Eco. Env. & Cons. 27 (2) : 2021; pp. (888-893)
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ISSN 0971–765X

Effect of alkali solution dosage on sugarcane bagasse ash based sustainable alkali activated slag concrete

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(Received 6 September, 2020; Accepted 13 October, 2020)

ABSTRACT

Production of ordinary Portland cement (OPC) contributes around 7% of global carbon dioxide (CO_2) to environment. In order to reduce the environmental impact caused by OPC production sustainable material development is essential and also sustainable material development plays a vital role in present day construction practice too. Alkali activated slag (AAS) binders is one such sustainable material. Present study investigates the effect of Na_2O dosage (4-5.5% of total binder content), modules of silica (Ms: 0.75-1.75) and bagasse ash (BA) replacement (0, 25, and 50%) to ground granulated blast furnace slag (GGBS) were studied on AAS concrete (AASC) mixture preparation. Mixtures which provide maximum compressive strength were considered as optimal mixture. BA replacement in AASC mixture results in decrease in compressive strength. Further, maximum compressive strength is observed in mixture prepared with alkaline solution of concentration of 5% Na_2O dosage, and M_S of 1.

Key words : *Sugar Cane Bagasse Ash, Ground Granulated Blast Furnace Slag, Compressive Strength, Modules of Silica, Alkaline Solution.*

Introduction

India is the second largest sugar producing country and stands next to China, Brazil and Thailand occupies third and fourth position respectively in production of sugar. Sugar cane and sugar beet are the main sources for the production of sugar. Sugar cane is the highest cultivated crop in the world based on planted area. Sugar cane provides 80% of contribution for the production of sugar (Klathae *et al*., 2020). During the production of sugar, sugar cane will be crushed to extract juice and spent sugar cane will be collected as fibrous residue called as bagasse. Due to the development in sugar industry, bagasse is utilized and burnt in cogeneration plant for electric power generation. Burning of bagasse results in ash called as bagasse ash (BA). BA obtained is unutilized and disposed off in landfill areas. Since, BA is rich in silica minerals, several researchers utilized the BA as supplementary cementitious materials as a partial replacement to OPC in concrete production.

Chindaprasirt *et al*. (2020) studied the effect of high volume BA replacement in OPC based concrete. BA used is processed to fine size in ball mill for about a time of 120 min. Total binder content considered was around 500 kg/m^3 for the preparation of concrete. Binary (OPC + BA) and ternary (OPC + BA + Flyash (FA)) binder mixtures were experimented. Super plasticizers were used in the BA based concrete mixture to maintain required workability. Compressive strength of BA based concrete mixtures were lesser compared to control concrete mixture. However, critical pore size is reduced compared to control concrete, due to pozzolanic reaction. Ternary concrete mixture i.e., OPC + 50%BA + 20%FA concrete shows better result in terms of compressive strength, and chloride resistance.

Alkali activated binders (AAB) are the new generation binders and clinker-free binder matrix. AAB has several classification in it, few are alkali activated slag (AAS), Geopolymers, alkali activated slag/fly ash (AASF) etc., AABs are generally produced by activating the natural minerals or industrial wastes like GGBS, FA, metakaolin (MK), silica fume (SF) etc., (which are primarily rich in calcium, alumino-silicates silica) by using alkaline solutions. Deepika *et al.* (2017) studied the effect of GGBS replacement (0, 10 and 20%) in BA based AAB. Also effect of curing condition (ambient and heat curing), effect of alkaline solution type (sodium and potassium based), and effect of activator dosage (6, 8 and 10 Molarity) were also investigated. Result shows, as the GGBS content increases, the compressive strength increases, due to dense moisture formation. Ambient cured specimens shows higher compressive strength values compare to heat cured specimens. Potassium based alkaline activator shows higher compressive strength compared to sodium based activator. As the increase in the alkaline dosage from 6 to 10 Molarity, increase in compressive strength is observed. Further, BA based AAB found to be satisfactory in preparation of paver block.

Though lot of literature available on BA based AAB mixture preparation (Castaldelli *et al.*, 2013; Pereira *et al.*, 2015; Castaldelli *et al.*, 2016; Murugesan *et al.*, 2020, and Deepika *et al.*, 2020). Important factors like, concentration of alkaline solution in terms of Na_2O dosage and Modules of silica (Ms) in preparation of BA based AAB were not yet carried out. In order to ascertain this problem, present study aims to study the effect of three different input variables like, BA replacement, Na_2O dosage, and Ms in alkali activated slag concrete (AASC). Compressive strength of AASC mixture was considered as response variable. Based on compressive strength values BA level, Na_2O dosage, and Ms input values for preparation of AASC mixture were optimized.

Materials and Methodology

Production of AASC mixture requires different ingredients like, binder, fine aggregate, coarse aggregate, alkaline solution and water. Binders used in the present study are BA, and GGBS. BA is obtained from M/s. The Pandavapura Sahakara Sakkare Karkhane, Ltd. Pandavapura, Mandya, Karnataka, India. GGBS is obtained from M/s Jindal steel works cement, Ltd. Bellary, Karnataka, India. BA, and GGBS are black and white in color respectively. Specific gravity, Blaine's fineness, and loss on ignition values of BA are 2.1, 240 m^2/kg, and 4.2 respectively. Whereas, GGBS has specific gravity, Blaine's fineness, and loss on ignition values of 2.84, 380 m^2/kg, and 1.1 respectively. 300μm passing BA is used as binder to reduce the fibrous material.

Fine aggregate used in the present study is natural river sand of size less than 4.75mm. Fine aggregate is obtained from the local market. Physical properties of fine aggregate were evaluated based on specification and guidelines given in Bureau of Indian Standards i.e., IS: 2386-2002). Specific gravity, water absorption, compacted bulk density, gradation, and fineness modulus were 2.56, 1%, 1672 kg/m^3, Zone II, and 2.48 respectively. Coarse aggregate used in the present study is well graded crushed granitic aggregate of size less than 20mm. Coarse aggregate used is obtained from local crusher plant and siliceous in its chemical composition. Physical properties like, specific gravity, water absorption, and compacted bulk density were determined based on the Bureau of Indian Standards i.e., IS: 2386-2002. Specific gravity, water absorption, and compacted bulk density of coarse aggregate used are 2.68, 0.5%, and 1658 kg/m^3 respectively.

Alkaline solution is prepared using sodium hydroxide (NaOH) pellets, sodium silicate (Na_2SiO_3) solution and water. NaOH and Na_2SiO_3 are procured from the local market. Water available in laboratory is used in the present studied. Na_2SiO_3 is having different chemical composition of Na_2O (8.5%), SiO_2 (28%) and H_2O (63.5%). Different concentrations of alkaline solution (i.e., Na_2O (4-5.5%) and Ms (0.75-1.75) dosage) is prepared using the literature (Kumar *et al.*, 2020). From Table 1 it is noted that, increase in N_2O dosage results in high quantity of NaOH and increase in Ms ratio results in high quantity of Na2O.

Alkali activated slag/bagasse ash (AASBC) concrete mixture preparation

AASBC mixture is prepared using guidelines provided in Bureau of Indian Standard (IS: 10262-2009). Table 1 gives the details of different quantity of materials used in the present study. Total 18 AASBC mixtures were designed and prepared to study the effect of concentration of alkaline solution in AASBC mixtures. Total binder content of 430 kg/m^3 is used in present study with water to binder ratio of 0.4. AASBC were prepared in ribbon type mixer. Mixing is done for 3 minutes to ensure cohesive and relatively homogeneous mixture. Due to viscous nature of alkaline solution prepared, there were no signs of bleeding of water from AASBC mixture prepared. Workability of the mixtures was maintained in between 50-75 mm. Compressive strength of different AASBC mixtures was carried out using 100 mm cubic mould. Compressive strength testing is done using guidelines provided in Bureau of Indian Standard (i.e., IS: 516-2004). Average of three compressive strength values were used as compressive strength of AASBC mixtures.

Results and Discussion

Elemental analysis on binders

In order to get confirmation of alumino-silicate materials present in binders, energy-dispersive X-ray spectroscopy (EDAX) was used. Scanning electron microscope (SEM) images are obtained by Carl Zeiss scanning electron microscope. Elemental analysis was carried using EDAX. Table 2 shows elemental analysis results of GGBS and BA. Figure 1 and 2 shows, SEM image of GGBS and BA. GGBS mainly composed of calcium, alumina and silicon rich minerals of total percentage of around 90%. BA mainly composed of silicon rich minerals of 82%, traces of calcium, alumina, potassium, and iron minerals were also present. Figure 2 confirms silica rich material which helps in alkali activation of slag.

Effect of alkali solution concentration and replacement level of BA in AAS system

Figure 3 shows compressive strength variation of AASBC mixture with different levels of Ms (0.75-1.75) and 4% Na_2O dosage. Compressive strength of AASBC found to be in the range of 44 MPa to 62 MPa. With 0% BA based AASBC mixture, compressive strength increases with increase in Ms i.e., upto 1.25. Increase is around 12% in compressive strength of 1.25 Ms based AASBC mixture with re-

Table 1. Different ingredients used in preparation of BA based AASBC mixture

Sl. No.	Na_2O (%)	Ms	Quantity of materials (kg/m^3)						
			GGBS	BA	FA	NCA	H_2O	NaOH	Na_2SiO_3
1	4	0.75	430	0	627	1166	142.7	17.1	46.1
2	4	1	430	0	624	1161	133	15.5	61.4
3	4	1.25	430	0	621	1155	123.2	13.8	76.8
4	4	1.5	430	0	618	1150	113.5	12.1	92.1
5	4	1.75	430	0	615	1144	103.7	10.4	107.5
6	4	0.75	323	107	614	1142	142.7	17.1	46.1
7	4	1	323	107	611	1137	133	15.5	61.4
8	4	1.25	323	107	608	1131	123.2	13.8	76.8
9	4	1.5	323	107	605	1125	113.5	12.1	92.1
10	4	1.75	323	107	602	1120	103.7	10.4	107.5
11	4	0.75	215	215	601	1118	142.7	17.1	46.1
12	4	1	215	215	598	1112	133	15.5	61.4
13	4	1.25	215	215	595	1107	123.2	13.8	76.8
14	4	1.5	215	215	592	1101	113.5	12.1	92.1
15	4	1.75	215	215	589	1096	103.7	10.4	107.5
16	4.5	1	215	215	594	1106	128.1	17.4	69.1
17	5	1	215	215	590	1099	123.2	19.3	76.8
18	5.5	1	215	215	587	1092	118.4	21.3	84.5

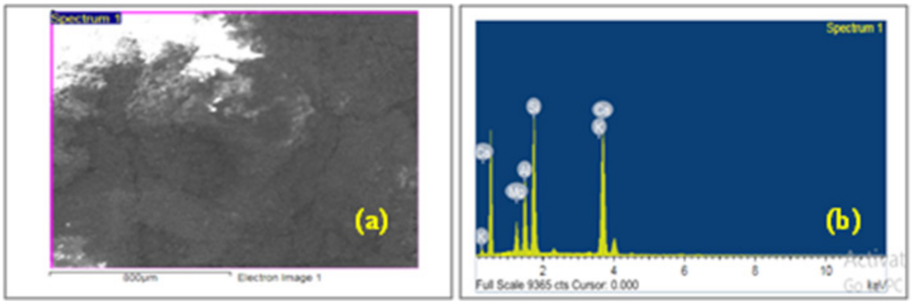

Fig. 1. SEM-EDAX analysis of ground granulated blast furnace slag

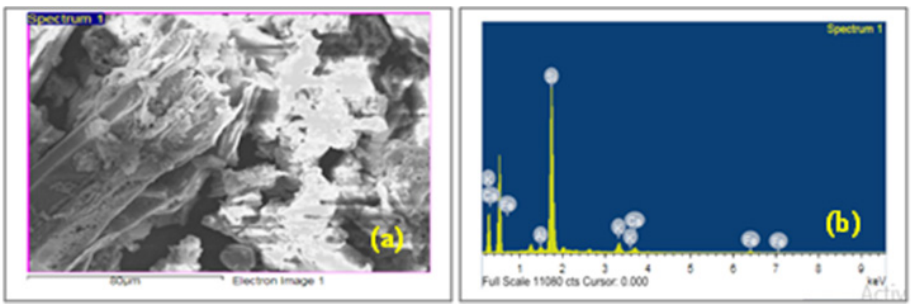

Fig. 2. SEM-EDAX analysis of sugarcane bagasse ash

spect to 0.75 Ms. Further increase in Ms value (i.e., 1.5 to 1.75 Ms) results in almost comparable compressive strength with respect to 0.75 Ms based AASBC mixture. Similar observation were also made with 25% BA based AASBC mixture. 7% increase in compressive strength is noted with 1.25 Ms based AASBC mixture compared to 0.75 Ms based AASBC mixture, and further increase in Ms value (i.e., 1.5 to 1.75 Ms) results in almost comparable compressive strength with respect to 0.75 Ms based AASBC mixture. Increase in compressive upto Ms of 1.25 may be due to participation of reactive silica present in Na_2SiO_3 and comparable compressive strength may be due to excess of reactive silica from Na_2SiO_3 (Palankar *et al.*, 2014; Kumar *et al.*, 2020). Interestingly in 50% BA based AASBC mixture, highest compressive strength is observed with 1 Ms. 9% increase is observed with respect to 0.75 Ms based AASBC mixture. Highest value of compressive strength observed may be due to the contribution of reactive silica present in BA. The reduction of Ms is one way advantageous of reduction of embodied energy required to produce alkali silicates (Palankar *et al.*, 2014; Kumar *et al.*, 2020).

With all the levels of Ms ratio, reduction in compressive strength is observed with BA based AASBC mixture compared to 100% GGBS based AASBC mixture. Decrease in the strength were in the range of 3.5-8.7% with 25% BA based AASBC mixture compared to 100% GGBS based AASBC mixture with all the levels of Ms values. Similarly, reduction in compressive strength is predominant in case of 50% BA based AASBC mixture compared to 100% GGBS based AASBC mixture. Decrease in the compressive strength of 50% BA based AASBC mixture were in the range of 14.5-23.4% compared to 100% GGBS based AASBC mixture. Decrease in compressive strength is due to the reduction in formation of C-S-H, C-A-S-H gels with addition of BA in AASBC mixture (Palankar *et al.*, 2014; Kumar *et al.*, 2020).

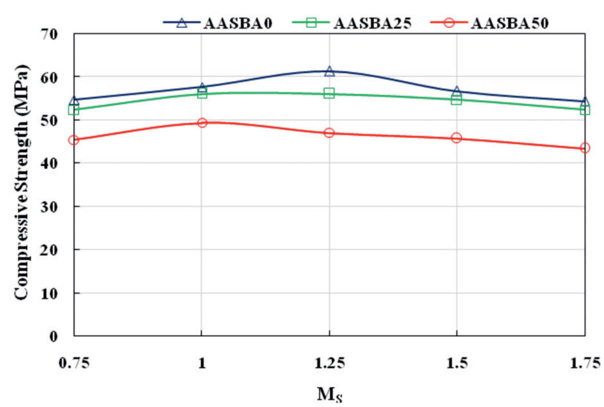

Fig. 3. Compressive strength variation of AASBC mixture with 4% Na_2O dosage with different levels of Ms

Table 2. Detailed elemental composition of GGBS and BA.

Binder	Atomic weight (%)					
	Si K	Al K	Ca K	Mg K	K K	Fe K
GGBS	32.89	15.18	44.46	7.02	0.45	-
BA	81.94	1.93	4.23	-	8.13	3.78

Further to enhance the compressive strength of BA based AASBC mixture, 50% BA based AASBC mixtures were redesigned by considering Na_2O dosage of 4, 4.5, 5, and 5.5 % for the Ms of 1. Figure 4 shows compressive variation of AASBC50 mix for different levels of Na_2O dosage. Compressive strength found to be in the range of 50-56MPa. Increase in compressive strength is observed with increase in Na_2O dosage. 7.4, 13.52, and 10.53% compressive strength gets increased with 4.5, 5, and 5.5% Na_2O dosage respectively for 50% BA based AASBC mixture. Maximum compressive strength observed in 5% Na_2O dosage. Beyond 5% of Na_2O dosage dissolution process in formation of C-A-S-H and N-A-S-H is not effective.

BA replacement restricted to 50%, due to the main reason that, reduction in compressive strength compared to 100% GGBS based AASBC mixture. Nevertheless, high volume BA can be activated with higher Na_2O dosage but higher quantity NaOH and Na_2SiO_3 results in higher energy consumption and higher CO_2 emission to environment.

Conclusion

As stated in earlier section, bagasse is the residue of sugarcane, which is obtained after extraction of juice. The bulk amount of bagasse waste produced in sugar factories requires a meaningful disposal scheme. Since, bagasse has good calorific properties; it is being used as the principal fuel in cogeneration plants for electric power generation. The burning of bagasse as fuel leaves bulk quantity of ash called bagasse ash (BA). Present study utilizes BA with different levels of replacement to GGBS, as a binder in AASBC mixture under different alkaline solution concentration. Following are the few conclusions drawn from the present investigation.

1. Parabolic variation in compressive strength of AASBC mixture is observed with increase in Ms. Increase in compressive strength is observed with 0.75 to 1.25 Ms values. Beyond the 1.25 Ms value compressive strength gets reduces with higher amount of unutilized reactive silica with all the AASBC mixture.
2. As the amount of percentage of BA replacement increases (i.e., 0 to 50% as binder to GGBS), compressive strength of concrete gets reduced. Due to the reduced amount of C-A-S-H gel formation.
3. Increase in Na_2O dosage (i.e., 4-5.5%) results in the increase of compressive strength of 50% BA based AASBC mixture, due to the higher rate of dissolution of BA used. When the alkaline solution concentration gets beyond 5% Na_2O dosage, further increase in compressive strength of AASBC mixture is negligible.

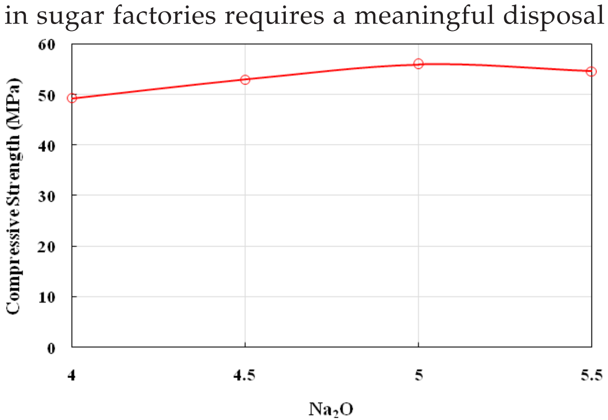

Fig. 4. Compressive strength variation of AASBC mixture with Ms = 1, and with different levels of Na_2O dosage

Acknowledgement

This work was elaborated with the support of Department of Civil Engineering, PES College of Engineering, Mandya, India. Authors are thankful to M/s The Pandavapura Sahakara Sakkare Karkhane Ltd, Pandavapura, Mandya, Karnataka, India for providing bagasse ash to conduct experimental investigation.

References

Bureau of Indian Standards. 2002. IS 2386: Methods of test for aggregates for concrete. New Delhi, India
Bureau of Indian Standards. 2004. IS 516: Methods of tests

for strength of concrete. New Delhi, India.

Bureau of Indian Standards. 2009. IS 10262: Concrete mix proportioning - Guidelines. New Delhi, India.

Castaldelli, V.N., Akasaki, J.L., Melges, J.L., Tashima, M.M., Soriano, L., Borrachero, M. V., Monzó, J. and Payá, J. 2013. Use of slag/sugar cane bagasse ash (SCBA) blends in the production of alkali-activated materials. *Materials.* 6 (8): 3108-3127.

Castaldelli, V.N., Moraes, J.C.B., Akasaki, J.L., Melges, J.L.P., Monzó, J., Borrachero, M.V., Soriano, L., Payá, J. and Tashima, M.M. 2016. Study of the binary system fly ash/sugarcane bagasse ash (FA/SCBA) in SiO_2/K_2O alkali-activated binders. *Fuel.* 174: 307-316.

Chindaprasirt, P., Kroehong, W., Damrongwiriyanupap, N., Suriyo, W. and Jaturapitakkul, C. 2020. Mechanical properties, chloride resistance and microstructure of Portland fly ash cement concrete containing high volume bagasse ash. *Journal of Building Engineering.* 31 : 101415.

Deepika, S., Anand, G., Bahurudeen, A. and Santhanam, M. 2017. Construction products with sugarcane bagasse ash binder. *Journal of Materials in Civil Engineering.* 29 (10): 04017189.

Klathae, T., Tanawuttiphong, N., Tangchirapat, W., Chindaprasirt, P., Sukontasukkul, P. and Jaturapitakkul, C. 2020. Heat evolution, strengths, and drying shrinkage of concrete containing high volume ground bagasse ash with different LOIs. *Construction and Building Materials.* 258: 119443.

Kumar, C.B., Yaragal, S.C. and Das, B.B. 2020. Ferrochrome ash - Its usage potential in alkali activated slag mortars. *Journal of Cleaner Production.* 257 : 120577.

Murugesan, T., Vidjeapriya, R. and Bahurudeen, A. 2020. Development of sustainable alkali activated binder for construction using sugarcane bagasse ash and marble waste. *Sugar Tech.* 22 (5) : 885-895.

Palankar, N., Shankar, A.U.R. and Mithun, B. 2014. Experimental investigation on aircured alkali activated ggbfs-fly ash concrete mixes. *International Journal of Advanced Structures and Geotechnical Engineering.* 3 (4): 326-332.

Pereira, A., Akasaki, J.L., Melges, J.L., Tashima, M.M., Soriano, L., Borrachero, M.V., Monzó, J. and Payá, J. 2015. Mechanical and durability properties of alkali-activated mortar based on sugarcane bagasse ash and blast furnace slag. *Ceramics International.* 41 (10): 13012-13024.