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Experimental investigation on properties of interface between concrete layers

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HIGHLIGHTS

- Mechanical and permeability tests were conducted to examine the characteristics of concretes with different layer interfaces.
- Casting interval time should be controlled within the initial setting time.
- Thickness of the layer interface increases with casting interval time.
- Electrical tests can be used to evaluate the permeability of the layer interface.

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ABSTRACT

The integration and permeability of the interface between concrete layers of a dam considerably affect its structural functionality and safety. To understand the interface properties, several tests were conducted to examine the various characteristics of specimens with different layer interfaces. The mechanical property in terms of bond strength was assessed using the splitting tensile test, which was affected by interval time. On the other hand, the ultrasonic pulse test was used to confirm the influence of the interface on ultrasonic attenuation. The chloride and water permeability were also investigated by means of the rapid chloride permeability, alternating current resistance, and water permeability tests. The results of these tests proved that longer interval times lead to a weaker bond strength and higher permeability, which are harmful to layer structures. The change rules of mechanical and permeability properties were confirmed by the optical micrograph and hardness distribution of the overlay transition zone. Finally, the relationships among these tests were analyzed, and strong correlations demonstrated that the non-destructive ultrasonic pulse test and rapid electrical test could be employed to predict and evaluate the bond strength and permeability of a layered interface.

1. Introduction

Roller-compacted concrete (RCC) is a no-slump concrete for mass concreting such as in dams. Roller-compacted concrete dams (RCCDs) have been developed mainly for cost reduction, rapid construction, and rapid implementation of technology for emergency projects [1]. RCCD is usually poured layer by layer with different interval times, so that the mechanical and permeability properties of RCC are very different from those of ordinary concrete. The main problem of RCCDs is the integration of the roller-compacted layer. Engineering practice has proved that the roller compacted layer is usually the weakest structure of the dam and also the main channel for seepage through the dam body [2–5]. For conventional concrete dams, prolonged exposure of horizontal construction joints often results in poor bond strength between placement lifts [6]. Thus, it is necessary to study the property of the interface between concrete layers.

The integration of layers is mainly influenced by the interval time between layers, Vebe consistency, mix proportion, and weather condition. Among these four different factors, interval time is the most important during the construction process [7]. To ensure an acceptable and durable integration, different techniques are applied to evaluate the properties of a layer interface. Although much effort has been made toward assessing the strength, creep behavior, thermal properties, and permeability of layer interfaces, the available data on microstructure and electrical property are insufficient [5]. It should be emphasized that conventional evaluation methods like bond strength and water

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permeability tests are complex and time-consuming, and therefore, the introduction of simple and rapid tests is important.

Ultrasonic pulse technique is one of the most popular non-destructive techniques used in the assessment of concrete properties. In recent years, it has been used to quantitatively assess the damages within a concrete section [6,8,9]. The layer interface of RCC is usually regarded as a continuous region; therefore, the ultrasonic pulse can be used to investigate it [10]. For the past decades, electrical tests have been proposed to measure the electrical property of concrete owing to their rapid and reliable implementation [11–13]. Moreover, electrical property is often related to permeability [14,15].

The main objective of this study is to evaluate the mechanical and permeability properties of the interface between concrete pouring layers. In this case, several test methods, namely splitting tensile, ultrasonic pulse, rapid chloride permeability, alternating current resistivity, and water permeability were employed. We prepared six groups of two-layer specimens based on different interval times between pouring of the two layers. Different time intervals surely induce different structures around the interfaces, which can be related to the mechanical and permeability properties. Besides the tests on macroscopic properties, the microstructure of the interface was also observed by microhardness testing. Finally, the correlations between different test results were compared and analyzed.

2. Experimental program

2.1. Materials and mix proportion

Samples were prepared using ordinary Portland cement (OPC) with chemical composition as provided in Table 1. Crushed stones with a maximum size of 20 mm were used as natural coarse aggregate, and natural river sand with fineness modulus of 2.8 as fine aggregate. A water/cement ratio of 0.5 was used. The initial and final setting time of concrete are measured following ASTM C403 [16]. The mix proportions for all samples are given in Table 2 along with the 28-day compressive strength and different setting times.

2.2. Preparation of samples

The concrete samples were prepared following the pouring process of RCC. As shown in Fig. 1, samples were poured in two steps: half height of molds first (substrate) and the remaining half (overlay) was poured after a certain time. According to different interval times, the samples were classified into six groups as listed in Table 3 [17]. Group C1 was called bulk specimen, and the other groups were called composite specimens with different types of interfaces. Concrete samples were poured in the cubical mold (100 × 100 × 100 mm) and cylindrical mold (ø100 × 200 mm). After pouring, all specimens were wrapped with plastic sheets and left to set in their respective molds for 24 h. On the second day, the specimens were de-molded and cured under laboratory conditions (temperature 20 ± 2 °C; relative humidity ≥ 95%). Immediately after the specified curing periods, 50 mm long disks were cut from the middle part of the cylindrical specimens and cured until the test age of 28 days. The completed composite specimens for different tests are shown in Fig. 2. The cubic specimens were prepared for mechanical bond and ultrasonic pulse tests, while the cylindrical specimens for chloride and water permeability tests.

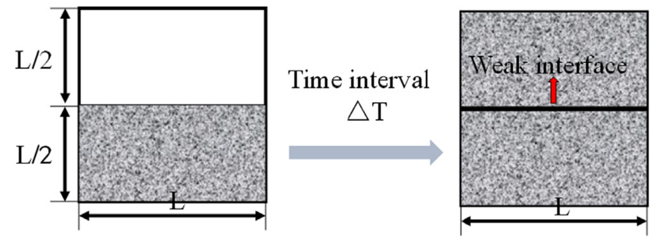

Fig. 1. Concrete pouring process following RCC.

2.3. Test procedures

2.3.1. Splitting tensile test

The splitting tensile test in accordance to ASTM C496 [18] was performed to evaluate the bond strength between the substrate and overlay. In this work, the specimens were cubes instead of cylinders as geometry has little effect on tensile test [19]. Before testing, two steel strips were placed at the bottom and top of specimens (as shown in Fig. 3) for uniform distribution of tension. The splitting tensile strength was calculated using Eq. (1).

$$f_t = \frac{2P}{\pi A} \tag{1}$$

where f_t is the interfacial tensile strength (MPa), P is the maximum load (N), and A is the area of interface (mm^2).

2.3.2. Ultrasonic pulse test

An ultrasonic pulse test (UPT) is generally carried out to detect and evaluate damage in concrete as a non-destructive method. The layer interface of a composite specimen can be regarded as a "weak structure," and UPT is applied to evaluate the effect of this structure on concrete. A photograph of the experimental setup is shown in Fig. 4.

Before testing, the transmitting and receiving probes were fixed at opposite sides of the cube specimens and in the direction perpendicular to the interface. In the UPT, ultrasonic waves were generated by a wave generator and magnified by a power amplifier. The waves were displayed on the oscilloscope screen and the corresponding digital information was processed by a computer [10].

2.3.3. Rapid chloride permeability test

The rapid chloride permeability test (RCPT) is the most common testing method for determining the relative permeability owing to its speed and simplicity [20–22]. The disk specimens (ø100 × 50 mm) were transferred to the test cell, which was filled with 0.3 M NaOH solution in the positive reservoir and 3.0% NaCl solution in the negative reservoir (see Fig. 5). A direct current of 60 V was applied across the specimen, and data were recorded at 5 min intervals, covering a total period of 6 h. Apart from the total charge (in coulombs) passed, the initial current has been found to also relate to the resistance to chloride ion penetration [23].

2.3.4. Alternating current test

RCPT has some uncertainties as the specimens may have a high level of current during the test. The current can result in heating and in enhancing the charge passed, which is known as the Joule effect [24]. The alternating current (AC) test can overcome this disadvantage by adopting a resistance to represent chloride permeability [25]. Before testing, all the specimens (ø100 × 50 mm) were vacuum water-saturated as in RCPT. The amplitude of the sinusoidal voltage was 1 V, and the frequency was 10 kHz. We designed electrodes made of copper, which were protected by a PVC envelope with details as shown in Fig. 6a. The mattress of the stainless steel was thick and flexible enough to ensure a sufficient contact with disk

Table 1
Chemical composition of cement.

Components	CaO	SiO_2	Al_2O_3	MgO	SO_3	Fe_2O_3	Na_2O	K_2O	LOI
% By weight	47.87	25.12	11.29	5.52	2.95	2.39	0.65	0.60	2.63

Table 2
Mix proportion of concrete.

Constituent	OPC 42.5R	Coarse aggregate	River sand	Water	Cube strength	Initial setting time	Final setting time
Proportion (kg/m^3)	416	1070	602	208	55.0	4.5 h	10.2 h