Durability of Lightweight Aggregate Concrete Incorporating High Volume Fly Ash

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Abstract. This study experimentally investigated the durability of lightweight aggregate concrete (LAC) containing high volume fly ash (FA). Two kinds of concrete with natural aggregate and lightweight aggregate were adopted. Concrete mixtures made with 0%, 30% and 60% replacement of cement with Class F FA were prepared for testing. Water-cementitious material ratios ranged from 0.34 to 0.50. The compressive strength, the resistance to chloride-ion penetration, and the water permeability of concrete were measured and presented. Test results indicate that the LAC containing FA may present a long-term strength gain that the strength of concrete with 60% FA was close to that of the control concrete at 91 days. The LAC with high volume FA (60%) may greatly improve the durability by reducing the water permeability and chloride-ion penetration.

Keywords: fly ash, lightweight aggregate concrete, water permeability, chloride-ion penetration, durability.

1 Introduction

In order to reduce reservoir sediments in Taiwan, researchers studied the manufacturing of synthetic lightweight coarse aggregates (LCA) by reservoir sediment, and some of them also investigated the engineering properties of concrete made with this aggregate [1-2]. In addition, producing cement emits a lot of carbon dioxide, how to reduce the amount of cement in concrete becomes an important research issue [3]. Some studies investigated the engineering properties of concrete with high volume fly ash (HVFA). Their research results showed that concrete with HVFA (replacement ratio exceeds 50% of cement) can still maintain good engineering properties [4-5]. However, most of them only discuss natural coarse aggregate concrete (NCA), and rarely discuss lightweight coarse aggregate concrete (LAC) with HVFA. In this study, the compressive strength and durability of LAC with HVFA were discussed.

2 Experimental Program

2.1 Materials

(1) Cement: Type I Portland cement with a specific gravity of 3.15.
(2) Fly ash (FA): low-calcium fly ash with a specific gravity of 2.31, a loss on ignition of 4.62% and a CaO composition of 5.91%.
(3) Natural fine aggregate (NFA): natural river sand with a specific gravity of 2.60 and fineness modulus of 2.40.
(4) Natural coarse aggregate (NCA): crushed river stone with a specific gravity of 2.61, bulk density of 1470 kg/m^3 and D_{max} of 19 mm.
(5) Lightweight coarse aggregate (LCA): it was made from reservoir silt in Taiwan, with a specific gravity of 1.34, a 24-hour water absorption rate of 9.4%, a particle size of 5~20mm and a bulk density of 785 kg/m^3.
(6) Superplasticizer (SP): High performance water-reducing agent of Type G with a specific gravity of 1.2 ± 0.02 and the pH value of 7.0 ± 1.0.

2.2 Mixture proportion and specimen preparation

The mixture proportions of concrete were designed according to the ACI 211 for providing the compressive strength of 35 MPa at 28 days. The water to cementitious material ratio (w/cm) ranged from 0.34 to 0.50, and the FA content as cement replacement ranged from 0% to 60% by weight of the total cementitious materials. The mixture proportions are shown in Table 1. Test specimens include cylinder specimens (φ100×200mm, φ150×50mm) for compressive strength and water permeability tests, and cylinder specimen (φ100×50mm) for chloride-ion permeability test.

Table 1 Mixture proportions of concrete

Specimen no.	w/cm	Water	Cement	Fly ash	NFA	NCA	LCA	SP
		kg/m^3						
NCF00	0.50	210	420	0	800	860	0	1.05
NCF30	0.42	176	294	126	825	860	0	2.44
NCF60	0.34	142	168	252	850	860	0	4.20
LCF00	0.50	210	420	0	570	0	666	0
LCF30	0.42	176	294	126	619	0	666	1.43
LCF60	0.34	142	168	252	669	0	666	2.27

* NC is normal aggregate concrete, LC is lightweight aggregate concrete, F30 cement replacement ratio of fly ash. The containing water of Superplasticizer (SP) is not calculated in the mixture design.

2.3 Test procedure

The compressive strength test that meets the requirement of ASTM C 39 was performed. According to ASTM C 1202, the resistance of concrete to the penetration of chloride-ion was measured in terms of the charge passed through the concrete in coulombs. The water permeability of concrete was tested using a water permeability apparatus subjected to a water pressure of 0.29 MPa for 3 hours to determine the flow through the concrete specimen, which was calculated with Eq. (1):

$$\text{Water permeability} = [(m_2 - m_1) / m_2] \times 100\% \quad (1)$$

where m_1 = initial weight of specimen, m_2 = specimen weight after test.

3 Test results and discussion

3.1 Compressive strength of concrete

Figure 1 presents the test results of the compressive strength of concrete mixtures. It shows that the strength development of the natural aggregate concrete (NAC) and lightweight aggregate concrete (LAC) series presented a similar trend. At 7 days, the compressive strength for both kinds of control concrete were higher than that of the concrete with fly ash (FA). At 91 days, two kinds of the concrete showed that the strength of the concrete with 30% FA exceeded that of the control concrete, and the strength of concrete with 60% FA were close to that of control concrete. These results indicate that the FA mixtures had long-term strength gain than that of the control mixtures. In general, NAC series had higher compressive strength than that of LAC series at all of the test ages.

3.2 Water permeability

As illustrated in Figure 2, the water permeability of concrete decreased with the age for both kinds (NAC and LAC) of concretes. The water permeability of NAC is superior to that of LAC. In addition, incorporating FA in concrete may reduce the water permeability of concrete. This can be particularly found in NCF60 and LCF60 (containing 60% fly ash) at later age of 91 days, which have water permeability of 1.76% and 2.51%, compared less than those of NCF00 and LCF00 of 3.16% and 74.93%, respectively. These results signify the facts that the LACs containing high replacement level FA of 60% at long-term ages, may exhibit lower water permeability, namely superior durability to the concrete without FA.

3.3 Resistance to chloride-ion penetration

Table 2 summarized the measured results for the resistance of concrete to the chloride-ion penetration. It shows, the characteristic of the resistance to chloride-ion penetration of LAC was almost similar to NAC, in which the resistance to the chloride-ion penetration of concrete incorporating FA was higher than that of the control concrete without FA. At 91 days the total charge passed, in coulombs (C), were 1495 C and 3355 C (classified as low and moderate permeability) for NCF60 and LCF60, and were 6132 C and 11518 C (high permeability) for NCF00 and LCF00, respectively. This indicates that incorporating high replacement level (60%) of FA in concrete may greatly reduce the chloride-ion penetration, resulting in the improvement of the durability of concrete. This is believed to be due to contribution of the pozzolanic effect of FA mixtures.

Table 2 Test results of chloride-ion penetration

Specimen no.	Total charge passed (coulombs)			Classification of the chloride-ion permeability*
	28-day	56-day	91-day	
NCF00	9605	6267	6132	high/high/high
NCF30	8464	2851	1877	high/moderate/low
NCF60	4695	2295	1495	high/moderate/low
LCF00	13333	12188	11518	high/high/high
LCF30	11823	7095	3887	high/high/moderate
LCF60	8330	5215	3355	high/high/moderate

* Charge passed, chloride permeability, coulombs: > 4000C = high, 2000 - 4000C = moderate, 1000 - 2000C = low, 100 - 1000C = very low, < 100C = negligible

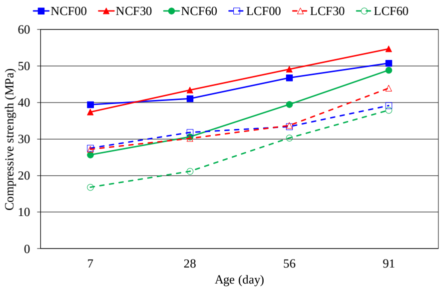

Fig. 1. Compressive strength of concrete.

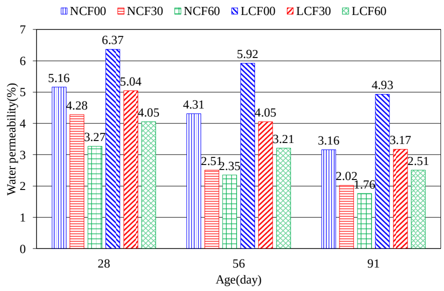

Fig. 2. Water permeability of concrete.

4 Conclusion

Based on the results of the experimental work, the compressive strength of LAC is lower than that of NAC with similar mixture proportion, however, the LAC incorporating 60% FA had superior characteristics of the resistance to the chloride-ion penetration and water permeability to the LAC without FA. This indicates that LAC with high volume FA (60%) may greatly improve the durability of LAC.

References

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