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MECHANICAL PROPERTIES OF HIGH PERFORMANCE CONCRETE MADE WITH HIGH CALCIUM HIGH SULFATE FLY ASH

Yamei Zhang, Wei Sun and Lianfei Shang[1]
Department of Materials Science and Engineering
Southeast University, 210096, Nanjing, China
[1]Nanjing Ningyuan Science and Technology Development Company, China

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ABSTRACT

A high calcium fly ash with high SO_3 content was used to produce high performance concrete. In all the mixes, the fly ash contents of 50% and 60% by weight were applied. Although fly ash cement pastes showed severe volume unstability and poor pore structure development, mortars and concretes incorporating high mass high calcium fly ash exhibited good performance in both fresh and hardened state as those with low calcium fly ash did. The 3d and 28d compressive strength of mortars reached 25.2 ~ 42.2MPa respectively with the water binder ratio varying from 0.30 to 0.24. What is noticeable is that all the mortars and concretes showed good strength developing tendency with the 90d compressive strength up to 67.3 ~ 85.5MPa. This investigation reveals once more the fact that some materials which are not up to standard can still play a special role so long as the components are carefully chosen and proportions properly designed. © *1997 Elsevier Science Ltd*

Introduction

For half a century researchers have studied the chemical compositions and physical properties of all kinds of fly ashes and their usage in concretes (1-6). Because of the inherent variability of the ashes due to the different sources, geological history and processing methods, the use of fly ash in concretes has been very cautious. Generally, fly ash as a cementitious component, its SO_3 content should not be too high, say, 3% is the upper limitation on Chinese specification GB1596-91, otherwise the formation and development of ettringite (AFt) in concrete may cause expansion and cracking and thus worsen the properties of concrete. Particularly, when we want to mix high performance concrete, the use of unqualified materials is generally regarded as undesirable.

Literatures showed that high volume fly ash cement pastes had a more porous structure at early curing ages than pure cement pastes did, however, the structure grew denser and denser as time went on (7,8). From this point of view, porous structure does no good to the development of early strength for ordinary concrete, but it is no doubt that the development of crystals or expansive substances in porous condition shall densify the matrix. On the basis of the view, the high calcium fly ash with high SO_3 content was employed to mix high per-

TABLE 1

Chemical Analysis of Cement and Fly Ashes (% by Weight)

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	L.O.I.
C	21.17	5.19	4.97	64.52	1.08	-	-	2.30	1.19
c-FA	45.00	11.03	13.87	12.65	1.20	1.33	4.25	5.71	0.25
f-FA	45.47	7.76	31.11	2.74	1.10	0.64	0.35	1.49	5.04

formance concrete in this paper to achieve the goal of changing waste into treasure. A low calcium fly ash was used for comparison as well.

Experimental

Materials. The chemical compositions and physical properties of cement (C), high calcium fly ash (c-FA) and low calcium fly ash (f-FA) are given in Table 1 and 2 separately.

The sand was a standard sand in mortars and an ordinary river sand in concretes. The maximum diameter of coarse aggregate was 15mm. A high range water reducer was applied.

Incorporating fly ash in concretes may influence setting time, some fly ashes shall delay the setting, others shall accelarate it or have little influence on it at all. In particular when the fly ash content is high, the influence may be not ignored some times. The initial and final setting time of different fly ash cement pastes was examined to decide the ultimate content of fly ash. Because of the high content of SO_3 in c-FA, the volume stability of different fly ash cement pastes was tested as well.

The mix proportions of mortars are listed in Table 3, for all the mortars, the binder to sand ratio was 1:2. Mortar size was 40 × 40 × 160 mm. Water to binder ratio of 0.30 and 0.24 were applied to all the mixes except the reference one with a water binder ratio of 0.24, for which the mixture was too dry to get a suitable workability. The compressive and flexual strength at various ages were tested. The mix proportions of concretes are shown in Table 4. The size of concrete prisms was 100 × 100 × 100mm. The slump and compressive strength at different ages were measured. The workability of mortars and concretes were adjusted by changing the content of water reducer. All the samples were cured under standard condition.

Various fly ash cement pastes were also prepared and cured in water at 20°C for the test of porosity with a mercury intrusion porosimetry.

TABLE 2

Physical Properties of Cement and Fly Ashes

	Specific gravity (g/cm^3)	Specific area (cm^2/g)	45 m sieve residue (%)	Water demand ratio	28d compressive strength ratio
C	3.1	3200	9.2	100	100
c-FA	2.6	4810	11.5	91	88
f-FA	2.3	5960	1.7	89	97

TABLE 3

Mix Proportions (by Weight) and Flow Diameter of Mortars

Series	Water	C	c-FA	f-FA	Water reducer (%)	Flow diameter (mm)
1FA0	0.30	1	0	0	2.00	155
1c-FA50	0.30	0.5	0.5	0	0.50	158
1c-FA60	0.30	0.4	0.6	0	0.47	160
1f-FA50	0.30	0.5	0	0.5	0.60	145
1f-FA60	0.30	0.4	0	0.6	0.57	150
2c-FA50	0.24	0.5	0.5	0	1.06	158
2c-FA60	0.24	0.4	0.6	0	0.98	158
2f-FA50	0.24	0.5	0	0.5	1.30	152
2f-FA60	0.24	0.4	0	0.6	1.20	148

Results and Discussion

Setting Time and Volume Stability. Experimental results of setting time and volume stability are concluded in Table 5. It is evident that both fly ashes at high contents greatly delayed the initial and final setting time. If the content of c-FA reached 70%, the final setting time exceeded 12 hours, so it is improper to use such a content of fly ash in concrete in order to achieve desirable early strength. From the results of stability testing, all the c-FA cement pastes exhibited distinct expansion, which was unqualified for this fly ash to be used in ordinary concrete. With the increase of c-FA content in pastes, the expansion increased under condition without restraint.

Strength Development of Mortars and Concretes. Fig. 1 and Fig. 2 illustrate the development of compressive and flexual strength of mortars. It can be seen that the 3d strength decreased sharply due to the large amount of fly ashes included in mortars. Two major factors considered in this experiment, the water binder ratio and the fly ash replacement content of cement, greatly influenced the 3d compressive and flexual strength. For c-FA cement mortars with a water binder ratio of 0.30, the 3d compressive strength reduced from 30.5MPa to 25.2 MPa when the content of c-FA varied from 50% to 60%. For the case of 0.24 water binder ratio, the value changed from 42.2MPa to 36.0MPa. At later ages, the compressive strength of both fly ash cement mortars grew rapidly at a much faster rate than

TABLE 4

Mix Proportions (Kg/m^3) and Slump of Fresh Concretes

Series	Water	C	c-FA	f-FA	Sand	Coarse aggregate	Water reducer	Slump (mm)
FA0	148	550	0	0	613	1139	11.0	180
c-FA50	148	275	275	0	613	1139	5.2	140
c-FA60	148	220	330	0	613	1139	4.7	155
f-FA50	148	275	0	275	613	1139	5.5	200
f-FA60	148	220	0	330	613	1139	4.4	196

TABLE 5

The Setting Time and Volume Stability of Fly Ash Cement Pastes

Binder	Initial setting time	Final setting time	Average expansion diameter (mm)	Volume stability
100%C	2h35min	4h32min	-	Qualified
50%C+50%f-FA	6h54min	9h03min	-	Qualified
30%C+70%f-FA	8h55min	11h05min	1.9	Qualified
60%C+40%c-FA	-	-	5.5	Unqualified
30%C+70%c-FA	9h50min	14h23min	40.8	Unqualified

that for reference mortars (FA0), the 28d compressive strength reached 67MPa and 71MPa for c-FA cement mortars at the water binder ratio of 0.24 for the content of 50% and 60% respectively, both surpassed that of reference one with a water binder ratio of 0.30 at the same age. At 90 days, for 0.30 water binder ratio, the compressive strength also caught up with and even exceeded that of reference mortar. It is noticed in particular that the effect of water binder ratio on flexual strength appears to be more evident than that on compressive strength. At high water binder ratio of 0.30, the flexual strength before 28 days grew slower, while improved much more after 28 days when compared with that for water binder ratio of 0.24.

The water binder ratio for concrete specimens was 0.27. From Fig. 3, it is known that fly ash concretes showed satisfactory compressive strength developing tendency, which complied with the results of mortars. The compresssive strength of c-FA concretes at 28 days was about 84 ~ 91% of that of reference concrete, at 90 days, the strength surpassed that of reference one.

Porosity of Fly Ash Cement Pastes. Fig. 4 gives the pore distribution of different fly ash cement pastes with a water binder ratio of 0.27. All the pastes were cured in water under 20 ± 3°C. It is evident that, till 28 days the high fly ash cement pastes had a much higher porosity than pure cement pastes did. The porosity increased with the increase of fly ash and declined with time except the one which had a c-FA content of 70%. At 3 days, the porosity

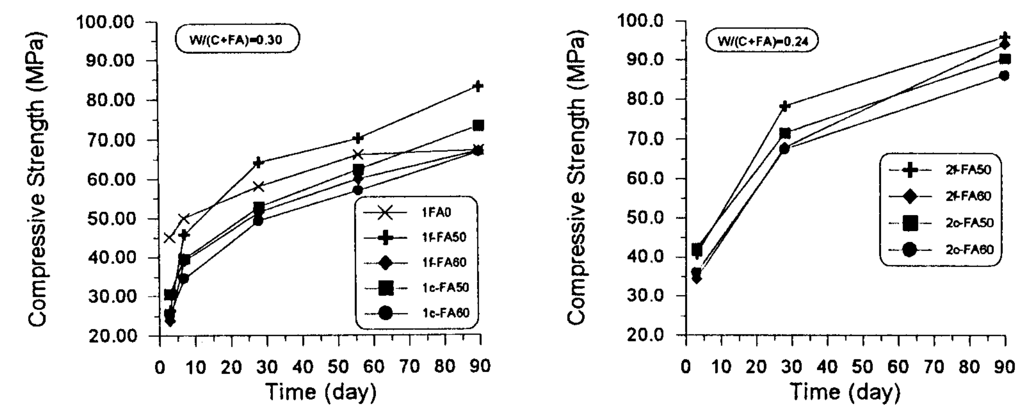

FIG. 1.
Evolvement of compressive strength of mortars.

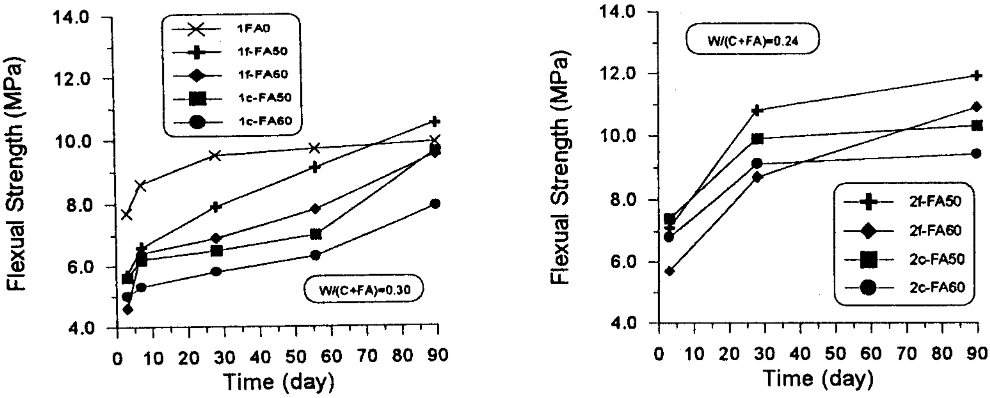

FIG. 2.
Evolvement of flexural strength of mortars.

of each fly ash cement paste at same replacement level was very close, during 7 to 28 days, however, the reduction of porosity of c-FA cement pastes was only a little for pastes with 50% replacement. For the case of 70% replacement, the porosity went up, it can be seen that, the amount of large and harmful pores is very high.

Discussion. Testing results of volume stability and porosity indicated that severe expansion and cracking took place in c-FA cement pastes. However, study also showed the fact that concrete containing large amount of c-FA exhibited excellent mechanical properties. The contradictory results might be explained as: For c-FA cement pastes, due to the formation of ettringite and its expansion under the condition without restraint of aggregate, the pastes cracked. But in mortars and concretes, because of the special structure of high porosity of matrix, the expansive ettringite might fill up and densify the structure, on the other hand, aggregate might restrain the expansion. In concrete, the effect of coarse aggregate on inhibiting expansion is especially prominent. So the formation of ettringite might increase the early strength at this standpoint of view. The slightly higher early strength of c-FA concrete than that of f-FA concrete conformed this.

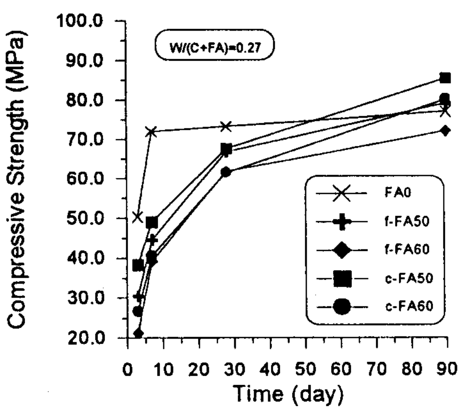

FIG. 3.
Evolvement of compressive strength of concretes.

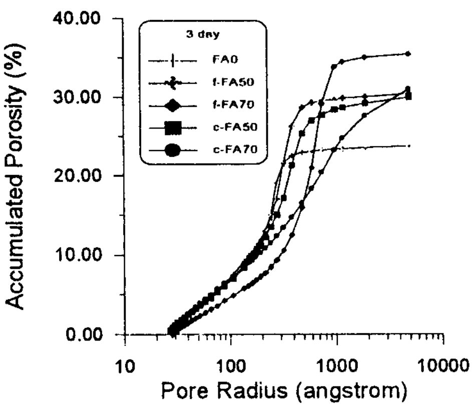

FIG. 4 (a).
The curve of pore distribution at 3 days.

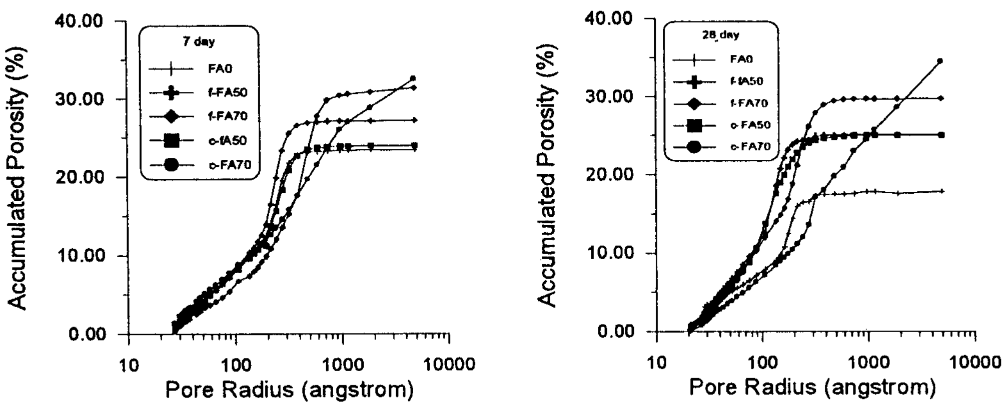

FIG. 4. (Continued)
(b) The curve of pore distribution at 7 days, (c) The curve of pore distribution at 28 days.

Conclusions

1. Cement paste incorporating high content of high calcium fly ash with high SO_3 showed severe volume unstability and poor pore structure evolvement, this indicated the appearance of ettringite in paste.
2. Mortars containing high content of high calcium fly ash (50% and 60% cement replacement) exhibited excellent compressive and flexual strength development. At 90 days, the strength surpassed that of reference ones.
3. High content high calcium fly ash concrete showed good compressive strength evolvement tendency. The early strength was a little higher than that of high content low calcium fly ash concrete.
4. The densifying effect of expansive ettringite on matrix and the restraining effect of aggregate on expansion should be responsible for the satisfactory mechanical properties of high content high calcium fly ash concrete.
5. From this study, it is noticeable that some materials, though not in compliance with some specifications, can still be efficiently used so long as they are properly designed.

Acknowledgment

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