Pak. J. Sci. Ind. Res. 2010 **53** (2) 68-71

Thermal Activation of Bagasse Ash in High Strength Portland Cement Mortar

Noor-ul-Amin
Department of Chemistry, Abdul Wali Khan University, Mardan, Pakistan

(received September 18, 2009; revised January 27, 2010; accepted January 28, 2010)

Abstract. The pozzolonic reactivity of bagasse ash was enhanced using thermal activation technique by curing mortar specimens containing bagasse ash, at 20, 40 and 60 °C and the samples were tested for compressive strength at the age of 3, 7 and 28 days. Results indicated that bagasse ash is very sensitive to temperature rise and thus the application of thermal activation is very useful when early age strength development is desired. Bagasse replacement by 30% at 40 °C and 60 °C increased the mortar strength at 7 days by 10 and 18% more than the control, respectively.

Keywords: bagasse ash, thermal activation, portland cement mortar

Introduction

Different types of pozzolanic material are widely used for cement replacement in high strength Portland cement mortars and concrete for improving mechanical properties and durability and bringing environmental and economic benefits. The reasons for partially replacing cement in mortar and concrete with pozzolanic materials are diverse, which include strength enhancement and improvement in durability (Coleman and Page, 1997; Wild *et al*., 1996; Caldarone *et al*., 1994). There are also clear environmental advantages in reducing the quantity of cement used in construction materials. Indeed, cement production is highly energy intensive process involving significant environmental damage with respect to CO_2 production and raw material acquisition (Schindler, 2004).

Various studies have investigated ways to enhance the reactivity of the pozzolanic material. The principal aim of these attempts was to enhance the reactivity of the pozzolan, so as to improve the mechanical and durability properties of the final product. Prolonged grinding curing at elevated temperatures, alkali-activation and chemical activation are some of the methods that have been used to achieve this target (Xie and Xi, 2001; Shi and Day, 2000; 1995; 1993; Palomo *et al*., 1999; Bouzoubaa *et al*., 1997). The efficiency, however of some of these methods is debatable being too energy demanding, while others fail simple cost-benefit analysis. For example Helmuth (1994) suggested the grinding of Portland cement to very high specific area for use with slag to overcome the problem of low early strength. Schroder (1968) showed that with slag contents up to about 50-60%, the early strength is mainly determined by the fineness of the clinker fraction and then by that of the slag fraction. With cements of higher slag content, the fineness of slag was found to be of major importance at all ages. Wainwright and Tolloczko (1986), using temperature matched curing, indicated that concretes containing 50 and 70% slag replacement were far more sensitive to increases in temperature, with respect to their strength development, than equivalent Portland cement concretes. Further, Brooks and Al-Kaisi (1990) were able to use the adiabatic temperature rise of mass concrete to estimate the strength of OPC and OPC/slag concretes. They observed that 28-day strength of OPC/slag clearly exceeded those of OPC concrete only. This difference in behaviour has been attributed to the reduction of the overall quantity of C_3S in blended cement, which results in some C_3S hydrates being replaced by slower forming slag hydrates.

E-mail: noorulamin_xyz@yahoo.com

The objective of the present work is to evaluate the bagasse ash as supplementary cementitious material and its activation by thermal method to enhance the reactivity of bagasse ash and to improve the mechanical properties and durability of the final mortar.

Materials and Methods

Chemical composition of high strength Portland cement and bagasse ash used are given in Table 1 and physical parameters of bagasse ash, in Table 2. High strength Portland cement was ground to a fineness of 310 m^2/kg. The sand used in the mortar had a specific gravity of 2.5 and a fineness modulus of 2.65. Bagasse ash was obtained from the Premier Sugar Mill Mardan (PSM), Khazana Sugar Mill Peshawar (KSM) and Frontier Sugar Mill (FSM), Thaktbhai, Mardan. The samples were collected randomly from the heaps present in the yard of

Table 1. Chemical composition of cement and bagasse ash

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Cement	21.55	5.69	3.39	64.25	0.85	0.33	0.59	2.47
Bagasse ash	87.40	3.60	4.90	2.56	0.69	0.15	0.47	0.11

Table 2. Physical parameters of bagasse ash

Moisture (%)	Ash (%)	LOI (%)	Calorific value (kcal/kg)	Fineness passing 50 µm sieve
2.93	86.69	8.45	50	50

the sugar mills and carried to the laboratory in polyethylene bags. Bagasse ash was black in color due to the high amount of carbon content. The mill fired bagasse ash was further burnt under controlled temperature at 90 °C for one hour, which brought down the carbon content up to 4.5 %.

Determination of setting time. Setting time of the mortars was determined in accordance with British Standard EN196-3 (2005a) using the Vicat apparatus.

Determination of compressive strength. Compressive strength of all the mortars was tested according to British Standard EN196-1 (2005b). Cement-sand-water mass ratio was 1-3-0.5. The mixtures were tested for compressive strength at 3, 7, and 28 days. Three cubes were tested for each data point and the average were reported with standard deviation less than 8%. The samples were remolded, 24 h after casting, and then cured in a controlled environment at 98% relative humidity at the temperature of 20, 40 and 60 °C until tested.

Results and Discussion

Setting time. Table 3 presents the result of the setting time. It is evident that the effect of increasing bagasse ash replacement level was to delay the initial setting time of mortar probably resulting from the dilution effect and the latent properties (Eren, 2002). The effect of 30% ash replacement resulted in retardation in the initial and final setting time by about 1 h and 1.5 h, respectively. However, increasing bagasse ash content from 30% to 50% did not produce any significant difference in the setting time.

Table 3. Setting time of the mortars containing bagasse ash

Bagasse ash (wt%)	Initial setting time (min)	Final setting time (min)
0	145	188
30	210	279
50	221	290

Compressive strength with activated ash. Compressive strength development for the cement mortars containing different percentages of bagasse ash, cured at different temperatures is shown in Fig. 1-3. A general feature observed in all the samples is that the initial strength increased with an increase in temperature, but this tendency is reversed with aging. This behaviour is similar to that observed by several other investigators (Eren, 2002). It suggests that curing at higher temperature results in non-uniform distribution of the hydration products within the microstructure, while at low temperature, hydration products have sufficient time to diffuse and precipitate relatively more uniformly throughout the cement matrix. The results of increasing curing temperature from 20 °C to 40 °C can be compared with those of Barnet *et al.* (2006), who studied in UK that mortars containing 35% slag replacement, gained 115% of strength after 3 days. However, mortars with 30% bagasse ash content achieved 90% of strength gain after the same period. This result indicated that bagasse ash was less sensitive to elevated temperatures than slag. This could be explained by their different activation energies. Fig. 2 and 3 show that at 28 days the reduction in strength, as a result of increasing

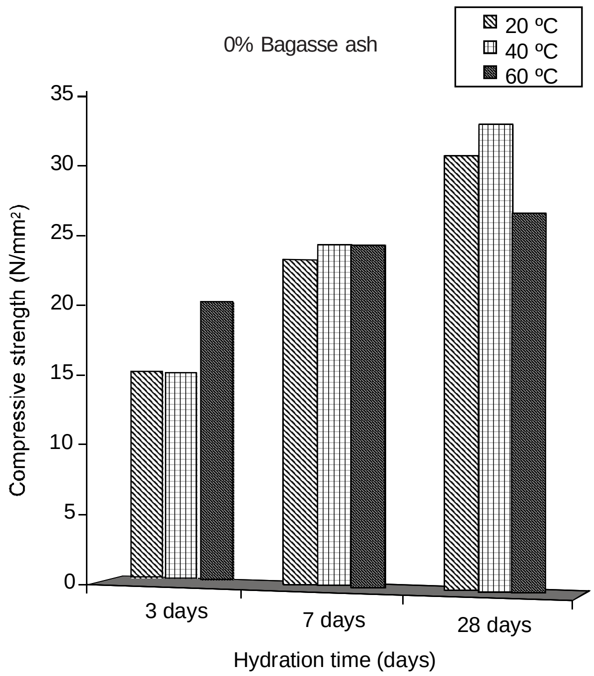

Fig. 1. Effect of curing temperature on the mortar strength without bagasse ash.

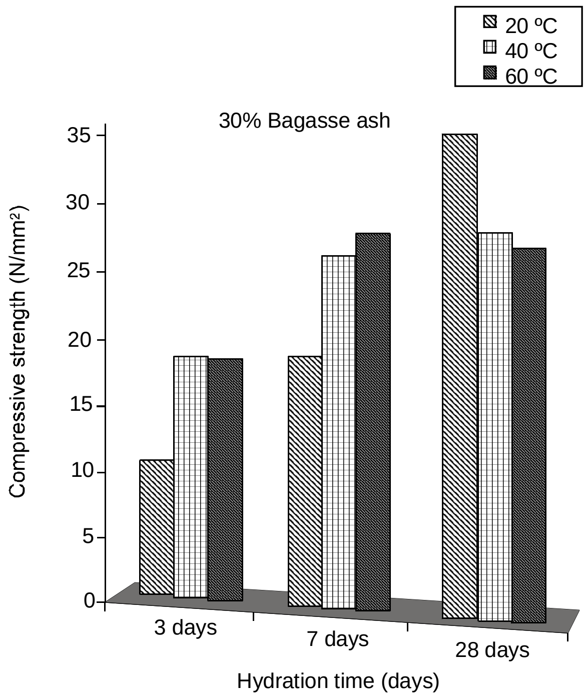

Fig. 2. Effect of curing temperature on the ash mortar strength containing 30% bagasse ash.

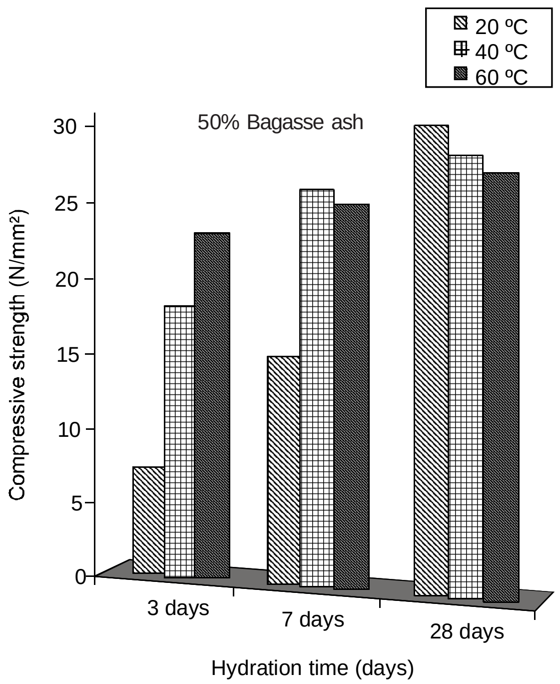

Fig. 3. Effect of curing temperature on the ash mortar strength containing 50% bagasse ash.

temperature in the mortars incorporating 30 and 50% of ash, was more pronounced than the corresponding mortars cured at 20 °C. The difference in strength development between the mortars was clearly apparent as shown in the figures. Cement mortars cured at 40 and 60 °C started to show a reduction in strength development after about one week compared with mortar cured at 20 °C. However, in bagasse ash cement mortars with 30 and 50% replacement level, strength development started to slow down after about 2 and 3 weeks, respectively. This suggests that increase in ash replacement will delay the reduction of strength development. Some authors referred to this phenomenon as the cross-over effect. Eren (2002) reported similar finding using fly ash to combat the loss of strength that would have resulted from the use of cement concrete without any replacement. The gain in strength development at early age increased with the increase in ash content and the loss of strength decreased also with the increase in ash content at later age. This shows the beneficial effect of incorporating bagasse ash in concrete when applying thermal activation. Thus, ash cement is more sensitive to changes in temperature than high strength Portland concrete. These findings are in agreement with the results observed by Wainwright and Tolloczko (1986). The strength of mortar containing 30% ash cured at 40 °C reached that of the mortar cured at 60 °C after 3 days of curing and exceeded it after 28 days. With 50% replacement level, the mortar cured at 40 °C achieved the strength of 60 °C cured mortar after 7 days and exceeded it after 28 days. The effect of curing at 40 °C and 60 °C was to increase the early age strength of bagasse ash mortar (both for 30% and 50% replacement) over that of the ash mortar, cured at 20 °C. This initial gain in strength for ash mortar, as a result of temperature, slows down after about 10 days but picks up again for the mortar, cured at 40 °C, reaching that of the counterpart cured at 20 °C. This suggests that 40 °C is the optimum temperature for strength development in both 30 and 50% ash cement mortars. In the same way, Escalante-Garcia and Sharp (2001) found the optimum temperature, in slag-cement paste with 60% of slag, to be around 30 °C. The highest strength value was reported for the mortar containing 30% bagasse ash cured at 40 °C, indicating that this replacement level is the most favourable for this blended cement.

Conclusion

Thermal treatment of bagasse ash is a very good activation technique to increase the strength development of mortar. The gain in strength at 7 days for mortar with 30% bagasse ash replacement cured at 40 °C and 60 °C was 10 and 18% higher than those for the control, respectively. The test results demonstrate that the application of thermal activation is very useful when early age strength development is desired. Increasing curing temperature for ash cement mortar increases the strength at early age and reduces it at later age. The curing temperature of 40 °C seems to be optimum for strength development of the ash cement.

References

Barnet, S.J., Soutsos, M.N., Millard, S.G., Bungey, J.H. 2006. Strength development of mortars containing ground granulated blast-furnace slag: Effect of curing temperature and determination of apparent activation energies. *Cement and Concrete Research*, **36:** 434-440.

Bouzoubaa, N., Zhang, M.H., Bilodeau, A., Malhotra, V.M. 1997. The effect of grinding on the physical properties of fly ashes and a high strength Portland cement clinker. *Cement and Concrete Research*, **27:** 1861-1874.

British Standard EN 196-3, 2005a. Methods of testing cement. Part 3. *Determination of Setting Times and Soundness, British Adopted European Standards*, pp. 18, British Standards Institution, UK.

British Standard EN 196-1, 2005b. Methods of testing cement. Part 1. *Determination of Strength. British Adopted European Standards*, British Standards Institution, UK.

Brooks, J.J., Al-Kaisi, A.F. 1990. Early strength development of Portland and slag cement concretes cured at elevated temperatures. *ACI Materials Journal*, **87:** 503-507.

Caldarone, M.A., Gruber, K.A., Burg, R.G. 1994. High reactivity metakaolin: a new generation mineral admixture. *Concrete International*, **16:** 37-40.

Coleman, N.S., Page, C.L. 1997. Aspect of the pore solution chemistry of hydrated cement pastes containing metakaolin. *Cement and Concrete Research*, **27:** 147-154.

Eren, O. 2002. Strength development of concrete with ordinary Portland cement, slag or fly ash cured at different temperatures. *Materials and Structures/ Materiaux et Construct*, **35:** 536-540.

Escalante-Garcia, J.I., Sharp, J.H. 2001. The microstructure and mechanical properties of blended cements hydrated at various temperatures. *Cement and Concrete Research*, **31:** 695-702.

Helmuth, R.A. *et al*., 1994. *Performance of Blended Cements made with Controlled Particle Size Distribution*. ASTM SP 897, G. Frohnsdorff (ed.), Philadelphia, USA.

Palomo, A., Grutzeck, M.W., Blanco, M.T. 1999. Alkali-activated fly ashes; a cement for the future. *Cement and Concrete Research*, **29:** 323-1329.

Schindler, A.K. 2004. Effect of temperature on hydration of cementitious materials. *ACI Materials Journal*, **101:** 72-81.

Schroder, F. 1968. Blast furnace slag and slag cements. In: *Proceeding of Fifth International Symposium on the Chemistry of Cements*, vol. **4,** pp.149-199, Tokyo, Japan.

Shi, C., Day, R.L. 2000. Pozzolanic reaction in the presence of chemical activators. Part I: Reaction kinetics. *Cement and Concrete Research*, **30:** 51-58.

Shi, C., Day, R.L. 1995. Acceleration of the reactivity of fly ash by chemical activation. *Cement and Concrete Research*, **25:** 15-21.

Shi, C., Day, R.L. 1993. Acceleration of strength gain of lime-pozzolan cements by thermal activation. *Cement and Concrete Research*, **23:** 824-832.

Wainwright, P.J., Tolloczko, J.J.A. 1986. Early and later age properties of temperature cycled slag-OPC concretes. In: *Proceedings of The Second International Conference on Fly Ash Silica and Fume, Slag and Natural Pozzolanas in Concrete*, CANMET/ACI SP-91, vol. **2**, pp. 1293-1321.

Wild, S., Khatib, J.M., Jones, A. 1996. Relative strength, pozzolanic activity and cement hydration in superplasticised metakaolin concrete. *Cement and Concrete Research*, **26:** 1537-1544.

Xie, Z., Xi, Y. 2001. Hardening mechanisms of an alkaline-activated class F fly ash. *Cement and Concrete Research*, **31:** 1245-1249.