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Studies undertaken at the Central Building Research Institute to determine the potentiality of bagasse ash as a pozzolana are described. The chemical analysis, physical properties, microscopic studies and granulometric characteristics of the ashes obtained from several big and small industries, are described. The lime reactivity of the ashes with different fineness and the method of its further improvement to the desired level, properties of the ash-lime mixture and development of a quick setting lime-ash mixture have also been discussed. The hydration products in the lime ash mixture as studied by DTA have been found to be of the C-S-H type showing thereby the pozzolanic nature of this ash and its utility as a potential pozzolana.

Bagasse is a waste material of the industry. It is mainly used as a fuel by the parent agro-industries and only a small quantity of it is used by packing paper and card board manufacturers.

The ash obtained from the boilers of the jaggery and sugar industries is produced mainly by the burning of bagasse. It is thrown as waste and used mainly as a filling material for low lying areas.

The quantity of bagasse is estimated to be of the order of 25.2 tonnes, based on average production of 8.4 million tonnes of sugar per year[1]. The average composition of bagasse is: moisture, about 45-52 %; fibre, 32-52 % and soluble solids, 2-6 %[2,3].

The ash content of bagasse on calcination is found to be around 3-4 % on dry basis[4]. The ash that may be obtained from the sugar factories in the organised sector may thus be of the order of 0.38 million tonnes; in addition, about 0.75m tonnes of ashes are obtained from the rural raw sugar industries where 60 per cent of cane produced is used, and these two together total up to 1.13 million tonnes of bagasse ash available annually.

On a preliminary observation of the chemical constituents in the ashes it was found that silica and alumina were predominant. Therefore, it was thought proper to use this material as a pozzolana. Pozzolanas are substances which contain siliceous and aluminous constituents in reactive form which are not hydraulic in themselves but produce hydraulic constituents in combination with lime in presence of moisture[5] at ordinary temperature. Several types of pozzolanas, e.g. burnt clay, ashes from the volcanoes, cinder (locomotive ash), flyash, rice husk ash, etc. have been in use in various parts of the world for lime pozzolana and portland-pozzolana cements, etc.

A study was undertaken at the Central Building Research Institute (CBRI) to find out the use of this type of ash as pozzolana. Samples from several industries around Roorkee were collected and their pozzolanic properties and use in lime mortars, etc. were determined. These have been described in this paper.

Materials

Bagasse ash—The samples of ashes from thirteen units situated around Roorkee (India) within 20 km distance were collected, out of which one sample was obtained from a sugar factory, two were from mini sugar plants and others were from cottage level jaggery producing units. One sample was obtained from a unit where sugarcane leaves were employed as fuel.

The chemical analyses of these ashes are shown in Table 1.

Lime—The lime for the purpose of evaluation of these ashes was obtained from a commercial lime plant. The chemical analysis of the lime carried out according to IS:6932-1973 was as follows: Loss on ignition 3.60 %, SiO_2 0.90 %, R_2O_3 0.75 %, CaO 92.70 % and MgO 2.01 % and on hydration the available lime content as $Ca(OH)_2$ was 90.2 % (IS:1514-1954).

Experimental procedure

Evaluation as pozzolana—The ashes were analysed for their chemical constituents and physical properties according to IS:1727-1967 (*Methods of Test for Pozzolanic Materials*).

Samples of two ashes as such were also subjected to sieve analysis to get an idea about the particle size distribution.

Microscopic examination—The ashes were examined petrographically for their mineralogical and crystal nature under the panphot microscope at a magnification of 200 times.

Effect of grinding—Some ashes were ground further in a ball mill and their surface area was determined with the help of air permeability apparatus; these were also subjected to lime reactivity evaluation to find out the effect of grinding of these ashes on pozzolanic properties.

Differential thermal analysis—Some ashes and the lime ash mixture, cured for different periods in moist air and under water after completed drying were analysed with the help of a laboratory assembled DTA apparatus. γ-Alumina was used as reference material. The heating rate was maintained at 10°C per minute.

Preparation of lime-bagasse-ash mixture—Bagasse ash No. 1 was taken as a typical sample for these studies. It was used for making mortar as such and after grinding to pass through 50, 100 and 200-mesh sieve respectively.

The ash in each case was mixed with hydrated lime in the ratios of 2:1 and 3:1 by volume.

Table 1—Chemical Analyses of Bagasse Ashes

Constituents	Ash sample no. 1	2	3	4	5	6	7	8	9	10	11	12	13
Loss on ignition	6.30	1.45	3.27	1.44	4.44	3.91	0.81	6.57	4.90	5.30	0.45	0.50	5.36
SiO_2	68.39	70.60	66.27	72.61	65.30	66.70	74.10	70.72	70.62	68.31	73.50	73.48	69.39
R_2O_3	18.52	18.31	20.40	18.43	19.60	19.20	16.32	17.51	17.05	16.94	18.60	19.00	18.57
CaO	3.51	5.12	5.23	2.77	6.40	5.13	3.77	3.24	4.74	6.71	5.52	4.47	3.81
MgO	2.04	3.11	3.33	3.56	2.55	3.32	3.15	1.36	1.87	1.03	1.44	1.72	1.22

Mortar was prepared by additions of water. The flow of the mortar was maintained at 110 ± 5 % according to IS:2750-1966. This mortar was used for determining the compressive strength. 50mm cubes as per IS:2250-1973 were prepared for this purpose. The cubes were moist-cured in the cases where ash as such and passing through 50 and 100 mesh sieves were used. The cubes in the case of 200 mesh were moist cured for only 7 days and then dipped in water till the test period was over. The compressive strength of the cubes after 7,14,28,90 and 365 days of curing was determined.

Quick setting lime-ash binder—Attempt was also made to obtain a quick setting lime-ash mixture which may set and harden quicker than the conventional mixture. This was accomplished by intergrinding a mixture of hydrated lime-bagasse ash alongwith 10 per cent of ordinary portland cement (IS:269-1978) and 4 % gypsum with $CaSO_4.2H_2O$ content of 80 % (IS:1290-1965) in a ball mill till the mixture attained a fineness of passing 90 % through 200 mesh (75 μ) sieve. The mixture so prepared was evaluated as per IS:4098-1967.

Discussion

The results of chemical analysis as given in Table 1 show that these basic values are well within required limits[6,7]. The magnesia content is also vary very close to the limits. On the basis of chemical analyses these ashes may be recommended for use as pozzolana.

The results of sieve analysis (Table 2) show that the ashes do not contain high percentage of very fine fraction material but they are like the ordinary surkhi available in the market[8].

The microscopic examination (Table 3) reveals that silica was present predominantly in amorphous state along with some secondary and cryptocrystalline quartz. The iron oxide and carbonaceous impurities were observed to be present as coatings over the silica grains. Due to the presence of this type of coating on silica grains the reactive sites were not easily

Table 2—Sieve Analysis of Ash

Retained on IS Sieve No.	Sample No. (Percentage retained) 1	2
240	16	20
120	11	12
60	6	4
30	29	31
15	23	20
Passing 15	15	13

Table 3—Petrographic Results of Ashes

Identified minerals	Results
Quartz	Eminently as amporphous phase along with crypto crystalline quartz
Iron oxide	Magnetite form. Hematite also present in traces. Occasionally present on silica grains as coating.
Carbonaceous matter	Little amount, present as coating or adhering to the grains

Table 4—Lime Reactivity Values of Ashes

Bagasse ash No.	Specific surface (cm²/g)	Lime reactivity value (kg/cm²)
1	3208	29.6
2	3190	27.2
3	3300	40.0
4	3210	33.2
5	3306	30.0
6	3208	27.6
7	3195	26.8
8	3222	28.6
9	3190	28.0
10	3271	33.0
11	3330	41.5
12	3290	30.8
13	3200	32.2

Table 5—Effect of Grinding on Lime Reactivity Value of Ashes

Bagasse ash No.	Specific surface, (cm²/g)	Lime reactivity value (kg/cm²)
1	4510	42.1
10	4570	50.3
13	4556	47.8

available for reaction and therefore the lime reactivity value in case of these ashes was found to be low. Fine grinding exposes more active[9] surfaces for reaction making it more suitable as pozzolana as indicated by the results given in Table 4. The results on grinding of ashes Nos 1,10,13 given in Table 5 show that the increase in Blain's fineness from 3200 cm^2 to about 4500 cm^2/g results in an increase of the lime reactivity from 29.6, 33.0 and 32.2 kg/cm^2 to 42.1, 50.3 and 47.8 kg/cm^2 respectively in above three ashes. This clearly indicate the suitability of bagasse ash as a pozzolana like flyash, burnt clay, pozzolana, etc.

The results on the evaluation of use of bagasse ash for making mortar in the conventional manner with reference to the determination of compressive strength and setting time are given in Tables 6 and 7. In these cases the ash No. 1 with different finenesses was used. The lime and bagasse ash in several proportions were mixed. The ground ash mortar developed better strength than the strength obtained with ground ash; even the slightly ground ash developed strength comparable to the mortar with ordinary market surkhi and cinder, etc.[10,11]. The setting time determination also showed that only the fine ash lime mix possessed setting time within 48 hours, which is one of the requirements of LP-7 type lime-pozzolana mixture as per IS:4098-1967. These results confirm the suitability of the bagasse ash as pozzolana.

Table 6—Compressive Strength of Lime-ash (No. 1) Mortars

Mix proportion by volume Lime:	Ash	Fineness	7 days	14 days	28 days	90 days	365 days
1	1	As such	No strength	2.71	3.93	14.87	36.02
1	2		"	2.22	4.10	14.09	36.10
1	3		"	1.98	3.59	13.07	28.21
2	1		"	3.88	3.88	7.85	30.97
1	1	Passing 50-mesh sieve	2.63	6.09	11.86	23.80	38.08
1	2		2.57	8.37	16.81	31.23	48.39
1	3		2.04	8.06	15.37	22.76	40.40
1	1	Passing 100-mesh sieve	3.70	5.75	14.03	28.38	50.42
1	2		4.49	9.99	23.24	54.86	79.22
1	3		4.10	8.37	20.80	46.73	63.10
1	1	Passing 200-mesh sieve	5.90	11.34	26.63	49.34	76.30
1	2		6.86	12.72	31.30	64.47	91.24
1	3		6.02	11.94	29.54	58.21	79.25

In Table 8 the results on properties of quick setting lime-bagasse ash mixture developed as per the method described in this paper are given. The properties, e.g. setting and gain of strength etc., were found better than the conventional type mixture given in Tables 6 and 7. The compressive strength and setting time are important properties for mortars and the quick setting lime-bagasse ash mixture has both these properties, much improved. The strength is found to improve 3-4 times better than the ordinary lime-bagasse ash mixture. The quick setting hydraulic binder has higher sand carrying capacity also. It can also be made available in ready-to-use-form.

Table 7—Setting Time of Conventional Lime-ash (No. 1) Mixture (ratio 1:2)

Ash fineness	Setting time	
	Initial hr	Final hr
As such	No setting upto 48 hr	—
Passing 50-mesh sieve	No setting upto 48 hr	—
Passing 100-mesh sieve	46 hr	84
Passing 200-mesh sieve	27	47

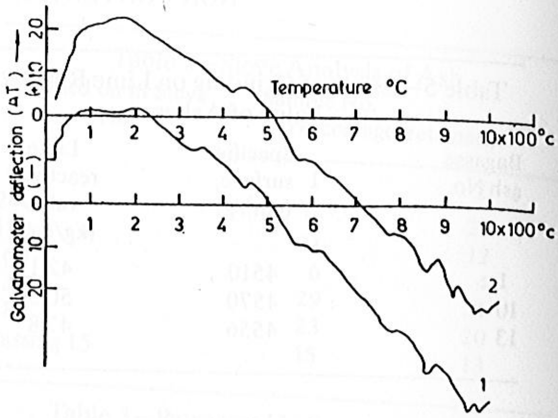

Fig. 1—DTA thermograms of bagasse ash

The DTA thermograms of bagasse ashes in Fig. 1 show that the bagasse ash is composed mainly of free silica and some unburnt carbon. After a temperature of 850°C the sample fuses. Fig. 2 shows that the reaction between lime and bagasse ash continues for sufficiently

Table 8—Physical Properties of Quick Setting Lime-Ash Mixture (Hydraulic Binder)

Property	Result obtained Binder with Ash No.					
	1		10		13	
Fineness						
Per cent residue on 90 μ sieve	1.2		1.7		1.5	
Per cent residue on 75 μ sieve	3.8		4.9		5.0	
Setting time						
Initial (minutes)	45		50		50	
Final (minutes)	370		540		470	
Compressive strength (kg/cm²)						
Binder: Sand	7 days	28 days	7 days	28 days	7 days	28 days
1 0 (%)	14.70	76.56	12.05	69.02	16.20	89.30
1 3 (%) (absolute volume)	7.81	31.20	6.31	26.38	8.13	37.50
Water retention (%)	71	—	71	—	71	—

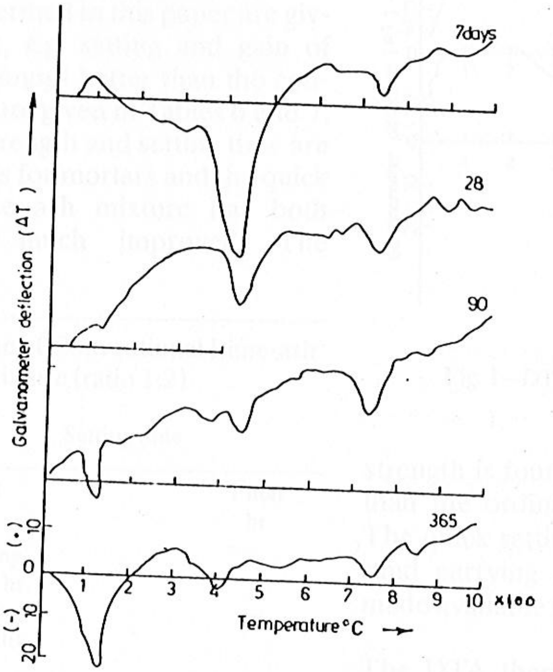

Fig. 2—DTA thermograms of lime-bagasse ash mixture cured for various periods

long time at room temperatures and therefore, the strength development also continue over long periods as is generally the case in lime-pozzolana mixture. The fixation of lime in the reaction mixture is indicated with DTA endothermic effects for CSH gel, C-A-H phase and $Ca(OH)_2$, etc. in the hydrated phases of different curing periods. The peaks at about 115°, 355° and 450°C are indicative of these phases respectively. The consumption of $Ca(OH)_2$ increases with the passage of periods of moist and water curing and in a year most of the $Ca(OH)_2$ is consumed in lime pozzolana reaction. In the 90 days and one year cured hydrated products the C-S-H phase become more prominent as indicated by sharp endothermic peaks at 115°C and exothermal effect at about 820°C.

Conclusions

The investigations and results discussed in thi paper show that bagasse ash has a great poten tial to be used as a pozzolana like flyash, cin der or surkhi for preparation of lime-pozzola na mortars after a little grinding. This can als be utilized for production of ready-to-use lim pozzolana mixture conforming to IS:4098 a cottage industry level. Its use shall also resul in conservation of energy.

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