Physicochemical Study of Bagasse and Bagasse Ash from the Sugar Industries of NWFP, Pakistan and Its Recycling in Cement Manufacturing

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Summery: Bagasse and bagasse ash, obtained from the local sugar mills of North West Frontier Province (NWFP), Pakistan, were analyzed for both physical and chemical parameters. Among the physical parameters, the moisture, ash contents, volatile matter, loss on ignition, and calorific value have been determined while the chemical constituents such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, carbon and sulfur were also determined in both baggase and baggase ash. The physico-chemical characterization of baggase ash suggests that it can be used as a part of the cement admixture, which could be cost effective and environmentally sustainable.

Introduction

Cement is the third most energy intensive material to produce on per ton basis, after steel and aluminum. Cement industry consumes raw material rich in silica, alumina, iron and calcium. Therefore, this industry has been actively involved in finding ways to use waste products in the manufacturing of cement both as secondary fuel and raw material. Fly ash is a pozzolan, a silica, alumina, and calcium based material, which in the presence of water chemically combines with the free lime contained in the fly ash and produces a cementitious material with excellent structural properties [1-5]. Ashes from combustion of coal are the major industrial by-products that are suitable for use as mineral admixtures in Portland cement. High carbon fly ash is also being utilized as both a source of fuel and raw material in the cement and construction material [6]. Fly ash is rich in all or some of these contents and can be used as a raw material. High carbon fly ash has the additional benefits of being a source of fuel. Environmentally, it provides a sound method for recycling non-hazardous waste and conserving natural resources [7]. Economically, its use can replace some of the raw materials; reduce the energy cost, and increasing revenues from the cement industry. In terms of the cement itself, benefits can include a decrease in alkali contents and improved burnability, resulting in energy savings and production of cement with better hydraulic properties [8].

Bagasse is fibrous residue of cornstalk that is obtained after the extraction of sugarcane juice by the milling process. The ready availability of bagasse, as a by-product of sugar production, has always made it an attractive fuel for the sugar industry and covers the energy requirements (electricity / steam) of the industry and leave 0.26 % of residual ash. Thus it has been used as fuel in the boilers of the sugar factories since the beginning of the 20th century.

Sugar manufacturing is the major agro-industry in Pakistan. In the year 2005 Pakistan produced about 54 million tons of sugarcane, which was mainly used to produce sugar. Each ton of sugarcane generates approximately 26 % of bagasse. Therefore, considering the production of 2005, about 0.5 million ton of residual ash become available in Pakistan per year. While, this ash found no use and is discarded and dumped around the factory premises. This unwise disposal causes environmental nuisance.

The objective of this work is to characterize the bagasse ash produced by three local sugar mills (*i.e.*, Premier sugar mill, Mardan, Khazana sugar mill and Frontier sugar mill, Takhtbhai) of North West Frontier Province (NWFP) of Pakistan in terms of its chemical composition, physical properties, and pozzolanic activity in order to undertake further study to evaluate how far it meets the existing specifications of Portland cement.

Results and Discussion

Bagasse may contain various amounts of sand or soil, especially in wet harvesting conditions,

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and may also vary in moisture content, depending upon the harvesting conditions and the conditions of the milling train. It consists of lignocellulose, insoluble inorganic matter (ash), water-soluble material (brix) and water. The bagasse samples were analyzed for moisture and ash contents by thermogravimetric analyzer (TGA). The results are reported in Table-1. Moisture contents of bagasse samples range from 8.78 % to 9.55 %. The average moisture present in these samples is 9.18 %. The ash content varies from 3.01 % to 4.05 %. Both moisture and ash contents in the Bagasse samples exhibit little variation.

Table-1: Physical analysis of bagasse collected from sugar mills of NWFP.

Sample No	Moisture %	Ash %
S_1	9.21	3.23
S_2	9.26	3.01
S_3	9.07	4.05
S_4	8.88	3.03
S_5	8.97	3.64
S_6	8.78	3.27
S_7	9.52	3.51
S_8	9.55	3.81
S_9	9.34	3.62
Average	9.18	3.46

The results of bagasse ash analysis by TGA are given in Table-2.. The avergae moisture contents are 2.32 %, 2.91 %, and 3.57 % for the samples from Premier sugar mill (PSM), Khazana sugar mill (KSM) and Frontier sugar mill (FSM), respectively. The average loss on ignition (LOI) is 14.48 %, 11.51 % and 14.36 % in PSM, KSM and FSM, respectively. The value of LOI is mainly attributable to unburned carbon in the ash that can have a potential fuel value. The remaining average residue (ash) after ignition is 85.58 %, 88.61 % and 85.88 % for PSM, KSM and FSM, respectively.

Table-2: Analysis of bagasse ash using of Thermo-gravimetric analyzer.

Sampling Station	Sample Code	Moisture (%)	Ash (%)	Loss on Ignition (%)
Premier sugar mill Mardan (PSM)	S_1	2.25	85.58	14.45
	S_2	2.35	85.21	14.80
	S_3	2.36	85.95	14.20
	Average	2.32	85.58	14.48
Khazana sugar mill Peshawar(KSM)	S_4	2.95	88.47	11.60
	S_5	2.76	88.62	11.40
	S_6	3.02	88.75	11.52
	Average	2.91	88.61	11.51
Frontier sugar mill Thakt-Bhai (Mardan) (FSM)	S_7	3.56	85.85	14.25
	S_8	3.68	85.66	14.44
	S_9	3.46	86.14	14.38
	Average	3.57	85.88	14.36

The calorific values of bagasse ash as determined by bomb calorimeter are shown in Table-3. The average calorific values are 50, 48.33, and 49.67 kcal/kg in the ash samples of PSM, KSM and FSM, respectively. Table-4 shows that the average sulfur contents in the samples of PSM, KSM and FSM are 0.213 %, 0.173 %, and 0.233 %, respectively and the carbon contents are 16.33 %, 23.33 %, and 16.33 % for PSM, KSM and FSM, respectively. The appreciable amount of carbon contents in the Bagasse show an incomplete burning of bagasse. About 16 % carbon remains unburned in PSM and FSM while in KSM about 23 % carbon remains unburned. It seems that the burning system has some inherent problems, which hampers complete burning of bagasse. This problem is more pronounced in the case of KSM.

Table-3: Analysis of bagasse ash through bomb calorimeter.

Sampling Station	Sample Code	Calorific Value (kcal/kg)
Premier sugar mill Mardan (PSM)	S_1	50
	S_2	50
	S_3	50
	Average	50.00
Khazana sugar mill Peshawar(KSM)	S_4	48
	S_5	49
	S_6	48
	Average	48.33
Frontier sugar mill Thakt-Bhai (Mardan) (FSM)	S_7	50
	S_8	49
	S_9	50
	Average	49.67

Table-4: Analysis of bagasse ash through carbon-sulfur detector.

Sampling Station	Sample Code	Sulfur (%)	Carbon (%)
Premier sugar mill Mardan (PSM)	S_1	0.22	15
	S_2	0.21	16
	S_3	0.21	18
	Average	0.213	16.33
Khazana sugar mill Peshawar(KSM)	S_4	0.17	24
	S_5	0.18	23
	S_6	0.17	23
	Average	0.173	23.33
Frontier sugar mill Thakt-Bhai (Mardan) (FSM)	S_7	0.23	15
	S_8	0.24	16
	S_9	0.23	18
	Average	0.233	16.33

The chemical analysis of various oxides in the bagasse ash from three sugar mills (*i.e.*, PSM, KSM and FSM) are given in Table-5. The results show that the average amount of SiO_2 in all the samples of ash of these sugar mills is 87.87 % and is present as a major constituent in the ash. Other minor constituents are Al_2O_3 (2.47 %), Fe_2O_3 (4.05 %), CaO

Table-5: Chemical analysis of bagasse ash collected from sugar mills of NWFP.

Oxides %	Percent Composition									Average
	PSM			KSM			FSM			
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	
SiO_2	87.4	87.23	88.65	90.09	89.89	88.36	85.65	86.25	87.32	87.87
Al_2O_3	3.60	3.45	3.65	1.77	1.84	1.72	2.15	1.99	2.02	2.47
Fe_2O_3	4.90	5.02	4.26	2.65	2.71	2.82	4.82	4.75	4.56	4.05
CaO	2.56	2.49	2.64	2.68	2.75	2.65	3.39	3.25	3.35	2.86
MgO	0.69	0.71	0.63	0.66	0.72	0.62	1.98	2.02	1.87	1.10
Na_2O	0.15	0.14	0.15	0.28	0.27	0.25	0.11	0.11	0.10	0.17
K_2O	0.47	0.47	0.45	0.32	0.35	0.32	0.58	0.57	0.41	0.44
SO_3	0.11	0.12	0.11	0.16	0.15	0.12	0.23	0.21	0.20	0.16
Total	99.88	99.63	100.54	98.61	98.68	96.86	98.91	99.15	99.83	

(2.86 %), MgO (1.10 %), Na_2O (0.17 %), K_2O (0.44 %) and SO_3 (0.16 %). It is clear from the Table-5 that no significant variation in all these oxides occurs in the Bagasse ash of the three sugar mills.

The pulverized fuel ash or the so called fly ash (FA), emitted as a particulate matter in the effluent gas of coal based thermal power plants, is a pozzolanic material. The blast furnace slag (BFS) is a waste product, recovered in a granulated form, from the blast furnace manufacturing pig iron in steel plants. The use of these materials, as admixtures to cement, is based on long experience. For a comparison, the typical chemical compositions of fly ash (FA) and blast furnace slag (BFS), obtained in different countries, along with the bagasse ash (BA) of this study are presented in Table-6 [9]. It is clear from this table that these ashes contain essential ingredients for cement manufacturing. There is also a significant difference in the concentration of oxides in FA, BFS, and BA (Table-6).

There is always close relationship between the chemical and the mineralogical composition in the Portland cement. However, it is not so in case of mineral admixtures. It is only when the siliceous and the aluminous materials present in these pozzolanic admixtures hydrate at slow rate in alkaline medium and the existing silica and alumina react with lime and form of cementitious products [8]. The characteristics of these substances give them a considerable importance in concrete formation. This is contrary to the hydration of Portland cement, where the principal silicates (C_3S and C_2S) and aluminate (C_3A), present essentially in the crystalline form, react with water to provide desired silica and alumina for the formation of cementitious compounds. Hence, while evaluating the suitability of mineral admixtures for blended cement, their mineralogical composition should be considered together with the chemical composition. Table-7 compares the chemical analysis of Portland cement with the analysis of bagasse ash obtained during the present study. It is evident form Table-7 that the bagasse ash contains all the ingredients, which are required in cement manufacturing. This strengthens the possibility of bagasse ash to be used as a part of cement admixture. However, there is one major

Table-6: Analysis of different types of ashes from different Countries [9].

S. No.		Country	Chemical Composition in %								
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
1.	Coal Fly Ash	France	48.10	24.68	6.50	1.41	1.82	0.56	4.06	--	11.7
		UK	50.09	28.10	11.70	1.62	1.54	0.28	0.62	--	1.27
		Germany	1.20	29.60	6.80	3.40	1.20	0.60	3.10	0.50	3.30
		USA	52.24	19.01	15.71	4.48	0.89	0.82	2.05	1.34	0.92
		India	58.06	26.40	4.810	2.23	0.69	0.40	0.12	0.28	5.39
		Japan	59.60	31.20	2.30	1.40	0.50	0.70	0.50	0.20	--
		China	52.30	31.70	4.70	2.13	0.56	0.25	0.47	0.51	4.50
2.	Blast Furnace Slag	France	25.00	12.00	2.00	43.00	8.00	--	--	0.90	--
		UK	35.00	16.00	0.80	40.00	6.00	--	--	1.70	--
		Germany	35.00	12.00	0.30	42.00	7.00	--	--	1.30	--
		USA	34.00	10.00	0.80	41.00	11.00	--	--	1.30	--
		India	31.61	21.53	0.95	34.71	7.12	0.49	0.36	0.10	0.72
		Japan	32.70	13.40	0.50	41.60	6.90	0.20	0.30	0.30	0.60
3.	Bagasse Ash	Brazil	78.34	3.55	3.61	2.15	1.65	0.12	3.46	--	0.42
		Pakistan (Present work)	87.87	2.47	4.05	2.86	1.10	0.17	0.44	0.16	13.45

Table-7: Chemical analysis of portland cement and bagasse ash.

Admixtures	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	CaO %	MgO %	Na_2O %	K_2O %	SO_3 %
Portland Cement	21.55	5.69	3.39	64.25	0.85	0.33	0.59	2.47
Bagasse Ash	87.87	3.60	4.90	2.56	0.69	0.15	0.47	0.11

problem in the present untreated samples of bagasse ash, containing about 16 % unburned carbon, which may affect the cement strength. This problem can be overcome by adding the bagasse ash as a raw mix during the clinkering process. This can be advantageous in two ways: (1) the unburned carbon will supplement the energy requirement needed for clinkerization and (2) it will render the bagasse ash free of carbon. The remaining residue will be an addition to the cement as a raw mix. Both of these advantages will result in reduction in the cost of production of cement. However, since the composition of bagasse ash does not match with that of each corresponding constituent of the cement, therefore, a careful and intelligent raw mix designing must be needed in order to make the possibility of addition of bagasse ash compatible with the cement composition without affecting the strength and quality of the cement.

Experimental

In this work both bagasse and bagasse ash from the local sugar mills have been analyzed for their physical and chemical properties. Samples of bagasse and bagasse ash were collected from three, randomly selected sugar mills, *i.e.,* Premier sugar mill, Mardan, Khazana sugar mill, Peshawar and Frontier sugar mill, Thaktbhai, Mardan. A number of samples of both the materials were collected from different heaps inside the sugar mill and thoroughly mixed before final samples were taken from these mixed samples. Following this procedure three samples from each mill were collected. The sampling date was recorded on the plastic bags in which the samples were sealed and properly tagged for identification purpose. Bagasse was in the form of crushed pieces ranging in size from 0.5-10 mm, which was ready for burning in the mill. These samples were taken to the laboratory for analysis.

Moisture and ash contents, loss on ignition and amount of volatile matter in bagasse ash were determined by thermogravimetric analyzer (TGA 701 LECO Corporation). Calorific values of bagasse ash were determined by bomb calorimeter (AC-350 LECO Corporation). Carbon and sulfur was determined by carbon-sulfur analyzer (SC-144 DR Dual Range Sulfur and Carbon Analyzer 2001 LECO Corporation). The major and minor elements in the ash after complete loss on ignition were determined by X-ray fluorescence XRF) for which glass beads were prepared for all ash samples. For this purpose one gram powdered ash was mixed with six gram of dilithium tetraborate (Spectromelt, Merck) in a platinum crucible to which 0.001g of lithium bromide (Merck) was also added. The ingredients were thoroughly mixed. The crucible was heated in a muffle furnace at 1150 °C for 15 min. Then the contents of the crucible were transferred into a platinum mould inside the furnace to acquire the shape of the mould, which was cooled to obtain a glass bead. After calibrating the XRF with certified standards, the sample beads, prepared for all the samples, were run on the machine and the results were obtained.

Conclusions

Bagasse ash analysis from sugar industry shows that it contains unburned carbon along with the other constituents present in Portland cement. The carbon contents of the baggase ash can provide a fuel supplement for the energy intensive manufacturing process. Thus, this ash can be considered as one of the potential raw material in cement manufacturing and can be added during the clinkerization process. It will help to remediate the environmental pollution problem and reduce the cost of production of cement.

References

1. O. S. B. Al-Amoudi, M. Maslehuddin and M. M. Saddi, *Cement and Concrete Aggregate*, **92**, 15 (1995).
2. Saraswathy, S. Muralidharan, K. Thangavel and S. Srinivasan, *Advances in Cement Research*, **14**, 9 (2002).
3. M. D. A. Thomas, M. H. Shehata and S. G. Shashiprakash, *Journal of Testing and Evaluation*, **21**, 75 (1999).
4. S. Goni, A. Guerrerl, M. P. De Luxan and A. Macias, *Materials Research Bulletin*, **35**, 1333 (2000).
5. Guerrero, S. Goni and A. Macias, *Cement and Concrete Research*, **30**, 1231 (2000).
6. J. I, Bhatty, J. Gajda and F. M. Miller, *Cement and Americas,* May, 1 (2001).
7. C. Shi, R. L. Day and J. Qian, *Cement and Concrete Research*, 227 (2001).
8. R. Wang, V. Trettin and R. Rudert, *Advances in Cement Research*, **15**, 29 (2003).
9. J. D. Bapat, *Advances in Cement Research*, **13**, 139 (2001).