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Influence of fly ash on the mechanical properties of frame concrete

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ABSTRACT

Fly ash dumped not only consumes landfills, but also pollutes environment. With the aim of sustainable development, the isolated contribution of fly ash in concrete to the mechanical properties of frame concrete is investigated, and experiments were carried out over water–binder ratios ranging from 0.30 to 0.42 and fly ash–binder ratios from 0% to 30%, based on concrete framework model theory. The compressive and flexural strengths of frame concrete and corresponding mortar matrix were determined on 28 days, 56 days and 90 days. The 28-day compressive and flexural strengths of concrete and mortar matrix decreased with fly ash incorporation, and increased on 56 days and 90 days due to curing ages and pozzolanic reaction. It can be concluded that the optimum of fly ash is not a constant one but depends on the water–cementitious materials (w/cm) ratio of the mix. Based on the test results, concrete framework equation has been developed using statistical methods.

1. Introduction

Fly ash is a by-product of the coal power generation. The demand of electric power is increased with the development of industry, and power stations now produce much fly ash annually. Most of them are dumped, while environmental situations will not permit the dumping of large amount of waste fly ash, which will increase every year. Concrete manufacturing consumes lots of natural resources energies, and the environmental impact of the production of the raw ingredients of concrete is considerable. To cope with the problem between the resources and environment, a number of studies have been conducted in the architectural field in recent years on applying a large of amount of fly ash to concrete (Berry, Hemmings, & Cornelius, 1991; Feldman, Carette, & Malhotra, 1991; Malhotra, 1991; Siddique, 2004). It is well documented that use of fly ash in concrete results in a significant improvement in the mechanical properties of concrete for long term strength, but researchers are yet to arrive at a unique conclusion regarding the optimum fly ash replacement percentage, and different researchers have reported different replacement levels as optimum for obtaining maximum strengths of concrete (Hwang, Noguchi, & Fuminiro, 2004; Oner, Akyuz, & Yildiz, 2005; Siddique, 2004). Although the literature is rich in reporting on fly ash concrete, most of the researcher works are centered on the compressive strength, and the technical data on flexural tensile strength is quite limited. As a result, the isolated effect of fly ash on the properties of concrete is yet to be exhaustively investigated.

Human progress depends on the material development. Concrete is the main building materials in 21st century. According to the traditional concrete theory, concrete should be examined as a three-phase material consisting of aggregates, cement paste and transition zone between them. From recent studies, on one hand the theory confused contributions to the fine and coarse aggregate on concrete properties; on the other hand it mislead the effect on water–cement ratio (Wang, Wang, Su, & Cui, 2011). Many properties of hardened concrete depend on coarse aggregate, mortar matrix, and transition zone. Therefore, the coarse aggregate also played a major role in determining the cost and workability of concrete mixtures, and it was inappropriate to treat the aggregate with any less respect than cement (Kumar Mehta & Monteiro, 2006). In order to express the effect of coarse aggregate in modern concrete, Wang Lijiu presented concrete framework model theory (Wang, Wang, & Meng, 2009). According to the concrete framework theory, concrete may be assumed to multiphase material consisting of coarse aggregate embedded in mortar matrix and interfacial zone between the particles of coarse aggregate and mortar matrix, and the strength of the concrete is determined mainly by the characteristics of the mortar matrix, coarse aggregate and the interface.

Sustainable development should be resolved the contradictions among the resources, energies and environment. Fly ash used in concrete not only resolves the resources and energies, but also protects the environment. It is significant to cope with the problem of fly ash. This study aims at determining the role of fly ash on frame concrete, based on the view of sustainable development. To deter-

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Table 1
Grading of coarse aggregates.

The maximum size/mm	Different grade content of coarse aggregate%					
	2.36–4.75/mm	4.75–9.5/mm	9.5–16/mm	16–19/mm	19–26.5/mm	26–31.5/mm
26.5	0	16	20	32	30	4

Table 2
Chemical ingredients of fly ash.

Type	Loss on ignition	CaO	Al_2O_3	SiO_2	MgO	K_2O	Na_2O	Fe_2O_3
Fly ash/%	3.42	6.61	30.61	50.96	0.63	0.78	0.17	5.61

mine the isolated contribution and the maxim dosage of fly ash on frame concrete.

2. Experimental program

2.1. Materials

The constituent materials used in the program were tested to comply with the relevant Chinese Standards. The cement used was Ordinary Portland Cement, having 28-day compressive strength of 65.32 MPa and flexural strength 9.17 MPa, density 3.15 g/cm^3 and surface area 350 m^2/kg. Natural river sand having fineness modulus of 2.8 was used. Natural coarse aggregate employed in this study was limestone. Table 1 shows the grading of coarse aggregate, vibration bulk density 1700 kg/m^3, apparent density 2745 kg/m^3, vibration porosity 38.07%. Fly ash conforming to GB/T1596-2005 is produced by Huadan power generation in Dandong, and the chemical ingredients are given in Table 2. Tap water and high water reducing admixtures [superplasticizer (SP)] were employed for the mixing.

2.2. Experimental procedure

In order to investigate the isolated effect of fly ash on frame concrete, only cement was replaced by fly ash at different constant water–binder ratios, keeping other mix design variables, like quality of ingredients, mix proportions, the aggregate–binder, coarse–fine ratios, dosage of SP, and mixing procedures. The mix proportions are presented in Table 3.

The mixing procedure and time were kept constant for all the concrete mixes investigated. For all the compressive strength determination, 150 mm cubes specimens were used, and 100 mm × 100 mm × 400 mm beams for flexural tensile strength evaluation. After being cast all the specimens were covered with their lids and stored in the laboratory environment maintained at 23 ± 2 °C and 45 ± 5% relative humidity (RH). The specimens were demoulded after 24 h of casting. Then the molds were stripped and specimens were cured in standard curing room until testing. The concrete properties were tested according to Chinese Standard GB/T 50080-2002 and GB/T 50081-2002. Each strengths value was the average of the strength of the three specimens.

3. Results and discussion

3.1. Compressive strength

Figs. 1–4 shows the variation of compressive strength of concrete and its corresponding mortar matrix with fly ash replacement percentage at different ages. As it can clearly be seen from the data, when fly ash was added in place of part of cement, the 28-

Table 3
Mix proportions.

w/cm ratio	Cement/kg/m^3	Fly ash		Aggregate/kg/m^3		Water/kg/m^3	SP/%
		%	kg/m^3	Fine	Coarse		
0.30	510	0	0	653	1122.5	153	3
	484.5	5	25.5				
	459	10	51				
	433.5	15	76.5				
	408	20	102				
	382.5	25	127.5				
0.34	500	0	0	640	1100	170	3
	475	5	25				
	450	10	50				
	425	15	75				
	400	20	100				
	375	25	125				
0.38	490	0	0	628	1078	186.2	3
	465.5	5	24.5				
	441	10	49				
	416.5	15	73.5				
	392	20	98				
	367.5	25	122.5				
	343	30	147				
0.42	480	0	0	616	1058	201.6	3
	456	5	24				
	432	10	48				
	408	15	72				
	384	20	96				
	360	25	120				
	336	30	144				