Technical Specification: Hybrid Electrochemical Treatment of Steel in Concrete

Introduction

An assessment of the structure has identified visual damage to the concrete as a result of chloride ion attack. A hybrid electrochemical treatment system has been proposed for installation to selected corroding elements on the structure.

The purpose of the hybrid electrochemical treatment is to provide long-term corrosion protection of the steel reinforcement in concrete subject to attack by aggressive agents such as sodium chloride.
An International Standard for Cathodic Protection of steel in concrete (ISO 12696:2016) details the requirements of an electrochemical protection system.

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

1 Scope

This Technical Specification specifies a procedure for applying a Hybrid Strip anode system to an existing reinforced concrete structure. It is applicable to atmospherically exposed parts of structures with mild steel reinforcement embedded in concrete.

This Technical Specification does not apply to concrete containing epoxy-coated, stainless steel or galvanized reinforcement and should be adjusted for use on pre-stressed steel.

2 Normative references

This Technical Specification incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. Subsequent amendments to or revisions of any of these publications apply to this Technical Specification only when incorporated in it by amendment or revision. For undated references, the latest edition of the publication referred to applies (including amendments).

EN 12696:2016, Cathodic protection of steel in concrete.
ENV 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 use of products and systems.
DD CEN/TS 14038-2:2011, Electrochemical re-alkalization and chloride extraction treatments for reinforced concrete
EN ISO 8044:1999, Corrosion of metals and alloys — Basic terms and definitions
'Hybrid Corrosion protection of chloride-contaminated concrete', Glass et al, Construction Materials, 2008, 161, 163-172.
ISO 9001:2015 Quality Management System (QMS)

3 Terms and definitions

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

3.1 Hybrid electrochemical re-passivation treatment – an electrochemical treatment with the objective of generating a passive environment around the steel reinforcing bar in reinforced concrete utilising a temporary applied impressed current and on subsequent removal of the impressed current power source, offering long term galvanic protection of the reinforcing steel.

4 Principle

The Hybrid electrochemical re-passivation system comprises a discrete sacrificial anode embedded in a proprietary mortar within saw cut chases in the reinforced concrete. An impressed current is passed through the Hybrid Strip discrete anodes and the steel until 50kC per m² of steel of charge has been delivered to the steel. This is typically a 1 – 2 week process using an external DC power source (1.5 to 8V batteries or power supply) where the Voltage and conductivity of the concrete determine the time required to complete the first impressed current phase. The power source is removed after this impressed current treatment and the Hybrid Strip anode then acts as a sacrificial anode passing current to the reinforcing steel.

Note - Details of the principle underlying this process are given in technical paper '*Construction Materials, 2008, 161, 163-172.'*

5 Assessment and repair of the structure

5.1 General

Prior to undertaking treatment with the Hybrid Strip anode system an assessment of the structure, including its physical condition, its structural integrity and the nature and extent of any repairs which may be needed, shall be performed in accordance with ENV 1504-9.

The investigations specified in 5.2 to 5.10 shall be carried out in order to:
determine the suitability of the structure for application of the Hybrid Electrochemical Treatment system;
provide information for the design of the Hybrid Electrochemical Treatment system.

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, galvanized, epoxy coated, stainless steel) and continuity of the reinforcement, reinforcement geometry, as well as the constituents and quality of the concrete.

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 the Hybrid Electrochemical Treatment system. All areas of the structure to be treated shall be checked for delamination of the concrete cover. Defects such as delamination, cracks, honeycombing or poor construction joints which could permit significant water penetration, or prevent current flow and thereby impair the effectiveness of the Hybrid Electrochemical Treatment system, shall be recorded and taken into account during the design process.

Note 1 - In areas which have been previously repaired, the methods of repairing and materials used should be identified, as far as possible.
Note 2 - The cause of any deterioration which is not attributable to corroding reinforcement shall be determined.
Note 3 - 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 undertaken.

5.4 Carbonation depth measurement

Carbonation depth shall be measured according to ENV 1504-9 at several locations to ascertain its extent and distribution.

5.5 Determination of chloride content

The chloride content of the concrete shall be determined according to ENV 1504-9 as a proportion of the mass of cement or concrete to ascertain its extent and distribution.

Concrete samples shall be taken from areas expected to have the highest possible chloride content in order to ascertain the maximum level of chloride contamination present.

5.6 Concrete cover thickness and reinforcement location assessments

Concrete cover thickness and reinforcement location shall be assessed in order to enable a determination to be made of comparative current flow through areas of varying cover depth, and to identify regions of varying reinforcement density. Any features that could influence the effectiveness of the Hybrid Electrochemical Treatment system, 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.

5.7 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 reinforcing bars exposed during concrete repairs or other works following the method and acceptance criteria as specified in EN 12696:2016, clause 7.1.

These measurements shall include the following:
a) the continuity between elements of the structure;
b) the continuity of metallic items, other than reinforcement.

Reinforcement size shall be identified from drawings when available and shall, in any case, be verified by direct measurements.

5.8 Potential Survey

A half-cell potential survey of appropriate sections of the structure to be treated should be obtained according to EN 12696:2016, noting environmental conditions at the time of the survey.

5.9 Tide assessment

For structures directly exposed to a marine environment, a knowledge of the extent of high/low tides should be ascertained and its influence on system design be assessed by a competent engineer.

6 Repair

6.1 General

All operations comprising concrete repair shall be performed in accordance with ENV 1504-9, except where stated otherwise below. Specific items concerning concrete reinstatement associated with the Hybrid Electrochemical Treatment system are detailed in sections 8 and 9.

6.2 Concrete removal

All delaminated and honeycombed concrete and repair materials with unacceptably high electrical resistivity (typically > 200 % of parent concrete resistivity) and/or containing any other materials that may impair the effectiveness of the Hybrid Electrochemical Treatment system 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 out or insulated.

6.3 Reinforcement preparation

Exposed reinforcement shall have any loose scale removed to ensure good contact between the steel and the repair material, and to ensure removal of any chloride slat deposits.

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

7. System Description

The Hybrid Electrochemical Repassivation system to be applied to the structure will consist of;
Discrete Hybrid Strip anodes typically 500mm in length x 20mm width x 5.5mm thickness shall be installed into slots cut within the concrete to a width of 12mm and a depth of 30mm.

a) The discrete Hybrid Strip anodes shall be embedded into the slots, spaced as per the design, using proprietary DuoCrete P embedding mortar, designed to activate and optimise current output from the anodes, at a typical density of 4-9 units/m² concrete surface depending on local conditions and steel density.

b) XLPE coated titanium feeder wire will be used to connect groups of Discrete Hybrid Strip anodes together to provide electrical contact between the units and also to facilitate connection to steel/power supply as required. The titanium feeder wire shall be installed in the saw cut chase and covered using a low shrink repair material. The Discrete Hybrid Strip anodes are connected electrically to a feeder wire, via a built-in crimp connector on the anode.

c) Steel connections shall be made to the reinforcing steel to facilitate application of the impressed current phase and direct connection for the galvanic phase. Typically, a minimum of two steel connections per group of anodes shall be made.

d) Anode treatment zone Each anode treatment zone shall be designed to; provide uniform current distribution to the reinforcing steel facilitate site application.

e) Typically, one anode treatment zone has a size not exceeding $40m^2$ of concrete surface.

f) The temporary power source shall be used to supply charge to the Discrete Hybrid Strip anodes, typically for 1 – 2 weeks after installation for traditionally reinforced structures and 12 weeks for prestressed structures. The power source is removed once the desired charge has been delivered to the steel, which is typically 50kC/m².

g) Permanent termination/monitoring enclosures shall be installed, into which the anode/steel connections shall be terminated. These are designed to allow re-access to the steel/anode connections at any future time such that further charge from an external power supply can be delivered at any point in the future, as an additional safety feature. In addition, measurements of the on-going operation of each zone of anodes shall be available from these enclosures

8. Materials and apparatus

8.1 Calibration of instrumentation

All instrumentation used to carry out the measurements specified in clauses 5, 8 and 9 shall have valid calibration certificates traceable to a national or European Standard of measurement.

8.2 Hybrid electrochemical re-passivation system components

8.2.1 General

The Hybrid Electrochemical Treatment anode system shall consist of an anode encapsulated in a mortar, buried in saw cut chases within the cover zone in the reinforced concrete structure.

8.2.2 Anode

The discrete Hybrid Strip anode shall be capable of distributing and sustaining the current required for the complete treatment. The discrete anodes shall comprise a sacrificial alloy anode that can be operated in both impressed current (DC 1.5 to 8V) and sacrificial modes. The discrete Hybrid Strip anodes shall typically be 500mm in length, 20mm in width, 5.5mm in thickness. The connection from the anode shall be of a material not susceptible to corrosion in normal conditions encountered in concrete (+500mV versus CSE), such as titanium. The discrete Hybrid Strip anodes are connected electrically to a feeder wire, via a built-in crimp connector on the anode.

The discrete hybrid Strip anodes shall be manufactured in the UK within an ISO 9001 approved facility.

8.2.3 Embedding mortar

The Discrete Hybrid Strip anodes shall be embedded in a proprietary activating mortar (DuoCrete P) for the full length of the anode in accordance with manufacturer’s installation instructions, leaving a minimum 10mm thickness of repair mortar covering the DuoCrete P. The proprietary mortar shall have sufficient ionic conductivity to enhance current delivery from the anode unit. The mortar should retain its pliable viscous properties for a minimum of 48 hours. The mortar shall be supplied in 310ml capacity cartridges or 10 litre pales and shall be applied into the saw cut chase using a suitable sealant or mortar gun to the base of the chase eliminating the generation of air voids.

8.2.4 Primary current delivery wire

The primary current delivery wire which delivers current from the DC power source to a group of connected anodes in the anode treatment zone will be formed of a material not susceptible to corrosion in normal conditions encountered in concrete, such as titanium. The anode feeder wire used for connecting discrete Hybrid Strip anodes shall be a minimum of 1.2mm diameter up to 1.6mm diameter XLPE coated (fire resistant) titanium to ASTM B265 grade 1.

8.2.5 Electrical connection for anode units

The individual anode units are connected to the primary current delivery wire using a non-metallic, corrosion resistant electrical connection.

8.2.6 Termination Enclosures

All enclosures for termination of anode/steel connections and monitoring of reference electrodes shall be IP65 rated and manufactured from polycarbonate which is self-extinguishing and resistant to abnormal heat and fire up to 960 °C (glow wire test) in compliance with IEC 60695-2-1 Standard.

Termination enclosures shall be located in each zone of discrete Hybrid Strip anodes to allow re-access to the system at any future point for monitoring or re-energising the system.

8.2.7 Repair mortar

The repair mortar used to reinstate the chases, saw cuts and break outs associated with the installation of the DuoGuard system shall be a low shrinkage material applied in accordance with ENV 1504-9.

8.3 Electrical cables

All cables shall be electrically double insulated using insulation resistant to the concrete environment (PVC cable is not considered a suitable insulation material in concrete). All cables shall be uniquely identified by colour of insulation and by zone number. The following colour code shall be used:

- cables to anodes (positive cables): RED;
- cables to reinforcement (negative cables): BLACK.
- cables to reference electrodes: BLUE

Cables shall be dimensioned to:
Carry the design current +25 % within a permissible temperature range allowed under national or European Standards; be of adequate mechanical strength for site application.

8.4 Temporary Power source

The DC power source voltage shall be not more than 8 V DC with a ripple content not exceeding 100 mV rms. 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 source supply unit and any enclosures shall be suitable for use in the environment in which it is to operate.

Note – The typical power supply voltage used is 8V which can be provided by using a 12V battery or power supply unit with converter to 8V.

9. System Installation

9.1 Design

With a knowledge of the physical characteristics of the structure described previously (Section 5), allied with an understanding of the client’s requirements, the Hybrid Electrochemical Repassivation system shall be designed by a competent engineer qualified to level 4 EN15257. The design will detail, as a minimum, the size and type of discrete Hybrid Strip anode, the location of the saw cut chases for installation of the discrete Hybrid Strip anodes, the total number of anodes to be installed, the depth of the chases, the number of discrete Hybrid Strip anodes in each zone, the location of associated steel connections, the location of reference electrodes, cabling locations and types, location and type of termination enclosures and the location of temporary power supplies.

A design risk assessment must be undertaken by the Design Engineer.

9.2 Electrical continuity

The electrical continuity of reinforcement shall be tested in accordance with 5.7 before applying the Hybrid Electrochemical Re-passivation system.

Each zone to be treated shall be provided with multiple connection points to the reinforcement steel.

Note – The method of electrical continuity assessment and acceptance criteria are specified in EN 12696:2016, clause 7.1. If discontinuous steel is found according to the criteria then continuity shall be established.

9.3 Electrical installation

Any electrical installation works shall be undertaken in accordance with applicable national or European electrical safety standards.

9.4 Anode installation

9.4. Undertake a reinforcing steel survey as follows;

9.4.1 Mark steel locations on concrete surface in conjunction with the design drawings with the aid of a cover meter

9.4.2 Mark locations for anode units on the concrete surface in conjunction with the design drawings with the aid of a cover meter.

9.4.3 Mark locations for saw cuts between the anode units in conjunction with the design drawings

9.4.4 Mark position for the temporary DC power source

9.4.5 Mark position for enclosures used ultimately for anode/steel location

9.5 Cut 12mm wide chases x 30 mm deep to a length of the anode +20mm long at the anode locations identified in the design and marked out as above.

9.6 Cut chases as identified above, 4mm wide x 15mm deep, between anode location chases for location of feeder wires.

All saw cuts shall be fully cleaned out prior to application of the embedding mortar. Chases shall be washed out with clean potable water over a period of at least 24 hours and kept wet until installation of the discrete Hybrid Strip anodes/embedding mortar, to optimise current distribution.

9.7 Make electrical connections to the reinforcing steel. Each zone of discrete Hybrid Strip anodes shall have a minimum of two associated steel connections, usually at either end of the 'string' of units.

Note – A method of making steel connections is to first expose the steel, drill a 4-4.5mm hole in the steel and rivet a titanium wire connection with a 3.2mm diameter stainless steel rivet (grip range 3.2-4.8mm). The electrical continuity can be checked as per the method and acceptance criteria specified in EN 12696:2016, clause 7.1.

9.8 Position the temporary DC power source.

9.9 Identify locations for the monitoring/termination housing enclosures. Fix the enclosures at the identified locations.

9.10 Electrically pre-connect the individual discrete Hybrid Strip anodes to the XLPE coated titanium feeder wire, via a built-in connector on the anode. Strip away a 3cm portion of the XLPE coating to reveal the titanium wire, insert the uncoated wire into the built in connector on the anode, and then crimp to ensure electrical continuity. The electrical resistance between the primary titanium anode wire and the individual discrete Hybrid Strip anodes should be checked to ensure electrical continuity (<1.0 Ω). With the discrete Hybrid Strip anodes now fixed onto the titanium feeder wire, the discrete Hybrid Strip anodes are removed from the chase prior to application of the proprietary DuoCrete P mortar.

9.11 Using a cartridge/mortar gun, apply proprietary DuoCrete P mortar into the slots, slowly retracting the gun from the base of the slot during DuoCrete P application, to avoid air voids. Insert the individual discrete Hybrid Strip anodes into the mortar – the mortar should flow to approximately 10mm from the concrete surface. The mortar will cover the anode body. Ensure that any trapped air is removed. The discrete Hybrid Strip anodes should be applied immediately after injection of the P mortar.

Note – the DuoCrete P mortar should only be applied and cured at a temperature greater than 5ºC.

9.12 The installation shall be checked for electrical shorts. A method statement must be provided by the contractor.

Electrical short test data shall be recorded and a copy provided to the engineer and CPT.

Note – A method for assessing electrical shorts in the installed discrete Hybrid Strip anode system is to measure the electrical potential difference between the reinforcing steel and the discrete Hybrid Strip anodes immediately after installation using a high impedance voltmeter. The potential difference should be greater than 300mV and stable.

9.13 The installed discrete Hybrid Strip anodes in each zone are connected to the respective DC temporary power source.

The titanium feeder wire from the discrete Hybrid Strip anodes is connected to the positive terminal;

The wire from the steel reinforcement is connected to the negative terminal.

This should preferably be completed within 1 hour of installation of the units.

9.14 Undertake a polarity check and record the data. The steel potential must shift more negative relative to the reference electrode. If the potential moves to a more positive potential relative to the reference electrode then the current should be disconnected immediately and professional advice sought. A method statement must be provided by the contractor.

Polarity check data will be recorded for all zones of Hybrid Strip anode application.

Note – A method of obtaining a polarity check is to place a surface reference electrode adjacent to a discrete Hybrid Strip anode and observe the change in potential registered as the impressed current is applied.

9.15 Fill the top 10mm of the slots with low shrink repair mortar within 2 hours of placement of the embedding mortar.

9.16 Activate the power source for ~1 week (~12 weeks for pre-stressed structures), or as defined in the engineering design. Exchange battery power units (if used) on a daily basis or as necessary to maintain charge capacity in excess of 50% (ensure that replacement batteries are kept fully charged). The voltage and current output for each zone shall be recorded on a daily basis. A method statement must be provided by the contractor.

Note – A method of determining voltage of the battery power supply uses a voltmeter directly reading from the terminals of the battery. A method of measuring the current delivered from the power supply is to measure the voltage drop across a 0.1Ω resistor placed in series with the circuit.

9.17 Each treated zone is logged as follows;

Zone	Date connected to power source	Date power source disconnected	Daily Voltage/V							Daily Current/mA						
			1	2	3	4	5	6	7	1	2	3	4	5	6	7

A copy of this data must be supplied to the engineer and Concrete Preservation Technologies Ltd.

9.18 On completion of the impressed current phase, disconnect the wires from the positive and negative terminals of the power source and run the wires from the titanium feeder wire from the discrete Hybrid Strip anodes and the titanium wire from the reinforcing steel in saw cuts to the appropriate enclosure. Make connections to either the logger or to the terminal blocks in the enclosure. Short the non-logged wires from steel and anode group together to run the system in sacrificial anode mode.

9.19 The feeder wires are buried in the chases using the repair mortar and the mortar allowed to cure according to the manufacturer's instructions. The discrete Hybrid Strip anodes are now operating in galvanic mode.

9.20 Clean the treatment area.

10 Process Monitoring

10.1 Visual inspection

Before the Hybrid Strip anode system is connected to the power supply for the 1st phase impressed current treatment, 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.

10.2 Routine inspection and maintenance

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

Phase 1 – Impressed current

a) Confirmation that the power supplies are functioning correctly and have sufficient charge capacity for the impressed current treatment
b) measurement of current delivery to each treatment zone as detailed in section 4
c) visual checks of cable insulation and anode connections, to confirm their proper functions.

Phase 2 – Galvanic protection

Confirmation of galvanic activity after the 1st phase impressed current treatment may be undertaken by measuring current between the Hybrid Strip anodes and the reinforcing steel after a period of typically 2 hours after disconnection of the power supply. A protective current will be observed from the Hybrid Strip anodes (An extended disconnection period may be required to allow oxygen access to the reinforcing steel).

All test data from site shall be recorded. A complete set of quality documentation shall be generated by the contractor end submitted to the client within 1 week of completion of each treatment zone.

Quality documentation shall include the following information;

a) Steel continuity measurements
b) Confirmation of correct anode installation
c) Daily current measurements from 1st phase treatment
d) Galvanic current measurements after completion of the 1st treatment phase.
e) Steel connection testing
f) Reference electrode installation testing
g) As-built drawings identifying location of Hybrid Strip anode zones, termination enclosures, reference electrodes and any associated cabling.

10.3 Acceptance Criteria

The immediate and continued effectiveness of the Hybrid Strip anode system shall be assessed using steel corrosion rate and current measurement.

10.3.1 Steel Corrosion Rate Measurement

This method uses the applied current density of a segment of the anode system and the steel potential shift achieved from application of the galvanic current to calculate the open circuit steel corrosion rate. The rest of the Hybrid Strip anode system should remain connected in sacrificial anode mode to act as a guard ring to the Hybrid Strip anode group to be tested. Small or large perturbation techniques can be utilised in measuring steel corrosion rates, the former identified with the polarisation resistance method and the latter using larger potential perturbations as detailed elsewhere (G.K.Glass, A.C.Roberts and N.Davison, 'Criteria for novel electrochemical treatments of steel in concrete', , Proceedings of the 7th International Conference on Concrete in Hot and Aggressive Environments, Volume 2, p.477-492, 13-15 October 2003).

Corrosion rates less than 1-2 mA/m^2 (less than 1-2μm of steel section loss per year) are in general deemed to be negligible rates obtained on passive steel.

10.3.2 Current output measurement

In order to confirm continued activity of the Hybrid Strip anode system in galvanic mode, the current output can be monitored.

Current flow between the Hybrid Strip anodes and the steel is measured in each zone using a shunt or across a known resistance, with a high impedance voltmeter.

Current output is substantially affected by the local environment, but current outputs of the order of 0.1-10mA per Hybrid Strip anode unit in galvanic mode are typical.

11. Final Report

On completion of the Hybrid Strip anode system installation a final report shall be issued by the contractor. It shall include the following information:

a) 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 Hybrid Strip anode system including:
   1) the surface area calculation for the reinforcement;
   2) a copy of the specification for the works;
   3) drawings in accordance with which the system was installed
d) a description of the preparation prior to treatment, including surface preparation, repairs, reinforcing bar continuity tests;
e) a summary and analysis of the data obtained during and after the application of the Hybrid Strip anode system, including current/voltage measurements in phase 1, installation continuity tests, galvanic activity tests, acceptance tests;
f) other relevant documents.