Mechanical Properties of Sustainable Concrete Containing Sugarcane Bagasse Ash: A Review

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Abstract - *Cement production contributes to greenhouse gasses by producing carbon dioxide due to the combustion of fossil fuels and electricity consumption. In this study, the performance of the sugarcane bagasse ash on the mechanical properties of concrete was critically reviewed. In the study, an attempt was made on the use of sugarcane bagasse ash in concrete production with their related issues. The mechanical properties of concrete incorporating sugarcane bagasse ash discussed like Compressive strength, flexural strength, split tensile strength, and modulus of elasticity.*

Keywords: Compressive strength, Flexural strength, Modulus of elasticity, Split tensile strength, Sugarcane bagasse ash.

1. Introduction

Different waste materials as well as by-products are used as pozzolanic materials in sustainable concrete in recent decades. The utilization of different supplementary cementitious materials (SCM) for the production of blended cement contributes to the achievement of robust and eco-friendly concrete [1]. Enormous quantities of sugarcane bagasse ash (SCBA) are generated as a by-product of cogeneration combustion boilers in the sugar industries. This material has been identified as a suitable additional binder material for use in concrete in many past research studies [2–7]. India is the second-largest producer of sugar cane and a significant volume of bagasse ash (67,000 tonnes/day) is directly disposed of to the nearest field, which are causing serious environmental issues in that area [8]. It is anticipated that the rapid implementation of bagasse-based new cogeneration plants (which are required by the government) would significantly increase the production of bagasse ash. Through the systematic processing and characterization, the use of bagasse ash as supplementary cementing material (SCM) provides a lucrative and environmentally-friendly alternative to its disposal. Some pozzolanic materials which are agricultural by-products such as sugarcane bagasse ash and rice husk ash should not be specifically used as a mineral admixture in concrete due to the presence of unburnt particles [8].

Proper characterization of new pozzolanic material, a thorough analysis of the impact of different processing methods on its pozzolanic efficiency, and performance evaluation of new materials in concrete are imperative instead of direct addition to concrete as substitute materials, to achieve an efficient pozzolanic material with the minimum amount of energy inputs. As desirable properties for blended cement manufactured using common mineral additives, additional strength benefit than control concrete due to pozzolanic activity, a substantial reduction in permeability due to pore improvement, lower hydration heat than ordinary Portland cement, and better long-term properties are recorded [9–12]. The efficiency of these concrete materials is directly correlated with their material characteristics [13–23]. Several other materials have been described with a local perspective all over the world, apart from traditional SCMs. One of the popular alternativesof SCM is sugarcane bagasse ash (SCBA), which is obtained after the managed burning of the bagasse (that is left over after separating the sugarcane juice) in cogeneration plants connected with the sugarcane industries. Bagasse ash (BA) from sugarcane is rich in amorphous silica which gives good pozzolanic properties [2, 3, 5, 7]. Several researchers have stated that BA shows promising behavior blended cement materials in concrete and has tremendous potential used in certain applications. [24]. Singh et al. [25] noted that the addition of 10% BA increased the compressive strength of cement paste at all ages of hydration.

Ganesan et al. [26] used 5 to 30% of ground bagasse ash (GBA) to partly substitute cement in concretes. They noticed that at 20% of GBA in binder could develop early and later compressive strength, there was reduced water permeability and enhanced chloride resistance in terms of charge passed (Coulombs) and chloride diffusion coefficient of concretes.

Guilherme et al. [27] reported that the use of 10%, 15%, and 20% of GBA in traditional and high-performance concretes has a marginal impact on compressive strength and modulus of elasticity concretes but it could enhance chloride ion penetration resistance of concretes. Chusilp et al. [28] showed that use of 20% of GBA in concrete produced the highest compressive strength, and the normalized compressive strength of 10%, 20%, and 30% of GBA was 106%, 113%, and 108% compared to control concrete at 90 days, respectively. Moreover, it had lower water permeability and a lower temperature rise than control concrete. High strength concrete with GBA was studied by Rukzon et al. [29] who showed that the compressive strength of concretes with GBA was not lower than control concrete (101–105% at 28 days) and the highest compressive strength was achieved when 10% of GBA was used in concrete.

Most of the studies suggested to use up to 25% cement substitution with SCBA. Also, in the various literature studies, it was found thatan increase in the compressive strength of concrete was up to 15% cement substitution and tensile strength was seen to increase up to 10% cement replacement [30–33]. Radke et al. [34] found a slight increase in strength with SCBA up to 10% cement substitution and then a decrease in strengths. The increase in strength may be attributed to the transformation of the C-H phase into the C-S-H phases upon a pozzolanic reaction, as reported by Muangtong et al. [35]. An increase in the bagasse ash content leads to a slight reduction in the workability, higher normal consistency, and longer setting time [36, 37, 38].

2. Physical and mineral characterization:

2.1 *Physical characterization:*

Sugarcane bagasse ash contains some moisture which can be removed by heating at 105–110 C for 24 hrs and incinerating at 600–800 C for 4–6 hrs. Cordeiro et al. [39] stated that the presence of unburnt carbon particles contributed to low specific gravity that's why fibrous particles can be removed by sieving and by rotating the ashes in a ball mill, fine particles are further reducing in size and shape which increases pozzolanic nature.

Cordeiro et al. [39] studied the reduction of particle size by vibratory mill grinding in a time period of 8 min to 240 min, where the particle size is reduced from 199 mm to 5.4 mm. Bahurudeen et al. [40] studied the rheological behavior of sugarcane bagasse ash concrete in presence of superplasticizers and reported that the fluidity increased with the increase in dosage of superplasticizer till saturation dosage.

Bahurudeen et al. [41] stated that initial and final setting time of processed bagasse ash samples increased compared to control samples which were due to carbon particles and non-reactive silica are present in a high amount in fibrous bagasse ash which is unfit for pozzolanic action. Reduction in particle size helps in increasing specific surface areas which further enhances the reactivity [42]. Bahurudeen et al. [43], they conducted various tests with the compatibility of sugarcane bagasse ash with superplasticizers and revealed that the cost is reduced by one-third of the original production cost when compared to conventional concrete.

2.2 *Mineral Characterization:*

Yogitha et al. [44] found the elemental composition of bagasse ash from Iran which was 64% and for Brazil 78% of silica. Similarly, Californian research presents 60%, Indian 86 % and Thailand ashes 65% of silica. This composition varies according to geographical location, crop, underground water, etc. Bahurudeen et al. [40] stated that plants consume Orth silicic acid from groundwater, which is later polymerized as amorphous silica in the plant cells. It is reported that due to the controlled burning of sugarcane bagasse in the cogeneration process, reactive amorphous silica is formed and exists as the main component in the residual ashes [41].

3. Hardened properties

Properties of hardened concrete are explained on the basis of its strength and performance under various types of loads and conditions. Main properties which comes under hardened properties are as below-

3.1 Compressive strength

Compressive strength is the property of concrete without any cracking or deflection to bear the load on its surface. On a compression testing machine (CTM) with a load-carrying capacity of 5000 KN, the compressive strength of the concrete is determined and provides the full load the concrete sample takes at the time of failure.

Zareei et al. [45] analyzed the compressive strength of concrete on cubic samples with a side length of 15 cm. They found a reduction in compressive strength by 8, 24, and 35 percentage for partial replacement of cement with 15, 20, and 25% bagasse ash. The main reason for the reduction in the strength of concrete was found due to the lower pozzolanic reactivity of bagasse ash because of hydroxide formation during burning and grinding processes [45,46,47,48,49].

Fig.1 suggests that sugarcane bagasse ash concrete maintains its strength up to a cement replacement of 15 percent. They inferred that the strength increased to a 10 percent cement replacement, which can be attributed to the dual function of pore size and grain size refinement associated with pozzolanic action. They concluded that strength was similar to the reference mix at 15 percent cement replacement and also there was a steady decrement in compressive strength for a further rise in the content of sugarcane bagasse ash (Gar et al. [50]). Similar findings were commonly obtained through the use of fly ash and other additional cementing admixtures of comparable silica content [51].

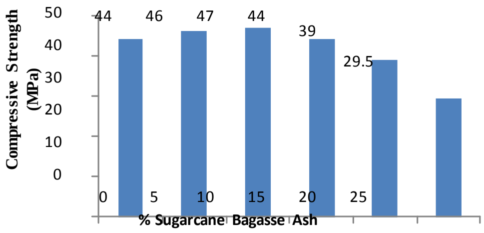

Fig.1 Compressive strength results [50].

Rerkpiboon et al. [52] studied the compressive strength of concrete with bagasse ash. They reported that the compressive strengths at 7 days were 33.1, 36.6, 35.2, 33.5, 32.7, and 28.8 MPa for concrete with 0, 10, 20, 30, 40, and 50 percentage bagasse ash as replacement of cement respectively (Fig. 2). The results indicated that the use of 10–30% of ground bagasse ash (GBA) to replace OPC by weight of binder in concrete could produce a higher compressive strength than control concrete when the medium particle size of GBA (d_{50}) was 5.68 μm. They suggested that the optimum replacement of bagasse ash to produce the highest compressive strength of concrete is 20% by weight of the binder. The high fineness of GBA produces a high and fast pozzolanic reaction since SiO_2 in GBA is highly reactive with $Ca(OH)_2$ from the hydration reaction of Portland cement to increase C–S–H gel in GBA concretes and filled up the voids in the concrete structure [53,54,55,56]. This confirmed that the high fineness of GBA is very important for concrete containing bagasse ash to achieve a high strength at an early age of concrete [52].

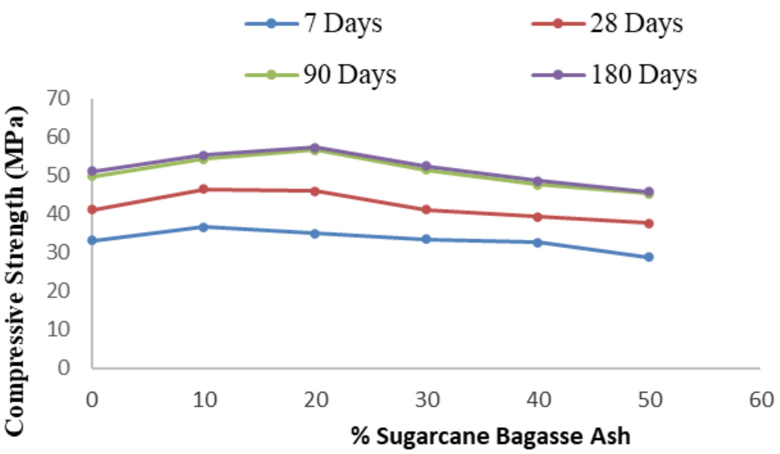

Fig.2 Compressive strength results [52].

From Table 1, it can be observed that the compressive strength was reduced with the increment of replacement of cement by sugarcane bagasse ash. At 30% replacement of cement by SCBA, the strength was found decreased by about 50%. The decrease in strength was due to larger particle size or less specific gravity or less bulk density. They represented that the decrease in strength was due to the unavailability of the required amount of calcium hydroxide. The nucleation sites are located in the area of the nonavailability zone of calcium hydroxide or it may have located at the area where calcium hydroxide can't reach, which results in lesser formation C-S-H gel which affects strength directly by Jagadesh et al. [57]. The pores were also increased due to larger particle size which reduced the strength [29].

Table 1 Compressive strength test results [57].

S.No.	% SBA	Compressive strength	
		7 Days	28 Days
1	0	11.18	18.19
2	5	10.67	17.43
3	10	10.15	15.67
4	15	9.70	14.46
5	20	8.34	12.92
6	25	7.30	11.60
7	30	6.02	9.32

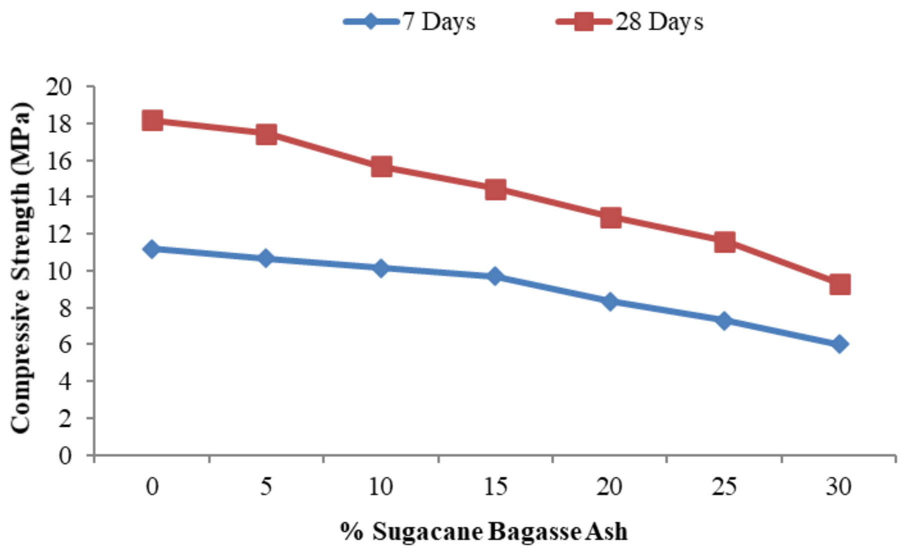

Fig. 3 Compressive strength results at 7 & 28 days [57].

Table 2 contains the compressive strength of concrete containing ground bagasse ash. They reported that the concretes containing 10%, 20%, and 30% ground bagasse ash by weight of binder had compressive strengths as 104%, 110%, and 107% of the control concrete and 106%, 113%, and 108% of the control concrete at the ages of 28 and 90 days, respectively. These results showed that ground bagasse ash is a good pozzolanic material. There are two factors responsible for the early strength (at 28 days) of the ground bagasse ash concrete compared to that of the control concrete. First, the pozzolanic reaction can be highly activated when the particle size is small [58]. Secondly, small particles of ground bagasse ash can fill the voids or air spaces in the concrete structure and thus produce denser concrete. This is referred to as the filler or packing effect [59]. It was found that the optimum fraction of ground bagasse ash replacing cement in concrete is 20%, as this proportion had the highest compressive strength (Chusilp et al. [60]).

Table 2 Compressive strength test results [60].

S.No.	% SBA	Compressive strength	
		28 Days	90 Days
1	0	36.9	41.8
2	10	38.2	44.4
3	20	40.5	47.4
4	30	39.3	45.0

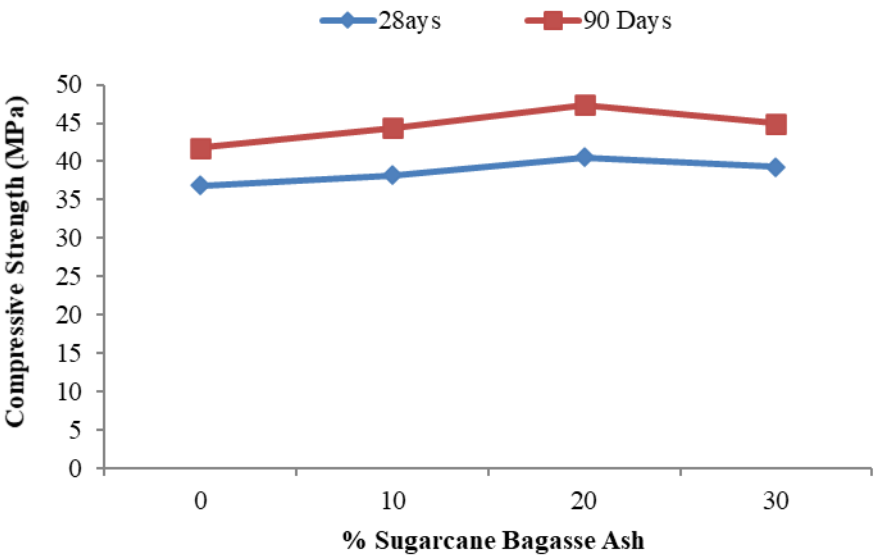

Fig. 3 Compressive strength test results [60].

3.2 Flexural strength

A flexural test is done to find out the tensile strength of the concrete. It tests the ability of an unreinforced concrete beam to withstand failure in loading. The results of the flexural strength test are expressed as modulus of rupture in MPa.

Fig. 5 illustrates a drop in the flexural strength of concrete made with sugarcane bagasse ash with an increase in the ash content. They represented the consistent drop in the flexural strength from the reference mix for all levels of cement replacement, unlike its compressive strength which showed an improvement in its residual strength up to 10% and sometimes even 15% cement replacements (Gar et al. [50]).

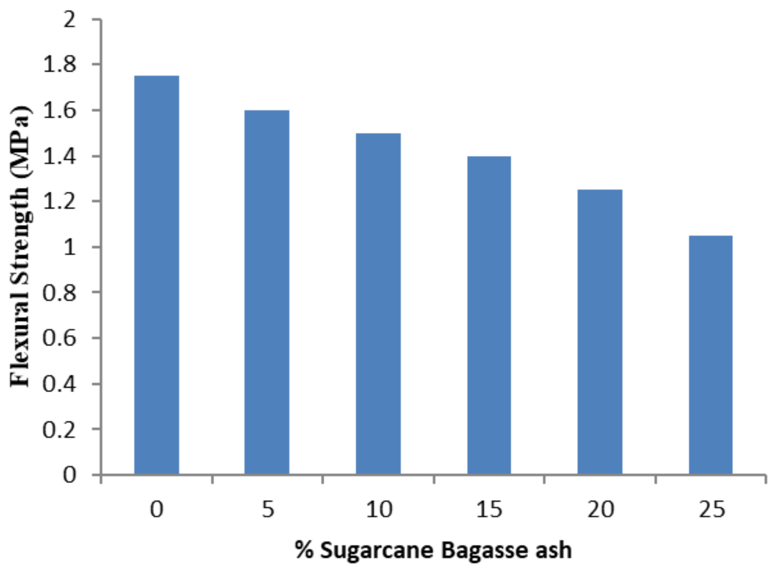

Fig.4 Flexural strength results [50].

Sharma et al. [61] examined flexural strength for the casted beams which were taken from the curing tank at age of 28 days after curing and tested after the surface water flows down from the surface of specimens. The standard size of the samples 100 x 100 x 500 mm was used. They reported that the flexural strength increased maximum up to 9% of SCBA replaced in concrete with cement at 28 days 8.5 N/mm^{2}as shown in Table 3.

Table 3 Flexural strength results [61]

S.No.	% SBA	Flexural strength
1	0	5.5
2	3	6.9
3	6	7.4
4	9	8.5
5	12	7.5

Jagadesh et al. [57] attempted to find out the flexural strength of SCBA blended concrete with respect to compressive strength for 7and 28days and reported in Table 4& Fig. 6. Because of the greater fibrous quality of SCBA, the flexural strength value is marginally higher (1.6%) in the case of 5% SCBA blended concrete. They found that the flexural strength value was equal to or slightly below the reference concrete value for a further rise in cement replacement by bagasse ash. The explanation for the decrease in flexural strength is either due to poor microstructure or due to lesser formation of hydration products. It was reported that the reasons for the reduction in flexural strength were the microfibrous nature of SCBA [62] (less than 30 mm in length) associated with the formation of C-S-H gel and the aluminate materials which results in the formation of thin plates or needles due to hydration [63].

Table 4 Flexural Strength result [57].

S.No.	% SBA	Flexural Strength	
		7 Days	28 Days
1	0	2.31	3.18
2	5	2.34	3.23
3	10	2.31	3.21
4	15	2.28	3.15
5	20	2.05	2.96
6	25	1.92	2.84
7	30	1.78	2.61

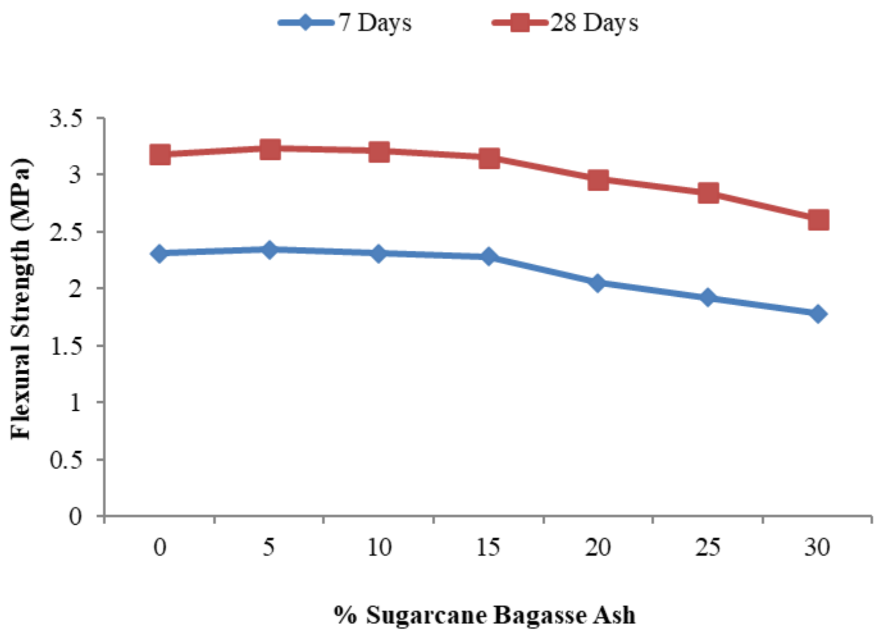

Fig. 5 Flexural strength result at 7 & 28 days [57].

3.3 Split tensile strength

This property for concrete relates to its tensile strength. This is obtained by performing a split tensile test on a concrete specimen. The concrete specimen in this test is taken as cylindrical. Tensile strength for the concrete specimen is defined as the tensile stresses developed due to the application of the compressive load at which the concrete specimen may crack.

The splitting tensile strength test was performed on cylindrical specimens with dimensions of 15 X 30 cm by Zareei et al. [45]. Fig. 7 shows the effects of varying percentages of bagasse ash on concrete's tensile strength. They found that the tensile strength of concrete decreased as compared with control concrete when cement replacement increased with sugarcane bagasse ash. The maximum reduction occurred at the replacement level of 25%.

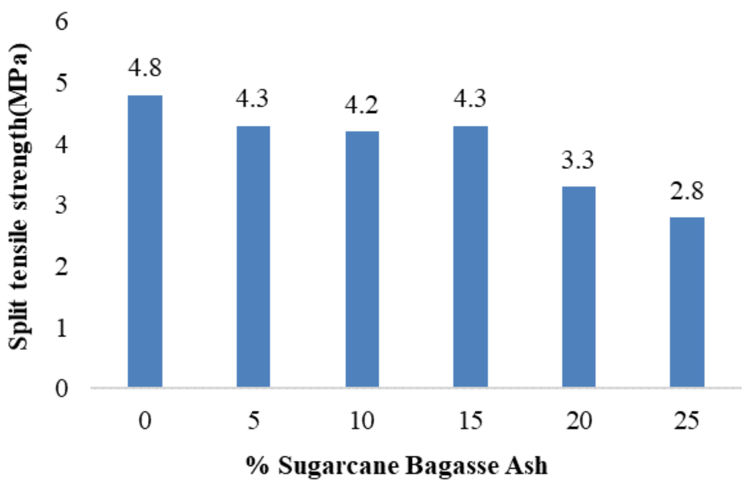

Fig. 6 Split tensile strength [45].

Rattanashotinunt et al. [64] stated that the splitting tensile strength of bagasse ash concretes tended to increase with the increase of compressive strength and also with the curing age. It was reported that the proportion of splitting tensile strength of concrete containing ground bagasse ash was in the range of 10-12 percent of its compressive strength [26]. The finding was also confirmed by previous studies showing that the splitting tensile strength of plain concrete was around 10% of its compressive strength [65, 66]. The study showed that the higher is the compressive strength of concrete; the lower is the splitting tensile strength as a percentage of compressive strength, this result was similar to other researchers on conventional concrete [67,68].

Table 5 Split tensile strength results [64]

S.No.	% SBA	Flexural Strength		
		28 Days	60 Days	90 Days
1	0	3.1	3.4	3.4
2	10	3.4	3.5	3.6
3	20	3.4	3.8	3.9

Fig. 9 shows the effects of the splitting tensile strength, which followed a similar pattern as found in compressive strength. It was reported that the maximum tensile strength was 33 and 40 percent higher than the reference mix at the age of 28 and 90 days when the replacement level was at 5 percent SCBA. The splitting tensile strength was found to be higher than that of the reference mix, up to 15 percent SCBA material, while 25 percent SCBA displayed a tensile strength close to that of the reference mix as represented in Table 6. The results were consistent with the research reported [69,70]. For higher replacement levels (more than 25% SCBA) the split tensile strength was reduced as compared with control concrete by Shafiq et al. [71].

Table 6 Split tensile test [71].

S.No.	% SBA	Split tensile strength	
		28 Days	90 Days
1	0	4.2	4.3
2	5	5.7	6.1
3	15	4.8	5.3
4	25	4.1	4.4
5	35	3.7	3.9
6	45	3.5	3.6

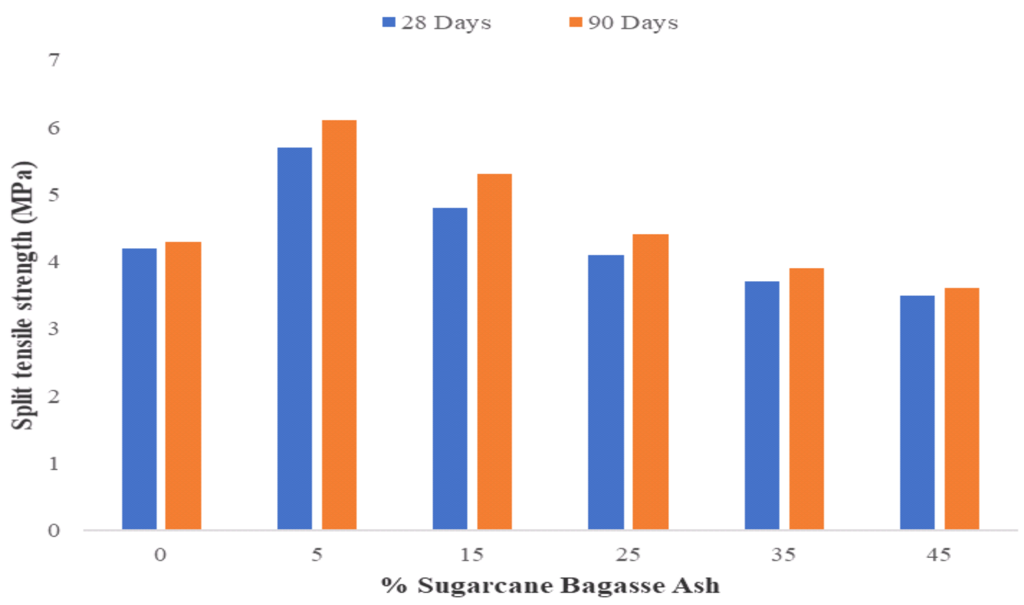

Fig.7 Split tensile test at 28 & 90 days [71].

3.4 Modulus of elasticity

The Modulus of elasticity of concrete is defined as the ratio between the stress applied and the corresponding strain In other words; it reflects the ability of concrete to deflect elastically.

Rattanashotinunt et al. [64] investigated the modulus of elasticity of concrete containing sugarcane bagasse ash which is represented in Table 7. They stated that with the curing age the modulus of elasticity of bagasse ash concrete tended to increase. These findings were consistent with those of Nassif et al. [72] and Sata et al. [73], who reported that with the curing age the modulus of elasticity of concretes containing pozzolanic materials such as fly ash and natural pozzolans, tended to increase.

Table 7 Modulus of elasticity [64]

S.No.	% SBA	Modulus of elasticity		
		28 Days	60 Days	90 Days
1	0	23.6	26.1	27.1
2	10	25.6	28.5	30.8
3	20	28.2	28.7	31.9

Rerkpiboon et al. [52] attempted to study bagasse ash concrete, where they found that the modulus of elasticity of control concrete and bagasse ash concrete increased with the increase in compressive strength. This finding also supported by several researchers, shows that the modulus of elasticity of concrete with pozzolanic material concrete is close to that of traditional concrete [74,75,76] and slightly higher than that mentioned by ACI 318 [77]. The modulus of elasticity of the control and bagasse ash concrete was slightly underestimated due to the different specimen sizes and coarse aggregate types [78]. They concluded that there was no effect on modulus of elasticity up to the 50% replacement of cement with sugarcane bagasse ash in bagasse ash concrete.

The modulus of elasticity (MOE) was experimentally investigated at 28 days by Jagadesh et al. [57] for SCBA blended concrete and the values obtained are given in Table 8 and Fig. 10.They reported that SCBA blended concrete's modulus of elasticity was 28.4 percent less than control concrete at 30 percent partial replacement of cement with bagasse ash and 4.9 percent higher modulus of elasticity than the control concrete for a 20 percent partial replacement. Other investigators have made similar observations [79,80,81]. The maximum increase in modulus of elasticity of SCBA mixed concrete was 6.94 percent, which may be due to lower pore size, fibrous structures [62,82], enhanced Interfacial Transition Zone, hydrated compound formation, filling impact, and SCBA microfibrous arrangement [83] in mixed concrete. The modulus of elasticity (MOE) obtained for 7 days was very less compared to that of the value obtained at 28 days. This is due to the hydration product formation, and due to the fibrous nature of SCBA, plates (calcium aluminate), reduction of voids, resulted in higher MOE values.

Table 8 Modulus of elasticity [57].

S.No.	% SBA	Modulus of Elasticity	
		7 Days	28 Days
1	0	13734	19619
2	5	13079	19205
3	10	12244	18032
4	15	11482	17265
5	20	10813	16392
6	25	10125	15157
7	30	9340	14044

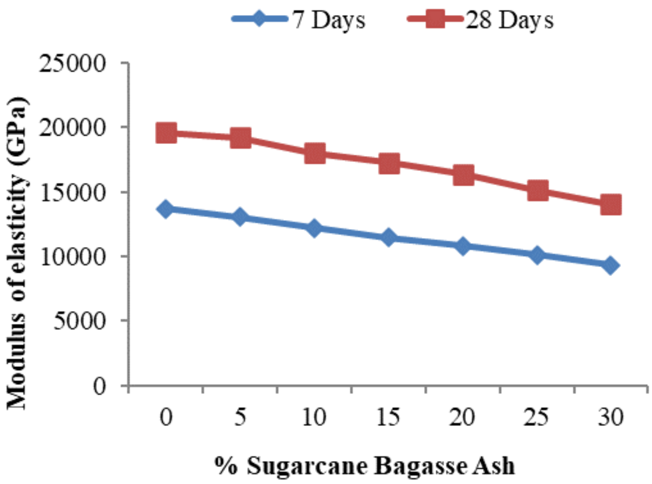

Fig.8 Modulus of elasticity [57].

4. CONCLUSIONS

Based on a thorough analysis of the works reported, the following conclusions can be drawn

- From the above study, we can conclude that increment in the compressive strength up to a certain percentage while the compressive strength decreased as the percentage of sugarcane bagasse ash increased. Also, there was an increment in compressive strength with the age of the curing period.
- The above study showed that there was a consistent decrease in concrete's flexural strength as the sugarcane bagasse ash content increased.
- The split tensile strength, compressive strength, and flexural strength increase with increase in substitution percentage of sugarcane bagasse ash up to a certain limit.
- Bagasse ash concrete's modulus of elasticity depends on its compressive strength and is similar to that of standard concrete.
- As the proportions of sugarcane bagasse ash increase to a certain limit, the split tensile strength, compressive strength, and flexural strength increase. With the rise in compressive strength and its value of around 10 percent of compressive strength, the splitting tensile strength of bagasse ash concrete appeared to increase.
- Concrete incorporated with sugarcanes bagasse ash is sustainable construction material which reduces the energy consumption as well as decrease pollution related problems.

REFERENCES

[1] Mackechnie JR, Alexander MG, Effect of SCM's on durability to enhance concrete sustainability, *J Green Build, 2010;* 4:52 60.

[2] Cordeiro GC, Toledo Filho RD, Fairbairn EM, Effect of calcination temperature on the pozzolanic activity of sugarcane bagasse ash, Construction and Building Materials, 2009; 23:3301–3.

[3] Nuntachai C, Chai J, Kraiwood K, Utilization of bagasse ash as a pozzolanic material in concrete, Construction and Building Material, 2009; 23:3352–8.

[4] Frias M, Villar E, Savastano H, Brazilian sugar cane bagasse ashes from the cogeneration industry as active pozzolans for cement manufacture, CemConcr Compos, 2011; 33:490–6.

[5] Cordeiro GC, Toledo Filho RD, Tavarse LM, Fairbairn EM, Hempel S, Influence of particle size and specific surface area on the pozzolanic activity of residual rice husk ash, CemConcr Compos, 2011; 33:529–34.

[6] Ganesan K, Rajagopal M, Thangavel K, Evaluation of bagasse ash as supplementary cementitious material, CemConcr Compos, 2007; 29:515–24.

[7] Cordeiro GC, Filho RD, Tavares LM, Fairbairn EM, Ultrafine grinding of sugarcane bagasse ash for application as a pozzolanic admixture in concrete, CemConcr Res, 2009; 39:110–5.

[8] Bahurudeen A, Santhanam M, Sugarcane bagasse ash – an alternative supplementary cementitious material, International conference on advances in civil engineering and chemistry of innovative materials, India, 2014; 837–42.

[9] Turanli L, Uzal B, Bektas F, Effect of large amounts of natural pozzolana addition on properties of blended cements, Cement Concr Res, 2005 ;35:1106–11.

[10] Langan BW, Weng K, Ward MA, Effect of silica fume and fly ash on heat of hydration of Portland cement, CemConcr Res, 2002; 32:1045–51.

[11] Laibao L, Yunshen Z, Wenhua Z, Zhiyong L, Lihua Z, Investigating the influence of basalt as mineral admixture on hydration and microstructure formation mechanism of cement, Constr Build Mater, 2013; 48:434–40.

[12] Turanli L, Uzal B, Bektas F, Effect of material characteristics on the properties of blended cements containing high volumes of natural pozzolans, CemConcr Res, 2004; 35:2277–82.

[13] Mostafa NY, El-Hemaly SAS, Al-Wakeel EI, Korashy SA, Brown PW, Characterization and evaluation of the pozzolanic activity of Egyptian industrial by-products I: silica fume and de-aluminated kaolin, CemConcr Res, 2001; 32:467–74.

[14] Sahmaran M, Christianto HA, Yaman IO, The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars, CemConcr Compos, 2006; 28:432–40.

[15] Nehdi M, Rahman MA, Estimating rheological properties of cement pastes using various rheological models for different test geometry, gap and surface friction, CemConcr Res, 2004; 34:1993–2007.

[16] Palacios M, Puertas F, Bowen P, Houst YF, Effect of PCs superplasticizers on the rheological properties and hydration process of slag-blended cement pastes, J Mater Sci, 2009; 44:2714–23.

[17] Park CK, Noh MH, Park TH, Rheological properties of cementitious materials containing mineral admixtures, CemConcr Res, 2005; 35:842–9.

[18] Jayashree C, Study of cement-superplasticizer interaction and its implications for concrete performance,Doctoral thesis, Indian Institute of Technology , Madras, India, 2009.

[19] Chopra SK, Ahluwalia SC, Laxmi S, Technology and manufacture of rice husk masonry cement, ESCAP/RCTT Third Workshop on Rice Husk Ash Cement, 1981.

[20] Nair DG, Fraaij A, Klaassen AAK, Kentgens APM, A structural investigation relating to the pozzolanic activity of rice husk ashes, CemConcr Res, 2008; 38:861–9.

[21] Bensted J, Barnes P, Structure and performance of cements, 2nd ed., NewYork : Spon Press, 2000.

[22] Rashad AM, Metakaolin as cementitious material: history, scours, production and composition – comprehensive overview, Constr Build Mater, 2013; 41:303–18.

[23] Jolicoeur C, Simard MA, Chemical admixture–cement interaction: phenomenology and physico-chemical concepts, CemConcr Compos, 1998; 20:87–101.

[24] Alavéz-Ramírez R, Montes-García P, Martínez-Reye J, Altamirano-Juárez DC, Gochi-Ponce Y, The use of sugarcane bagasse ash and lime to improve the durability and mechanical properties of compacted soil blocks, Construction and Building Materials, 2012; 34:296-305.

[25] Singh NB, Singh VD, Rai S, Hydration of bagasse ash-blended Portland cement, Cement and Concrete Research, 2000; 30 (9):1485-1488.

[26] Ganesan K., Rajagopal K., Thangavel K., Evaluation of bagasse ash as supplementary cementitious material, Cement and Concrete Composites, 2017;29 (6):515-524.

[27] Guilherme A, Simard MA, Rheological properties of cementitious materials containing mineral admixtures, CemConcr Res 2009;38:912–10.

[28] Chusilp N, Jaturapitakkul C, Kiattikomol K., Utilization of bagasse ash as a pozzolanic material in concrete, Construction and Building Materials, 2009; 23 (11):3352-3358.

[29] Rukzon S, Chindaprasirt P, Utilization of bagasse ash in high-strength concrete, Materials and Design, 2012; 34: 45-50.

[30] Paula MO, Tinoco IFF, Rodrigues CS, Saraz JAS, Sugarcane bagasse ash as partial Portland cement replacement material, Scielo, 2010; 77 (163): 47–54.

[31] Castaldelli VN, Akasaki JL, Melges JL, Tashima MM, Soriano L, Borrachero MV, Monzó J, Payá J, Use of slag/sugarcane bagasse ash (SCBA) blends in the production of alkali-activated materials, J. Mater., 2013; 6:3108–3127.

[32] Srinivasan R, Sathiya K, Experimental study on bagasse ash in concrete, Int. J. Serv. Learn. Eng., 2010; 5 (2).

[33] Kawade UR, Rathi VR, Vaishali D, Girge D, Effect of use of bagasse ash on strength of concrete, Int. J. Innovat. Res. Sci., 2013; 2 (7).

[34] Radke B, Sugarcane bagasse ash waste, Biofuels and Agriculture – A Technical Overview, State of Food and Agriculture, 2012.

[35] Muangtong P, Sujjavanich S, Boonsalee S, Poomiapiradee S, Chaysuwan D, Effects of fine bagasse ash on the workability and compressive strength of mortars, Chiang Mai J. Sci., 2013; 40 (1); 126–134.

[36] Hailu B, Dinku A, Application of sugarcane bagasse ash as a partial cement replacement material, J. EEA, 2012; 29.

[37] Rao KMV, Shobha M, Dakshina MNR, Effect of elevated temperature on strength of differently cured concretes-an experimental study, Asian J. Civ. Eng., 2011; 12(1): 73–85.

[38] Qomi R, Physical origins of thermal properties of cement paste, Phys. Rev. Appl., 2015; 3:064010.

[39] CordeiroGC,Filho RDT, Tavares LM, Influence of mechanical grinding on the pozzolanic activity of residual sugarcane bagasse ash. In Conference proceedings RILEM, Barcelona, Spain, 2004; 731–740.

[40] Bahurudeen A, Santhanam M, Development of sugarcane bagasse ash-based Portland pozzolana cement and evaluation of compatibility with superplasticizers, Constr Build Mater, 2014; 68:465-475.

[41] Bahurudeen A, Memon SA, Obaid H, Assesment of pozzolanic performance of sugarcane bagasse ash, J Mater Civil, 2016; 28 (2):04015095.

[42] Cordeiro GC, Filho RDT, Tavares LM, Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars, Cem. Concr. Comp, 2008; 30 (5):410–418.

[43] Bahurudeen A,Memon SA, Obaid H, Performance evaluation of sugarcane bagasse ash blended cement in concrete, Cem. Concr. Comp, 2015; 59:77–88.

[44] Yogitha B,Karthikeyan M,Reddy MGM, Progress of sugarcane bagasse ash applications in production of Eco-Friendly concrete - Review, Materials Today: Proceedings, 2020; xxx (xxxx):xxx.

[45] Zareei SA, Ameri F, Bahrami N, Microstructure, strength, and durability of eco-friendly concretes containing sugarcane bagasse ash, Construction and Building Materials, 2018; 184: 258–268.

[46] Cordeiro GC, Tavares LM, Toledo FRD, Improved pozzolanic activity of sugar cane bagasse ash by selective grinding and classification, Cem. Concr. Res., 2016; 89:269–275.

[47] Sessa TC, Silvoso MM, Vazquez EG, Qualharini EL, Haddad AN, Amaral LA, Study of the technical capability of sugarcane bagasse ash in concrete production, Trans Tech Publ, 2016; 53–57.

[48] Sua-iam G, and Makul, N, Use of increasing amounts of bagasse ash waste to produce self-compacting concrete by adding limestone powder waste, Journal of Cleaner Production, 2013;xxx: 1-12.

[49] Akram T, Memon SA, Obaid H, Production of low-cost self-compacting concrete using bagasse ash, Construction and Building Materials, 2009; 23(2):703-712.

[50] Gar PS, Suresh N, Bindiganavile V, Sugar cane bagasse ash as a pozzolanic admixture in concrete for resistance to sustained elevated temperatures, Construction and Building Materials, 2017; 153: 929–936.

[51] Shang HS, Yi TH, Behavior of HPC with fly ash after elevated temperature, J. Adv. Mater. Sci. Eng, 2013; Article ID 478421.

[52] Rerkpiboon A, Tangchirapat W, Jaturapitakkul C, Strength, chloride resistance and expansion of concretes containing ground bagasse ash, Construction and Building Materials, 2015; 101: 983–989.

[53] Cordeiro GC, Toledo FRD, Tavares LM, Fairbairn EMR, Pozzolanic activity and filler effect of sugarcane bagasse ash in Portland cement and lime mortars, CemConcr. Compos, 2008; 30:410–418.

[54] Kroehong W, Sinsiri T, Jaturapitakkul C, Effect of palm oil fuel ash fineness on packing effect and pozzolanic reaction of blended cement paste, Proc. Eng., 2011; 14:361–369.

[55] Jaturapitakkul C, Tangpagasit J, Songmue S, Kiattikomol K, Filler effect and pozzolanic reaction of ground palm oil fuel ash, Constr. Build. Mater, 2011; 25:4287–4293.

[56] Chi MC, Effects of sugar cane bagasse ash as cement replacement on properties of mortars, Sci Engg Comp Mater, 2012; 19 (3):279–285.

[57] Jagadesh P, Ramachandramurthy A, Murugesan R, Evaluation of mechanical properties of Sugar Cane Bagasse Ash concrete, Construction and Building Materials, 2018; 176:608–617.

[58] Kiattikomol K, Jaturapitakkul C, Songpiriyakit S, Chutubtim S, A study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials, CemConcr Comp, 2001; 23:335–43.

[59] Isaia GC, Gastaldini ALG, Moraes R, Physical and pozzolanic action of mineral additions on the mechanical strength of high performance concrete, CemConcr Comp, 2003; 25:69–76.

[60] Chusilp N, Jaturapitakkul C, Kiattikomol K, Utilization of bagasse ash as a pozzolanic material in concrete, Construction and Building Materials, 2009; 23:3352–3358.

[61] Sharma S, Partial replacement of cement with sugarcane bagasse ash, International Journal of Engineering Applied Sciences and Technology, 2019; Vol. 4, Issue 4, ISSN No. 2455-2143:87-93.

[62] Jagadesh P, Ramachandramurthy A, Murugesan R, Sarayu K, Micro analytical studies on sugar cane bagasse ash, Sadana – Acad. Sci., 2015; 40 (5):1629– 1638.

[63] Souza LMS, Fairbairn EMR, Filho RDT, Corderio GC, Influence of initial CaO/SiO_2 ratio on hydration of Rice Husk Ash – $Ca(OH)_2$ and sugar cane bagasse ash – $Ca(OH)_2$ pastes, Quim. Nova, 2014; 37 (10):1600–1605.

[64] Rattanashotinunt C, Thairit P, Tangchirapat W, Jaturapitakkul C, Use of calcium carbide residue and bagasse ash mixtures as a new cementitious material in concrete, Materials and Design, 2013; 46:106–111.

[65] Yazici H, The effect of silica fume and high-volume class C fly ash on mechanical properties, chloride penetration and freeze-thaw resistance of self-compacting concrete, Constr Build Mater, 2008; 22(4):456–62.

[66] Siddique R, Schutter GD, Noumowe A, Effect of used-foundry sand on the mechanical properties of concrete, Constr Build Mater, 2009; 23(2):976–80.

[67] Haque MN, Kayali O, Properties of high-strength concrete using a fine fly ash, CemConcr Res, 1998; 28(10):1445–52.

[68] Shannag MJ, High strength concrete containing natural pozzolana and silica fume, CemConcr Compos, 2000; 22(6):399–406.

[69] Srinivasan R and Sathiya K, Experimental study on bagasse ash in concrete, International Journal for Service Learning in Engineering, 2010; 5(2): 60–66.

[70] Mahmud H, Malik MFA, Kahar RA, Zain MFM, Raman SN, Mechanical properties and durability of normal and water reduced high strength grade 60 concrete containing rice husk ash, Journal of Advanced Concrete Technology, 2009; 7(1):21–30.

[71] Shafiq N, Hussein AAE, Nuruddin MF, Mattarneh HA, Effects of sugarcane bagasse ash on the properties of concrete, Engineering Sustainability Volume, 2016.

[72] Nassif HH, Najm H, Suksawang N, Effect of pozzolanic materials and curing methods on the elastic modulus of HPC, CemConcr Compos, 2005; 27(6):661–70.

[73] Sata V, Jaturapitakkul C, Kiattikomol K, Influence of pozzolana from various byproduct materials on mechanical properties of high-strength concrete, Constr Build Mater, 2007; 21(7):1589–98.

[74] Nassif HH, Najm H, Suksawang N, Effect of pozzolanic materials and curing methods on the elastic modulus of HPC, Cem. Concr. Compos., 2005; 27 (6):661–670.

[75] Tangchirapat W, Buranasing R, Jaturapitakkul C, Chindaprasirt P, Influence of rice husk–bark ash on mechanical properties of concrete containing high amount of recycled aggregates, Constr. Build. Mater, 2008; 22:1812–1819.

[76] Tangchirapat W, Jaturapitakkul C, Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash, Cem. Concr.Compos., 2007; 32:767–774.

[77] ACI Committee 318, Building code requirements for structural concrete, ACI 318-11, American Concrete Institute, 2011: 111.

[78] Neville AM, Properties of concrete, forth ed. Tottenham, London, 1995:418–449.

[79] Nassif HH, Najm H, Suksawang N, Effect of pozzolanic materials and curing methods on the elastic modulus of HPC, Cem. Concr. Compos., 2005; 27 (6): 661–670.

[80] Tangchirapat W, Jaturapitakkul C, Chindaprasirt P, Influence of rice husk–bark ash on mechanical properties of concrete containing high amount of recycled aggregates, Constr. Build. Mater., 2008; 22:1162–1179.

[81] Tangchirapat W, Jaturapitakkul C, Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash, Cem.Concr. Compos., 2007; 32: 767–774.

[82] Corderio GC, Filho TRD, Tavares LM, Pozzolanic activity and filler effect of sugar cane bagasse ash in Portland cement and lime mortars, CemConcr Comp, 2008; 30:410–418.

[83]. Akasaki JL, Fioriti CF, Paya J, Performance of mortars produced with incorporation of sugar cane bagasse ash, RevistaIngenieria de construction, 2014; 29(2):187–199.