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Influence of class F fly ash on the abrasion–erosion resistance of high-strength concrete

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Abstract

This study investigates the abrasion–erosion resistance of high-strength concrete (HSC) mixtures in which cement was partially replaced by four kinds of replacements (15%, 20%, 25% and 30%) of class F fly ash. The mixtures containing ordinary Portland cement were designed to have 28 days compressive strength of approximately 40–80 MPa. Specimens were subjected to abrasion–erosion testing in accordance with ASTM C1138. Experimental results show that the abrasion–erosion resistances of fly ash concrete mixtures were improved by increasing compressive strength and decreasing the ratio of water-to-cementitious materials. The abrasion–erosion resistance of concrete with cement replacement up to 15% was comparable to that of control concrete without fly ash. Beyond 15% cement replacement, fly ash concrete showed lower resistance to abrasion–erosion compared to non-fly ash concrete. Equations were established based on effective compressive strengths and effective water-to-cementitious materials ratios, which were modified by cement replacement and developed to predict the 28- and 91-day abrasion–erosion resistance of concretes with compressive strengths ranging from approximately 30–100 MPa. The calculation results are compared favorably with the experimental results.

Keywords: Abrasion–erosion resistance; High-strength concrete; Fly ash; Water-to-cementitious materials ratio

1. Introduction

Most of the abrasion–erosion damage is caused by the action of water-borne particles (silt, sand, gravel and other solid) rolling and grinding against the concrete surface during hydraulic structure operation. The areas most likely to suffer from damages include spillway aprons, stilling basins, sluiceways, drainage conduits and tunnel linings [1]. Abrasion–erosion damage to the concrete in these structures leads to always a maintenance problem. The damage of abrasion–erosion typically ranges from a few inches to several feet, and, in some cases, severe damage occurs after only a few years of operation. Minor abrasion–erosion is not a problem but severe abrasion–erosion can jeopardize concrete structural integrity. To protect the hydraulic concrete structure from abrasion–erosion requires durable and abrasion–erosion resistant concrete mixtures.

The abrasion–erosion resistance of concrete is markedly influenced by such factors, as aggregate property and dosage, concrete strength, mixture proportion, the use of supplementary cementitious materials, fiber addition, curing conditions and surface finishing [2–8]. Many previous studies [2,6,9] have indicated that concrete abrasion resistance depends mainly on the compressive strength of concrete. Therefore high-strength concrete (HSC) with superior resistance to abrasion–erosion is

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sometimes applied as abrasion-resistant coatings of hydraulic structure [10]. However, high-strength concrete mixtures have a high cement content that enhances the heat of hydration and may cause increased shrinkage that results in a potential of cracking and low durability. To increase the service life of the hydraulic structures and keep them in a safe and reliable state as long as possible, hydraulic concrete must have high durability. Therefore, in most mixtures, cement is replaced partly with supplementary cementitious materials such as fly ash to reduce the hydration heat and increase the durability [11–15].

Using a rotating dressing wheel, Tikalsky et al. [12] evaluated the abrasion resistance of concrete. Fly ash contents ranging from 0% to 35% by weight of Portland cement were used with both class C and class F fly ashes. Analytical results indicated that concrete containing class C fly ash had better abrasion resistance than either ordinary Portland cement concrete or concrete containing class F fly ash.

Using the ASTM C944 test method, Naik et al. [6] assessed the abrasion resistance of concrete proportioned to have five kinds of cement replacements (15%, 30%, 40%, 50% and 70%) with one source of class C fly ash. Test results demonstrated that the abrasion resistance of concrete with cement replacement up to 30% was comparable to the reference concrete without fly ash. Beyond 30% cement replacement, fly ash concrete showed slightly lower resistance to abrasion compared to non-fly ash concrete.

Following the ASTM C779, Procedure C test method, Nanni [7] evaluated the abrasion resistance of roller compacted concrete using both laboratory and field specimens by replacing cement with 50% class C fly ash. The experimental results showed that: (i) testing under air-dry conditions produces approximately 30–50% less wear than under wet conditions; (ii) the addition of synthetic and steel fibers does not cause an appreciable change in abrasion resistance and (iii) improper moist-curing conditions produce more negative effects on surface quality than on compressive strength.

Bilodeau and Malhotra [13] examined the abrasion resistance of concrete incorporating 58% class F fly ash of totally cementitious materials. Test results revealed that fly ash concrete had worse abrasion resistance than concrete without fly ash.

Siddique [9] evaluated the abrasion resistance of concrete proportioned to have four kinds of fine aggregate replacement (10%, 20%, 30% and 40%) with class F fly ash. Test results indicated that: (i) abrasion resistance of concrete was strongly influenced by the compressive strength, regardless of fly ash content; (ii) abrasion resistance increased with the increase in fly ash content to replace fine aggregate; (iii) abrasion resistance increased with age for all mixtures and (iv) class F fly ash could provide a suitable partial replacement for fine aggregate in concrete, significantly increasing the substitution percentage utilization of class F fly ash.

The abrasion resistance of fly ash concrete has been studied under the air-dry condition, which is inappropriate for evaluating the abrasion of concrete surfaces subject to the abrasive action of water borne particles. Therefore, using the standard ASTM C1138 test method for concrete abrasion resistance (underwater method), the abrasion–erosion resistance of HSC is investigated on fly ash concrete, in which cement is partially replaced by one source of class F fly ash.

2. Materials and test procedures

2.1. Materials

2.1.1. Cement

The cement used was normal Portland cement Type I, which conforms to the current specifications as described in ASTM C 150 Type I. Table 1 lists its chemical and physical properties.

2.1.2. Fly ash

A class F fly ash from the Taichung Power Station in Taiwan was used. The fly ash complies with the requirements of ASTM C 618, and Table 1 lists its chemical and physical properties.

2.1.3. Aggregate

Sand used was natural river sand with a fineness modulus of 2.8, specific gravity of 2.63 and absorption of 1.06%. Coarse aggregate was crushed stone with a maximum size of 19 mm and specific gravity of 2.64. All aggregates comply with the specification of ASTM C 33 and contain no harmful substances.

2.1.4. Superplasticizer

A superplasticizer was a commercial material, which conformed to ASTM C 494 Type-G and was suitable for fly ash concrete.

Table 1
Characteristics of cement and fly ash

Oxide (%)	Cement	Fly ash
SiO_2	21.04	56.00
Fe_2O_3	5.46	24.81
Al_2O_3	2.98	5.30
CaO	63.56	4.80
MgO	2.52	1.48
SO_3	2.01	0.36
f-CaO	0.76	–
Loss on ignition (%)	1.38	5.78
Specific gravity	3.15	2.20
Specific surface (m^2/kg)	362	–
Fineness (% retain in 45 μm)	–	28.99