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Performance evaluation of binary blends of Portland cement and fly ash with complex admixture for durable concrete structures

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Abstract. This paper presents the results of a study on binary blends of Portland cement and fly ash with complex admixture used for the concrete structures to meet specific performance objectives in east coastal area of China. The concretes were evaluated for workability, strength, water permeability, drying shrinkage, sulfate resistance and electrical resistance. Environmental Scanning Electron Microscopy (ESEM) was used to examine the microstructure of concrete made by complex admixture compared with control batches without complex admixture. The combined efforts of fly ash and complex admixture led to an improvement in the workability, strength and durability.

Keywords: fly ash; durability; admixture; sulfate attack.

1. Introduction

Durability is the key issue in today's concrete technology, especially for those structures exposed to corrosive environment such as sulfate or chloride or both present in soils, ground waters, seawater etc. Use of pozzolanic admixtures such as fly ash, slag or silica fume has a great potential to improve the overall performance and lower the life-cycle cost of concrete (Chindaprasirt, *et al.* 2004). During the past decades, numerous researches have demonstrated that use of fly ash can effectively reduce various forms of deterioration:

• Improve resistance to sulfate attack by consuming the free lime; decrease permeability to

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prevent sulfate penetration from the environment into concrete and replace of cement to reduce the amount of reactive aluminates available (Chindaprasirt, *et al*. 2004, Zhang 1995).

• Improve resistance to the corrosion of the reinforcement by reducing chloride ions ingression (Bouzoubaâ, *et al*. 2000).

• Improve resistance to ASR by reacting with available alkali in the concrete (Shehata, *et al.* 2000, Wang 1999).

Because fly ash materials can exhibit significant variation in both chemical and physical properties whether coming from different sources or even within the same source (Erdogdu and Türker 1998), users need specific guidance to assist them in defining the performance requirements for a concrete application and the selection of optimal proportions of fly ash to produce the desired durable concrete. Few attempts have been made to optimize the use of fly ash to produce concrete mixtures that meet specific performance objectives such as workability, pumpability and reduction in shrinkage cracking.

2. Research significance

The purpose of this research project is to provide quantitative guidance for binary mixtures that can be used to produce low permeability and long lasting concrete structures to service in the rich sulfate environment in east coastal area of China, where construction needs other performance requirements such as good workability, pumpability, low hydration heat and low cost etc. The effort of this project is directed at producing test results that support the following specific goals:

• To assess the technical feasibility of use of combination of fly ash and complex admixtures.

• To evaluate the performance (both strength and durability) that can meet the special construction specifications.

3. Experimental methods

3.1. Materials

Cement and Fly ash : The chemical compositions of the cement and the fly ash, used in this study, are given in Table 1.

Fine aggregate : Medium size river sand with a modulus of fineness Mx = 2.8, and a density of 2.6 g/cm^3 was used.

Coarse aggregate : Crushed limestone with normal continuous grading, a density of 2.65 g/cm^{3}and a maximum diameter D_{max} of 31.5 mm was used.

Admixture : A complex admixture that is a mix of water-reducing admixture and micro-expansion admixture was used.

3.2. Mixture design

A factorial experiment was set up with different proportions of mixtures of cement, fly ash and complex admixture in the initial studies. Based on assessment of the preliminary optimizing test results. A fifteen percentage of cement replacement with fly ash (by cement weight) and five percentage of complex admixture (by cement weight) have been selected for this study. Control

Table 1 Chemical composition of cement and fly ash

	Portland cement Type I[a]	Fly ash[b]
Silicon dioxide (SiO_2)	20.77	77.32
Aluminum oxide (Al_2O_3)	5.78	3.64
Ferric oxide (Fe_2O_3)	4.73	2.62
Calcium oxide (CaO)	65.05	12.03
Magnesium oxide (MgO)	1.18	1.21
Sodium oxide (Na_2O)	0.41	0.11
Potassium oxide (K_2O)	0.82	0.25
Sulphur trioxide (SO_3)	0.94	<0.01
Loss on ignition	0.24	2.68

[a]Obtained from a cement plant from China, Portland cement Type I (GB175-1999).
[b]Obtained from a cement plant from China, the amount of the ash retained on 45 μm sieve was 27.9%, which meet the requirements of ASTM Class F ash.

Table 2 Mix proportion of concrete

Batches No.	W/C	W/B (water-to-binder)	Cement Kg/m^3	Sand Kg/m^3	Coarse aggregate Kg/m^3	Water Kg/m^3	Fly ash Kg/m^3	Complex admixture Kg/m^3
1	0.57	0.57	386	789	1005	220	-	-
2	0.66	0.53	319	722	978	211	79	-
3	0.56	0.44	309	712	1113	172	81	19
4	0.57	0.45	322	701	1052	182	84	20
5	0.52	0.41	347	671	1049	180	91	21

batches with similar W/C ratio without complex admixture or without fly ash were tested for comparison. The mixture proportions of five different batches are summarized in Table 2.

3.3. Testing method

Fresh concrete was tested for its slump, spread and drop time according to Chinese Standard GB/T50080-2002. The slump test was carried out after 10 and 60 minutes after mixing was completed to assess the slump loss. Cube batches were used for testing the compressive strength at the ages of 3, 7, 28, 60 and 90 days in accordance with GB/T50081-2002.

Cylinder batches were tested for the water permeability at 28 days following the standard GBJ82-85. The linear expansion of batch was measured and recorded at different ages to evaluate the shrinkage according to GBJ82-85.

Test of sulfate resistance was based on GB2420-81, the cylinder batches were cured under standard conditions for 28 days, then were immersed in a 5 percent Na_2SO_4 solution. The relative flexural resistance coefficient was calculated as a ratio of measured flexural strength of the batches to that of batches immersed in fresh water. The relative compressive resistance coefficient was taken as a ratio of compressive strength of the batches to that of batches immersed in fresh water.

Chloride penetration resistance was examined according to JTJ270-98. The test measures the electrical conductance of concrete immersed in sodium chloride solution. A higher measured value in ohms indicates lower chloride permeability.

4. Results and discussions

4.1. Effect of fly ash and complex admixture on workability, compressive strength and permeability

The measured workability of fresh concrete and water permeability of harden concrete results are summarized in Table 3. Comparison of three batches, batch #1 (cement only), batch #2 (cement+fly ash), batch #3 (cement+fly ash+complex admixture), shows that batch #1 has poor workability and pumpability which result in high permeability and low strength. With addition of fly ash, batch #2 has an improvement in both workability and pumpability, but the pumpability still could not meet the construction requirements for this special project. With addition of complex admixture in batch #3, both workability and pumpability can meet the construction requirements. The slump loss test on batch #3 is less than 20 mm within 60 minutes, which indicates concrete has a good cohesive and less prone to segregation.

The measured values of compressive strength are plotted against different ages of 3, 7, 28, 60 and

Table 3 The measured workability of fresh concrete and water permeability of harden concrete

Batches No.	Fresh concrete mixture workability			Water permeability of harden concrete	
	Slump (mm)	Spread (mm)	Drop Time (s)	Water Pressure (MPa)	Permeability Coefficient (cm/s)
1	170	27	4	1.0	9.4×10^{-10}
2	195	33	4	3.6	8.7×10^{-9}
3	205	52	14	3.6	1.3×10^{-9}
4	215	54	7	3.6	4.1×10^{-10}
5	215	52	16	3.6	8.6×10^{-10}

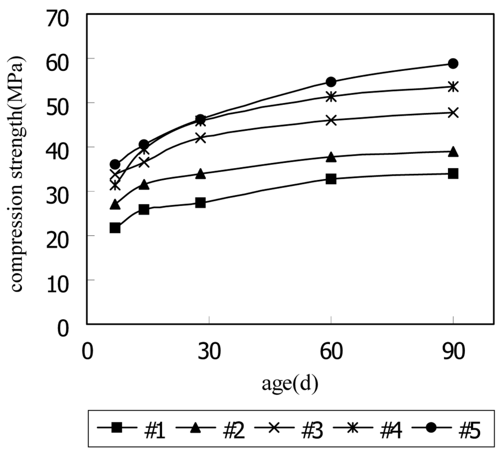


Fig. 1 Measured compressive strength vs hydration time for different batches

90 days as shown in Fig. 1. As seen from Fig. 1, batch #3 has a much higher strength than that of control ones (both #1 and #2); With same percentage by weight of cement replacement with fly ash and complex admixture, compressive strength and water permeability increase as the water cement ratio decreases.

The improvement of both workability and pumpability is the combined efforts of both fly ash and complex admixture. The spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix to provide a lubricant effect, and thus increase the workability, and the effect also improves concrete pumpability by reducing frictional losses during the pumping process (Jiang and Malhotra 2000).

The increases in strength is due to reduced W/B (water-to-binder), reducing the pore interconnectivity of concrete (Poon, *et al.* 2000). Therefore batch #3 has much higher strength in different ages than other two control batches (# 1 and #2).

The decreased in permeability is contributed to the overall pore size refinement and a densification of the transition zone between the cement paste and the coarse aggregate (Zhang 1995), which leads to an improved long-term durability and resistance to various forms of deterioration such as resistance to sulfate attack and resistance to corrosion.

4.2. Effect of fly ash and complex admixture on concrete shrinkage, sulfate resistance and chloride penetration

Normal concrete will occur plastic shrinkage when subjected to a dry environment, resulting in generate tensile stresses and ultimately leading to microcracking or cracking, which can significantly lower the resistance of concrete structure to corrosive agents. The complex admixture used in this study causes a slight expansion to the concrete during early stage and this reduces of shrinkage. All three batches #3, #4 and #5 exhibit a no harmful expansion at different hydration ages in a similar pattern as shown in Fig. 2, while the control batches (#1 and #2) show different degrees of shrinkage as shown in Fig. 3.

Both measured relative flexural and compressive resistance coefficients for batch #3 are plotted with immersed time (see Fig. 4). As seen from the figure, the relative resistance coefficients are

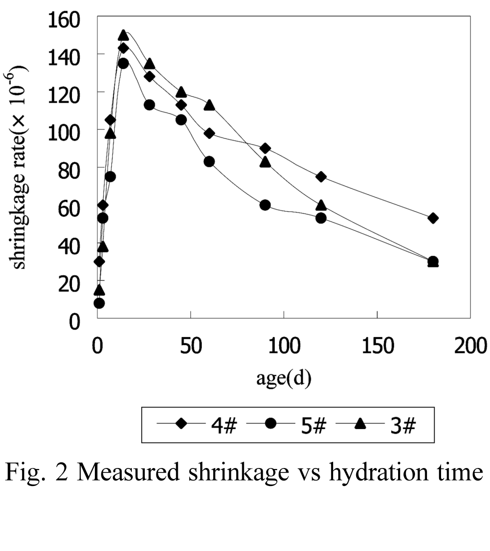


Fig. 2 Measured shrinkage vs hydration time

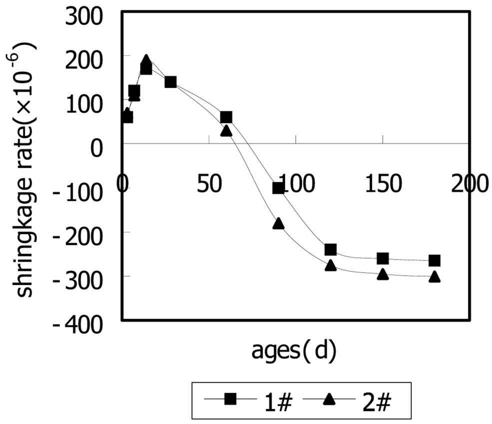


Fig. 3 Measured shrinkage vs hydration time

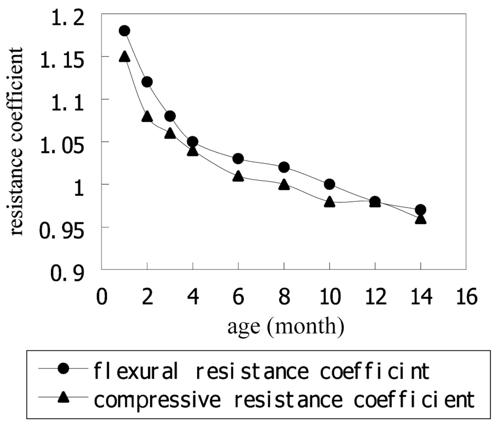


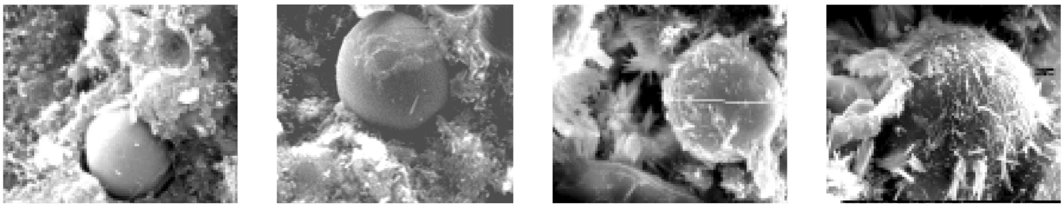
Fig. 4 Results of sulfate resistance

Table 4 Measured chloride permeability for different batches

Batches No.	Resistance (Ω)	Conductance ($\times 10^{-4}$S)	Conductance standard ($\times 10^{-4}$S)
1	463	21.6	20.6
2	396	24.8	
3	545	18.3	
4	590	16.9	
5	682	14.7	

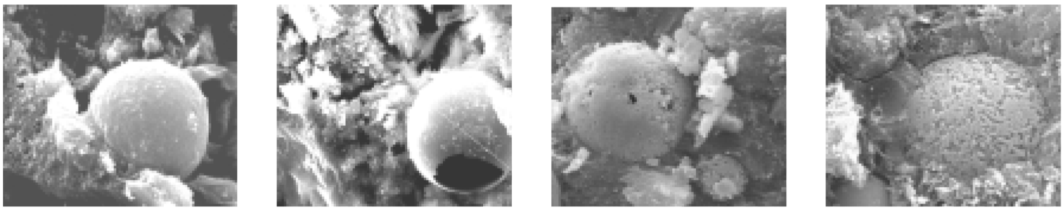
greater than 0.80 which required for the construction application. The results demonstrate that batch #3 has a good sulfate resistance.

The measured electronic resistances from the rapid chloride permeability test for different batches are presented in Table 4. As shown in the table, only control batch #1 does not meet the specification required for the concrete structures exposed to the splash zone, the other batches are



a. 3 days b. 7days c. 28 days d. 90 days

Fig. 5 ESEM images for the control batch (#2) without complex admixture



a. 3 days b. 7days c. 28 days d. 90 days

Fig. 6 ESEM images for the batch (#3) with complex admixture

well above the specified critical value. As water cement ratio decreases, the resistance of concrete to the chloride ions penetration increases.

4.3. Effect of fly ash and complex admixture microstructure of concrete

Environmental Scanning Electron Microscopy (ESEM) was used to examine changes in the microstructure of concrete with complex admixture versus control batches without complex admixture at different hydration ages. Fig. 5 illustrates the ESEM images for the control batch (#2) at the age of 3, 7, 28 and 90 days. As seen from those images, without using complex admixture, there are a few hydration products formed around the fly ash spherical surface during early stages (till 28 days), and even at 90 days there is only a small portion of fly ash's particle surface covered with hydration products. Fig. 6 presents ESEM images for the batch (#3) with complex admixture at the age of 3, 7, 28 and 90 days. As noticed from the those images, at 28 days the hydration products has filled around fly ash particle surface, and at 90 days it is hard to see the particles of the fly ash, most of them already participate the pozzolanic reactions and form additional cementitious compounds to strength concrete structure. The comparison results an indication that the complex admixture has effectively activated the pozzolanic reactions between fly ash and free lime in concrete, this can also be interpreted from the observe increased strength and decreased permeability in batch (#3) compared with that of batch (#2).

5. Conclusions

1. Binary blends of Portland cement and fly ash with complex admixture can be used to optimize

the development of low permeability, durable infrastructures.

2. The combination use of fly and complex admixture can improve workability, pumpability to meet the special construction applications.

3. The selected complex admixture should be used as an effective activator for fly ash pozzolanic reactions to enhance both compressive strength and durability of concrete.

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