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BSI Standards Publication

Electrochemical re-alkalization and chloride extraction treatments for rein-forced concrete

Part 2: Chloride extraction

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National foreword

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This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature. It should be applied on this provisional basis, so that information and experience of its practical application can be obtained.

Comments arising from the use of this Draft for Development are requested so that UK experience can be reported to the international organization responsible for its conversion to an international standard. A review of this publication will be initiated not later than 3 years after its publication by the international organization so that a decision can be taken on its status. Notification of the start of the review period will be made in an announcement in the appropriate issue of *Update Standards*.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into an international Standard, to extend the life of the Technical Specification or to withdraw it. Comments should be sent to the Secretary of the responsible BSI Technical Committee at British Standards House, 389 Chiswick High Road, London W4 4AL.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic protection.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**Electrochemical re-alkalization and chloride extraction
treatments for rein-forced concrete - Part 2: Chloride extraction**

Traitements électrochimiques de réalcalinisation et
d'extraction de chlorures applicables au béton armé - Partie
2: Extraction de chlorures

Elektrochemische Realkalisierung und
Chloridextraktionsbehandlungen für Stahlbeton - Teil 2:
Chloridextraktion

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Management Centre: Avenue Marnix 17, B-1000 Brussels

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Foreword

This document (CEN/TS 14038-2:2011) has been prepared by Technical Committee CEN/TC 219 “Cathodic protection”, the secretariat of which is held by BSI.

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Introduction

The purpose of chloride extraction is to rehabilitate a reinforced concrete part from corrosion activity and to provide long term corrosion protection of steel reinforcement in concrete which has been affected by chloride and to re-establish self protection ability. The duration of treatment is from several weeks up to as much as several months, depending on the amount of accumulated chloride, the permeability of the concrete, the layout of the reinforcement and other factors. The decision to terminate the application should be made according to the specific requirements detailed in this technical specification.

There are other electrochemical procedures that can be used to provide corrosion protection of steel in concrete structures. These include cathodic protection and re-alkalisation. There is a European standard for cathodic protection of steel in concrete (EN 12696) and a European Technical Specification for the re-alkalisation of carbonated concrete (TS 14038-1).

It has been assumed in the drafting of this Technical Specification that the execution of its provisions will be entrusted to appropriately qualified and competent people, for whose use it has been prepared.

1 Scope

This Technical Specification specifies a procedure for carrying out impressed current electrochemical chloride extraction from chloride bearing concrete in existing structures. It is applicable to atmospherically exposed parts of structures with ordinary reinforcement and/ or post-tensioned tendon ducts embedded in concrete. In the latter case, it is essential to verify that there is no risk of hydrogen embrittlement, if necessary by conducting trials and installing monitoring during the treatment.

This Technical Specification does not apply to pretensioned concrete, which may suffer hydrogen embrittlement on the stressing bars during chloride extraction, or to concrete containing epoxy-coated or galvanised reinforcement.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1504-2:2004, *Products and systems for the protection and repair of concrete structures: Definitions, requirements, quality control and evaluation of conformity - Part 2: Surface protection systems for concrete*

EN 1504-9, *Products and systems for the protection and repair of concrete structures - Definitions, requirements, quality control and evaluation of conformity - Part 9: General principles for the use of products and systems*

EN 12696, *Cathodic protection of steel in concrete*

EN 14629, *Products and systems for the protection and repair of concrete structures - Test methods - Determination of chloride content in hardened concrete*

EN 14630, *Products and systems for the protection and repair of concrete structures - Test methods - Determination of carbonation depth in hardened concrete by the phenolphthalein method*

EN ISO 8044:1999, *Corrosion of metals and alloys — Basic terms and definitions (ISO 8044:1999)*

3 Terms and definitions

For the purposes of this Technical Specification, the terms and definitions given in EN ISO 8044:1999 and EN 1504-2:2004 and the following apply.

3.1

chloride extraction

electrochemical treatment for providing a low chloride content and developing a high pH value to concrete, which surrounds reinforcing bars, corresponding to sound, carbonated or non-carbonated concrete.

4 Principle

Chloride extraction of reinforced concrete is performed by applying an electric field between the steel reinforcement embedded in the concrete and an anode surrounded by an alkaline electrolyte solution containing hydroxyl ions temporarily placed on the concrete surface. Dissolved, negatively charged ions – such as chloride – will be moved from the reinforcement to the external electrode. This is mainly a physical process.

Coincidentally, the electrochemical reactions occurring at the steel surface provide the evolution of hydroxyl ions by the reduction of oxygen and water. This process alkalises the concrete in the vicinity of the rebar as described in CEN/TS 14038-1.

NOTE 1 The chloride content cannot be reduced to zero; an usual target content is an average profile of 0.4 %, related to the cement mass. To achieve this, the driving voltage between reinforcement and external anode should be set as high as possible – usually ranging between 30 V and 40 V.

NOTE 2 The chloride extraction effect is not limited to the zone between concrete surface and next reinforcement layer, but can be triggered in greater depths of concrete, as long as reinforcement is present and is connected with the upper reinforcement layer. In such a case a multi-stage treatment is required. Even treatments from the opposite side of a concrete slab are possible, but require an extended time of application.

NOTE 3 If the reinforcement surface is covered by corrosion products, these oxides have to be reduced prior to the possible reduction of oxygen and water. During this period, which may consume theoretically up to 700 Ah/m², few if any hydroxyl ions can be developed. In such a case, hydrogen evolution is likely just as in the later stages of the chloride extraction treatment.

NOTE 4 Details of the principle underlying this process are given in the European Federation of Corrosion report [1].

NOTE 5 Some electrolyte materials may change the surface appearance of the concrete.

5 Assessment and repair of the structure

5.1 General

Prior to undertaking chloride extraction, an assessment of the structure, including its physical condition, its structural integrity and the nature and extent of any repairs which might be needed, shall be performed in accordance with EN1504-9.

The investigations specified in 5.2 to 5.8 shall be carried out in order to:

- a) determine the suitability of the structure for chloride extraction;
- b) provide information for design and time of treatment.

5.2 Review of records

All available drawings, specifications, records and notes shall be reviewed for information on the location, quantity, nature (e.g. mild or high strength steel, smooth or deformed bar, galvanised, epoxy-coated) and continuity of the reinforcement, as well as the constituents and quality of the concrete.

NOTE The possible sensitivity to reduction of bond strength should be evaluated in the case of smooth reinforcement.

5.3 Inspection

An inspection shall be carried out to ascertain the type, causes and extent of defects and any features of the structure or of its surrounding environment, which could influence the application and effectiveness of chloride

extraction. All areas of the structure which require chloride extraction shall be checked for delamination of the concrete cover. Defects such as delaminations, cracks, honeycombing or poor construction joints which could permit significant water penetration, or prevent current flow and thereby impair the effectiveness of the chloride extraction treatment, shall be recorded.

NOTE 1 In areas which have been previously repaired, the repair methods and materials should be identified, as far as possible. If the concrete behind the repair is to be treated with chloride extraction, the deviating electrical resistivity and porosity of the repair media should be considered.

The cause of any deterioration which is not attributable to corroding reinforcement shall be determined.

NOTE 2 If any signs of structural distress are evident, an assessment of both the load bearing capacity of the structure and the need for temporary or permanent strengthening or support should be made.

5.4 Determination of chloride content

The chloride content of the concrete shall be determined as a proportion of the mass of cement or concrete in accordance with EN 14629. Concrete samples shall be taken from areas expected to have the highest possible chloride content in order to ascertain whether chloride contamination is present and the profile from the surface through the cover to behind the reinforcement.

5.5 Carbonation depth measurement

Carbonation depth shall be measured in accordance with EN 14630. Carbonation depth shall be measured at several locations to ascertain its distribution.

NOTE In selecting locations for concrete sampling, the objective is to identify areas with various carbonation depths for comparison with post treatment data.

5.6 Concrete cover thickness and reinforcement location measurements

Concrete cover thickness and reinforcement location measurements shall be carried out in order to enable a determination to be made of comparative current flow through areas of thick and thin cover, and to identify regions of varying reinforcement density. Any features that could impair the effectiveness of chloride extraction, such as shielding of the reinforcement, caused by embedded metal mesh, metal fibres, metal plates, plastic sheets or non-conductive repair materials shall be identified. Points at which short circuits between the reinforcing steel and the anodes could occur shall be noted.

5.7 Alkali aggregate reaction

If the concrete of the structure which is to be treated with chloride extraction contains aggregates which may be sensitive to alkali, the risk of provoking an alkali aggregate reaction (AAR) should be considered prior to any treatment.

5.8 Reinforcement continuity and size

The reinforcement continuity shall be proven on site by measuring the electrical resistance between reinforcing bars in mutually remote locations across the structure and between all reinforcing bars exposed during concrete repairs (see 5.9.3) or other works following the method and acceptance criteria given in EN 12696. These measurements shall include the following:

- a) continuity between elements of the structure within each chloride extraction zone;
- b) continuity of metallic items, other than reinforcement, with the reinforcement itself.

Reinforcement size shall be identified from drawings when available and shall be verified by direct measurements.

5.9 Repair

5.9.1 General

All operations comprising repair shall be performed in accordance with EN 1504, except where stated otherwise in 5.9.2 to 5.9.3.

5.9.2 Concrete removal

All delaminated and honeycombed concrete and repair materials with unacceptably high electrical resistivity (>200 % of parent company resistivity) and/or containing any other materials that may impair the effect of chloride extraction shall be broken out to achieve a clean, physically sound concrete surface. Any tying wire, nails or other metal components at the concrete surface that are found in contact with the reinforcement shall be cut back or insulated.

NOTE If the removal and replacement of sound, but deviating resistive concrete is not feasible, separate anode zones of treatment have to be established, and an extended time of application is to be expected for areas with higher resistivity.

5.9.3 Reinforcement preparation

Exposed reinforcement shall have any loose scale removed to ensure good contact between the steel and the repair material, but there is no need to clean reinforcement to bright metal.

Primers or coatings and insulating/resistive bonding agents shall not be applied to the steel.

NOTE Continuity assessment, bonding and installation of all connections to reinforcement should be performed only after reinforcement preparation.

6 Materials and equipment

6.1 Calibration of instrumentation

All instrumentation used to carry out the measurements specified in Clauses 5, 7 and 8 shall have valid calibration certificates traceable to a national or European standards of measurement.

6.2 Anode system

6.2.1 General

The anode system shall consist of an anode and electrolyte reservoir containing the electrolyte solution on the concrete surface.

6.2.2 Anode

The anode shall be capable of distributing and sustaining the current required for the chloride extraction treatment.

6.2.3 Anode zone

Each anode zone should be designed to provide uniform current density to the reinforcing steel. Typically one anode zone has a size not exceeding 30 m² of concrete surface or a current output not exceeding 100 amperes.

6.2.4 Alkaline electrolyte solution

The alkaline electrolyte solution shall be capable of conducting the current between the anode and steel reinforcement.

6.3 Electric cables

All cables shall be insulated.

All cables shall be uniquely identified by colour of insulation (at least at the connectors) and by zone number. The following colour code shall be used:

- a) cables to anodes (positive cables): red;
- b) cables to reinforcement (negative cables): black.

Cables shall be dimensioned to:

- carry the design current +25 % within permissible temperature range allowed under national or European Standards
- be of adequate mechanical strength.

6.4 Power supply

The impressed current power supply shall be limited to 40V DC with a ripple content not exceeding 100 mV RMS with a minimum frequency of 100 Hz.

The AC power supply and its cabling shall conform to the requirements of an applicable electrical safety standard.

The DC outputs shall be constant current.

All fuses shall be labelled with circuit designation and fuse characteristics.

All output terminals shall be fully insulated from any metal within the box. The terminals shall be clearly marked "+ Anode" and "- Reinforcement".

The DC power supply unit shall be rated for continuous short-circuits, and suitable for the environment in which it is to operate.

7 Installation procedures

7.1 Electrical continuity

The electrical continuity of reinforcement shall be tested according to 5.8, before applying chloride extraction treatment.

Each anode zone to be extracted from chloride shall be provided with multiple connection points to the reinforcement steel.

7.2 Other metallic parts within the treatment area

If other metallic parts are within or close to the treatment area, such as connecting bolts of columns, railings etc, their electrical connection to the reinforcement has to be verified according to 5.8. Missing or bad electri-

cal connection can lead to the formation of bipolar electrodes on the said metallic parts. In such a case, an external, additional connection between the metallic parts and the reinforcement is to be established.

7.3 Performance monitoring

Each anode zone to be extracted from chloride shall be provided with the means necessary to monitor the development

- of voltage, current and signals at the reference electrodes per treatment zone;
- the chloride content in specified concrete locations;
- the total charge in ampere hours (Ah) and duration of the treatment.

An automatic switch-off should be implemented for safety reasons, if parameters get outside of specified limits.

7.4 Installation of anode system

Before installing the anode system, the concrete surfaces shall be free of electrically insulating contaminants.

Particular care shall be taken to avoid short circuits between the anodes and any metallic items at the surface of the concrete.

Each anode zone to be extracted from chloride shall be provided with multiple anode connections.

7.5 Protection of electrolyte solution

The electrolyte solution shall be protected against climatic changes (sun, rain, wind, frost) as appropriate.

7.6 Electrical installation

Installation works shall be undertaken in accordance with applicable electrical safety standards.

7.7 Preliminary testing and documentation

Prior to commissioning the installation, the following preliminary testing shall be carried out and the results documented.

- a) Polarity checks shall be carried out on all circuits.
- b) Electrical continuity shall be checked by measuring resistances of all anode connections and all cathode connections within each treatment zone.
- c) Insulation checks shall be carried out on all circuits to check the electrical insulation of the DC positive side from the DC negative side and from any metallic items on or adjacent to the concrete surface (e.g. scaffolding).
- d) After applying the electrolyte solution, anode/ cathode resistance and potential shall be measured for each anode zone to detect short circuits which shall be corrected prior to energising the system.

8 Commissioning, operation and termination of treatment

8.1 Visual inspection

Before the chloride extraction installation is energised, the installation and all its component parts shall be subjected to a complete visual inspection to check that all components and cables are properly installed, labelled and protected from environmental, human and animal damage.

8.2 Safety precautions

Especially when using chloride extraction in in-house areas, it is important to limit or to avoid chlorine evolution. Besides the hazards for health and environment, built-in metallic parts can be damaged severe by the corrosive effect of chlorine gas in wet climate.

8.3 Energising and adjustment of current output

Energising shall be undertaken only after completion of preliminary testing in accordance with 7.7 and visual inspection in accordance with 8.1.

The chloride extraction current density shall not exceed 10 A/m^2 of reinforcement surface for any extended period of time.

NOTE 1 By running at 40 V, the current density normally falls to 5 A/m^2 and less after a few days of operation

NOTE 2 Some researchers have recommended lower limits

8.4 Routine inspection and maintenance

Routine inspection shall be carried out at least once a day. The following checks shall be carried out:

- confirmation that all chloride extraction zones are functioning;
- confirmation that the current and time (Ah) monitoring system specified in 7.3 is correctly monitoring all chloride extraction zones;
- output voltage to each chloride extraction zone;
- visual checks of cable insulation and anode connections;
- control of electrolyte solution and supply to ensure that the entire chloride extraction zones are fully covered by the electrolyte system.

8.5 Chloride extraction process monitoring

In each zone of chloride extraction treatment the voltage, current, signals at the reference electrodes (where specified in the design) and time of treatment shall be measured and recorded at intervals not exceeding 1 hour or continuously.

It is recommended to take additional concrete samples during the treatment from the locations having surveyed before, in order to get knowledge about the extraction progress.

NOTE If possible, the amount of removed chloride shall be determined as an additional indication of the treatment progress.

8.6 Termination of treatment

There are no explicit, single criterion for the termination of the treatment. Because of the uneven conditions in the concrete (caused by different cement types, permeability, concrete cover, reinforcement layout), no specific correlation with electrical measurement values can be given. The decision when to terminate the application shall be made according to more than one of the following:

- Chloride content: An acceptable chloride profile and low chloride content in the rebar vicinity is reached. This should be in the range of 0.4 % by cement mass – at least in the rebar vicinity. It shall not exceed 0.8 % in any single case.

NOTE 1 In case of deep chloride ingress, chloride will be removed from the concrete cover zone and migrates from deeper concrete layers towards the anode. This may require a longer, multi-stage treatment, and the chloride content may even increase in the concrete cover zone during the first weeks.

- Electrical Charge: A total charge of 1,000 Ah/m² to 2,000 Ah/m² is impressed, depending on the degree of corrosion on the reinforcement. This is an indirect criterion, because the formation of hydroxyl ions on the reinforcement surface give an increased resistance against chloride induced corrosion.

NOTE 2 In some cases such as limited chloride ingress or extensive repair with chloride free concrete, a lower charge density threshold down to 200 Ah/m² may be appropriate

NOTE 3 The allowance for current discharge to other reinforcement may be by calculation of all reinforcement surface area within a particular depth of concrete, typically 200 mm. Alternatively the allowance may be of the reinforcement surface area of deeper layers and the assumption that second and subsequent reinforcement layers will receive typically 30 % of the current density received by the reinforcement layer above it.

- Survey of rest potentials: The repeated measurement of rest potentials shall give evidence about the elimination of macro elements within the reinforcement. This survey should be done ca 4 to 6 months after completing the chloride extraction application and shall also include areas adjacent to the treated area. The maximum potential difference over the scanned area shall not exceed 150 mV.

NOTE 4 The delay between end of treatment and potential survey is important to allow the concrete to dry and to enable the reinforcement to recover from the cathodic polarisation.

9 Final report

Upon completion of chloride extraction a final report shall be issued. It shall include the following information:

- a) general description of the structure, its location and physical condition;
- b) details of the parties associated with the refurbishment works (e.g. client, design engineer, supervising engineer, contractor, subcontractors) and their respective responsibilities;
- c) details of the design of the chloride extraction treatment including the surface area calculation for the reinforcement in order to demonstrate compliance with the requirements of clause 8.5
- d) copy of the specification for the works, including definition of acceptance criteria and drawings in accordance with which the system was installed and energised, indicating variations and key dates;
- e) description of the preparation prior to treatment, including surface preparation, repairs, reinforcing bar continuity tests and selected test locations for concrete sampling;
- f) process monitoring data: Ah charge records for each zone and any additional current and voltage values recorded during treatment;
- g) analysis of the results, including a consideration of any local abnormalities or variations in results followed by a statement of treatment effectiveness;
- h) other relevant documents.

10 Post-treatment coating and monitoring

If desired aesthetic or protective coating can be applied to chloride extracted concrete.

NOTE 1 Caution should be exercised in the selection of the coating and in the drying and surface preparation of the concrete prior to coating application. It should be considered that epoxy-based and similar coatings limit or exclude a further non-destructive measurement of corrosion activity. Therefore, the application of hydrophobic creams should be verified.

If desired, devices may be installed to enable post-treatment monitoring of the effectiveness of the treatment.

NOTE 2 Several suitable devices exist. For example, cast-in probes for potential and corrosion rate measurements.

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- [1] *Electrochemical rehabilitation methods for reinforced concrete structures - A state of the art report* - Edited by F Mietz, European Federation of Corrosion, Publication 24 (1998) IOM Communications Ltd, 1 Carlton House Terrace, London SW 14 5DB.
- [2] *COST 521: Corrosion of steel in reinforced concrete structures – prevention – monitoring – maintenance* Final Report, published at the final workshop 18-19 February 2002, Luxembourg
- [3] NACE – Recommended practice on electrochemical realkalization and chloride extraction from reinforced concrete
- [4] EN 61558-2-9, *Safety of power transformers, power supply units and similar products - Part 2-9: Particular requirements for transformers for class III handlamps for tungsten filament lamps (IEC 61558-2-9:2002)*
- [5] *COST 534: New Materials, systems, methods and concepts for prestressed concrete structures Final Report*, Published 2009, Theime Media Services, Delft (Netherlands)

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