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The use of sugarcane wastes in concrete

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Abstract

Cement production is held responsible of polluting the atmosphere with carbon dioxide (CO₂). The researchers have shown that manufacturing of one ton of cement releases about half ton of carbon dioxide into the atmosphere. So, there is a need to produce alternative cement instead of ordinary Portland cement (OPC). Waste materials such as sugarcane bagasse are difficult to dispose which result in environmental hazard. This study investigates the use of sugarcane wastes in concrete, where two forms of sugarcane wastes were used in this study. The first form was using the sugarcane bagasse ash as partial replacement of cement in both mortar and concrete mixes, where, in mortar, the used ratios were 5, 10, and 20% of the total weight of cement. But in concrete, the used ratios were 5, 7.5, and 10%. The samples were tested in compression and split tension. The results showed that the optimum ratio of using sugarcane bagasse ash as a partial replacement of cement was 5%. Similar results were obtained in both mortar and concrete sample. For the bagasse fibers, adding the fibers to the concrete mixture led to the reduction of compressive strength. But on the other hand, the addition of bagasse fibers reduced the crack width formed in the slab.

Keywords: Sugarcane bagasse ash, Ordinary Portland cement, Compressive strength, Splitting tensile strength

Introduction

According to the study prepared by the National Planning Center in Egypt, the volume of agricultural waste in Egypt which affects the environment reaches 35 million tons annually, of which about 23 million tons of plant waste, benefiting from about 11 million tons and losing 12 million tons. Agricultural corps produce large amounts of agricultural wastes. Some of them are reused as fertilizers for agricultural land, but the remaining amount is incinerated in uncontrolled and random ways and has a negative impact on the environment. This issue motivated the researchers to work hard to get the most benefit from these wastes. The first solution for these wastes is to recycle them by converting them to organic fertilizer, which is used to increase the organic matter in the soil and increase the biological activity [1, 2].

Another alternative is to use them in the production of feed for cattle where there is scientific research to the possibility of finding alternative feed from agricultural or field waste [3].

Also, the agricultural wastes can be used in concrete as a cementitious material to improve its mechanical properties because of the presence of silica and alumina in its

composition which catalyzes the pozzolanic reactions. One of these agricultural wastes is sugarcane wastes which had been utilized in concrete in different forms and have proved to be beneficial as it can improve the mechanical properties of concrete. For example, sugarcane juice was examined as a partial replacement of mixing water where it helped to delay the setting time of concrete [4]. Another form of sugarcane wastes is the bagasse ash as there were a lot of researches carried out to investigate the use of its ash as a replacement of cement in concrete and mortar [5–8]. The results obtained were promising as the result showed a significant increase in compressive strength of concrete when using sugarcane bagasse ash as a partial replacement of cement within certain limits of replacement. Another application of using the sugarcane wastes is the of the bagasse ash as a partial replacement of sand in concrete, where it proved to increase the compressive strength of foam concrete and to reduce the thermal conductivity of the concrete as well [9].

On the other hand, studies were carried out on the effect of using the sugarcane bagasse fiber itself in concrete [10, 11] and showed that the used of bagasse fibers itself improved some mechanical properties of concrete. It was reported that using bagasse fiber in normal concrete and light weight concrete up to 0.5% increased its compressive strength [12]. Another application for the bagasse fibers is to add them to soil blocks to improve its properties, where adding the fibers to the to the soil blocks contributed to a reduction in density of the blocks, which can be attributed to the low density of the fiber, and it is found also that the water absorption of the units increased significantly. But on the other hand, compressive strength and tensile strength of the reinforced soil blocks increased over the unreinforced soil blocks, and the optimum effectiveness of the enhancement was obtained at 0.5% mass content of the fibers to the soil [13].

Also, recent studies had been carried out on the bagasse fibers to investigate its effect when used as reinforcement in the composite materials [14–16]; the results showed that the use of sugarcane bagasse fibers improved the tensile strength and flexural strength and increase the impact absorbed energy when added to the composite materials. A recent study showed the feasibility of using the waste sugarcane bagasse fibers in the production of cement bricks [17]; the study showed that the bagasse fibers can be used to replace a portion of the cement used in the production of the bricks (1.5% replacement) without affecting the properties of the brick, and that can have an economical and environmental impact.

Methods

The experimental program was divided into three main phases: phase 1 was designed to examine the effect of sugarcane bagasse ash on the compressive strength of mortar cubes, phase 2 was designed to investigate the effect of sugarcane bagasse ash on the mechanical properties of concrete, and phase 3 was designed to examine the effect of using the bagasse fibers itself on the properties of concrete.

Five different types of samples were used in the experimental program where standard cubes of $50 \times 50 \times 50$ mm were used for the compression tests of mortar, cubes of dimensions $150 \times 150 \times 150$ mm were used for the compression test of concrete, standard cylinders 150×300 mm were used for the splitting tension test of concrete, prisms of dimensions $500 \times 100 \times 100$ were used for flexural test specimens, and finally slabs of

Table 1 Chemical composition of SCBA and OPC

Oxides	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	P ₂ O ₅
SCBA	26.94	1.66	1.5	8.54	5.29	7.95	3.11	21.4	8.18
OPC	21.2	4.67	5.05	64.73	1.5	2.05	0.3	0.22	–

Table 2 Physical properties of SCBA and OPC

Properties	OPC	SCBA
Specific gravity	3.15	2.14
Fineness(m ² /kg)	390	310
Color	Grey	Light grey
Initial setting time (min)	60	–

dimensions 800 × 800 × 100 mm were used to study the effect of adding bagasse fibers on the shrinkage cracks of concrete.

Material used

Sugarcane bagasse ash (SCBA)

The bagasse was obtained from juice extractors factories, where the sugarcane bagasse waste is washed in a tank with water and then dried by placing it in the sun. Then, it was left to burn completely in air up to 600 °C until it is converted totally to ashes; then, the ashes were placed in an oven and heated up to 200 °C; then, the temperature was maintained for 2 h to get rid of the remaining organic matters (carbon). After the ash was taken out of the oven, it was ground in a grinder to obtain finer particles.

Cement

Ordinary Portland cement (OPC) CEM I 42.5N produced by Suez Company was used in all mixes. The chemical composition of both sugarcane bagasse ash and OPC is given in Table 1. Physical properties of SCBA and OPC are shown in Table 2.

Aggregates

The coarse aggregate (dolomite) used in this experimental work was locally available in Egypt from Ataka Mountain in Suez city. The coarse aggregates had nominal maximum size of 12.5 mm and specific gravity of 2.58. The fine aggregate used in this investigation was natural siliceous sand, with fineness modulus 2.48. Testing on coarse and fine aggregate was carried out according to the Egyptian Standard Specification (1109/2002).

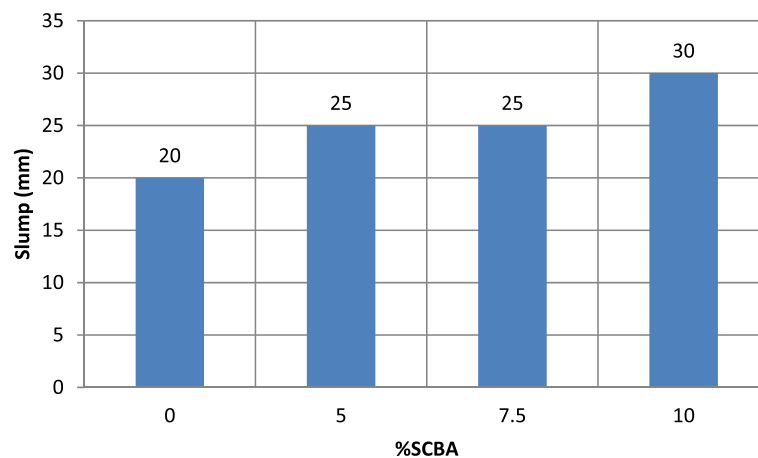
Mix proportions of specimens

In phase 1, the mortar cubes were mixed by using 3:1 proportions to determine its compressive strength, where three parts of sand was mixed with one part of cement and the W/C was 0.5. The replacement levels of cement by SCBA were selected as 0% (control mix), 5%, 10%, and 20%.

In phase 2, the concrete mix used in the experimental program was designed using the British method for design of concrete mixes “DOE.” The replacement levels of cement by

Table 3 Mixing proportions of all specimens

Mix no.	Gravel (kg/m ³)	Sand (kg/m ³)	Cement (kg/m ³)	SCBA (kg/m ³)	Water (kg/m ³)
Phase 2					
A	1302	701	300	–	150
B	1302	701	285	15	150
C	1302	701	277.5	22.5	150
D	1302	701	270	30	150
Phase 3					
I	1302	701	297	3	150
II	1302	701	294	6	150

**Fig. 1** Results of slump cone test

SCBA were selected as 0% (control mix), 5%, 7.5%, and 10%. For all specimens, water/binder (w/b) ratio was kept constant, and it was 0.5 where the total amount of binder content was 300 kg/m³ for every specimen. The content of fine and coarse aggregate is constant in all specimens.

In phase 3, sugarcane bagasse itself was used in cubes, prisms, and slabs. In cubes and prisms, the replacement levels of cement by sugarcane bagasse were 1% and 2% of the total weight of cement, but in slab, the replacement of cement with sugarcane bagasse took place with ratio 1% of the total weight of cement.

The concrete mix proportions of all specimens of phases 2 and 3 are shown in Table 3.

Results and discussion

Fresh concrete

Workability

In order to determine the workability of concrete, slump cone test was carried out. Freshly mixed concrete was tested for workability with different ratios of SCBA, and the results are given in Fig. 1. From results, it is shown that the more percentage of SCBA is used to replace cement in concrete, the more slump values are obtained; this can be attributed to the fact that the cement grains are finer than that obtained from the simple

way used to grind the bagasse ash. As a result, the bagasse ash had a lower specific surface area than the replaced cement which in return requires less amount of water to cover the surface leading to more slump values.

In phase 3 where bagasse fibers were added to the mix with ratios 1 and 2% of the total weight of cement, the slump was less than 15 mm.

Hardened properties

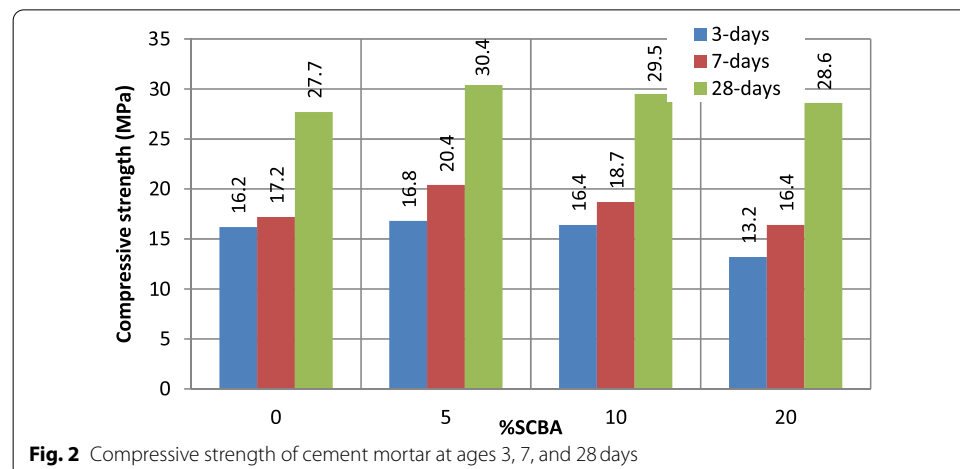
Compressive strength

In phase 1, the mortar cubes were tested at ages 3 days, 7 days, and 28 days. For this phase, only compression tests were carried out. The results are given in Fig. 2.

The compressive strength test results are presented in Fig. 2. The maximum compressive strength is observed at 5% SCBA replacement, and after this ratio, the results decreased. This sample gives strength up to 1.68, 2.04, and 3.04 MPa at ages 3, 7, and 28 days respectively. These results increased by 3.7%, 18.6%, and 9.75% at ages 3, 7, and 28 days respectively when compared with the control mix. This increase is due to the pozzolanic reaction as the C–H formed from the hydration process of cement reacts with silica in SCBA and forms more C–S–H.

In phase 2, the concrete cubes were tested in compression. The specimens in this phase were tested at ages 7 days and 28 days. The results obtained from the compression test are shown in Fig. 3.

The results are presented in Fig. 3. The compressive strength of the concrete samples with 5% replacement showed an increase of 17%, and 20.4% at ages 7 and 28 days respectively when compared with the control mix, while for the 7.5% and 10% replacements, the 7-day compressive strength of the specimens was almost the same value as the control one, but at 28-day age, there was a reduction in the compressive strength at both percentages of replacement. And hence, 5% SCBA represents the optimum value to replace the cement in concrete. Similar results were obtained previously by other researchers [8, 17, 18], where 5% showed the highest results obtained for compressive strength at 28-day age. A recent study [19] showed that a 5% replacement resulted in a reduction in strength at 28-day age, while for the same ratio but at 120-day age, the results had the highest compressive strength values when compared to the control specimens.



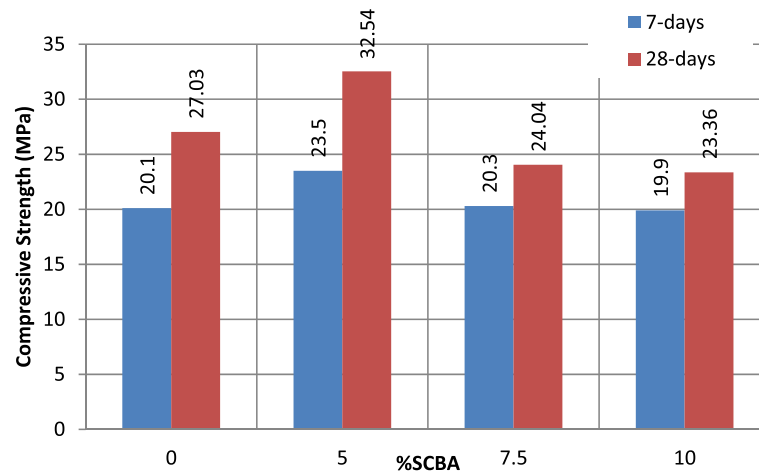


Fig. 3 Compressive strength of concrete cubes at ages 7 and 28 days

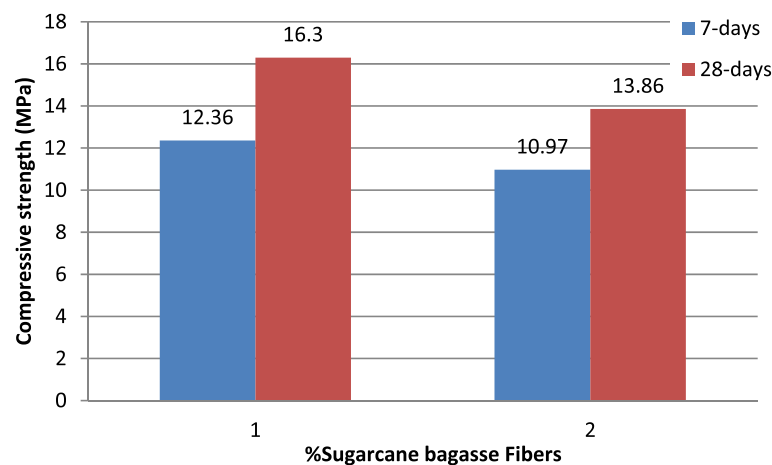


Fig. 4 Compressive strength of concrete cubes at ages 7 and 28 days made by using sugarcane fibers

For phase 3 where the bagasse fibers are added to the concrete mix, all the cube specimens showed a significant reduction in the compressive strength as shown in Fig. 4. These results can be referred to the improper treatment of fibers and mixing procedures, where the fibers should have had special treatment to get rid of the glucose. As it is well known that the glucose affects the setting time of cement and can affect the properties of concrete, also during the mixing of concrete, the fibers were dry, so when they were added to the mixture, they absorbed a considerable amount of water which resulted in harsh concrete, and during the mixing process, it was clear that the mix needs more water. Previous research [20] showed that the treatment of the bagasse fibers significantly affects the behavior of the concrete.

Splitting tensile strength

In phase 2, cylinders of size 15 cm diameter and 30 cm height were tested for splitting tensile strength at age 28 days. The results at which the samples failed are shown in Fig. 5.

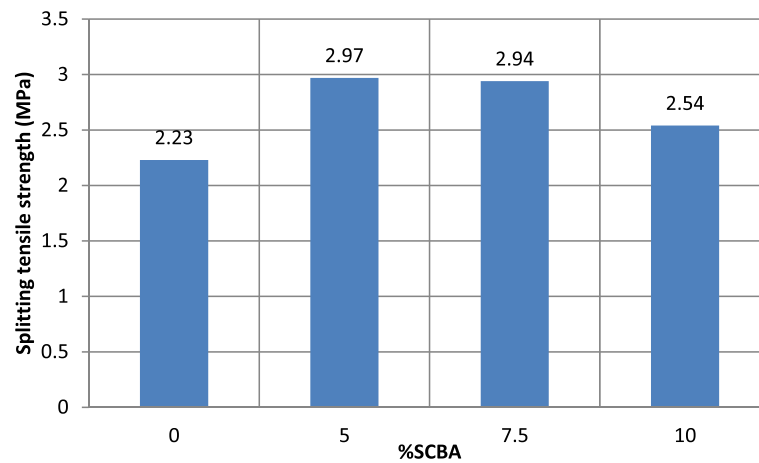


Fig. 5 Splitting tensile strength of concrete cylinders at age 28 days

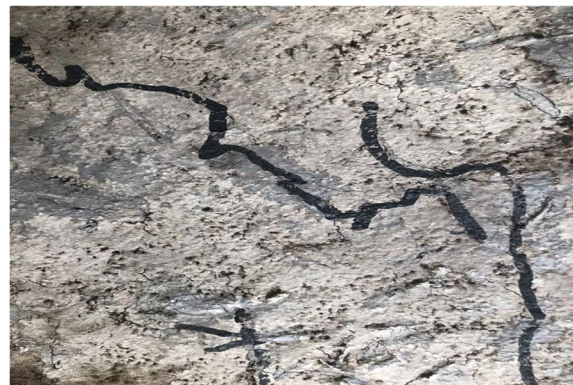


Fig. 6 Slab with fibers

The results of split tension test are presented in Fig. 4. The splitting tensile strength is up to 2.97 MPa at age 28 days. The optimum splitting tensile strength is observed at 5% SCBA replacement. This result showed an increase by 33.2% when compared with control mix.

Flexure strength

Prism specimens of size $500 \times 100 \times 100$ mm in phase 3, where sugarcane bagasse itself used, failed where all the results showed a significant reduction in flexural strength. Prism specimens were used only for bagasse fibers as it is thought to increase the flexural strength of the concrete. Since the obtained results were not satisfactory due to the aforementioned reasons (improper treatment of fibers), the results were disregarded.

Slab cracks

The bagasse fibers were added to concrete to check its effect on the crack formation in slabs, as the fibers can be used to bridge the cracks by resisting the tensile stresses obtained due to the shrinkage of concrete and to delay the formation of the cracks. Figures 6 and 7 show the cracks developed in the slab with fiber and in the control one.



Fig. 7 Control slab

The cracks formed in the slab with fibers were scattered in large numbers and smaller in length and width, while the cracks formed in the control slab (without fibers) were fewer but having wider in width and taller in the length. Although the bagasse fibers were not properly treated, but still it can help to resist the tensile stresses created within the concrete slab and to reduce the width of the formed cracks.

Conclusions

- Using SCBA as a partial replacement of cement proved to be significantly effective.
- There is an optimum percentage of replacement that gives the highest compressive strength and splitting tensile strength which was found to be 5% for SC in mortar, concrete cubes, and concrete cylinders.
- The results of optimum samples—which containing 5% SCBA—showed an increase in compressive strength by 20% and 33% increase in splitting tensile strength compared to control mix.
- Adding more SCBA after 5% results in decreasing the mechanical properties.
- The rate of gaining strength increases by time which can be attributed to the fact that using the ash results in the formation of more C-S-H compound as free CH from hydration process of cement would react with silica in SCBA that is characterized by long-term strength gaining.
- The workability of concrete increases by increasing the replacement percentage of SCBA in concrete.
- Using sugarcane bagasse fibers in concrete resulted in the formation of smaller cracks (in width and length) compared to the control specimen.

Abbreviations

SCBA: Sugarcane bagasse ash; OPC: Ordinary Portland cement.

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Authors' contributions

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Availability of data and materials

All materials were available locally in Egypt.

Declarations**Competing interests**

The authors declare that they have no competing interests.

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