Recycling of Bagasse Ash in Cement Manufacturing and its Impact on Clinker Potential and Environmental Pollution

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(Received 31st May 2008, accepted in revised form 18th August 2008)

Summary: In this investigation bagasse ash from sugar mills of North West Frontier Province (NWFP) has been used in the raw mix designing for high strength Portland cement as a raw material and subjected to clinkerization and cement formation. Different parameters of the resulting clinker and cement were studied and compared with the British and Pakistan standard specification. 5 % bagasse ash was found as the optimal limit to be blended and pulverized with other raw material prior to clinkerization which decreased the emission of carbon dioxide to the environment up to 1.73 %. Moreover it replaced 5 % clay from the raw meal.

Introduction

The utilization of fly ash in the construction industry is growing fast not only as blended cement but also to minimize the pollution of the environment. Due to its pozzolanic properties, there is a great potential for its use in the construction industry. Fly ash can be incorporated into nearly every stage of the production and use of cement. It can be used as a raw material in some cases because it contains some of the essential components needed for cement like lime, silica and alumina. Javed *et al.* [1] used carbon fly ash in cement manufacturing as a raw material. The chemical composition of the fly ash and other raw materials (limestone and shale) limited the fly ash addition in the kiln feed to approximately 6 %, which saved the fuel up to approximately 3.9 %, and increased the production up to 9.7 % besides improving other parameters also.

The use of coal fly ash conserves energy by reducing the demand for typical construction materials such as lime, cement and crushed stone, which take energy to produce. Each ton of fly ash used to replace a ton of cement and saves the equivalent for nearly one barrel of oil. During the production of one ton of cement, approximately one ton of carbon dioxide is also released. Ash, as already calcined, reduces the production of carbon dioxide. The replacement of cement with fly ash reduces greenhouse gas, lowers the cost of production and improves some properties of the concrete.

There are about 70 sugar mills in Pakistan which constitute a major agro-industry in Pakistan. These sugar mills use sugar cane as raw material for producing sugar. Our sugar industries are burning bagasse for energy production which is self sufficient in their energy requirement. It is an environment friendly practice due to its low emission of SO_2, NO_2 and CO_2 as compared to oil and other fossil fuels. The burning of bagasse in sugar mills generates bagasse ash which presently has no use in Pakistan other than discarding, dumping or earth filling, creating thus environmental nuisance around the sugar mills area. This serious problem demands to find out some economical use of bagasse ash so as to address this environmental pollution problem.

In the year 2005, according to a rough estimate, about 54 million tons of sugar cane was produced in Pakistan which was mainly used to produce sugar. Each ton of sugar cane generates approximately 26 % bagasse. It is used as a raw material for paper making due to its fibrous content and about 0.3 ton of paper can be made from one ton of bagasse. Its main use in Pakistan is energy production or steam generation for sugar industry itself by burning in boilers [2] etc.

Previously, in our laboratory we have studied the physicochemical properties of bagasse ash [3]. This study, *inter alia*, shows that the bagasse ash can be used in cement manufacturing as it contains some important pozzolanic material like, amorphous silica and alumina [4-9]. The pozzolanic materials are inorganic materials, either naturally occurring or industrial byproduct typically

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comprising siliceous compounds; or siliceous and aluminous compounds [10-12]. For example, coal fly ash, bagasse ash, silica fume, diatomaceous earth, calcined or uncalcined diatomite, calcined fullers earth, pozzolanic clays, volcanic ash, rice husk ash, natural and synthetic zeolites, slag and other sources of amorphous silica. The pozzolanas have little or no cementing value by themselves, but when finely ground, and in the presence of water react with calcium hydroxide at room temperature in order to form compounds with cementing properties [13-14]. However, the unburnt carbon, if present in the ash, hampers its use as such, as admixture to the cement. This problem can be solved if this ash is used with the raw mix before clinkerization, it can help in two ways; firstly, the unburnt carbon will supplement the fuel needed for clinkerization process, secondly, the remaining residue, after burning, will act as raw material of cement- as a partial replacement of clay, one of the major raw material of the cement.

The objective of the present study is multi folds and is oriented towards finding the potential use of bagasse ash in cement manufacturing. For this purpose we have used Bagasse ash as admixture to raw material of cement prior to clinkerization process and the resulting clinker and cement were characterized for their specifications and compared with the international standard such as British Standards and Pakistan Standard Specifications. Moreover, the optimum amount of bagasse that could be added in clinkerization stage was also determined so as to keep the resulting cement within the level of recommended limits of international specification. Lastly, a decrease in carbon dioxide emission due to raw material and material saving was also calculated by the use of bagasse ash.

Results and Discussions

Chemical composition of the raw meal for high strength Portland cement which is used in this work is given in Table-1. In our previous work we have determined the physical and chemical parameters of bagasse ash which has been reproduced in Table-2 [3].

On a close comparison of these two tables, it can be revealed that bagasse ash contains almost all the constituents which are essentially present in the high strength Portland cement. The only extraneous material which may be considered as incompatible with cement composition is the unburnt carbon. However, this carbon poses no problem, since it is converted in to CO_2 by oxidation and expelled during the clinkerization. An additional advantage of carbon is that it contributes heat for clinkerization as a result of the said oxidation process. This partially saves some energy which is an additional benefit of using bagasse ash in cement manufacturing. A careful look at Table-2 shows that the composition of bagasse ash does not match with that of high strength Portland cement, thus the random addition of bagasse ash with out any care may not serve the purpose as it may bring the final cement product that may not meet any of the standard specification. Thus in this work we have designed different raw mixes, by adding very little amount of the bagasse ash and then gradually increasing this amount so as to reach an optimum raw mix. The raw mixes were subjected to clinkerization and then the clinker was ground and mixed with gypsum to get final cement product. The clinker and the final cement were analyzed and characterized.

Table-1: Chemical Composition of the Raw Mix.

Analyte	High lime raw mix (designed) wt %
SiO_2	12.66
Al_2O_3	3.58
Fe_2O_3	2.20
CaO	43.60
MgO	1.00
Na_2O	0.20
K_2O	0.50
SO_3	0.10

Table-2: Physical and Chemical Parameters of Bagasse Ash.

Analyte	Bagasse ash Wt %
Moisture	2.93
Ash	86.69
Loss on ignition	13.45
Calorific value	49.33
Sulfur	0.21
carbon	18.67
SiO_2	87.40
Al_2O_3	3.60
Fe_2O_3	4.90
CaO	2.56
MgO	0.69
Na_2O	0.15
K_2O	0.47
SO_3	0.11

Bagasse ash was added with the raw mix, designed for high strength Portland cement (Table-1) in different percentages ranging from 1-7 % and thus different raw mixes for high strength Portland cement were prepared, the analysis of these raw mixes are given in the Table- 3.

Table-3: Chemical Composition of Raw Mixes containing Bagasse Ash.

	Bagasse ash added (Wt %)							
Analyte	RA_0	RA_1	RA_2	RA_3	RA_4	RA_5	RA_6	RA_7
SiO_2	12.66	13.41	14.15	14.90	15.65	16.40	17.14	17.89
Al_2O_3	3.58	3.58	3.58	3.58	3.59	3.59	3.59	3.60
Fe_2O_3	2.20	2.23	2.25	2.28	2.31	2.33	2.36	2.39
CaO	43.60	43.19	42.78	42.37	41.96	41.55	41.14	40.73
MgO	1.00	1.00	0.99	0.99	0.99	0.98	0.98	0.98
Na_2O	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
K_2O	0.50	0.50	0.50	0.50	0.50	0.49	0.50	0.50
SO_3	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Moduli								
MA	1.63	1.61	1.60	1.57	1.55	1.53	1.52	1.50
MS	2.19	2.31	2.43	2.54	2.66	2.77	2.88	3.00
LSF	1.06	1.00	0.94	0.89	0.85	0.80	0.77	0.73

It is clear from Table-2 that bagasse ash contains silica, alumina, and iron oxides in greater percentages and calcium oxide in smaller percentage as compared to raw mix used for the manufacturing of cement, so when it was blended with the raw mix, it increased the percentage of silica, alumina and iron and decreased the calcium oxide content in the resulting raw mix. The chemical analyses of the clinker resulting from the bagasse ash blended raw mixes are given in Table-4. The clinker was converted into cement and different parameters of the cement were studied and compared with the British and Pakistan standards.

Table-4: Effect of Bagasse Ash on the Chemical Composition of Clinker.

	Bagasse ash added (Wt %)							
Analyte	KA_0	KA_1	KA_2	KA_3	KA_4	KA_5	KA_6	KA_7
SiO_2	19.62	20.78	21.94	23.10	24.26	25.41	26.57	27.73
Al_2O_3	5.55	5.55	5.55	5.55	5.55	5.55	5.55	5.55
Fe_2O_3	3.41	3.45	3.49	3.54	3.58	3.62	3.69	3.69
CaO	67.58	66.94	66.31	65.67	65.04	64.40	63.69	63.06
MgO	1.55	1.55	1.54	1.54	1.53	1.53	1.50	1.49
Na_2O	0.31	0.31	0.31	0.31	0.31	0.31	0.28	0.28
K_2O	0.77	0.77	0.77	0.77	0.73	0.77	0.7	0.7
SO_3	0.15	0.15	0.15	0.15	0.16	0.16	0.16	0.16

Effect of Bagasse Ash on the Compressive Strength of Cement

The compressive strength of cement has been affected by the addition of Bagasse ash as shown in Fig. 1. The results show that the three days compressive strength of the cement decreases with the increase of Bagasse ash. The 3 days compressive strength of the high strength Portland cement CA_0 (control) is 34.14 N/mm^2, while with 1 % bagasse ash CA_1, it reduced to 31.52 N/mm^2. The same trend was found for further increase of bagasse ash. Up to 5 % of bagasse ash CA_5, the compressive strength remains

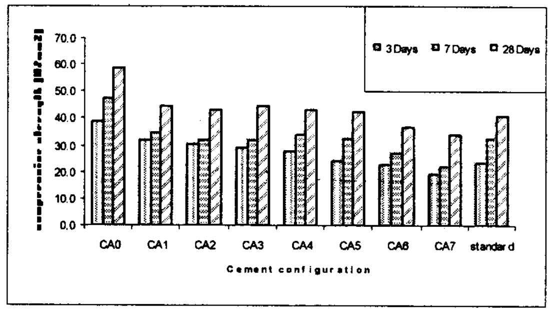

Fig. 1: Effect of bagasse ash on compressive strength of high strength Portland cement.

with in the standards, above which it goes below the standard i.e. 23 N/mm^2 (Fig. 1). With the addition of further bagasse ash, the compressive strength reduces significantly. (7 % ash reduces the compressive strength up to 18.97 N/mm^2), which is significantly less than the standard value.

7 days compressive strength of the high strength Portland cement, without bagasse ash (control) was recorded to be 47.38 N/mm^2, which reduced to 32.83 N/mm^2 with 5 % Bagasse ash, which is reasonably close to the standard value *i.e.* 32.34 N/mm^2 (British standard and Pakistan standard specification). The strength was brought out of range with further addition of Bagasse ash. It was 22.19 N/mm^2 for 7 % Bagasse ash.

28 days strength of the high strength Portland cement without adding bagasse ash was recorded as 58.41 N/mm^2.5 % bagasse ash reduced the strength up to 42.46 N/mm^2, which is well above the corresponding value *i.e.* 41.10 N/mm^2. However, above 5 % of ash, the strength decreases to a value which is lower than the corresponding value of strength. Thus, in conclusion 5 % Bagasse ash can be safely added to the cement without affecting the strength. However, further addition of bagasse ash can be possible by using high lime raw mix. This will reduce the amount of clay and increase the amount of limestone in the raw mix. The increase in limestone and decrease in clay will be compensated by bagasse ash due to its high silica content.

Effect of Bagasse Ash on Carbon Dioxide Emission

Raw material for cement contains calcium carbonate ($CaCO_3$) and magnesium carbonate

($MgCO_3$), both produce carbon dioxide on calcination as follows;

$$CaCO_3 \rightarrow CaO + CO_2$$
$$100 \quad 56 \quad 44$$

According to this equation every 56 g CaO is responsible for the production of 44 g CO_2. Since the normal raw mix of high strength Portland cement contains 42.55 % CaO (Table3), thus it produces 33.43 % CO_2. Similarly, production of CO_2 by $MgCO_3$ is given as follows;

$$MgCO_3 \rightarrow MgO + CO_2$$
$$84 \quad 40 \quad 44$$

In this case every 40g of MgO and 44g of CO_2 are produced together. Raw mix of high strength Portland cement contains 0.98 % MgO, which reflects 1.08 % production of CO_2. Thus total CO_2 produced is the sum of the two sources is 33.43 and 1.08 which amounts to 34.51 %. This is the normal amount of CO_2 produced from the calcination of raw material during cement manufacturing. When 5 % bagasse ash is used, in raw mix designing, the emission of CO_2 reduces to 32.78 % CO_2. Thus there is a decrease of 1.73 % emission of CO_2. So the use of bagasse ash helps in reducing the environmental pollution problem.

The use of bagasse ash in cement manufacturing, apart from energy saving and reducing the environmental pollution, also replaces clay up to approximately 5 %, which does not have any significant economical or otherwise impact.

Experimental

Preparation of Samples

Mill fired bagasse ash was collected from Premier Sugar Mill Mardan (PSM), Khazana Sugar Mill Peshawar (KSM) and Frontier Sugar Mill Thaktbhai Mardan (FSM). The samples were collected randomly from the heaps present in the yard of the sugar mills, and carried to the laboratory in polyethylene bags. The mill fired bagasse ash was black in color due to the high amount of carbon content. The physical and chemical parameters of bagasse ash are given in Table-1.

Laboratory scale clinkerization and cement preparation was carried out on small scale. The typical raw material like carbonaceous and siliceous materials was used for the raw mix designing and cement preparation. A different percentage of bagasse ash was used in the raw mix designing ranging from 1-7 % including control. These mixes were named as RA_0 for control and RA_1, RA_2, RA_3, RA_4, RA_5, RA_6, and RA_7, containing 1, 2, 3, 4, 5, 6 and 7 % bagasse ash respectively. The raw mixes were analyzed and processed for clinkerization. For clinkerization the control (with out bagasse ash) and blended raw mix containing bagasse ash in different ratios ranging from 1-7 %, was made moist with water and converted in to small pellets 5-10mm in diameter. The pellets were dried in oven at 100 °C for 1h and then heated at 1450 °C for 1h in a muffle furnace. The clinker specimens were designated as KA_0 for control and KA_1, KA_2, KA_3, KA_4, KA_5, KA_5 and KA_6, containing 1, 2, 3,4,5,6 and 7 % bagasse ash respectively. The clinker obtained, after complete analysis was pulverized with 5 % gypsum to get cement. The resulting cement samples were designated as CA_0 for control and CA_1, CA_2, CA_3, CA_4, CA_5, CA_6 and CA_7, containing 1,2,3,4,5,6 and 7 % bagasse ash respectively The clinker and cement samples were subjected to different analytical procedures for their characterization. The raw mix designing was made very carefully so as the contribution of different constituents of cement from bagasse ash may not exceed the permissible limits of these constituents in the final finished product of cement. It has been tried that maximum percentage of bagasse ash is utilized in the raw mix designing keeping in view, that parameters of the final product may remain within the standard limits.

Mineralogical Analysis

Mineralogical analysis of Bagasse ash was carried out by X-ray diffraction analysis, which is shown in Fig. 2. The material consists essentially of an amorphous silica structure with a wide scattering peak (hump) centered at about 22° 2θ, Cu Kα radiation. Small quantities of crystal-phases as quartz and crystobalite are also present. Raw material, clinker and cement were analyzed using atomic absorption and x-ray fluorescence spectrophotometer for which glass bead was formed from the test material. For this purpose one gram powdered

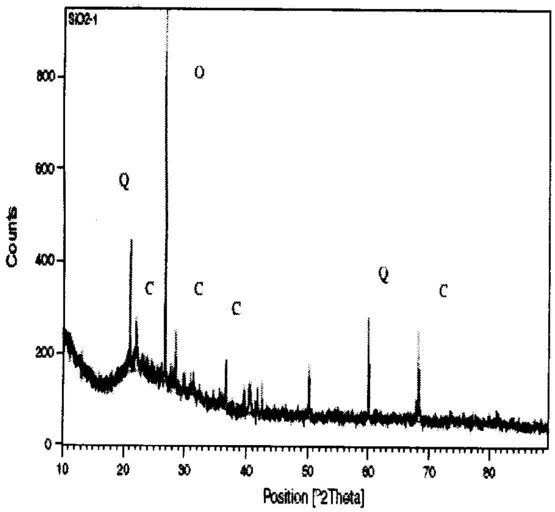

Fig. 2: X-Ray Diffraction analysis of Bagasse ash.

material was mixed with six gram of dilithium tetraborate (spectromelt Merck) in a platinum crucible to which 0.001g of lithium bromide (Merck analytical grade) was also added. The ingredients were thoroughly mixed. The crucible was heated in a muffle furnace at 1150 °C for 15 min. Then the content of the crucible was transferred to a platinum mould inside the furnace and shaked to acquire the shape of the mould. The mould was cooled and the glass bead was obtained. After calibrating the XRF with certified standards, the sample bead was subjected for analysis in the machine and the result was obtained.

Compressive Strength of Mortars

The compressive strength of all the mortars were measured after 3, 7 and 28 days in accordance to British standard BS EN 196-1 (2005) [15].

Conclusion

Bagasse ash was found to be the raw material which replaced about 5 % clay from the raw material and decreased the emission of CO_2 up to 1.37 %. The unburned carbon in the ash reduced the cost of production up to 6.46 %, while other parameters were found to be undisturbed. The optimal level of bagasse ash was found to 5 %.

Acknowledgments

The authors are very thankful to Prof. Dr Muhammad Rasul Jan (Director, Institute of Chemical Sciences), Prof. Dr. Hameedulla (Director, National Center of Excellence in Geology University of Peshawar) and Mr. Zafar Iqbal (Manager, Quality Control Cherat Cement Company Limited Nowshera, N. W. P. F. Pakistan) for their full cooperation.

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