Sudanese Sugar Cane Bagasse Ash: A Valuable by-Product for Concrete

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***Abstract*—Agricultural and industrial by-products are commonly used in concrete production as cement replacement materials or as admixtures to enhance the fresh and hardened properties of concrete as well as to minimize the negative environmental effects. Sugar Cane Bagasse Ash (SCBA) is one of the promising cement replacement materials, which potentially be used as a partial replacement of cement for producing concrete; properties of such concrete depend on the chemical composition, fineness, and burning temperature of SCBA. Approximately 1800 Million tons of sugarcane are annually produced all over the world, which leaves about 40-45% bagasse after juice extraction in sugar mills yielded an average annual production of about 700 Million tons of bagasse as a waste material. In this study the SCBA was incorporated in concrete from 5% to 50% by weight of cement. Effect of SCBA on workability, compressive strength, splitting tensile strength and bond strength of concrete was investigated. The results showed that incorporation of SCBA in concrete as partial replacement for cement up to 30% significantly enhanced the mechanical properties of concrete.**

***Index Terms*—Sugar Cane Bagasse Ash, workability, Compressive Strength, Splitting Tensile Strength, Bond strength.**

I. Introduction

Utilization of agricultural, industrial and agro-industrial by-products in the form of processed ash attracting researchers to explore their potential as cement replacement material or mineral admixture to the properties of concrete at multiple level. Utilization of established materials such as silica fume, fly ash and ground granulated blast furnace slag has proved as the high performance concrete ingredients. The benefits were mainly derived from presence of high SiO_2 content and amorphous mineralogical character, which caused high strength and stability of the end product [1] and [2]. It happens due to utilization of calcium hydroxide (free lime forms during cement hydration) reacts with the silica content present in the pozzolans and water that forms additional calcium silicate hydrate, which is called secondary gel, hence the compressive strength is enhanced [3].Since last few years tremendous efforts have been made to increase the use of cement replacement materials in concrete production because the cement production consumes high energy and is responsible for 5% of global anthropogenic CO_2 emission (each ton of cement produces about one ton of CO_2) and their use can also improve the properties of concrete [4].

Bagasse is an abundant waste produced in sugar factories after extraction of juice from Sugarcane. The huge supply of bagasse needs meaningful disposal. In many countries this type of bulky waste usually used as the boiler fuel in the sugar mills. Increasing cost of natural gas and fuel oil resulting high prices of electricity, due to calorific properties of bagasse waste; since last decade it is being used as the principal fuel in cogeneration plants to produce electric power [5] and [6].The burning of bagasse as fuel leaves bulk quantity of ash called sugarcane bagasse ash or SCBA. Sugar cane bagasse ash is recently accepted as a pozzolanic material, however, there is limited research data available on the effects of SCBA on the properties of concrete. Therefore, due to lack of research most of the bagasse ash is disposed in the landfills [7],and only a few studies reported the use of bagasse ash as partial replacement of cement in concrete[8]. Since, there is a continuous increase in the production of sugar worldwide. Approximately 1800 Million tons of sugarcane are annually produced all over the world, which leaves about 40-45% bagasse after juice extraction. Therefore, an average annual production bagasse is estimated as 700 Million tons, which is a bulky waste from sugar industry [9].Sugarcane plantations cover one-fifth of the arable land in Sudan, according to WADE report 2004: Sudan has the highest potential among the countries of eastern and southern Africa of producing electricity from bagasse and over 40% of its electricity can be produced from bagasse cogeneration [10].

Bond strength of concrete is an important factor for structural design, the axial force transferred from the reinforcing bar to the surrounding concrete results in the

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development of tangential stress components along the contact surface. The stress that acting parallel to the bar along the interface is known as bond stress. the bond strength is a combination of chemical adhesion, friction and mechanical interlocking between the bar and the surrounding concrete for the deformed bars [11].The bond strength was studied by different researchers for normal and light weight concrete and for different cement replacement materials such as silica fume was studied by [12] and [13], effect of fly ash on bond performance was also studied by [14].

As mentioned above there is limited research available on the utilization of SCBA as cement replacement material, CRM in concrete as compared to other well-known pozzolans such as silica fume, fly ash, ground granulated blast furnace slag and rice husk ash. In order to establish SCBA as an alternative cement replacement material for high performance concrete, many properties of concrete containing SCBA, such as compressive strength, splitting tensile strength, microstructure of interfacial transition zone (ITZ), long term durability and structural properties including bond strength need to be investigated. The principal aim of this research paper is to present the results of an experimental study performed to investigate the effect of SCBA on the mechanical properties of concrete namely compressive strength, splitting tensile strength and bond characteristic of concrete.

II. MATERIALS

The materials used in this study are:

The ordinary Portland cement (OPC) type 1 was used in this study it was complying with the requirements of BS 12 (1996)[15]and MS 522 (1989)[16]. The chemical composition of cement is shown in Table 1.Crushed Granite rocks with a maximum particle size of 20 mm that was employed as coarse aggregate in this study and mining sand with a maximum particle size of 4.75mm was used as fine aggregate according to BS 812-103.2 1989. A naphthalene formaldehyde sulphonate superplasticizer in the form of aqueous solution was used as water reducing admixture (WRA) for all concrete mixes.

A. Sugar Cane Bagasse Ash (SCBA)

The SCBA was obtained from Guneid Sugar factory, located in Gezira Province, Sudan. The obtained ash was further ground in a Los Angeles abrasion machine until the particles retained on 45μm-sieve were less than 5%. The chemical composition of SCBA was determined using X-Ray fluorescence technique, XRF, the results are given in Table 1. The major oxide observed in SCBA is silica (SiO_2), which is about 77.25%, the total summation of SiO_2+ Al_2O_3+ Fe_2O_3 is 87.83%, the calcium oxide, CaO is 4.05%, hence this ash classifies as class F pozzolan according to ASTM C618 2009[17]. The X-Ray diffraction (XRD) analysis of the SCBA shows the amorphous silica formation with traces of low quartz as shown in Fig. 1. The image of ground SCBA is shown in Fig. 2.

TABLE I. CHEMICAL COMPOSITION OF OPC AND SCBA

Oxide	Weight %	
	OPC	SCBA
SiO_2	20.44	77.25
Al_2O_3	2.84	6.37
Fe_2O_3	4.64	4.21
CaO	67.73	4.05
K_2O	0.26	2.34
MgO	1.43	2.61
Na_2O	0.02	1.38
P_2O_5	0.10	0.59
TiO_2	0.17	0.58
MnO	0.16	0.27
SO_3	2.20	0.11
LOI	-	1.4
SiO_2+ Al_2O_3+ Fe_2O_3	-	**87.83**

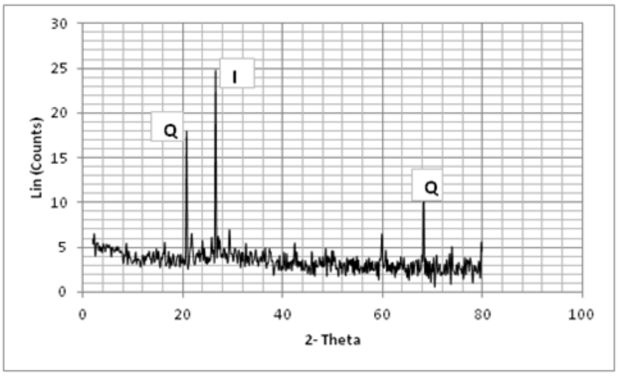

Figure 1. XRD Pattern of SCBA

Figure 2. Ground SCBA

III. EXPERIMENTAL PROGRAM

A. Concrete Mixing and Casting

A total of 11 concrete mixes were prepared, one of the mixes was made of 100% ordinary Portland cement (no SCBA content), denoted by NC and called the reference mix. The remaining 10 mixes were prepared by adding SCBA content as partial replacement to cement i.e. 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%; these mixes are denoted by SCBA content, e.g. 5%SCBA. Details of all mixes are given in Table II. All concrete ingredients were mixed according to the procedure given in BS1881-125: 1986[18], the superplasticizer dosage was kept constant as 0.6% by weight of cement.

B. Workability

The workability of the freshly mixed concrete was determined using slump test that was performed according to BS 1881: Part 102: 1983[19].

TABLE II. CONCRETE MIX PROPORTIONS

Mix Description	OPC	SCBA	CA	Sand	Water	SP
NC	500	0	945	745	190	3
5%SCBA	475	25	945	745	190	3
10%SCBA	450	50	945	745	190	3
15%SCBA	425	75	945	745	190	3
20%SCBA	400	100	945	745	190	3
25%SCBA	375	125	945	745	190	3
30%SCBA	350	150	945	745	190	3
35%SCBA	325	175	945	745	190	3
40%SCBA	300	200	945	745	190	3
45%SCBA	275	225	945	745	190	3
50%SCBA	250	250	945	745	190	3

C. Compressive Strength

The compressive strength was determined using 100 mm cubes at the age of 7, 28, 90 and 180 days curing. During compression test, the load on the cube was applied at a constant rate of 3.0 KN/s according to BS 1881: Part 111: 1983[20].

D. Splitting Tensile Strength

The split cylinder test was done on 100 mm diameter and 200 mm length cylinder specimen and the tensile strength was at 28, and 90 days of curing. The concrete cylinder was placed between the platens of the testing machine in the horizontal axis. The load was applied until the cylinder specimen split into two halves. The test was conducted according to BS 1881: Part 117: 1983[21].

E. Pull Out Test

The pull out test was conducted on a concrete cylinder 100 mm diameter and 200 mm height with a 12 mm diameter deformed steel bar of 652.4 MPa tensile strength embedded in concrete in order to determine the concrete-steel bond. The test was done in accordance with ASTM C 234-91a: 1999[22] with aid of universal testing machine with a loading rate of 0.367 KN/s as shown in Figure 3. The measured bond strength was obtained from the following equation:

$$f_{bd} = \frac{Pmax}{\pi \phi l_b} \quad (1)$$

The theoretical bond strength was calculated according to BS EN 1992-1-1 cited in [23]using the following equation:

$$fbd = 2.25\,\eta 1\,\eta 2\; fctd \quad (2)$$

The theoretical bond strength was also calculated according to [11] by using the following equation: $\sqrt{fc'}\left[2.28 - 0.208\,\frac{c}{db} - 38.212\,\frac{db}{lb}\right]$ (3)

Figure 3. Test Set up for Pull out Test

IV. RESULTS AND DISCUSSION

A. Effects of SCBA on Workability

Fig. 4 shows the slump values for all the concrete mixes. Since the water content and superplasticizer dosage was constant in all seven mixes, therefore, the effect of SCBA on workability of concrete can be better understood. As shown in Figure 4, the workability of concrete was linearly increased with the increment in the SCBA content. For reference concrete, NC the slump value was obtained as 160 mm, whereas for 30%, the slump was about 215 mm. It means the addition of SCBA content reduces the water demand in concrete for achieving a desired workability, which is a good news for high performance concrete. Although, the particle size of SCBA is much finer than the cement particle but its texture is more glassy similar to that of the fly ash particles, similar observation was also reported in the available research by others[24]and[25].

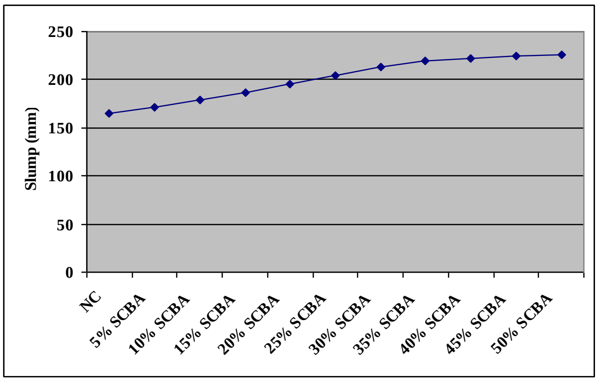

Figure 4. Effect of SCBA on the workability of concrete

B. Effect of SCBA on Compressive Strength

Fig. 5 shows the compressive strength of all mixes determined at the age of 7, 28, 90 and 180 days. At all ages, four mixes containing 5, 10, 15, and 20% SCBA showed higher compressive strength than the reference mix, NC, whereas mixes 25%SCBA and 30%SCBA showed further improvement in strength at the age of 90 and 180 days, which means SCBA has shown good pozzolanic reactivity. At the age of 28 days mixes 5%SCBA, 10%SCBA and 15%SCBA showed 91MPa, 88MPa and 84MPa compressive strength respectively in comparison to 62MPa, the compressive strength of the reference mix, NC. It is to be noted that reference mix NC has higher slump, while all mixes were having constant water content and dosage of superplasticizer. In case where the workability (slump value) of all mixes to be kept constant, SCBA mixes will require lower water content, hence the compressive strength will be further improved. 25%SCBA showed similar compressive strength at 28 days as the reference mix achieved, therefore it can be concluded that 25%SCBA mix is equivalent to the reference mix, NC, whereas 5% to 20% SCBA content is determined as optimum replacement for producing high strength concrete. 35%SCBA and 40%SCBA slightly reduced the compressive strength of concrete at 90 days and 180 days while 45%SCBA and 50%SCBA significantly reduced the 7-day and 28 day strength and a moderate reduction was observed at 90 and 180 days, this reduction can be attributed to the reduction in calcium hydroxide available for pozzolanic reaction which originated from the reduction in the cement content.

In general SCBA showed an excellent performance when included in concrete as partial replacement for cement up to 20% this can be attributed to 1) the high silica content present SCBA that enables pozzolanic reactivity and 2) ultra-fine particle size in SCBA significantly improve the microstructure that causes high early strength. The findings of this study are in agreement with other available researches[7], [8], [25]and[26].

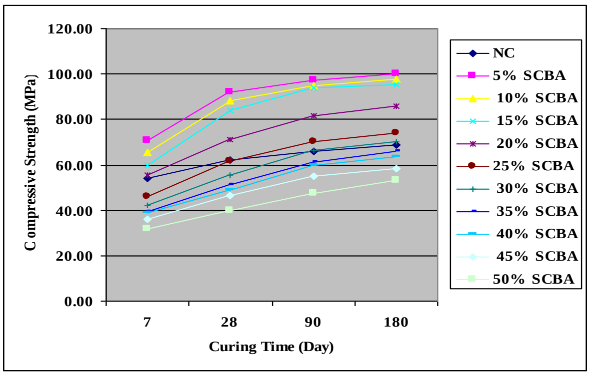

Figure 5. Effect of SCBA on the compressive strength of concrete

C. *Effect of SCBA on Splitting Tensile Strength*

The splitting tensile strength results at 28 and 90 days are shown in Figure 6. Effects of SCBA content on tensile strength follow similar trend that observed in compressive strength. The mix 5%SCBA showed highest tensile strength among all mixes, it showed 33% and 40% higher tensile strength than the reference mix, NC at the age of 28 and 90 days respectively. Up to 20%SCBA replacement level the splitting tensile strength was found higher than that of the reference mix. 25%SCBA showed the similar tensile strength as that of the reference mix, whereas 30%SCBA showed between 7% and 3.5% lower than the reference mix, the results are almost in the same line with[25].A slight reduction in the splitting tensile strength was observed for 35%SCBA and 40%SCBA mixes while 45%SCBA and 50%SCBA reduced the tensile strength by about 19% and 24% respectively as compared to the control mix. The ratio of the splitting tensile strength to the compressive strength at 28 days for all the mixes was calculated in the range of 5.9% to 7.9%, this ratio was decreased with the increase of compressive strength[27].

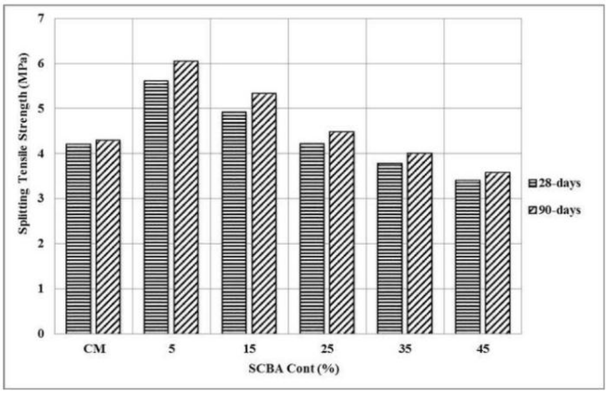

Figure 6. Effect of SCBA on splitting tensile strength of concrete

D. *Effect of SCBA on Bond Strength*

Fig. 7 shows the load versus slip for all tested specimens, and Table 3 presents the results of failure load, measured bond strength and the calculated bond strength according to BS EN 1992-1-1 and according to a formula suggested by[11],the results showed that 5%SCBA-25%SCBA improved the bond strength by 38-40% when compared to the reference normal concrete NC. The specimen NC failed by splitting and pullout of the bar while the specimens contained SCBA from 5% up to 25% failed due to Steel rupture, Steel rupture failure indicates that the bond between the bar and concrete is very high therefore the rupture occurred before the bond or interlocking between the bar and surrounding concrete fails. 30%SCBA-40% SCBA also improved the bond strength by 32%-38% over the reference concrete but their failure mode was a combination of pullout of the bar and concrete splitting. It can be observed that all SCBA specimens from 5%SCBA-40%SCBA had almost similar bond strengths in the range of 9.07-9.62 MPa but the mode of failure was different which indicates that the actual bond strength for the specimens 5%SCBA-25%SCBA has not been reached yet due to the steel rupture while 30%SCBA-40%SCBA reached their actual bond strength as they failed by concrete splitting and pullout of the bar which usually occurred when the concrete between the reinforcing bar ribs (concrete keys) becomes weak[13]. 45%SCBA and 50%SCBA showed slightly higher bond strengths compared to the reference concrete 4%-6% improvement was obtained and they failed by concrete splitting and pullout of the bar. The failure patterns are shown in Figure 8 and 9. The comparison of the measured bond strength obtained in this study and the theoretical bond strength calculated according to Euro code 2 is presented in Fig. 10.

4- Inclusion of 30% to 50% SCBA also improved the bond strength of concrete and the specimens failed due to rebar pull out and the concrete splitting which means the maximum bond strength has been achieved.

5- Bond characteristics are well correlated to the compressive strength of concrete i.e. the higher compressive strength of concrete the higher its bond strength. It is recommended that additional research on bond strength of SCBA concrete must be conducted to confirm the findings of this study.

6- It can be concluded that the Sudanese SCBA can be effectively utilized as cement replacement material in concrete, which will produce a concrete with good mechanical properties, reduce the cost of concrete by reducing the cement content in the mix, reduce the landfill volumes for its disposal and minimize its negative environmental impacts associated with its disposal and with the cement production.

7- This study will be beneficial not only for Sudan but also for all other Developing and sugar-producing countries and it will also assist to encourage the bagasse cogeneration for electricity generation in such countries which will reduce the cost of energy and this will minimize the CO_2, SO_2 and NO_x emissions from coal and other fossil fuels which will help in keeping clean environment for Humanitarian.

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LIST OF NOTATIONS

F_{bd}: Ultimate Bond Strength (MPa).
P_{max}: Ultimate axial tensile load (KN).
ϕ : Reinforcing steel bar diameter (mm) =12 mm for this study.
l_b: Embedded length (mm) = 200 mm for this study.
$\boldsymbol{\eta}_1$= Coefficient related to the quality of the bond condition and the position of the bar during concreting
= 1.0 for condition of good bond.
= 0.7 for all other cases and for bars in structural elements built with slipforms.
$\boldsymbol{\eta}_2$= Coefficient related to the bar diameter

= 1 for $\varphi \leq 40$mm
f_{ctd}= Design tensile strength
u= Bond stress
f'_c= Bharacteristic compressive strength of concrete.
c= Concrete cover.
d_b= Nominal diameter of the bar.
l_d= Embedded length of the reinforced bar.

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Experimental Responses of Jacketed RC Beams

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***Abstract*—Repair and strengthening of reinforced concrete (RC) beams is commonly carried out by "jacketing". Jacketing is the addition of concrete or cement mortar and steel reinforcement to an existing beam. This paper describes an experimental investigation into the behavior of reinforced concrete beams strengthened by jacketing. Static load tests to failure were carried out on five reinforced concrete shallow beams. The mortar used in the jacket was non-shrink cement grout. The steel bars were fixed to the beams by using two inexpensive and simple anchorage systems i.e., epoxy anchorage system and mechanical expansion anchors with steel plate anchorage system. Based on experimental results, it was noted that jacketing using mortar and steel bars is very effective method to enhance ultimate load carrying capacity of RC beams compared with control beams. Proposed anchorage systems were pr oved effective to securely attach the steel bars to the beam. The anchorage system with mechanical anchors is resulted into higher load carrying capacity of RC beams compared with epoxy anchorage system. The control beam failed at the peak ultimate load of 23.70 kN. The RC beams jacketed using epoxy anchorage were failed at 13% to 27% higher peak load compared with control beam, whereas RC beams jacketed using mechanical anchors were failed at 84% to 105% increased load compared with control beam.**

***Index Terms*—flexural strengthening, anchorage system, jacketing, epoxy, mechanical anchors**

I. Introduction

Strengthening reinforced concrete (RC) beams can be done by different methods such as steel plate jacketing [1], [2], jacketing by fiber reinforced concrete [3] jacketing by RC [4], [5] and recently jacketing by wrapping fiber reinforced polymer (FRP) composites [6], [7]. The technique of gluing mild steel plates to the soffits of reinforced concrete beams can be used to improve the flexural performance of RC beams as it increases the strength and rigidity and also reduces the flexural cracks widths in the concrete [8]. This plating technique has further advantages as it has been found in practice to be simple to apply. It does not reduce the height of the structure and can be applied while the structure in use. This procedure has been used to repair buildings [9] and to strengthen bridges [10], especially in many European countries. Steel jacketing is proved very effective and has been widely used all over the world, however, experimental tests show that shear and flexural forces can cause these externally bonded plates to peel away before the design load is reached [8]. Other issues such as corrosion, heavy weight and installation difficulties (in case of high rise buildings) are also reported. In recent years, fiber-reinforced polymer (FRP) composites are introduced and demonstrated to be successful for strengthening concrete structures. Common types of FRPs that have been successfully used for strengthening reinforced concrete beams are carbon (CFRP), glass (GFRP), and aramid (AFRP) [11]. A large number of studies have been carried out in the last decade on the behavior of FRP-strengthened beams. These FRPs are found very effective to enhance ultimate load carrying capacity and ductility of strengthened members. Many of these studies reported premature failures by de-bonding of the FRP with or without the concrete cover attached. The most commonly reported de-bonding failure occurs at or near the plate end, by either separation of the concrete cover or interfacial de-bonding of the FRP plate from the RC beam [12]. Tom Norris et al. (1997) performed an experimental study to investigate the behavior of damaged or understrength concrete beams retrofitted with thin carbon fiber reinforced plastic (CFRP) sheets. In their study, the CFRP sheets were epoxy bonded to the tension face and web of concrete beams to enhance their flexural strength. The effect of CFRP sheets on strength and stiffness of the beams was considered for various orientations of the fibers with respect to the axis of the beam. The authors concluded that CFRP sheets can provide the increase in strength and stiffness to existing concrete beams when bonded to the web and tension face. The failure mode of CFRP strengthened beams were reported as peeling of the CFRP [13]. Wu et al. (2011) has enlisted different methods which were successfully applied to prevent the FRP de-bonding such as mechanical anchors, near-surface mounted (NSM) installation, wrapping of FRP strips in different shapes, use of protruding fiber and anchor bolts, using comb-shaped anchors and mechanical-interlocking anchorage systems [14]. Although these FRPs are proved very successful for the strengthening propose due to their light weight, superior strength-to-weight ratios, corrosion

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