Pozzolanic behaviour of bagasse ash

A DERIVATIVE OF SUGAR CANE DISTILLATION, BAGASSE ASH, HAS PROPERTIES THAT MIGHT BE SUITABLE FOR USE IN BUILDING MATERIALS

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The CBRI investigations indicate that bagasse ash has to be considered as a pozzolanic material like fly ash or any other conventional pozzolana. High surface area is required to expose the grains which are coated with iron oxide and carbonaceous impurities. The authors consider that the material may be used for preparing lime ash mixture to be used locally as a mortar, especially in rural areas where availability is high.

Les investigations du CBRI indiquent que des cendres de 'bagasse' devraient être considérés comme une matière 'pozzolanique', du même genre que les cendres de 'fly' et de tout autre 'pozzolana' classique. Une grande surface est nécessaire pour exposer les grains couverts d'oxyde de fer et d'impuretés carbonifères. Les auteurs considèrent que cette matière peut servir dans la préparation des cendres de chaux pour le mortier, surtout dans les régions rurales où elle est abondante.

Keywords: bagasse ash, pozzolana, India, CIB Montréal

Introduction

There are a number of siliceous and argillaceous materials which are used as pozzolana in various parts of the world. Fly ash, cinders (as from locomotives), ashes from volcanoes etc. are used to obtain hydraulic binders whereas clays of different mineralogical origins on calcination produce pozzolanas of various grades. Recently rice husk ash [1] has also been recognized as a good pozzolanic material.

In India, as well as elsewhere, bagasse obtained after extraction of sugar juice from sugar cane is used as a source of heat energy to produce sugar, jaggery and other related products. The ashes obtained from such industries are generally used for filling uneven land and are not put to any other use at present.

The projected quantity of bagasse ash may be linked to the production of sugar which was about 120 lakh tonnes in the year 1990–1991 [2]. The quantity of bagasse was estimated to be about 30% of sugar cane, the sugar content averaged at 10%. About 40% of sugar cane is utilized by the sugar industry whereas 60% of sugar can is used in rural areas for jaggery and allied products. For seed purposes 10% of sugar cane is kept aside. The ash content of bagasse on calcination is found to be around 3% on dry basis [3, 4] and may thus be around 2 million tonnes per annum.

On a preliminary observation of the chemical constituents in the bagasse ash [5] it was found that it predominantly contains silica, alumina etc. as found in the pozzolanic materials. Therefore, it was thought worthwhile to study these ashes from a number of industries, big or small, for their pozzolanic properties and to utilize them as a component building materials.

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Materials

Bagasse Ash

The samples of ashes from 13 units situated around Roorkee (India) within 20 km were collected. 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 plant. The chemical analysis of the lime is given in Table 2.

Conventional pozzolanas

Four different samples of commonly available pozzolanas – surkhi (crushed brick bats), fly ash from thermal power station, cinders from railway yards and burnt clay pozzolana especially prepared as a reactive pozzolana – were taken. The chemical analyses and other properties of these samples are given in Table 3.

Table 1. Chemical analyses of bagasse ash

Constituents	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

Table 2. Chemical analysis of lime

Constituents	%
A. Loss on ignition	3.60
SiO_2	0.90
R_2O_3 ($Fe_2O_3 + Al_2O_3$)	0.75
CaO	92.70
MgO	2.01
B. $Ca(OH)_2$ on hydration	90.2

Fig. 1. Photomicrograph of bagasse ash (magnification ×200 times).

Sand

Throughout these studies, the same sample of sand conforming to IS: 650–1966 (Specification for Standard Sand for testing of cement) was used to prepare the mortars. To make concrete, sand from Badarpur with fine grading of 2.13 was used.

Coarse aggregate

Graded crushed aggregate produced from natural stone 1.0 cm and down having a fineness modulus up to 4.0 was used.

Experimental

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).

Microscopic examination

The ashes were examined petrographically under a panphot microscope at a magnification of 200 times (Fig. 1).

Effect of grinding

Three ashes were ground more finely than required for evaluation as a pozzolana in a ball mill and effect of fineness on lime reactivity value of these ashes was evaluated as per IS: 1727–1967.

Differential thermal analysis

Some ashes and lime-ash mixture cured for different periods in moist air (7 days) and under water (after 7 days) and after complete vacuum drying by checking further hydration by acetone washing were analysed with the help of DTA apparatus. Thermograms of bagasse ashes are given in Fig. 2, while Fig. 3 shows the thermogram of hydrated lime ash mixture paste cured for different periods.

Preparation of lime – bagasse and lime – conventional pozzolana mixture

Bagasse ash No. 1 was taken as a typical example for these studies. It was used for making mortar after grinding ash to pass a 200 mesh sieve. The ash and conventional

Table 3. Properties of conventional pozzolanas

Constituents	Flyash	Surkhi	Cinder	Burnt clay pozzolana
A. Loss on ignition	0.30	3.11	11.70	3.91
SiO_2	65.83	77.15	60.02	65.36
R_2O_3	27.72	16.08	23.76	24.45
CaO	1.62	2.13	2.14	5.77
MgO	0.90	0.41	1.03	0.06
B. Fineness, $Cm^2 g^{-1}$	4686	3300	3380	3290
C. Lime reactivity value $kg\ cm^{-2}$	52.0	24.0	22.3	85.7

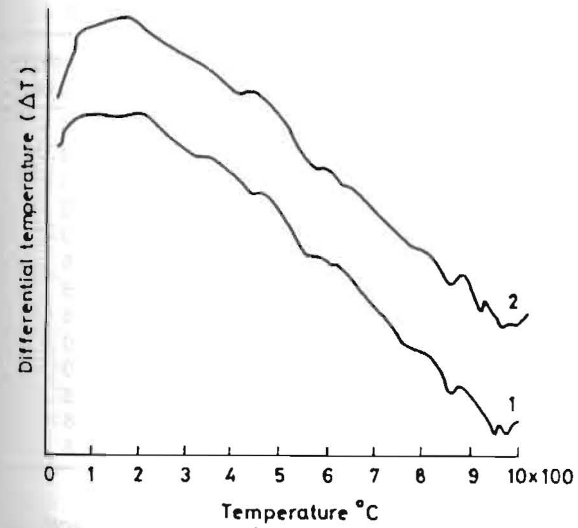

Fig. 2. DTA thermograms of bagasse ash.

pozzolanas in each case were mixed with dry hydrated lime in the ratio of 2:1 by volume. Mortar was prepared by adding water. The flow of the mortar was maintained at 110 ± 5% according to IS: 2250–1981 (Code of Practice for preparation and use of masonry mortars) and was used for preparing 50 mm cubes for determining compressive strength. The cubes were moist cured for 7 days and then dipped in water at a constant temperature of 27 °C ± 1 °C until the test period was over. The compressive strength of cubes prepared with bagasse ash

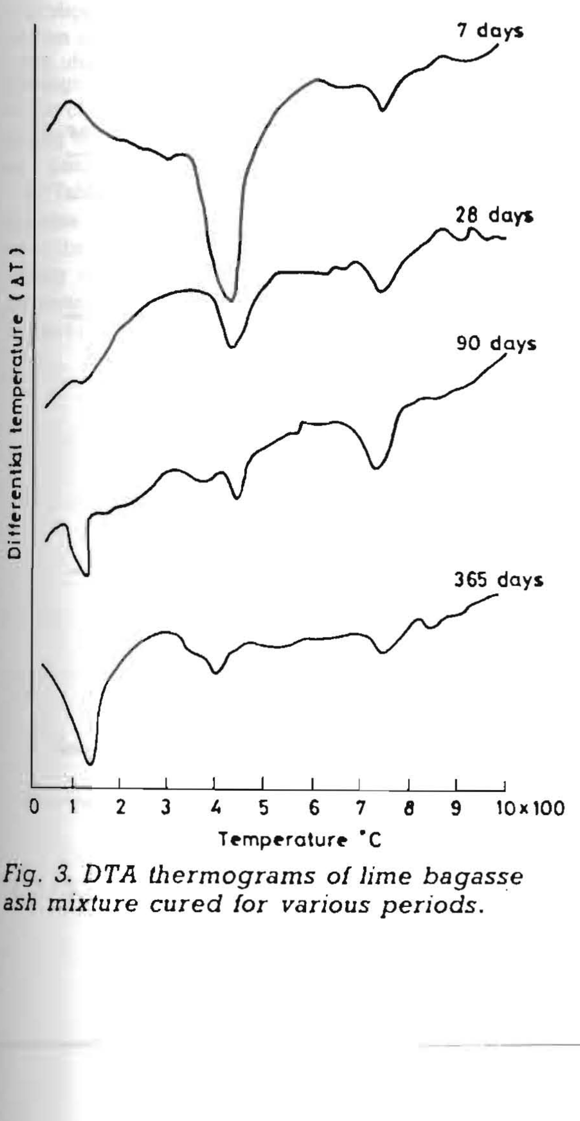

Fig. 3. DTA thermograms of lime bagasse ash mixture cured for various periods.

Table 4. Petrographic results from ash

Identified minerals	Results
Quartz	Eminently as amorphous phase along with cryptocrystalline quartz
Iron oxide	Magnetite form. Haematite also present in traces. Occasionally present on silica grains as coating.
Carbonaceous matter	Small amount, present as coating or adhering to the grains

and conventional pozzolanas are given in Table 4. Setting times were evaluated as per IS: 4098–1967 (specifications for lime Pozzolana Mixtures).

Quick setting lime–bagasse ash binder

An attempt was also made to obtain a quick setting lime ash mixture which may set and harden more quickly than the conventional mixture. This was accomplished by intergrinding a mixture of hydrated lime, bagasse ash along with 10% of ordinary portland cement passing IS: 269–1976 (specifications for ordinary and low heat portland cement) and 4% gypsum with 80% $CaSO_4 \cdot 2H_2O$ content (IS: 1290–1965, specifications for mineral gypsum) 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.

X-ray analysis

X-ray diffraction pattern of lime ash mixture cured for 365 days was obtained on a Phillips X-ray diffractometer having recorder with chart speed 0.5 cm per minute and exposure angle rate of 1° per minute using a target of Cu K-α radiations (Fig. 3).

Preparation of concrete blocks

Blocks with dimensions of 45 × 22.5 × 11.5 with two hollows of size 16 × 4 cm each and spaced 7 cm apart were cast with the help of a machine capable of vibrating and compacting the material. Water was added to the mix of binder, fine aggregate and coarse aggregate just sufficient for dry consistency. The concrete was then filled in the mould mounted on the machine. After compaction and vibration for two minutes, blocks were extruded and lifted on the plank support for curing and hardening under wet gunny bags. After 28 days' curing these blocks were tested according to relevant Indian Standards (Fig. 4).

Discussion of results

The results of chemical analyses given in Table 1 show that the loss on ignition values varies from 0.05 to 6.57. The silica varies from 65.30 to 74.1% and R_2O_3 content is between 16.32 to 20.40%. These values are well within required limits [6, 7]. The magnesia content is also very close to the limits. On the basis of chemical analysis these ashes may be suitable for use as pozzolana.

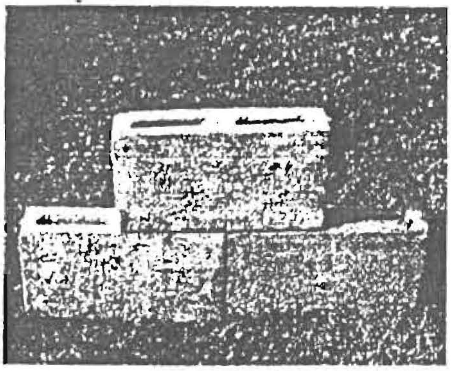

Fig. 4. Hollow concrete blocks.

The microscopic examination (Fig. 1, Table 4) revealed that silica was present predominantly in an amorphous state along with some secondary and crypto-crystalline quartz. The iron oxide and carbonaceous impurities were observed to be present as a coating over the silica grains. This type of coating means sites are not available for reaction and therefore the lime reactivity value was found to be low. Fine grinding exposes more reactive surfaces for reaction [8], making it more suitable as pozzolana as indicated by the results given in Tables 5 and 6. The results on grinding of ashes No. 1, 10, 13 given in Table 6 show that the increase in the Blain's fineness from 3200 $cm^2\ gm^{-1}$ to about 4500 cm^2/g results in an increase of the lime reactivity value from 29.6, 33.0 and 32.2 kg cm^{-2} to 42.1, 50.3 and 47.8 kg cm^{-2} respectively. This clearly indicates the suitability of bagasse ash as a pozzolana similar to fly ash, burnt clay pozzolana etc.

The results on the evaluation of bagasse ash for making mortar in the conventional manner with reference to the determination of compressive strength and setting time are given in Table 7, the properties of conventional lime pozzolana mortar are given for comparison. Bagasse ash was also evaluated for compressive strength and the results are given in Table 8. The ground ash mortar develops better strength than does unground ash; even

Table 5. Lime reactivity values of ashes

Bagasse ash no.	Specific surface, $cm^2\ g^{-1}$	Lime reactivity value, kg cm^{-2}
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 6. Effect of grinding on lime reactivity value of ashes

Bagasse ash no.	Specific surface, $cm^2\ g^{-1}$	Lime reactivity value, kg cm^{-2}
1	4510	42.1
10.	4570	50.3
13.	4556	47.8

Table 7. Properties of lime bagasse ash and other lime conventional pozzolana mixtures

	Mixture with				
Properties	Surkhi (prepared after crushing brick bats)	Flyash	Cinder (obtained from locomotives)	Burnt clay pozzolana	Bagasse ash
Setting time (hrs-min)					
Initial	24.30	19.00	27.0	4.30	27
Final	74.00	66.00	78.00	19.00	47
Fineness					
% retained on 90 μ sieve	1.4	1.5	2.0	1.7	2.0
Compressive strength, Kg cm^{-2} (1:2 by volume lime: Pozzolana)					
7 days	5.63	1.58	2.28	28.88	6.09
28 days	15.61	5.60	6.30	59.77	29.30

Table 8. Compressive strength of lime bagasse ash mortars

	Mix properties by volume 1:2 (lime:ash) Compressive strength				
Fineness	7 days	14 days	28 days	90 days	365 days
As such	no strength	2.22	4.10	14.09	36.10
Passing mesh 50	2.57	8.37	16.81	31.23	48.39
Passing mesh 100	4.49	9.99	23.24	54.86	79.22
Passing mesh 200	6.86	12.72	31.30	64.47	91.24

Table 9. Physical properties of quick setting lime–bagasse ash mixture

Property	Result obtained binder with ash no. 1		10		13		Specification on lime pozzolana mixture (LP20) IS: 4098–1967	
Fineness								
% retained on 150 μ sieve	0.8		0.7		0.7		Max 10	
Setting time initial (minutes)	45		50		50		Min 2 hours	
Final (minutes)	370		540		470		Max 36 hours	
Compressive strength Kg/cm²								
Binder : Sand (1 : 3)	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
	7.81	31.20	6.31	26.38	8.13	37.50	10	20
(On absolute volume basis)								
Water retention, %	71		71		71		70	

Table 10. Properties of building blocks

Sl No.	Property	Lime ash concrete blocks	IS Specification for Lime cement cinder hollow blocks (IS: 5498-1969)	Hollow cement concrete block specification (IS: 2185-1967)
1.	Dimension, cm	45 × 22.5 × 11.5	40 × 30 × 20	40 × 30 × 20
2.	Weight, Kg	21	21.5	21.5
3.	Compressive strength, Kg cm^{-2} (28 days)	40.5	18.0	50.0
4.	Drying strength	0.045	0.10	0.06
5.	Water absorption Kg m^{-3}	185	—	240
6.	Moisture movement %	0.03	0.05	0.03

the slightly ground ash develops a strength comparable to that of mortar made with conventional pozzolanas. The setting time also shows the suitability of the bagasse ash as a pozzolana.

In Table 9 the properties of the quick setting lime bagasse ash mixture developed using the method described in this paper are given. The properties – e.g. setting time and gain of strength etc. – were found to be better than the conventional mixture (Table 7). The compressive strength and setting time are important properties for mortars and the quick setting lime bagasse ash mixture has an improved performance. Strength is found to be 3–4 times more than that of the ordinary lime bagasse ash mixture. The quick setting hydraulic binder also has a higher sand carrying capacity. It can also be made available in a ready-to-use form

This binder has also been used to obtain machine made hollow-concrete blocks using the concrete 1:1.5:2.5 (on volume basis). The results are shown in Table 10, which

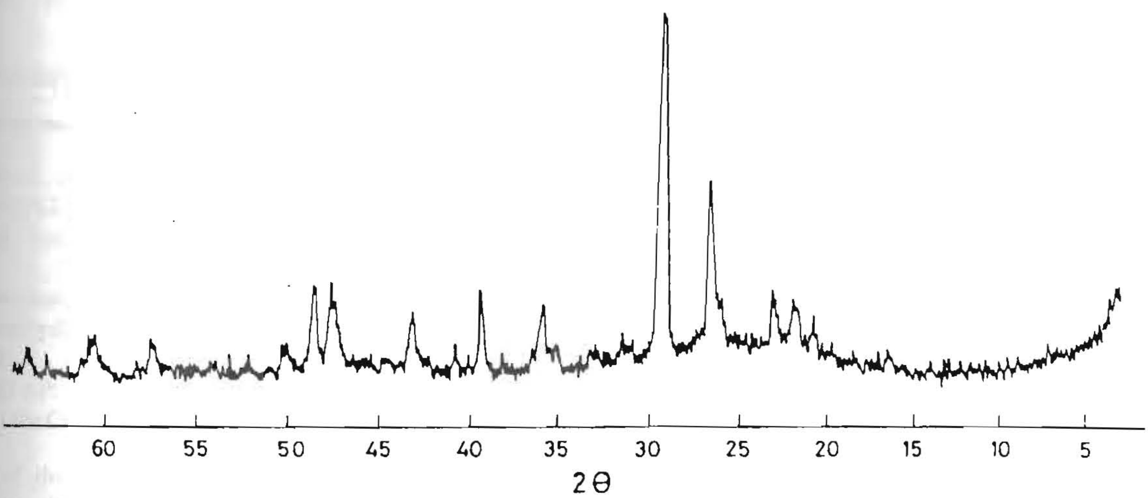

Fig. 5. XRD pattern of lime bagasse ash mixture paste hydrated for 365 days.

are comparable with the properties of blocks obtained with allied materials.

The DTA thermograms of bagasse ashes in Fig. 2 show that bagasse ash is composed mainly of free silica and some unburnt carbon. After a temperature of 850 °C the sample fuses. Figure 3 shows that the reaction between lime and bagasse ash continues for a sufficiently long time at room temperature and therefore, the strength development also continues over long periods as is generally the case with lime conventional pozzolana mixture. The fixation of lime in this reaction mixture is indicated on DTA curve with endothermic effects for CSH gel, CAH Phase and $Ca(OH)_2$ etc. in the hydrated phases of different curing periods; the peaks at about 115 °C, 355 °C 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 $Ca(OH)_2$ has been consumed in a lime pozzolana reaction. In 90 days and one year cured sample hydrated product CSH phase becomes more predominant as indicated by sharp endothermic peak at 115 °C and exothermal effect at about 820 °C.

The x-ray analysis of lime bagasse ash mixture paste hydrated for 365 days depicted in Fig. 4 corroborates the formation of badly crystallized CSH as principal phase along with C_3AH_6. Presence of $Ca(OH)_3$ and free silica is also indicated.

Conclusions

The investigations and results described in this paper reveal that bagasse ash has about two-thirds silica contained in it and most of this is present in an amorphous state. Bagasse ash has to be considered as a pozzolanic material like fly ash or any other conventional pozzolana. A high surface area is required to expose the grains which are coated with iron oxide and carbonaceous impurities. Differential thermograms and XRD pattern indicate the fixation of lime with the passage of time, and the hydration product is predominantly CSH.

Bagasse ash, thus, may be utilized for the preparation of lime ash mixture to be used on site as a mortar particularly in rural areas where its availability is high. Its use will also result in the conservation of energy.

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