Raw Mix Designing and Clinkerization of High Strength Portland Cement with Bagasse Ash and its Impact on Clinker Moduli and Fuel Consumption

[1]NOOR-UL-AMIN*, [1]KHURSHID ALI AND [2]MUHAMMAD TAHIR SHAH
[1]*Institute of Chemical Sciences, University of Peshawar, Pakistan.*
[2]*National Center of Excellence in Geology, University of Peshawar, Pakistan.*

(Received 23rd June 2008, accepted in revised form 17th January 2009)

Summary: This paper discusses the utilization of bagasse ash from the sugar mills of North West Frontier Province (NWFP), Pakistan in the raw mix designing for high strength Portland cement; and its impact on clinker moduli and fuel consumption. The resulting clinker and cement was found with in the British and Pakistan standard specifications. 5 % bagasse ash was found as the optimal limit to be blended and pulverized with other raw material prior to clinkerization which saved 6.46 % energy. Among the moduli modulus of alumina (MA), modulus of silica (MS) and lime saturation factor (LSF) were studied. It was found that with 5 % bagasse ash, all the moduli remained with in standards.

Introduction

The utilization of different ashes in cement at different stages is nowadays considered a common practice in the construction sector. However, the quantities that are produced globally are steadily increasing, exceeding the utilization rates that in most countries remain low. The amounts that remain unused obviously create acute environmental problems and moreover inhibit the path towards sustainability [1].

It is a fact that cement is the major construction material through out the world [2, 3]. Industrial wastes like blast furnace slag, coal fly ash, silica fume and hazel nutshell are being used as a supplementary cement replacement material and agricultural waste like rice husk ash, wheat straw ash and bagasse ash as pozzolanic material [4-8]. When pozzolanic materials are added to cement, the silica (SiO_2) present in these materials reacts with free lime released during the hydration of cement and forms additional calcium silicate hydrate (CSH) as new hydration products [9], which improve the mechanical strength of the cement mortar and concrete. The ashes produced by the burning process at incinerating temperature transform silica into amorphous phase whose reactivity is directly proportional to the specific surface area [10]. The ash so produced, after pulverizing is mixed with cement at different stages.

In Pakistan, about 70 sugar mills produce about 14 million tons of bagasse annually which is mainly used as energy source to produce steam and power. Our sugar industries are burning bagasse for energy production which are self sufficient in their energy requirement. It is an environment friendly practice due to its low emission of SO_x, NO_x and CO_x 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 [11], 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.

Bagasse ash can be used in cement manufacturing as it is pozzolonic, containing amorphous silica, and alumina [12, 13]. The pozzolana is inorganic material, either naturally occurring or industrial byproduct typically comprising siliceous compounds; or siliceous and aluminous compounds [14]. 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 no cementing value by themselves, but when finely

*To whom all correspondence should be addressed.

ground and in the presence of water react with calcium hydroxide at room temperature in order to form compounds with cementing properties [15].

The unburnt carbon, which is 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 [12].

The objective of the present work is to find out the potential use of bagasse ash in cement manufacturing as a fuel source and raw material. For this purpose bagasse ash has been used as admixture to raw material of cement prior to clinkerization process and the resulting clinker was characterized. Moreover, the optimum amount of bagasse ash that could be added in clinkerization stage was also determined so as to keep the resulting clinker and cement within the level of recommended limits of international specification and fuel saving was calculated.

Results and Discussions

Chemical composition of a typical raw mix of high strength Portland cement and bagasse ash is given in Table-1 [12]. The two compositions on comparison reveal that bagasse ash contains almost the same constituents except the unburnt carbon which is extraneous and incompatible with cement composition. 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-1 shows that the composition of bagasse ash does not match with that of that of high strength Portland cement, thus addition of bagasse ash randomly with out any care may not serve the purpose as it may bring the final cement product of the composition which may or 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

Table-1: Chemical Composition of Typical Raw mix for High Strength Portland cement and Bagasse ash (wt %) [12].

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Typical cement raw mix	14.60	3.83	2.28	42.55	0.98	0.18	0.46	0.10
Bagasse Ash	87.40	3.60	4.90	2.56	0.69	0.15	0.47	0.11

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.

Bagasse ash was pulverized with raw mix in different ranging from 1-7 % and thus different mixes for high strength Portland cement were prepared. These mixes were named as RA_0, RA_1, RA_2, RA_3, RA_4, RA_5, RA_6 and RA_7 containing 0, 1, 2, 3, 4, 5, 6 and 7 % bagasse ash, the analysis of these raw mixes are given in the Table-2. The raw mixes containing different quantity of bagasse ash was converted into clinker and cement whose different parameters were studied and compared with the British and Pakistan standards.

Table-2: Chemical Composition of Bagasse Ash Raw mix (wt %).

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Control	12.66	3.58	2.20	43.60	1.00	0.20	0.50	0.10
RA_1	13.41	3.58	2.23	43.19	1.00	0.20	0.50	0.10
RA_2	14.15	3.58	2.25	42.78	0.99	0.20	0.50	0.10
RA_3	14.90	3.58	2.28	42.37	0.99	0.20	0.50	0.10
RA_4	15.65	3.59	2.31	41.96	0.99	0.20	0.50	0.10
RA_5	16.40	3.59	2.33	41.55	0.98	0.20	0.49	0.10
RA_6	17.14	3.59	2.36	41.14	0.98	0.20	0.50	0.10
RA_7	17.89	3.60	2.39	40.73	0.98	0.20	0.50	0.10

Effect of Bagasse Ash on the Moduli of Clinker

As the addition of bagasse ash changed the composition of raw mix and clinker, the moduli of the resulting clinker also changed significantly. These changes in the moduli are graphically shown in Fig. 1. From the figure, it is clear that alumina modulus (MA) of the raw mix decreases from 1.63 to 1.50 with the addition of bagasse ash, silica modulus (MS) increases from 2.19 to 3.00 and lime saturation factor (LSF) also decreases from 0.06 to 0.73 with the addition of 7 % bagasse ash.

The decrease in alumina modulus (MA) of cement raw mix may be attributed to the greater amount of alumina in the Bagasse ash (3.6 %).

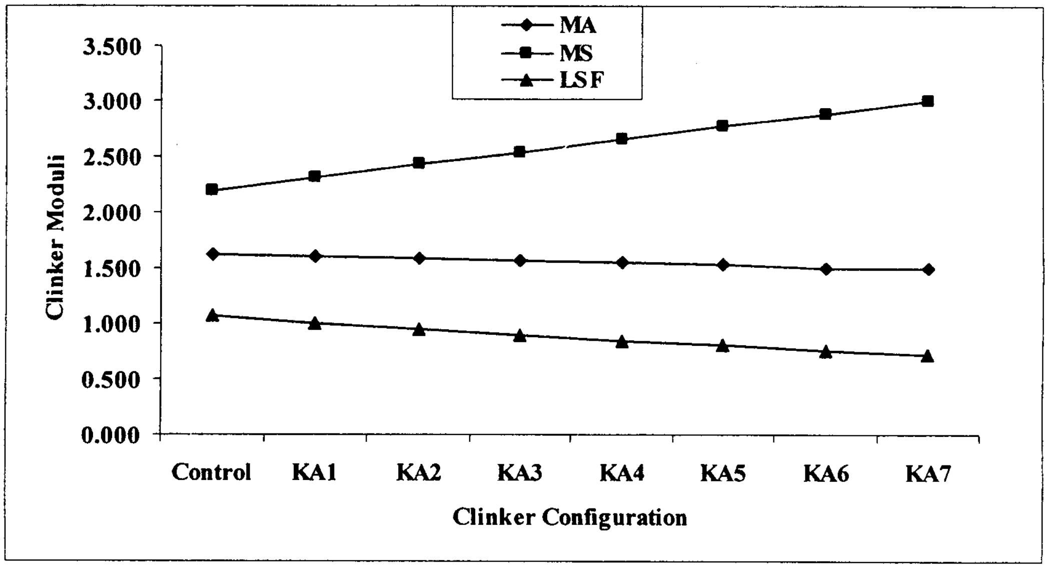

Fig. 1: Effect of Bagasse ash on, (a) alumina modulus (MA), (b) silica modulus (MS), (c) lime saturation factor (LSF) of clinker.

According to British standards specification, MA ranges from 1.3 to 2.5, if it exceeds the upper limit, the viscous slag and high early strength is exhibited. Similarly if it is less than 1.3, then fluid slag, low early strength and low heat of hydration occur. Addition of Bagasse ash, up to 5 %, does not result in crossing the limits of MA.

The recommended and acceptable range of MS is 2 - 3. If the MS is below this range, burning become very easy but excessive liquid phase and low strength cement is obtained. At the upper limit of MS, the high strength cement is obtained but the burning become very difficult, if it crosses the upper limit, then no clinkerization take place at all. This study shows that the bagasse ash does not make the MS out of range, though the burning will become hard.

The normal and acceptable range of LSF is 0.90-0.98. It does not create any problem in cement manufacturing process and its strength, even if reaches as low as 0.8, however, it should not be less than 0.8. From the result of the present study it can be noted that 5 % bagasse ash decreases the LSF from 1.06 to 0.86, while 7 % addition of bagasse ash decreases the LSF up to 0.73, which is significantly out of the acceptable range. Looking to the MA, MS and LSF results, it can be concluded that the optimal level of bagasse ash in the raw mix prior to clinkerization is 5 %.

Effect of Bagasse Ash on Heat of Clinkerization

Heat of clinkerization is the sum of heat required to carry out all the chemical reactions during the clinker formation. This may be theoretically calculated as the algebraic sum of all the endothermic and exothermic reactions taking place in clinkerization process [15]. Heat of clinkerization depends upon the chemical composition of cement raw mix used. The result obtained represents only that amount of heat which must be imparted to the feed to turn it into one ton of clinker. It does not include heat losses in the system nor does it account for the heat that is recoverable from the hot clinker after the clinkering reaction is completed. The result, however, take in to account the exothermic reaction at clinkering temperature.

The calculated heat of clinkerization is different from the observed one in cement plant on large scale, when the clinkerization is taking place in the rotary kiln. The reason is that, heat is being lost during clinkerization in two ways, firstly from the kiln shell in the form of thermal radiation. Secondly, during the cooling of the clinker in the clinker cooler, though, some of which is recycled in the plant to calcine the raw material in the multicyclone.

The heat of clinkerization of all specimens of clinker including control is reported in Table-3. From the table, it is obvious that heat of clinkerization of clinker designed in this work without bagasse is 437.7 kcal/kg. With 1, 2, 3, 4, 5, 6 and 7 % bagasse ash, heat of clinkerization reduced to 426.9, 416.0, 405.2, 394.4, 383.5, 372.0 and 361.1 kcal/kg, respectively. As the optimal level of bagasse ash is 5 % [16], so the minimum possible heat of clinkerization with 5 % bagasse ash is 383.5 kcal/kg. The heat of clinkerization of normal clinker in cement plant is 410 kcal/kg [17, 18], when 5 % bagasse ash is added with the raw mix, heat of clinkerization becomes 383.3 kcal/kg. Thus there is 6.46 % energy saving which is attributable to 5 % bagasse ash in the cement.

Table-3: Heat of Clinkerization calculated for one kg of Clinker.

Percentage of bagasse ash added with raw mix	kcal/kg
Control	437.7
CA_1	426.9
CA_2	416.0
CA_3	405.2
CA_4	394.4
CA_5	383.5
CA_6	372.0
CA_7	361.1

Experimental

Samples Preparation

Samples of bagasse ash were collected from Premier Sugar Mill (PSM) Mardan, Khazana Sugar Mill (KSM) Peshawar and Frontier Sugar Mill (FSM) Thaktbhai Mardan 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.

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 blended raw mix with out bagasse ash (control) and containing bagasse ash in different ratios ranging from 1-7 %, was made moist with water and made small pellets ranging in size 5-10 mm 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 samples were subjected to different analytical procedure for their characterization using XRF to study alumina modulus (MA), silica modulus (MS) and lime saturation factor (LSF) of the resulting clinker. The raw mix designing has been made in such a way to utilize maximum percentage of bagasse ash keeping in view, that parameters of the final product may not go out of the standard limits.

Elemental Analysis

X-Ray fluorescence (XRF) spectrophotometer, PW 2582/00 (Philips) and atomic absorption spectrometer (3300 Perkin Elmer), were used for the analysis of raw material, clinker and cement. For XRF, glass bead was made from the test material. For this purpose one gram powdered material was mixed with six gram of dilithium tetraborate (Spectromelt, Merck) in a platinum crucible to which 0.001 g 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 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.

Conclusion

Bagasse ash was found to be the raw material for cement manufacturing which replaced about 5 % clay. The unburned carbon in the ash reduced the cost of production up to 6.46 %, while other parameters were found to be undisturbed. MA, MS and LSF of the clinker showed that 5 % of bagasse ash can be pulverized with the other cement raw mix after proper designing.

Acknowledgement

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

References

1. P. K. Mehta, *Role of Pozzolanic and Cementitious Materials in Sustainable Development of the Concrete Industry*, Conference on Bagasse ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Bangkok, 1 (1998).
2. S. K. Antiohos, A. Papageorgiou, V. G. Papadakis and S. Tsimas, *Construction and Building Materials*, **22**, 1191 (2008).
3. A. Bentur, *Journal of Materials in Civil Engineering*, **14**,.1 (2002).
4. P. Mira, V. G. Papadakis and S. Tsimas, *Cement and Concrete Research*, **32**, 5 (2002).
5. S. K. Antiohos, V. G. Papadakis, E. Chaniotakis and S. Tsimas, *Cement and Concrete Research*, **37**, 6 (2007).
6. H. Biricik, F. Akoz, I. Berktay and A. N. Tulgar, *Cement and Concrete Research*, **29**, 637 (1999).
7. A. Demirbas and A. Asia, *Cement and Concrete Research*, **28**, 8 (1998).
8. A. A. Boating and D. H. Skeete, *Cement and Concrete Research*, **20**, 14 (1990).
9. P. K. Mehta, Rice husk ash a unique supplementary cementing material. Proceeding international symposium on advances in concrete technology. 2nd ed. Canmet, p. 419 (1994).
10. I. Ali, Biomass: An ideal fuel for sugar mills for steam/ power generation. Fuel research centre, PCSIR, Karachi, **19**, 17 (2004).
11. V. G. Papadakis and S. Tsimaš, Supplementary Cementing Materials for Sustainable Building Sector Growth, European Commission DGXII, Marie Curie Fellowship, Final Scientific Report, Project No HPMF-CT-1999-00370, National Technical University of Athens, Greece (2001).
12. K. Ali, N. Amin and M. T. Shah, *Chinese Journal of Geochemistry*, **27**, 242 (2008).
13. M. Nehdi and A. A. Khan, *Cement Concrete and Aggregate*, **23**, 1 (2001).
14. U. Kääntee, R. Zevenhonven, R. Backman and M. Hupa, *Nordic Concrete Research, Publication*, **30**, 21 (2003).
15. C. Shi and J. Qian, *Advances in Cement Research*, **13**, 4 (2000).
16. N. Amin, K. Ali and M. T. Shah, *Journal of the Chemical Society of Pakistan*, 31, 1 (2009) (in press)
17. F. M. Miller and T. Conway, *Cement Concrete and Aggregate*, **25**, 2 (2003).
18. E. Jons, S. Hundebol, Production of heat of reaction of cement raw meal, Vol. **48**, ZKG, International, p. 35 (1995).