ACTA TEHNICA CORVINIENSIS – Bulletin of Engineering
Tome VII [2014] Fascicule 3 [July – September]
ISSN: 2067 – 3809

[1.] T. S. ABDULKADIR, [2.] D. O. OYEJOBI, [3.] A. A. LAWAL

EVALUATION OF SUGARCANE BAGASSE ASH AS A REPLACEMENT FOR CEMENT IN CONCRETE WORKS

[1-3.] Department of Civil Engineering, University of Ilorin, Ilorin, NIGERIA

Abstract: *This research evaluates the suitability of SCBA as a partial replacement for cement in concrete productions. Total weight of 34.7kg of sugarcane bagasse (SCB) was obtained and burnt at 700^{0}C. A total of 2.71kg of SCBA was obtained after passing the residual through 45μm sieve, standard size of ordinary portland cement (OPC). Chemical test was conducted on SCBA to evaluate its percentage composition. It was then used to replace OPC by weight in ratio of 0%, 10%, 20% and 30%. Total of 48 pieces of 100mm concrete cubes of design mix ratio 1:1.66:2.77 were prepared. The cubes were tested at 7, 14, 21 and 28days of curing ages for density and compressive strength. The results of chemical test showed that SCBA has pozzolanic properties having met ASTM-595 (1985) with total sum of silica, alumina and ferric composition of 80.55%. The results showed a decrease in concrete density with increase in % replacement of SCBA. Average compressive strength of 26.8N/mm^2 was obtained for control specimens at 28days (i.e. 0% SCBA) while 22.3, 20.1 and 17.3N/mm^2 compressive strength at 28days were obtained for 10%, 20% and 30% replacement respectively. Pozzolanic activity index (PAI) of 83.2%, 75% and 64.5% were obtained. This showed that only 10% and 20% replacement of cement by weight of SCBA satisfied ASTM-595(1985) specification for PAI. It was concluded that SCBA is a low weight material and 10% replacement of SCBA has the highest PAI. Also, 10% and 20% replacement of SCBA with compressive strengths of 22.3N/mm^2 and 20.1N/mm^2 are recommended for reinforced concrete.*
Keywords: *SCBA, compressive strength, PAI, pozzolanic properties, concrete productions*

INTRODUCTION

Initiatives are emerging worldwide to control and regulate the management of sub-products, residuals and industrial wastes in order to preserve the environment from contamination. A good solution to the problem of recycling of agro-industrial residues would be by burning them in a controlled environment and use the ashes (waste) for more noble means (Ghavami et al., 1999). Utilization of such wastes as cement replacement materials may reduce the cost of concrete production and also minimize the negative environmental effects with disposal of these wastes. Silica fume, rice husk ash, fly ash, met kaolin and ground granulated blast furnace slag are well established wastes with pozzolans because of high silica content in their chemical compositions. According to Sirirat and Supaporn (2010), the calcium hydroxide (unfavorable product from the cement hydration) released during the hydration of OPC reacts with silica present in the pozzolans and water to form additional calcium silicate hydrate which is responsible for the compressive strength in concrete.

Sugarcane is an important food crop for tropics and subtropics. It is the major raw materials used for sugar production. Sugarcane bagasse (SCB) is the waste produced after juice extraction from sugarcane. The Sugarcane bagasse ash (SCBA) is obtained as by product of control burning of sugarcane bagasse. SCBA constitutes an environmental nuisance as they form refuse heaps in areas they are disposed. It is cultivated in about seventy four countries between 40^{0}N and 32.5^{0}S, approximately encompassing half of the globe (Agboire et al., 2002). Brazil and India are the world's major sugarcane producing countries with Brazil having over of 719 million tons in 2010 and recorded one-third of the world's total sugarcane (Kajima, 2012). Nigeria produced over 15 million tons of sugarcane last year. Some states where sugarcane is mostly produced in Nigeria are Sokoto, Taraba, Niger, Kogi and generally most Northern part. SCBA from sugar producing companies is not readily available since most developing countries relied on imported sugar import. In the past, SCB was burnt as a means of solid waste disposal. But with the increasing cost of the natural gas, electricity and fuel, and with the calorific properties of these wastes, bagasse has been used as the principal fuel in cogeneration plants to produce electric power (Aigbodion et al., 2010). SCBA is usually obtained under controlled burning conditions in the bailers of the cogeneration processes (Aigbodion et al., 2010). Thus, the ash may contain black particles due to the presence of carbon and crystalline silica when burning occurs under high temperature (above 800^{o}c) or for a prolonged time. The nature of ash can be altered by controlling the parameters such as temperature and rate of heating (Ganesan et al., 2007). Search for alternative binders or cement replacement materials has become a challenge for national development and forward planning (Oluremi, 1990). Since last few years, tremendous efforts have been made to increase the use of materials to partially replacement cement in concrete works. According to Swamy (1986), supplementation of cement production with natural pozzolans has proved attractive in developing countries. In recent years, there have been projects to develop known deposits in Indonesia, Tanzania, Trinidad, Dominica and other countries. Beside SCBA, rice husk ash, palm kernel husk ash, fly ash, ground blast-furnace slag and silica fume have pozollanic properties that can be used in partial replacement of cement. Megat (2011) investigated the effect of silica fume, metakoalin, fly ash and granulated blast fume on workability, compressive strength, elastic modulus and porosity of high strength concrete. Concrete produced from partial replacement of cement with SCBA has reaction formed by silicate, SiO_2 from SCBA and slaked lime, $Ca(OH)_2$ from cement to form calcium silicate hydrate which is responsible for the compressive strength (Baguant, 1995). The quality of concrete produced from SCBA beyond an optimum quantity of SCBA will leaches out silicate which does not contribute to the strength of concrete (Baguant, 1995). In the search for local building materials which is cheaper and readily available, the pozzollanic activity of SCBA is investigated and assessed in this research work by determining the strength of the mixtures when portion of cement is partially replaced.

MATERIALS AND METHODS

Materials

Ordinary Portland cement was used for the experiment. The cement conforms to BS 12 (1996). The fine aggregate was sourced from a construction site on the University of Ilorin, Ilorin, Nigeria. BS 812 (2002) that deals with testing aggregates was used in carrying out laboratory tests on the aggregates. SCBA was prepared at Department of Civil Engineering, Kwara State Polytechnic (Institute of Technology), Ilorin, Nigeria by burning SCB in blast furnace. The furnace was first heated to a temperature of 700^{0}C then off. The SCB was then put in the blast furnace till subsequent day and grayish-black ash was obtained. The ash was then weighed and sieved with a 425μm standard sieve and the quantity retained on the sieve (black carbon) was weighed and discarded. The ash collected was later weighed and grinded to fineness of 45μm sieve (conforming to American Society for Testing and Materials - ASTM C595-85 standard specification for blended hydraulic cements).

Laboratory Tests

These include the determination of chemical composition of SCBA, physical tests on aggregates and the SCBA concrete. The tests carried out include the following: gradation test/sieve analysis, specific gravity, water absorption capacity and moisture content, bulk density, slump test and compressive strength test. Chemical test to determine the composition of SCBA was conducted at Department of Chemistry, University of Lagos, Nigeria. The method adopted was atomic absorption spectrometric method of analysis.

Production of Concrete Cubes

SCBA, water, OPC, fine and coarse aggregate were used in producing concrete in mould of size 100x100x100mm. The mix design used for the production of cubes was 1:1.66:2.77 for characteristic strength of 25 N/mm^2 at 28 days.

The target mean strength was calculated to be 31.56N/mm². Batching by volume was adopted due to the light weight of SCBA. When batched by weight, the concrete produced was very low in workability and no binding take place. The quantity of cement required to produce concretes was partially replaced with SCBA. The percentage replacements of SCBA with cement were 0%, 10%, 20% and 30%. The volume of water used for each cube was 210m1. The internal parts of the moulds were thinly oiled for easy removal of the concrete samples from the mould. The mould was filled with fresh concrete in three layers. First layer filling about one-third of the mould was tapped with a tamping rod 25 times before another layer was added. After the third layer was tapped the surfaces of the concrete was then smoothen with a hand trowel and allowed to be hardened before removal from the mould and cured in water. Forty eight (48) cubes were produced for 7, 14, 21 and 28 days curing age (i.e. 12 cubes per age). The quantity of cement required to produce concretes was partially replaced with SCBA in percentage.

RESULTS AND DISCUSSION

Preparation of SCBA and Physical Tests on Aggregates

In the preparation of SCBA, total weight of 34.7kg SCB was collected and incinerated in furnace yielded 5.512kg of SCBA. This was sieved through 425μm to remove black carbon and 4.82kg of SCBA was collected. The percentage of SCBA obtained from SCB was 15.9%. Total usable SCBA obtained passing through 45μm sieve was 2.7Kg (conforming with ASTM-C595, 1985).

The particle size distribution is the analysis of soil samples which involves the determination of the percentage by mass of particles within the different size ranges. The particle size distribution of a coarse and fine aggregates used was determined by the method of sieving. 1000g and 3000g of oven dried samples of fine and coarse aggregates respectively were passed through series of standard test sieves having successively smaller mesh sizes. The mass of sample retained in each sieve was determined and the cumulative percentage by mass passing each sieve was calculated. This was used in analyzing uniformity and gradation of samples. Particle size distribution curve of fine and coarse aggregates are shown in Figures 1 and 2.

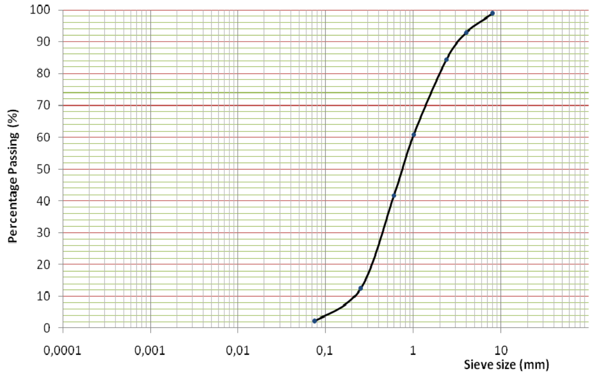

Figure 1: Graph of percentage passing of fine aggregate Vs sieve size (mm)

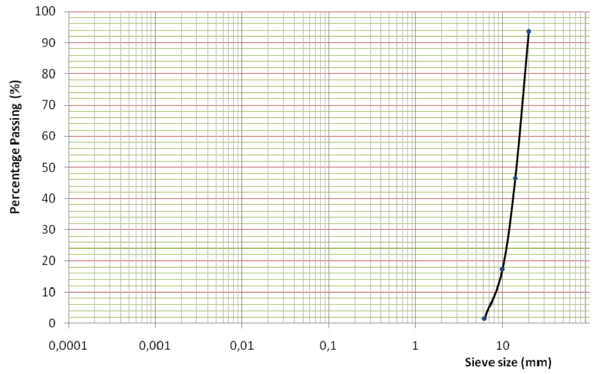

Figure 2: Graph of percentage passing of coarse aggregate Vs sieve size (mm)

The effective size of particle size distribution (PSD) at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing are 0.22mm, 0.60mm and 1.50mm respectively for fine aggregates. Similarly, the effective size at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing are 8.20mm, 13.00mm and 17.00mm respectively for coarse aggregates. Coefficient of uniformity, C_u and coefficient of curvature C_c for fine and coarse aggregates were estimated to be 6.8 and 1.1, and 2.07 and 1.22 for fine and coarse aggregates respectively. These results revealed that the aggregates satisfied ASHTTO classification of $Cu>4$ and $1<Cc<3$ for the aggregates.

The average specific gravities (G_s) of 2.43 and 2.77 were respectively obtained for fine and coarse aggregates through standard procedure of analysis. Also, the water absorption capacities of 20.3% and 1.9% were equally obtained.

Chemical Analysis Test on SCBA

The chemical test to determine the percentage composition of compounds present in SCBA was carried out at the Department of Chemistry, *University of Lagos, Lagos state, Nigeria. The method adopted was atomic absorption spectrometric method. The results are as shown in Table 1.*

Table 1: Percentage Composition of Each Oxide of SCBA

Oxides	% composition by mass
SiO_2	72.853
Fe_2O_3	6.961
Al_2O_3	1.077
PbO	ND
Na_2O	1.968
CaO	9.968
MgO	6.491
K_2O	6.768
CuO	0.096
LOI	4.233

The results of chemical analysis of SCBA in Table 1 and chemical component of OPC as stated by Nwofar and Sule (2010) showed that SCBA has a considerably high percentage of silicon oxide when compared to OPC. According to ASTM-595(1985), summation of silica, alumina and ferric components for pozzolanic materials must not less than 70% (ASTM, 1985). The results in Table 1 yielded 80.55% and thus SCBA is pozzolanic material.

The result of workability of concrete (slump test) for 0%, 10%, 20% and 30% replacement of SCBA are shown in the Figure 3. The effect of SCBA on the workability of the fresh paste decreases with increase in percentage of SCBA. This shows that SCBA absorbed more water than cement.

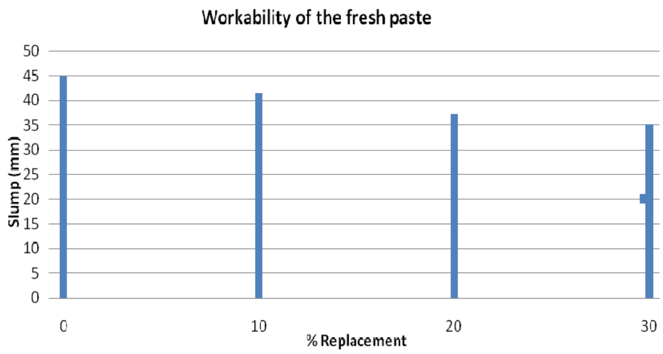

Figure 3: Graph of slump (mm) against % replacement

For different cubes of concrete produced with various percentage replacement of cement with SCBA, densities and compressive strengths were measured at different ages of curing and average computed. Figure 4 shows the variation of average density with % replacement. The results indicated that the average density decreases with increase in percentage replacement of SCBA with cement. The compressive strength of the concrete cubes for all the mix ratios increases with curing age and decreases as the SCBA content increases. The percentage reduction of compressive strength for 10%, 20% and 30% replacement of cement with SCBA compared with control are 16.8%, 25% and 35.5% respectively. Figure 5 shows the variation of compressive strength of hardened concrete with increase in percentage of SCBA. Figure 6 shows the variation of compressive strength N/mm² with curing ages. The compressive strength decreases with increase in SCBA while it increases with increase in curing age. Concrete made from OPC (0% ash) has higher compressive strength at 28 days of curing than concrete made by varying SCBA to cement content.

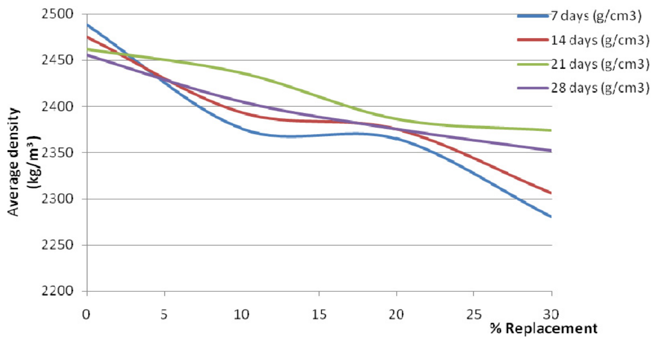

Figure 4: Variation of average density with % replacement

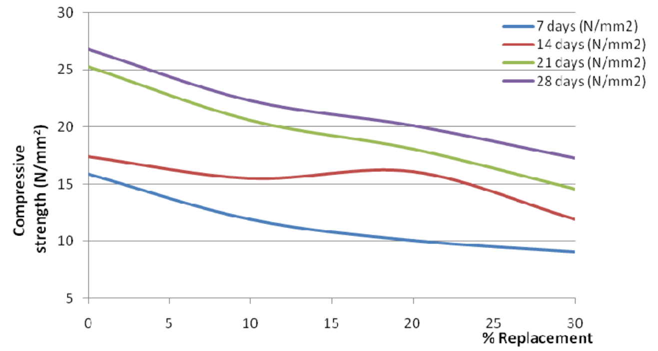

Figure 5: Variation of compressive strength N/mm² with % replacement of cement with SCBA

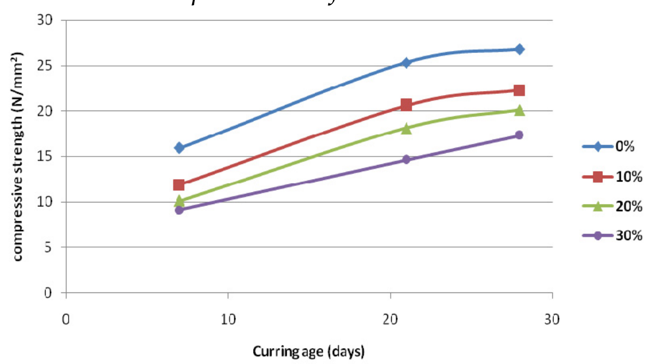

Figure 6: Variation of compressive strength N/mm² with curing ages

The PAI of different percentage replacement of SCBA as expressed in ratio of compressive strength of different percentage replacement to that of control specimen (i.e. 0% SCBA replacement) were obtained to be 83.2%, 75% and 64.5% for 10%, 20% and 30% of SCBA replacement respectively. 10% and 20% replacement satisfied the ASTM C595–85 specification that the PAI with OPC should be of minimum of 75% PAI.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Investigation of SCBA as partial replacement of cement in concrete production has been explored. The conclusions are as follows;

(i) *The calculated target mean strength of 31.56N/mm² was not achieved. This may be as a result of some factors like mode of mixing (hand mixing), compaction and the reactivity of the SCBA.*

(ii) *For control, the compressive strength was 26.8N/mm². This can be used for plain and reinforced concrete with lightweight aggregate and reinforced concrete with normal aggregate.*

(iii) *10% replacement of cement with SCBA yielded compressive strength of 22.3N/mm² and 83.2% of PAI; 20% replacement yielded 20.1N/mm² and 75% of PAI, and 30% replacement yielded the compressive strength of 17.3N/mm² and 64.5% of PAI. 10% and 20% replacement can be used for reinforced concrete with normal aggregates and 30% for reinforced concrete with lightweight aggregates.*

(iv) *The compressive strength of the concrete cubes for all the mix ratios increases with curing age and decreases as the SCBA content increases. The percentage reduction of compressive strength for 10%, 20% and 30% replacement of cement with SCBA compared with control are 16.8%, 25% and 35.5% respectively.*

(v) *From the density result, the SCBA concrete can be classified as normal weight concrete. The percentage reduction in density for 10%, 20% and 30% replacement of cement with SCBA are 2.7%, 6.7% and 8.47% respectively.*

(vi) *It was clearly shown that SCBA is a pozzolanic material that has the potential to be used as partial cement replacement material and can contribute to the environmental sustainability.*

Recommendations

SCBA is a pozzolana and can be recommended for use as partial replacement of cement in concrete production at a percentage up to 20%. For environmental sustainability, SCB can be utilized for the production of lightweight, durable and cheap concrete. Since it is available in significant quantities across the country

Acknowledgement

The authors acknowledge the management of Departments of Civil Engineering, Kwara State Polytechnics; Chemistry, University of Lagos and Civil Engineering, University of Ilorin for providing technical supports and other useful information in carrying out this study.

References

[1.] *Aigbodion, V. S, Hassan, S. B, Ause, T. and Nyior, G. B.: Potential Utilization of Solid Waste (Bagasse Ash), Journal of Minerals & Materials Characterization & Engineering, 9, pp. 67-77, 2010*

[2.] *Agboire, S., Wada, A. C. and Ishaq, M. N.: Evaluation and Characterization of Sugarcane Germplasm Accessions for their Breeding Values in Nigeria, The Journal for Food Technology in Africa, Vol. 7, No 1, pp. 33-35., 2002.*

[3.] *ASTM Standards, Concrete and Mineral Aggregates Section 4 Volume 04.01, cement, Lime, Gypsum and Section 4, Volume 04.02, USA, 1985.*

[4.] *Baguant, K.: Properties of Concrete with Bagasse Ash as Fine Aggregate, International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete,153 (18), pp. 315-337, 1995.*

[5.] *British Standard 12:112: Specifications for Aggregate Type, British Standard Institution, London, 1996.*

[6.] *British Standard 812: Methods of sampling and Testing of Mineral Aggregates, Sands and Fillers. British Standard Institution, London, 2002.*

[7.] *Cordeiro, G. C, Toledo R. D. and Fairbairn, E. M.: Ultrafine Sugarcane Bagasse Ash: High Potential Pozzolanic Material for Tropical Countries, IBRACON Structures and Materials Journal, 3: pp. 50-58, 2010.*

[8.] Ganesan K., Rajagopal, K. and Thangavel, K.: Evaluation of Bagasse Ash as Supplementary Cementitious Material, Cement & Concrete Composites. 29, pp. 515–524, 2007.
[9.] Ghavami, K., Toledo, R. D. and Barbosa, N. P.: Behavior of Composite Soil Reinforced with Natural Fibres. Cement and Concrete Composites, 1999.
[10.] Kajima (2012), Available at http//www.kajima.co.jp/ir/annual/2012/research-development.html
[11.] Megat, M. A., Brooks, J. J., Shahid, K. and Patrice R.: Influence of Supplementary Cementitious Materials on Engineering Properties of High Strength Concrete, Construction and Building Materials, 15: pp. 2639–2648, 2011.
[12.] Nwofar, I. C. and Sule, S.: Stability of Groundnut Shell Ash (GSA) with Ordinary Portland Cement (OPC) Concrete in Nigeria, 2010.
[13.] Oluremi, A. A.: Input of Local Materials in Building as a Means of Reducing Cost of Construction. Journal of Nigeria Institute of Quantities Surveyors, Nigeria, pp. 12 – 14, 1990
[14.] Sirirat, J. and Supaporn, W.: Pozzolanic Activity of Industrial Sugarcane Bagasse Ash, Journal of Science and Technology, 17: pp. 349-357, 2010.
[15.] Swamy, R. N.: Pozzolana - A Review, AC1 Journal USA Vol. 72 No 5, pp. 225 – 232, 1986.

ACTA Technica CORVINIENSIS
BULLETIN OF ENGINEERING
ISSN:2067-3809