Utilization of sugarcane bagasse ash in concrete as partial replacement of cement

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Abstract. This research addresses the suitability of sugarcane bagasse ash (SCBA) in concrete used as partial cement replacement. Two grades of concrete M15 and M20 were used for the experimental analysis. The cement was partially replaced by SCBA at 0%, 5%, and 10%, by weight in normal strength concrete (NSC). The innovative part of this study is to consider two grades of concrete mixes to evaluate the performance of concrete while cement is replaced by sugarcane bagasse ash. The cylindrical specimens having size 150 mm x 300 mm were used and tested after curing period of 7, 14 and 28 days. It was observed through the experimental work that the compressive strength increases with incorporating SCBA in concrete. Results indicated that the use of SCBA in concrete (M20) at 5% increased the average amount of compressive strength by 12% as compared to the normal strength concrete. The outcome of this work indicates that maximum strength of concrete could be attained at 5% replacement of cement with SCBA. Furthermore, the SCBA also gives compatible slump values which increase the workability of concrete.

1. Introduction
Sugarcane is main food crop in tropical and subtropical countries. It is the major resource for the sugar production. Sugarcane bagasse (SCB) is the waste created after juice extraction from sugarcane. The Sugarcane bagasse ash (SCBA) is acquired through the control burning of sugarcane bagasse. The SCB creates the environmental nuisance due to direct disposal on the open lands and forms garbage heaps in that area [1]. According to Barroso [2] that one ton sugarcane generates the 280 kg of bagasse waste. It generates economics as well as environmental related issues, to solving this issues, enormous efforts have been global towards the bagasse waste management i.e. handling, disposed-off and application. To reduce the environmental burden, the usage of waste materials in concrete is a significant aspect, the sugarcane bagasse ash (SCBA) is a waste material of sugar industry, which has a good potential to utilize in concrete as cement replacement. Sugarcane is main crop and besides that high worth crop of south Asia normally termed as cash-crop. It is important to sugar and production related to it. The sugar industry plays an essential part in the countrywide economy of Pakistan. According to the report of Pakistan sugar mills association, Pakistan produced 65.45 million tons of sugarcane in the year 2015-16 and production of year 2016-17 is forecasted at 71.371 million tons [3]. Furthermore, globally, the researchers are concentrating on usage of both industrial and agricultural waste, as raw material sources for the industry, the appropriate usage of this waste material would not
only be economical benefits, but may also result in foreign exchange wages and environmental pollution control [4].

Cement is the most widely consumable material in the infrastructure development works. It is considered as a durable material of construction. However, the environmental issue of cement has become a rising concern, as cement industries are accountable around 2.5% of total worldwide waste emissions from industrial sources [5, 6]. It is need of time to rise the use of cement replacement materials in the concrete which can reduce the significant amount of cement consumption, because the production of cement required huge energy and conferring to Asma [7] it is also accountable for 5% of global anthropogenic CO2 release (every ton of cement produces around 01 ton of CO2), and their usage can also improve the properties of concrete. The burning of organic waste of sugar industry known as bagasse, produces the considerable amount of ash named as sugarcane bagasse ash (SCBA).

SCBA is freshly acknowledged as a pozzolanic material; though, there is partial research statistics accessible to the effects of SCBA on the behavior of concrete. Therefore, it was highly recommended to conducting research on the bagasse and their impact on concrete behavior. Generally, the bagasse waste is disposed to the landfills or disposal sites where ever present in the country and rare studies has been conveyed yet. The bagasse ash can be used as partial cement replacement in concrete. Meanwhile, in the present era there is a huge rise in the production of sugar worldwide, and almost 1500 Million tons of sugarcane are yearly produced in all over the world, which leaves around 40 - 45% bagasse afterward juice removal. So, a normal yearly production of bagasse is projected as 600Million tons, which is a bulky waste from sugar industry [8]. For the construction industry the concrete is one of the most important item which is prepared for mixing of cement, fine aggregates and coarse aggregates and within the concrete the role of cement is very vital. Without cement, one cannot build reinforced structures. However, the high used of cement are an important concern of world environmental professionals. Considering the facts, one of the effective way to reduce the environmental impact is to use mineral admixtures, as a partial cement replacement in concrete, which will have the possible to cost reduction, energy conservation, and waste emission minimization.

Furthermore, Malyadri [9] has carried out the research on SCBA with 5% cement replacement in M25 (1:1:2) grade of concrete and found that the increase in the strength of concrete with use of SCBA but he never produce the optimum amount of SCBA that proposed to be utilized in sustainable concrete production. In addition to that Kawade [10] has carried out the research work on sugarcane bagasse ash as a partial replacement of cement with 10%, 15%, 20%, 25% & 30% cement replacement in M20, M30 & M40 grades of concrete and found that the OPC could favorably be replaced with SCBA up to maximum replacement of 15%. Although, the optimal replacement value of SCBA content was attained as 15.0%.

Therefore, realizing the significance of the issue, this research work is carried out to find out the optimum percentage cement replacement of SCBA in M15 & M20 grades of concrete, because grades M15 or M20 are widely used for reinforced concrete works. Grades M40 used for very heavy reinforced concrete/pre-cast/pre-stressed and M30 used for heavy reinforced concrete/pre-cast [11]. Hence, the object of this research is to evaluate the performance of concrete while incorporating sugarcane bagasse ash as cement replacement in different mixes proportions.

2. Methodology

2.1 Material used for the research

2.1.1 Cement. The ordinary Portland cement (ASTM C150 Type-I) was used in this research to prepare the control specimens.

2.1.2 Fine aggregate. Fine aggregate (commonly known as hill sand) free from debris were brought from nearby having 2.61 of specific gravity and size below 4.75 mm were used.
2.1.3 Coarse aggregate. Coarse aggregate commonly known as crushed aggregates were also brought from nearby having 2.65 of specific gravity and nominal maximum size of 20 mm were used.

2.1.4 Water. Water (palatable liquid) accessible within the campus laboratory were utilized for the mixing and curing of concrete cylinders.

2.1.5 Sugarcane bagasse ash. Sugarcane bagasse brought from vicinity of Khairpur Mir’s, Pakistan and was burnt in a closed drum (uncontrolled burning), SCBA was obtained after passing through 300μm standard sieve used for experimental study. Figure 1 and 2 shows the sugarcane bagasse ash after passing from sieved size 300μm and sugarcane bagasse ash retained materials on sieved 300μm respectively after the process of sieving.

![Figure 1. Bagasse ash after passing from sieve 300μm.](image1)

![Figure 2. Bagasse ash retained materials on sieve 300μm.](image2)

2.1.6 Density & microstructure of SCBA. The density basically defines as the mass per unit volume and Aigbodion [12] mentioned that the sugarcane bagasse ash is very light weight material and its density normally about 1.95g/cm³. The obtained density value fall within the category of carbon and silica which is 1.8 and 2.2 g/cm³ respectively [13, 14]. Furthermore, figure 3 represents the structure, size and shape of the particles varies; however, it can be classified into three main groups; prismatic, spherical and fibrous and SCBA sample analysis under XRD analysis, which indicated that bagasse ash, having substantial amount of silica particles. The SEM image also demonstrated that SiO₂ and carbon have a fine structure, the latter having a finer one. This could be associated with pore size of 4.29 Å against carbon which has substantial surface area in the range of hundreds of square meters per gram and microspores with pore size maxima around 3.36Å [15]. This is comparable to SCBA acquired in previous findings [2, 12, 15].

![Figure 3. SEM structure of the SCBA [12].](image3)

Subsequently, the typical chemical composition of bagasse ash as demonstrated by Idris [4] are provided in table 1.
Table 1. Typical chemical composition of bagasse ash [4].

| S.No. | Component | Percentage |
|-------|-----------|------------|
| 1.    | SiO₂      | 65         |
| 2.    | Al₂O₃     | 3.95       |
| 3.    | Fe₂O₃     | 9.17       |
| 4.    | CaO       | 12.6       |
| 5.    | MgO       | 0.6        |
| 6.    | SO₃       | 0.1        |
| 7.    | L.O.I     | 9.02       |

2.2 Casting of specimen

For the experimental analysis total 36 concrete specimens were casted (refer table 2). The size of each specimen was taken as 150 mm diameter and 300 mm length cylindrical in shape. Concrete mixes were prepared as per grades given in the table 2, then, concrete cylinders were kept for the curing purpose as shown in figure 4, for the period of 7, 14 and 28 days. While preparing the concrete cylinders, the slump test was also checked for the each grade for NSC and after replacing the SCBA in concrete. Afterward, cement is replaced by SCBA as per percentage given in the table 2 and same shall be cured for the mentioned period of time. For the each grade of concrete the pair of cylinders were casted to check the average results. After the completion of the required curing period every specimen was checked for the compressive strength in the compressive strength machine as shown in figure 5. After the necessary investigations tested samples will be placed outside of the laboratory as shown in figure 6.

Table 2. Quantity of specimens.

| % of SCBA | Mix Proportions | M20 (1:1 ½:3) | M15 (1:2:4) |
|-----------|-----------------|---------------|-------------|
| 0         | 2 x 3 = 6       | 2 x 3 = 6     |             |
| 5         | 2 x 3 = 6       | 2 x 3 = 6     |             |
| 10        | 2 x 3 = 6       | 2 x 3 = 6     |             |
| Sub Total:| 18              | 18            |             |
| Total specimens |            | 36            |             |

Figure 4. Specimen in curing tank.  
Figure 5. Specimen testing for compressive strength.  
Figure 6. Specimen after testing.
3. Results and discussion
The slump test was performed for the concrete with and without SCBA to check the consistency of NMC and the observed result are reported in table 3.

Table 3. Slump values of different grades of concrete.

| Sr.No. | Mix Proportion | OPC % Replacement with SCBA | Average slump value (mm) | Increase |
|--------|----------------|-----------------------------|--------------------------|----------|
| 1      | M20 (1:1 ½:3) | 0%                          | 27.89                    | -        |
| 2      |                | 5%                          | 42.50                    | 34%      |
| 3      |                | 10%                         | 51.12                    | 45%      |
| 4      |                | 0%                          | 31.94                    | -        |
| 5      | M15 (1:2:4)   | 5%                          | 37.48                    | 15%      |
| 6      |                | 10%                         | 44.64                    | 28%      |

After the execution of slump test for concrete grade M15 & M20, the continuous rise in the slump value were recorded, when cement replaced by SCBA. The range for slump test was targeted in between 25 mm to 75 mm (as recommended by ACI). It is prominent that slump value represent the workability of fresh mix concrete and the observed values fall in the category of low and medium degree of workability. Therefore, the usage of super plasticizer (SP) is not essential in this case.

3.1 Compressive strength of concrete
The compressive testing machine was used to test the entire concrete cylinders for crushing strength at 7, 14 and 28 days respectively. The compressive strength for concrete grade M20 (1:1 ½:3) and M15 (1:2:4) were investigated for the control mix and while cement was partially replaced by SCBA. The results of compressive strength test at different curing periods are provided in table 4 and 5. Through the laboratory observations it was perceived that early age strength is lower than the later age strength, because concrete gain its strength with the passage of time.

Table 4. Compressive strength of concrete for M20 (1:1 ½:3).

| OPC % replacement with SCBA | 7 days | 14 days | 28 days | Avg. Compressive Strength (N/mm²) 7 days | Avg. Compressive Strength (N/mm²) 14 days | Avg. Compressive Strength (N/mm²) 28 days |
|-----------------------------|--------|---------|---------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
| 0                           | 18.07  | 20.68   | 26.60   | 17.16                                     | 20.33                                     | 25.525                                    |
| 16.25                       | 19.98  | 24.45   |         |                                            |                                           |                                           |
| 5                           | 21.39  | 26.78   | 29.92   | 20.92                                     | 25.11                                     | 28.500                                    |
| 20.45                       | 23.44  | 27.10   |         |                                            |                                           |                                           |
| 10                          | 19.52  | 22.84   | 5.81    | 19.225                                    | 21.09                                     | 26.435                                    |
| 18.93                       | 19.34  | 24.06   |         |                                            |                                           |                                           |
Figure 7. Average compressive strength of concrete grade M20 containing different percentage of SCBA at different curing periods.

The compressive strength test results has been presented in figure 7 and it was observed that if cement is replaced by SCBA in concrete at 5% then the average amount of compressive strength will concrete for M20 grade at 28 days curing period around 12% strength increased as compared to the normal mix concrete.

### Table 5. Compressive strength of concrete for M15 (1:2:4).

| OPC % replacement with SCBA | Compressive Strength (N/mm²) | Avg. Compressive Strength (N/mm²) |
|-----------------------------|------------------------------|----------------------------------|
|                             | 7 days | 14 days | 28 days | 7 days | 14 days | 28 days |
| 0 %                         | 17.30  | 18.50   | 24.11   | 16.025 | 18.19   | 23.805  |
| 5 %                         | 14.75  | 17.88   | 23.50   |         |         |         |
| 10 %                        | 18.89  | 21.95   | 27.20   | 17.645 | 20.56   | 26.775  |
|                             | 16.40  | 19.17   | 26.35   |         |         |         |
| 10 %                        | 17.54  | 20.62   | 24.67   | 16.805 | 19.35   | 24.16   |
|                             | 16.07  | 18.08   | 23.65   |         |         |         |
Subsequently, experimental analysis has done for concrete grade of M15. The result of compressive strength test for grad M15 has been presented in figure 8. The higher results were recorded at 28 days curing period, when cement is replaced with SCBA in concrete at 5% then the average amount of compressive strength will increase about 11.50% as compared to the normal strength concrete. Furthermore, for the both grade (M20 and M15) of concrete while containing SCBA, the compressive strength were detected as lower at the early ages but improves significantly by increasing the curing period. This phenomena of gaining strength with increasing curing time is comparable with previous findings while using cement replacement materials [16].

4. Conclusion

This research was successfully carried out, to the establishment of SCBA as an alternative cement replacement material in concrete. After the detailed investigation the following conclusions have been drawn:

- SCBA in concrete gives the higher compressive strength as compared to the normal strength concrete, hence optimal results were found at the 5% replacement of cement with SCBA.
- The usage of SCBA in concrete is not only a waste-minimizing technique, also it saves the amount of cement.
- The replacement of cement with SCBA increases the workability of fresh concrete; therefore, use of super-plasticizer is not essential.
- It is recommended that future research should be performed to assess the use of SCBA in concrete for several properties of concrete for example modulus of elasticity, flexure test, split tensile test, drying shrinkage etc.

5. References

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