NACE Publication 01101
Item Number 24214
ISBN #1-57590-386-5
Reaffirmed February 2018
Approved May 2001

NACE Publication 01101
Electrochemical Chloride Extraction from Steel-Reinforced Concrete—A State-of-the-Art Report

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Foreword

NACE technical committee reports are intended to convey technical information or state-of-the-art knowledge regarding corrosion. In many cases, they discuss specific applications of corrosion mitigation technology, whether considered successful or not. Statements used to convey this information are factual and are provided to the reader as input and guidance for consideration when applying this technology in the future. However, these statements are not intended to be recommendations for general application of this technology, and must not be construed as such.

The purpose of this NACE technical committee report is to present state-of-the-art information on electrochemical chloride extraction (ECE) from conventionally reinforced concrete surfaces. Included are discussions of common industry practices used by design engineers to control corrosion of reinforcing steel in portland cement concrete structures through the application of ECE.

This report is intended for use by engineers attempting to protect corroding reinforced concrete structures by the use of electrochemical treatment techniques. The information presented in this report is limited to ECE for atmospherically exposed reinforced concrete and is not applicable to prestressed or post-tensioned elements or concrete containing epoxy-coated reinforcing steel, galvanized steel, or other coated or nonferrous reinforcement.

This report, focusing on electrochemical chloride extraction, is Part I of a two-part series. Part II is intended to focus on the realkalization of carbonated concrete structures.

This technical committee report was originally prepared in 2001 by Task Group (TG) 054, "Electrochemical Chloride Extraction and Realkalization of Reinforced Concrete."[1] In 2018, it was reaffirmed by TG 920. It is issued by NACE under the auspices of administrative Specific Technology Group (STG) 01, "Reinforced Concrete."

[1] Chair John Broomfield, Consulting Corrosion Engineer, London, UK.

Introduction

Reinforced concrete is a versatile and widely used construction material. Its excellent performance and durability rely on the compatibility of the steel with the concrete surrounding it and the ability of the concrete to protect the steel from corrosion in most circumstances.

Unfortunately, corrosion protection is not guaranteed, and can fail if sufficient chlorides (usually in the form of sea salt, deicing salt, or chloride contamination of the original mix) or atmospheric carbon dioxide (CO_2) penetrate the concrete and break down the passive layer that protects the steel. This breakdown of the passive oxide layer leads to corrosion of the reinforcing steel if sufficient oxygen and water are available. Corrosion generally leads to the formation of a high-volume corrosion product that cracks the concrete leading to spalling of the cover zone, directly exposing the steel to the corrosive atmosphere. If untreated, corrosion leads to structural failure.

Regardless of the cause of depassivation (chlorides or carbonation), corrosion occurs by the movement of electrical charge from an anode (an area of steel where steel is dissolving) to the cathode (an area of steel where a charge-balancing reaction occurs, turning oxygen and water into hydroxyl ions). This means that the process is both electrical and chemical, i.e., electrochemical. In the case of chloride attack, patch repairs are only a local solution to corrosion, and repairing an anode can accelerate corrosion in adjoining areas.

One solution to this problem involves applying an electrochemical treatment that suppresses corrosion. Figure 1 shows the basic components of an electrochemical treatment system. The components are a direct current (DC) power source and an anode (temporary or permanent), usually distributed across the surface of the concrete. Electrochemical methods work by applying an external anode and passing current from it to the reinforcing steel so that all of the steel becomes a cathode.

Three electrochemical techniques are used to counter corrosion of steel in concrete. The first of these techniques is cathodic protection (CP). A newer alternative for chloride-contaminated structures is electrochemical chloride extraction (ECE), also known as electrochemical chloride removal (ECR), or desalination, as the process is called in Europe. A method for treating carbonated concrete has been developed and is gaining rapid acceptance as a rehabilitation method for carbonation in buildings and other structures. This is known as realkalization.

Chloride removal was the subject of two major studies conducted under Federal Highway Administration[2] (FHWA) contracts in the 1970s.[1,2] Both of these studies, as well as follow-up reports, concluded that chloride removal by electrochemical migration is a promising technique for use on chloride-contaminated concrete.

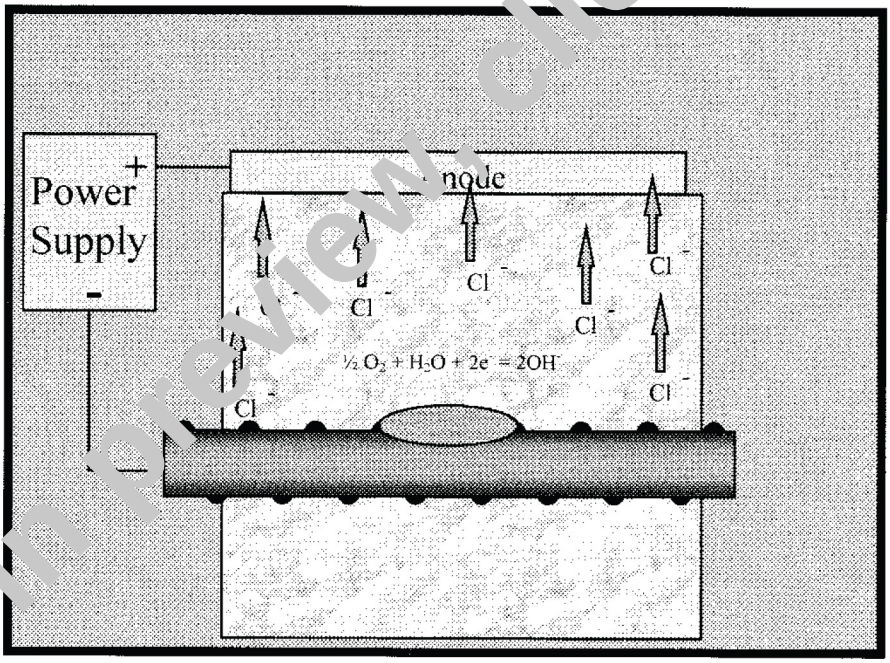

Figure 1: Schematic Diagram of Electrochemical Treatment System

Further research was undertaken in Norway by a private company, and under the Strategic Highway Research Program[3] (SHRP) in the U.S.A. As a result of that research, a number of patents were published. Some of the principal U.S. patents directly relating to ECE are listed in the bibliography. The list is not comprehensive, can include expired patents, and does not include patents from other countries.

[2] Federal Highway Administration (FHWA), 1200 New Jersey Ave, SE, Washington, DC 20590.
[3] Strategic Highway Research Program (SHRP), Transportation Research Board, 500 Fifth St., NW, Washington, DC 20001.