closed. Then the trap door was open 5 minutes after the second fill of the funnel and allows the concrete to flow out under gravity. Simultaneously, the stopwatch was start when the trap door was opened and the time for the discharge to complete was recorded.

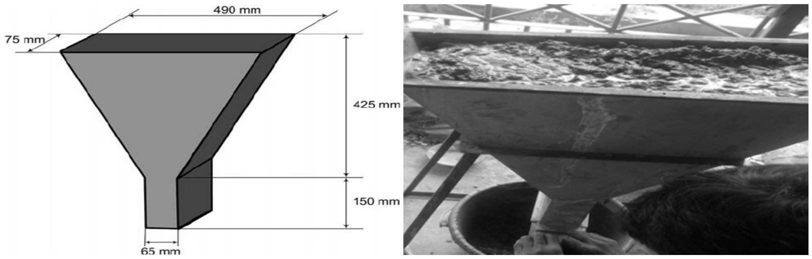

Figure 2. V-funnel test

2.2.3 L-box test method

The vertical section of the apparatus was filled with the concrete sample. Leave it to stand for 1 minute. The sliding gate was lifted to allow the concrete to flow out into the horizontal section. When the concrete stops flowing, the distances "H1" and "H2" were measured. H2/H1 was calculated. This was an indication of the degree to which the passage of concrete through bars was restricted. The test was performed within 5 minutes.

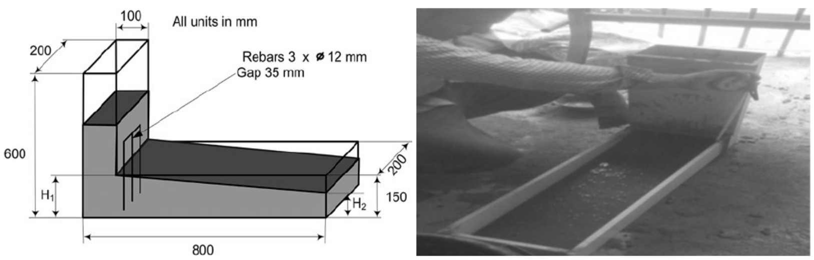

Figure 3. L-box test

2.3 Mix Design Procedure for SCC

Modified NAN-SU (Su et al., 2001) method was used in this thesis for mix design procedure for SCC. The principal consideration of this method is to fill the paste of binders into voids of the aggregate framework piled loosely. The loose unit weight of the aggregate is according to the shoveling procedure of ASTM C29. Usually, the volume ratio of aggregate is about 52–58%. The strength of SCC is provided by the aggregate binding by the paste at hardened state, while the workability of SCC is provided by the binding paste at fresh state.

Main objectives of the trial mix is to find out a suitable water-cement ratio where cement can be partially replaced by SCBA upto 20% by weight without compromising compacting characteristics of fresh SCC. Different trial mixes were designed with water-cement ratios from 0.35 to 0.58 and also with superplasticizer content from 1.9% to 2.5% of total binders (cement + SCBA) content, where total cementitious materials were partially replaced by SCBA at various percentages from 0% to 20%. A total of 10 trial mix was done.

Table 2. Detail of all trial mixes of SCC

Water-cement ratio	0.35	0.40	0.43	0.45	0.48	0.58	0.54	0.52	0.50	0.50
Superplasticizer content	1.90	1.90	2.00	2.00	2.10	2.50	2.35	2.2	2.15	2.15
(Cement+SCBA) Weight basis %	100% + 0%	100% + 0%	100% + 0%	100% + 0%	100% + 0%	80% + 20%	90% + 10%	90% + 10%	95% + 5%	85% + 15%
Slump flow (limit 600 – 750 mm)	Below 600 mm	Below 600 mm	Below 600 mm	Below 600 mm	Below 600 mm	768	686	667	646	634
Remarks						water bleeding occur	slight water bleeding occur	slight water bleeding occur	no water bleeding occur	no water bleeding occur

From these mixes we can see that, when cement was partially replaced by SCBA at 5% and 15% with a water-cement ratio of 0.50 and superplasticizer content of 2.15%, compacting characteristics of fresh SCC were within the recommended limit and also in these percentages no water bleeding was occurred in SCC.

Data for Mix Design

1) Packing Factor (PF) = 1.12
2) Maximum size of aggregates = 16 mm
3) Sp. gravity of Cement (Gc) = 3.15
4) Sp. gravity of Fine Aggregates, FA (Gs) = 2.62
5) Sp. gravity of Coarse Aggregates, CA (Gg) = 2.66
6) Volume ratio of fine to total aggregates (s/a) = 0.56
7) Superplasticizer content = 2.15 % of binders
(Total content superplasticizer = 40% solid portion + 60% liquid portion)
8) Unit volume mass of FA in loose condition (Wsl) = 1481.10 kg/m^3
9) Unit volume mass of CA in loose condition (Wgl) = 1397.20 kg/m^3
10) Water-cement ratio by weight (w/c) = 0.50
11) Size of SCBA = 0.075 mm

Final Mix Design Calculation

Concrete target strength (cube) = characteristic cube compressive strength, f_{ck} = M 41.9 = 41.9 MPa
As per BS EN 206:2013, target strength (cube) = 41.9 MPa = target strength (cylinder) = 32.61 MPa

Step 1: Calculation of quantity of Fine and Coarse aggregate.

The coarse aggregate and fine aggregate contents are determined by knowing packing factor (PF). PF is the ratio of mass of aggregates of tightly packed state in SCC to that of loosely packed state in air.

$$Wg = PF \times Wgl(1 - s/a) \quad ------ \text{(i)}$$

$$Ws = PF \times Wsl(s/a) \quad ------ \text{(ii)}$$

Step 2: Calculation of cement content

Modified Nan Su method proposes following equation for the determination of cement content in SCC. Generally, High Performance Concrete or SCC used in Taiwan provides a compressive strength of 0.14 Mpa/kg of cement. However, this was not enough for normal grades to gain the required strength, hence modification factor were introduced as per LSCC (Paul and Mathew, 2012).

Cement content, $C = Mf \times \{fck(MPa)/0.14\}$ ------ (iii)

Modification factor, $Mf = (fck^2/1400) - (fck/12) + 3.75$ ------ (iv)

Step 3: Calculation of mixing water content required by cement

The relationship between compressive strength and water cement ratio in SCC is similar to that of conventional concrete.

$$Wwc = (w/c) \times C \quad ------ \text{(v)}$$

Step 4: Calculation quantity of filler

Filler is used to increase the content of powder. No filler was used in the experiment, so no need to calculate amount of filler ($W_f = 0$) and water content required by filler paste ($W_{wf} = 0$)

Step 5: Calculation of mixing water content needed in SCC

The mixing water content required (W_w) for SCC is the total amount of water needed for cement and filler in mixing. Therefore, it can be calculate as follows.

$$Ww = Wwc + Wwf \quad ------ \text{(vi)}$$

Step 6: Calculation of superplasticizer dosage

Water content of the superplasticizer can be regarded as part of the mixing water. If dosage of superplasticizer used is equal to n% of the amount of binders and its solid content of superplasticizer is m%, then the dosage can be obtained as follows:

Dosage of superplasticizer used, $Wsp = n\% \times (C + Wf)$ ------ (vii)

Water content in superplasticizer, $Wwsp = (1 - m\%) \times Wsp$ ------ (viii)

Step 7: Adjustment of mixing water content needed in SCC
According to the moisture content of aggregates at this mix, the actual amount of water used for mixing should be adjusted. Adjustment of mixing water content = $Wwc - Wwsp$ ‒ ‒ ‒ ‒ ‒ ‒ (ix)

2.4 Experimental Works

In this experimental investigation, cement was partially replaced with SCBA upto 20% by weight to study the effect on strength and workability of SCC. A total of five set of cylinders (height = 300mm and diameter = 150mm) were casted for testing. For each percentage of SCBA three numbers of cylinders were made separately for 7 days and 28 days. A total of 30 cylinders were casted in this experiment. The ingredients of concrete were thoroughly mixed in mixer machine till uniform thoroughly consistency was achieved. Filling ability (flowability), passing ability & segregation resistance of each percentage were tested and each set of cylinders were cured for 7 days and 28 days separately. The test for compressive strength was conducted using universal testing machine.

Table 3. Final mix design details of SCC where cement replaced by SCBA

Cylinder designation	Weight basis percentage (Cement + SCBA)	No. of cylinder	Cement content (kg/m^3)	SCBA content (kg/m^3)	Fine aggregate content (kg/m^3)	Coarse aggregate content (kg/m^3)	Super plasticizer content (kg/m^3)	Water-cement ratio	Water (kg/m^3)
G	100% + 0%	6	459.437	0	928.95	688.54	9.878	0.50	223.792
H	95% + 5%	6	436.465	22.972	928.95	688.54	9.878	0.50	223.792
I	90% + 10%	6	413.493	45.944	928.95	688.54	9.878	0.50	223.792
J	85% + 15%	6	367.550	68.916	928.95	688.54	9.878	0.50	223.792
K	80% + 20%	6	344.578	91.887	928.95	688.54	9.878	0.50	223.792

3 Results and Discussions

Cement was replaced by SCBA in SCC by weight of 0%, 5%, 10%, 15% and 20% of cement. Workability requirement tests and compressive strength test results of SCC where cement was replaced by SCBA by weight upto 20% were shown in following.

3.1 Workability of SCC Using SCBA

Table 4. Results of Slump flow, V-funnel and L-box tests of the final mix design of SCC

Cylinder designation	Slump flow (mm)	T50 cm Slump flow (sec)	V-funnel flow (sec)	V-funnel at T5 minutes time increased (sec)	L-box test result (h2-h1)	Remarks
Recommended limit	600-750	2 - 15	6 - 20	0 - +3	0.8 - 1	
G	680	4	7	0 - +1	0.807	no water bleeding occur
H	648	4	8	0 - +3	0.81	no water bleeding occur
I	637	7	10	0 - +2	0.85	no water bleeding occur
J	635	9	10	0 - +3	0.80	no water bleeding occur
K	616	10	12	0 - +2	0.80	no water bleeding occur

The above table shows that when cement was partially replaced by SCBA from 0% to 20% in SCC, all the test values from cylinder-G (0%) to cylinder-K (20%) of filling ability, passing ability and segregation resistance are within the recommended limit and no water bleeding was occurred in these tests. In slump flow test, the test result values were decreased gradually with the percentage of SCBA content increased and from other test results no significant change was observed.

3.2 Compressive Strength of SCC Using SCBA

Table 5. 7 and 28 days compressive strength, percentage of strength gain by 7 and 28 days test results compare to target strength where cement replaced by SCBA upto 20% in SCC

Cylinder designation	7days compressive strength (MPa)	28 days compressive strength (MPa)	Target strength of concrete (MPa) at 28 days	Strength at 7 days compared to target strength (%)	Strength at 28 days compared to target strength (%)
G	23.79	33.74	32.61	72.95	103.47
H	21.63	29.31	32.61	66.33	89.88
I	16.65	24.89	32.61	51.06	76.33
J	11.30	23.05	32.61	34.65	70.68
K	9.78	17.25	32.61	29.99	52.90

In normal condition where cement was not replaced with SCBA in SCC has a compressive strength = 33.74 MPa at 28 days, which greater than target strength = 32.61 MPa. Usually, 7 days test result gains at least 65% of concrete design strength or target strength. At normal condition, where cement was not replaced with SCBA in SCC gain 72.95% of target strength and 5% cement replaced with SCBA cylinder gain 66.33% of target strength at 7 days which is greater than desire strength. Also at 5% cement replaced with SCBA, SCC gain 89.88% of target strength at 28 days and at 15% SCBA use SCC gain more than 70% of target strength at 28 days. Throughout the whole experiment it was visually observed that when cement was partially replaced by SCBA in SCC, viscosity of the concrete enhanced gradually from 0% to 20%.

4 Conclusions

Cement was replaced by SCBA in this SCC by weight upto 20%. Workability requirement tests and compressive strength test results of SCC were shown in the above section. From experimental investigation and discussion of results, the following conclusions are drawn-

- In this paper SCC was developed using SCBA as partial replacement of cement upto 20%.
- Packing Factor = 1.12; Maximum size of aggregates = 16 mm; Volume ratio of fine to total aggregates = 0.56; Superplasticizer content = 2.15 % of binders; Water-cement ratio = 0.50; Size of SCBA = 0.075 mm, with these condition SCC using SCBA upto 20% gain desire workability of fresh SCC and also no water bleeding was occurred in these tests.
- SCBA can be used as viscosity modifying agent in SCC.
- SCBA mainly contain silica which can be used as mineral admixture or filler material in concrete which has some pozzolanic properties.

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