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Water Absorption Tests for Measuring Permeability of Field Concrete

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16. Abstract

The research results from CFIRE Project 04-06 were communicated to engineers and researchers in this project. Specifically, the water absorption of concrete samples (i.e., 2-in. thick, 4-in. diameter discs cut from concrete cylinders) was found strongly related to the chloride permeability of the samples. A test procedure was proposed based on the comments from the engineers and researchers in the related areas, and the ASTM standards. Tests are needed following this procedure to facilitate the acceptance of the generated data and the comparison with the related data in the literature.

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Water Absorption Tests for Measuring Permeability of Field Concrete

Final Report

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Disclaimers

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No tables were included in the report.

Nomenclature

A	Mass of oven-dry samples
B	Mass of saturated surface dry samples

Chapter 1 Introduction

1.1 Introduction

Aging of concrete bridges is mainly caused by traffic loads, especially heavy trucks, and various environmental attacks [1-3]. Much research has been conducted to understand the deterioration mechanisms by the environmental attacks, and technologies have been developed for durable concrete construction, including proper selection of raw materials, optimal mixture design including admixtures, and adequate curing processes [3,4]. Meanwhile bridge decks constructed with laboratory-proven durable concrete often do not perform well, and repairs and replacements are needed within their design life [5-8]. Such undesired performance may be attributed to the conditions of the field concrete, which are different from the laboratory setup/environment.

Concrete in the field is subjected to combined mechanical stresses and environmental attacks [9-12]. Previous research has focused on tensile stress induced cracks in concrete [13-17]. However, it is recognized that such discrete cracks contribute to an earlier onset of corrosion of reinforcement, but they do not significantly shorten the life of concrete bridge decks [10]. Meanwhile, researchers have also found that concrete bridge with a higher truck traffic volume have higher deterioration rates [18,19]. To better understand the bridge deterioration mechanisms, the UWM research team, with CFIRE funding (Project 04-06), tested a hypothesis that the durability of field concrete is affected by compressive stress induced microcracks likely caused by truck loads, freeze-thaw cycles, and the combined actions.

In Project 04-06, a total of twenty four 4×8 in. cylinders, made from commercial air-entrained concrete with the standard mixture, Grade A-FA specified by Wisconsin Department of Transportation (WisDOT) for bridge constructions, were subjected to predefined compressive loads (equivalent to 40 to 80 percent of the measured strength). The cylinders were then subjected to 300 freeze-thaw cycles following a procedure similar to that described in ASTM C 666 [21]. The standard freeze-thaw procedure was modified because the concrete cylinders used in the study were larger than the standard freeze-thaw specimen.

Weight loss has been viewed as an important index for the freeze-thaw damage to concrete [22]. Most cylinders in Project 04-06 lost less than 1 percent of their original weight after 300 freeze-thaw cycles, indicating that the air-entrained concrete would perform well according to ASTM C 666 procedure A. However, the standard testing procedure (though without measured dynamic modulus) failed to reflect the actual internal damage in concrete characterized by microcracks. Rapid chloride ion penetrability (RCIP) tests [23] instead were conducted on the discs sliced from the cylinders to evaluate the chloride permeability of concrete samples after the combined mechanical loading and freeze-thaw cycles.

The total charges passed through each sample were plotted in Fig. 1.1 against the compressive stress levels. The RW samples allowed very small amount of charge passing through because the cylinders were cured in water while the other loaded cylinders were subjected to 300 freeze-thaw cycles. The results of RD samples indicated that the freeze-thaw cycles caused internal damage in the air-entrained concrete, and the concrete sample deteriorated to have moderate chloride permeability. The increase in the chloride permeability was attributed to the internal microcracks, which can be confirmed by scanning electron microscopic images, shown in Fig. 1.2.

The combined mechanical loading and freeze-thaw cycles caused greater damage to concrete that can be represented by an increase in the microcrack density. The reference specimen (RW) in Fig. 1.1 clearly shows the microstructure of the cement paste in between two pieces of coarse aggregates, including voids in a variety of sizes. The RD specimen, after the 300 freeze-thaw cycles, developed microcracks, which were mainly initiated around a relatively large void. The D40 specimen, after being subjected to a load that created a compressive stress equal to 40 percent of the measured concrete strength and the 300 freeze-thaw cycles, showed much more microcracks, both near a large void and in the cement matrix. The microcracks inside the examined concrete samples had a largest width of 10 micrometers, different from the visible surface cracks due to tensile stresses in concrete. These microcracks can interconnect into a passageway for chloride ions, thus increasing the permeability of the concrete.

Estimating the microcrack density is difficult with a microscopic image analysis because the image analysis could only cover a small region at a time. Therefore, the water absorption capacities were measured for the air drying samples before the rapid chloride permeability tests. The tests showed that the water absorption, which indicates the amount of accessible microcracks and air voids in concrete, is strongly related to the chloride permeability of the concrete samples, as shown in Fig. 1.3. The strong correlation indicated that the microcracks and air voids in concrete that can be accessed by outside water and aggressive chemical are critical for the concrete durability. Such microcracks may be initiated from both environmental attacks and mechanical loading such as the truck loads on a bridge deck. It is envisioned that other damage to concrete protective layers such as salt scaling and abrasion would further increase the accessible microcracks and air voids, thus increase the permeability of concrete. This relationship, after being further verified, can lead to a convenient way to estimate the chloride permeability of field concrete.

1.2 Objectives

This is a technology transfer and implementation project. The objectives of the project were to

1. communicate with engineers and researchers about the major findings for Project 04-06;
2. collect data similar to those obtained in Project 04-06;
3. establish a test procedure; and
4. create a website for technology dissemination.

1.3 Report Organization

Engineers and researchers have provided comments on the experimental tests in Project 04-06. No similar data was available in the literature though specimens (i.e., 4-in. diameter, 2 in. thick concrete samples) have been collected. Hence, only the revised test procedure is documented in this report in Chapter 2. The project website can be found at https://pantherfile.uwm.edu/jzhao/www/CFIRE_pages/DDC_index.html.

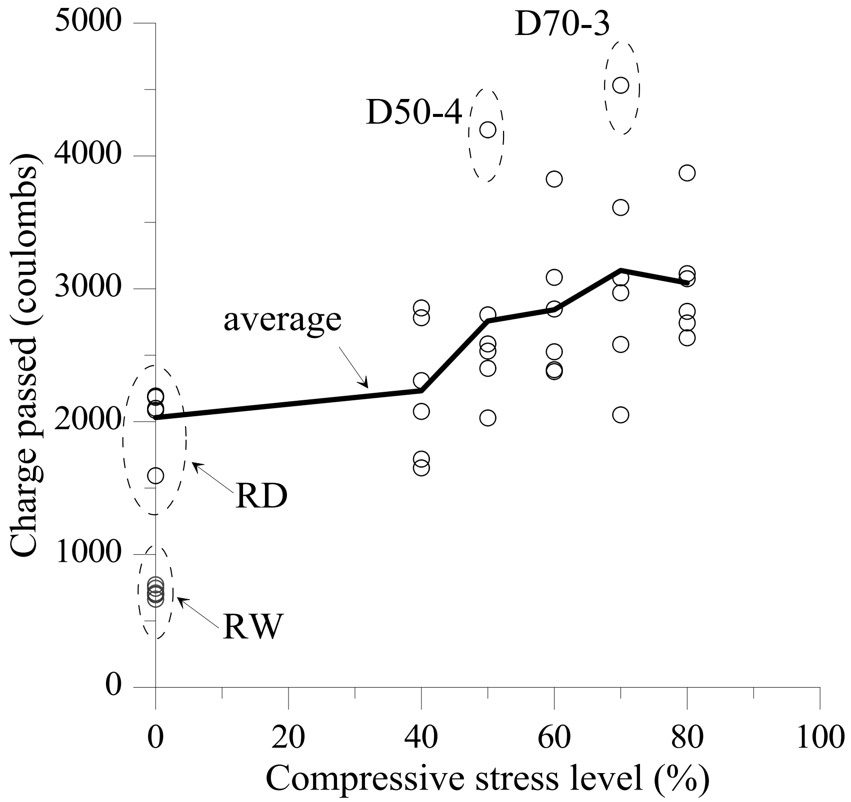

Fig. 1.1 Charge passed through samples subjected to various levels of loads

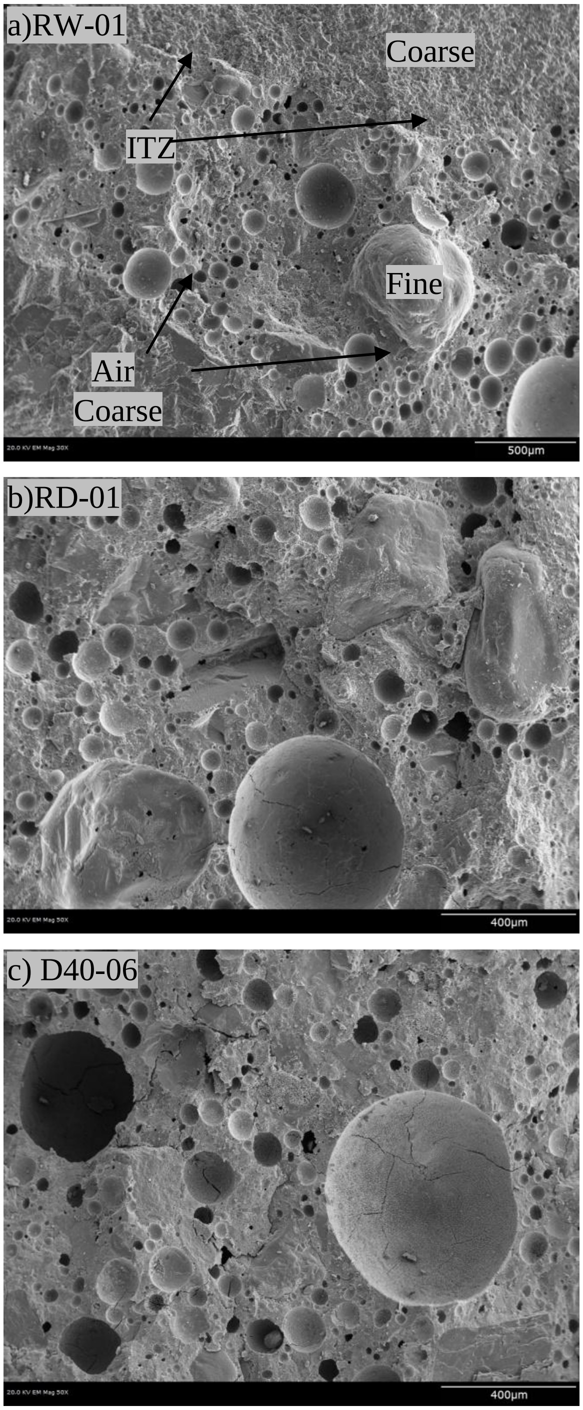

Fig. 1.2 Comparison of micrographs for samples after various loading

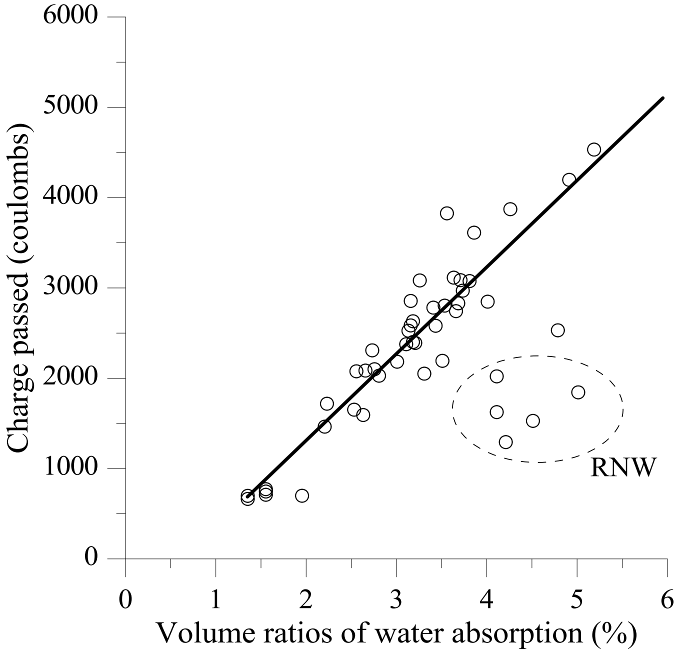

Fig. 1.3 Charge passed through samples with various levels of microcracks

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Chapter 2 Test Procedure

2.1 Introduction

The test procedure in Project 04-06, including sample preparation, can be better regulated by the existing ASTM standards. Specifically, 1) more assessment means, such as dynamic modulus, should be used to complement the rapid chloride permeability in assessing the concrete durability; 2) oven drying samples should be used for water absorption tests; and 3) the measured water absorption should be compared with durability factors to better correspond the new data to historic data for freeze-thaw damage of concrete.

2.2 Proposed Test Procedure

2.2.1 Scope

2.2.1.1 This test method is used to evaluate the permeability of concrete, which may be deteriorated under mechanical stresses and environmental attacks. The permeability is evaluated through measuring the water absorption of concrete samples (4×2 in. circular discs) and confirmed by their chloride permeability.

2.2.1.2 The concrete samples may be obtained from the field through coring or from cylinders in the laboratories.

2.2.1.3 This test method is not intended to evaluate the permeability of hardened concrete samples that have not been subjected to any mechanical loads or environmental attacks.

2.2.2 Significance and Use

2.2.2.1 This test method is useful in developing the data required to establish correlations between permeability of concrete and water absorption of concrete samples. Once verified, the permeability of field concrete can be evaluated simply by measuring the water absorption of core samples.

2.2.2.2 This test method is not intended to address all of the safety/durability concerns. It is the responsibility of the user of this method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2.2.3 Referenced Documents

• C 31/C 31M	Practice for Making and Curing Concrete Test Specimens in the Field
• C 42/C 42M	Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
• C 125	Terminology Relating to Concrete and Concrete Aggregates
• C 192/C 192M	Practice for Making and Curing Concrete Test Specimens in the Laboratory

C 215	Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens
C 642	Test Method for Density, Absorption, and Voids in Hardened Concrete
C 666/C 666M	Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing
C 1202	Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
C1585	Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes
BS 1881-122	Method for Determination of Water Absorption

2.2.4 Apparatus

2.2.4.1 *Coring machine*, with a cylindrical bit having a set of diamond cutting edge for cutting a 4±1/8 in. diameter core. The coring bit should be able to cut at least 2 in. deep into concrete.

2.2.4.2 *Cutting machine*, with a diamond impregnated blade cable of slicing 2 in. thick samples from a cored specimen according to C 42/C 42M or a cylinder specimen according to C 31/C 31M.

2.2.4.3 *Balance*, complying with Specification C 1005 and with sufficient capacity for the test specimens and accurate to at least 0.01 g.

2.2.4.4 *Drying oven*, a well ventilated chamber capable of maintaining a temperature at 105±5 ºC, and having sufficient internal space.

2.2.4.5 *Vacuum Saturation Apparatus*, a setup according to C 1202.

2.2.4.6 *Coating Apparatus and Materials*, according to C 1202.

2.2.4.7 *Dynamic Testing Apparatus*, according to C 666/C 666M

2.2.5 Reagents and Materials

2.2.5.1 *Sealing Material*, strips of low permeability adhesive sheets, epoxy paint, vinyl electrician's tape, duct tape, or aluminum tape.

2.2.5.2 *Reagents, Materials, and Test Cells*, needed to conduct rapid chloride permeability tests according to C 1202.

2.2.6 Test Specimens

2.2.6.1 Sample preparation and selection. The test samples should be 4±1/8 in. diameter discs.

2.2.6.2 The cylinders can be core samples following procedures in C 42/C 42M or cylinders cast in the laboratory following procedures in C 192/C 192M.

2.2.6.3 When cylinders cast in the field are expected to represent a larger structural element such as a bridge deck, care must be taken that the cylinders receive the same compaction and curing procedures. The samples should be subjected to a similar history of loading and environmental attacks.

2.2.6.4 Transport the cores or field-cured cylinders to the laboratory in sealed (tied) plastic bags.

2.2.6.5 The age of the concrete samples when the tests are performed must be documented.

2.2.7 Procedure

2.2.7.1 Place cylinders and core samples (longer than 6 in.) in the environmental chamber at a temperature of 50±2°C and RH of 80±3 % for 3 days.

2.2.7.2 Measure the fundamental frequencies of the cylinders according to C 215. Calculate the relative dynamic modulus of elasticity according to C 666/C 666M. If the number of freeze-thaw cycles is known, calculate the durability factor according to C 666/C 666M.

2.2.7.3 Slice 2±1/8 in. thick discs from the cylinders using a water-cooled diamond saw. The cut should be parallel to the top of the core, and use a belt sander to remove any burrs on the end of the specimen.

2.2.7.4 Seal the side surface of each specimen with a suitable sealing material. Seal the end of the specimen that will not be exposed to water using a loosely attached plastic sheet.

2.2.7.5 Measure the mass of the sealed specimen to the nearest 0.01 g and record it as the initial mass.

2.2.7.6 Dry the samples in an oven at a temperature of 100 to 110°C for not less than 24 h. After removing each specimen from the oven, allow the samples to cool in dry air (preferably in a desiccator) to a temperature of 20 to 25°C and determine the mass. This mass is the reference (A) for the calculation of the water absorption.

2.2.7.7 Condition the samples according to C1202 using a vacuum saturation apparatus. Remove surface moisture with a towel, and determine the mass of the saturated samples. This mass (B) is used in the calculation of the water absorption.

2.2.7.8 Measure the chloride permeability of the samples according to C1202.

2.2.8 Calculation

2.2.8.1 By using the values for mass determined in accordance with the procedures described in Section 2.2.7, make the following calculation:

Absorption, % 5 = $[(B-A)/A]\times 100$

2.2.9 Report

Report the following:

2.2.9.1 Date and age when concrete was sampled or cast,

2.2.9.2 Source of sample, and relevant background information on sample such as mixture proportions, curing history, and loading history, if available.

2.2.9.3 Mass of samples before and after drying, saturation, and chloride permeability test.

2.2.9.4 A lot of chloride permeability, in terms of charges passing the sample, versus the water absorption of the sample.

2.2.10 Precision and Bias

2.2.10.1 The repeatability coefficient of variation has been determined to be 6.0 % in preliminary measurements for the absorption as measured by this test method for a single laboratory and single operator.

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Chapter 3 Summary and Future Research

3.1 Summary

The research results from CFIRE Project 04-06 were communicated to engineers and researchers in this project. No similar data was obtained though samples were collected, which meet the requirements established for future tests.

A test procedure was proposed based on the comments from the engineers and researchers in the field, and the related ASTM standards. Future tests following this procedure will facilitate the acceptance of the data and comparison with the related data in the literature

3.2 Future Research

The proposed test procedure should be verified using the tests of both laboratory samples and samples from the field. The test results should be correlated to other tests of concrete durability. The fundamental knowledge should be used in the prediction of service life of new and existing bridges and other structures.

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