

Paper No.
16339



Update on the Evaluation of Grout Robustness and Corrosion by Accelerated Corrosion and Rapid Macrocell Testing

Samanbar Permeh,
Rutambara Sonawane,
and Kingsley Lau
Florida International University
10555 W. Flagler St., Miami, FL 33174

Matthew Duncan
and Ron Simmons
State Material Office
Florida Department of Transportation
5007 N.E 39th Ave. Gainesville, FL 32609

ABSTRACT

Severe corrosion of steel strand and tendon ducts in association with physically and chemically deficient grouts were documented in Florida bridges utilizing prepackaged thixotropic grouts. Testing to evaluate grouts for their corrosion protection has been implemented for material specifications; however, available methodologies do not consider the effects of grout deficiencies that can form. Testing to assess grout robustness by developing physical and chemical deficiencies to identify performance limits have been recently considered by industry and state transportation departments. It was the interest of this work to identify corrosion testing methods that would account for grout physical and chemical deficiencies. Experimental testing using a modified accelerated corrosion test and a modified rapid-macrocell test was conducted for three grout materials mixed and cast under non-ideal conditions (grout pre-exposure and grout mixed with 10% excess mix water) to promote material deficiency to assess the suitability of the laboratory test methods for use in practice.

Keywords: Grout, Post-Tension, Corrosion, Deficient, Bridge, Accelerated Corrosion Test, Rapid Macrocell Testing

INTRODUCTION

Prestressed concrete bridge construction including post-tensioned methods has been widely used. It allows the construction of bridges with a long span and opens up a range of design possibilities.¹⁻² For bonded tendons in post-tensioned bridge design, the high strength steel strand within the tendon duct is stressed and encapsulated with grout, allowing for stresses to develop along the length of the tendon. The grout also provides barrier protection from the external environment in addition to the concrete element and the tendon pipe material.³⁻⁴ As the grout is typically made from Portland cement, the steel strand is further protected from corrosion by the development of a passive layer in the alkaline grout pore water solution. These corrosion protection levels often are effective to prevent corrosion of the steel strand; however, there have been several cases of premature corrosion in Florida bridges and elsewhere.⁵⁻¹⁷ Many of those

cases were related to the inadequate or degraded protection of the strand at joints where moisture and chloride ions can penetrate.⁸ Other cases were related to the development of void spaces within the tendon due to the formation of bleed water in neat grouts.⁵⁻⁷ Some recent cases that involved low-bleed thixotropic grouts were associated with physically and chemically deficient segregated grout characterized as moisture-rich, low cement content material and high concentrations of sulfate and alkali ions.¹⁸⁻²⁶

All of these issues have proven the importance of having good grout quality to extend the service life of bonded post-tensioned tendons. Several testing approaches relating to the corrosion performance of steel strand in the grouts have been considered, including accelerated corrosion testing such as that made for conventional steel reinforcement in concrete.²⁷⁻³² Trejo et al., 2009 evaluated accelerated corrosion test procedures including the mini-macrocell test, the concrete chloride ion assessment test (also referred to as the concrete corrosion inhibitor association test), and the accelerated chloride threshold test.³⁰ Several studies have implemented similar forms of accelerated corrosion test for post-tensioning systems including anodic potentiostatic tests and rapid macrocell tests.

The application of an anodic potentiostatic test was originally developed in consideration of chloride penetration through damaged tendon ducts as part of a Federal Highway Administration (FHWA) research project in 1992 on the durability of bonded tendons in post-tensioned bridge structures.³³ The FHWA post-tensioning tendon installation and grouting manual (2013)⁴ continues to refer to this test method. The test method was further developed by Schokker, 1999³⁴, and Hamilton et al, 2000³⁵ and addressed complications with the electrochemical polarization test parameters. Schokker et al, 2006³⁶ included the linear polarization resistance method to provide more practical testing than the anodic potentiostatic tests.

Based on the research by Schokker and Hamilton, the Post-Tensioning Institute (PTI) made provisions in the PTI M55 Specification for Grouting of Post-Tensioned Structures for an accelerated corrosion test (ACT) for the assessment of grout materials.³⁶ The test method was intended for quality control and developmental purposes but provides criteria for the acceptance of a grout material following a two-step process. The ACT gives provision for acceptance of grout materials that exhibit a polarization resistance greater than 700kΩ-cm² measured by the linear polarization resistance method. The polarization resistance of steel embedded in the test grout material would give a quick indication if there are any components in the grout mixture that would allow depassivation of the steel to occur. A grout material that does not meet this criteria can then be tested by an anodic potentiostatic polarization test of the grouted specimen immersed in chloride solution and polarized to +200mV_{SCE} where the time to corrosion must exceed that of a neat grout. The polarization would allow fast migration of the chloride ion through the grout and holds the steel at a large anodic polarization that would allow fast detection of corrosion once chloride-induced corrosion initiates. As mentioned earlier, this test component derived from the viewpoint of the ability of the grout to resist chloride penetration through the grout as can occur in scenarios where there is incomplete protection provided by the tendon duct and reinforced concrete structural element. Current specifications in Florida and Virginia require prepackaged grout materials to be tested according to the PTI ACT method. Grouts that exhibit a time to corrosion in the anodic potentiostatic test exceeding 1,000 hours is considered satisfactory.

The rapid-macrocell test was developed under the Strategic Highway Research Program (SHRP)³⁷ for testing of corrosion of steel rebar and has been adopted for testing of corrosion resistant reinforcing steel rebar³⁸⁻³⁹ including in standard specifications for testing of stainless steel rebar in ASTM A955 Annex 2.²⁸ The rapid macrocell test has also been used in research for steel strand in grouts.^{12-14,40-41} The test method separates two unique test cells, each comprised

of a steel electrode embedded in cementitious material or immersed in a representative test solution. The two test cells are electrically coupled with wire and a shunt resistor and ionically coupled via a salt bridge (such as agar admixed with salt). Each test cell is assumed to develop net anodic behavior or net cathodic behavior after its galvanic coupling where a net macrocell current can develop. In order to develop the macrocell, the test grout and electrolyte in each cell should maintain its net anodic or net cathodic condition. With these test conditions controlled, the rapid-macrocell test can be used to differentiate corrosion conditions with small test elements and basic electronic instrumentations. For the case of assessing chemically deficient grouts, the anode component should maintain those characteristics that allow for corrosion initiation (such as pH, chloride concentration, sulfate concentration, etc.).¹⁹⁻²²

Due to the corrosion tendon failures in a Florida bridge in 2011⁹ associated with a prepackaged thixotropic grout that had developed material segregation, it was of interest to identify corrosion testing methods that would account for grout physical and chemical deficiencies. Preliminary testing using a modified accelerated corrosion test and a modified rapid-macrocell test was conducted for grout materials mixed and cast in non-ideal conditions to promote material deficiency to assess the suitability of the laboratory test methods for use in practice and an update on the research findings are presented here.

METHODOLOGY

The experiments incorporated testing of grout subjected to adverse conditioning and mixing (such as grout pre-hydration and adding excess mix water) to promote grout deficiencies. The results of the testing described next are not meant to assess the performance of commercially available grout materials that are properly used. Rather, the testing is used for research purposes to identify test methodologies that can be adopted to address grout deficiencies.

Modified Accelerated Corrosion Test (ACT)

Test experiments followed the general framework of the PTI ACT³³ but included an approach to assess the robustness of grout materials in terms of segregation by using pre-exposed grouts with improper storage and adding 10% additional mix water beyond the grout manufacturer's recommended limit. The test method included casting 14-inch, 1-inch diameter grout specimens with an embedded 7-wire prestressing steel strand using PVC pipe as a mold. Only a 3.5-inch section of the PVC pipe is opened to directly expose the grout specimen to the test solution; however, the corrosion testing likely would include attenuation of current to polarize an extended length of embedded steel. The grout products were mixed with an electric mixer and hand poured into the PVC mold. Specimens were demolded in two subsets: 28-day and 56-day curing within the mold and stored in 100% RH. Specimens were cast as listed in Table 1.

The corrosion testing generally followed the PTI ACT protocols including linear polarization resistance (LPR) in a saturated calcium hydroxide solution and an anodic potentiostatic polarization test in 5% NaCl solution. In the work presented here, the center king-wire of the 7-wire strand was extended above the grout and that top portion of the above the grout was then covered with acrylic paint to avoid the effects of carbonation. A stainless-steel rod was used as the counter electrode. Silver/silver-chloride electrodes were used as the reference electrodes for the multiplexed test. A saturated calomel electrode was used as a reference electrode for the LPR measurements and supplemental open-circuit potential (OCP) measurements.

Table 1
Accelerated Corrosion Test Specimen

Name	Water	Number of Samples Cast	Grout Curing Time
Grout A	Pre-Exposed, 10% Excess	8	28-days
		4	56-days
	As-received, Control	4	28-days
		2	56-days
Grout B	Pre-Exposed, 10% Excess	8	28-days
		4	56-days
	As-received, Control	4	28-days
		2	56-days
Grout C	Pre-Exposed, 10% Excess	8	28-days
		4	56-days
	As-received, Control	4	28-days
		2	56-days
Neat Grout	0.45 w/c	10	28-days
		2	56-days

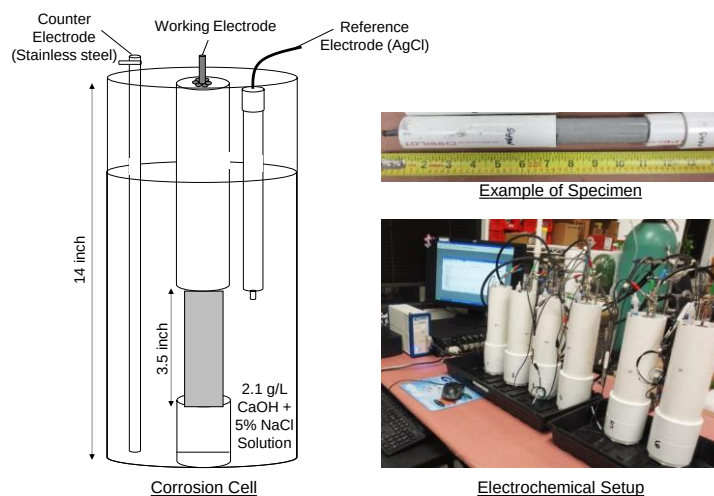


Figure 1: Schematic and test setup of anodic potentiostatic test

The LPR testing was made starting at the OCP and cathodically polarized the specimen 25 mV. The anodic regime of the polarization prescribed by the PTI guide³³ was not followed to avoid the effects of the anodic polarization. A scan rate of 0.05 mV/s was used. The analyzed region was the linear portion of the scan that typically developed at the last 10 mV. This approach also would minimize the contributing effects from the steel double-layer capacitance. Electrochemical impedance spectroscopy (EIS) was conducted at the OCP condition using a 10 mV AC perturbation in the frequency range of 100,000 >f> 1,1000 Hz sampling at 10 points per decade. The solution resistance, R_s , was fit to the high-frequency limit of the Randles circuit and was used to correct for the measured polarization resistance by LPR (R_p') following the equation $R_p = R_p' - R_s$. Specimens were further evaluated by anodic potentiostatic polarization tests set to +200mV_{SCE}.