Pergamon

Cement and Concrete Research, Vol. 25, No. 2, pp. 449-456, 1995

0008-8846/95 $9.50+.00

0008-8846(95)00031-3

EARLY-STRENGTH DEVELOPMENT OF PORTLAND CEMENT MORTARS CONTAINING AIR CLASSIFIED FLY ASHES

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(Refereed)
(Received May 3; in final form September 14, 1994)

ABSTRACT

A study of the effect of different fly ash sized fractions on compressive and flexural strength of blended cement mortar is presented. Mortars containing fly ashes, replacing 15 to 60 % of Portland cement, were prepared, and compressive and flexural strengths compared with "only cement" mortar. The influence of curing temperature was also studied. The study reveals that: a) compressive and flexural strength for mortars containing fly ash (or their sized fractions) are significantly enhanced when curing temperature is raised; b) the content of fly ash finest particles (less than 10 μm) is a crucial parameter for yielding a compressive strength enhancement; c) Good correlations between strengths and particle mean diameters were observed when fly ash percentage of substitution was 60 % .

Introduction

Fly ashes produced by thermoelectric power plants are generally suitable for using as a substitute of cement in mortar and concrete mixes. However, the nature of the coal and the combustion process produce fly ashes with different chemical and physical characteristics. Studies on the properties of these materials and their influence on mortar and concrete properties are necessary for their adequate and effective use.

The fineness of a fly ash is one of the parameters that have a crucial influence on fresh or hardened mortar and concrete properties. So, water demand and workability of Portland cement/fly ash mixtures mainly depend on fineness, shape morphology and particle size distribution of the fly ash used (1). On the other hand, the particle-size and crystalline/amorphous ratio play an important role in their reactivity towards lime, due to the pozzolanic reaction that takes place mainly on the surface of the particles (2). Fly ashes with different fineness can be obtained directly from the electrostatic precipitators of the thermal power plant, or, alternately, in the laboratory using horizontal or spiral-shaped air current or sieves; generally, the sized fractions obtained show similar chemical composition (3-6), but, in general, glassy content is greater for the finest fractions (5). Obviously, in addition to specific surface area, the pozzolanic reaction rate is influenced by this fact.

Recently, studies on the effect of particle size distribution of classified fly ashes have been carried out (5–8). On the other hand, it is well-known that heating curing is usually necessary for increasing the rate of strenght developments of mortars containing fly ashes (9) or natural pozzolans (10). Data from accelerated tests may be important to estimate the pozzolanic activity of fly ashes.

This paper studies the influence of different fly ash sized fractions obtained using an aerodynamic tunnel on the compressive and flexural strength of Portland cement/fly ash mortars.

Experimental

Materials: The various mortar mixes were prepared using commercial Spanish ordinary cement II–F/35A which consists on a mixture of an ASTM type I ordinary Portland cement with a finely ground inert limestone (13% by mass). Chemical and mineralogical composition (Bogue calculation) of clinker Portland cement were: SiO_2, 20.8%; Al_2O_3, 4.6%; Fe_2O_3, 4.8%; CaO, 65.6; MgO, 1.2%; SO_3, 1.7%; Na_2O, 0.07%; K_2O, 1.0; C_3S, 66.5; C_2S, 9.5%; C_3A, 3.9%; C_4AF, 14.7%. Fine aggregate: natural sand with 3.56 fineness modulus. Fly ash: the source of this material was the thermoelectric power plant of Andorra (Teruel–Spain); this fly ash has a low calcium content (class F according to ASTM C–618). The original fly ash (T0) was separated in to several size fractions using an aerodynamic tunnel with an horizontal air current (5) (four fractions were obtained, T1, T2, T3 and T4, being T1 the coarsest fraction and T4 the finest one). Each sized fraction was homogenized before preparing mortars. Chemical and granulometric data of the initial fly ash (T0) and size fractions (T1, T2, T3, T4), and analytic data for water used for preparing and curing the specimens are reported in a previous paper (11). Additionally, granulometric distributions of fly ash fractions with respect to the original fly ash (T0) are shown in figure 1.

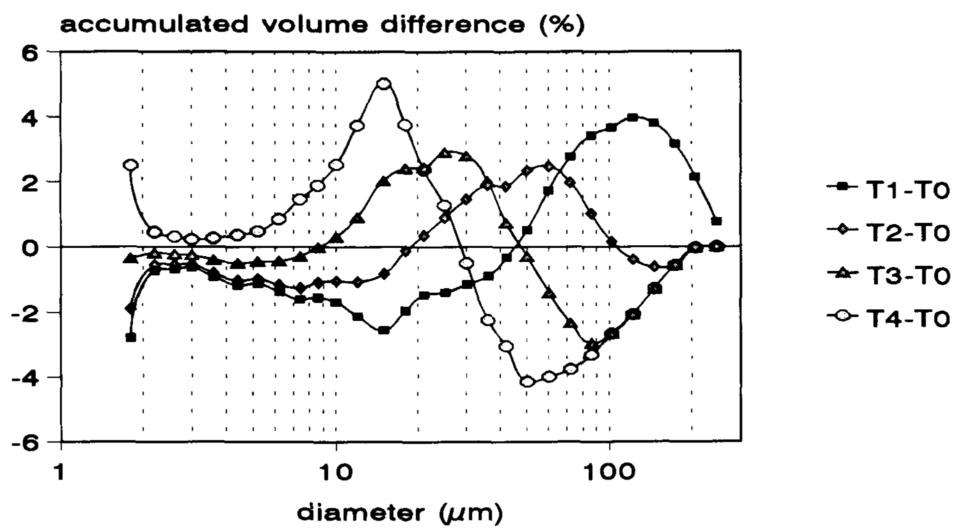

FIG. 1
Granulometric distributions of fly ash size fractions (T1, T2, T3 and T4) with respect to original fly ash (T0).

Apparatus and procedures: Particle size distributions were recorded using a Sympatec Helos Analyzer. Preparation of mortars was carried out according to ASTM C–305, mixing 450 g of Portland cement, 1350 g of natural sand and 225 mL of water for control mortars. The rest of the mortars were prepared replacing a mass percentage of Portland cement by fly ash (original or sized fractions). Mortars were put in a mold to obtain 16x4x4 cm specimens,

TABLE 1. Mix proportions for preparing mortars.

No.	Cement (g)	Fly ash (g)	Type Fly ash	water (mL)	No.	Cement (g)	Fly ash (g)	Type Fly ash	Water (mL)
1	450	–	–	225	11	315	135	T2	213
2	382	68	T0	219	12	248	202	T2	205
3	315	135	T0	211	13	180	270	T2	200
4	248	202	T0	207	14	382	68	T3	214
5	180	270	T0	201	15	315	135	T3	206
6	382	68	T1	222	16	248	202	T3	202
7	315	135	T1	218	17	180	270	T3	194
8	248	202	T1	212	18	315	135	T4	206
9	180	270	T1	206	19	180	270	T4	191
10	382	68	T2	219					

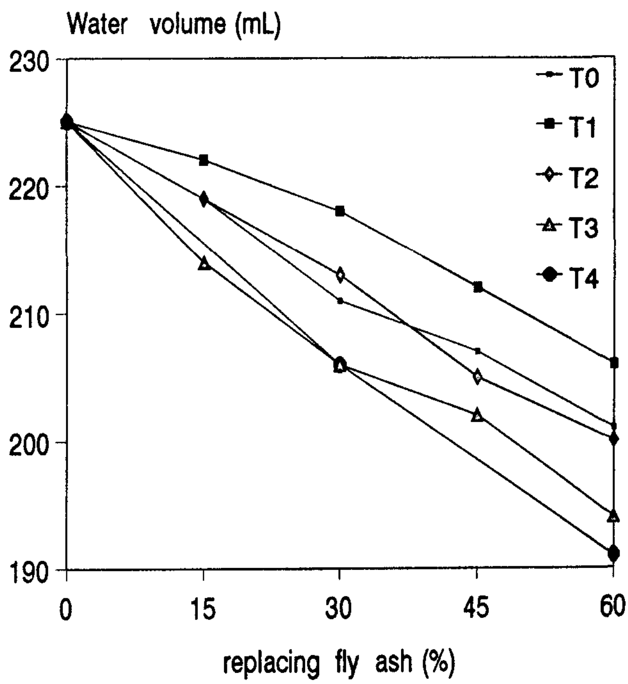

FIG. 2
Correlation between water volume and replacing fly ash

which were stored in a moisture room (20±1 ºC) for 24 hours. Afterwards, the specimens were demoulded and stored under water at 20±1 ºC or at 40±1 ºC until the time of the test. Compressive and flexural strengths were measured for each specimen at 28 days. Flexural procedure was a center point load and then the two portions were tested in compression.

Results and Discussion

Mix proportions (Table 1) were determined according to workability values of mortars already reported (7). Water contents for a mortars containing fly ashes were designed for obtaining the same flow table spread (FTS) of a mortar containing 1:2 water/cement ratio. Figure 2 shows the water contents for mortars with 15, 30, 45 and 60 % fly ash replacing Portland cement which gave the same FTS value as "only cement" mortar. It can be noticed that the required water volume was lower when the replacing percentage of fly ash was increased and, additionally, the highest water volumes for a given replacing percentage were required for mortars with T1 sized fraction (the coarsest fraction) and the lowest one for T3 and T4 sized fractions (finest samples); T0 and T2 required similar water contents.

Specimens (No.1–19) were cured for 28 days at 20 ºC and compressive (Rc) and flexural (Rf) strengths were determined at this age. Figure 3a shows Rci/Rc1 values for this series, being Rc1 compressive strength for "only cement" mortar (No.1) and Rci compressive strength for specimens containing fly ash. This figure reveals that mortars containing 15 or 30 % of fly ash replacing cement (except for T1) gave similar compressive strength (Rci/Rc1 > 0.90) to the "only cement" mortar. This fact indicates that the plastizicing effect of the fly ash is an important property for obtaining mortars with high compressive strength. The water reducing and the filler effects and, probably, early pozzolanic reaction could contribute to strength development, and compensate the partial substitution of cement in mortars containing low percentages of fly ashes (15–30 %). On the other hand, when substitution percentage is greater (45 or 60 %) Rci/Rc1 values decrease: approximately 0.78 for 45 % and 0.5–0.6 for 60 % substitution percentage, whereas mortars containing T1 sized fraction yield the lowest values as mentioned before. For the highest substitution percentage (60 %) a good correlation between Rci values and particle mean diameter of fly ash was noted (figure 4): samples with lowest particle mean diameter yielded highest compressive strength values; possibly, differences among the role of fly ash sized fractions can be easily revealed when percentage of fly ash is high.

Flexural strength values (Rf) show a similar trend. Figure 3b shows the correlation between Rfi/Rf1 values (Rf1 flexural strength for "only cement" mortar and Rfi for mortar containing fly ash) and fly ash substitution percentage. Interestingly, Rfi/Rf1 values for the 15 and 30 % substitutions are >0.9. No differences among the sized fractions were observed for the 15% experiment and 30% experiment values were equal or greater than the 15%. A decrease was observed for 45 and 60 % substitution percentages. Again, a good correlation between Rf and particle mean diameter was noted when the percentage of fly ash is 60 % (figure 4).

In order to study the influence of a 40 ºC curing temperature on enhancing strengths, a 30 % fly ash substitution was selected due to good results obtained in the 20 ºC experiment. Mix proportions repeated at 40 ºC were numbers 1,3,7,11,15 and 18 (Table 1). The results obtained for compressive and flexural strength comparing 20 and 40 ºC curing temperature are presented in figure 5 (a and b). In this figure Rci/Rc1 and Rfi/Rf1 ratios enhancement are noted when curing temperature was increased from 20 to 40 ºC, due to pozzolanic reaction (12). However, no significant differences in compressive strength were observed among specimens cured at 40 ºC, except for mortar with T4 sized fraction (figure 5a, 40 ºC). This effect might be due to the difference in the content of particles with diameters less than 10 μm which were similar for T0, T1, T2 and T3 fly ashes, whereas the T4 size fraction contained a significantly greater amount of the finest particles. Probably, pozzolanic reaction

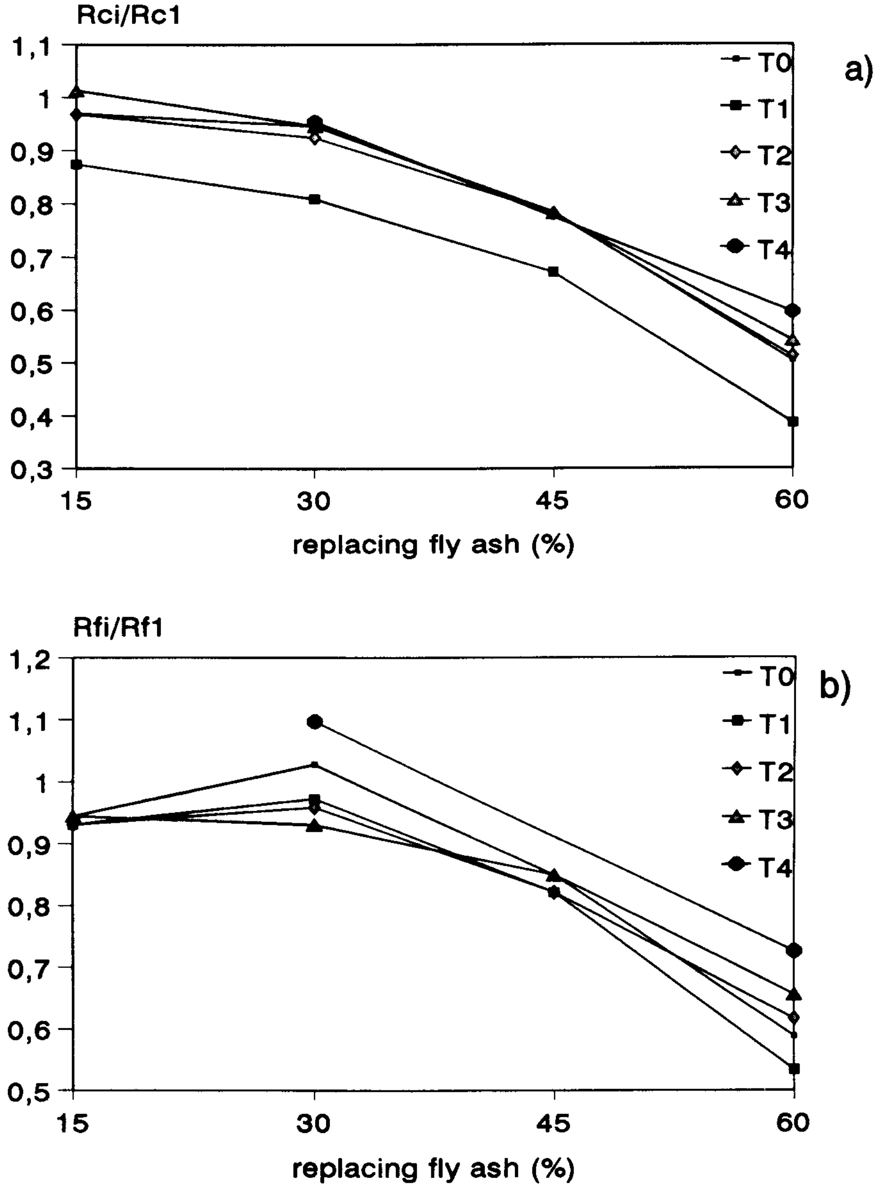

FIG. 3

Correlations between relative strength values for mortars and the replacing percentage of fly ashes (T0, T1, T2, T3 and T4): a) compressive strength; b) flexural strength.

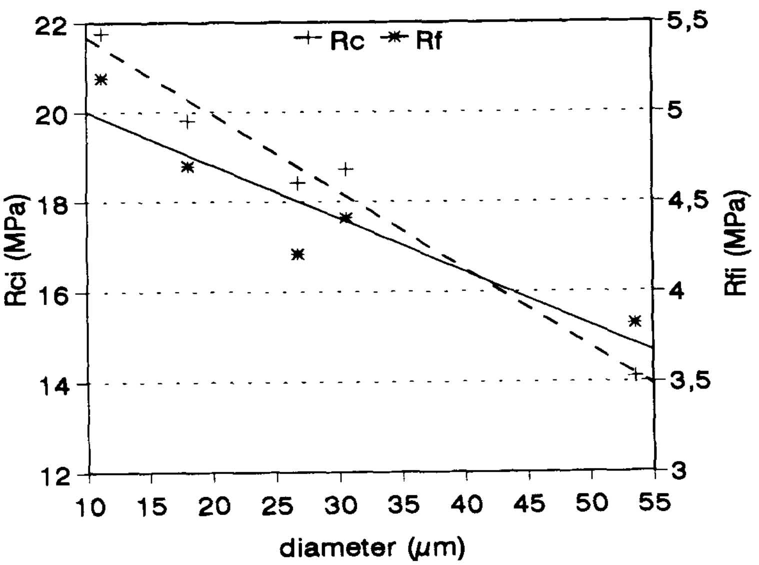

FIG. 4
Relation between 28-day strengths of specimens containing 60% of fly ash replacing cement and fly ash particle mean diameters (dotted line: Rc)

mainly take place on the finest particle surface and, for instance, compressive strength values in these conditions depends not on specific surface or particle mean diameter, but on the content of finest particles. Flexural values showed a particular trend: in all cases Rf values for specimens containing fly ash were significantly greater than the "only cement" specimen.

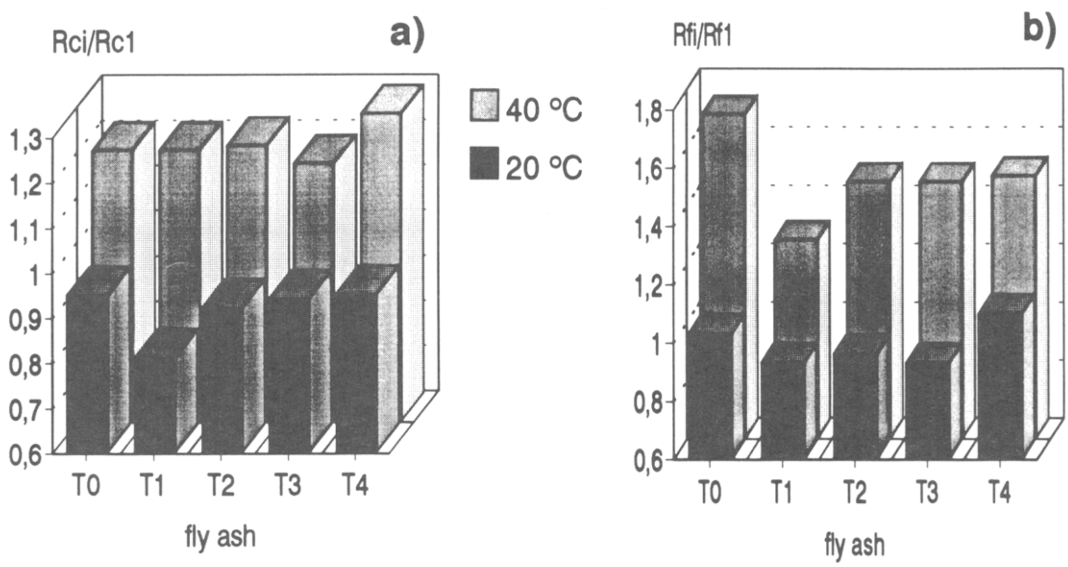

FIG. 5
Effect of curing temperature: strength comparison between "only cement" mortar and fly ash mortars: a) compressive strength; b) flexural strength.

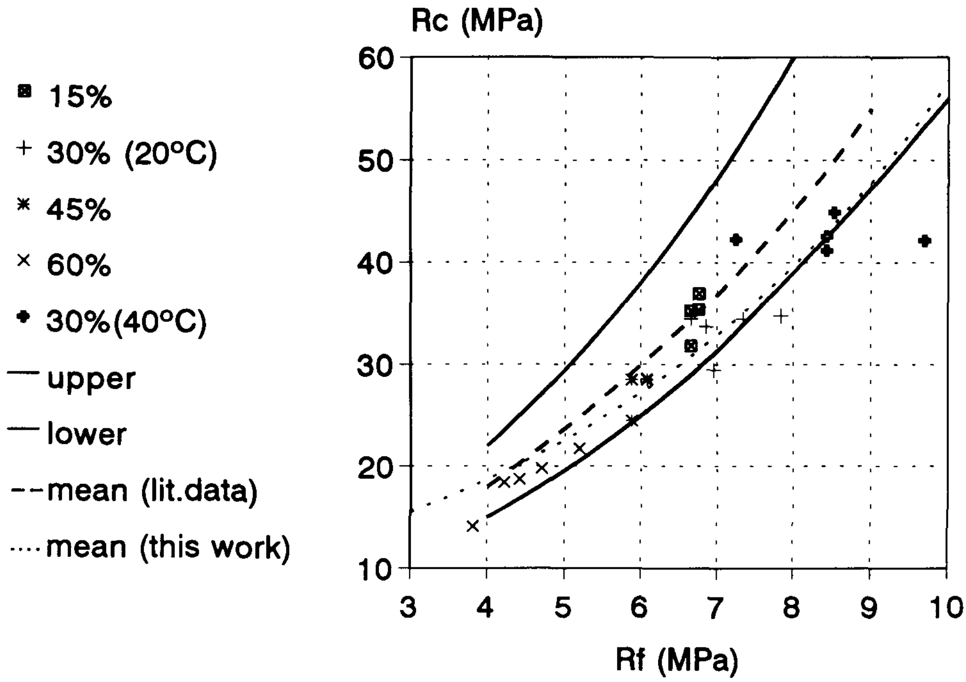

FIG.6
Relation between compressive and flexural strengths

Interestingly, specimens with original fly ash T0 yield the highest value, which may be attributed to the granulometric distribution (figure 4b, 40 ºC).

Figure 6 shows the relationship between Rc and Rf. The results obtained indicated that most Rc and Rf values are contained within reported limits (13). In all cases, the original fly ash and the sized fractions yielded Rc/Rf ratios nearer lower limit.

Conclusions

1- Partial substitution of cement by fly ash produced a decrease of water requirement (increase of FTS and reduction of water/cement+fly ash ratio). Additionally, this effect was more important for finest fly ash sized fractions.

2- In 20 ºC curing experiment, at 28 days, when water/cement+fly ash ratio was slightly reduced, replacement by 15 and 30 % fly ash does not produce a significant loss of flexural and compressive strengths compared to "only cement" specimens, except for the coarsest fly ash fraction (T1).

3- Same experience at 40 ºC showed an increase of compressive and flexural strength for 30 % substitution: in all cases strengths always are greater than the "only cement" ones. It demonstrates that the pozzolanic character of fly ashes was enhanced at higher temperatures. No differences in compressive strength among the original fly ash T0 and the sized fractions (except T4 fly ash fraction) were observed.

4- Except for the finest fraction (T4), fly ash substitution larger than 30 % (45 and 60 %) produced a significant decrease in strength compared to the "only cement" specimen.

5- In general, enhancement of compressive strength related mainly with content of fly ash particles smaller than 10 μm. This tendency was not observed for flexural strength; in this case granulometric distribution and fly ash fineness appeared to be important.

6- Good correlations between strengths and particle mean diameters were observed when fly ash percentage of substitution was 60 %.

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