Effect of Coarse Aggregate Gradation on the Strength Properties of Bagasse Ash Concrete

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ABSTRACT

This study investigated the coarse aggregate grades and the use of sugarcane bagasse ash as a replacement for cement to examine their effect on concrete strength. Ten concrete mixes were prepared in two groups using a 1:2:4 mix ratio and a 0.48 water-to-binder ratio. Sugarcane bagasse ash was used in 0 and 10% dosages by weight of cement. Five grades of aggregates were used: 4.75-7, 7-10, 10-13, 13-20, and 4.75-20mm. Six 6"/12" concrete cylinders were prepared for each group and cured for 28 days to test their compressive and split tensile strengths. The results showed that bagasse ash caused a reduction in strength properties in both well- and specific-graded concrete. It was also observed that 10-13mm aggregate concrete with and without bagasse ash had more strength than the respective well-graded. Although a minimum decrease in strength was observed, a 10% dosage of sugarcane bagasse ash was optimal to save cement content in both specific and well-graded aggregate concrete. This study provides a new framework for using graded coarse aggregates and replacing cement with bagasse ash.

Keywords-compressive strength; tensile strength; green concrete; sugarcane bagasse; sustainability; waste management

I. INTRODUCTION

Concrete is the most widely used material in the industry, giving the freedom to construct the desired shapes, orientations, and sizes. However, it requires good care and control in the use of constituent materials to ensure the proper strength of the final product. The recent boom in construction gives beautiful and eye-catching infrastructures but consumes a large quantity of natural and man-made ingredients. The use of aggregates has reached an alarming situation due to the depletion of conventional natural sources. Moreover, the demand for cement causes a serious environmental problem due to the emissions of harmful gases. The boom in construction has also posed a serious problem for demolition and construction waste due to the unavailability of dumping space, particularly in city centers. Construction is not the only industry that produces waste at a serious level, as several other primary industrial processes also generate waste that requires proper dumping. The sugar industry is one such example, as it uses sugar cane for its primary processes and generates bagasse in large quantities. Bagasse is used in the development of secondary products, but residuals remain a serious issue.

The ingredients of the concrete matrix have many advantages and some disadvantages. The search for alternative materials for concrete ingredients to overcome its weaknesses and conserve natural sources or reduce the use of man-made materials is an active research area. Several alternative materials have been proposed to be used in the concrete matrix, such as residual waste from primary industrial processes. Bagasse ash is one of them. Different materials have shown different behaviors for fresh and hardened properties with strength variation. The preparation of concrete requires good care in the use of materials to ensure the proper strength of the final product. Well-graded aggregates are among them, but in many cases, coarse aggregates are not well-graded. Sometimes, aggregate gradation is not performed and there is a chance that such concrete will have poor strength in its hardened state despite good care in batching, mixing, placing, and curing. The current study investigated the effect of coarse aggregate gradation on concrete strength properties using bagasse ash as a partial replacement of cement. This study not only examined the effect of gradation on strength but also used an indigenous waste material as a partial cement replacement, as it could tackle the waste management problem to some extent.

II. LITERATURE REVIEW

The controlled burning of sugar bagasse produces ash that has cementitious properties and has been used in concrete as a partial replacement for cement in various studies. In [1], the use of bagasse ash in concrete was reviewed, concluding that it has good cementitious properties and can be used in concrete to alter its properties. In [2], bagasse ash was used in various dosages to develop M20 concrete, the test results of 7- and 28-day cured specimens showed a comparable increase in split tensile strength and workability of the 10% dosage specimens, but an additional increase in ash dosage resulted in a decrease in split tensile strength and workability. The same results were also observed in [3]. In [4], bagasse ash was used in various dosages as a replacement for cement to develop M30 concrete, and the test results of 7- and 28-day cured specimens showed increased compressive, split tensile, and flexural strength for up to 20% dosage of bagasse ash, but further addition of ash resulted in decreased strength and workability of the concrete. On the other hand, in [5], bagasse ash was used to produce M20 concrete, the test specimens were cured for 7, 14, and 28 days, and the results showed that the 25% dosage was optimal for the strength properties while the 15% was optimal for workability. In [6], M20 grade concrete was made with 0-30% sugarcane bagasse ash, and the test results of cubes, cylinders, and prisms cured for 7, 14, and 28 days showed that 25% replacement of cement with ash was optimal with a negligible decrease in strength properties. In [7] and [8], sugarcane ash was used up to 15 and 25%, respectively, to produce M25 concrete, and the test results showed that 5% and 15% were the optimal dosages, respectively.

In [9], bagasse ash was used in 0-25% dosages to produce M25 concrete and the test results of 7- and 28-day cured samples showed that 15% was the optimal, as it reduced only 7, 1, and 6% compressive, tensile, and flexural strength, respectively. In [10], bagasse ash was used as a 20% cement replacement to develop M25 concrete, and the results showed an increase in slump with the increase in the dose of bagasse ash. Maximum residual compressive strength equal to 26.45MPa in comparison to 27.7MPa, and tensile strength equal to 1.89MPa in comparison to 1.94MPa were observed at the 5% dosage, concluding that this was the optimal bagasse ash dosage for cement replacement. Similarly but for M20 concrete, the 5% dosage was observed as the optimum for compressive, tensile, and flexural strength with different residual strength values [11]. In [12], the 6% dosage was found as the optimal level of cement replacement. In [13], a 2% dose was observed to be optimal in terms of strength of the bagasse ash concrete. In [14], bagasse ash was used to produce M20 and M15 concrete, where a 45% and 28% increase in slump was recorded at replacement levels of 5% and 10%, and the increase in compressive strength was recorded as equal to 11.6% and 3.5% at dosages of 5% and 10%, respectively. A similar trend was observed for the strength of M15 concrete, concluding that 5% was the optimal dosage of ash regarding the increase in compressive strength. In [15, 16], M30 and M35 concrete was produced using bagasse ash, respectively, concluding that a 15% dosage had the optimum strength parameters. Bagasse ash was also used in [17-21] to examine dose optimization for the strength properties of concrete. Table I summarizes the results of sugarcane bagasse ash as a cement replacement published in various studies.

The strength of concrete is the key property for proper durability and serviceability during the service life of structures. Well-graded aggregates in concrete matrix ensure proper strength of the final product. However, unfortunately, in many cases, the gradation of the aggregates is omitted, resulting in unevenly graded aggregates that affect the final strength of the hardened concrete. The effect of gradation on concrete strength was studied in [22]. Using well-graded, uniform, and gap-graded aggregates, M20 concrete was tested for slump, compaction factor, and compressive strength. The results showed that the gradation of fine aggregates was more influential than that of coarse aggregates. The compaction factor test was more sensitive and gave better results for gap-graded aggregates and similar were the results of the compressive strength test. Therefore, this study argued that although well-graded aggregates result in better concrete, the presence of large particles prevents homogeneity when concrete is stressed.

TABLE I. SUMMARY OF LITERATURE REVIEW

	Reference	Parameters of study	Concrete	Opt. dosage
1	[2], [3]	Workability, CS, TS	M20	10%
2	[4]	Workability, CS, TS, FS	M30	30%
3	[5], [6]	Workability, CS, TS, FS	M20	25%
4	[7]	CS, TS	M25	5%
5	[8]	CS	M25	15%
6	[9]	CS, TS, FS	M25	15%
7	[10]	CS, TS	M25	5%
	[11]	CS, TS, FS	M20	
8	[12]	CS, TS, FS	M20	6%
9	[13]	Workability, CS	M30	2%
10	[14]	CS	M20, M15	5%
11	[15]	CS, TS, FS	M30	15%
	[16]	CS, TS, Voids	M35	
12	[17]	CS, TS	M20	8%
13	[18]	Workability, FS	M25	10%
14	[19]	Slump, compaction factor, CS	M35	10%
15	[20]	CS	M35	10%
16	[21]	CS, FS	M35	10%

In [23], the effect of uniformly graded aggregates was examined in geopolymer concrete with fly ash and GGBS. A comparison of G40 and M40 showed better performance of 12.5mm size aggregates in thin precast elements than conventional concrete. In [24], the effect of different grading of the aggregates was investigated on conventional concrete by designing 8 different mixes, concluding that the compressive strength of concrete can be improved by more than 50% by altering the grade of aggregates. In [25], the effects of the type and size of aggregates were investigated on the compressive strength of concrete, examining three types, (quartzite, granite, and river gravel) and three sizes (12, 20, and 40mm) along with fly ash and superplasticizer to evaluate density, compressive strength, and tensile strength. The results showed that the 12mm quartzite aggregates had the highest strength. In [26], the effects of aggregates from different sources in Pakistan were studied, using 28-day cured samples of a 1:2:4 mixture, and the results showed a very good increase in compressive strength using a combination of fine aggregates from Lawrencepur and Kashmore in equal proportions than aggregates from one source alone. In [27-28], the effect of gap gradation was studied on the workability and flexural strength of concrete, showing a good increase in both test parameters for mixes with aggregates less than 5mm, but gap-graded concrete required more binder contents than usual to ensure workability and strength. Thus, there was an argument that although careful gap gradation may result in more strength of the final product, well-graded concrete is better for binder content and durability. In [29], a completely different phenomenon was observed regarding binder content, showing that 15% less binder can be used for the same strength with careful gap gradation of aggregates. In [30], the effect of uniformly graded 1:1.5:3 concrete was studied for its workability and strength properties, using aggregates of 9.5, 12.7, and 19.1mm. A three times higher slump value was noticed compared to well-graded aggregates with a decrease in slump values as aggregate size increased. The compressive strength was also recorded as 5%, 16%, and 21% higher than that of well-graded aggregates. Moreover, cement-treated aggregates did not have any positive impact on the strength of rigid pavements. In [31-33], aggregate gradation was attempted to minimize the cost of concrete by reducing the cement content. Furthermore, recycled coarse aggregates from demolished concrete have also been used in concrete to study the effect of fly ash on strength properties [34], water penetration of recycled aggregate concrete [35], compressive strength of no-fines recycled aggregate concrete [32], and flexural strength of no-fines recycled aggregate concrete [36].

The evident scatter of these results indicates that more studies are required to reach a certain level of confidence in the use of the materials. This study performed a laboratory investigation on the combined effect of different gradations of coarse aggregates and sugarcane bagasse ash as cement replacement on the strength properties of concrete.

III. MATERIALS AND TESTING

This study used ordinary Portland cement under the brand name Pakland, and with a value of 2.79. Fine aggregates passing through the 4.75mm sieve were obtained from approved quarries, which had a specific gravity of 2.62. Coarse aggregates were also obtained from the same quarries, having a size between 4.75-20mm and 2.8 specific gravity. The coarse aggregates were washed and dried before being used in the concrete mix. To achieve the proposed target, coarse aggregates were sieved and separated into groups of 4.75-7mm, 7-10mm, 10-13mm, and 13-20mm, to produce four concrete batches. Additionally, one batch of concrete with coarse aggregates between 4.75-20mm (well-graded aggregates) was also prepared. Therefore, five batches of concrete were prepared. Filtered tap water from the city water supply, having a pH of 7.1, was used for washing the aggregates, preparing the concrete mix, and curing.

The sugarcane primarily used in the preparation of sugar contained approximately 26% of bagasse, 50% moisture, and 0.62% residual ash. Figure 1 shows the sugarcane bagasse obtained from a sugar mill in Nawabshah. The sugarcane bagasse was dried in open air for a few days followed by controlled burning at 700°C. The residual bagasse ash contained 50% cellulose, 25% hemicellulose, and 25% lignin. Table II shows the chemical analysis of bagasse ash. It should be noticed that its silica and alumina contents provide good cementitious properties. The ash was then used as a 10% replacement of cement by weight in 5 batches with 10% bagasse ash and another 5 batches without bagasse ash to compare the test results. For all mixes, a 1:2:4 ratio and a 0.4 water-to-binder ratio were used. The batching of ingredients was performed by weight. All the ingredients were then mixed in a concrete mixer until the formation of a uniform paste, and 10 standard-size cylinders (6×12″) were prepared in each batch. The inner of the molds was oiled and the concrete was filled in three layers. A table vibrator was used to achieve the proper compaction. The molds were then left for 24 hours to let the concrete harden. Figure 3 shows some selected samples.

After 24 hours, the specimens were de-molded, allowed to dry in the air for a day, and immersed in potable water for 28-day curing, as shown in Figure 4.

TABLE II. CHEMICAL ANALYSIS OF SUGARCANE BAGASSE ASH

#	Component	Mass percentage
1	Silica (SiO_2)	66.89
2	Alumina (Al_2O_3)	29.18
3	Ferric oxide (Fe_2O_3)	
4	Calcium oxide (CaO)	1.92
5	Magnesium oxide (MgO)	0.83
6	Sulphur tri oxide (SO_3)	0.56
7	Loss of ignition	0.72

Fig. 1. Sugarcane bagasse.

Fig. 2. Bagasse ash.

Fig. 3. Specimens.

After curing, the specimens were taken out of the water and allowed to dry in the laboratory for one day. In each batch, 5 specimens were used to evaluate their compressive strength and 5 were used to determine the split tensile strength. The specimens were tested in a compressive strength machine under gradually increasing load until failure, following the ASTM C39 [37]. Figure 5 shows some specimens during testing. The load was then converted into compressive strength using the standard formula for the purpose $\sigma=P/A$.

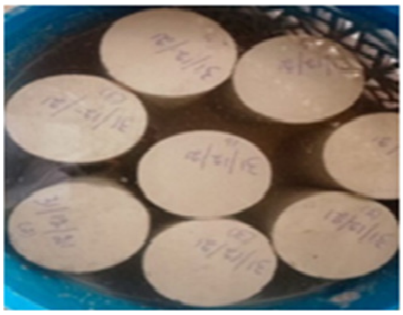

Fig. 4. Curing.

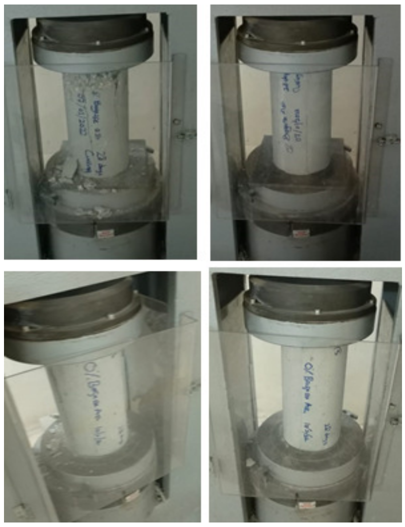

Fig. 5. Compressive strength test.

Fig. 6. Split tensile strength test.

The specimens were laterally loaded onto a universal testing machine, following ASTM C496 [38], with a gradually increasing load at a rate of 0.5kN/sec to determine their tensile strength, as shown in Figure 6. The crushing load was recorded and converted into split tensile strength using the standard formula $f=2P/\pi LD$. Table III shows the results obtained from the compressive and tensile strength tests for all specimens.

TABLE III. COMPRESSIVE AND TENSILE STRENGTH

Concrete mix	#	Compressive strength (MPa)		Split tensile strength (MPa)	
		Bagasse ash percentage (%)			
		0	10	0	10
M1:	1	27.15	23.99	2.66	2.45
4.75-7	2	28.41	27.95	2.82	2.24
	3	29.79	19.48	2.74	2.27
M2:	1	32	29.41	2.96	2.7
10-Jul	2	35.3	28.81	3.21	2.66
	3	32.19	28.47	3.06	2.54
M3:	1	34.39	30.93	3.39	2.8
13-Oct	2	35	31.45	3.16	2.85
	3	37.67	28.93	3.11	2.7
M4:	1	31.76	27.67	3.18	2.66
13-20	2	32.97	27.95	3	2.5
	3	32.61	28.07	3.12	2.51
M5:	1	33.36	31.91	2.98	2.74
4.75-20	2	33.75	27.91	3.19	2.78
	3	33.51	28.51	3.19	2.73

IV. RESULTS AND DISCUSSION

Figure 7 shows the compressive strength of concrete with 0% and 10% bagasse ash. Although there is a fluctuating trend in the compressive strength of individual samples, the difference in the strength of individual samples is small. Table IV and Figure 8 show the average compressive strength of the samples per batch. It can be observed that the compressive strength of concrete with bagasse ash was smaller than the one without. Although the ash has good cementitious properties, they are not equal to cement's, therefore cement replacement with ash affects the strength. Furthermore, it can be observed that the gradation of concrete had also an impact on the final strength. The maximum strength in concrete without bagasse ash was recorded in M3 (10-13mm aggregates), as its value was even higher than the compressive strength of well-graded aggregates (+6.4%). M1 and M2 mixes had less strength than M5, due to the smaller size of aggregates which have less strength. M4 also had less strength than M5. The mix contained large-sized aggregates, and the lack of small-sized particles should have resulted in voids inside the body of concrete resulting in less strength. M3 had the highest strength among the considered mixes due to medium-sized particles being able to contribute strength and fill the voids of the concrete. The fourth column lists the deviation of the average compressive strength of concrete mixes with and without 10% bagasse ash. The lowest error was recorded in M5 with well-graded aggregates and then in M2 with 7-10mm aggregates. This shows that small-sized aggregates in the concrete matrix gave better strength results, but the effort required to separate the grades is more. The last two columns of the table list the percentage deviation of the strength concerning the well-graded aggregates without bagasse ash. Figure 9 shows the percentage error of concrete with bagasse ash versus without bagasse ash and with well-graded aggregates. Table III and Figure 9 show that M3 had the least reduction in compressive strength due to the reasons mentioned above.

Figure 10 shows the split tensile strength for individual samples with and without bagasse ash. Table V shows the average split tensile strength of all specimens in each group, along with the percentage change of each group and for well-graded aggregates without bagasse ash. The results are listed in a pattern similar to those of average compressive strength. Table V and Figures 10-12 show that again the M3 mix (10-13mm aggregates) had the maximum split tensile strength for both concrete types. Graded aggregate concrete had an increase of 3.58% compared to well-graded aggregate concrete, but when using 10% bagasse ash it had a decrease of 10.54% in tensile strength. The decrease was the lowest among all the grades used. It can be further observed that the variation in split tensile strength of M3 concrete with and without bagasse ash was approximately 9%. The same percentage was recorded for concrete with well-graded aggregates.

TABLE IV. AVERAGE COMPRESSIVE STRENGTH

Average compressive strength			% change		
Mix: mm	Bagasse ash		Same group	Well graded agg.	
	0%	10%	10%	0%	10%
M1: 4.75–7	28.45	23.81	-16.33	-15.18	-29.02
M2: 7-10	33.16	28.9	-12.86	-1.13	-13.84
M3: 10-13	35.69	30.44	-14.71	6.4	-9.26
M4: 13-20	32.45	27.89	-14.03	-3.26	-16.84
M5: 4.75-20	33.54	29.44	-12.22	0	-12.22

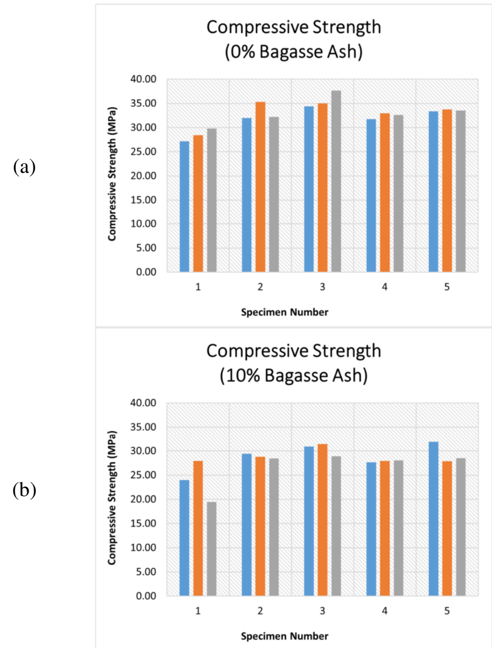

Fig. 7. Compressive strength: (a) 0% bagasse ash, (b) 10% bagasse ash.

TABLE V. AVERAGE SPLIT TENSILE STRENGTH

Average split tensile strength			% change		
Mix	Bagasse ash		Same group	Well-graded aggregates	
	0%	10%	10%	0%	10%
M1: 4.75-7	2.74	2.32	-15.36	-11.87	-25.41
M2: 7-10	3.07	2.63	-14.31	-1.2	-15.34
M3: 10-13	3.22	2.78	-13.63	3.58	-10.54
M4: 13-20	3.1	2.56	-17.47	-0.41	-17.8
M5: 4.75-20	3.11	2.75	-11.54	0	-11.54

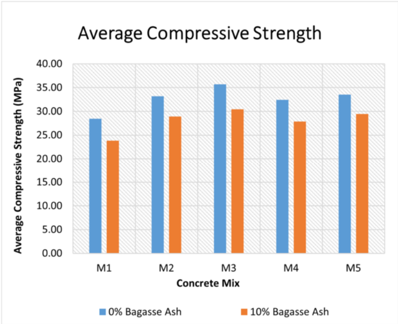

Fig. 8. Average compressive strength.

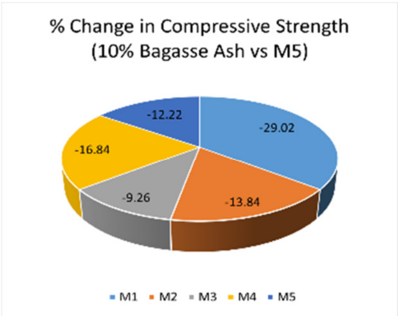

Fig. 9. % change of compressive strength.

(a)

(b)

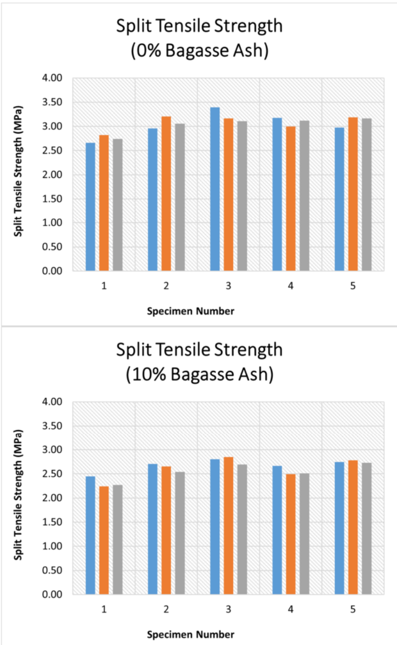

Fig. 10. Split tensile strength: (a) 0% bagasse ash, (b) 10% bagasse ash.

The above findings clearly show that the gradation of aggregates affects the strength properties of concrete. Medium-sized aggregates (10-13mm) give better strength, even than well-graded aggregates, due to the binding of the bagasse ash and the fineness that fills the gaps between the aggregates, as it not only reduces the voids but also improves the strength of concrete. On the other hand, it is also evident that the effort involved in separating the aggregates in case of a normal supply of the material or grading the large blocks to the required size is large compared to the gain in strength (+6.4%). Therefore, the use of well-graded aggregates is encouraged. However, if favorable, the above-mentioned grade of aggregates may be used for better strength. Sugarcane bagasse ash has good cementitious properties. For the grade of aggregates mentioned above, 10% bagasse ash reduced compressive and tensile strength by 9.26% and 10.54%, respectively, which is small and may be tolerable for saving cement content. Even with well-graded aggregate concrete, the percentage reduction in compressive and tensile strength was about 12%. Thus, it is concluded that a 10% dosage of bagasse ash is optimal for specific or well-graded aggregate concrete.

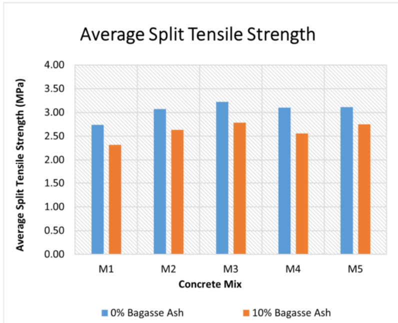

Fig. 11. Average split tensile strength.

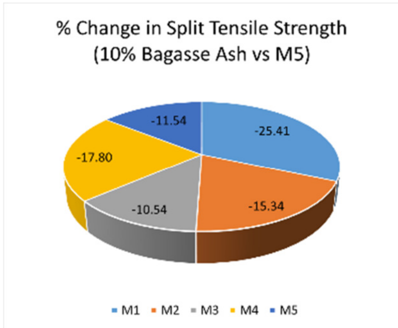

Fig. 12. Error % in split tensile strength.

V. CONCLUSION

This study conducted a laboratory investigation on the effect of different grades of coarse aggregates and sugarcane bagasse ash on the strength properties of concrete, finding that both materials affect them. Small-sized aggregates alone in the concrete matrix fill the voids properly but demand higher binder content due to the larger surface area, resulting in reduced strength. Large-sized aggregates alone leave more voids in the concrete body, also reducing its final strength. Medium-sized particles are better from both perspectives, as they reduce voids and show maximum strength properties. Although bagasse ash has good cementitious properties, these are lower than cement's. The use of bagasse ash reduces both cement content and the strength properties of concrete, however, the reduction in strength is small, about 9% and 11% for compressive and tensile strength, respectively. In addition, bagasse ash in well-graded aggregate concrete showed a marginal reduction of 12% in strength. Thus, a 10% dose of bagasse ash is proposed as optimal. The results showed that concrete with 7-13mm coarse aggregates had more strength than well-aggregated concrete, but the effort required to separate or produce this grade of aggregate is possibly higher than the strength increase (6.4%). Therefore, this study proposes well-graded aggregates with sugarcane bagasse ash.

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