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Improving the abrasion resistance of hydraulic-concrete containing surface crack by adding silica fume

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Abstract

Abrasion damage generally results from constant friction and impact of waterborne silt, sand, gravel, rocks, ice, and other debris on concrete surfaces during the operation of a hydraulic structure. In this study, a waterborne abrasion over a large area of the test slab was developed to investigate the influence of surface cracks on the abrasion–erosion resistance of concretes, with variable surface crack type and silica fume content. The test results concluded that: (1) the abrasion rate is higher for water flow impinging directly on the crack than that above the crack; (2) increased crack width reduces the abrasion resistance of the tested concrete; (3) the abrasion rate increased with the angle of the crack to the water flow; and (4) the abrasion resistance increased with the addition of silica fume for concrete having a surface crack. These findings and may be of interest to engineers designing concrete hydraulic structures.

Keywords: Abrasion resistance; Surface crack; Silica fume; Waterborne sand flow

1. Introduction

The rivers on Taiwan area have almost steep slope and rapid flow accompanied with sand and gravel. Concrete for use in hydraulic structures must possess adequate abrasion resistance for fast-flowing water and sediment of each specific application [1–3]. To increase the service life of large water conservancies and to keep them running safely and reliably for as long as possible, hydraulic concrete requires a high durability and abrasion resistance. The cracks and abrasive wear that result from attack by water borne sand/stone at high flow speed or impact from great rocks have become a major problems for hydraulic concrete. The current experimental studies focus on the abrasion effects that are associated with the composite properties of concrete. Several strategies are known to improve concrete resistance to abrasion, such as the increase in concrete compressive strength, the enhancement of coarse aggregate content and hardness, or the addition of polymers, reinforcing fibers, and silica fume to the concrete [4–9]. Nevertheless, abrasion resistance is not a bulk property such as strength but rather is a surface property that depends primarily on surface layer characteristics [10]. Concrete is known to be intrinsically porous and brittle making surface cracking inevitable [11]. Concrete surface cracking is easily caused by plastic shrinkage, drying shrinkage, and restrained early-age thermal movement or from surface damage, overloading and bad quality of construction, and so on, and may result in crack growth and an unpredictable failure [12]. Since the abrasion of concrete that results from impact by water borne particles and matrix removal by fracture is a mechanical degradation process, the surface characteristics become more significant [13]. Accordingly, it is predictable that the abrasion of concrete should account for local stress and strain effects since the crack aperture grows with increasing of the waterborne sand impact load.

In this study, a waterborne abrasion over a large area of the test slab was developed. The test procedure was carried

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out by combining the impact load of a water-jet and the shear/friction forces of the sand particles that come with it. To realistically cover materials used in hydraulic structures, a series of concrete specimens were made with two levels of cement replacement (5% and 10%) with silica fume to investigate the influence of surface crack types on the abrasion resistance of concrete, as well as the influence of adding silica fume.

2. Experiment

2.1. Test variables

This study considered two types of water flow impinging sites, namely site A: impact at 50 mm distance above the crack and, site B: water borne sand flow impact directly on the crack as shown in Fig. 1. The man-made crack on the concrete surface had the following dimensions, width 1, 2, or 3 mm and length 50 mm, and ran at angles of 0°, 45°, and 90° to the water flow, respectively, as shown in Fig. 2. Additionally, the test specimens containing two different silica fume contents 5% and 10% (by weight of cement), respectively, prepared with a surface crack width of 1 mm.

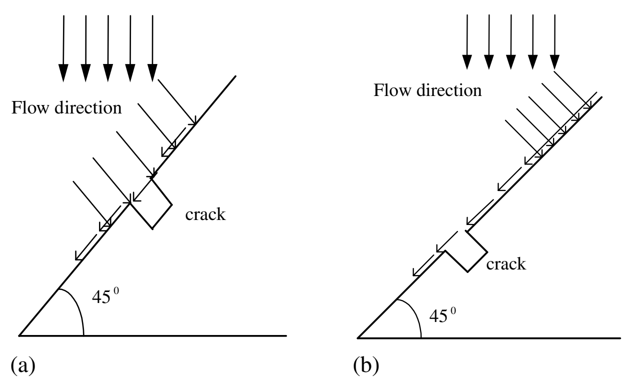

Fig. 1. Water borne sand flow impinging site: (a) impinging site above crack site A and (b) impinging site on the crack site B.

2.2. Materials and mixture proportions

Material used in manufacturing test specimens include : (1) Type I Portland cement in compliance with the ASTM C150 requirements; (2) river sand having a fineness module of 2.98, a specific gravity of 2.66; (3) crushed coarse aggregate with a maximum size of 20 mm, specific gravity of 2.64, absorption of 1.2%, and dry-rodded unit weight of 1682 kg/m^3; (4) silica fume with a specific gravity of 2.21; (5) superplasticizer (SP) conforming to ASTM C494 type-G with a specific gravity of 1.1; and (6) fresh water.

Three water to cement ratio (w/c) of 0.36, 0.38, and 0.40, a maximum coarse aggregate size of 20 mm and two levels cement replacement (5% and 10%) with silica fume were selected for designing the mixture proportions to meet the test need. The mixing details are presented in Table 1. The slump of concrete was 200 ± 3 mm, and the air content was 1.5 ± 0.5%.

2.3. Specimens preparation

Concretes made with each mixture proportion were cast to form a series of 50 mm thick 200 mm square slabs, and cylinder of 152 mm in diameter and 305 mm in length. The plastic-cards (width 1, 2, and 3 mm) were placed on the crack seats prior to placing concrete in the square slabs. After casting, the specimens were covered with a plastic sheet to minimize the moisture loss and stored in a laboratory room (23 ± 2 °C) for 24 h. Test specimens were then demolded and moist cured in a lime-saturated tank filled with tap water at a temperature of 23 ± 1.7 °C for 28 days. At the end of curing period the specimens were removed and tested immediately.

The measured average abrasion rate of the six plates was designated as the representative data of each concrete mix for reference use. Likewise, the measured average compressive strength was also used as representative data. Table 1 lists the measured compressive strength of the concretes at 28 days ages.

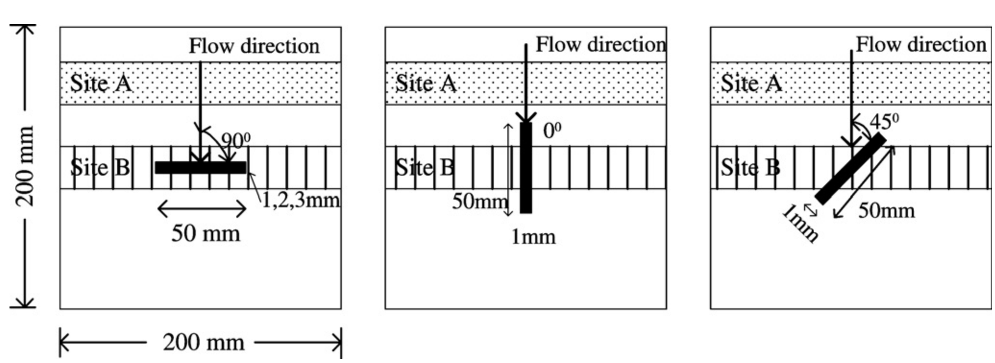

Fig. 2. The crack type on concrete surface.