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Part III - Steel Structures

> Vol.1 Durability factors and requirements

- Environment
- Material properties
- Specific requirements for durability

> Vol.2 Deterioration

- Classification of defects
- Mechanisms

> Vol.3 Testing techniques


- Non-destructive testing methods (NDT)
- Destructive testing methods (DT)
- Adequacy of testing to the damage

> Vol.4 Repair methods

- Methods for repairing damage in steel elements
- Methods for improving fatigue performance
- Adequacy of repair to the damage


> Vol.5 Protection systems

- Cathodic protection
- Coating systems
- Surface preparation



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Deterioration processes

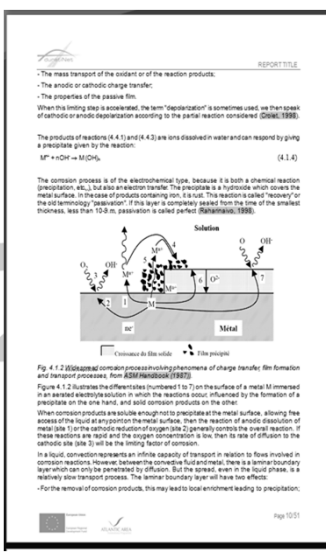


Fig. 4.1.2 Schematic diagram of the electrochemical process of corrosion. The diagram shows the anodic and cathodic reactions occurring on the surface of a metal M immersed in an aqueous electrolyte solution. The anodic reaction (1) is the oxidation of the metal, and the cathodic reaction (2) is the reduction of oxygen. The overall reaction (3) is the corrosion of the metal.

Fig. 4.1.3 Schematic diagram of the electrochemical process of corrosion. The diagram shows the anodic and cathodic reactions occurring on the surface of a metal M immersed in an aqueous electrolyte solution. The anodic reaction (1) is the oxidation of the metal, and the cathodic reaction (2) is the reduction of oxygen. The overall reaction (3) is the corrosion of the metal.

Degradation mechanisms

Chemical & biological

Corrosion

Physical

Fatigue


Other

High temperature

Water retaining


overloading

Accidental loads



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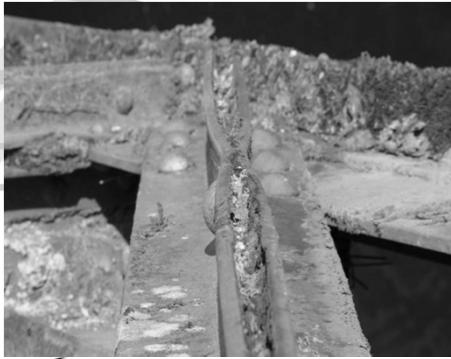
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Defects

Contamination


Distortion





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Defects

Translation


Crack





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Defects

Deterioration


Loss of material





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Volume 3

TESTING TECHNIQUES

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Testing techniques









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| INSPECTION TECHNIQUES | |
|-------------------------------------|--|
| MAGNETIC PARTICLES TECHNIQUE | |
| Objectives | Detection of surface and subsurface discontinuities, defects in metallic elements |
| Application field | a |
| Principles | The technique consists in applying to a ferromagnetic material a magnetic field with simultaneous pulverization of revealing made up of very fine iron oxide particles. The surface defects cause at their place a magnetic flux leakage on which the particles of the revealing accumulate. Detection of the indications or defects is done in visible light with coloured particles or in U.V. light with fluorescent particles. b Before the test, metal parts are cleaned (oil, corrosion product, paint, ...). c Applicable mainly to welds with internal defects at the surface or subsurface (2 to 2 mm). d Several commercial systems available. e |
| Equipment and accessories | NOT used |
| Destructive features | NO LCR |
| Cost of inspection | Low/Low |
| Access to elements | Medium/Low |
| Interpretation | High/Low |
| Conditions of application in situ | Traverse test (MT) Preliminary work: surface cleaning Environmental restrictions: electromagnetic perturbations Time consumption: medium |
| Advantages | Detection of surface or subsurface defects Several magnetisation methods Estimation of the length of cracks Applicable only to ferromagnetic materials Surface must be cleaned to metal before inspection (time consuming in presence of corrosion) |
| Limitations | Surface must be cleaned to metal before inspection (time consuming in presence of corrosion) |
| Accuracy | High/Low |
| Standards | EN 12307: Non-destructive testing - Penetrant testing and magnetic particle testing - Visual criteria ISO 9001: Non-destructive testing - Magnetic particle testing - Part 1: General ISO 9002: Non-destructive testing - Magnetic particle testing - Part 2: Detection method ISO 9003: Non-destructive testing - Magnetic particle testing - Part 3: Evaluation ISO 17025: Non-destructive testing of welds - Magnetic particle testing of welds - Acceptance rules - B |
| Examples | <div style="display: flex; justify-content: space-around;">   </div> |
| Application under development | a |
| References | EN 12307: Non-destructive testing - Penetrant testing and magnetic particle testing - Visual criteria ISO 9001: Non-destructive testing - Magnetic particle testing - Part 1: General ISO 9002: Non-destructive testing - Magnetic particle testing - Part 2: Detection method ISO 9003: Non-destructive testing - Magnetic particle testing - Part 3: Evaluation ISO 17025: Non-destructive testing of welds - Magnetic particle testing of welds - Acceptance rules - B |
| Conclusion, status | Under development |





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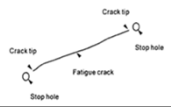

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| STEEL STRUCTURES | |
|--|--|
| <p>STOP HOLE</p>  | <p style="text-align: right;">REPAIR METHODS</p>  |
| Description | Stop hole consists in drilling a hole at or close to the crack tip to reduce the local stress concentration and prevent crack propagation. |
| Defect(s) | Small through-thickness cracks subjected to low stress ranges in plates or plate components of structural elements, and to arrest the crack tip of large cracks provided that the remaining length of the crack is repaired by either welding or bolted splice plates. |
| Generic | Fatigue life extension technique of cracked structural elements, in both welded and bolted/riveted structures. |
| Advantages/Disadvantages | Simple, economic and used as a temporary or emergency repair method. |
| Effectiveness | In welded structures, stop hole is good for fatigue cracking due to lack of fusion, cold cracks, restraint and web breasting and may also be applied for causes such as vibration, web gaps and geometrical changes. In bolted and riveted structures, this method is excellent for out-of-plane bending, good for problems such as secondary stresses, and fair for local stress concentration. |
| Limits | Should be used together with other repair methods but it can be considered permanent if specific conditions are fulfilled. It is very dependent on the operator skill and experience. Special care is also required when crack fronts are not uniform through the thickness. |
| Control | Visual inspection and NDT such as liquid penetrant testing, according to EN 571-1 [45] and EN ISO 23277 [55], if the crack tip was not intercepted, the hole should be slightly enlarged. |
| Specific equipment | Drilling machines, such as a portable magnetic drill machine. Protective clothing and equipment. |
| Social | Service disruption: Yes <input type="checkbox"/> No <input type="checkbox"/> |
| Health | Yes <input type="checkbox"/> No <input type="checkbox"/> |
| Ecology | Yes <input type="checkbox"/> No <input type="checkbox"/> The waste caused by drilling should be collected. |
| Preliminary works | Yes <input type="checkbox"/> No <input type="checkbox"/> |
| Specialized labour | Yes <input type="checkbox"/> No <input type="checkbox"/> |
| Time consumption | Low <input type="checkbox"/> Medium <input type="checkbox"/> High <input type="checkbox"/> |
| Posterior works | Yes <input type="checkbox"/> No <input type="checkbox"/> Restoration of protective system depending on the material. |
| Cost | Low <input type="checkbox"/> Medium <input type="checkbox"/> High <input type="checkbox"/> |
| Standards | No available European standards. Literature referred in the manual text. |



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REPAIR TECHNIQUES / SYSTEMS FOR PROTECTION OF STRUCTURAL STEEL

| | |
|---|--|
| <p>many types of paints. Good resistance to acidic conditions, unlike metal coatings, and different materials available for different requirements.</p> <p>No limits on size and type of structure.</p> <p>Generally, application is straightforward.</p> | <p>defect, but it may be prevented by adopting suitable quality control procedures.</p> <p>The expected life is difficult to predict, even with standards and specifications, unlike metal coatings.</p> |
|---|--|

4.3 Protective coating systems

4.3.1 Paint coatings

General

The most applied protective system to metallic structures is paint coating. This type of protective system provides several advantages such as ¹⁰⁰ easy applicability; no limitation on the size of protected elements and decorative finishing.

Paint and paint coating are 2 different terms where paint is the liquid material and paint coating is the protective film formed after drying. Paint is normally constituted by binder, pigment and solvent. The protective film is formed by solvent evaporation and binder conversion into a solid paint film. The paint may also have other constituents, e.g. diluents, depending on the required properties which are best preserved when selecting an appropriate application technique. Both liquid paint and paint coating require different properties¹⁰⁰.

The properties of paint should include ¹⁰⁰ capability of application and drying under specified conditions; capacity to provide good adhesion and required decoration; and ability to provide a dry film with suitable properties, e.g. hardness, gloss, etc.

Standard EN ISO 12944-5¹⁰⁰ describes several types of paint used in the protection of steel structures against corrosion. Annex A from the same standard contains numerous tables where some of the most common paint systems are characterized and divided according to their corrosivity category.

Paint properties are determined mainly by the type of binder used. Table 16 from Annex C in Standard EN ISO 12944-5¹⁰⁰, provides the main physical and mechanical properties of different generic types of paint.

Table 16. General properties of different generic types of paint¹⁰⁰

| Substrate | Epoxy (epoxy resin) | Polyurethane (isocyanate) | Acrylic (acrylic resin) | Alkyd (alkyd resin) | Polyurethane (isocyanate) | Polyurethane (isocyanate) | Polyurethane (isocyanate) | Polyurethane (isocyanate) | Polyurethane (isocyanate) | Polyurethane (isocyanate) |
|-----------------|---------------------|---------------------------|-------------------------|---------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| Stability | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good |
| Adhesion | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good |
| Flexibility | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good |
| Hardness | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good |
| Gloss retention | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good |

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REPAIR TECHNIQUES / SYSTEMS FOR PROTECTION OF STRUCTURAL STEEL

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| <p>Colour retention</p> <p>Resistance to chemicals</p> <p>Water immersion</p> <p>Rain/condensation</p> <p>Solvents</p> <p>Solvents (splash)</p> <p>Acids</p> <p>Acids (splash)</p> <p>Alkalies</p> <p>Alkalies (splash)</p> <p>Resistance to dry heat</p> <p>Up to 70°C</p> <p>70°C to 120°C</p> <p>120°C to 150°C</p> <p>150°C to 400°C</p> <p>Abrasion resistance</p> <p>Impact resistance</p> <p>Flexibility</p> <p>Hardness</p> | <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center;">A</td><td style="text-align: center;">B</td><td style="text-align: center;">C</td><td style="text-align: center;">D</td><td style="text-align: center;">E</td><td style="text-align: center;">F</td><td style="text-align: center;">G</td><td style="text-align: center;">H</td><td style="text-align: center;">I</td><td style="text-align: center;">J</td><td style="text-align: center;">K</td><td style="text-align: center;">L</td><td style="text-align: center;">M</td><td 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</tr></table> | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM | AN | AO | AP | AQ | AR | AS | AT | AU | AV | AW | AX | AY | AZ | BA | BB | BC | BD | BE | BF | BG | BH | BI | BJ | BK | BL | BM | BN | BO | BP | BQ | BR | BS | BT | BU | BV | BW | BX | BY | BZ | CA | CB | CC | CD | CE | CF | CG | CH | CI | CJ | CK | CL | CM | CN | CO | CP | CQ | CR | CS | CT | CU | CV | CW | CX | CY | CZ | DA | DB | DC | DD | DE | DF | DG | DH | DI | DJ | DK | DL | DM | DN | DO | DP | DQ | DR | DS | DT | DU | DV | DW | DX | DY | DZ | EA | EB | EC | ED | EE | EF | EG | EH | EI | EJ | EK | EL | EM | EN | EO | EP | EQ | ER | ES | ET | EU | EV | EW | EX | EY | EZ | FA | FB | FC | FD | FE | FF | FG | FH | FI | FJ | FK | FL | FM | FN | FO | FP | FQ | FR | FS | FT | FU | FV | FW | FX | FY | FZ | GA | GB | GC | GD | GE | GF | GG | GH | GI | GJ | GK | GL | GM | GN | GO | GP | GQ | GR | GS | GT | GU | GV | GW | GX | GY | GZ | HA | HB | HC | HD | HE | HF | HG | HH | HI | HJ | HK | HL | HM | HN | HO | HP | HQ | HR | HS | HT | HU | HV | HW | HX | HY | HZ | IA | IB | IC | ID | IE | IF | IG | IH | II | IJ | IK | IL | IM | IN | IO | IP | IQ | IR | IS | IT | IU | IV | IW | IX | IY | IZ | JA | JB | JC | JD | JE | JF | JG | JH | JI | JJ | JK | JL | JM | JN | JO | JP | JQ | JR | JS | JT | JU | JV | JW | JX | JY | JZ | KA | KB | KC | KD | KE | KF | KG | KH | KI | KJ | KK | KL | KM | KN | KO | KP | KQ | KR | KS | KT | KU | KV | KW | KX | KY | KZ | LA | LB | LC | LD | LE | LF | LG | LH | LI | LJ | LK | LL | LM | LN | LO | LP | LQ | LR | LS | LT | LU | LV | LW | LX | LY | LZ | MA | MB | MC | MD | ME | MF | MG | MH | MI | MJ | MK | ML | MM | MN | MO | MP | MQ | MR | MS | MT | MU | MV | MW | MX | MY | MZ | NA | NB | NC | ND | NE | NF | NG | NH | NI | NJ | NK | NL | NM | NN | NO | NP | NQ | NR | NS | NT | NU | NV | NW | NX | NY | NZ | OA | OB | OC | OD | OE | OF | OG | OH | OI | OJ | OK | OL | OM | ON | OO | OP | OQ | OR | OS | OT | OU | OV | OW | OX | OY | OZ | PA | PB | PC | PD | PE | PF | PG | PH | PI | PJ | PK | PL | PM | PN | PO | PP | PQ | PR | PS | PT | PU | PV | PW | PX | PY | PZ | QA | QB | QC | QD | QE | QF | QG | QH | QI | QJ | QK | QL | QM | QN | QO | QP | QQ | QR | QS | QT | QU | QV | QW | QX | QY | QZ | RA | RB | RC | RD | RE | RF | RG | RH | RI | RJ | RK | RL | RM | RN | RO | RP | RQ | RR | RS | RT | RU | RV | RW | RX | RY | RZ | SA | SB | SC | SD | SE | SF | SG | SH | SI | SJ | SK | SL | SM | SN | SO | SP | SQ | SR | SS | ST | SU | SV | SW | SX | SY | SZ | TA | TB | TC | TD | TE | TF | TG | TH | TI | TJ | TK | TL | TM | TN | TO | TP | TQ | TR | TS | TT | TU | TV | TW | TX | TY | TZ | UA | UB | UC | UD | UE | UF | UG | UH | UI | UJ | UK | UL | UM | UN | UO | UP | UQ | UR | US | UT | UU | UV | UW | UX | UY | UZ | VA | VB | VC | VD | VE | VF | VG | VH | VI | VJ | VK | VL | VM | VN | VO | VP | VQ | VR | VS | VT | VU | VV | VW | VX | VY | VZ | WA | WB | WC | WD | WE | WF | WG | WH | WI | WJ | WK | WL | WM | WN | WO | WP | WQ | WR | WS | WT | WU | WV | WW | WX | WY | WZ | XA | XB | XC | XD | XE | XF | XG | XH | XI | XJ | XK | XL | XM | XN | XO | XP | XQ | XR | XS | XT | XU | XV | XW | XX | XY | XZ | YA | YB | YC | YD | YE | YF | YG | YH | YI | YJ | YK | YL | YM | YN | YO | YP | YQ | YR | YS | YT | YU | YV | YW | YX | YY | YZ | ZA | ZB | ZC | ZD | ZE | ZF | ZG | ZH | ZI | ZJ | ZK | ZL | ZM | ZN | ZO | ZP | ZQ | ZR | ZS | ZT | ZU | ZV | ZW | ZX | ZY | ZZ |
| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM | AN | AO | AP | AQ | AR | AS | AT | AU | AV | AW | AX | AY | AZ | BA | BB | BC | BD | BE | BF | BG | BH | BI | BJ | BK | BL | BM | BN | BO | BP | BQ | BR | BS | BT | BU | BV | BW | BX | BY | BZ | CA | CB | CC | CD | CE | CF | CG | CH | CI | CJ | CK | CL | CM | CN | CO | CP | CQ | CR | CS | CT | CU | CV | CW | CX | CY | CZ | DA | DB | DC | DD | DE | DF | DG | DH | DI | DJ | DK | DL | DM | DN | DO | DP | DQ | DR | DS | DT | DU | DV | DW | DX | DY | DZ | EA | EB | EC | ED | EE | EF | EG | EH | EI | EJ | EK | EL | EM | EN | EO | EP | EQ | ER | ES | ET | EU | EV | EW | EX | EY | EZ | FA | FB | FC | FD | FE | FF | FG | FH | FI | FJ | FK | FL | FM | FN | FO | FP | FQ | FR | FS | FT | FU | FV | FW | FX | FY | FZ | GA | GB | GC | GD | GE | GF | GG | GH | GI | GJ | GK | GL | GM | GN | GO | GP | GQ | GR | GS | GT | GU | GV | GW | GX | GY | GZ | HA | HB | HC | HD | HE | HF | HG | HH | HI | HJ | HK | HL | HM | HN | HO | HP | HQ | HR | HS | HT | HU | HV | HW | HX | HY | HZ | IA | IB | IC | ID | IE | IF | IG | IH | II | IJ | IK | IL | IM | IN | IO | IP | IQ | IR | IS | IT | IU | IV | IW | IX | IY | IZ | JA | JB | JC | JD | JE | JF | JG | JH | JI | JJ | JK | JL | JM | JN | JO | JP | JQ | JR | JS | JT | JU | JV | JW | JX | JY | JZ | KA | KB | KC | KD | KE | KF | KG | KH | KI | KJ | KK | KL | KM | KN | KO | KP | KQ | KR | KS | KT | KU | KV | KW | KX | KY | KZ | LA | LB | LC | LD | LE | LF | LG | LH | LI | LJ | LK | LL | LM | LN | LO | LP | LQ | LR | LS | LT | LU | LV | LW | LX | LY | LZ | MA | MB | MC | MD | ME | MF | MG | MH | MI | MJ | MK | ML | MM | MN | MO | MP | MQ | MR | MS | MT | MU | MV | MW | MX | MY | MZ | NA | NB | NC | ND | NE | NF | NG | NH | NI | NJ | NK | NL | NM | NN | NO | NP | NQ | NR | NS | NT | NU | NV | NW | NX | NY | NZ | OA | OB | OC | OD | OE | OF | OG | OH | OI | OJ | OK | OL | OM | ON | OO | OP | OQ | OR | OS | OT | OU | OV | OW | OX | OY | OZ | PA | PB | PC | PD | PE | PF | PG | PH | PI | PJ | PK | PL | PM | PN | PO | PP | PQ | PR | PS | PT | PU | PV | PW | PX | PY | PZ | QA | QB | QC | QD | QE | QF | QG | QH | QI | QJ | QK | QL | QM | QN | QO | QP | QQ | QR | QS | QT | QU | QV | QW | QX | QY | QZ | RA | RB | RC | RD | RE | RF | RG | RH | RI | RJ | RK | RL | RM | RN | RO | RP | RQ | RR | RS | RT | RU | RV | RW | RX | RY | RZ | SA | SB | SC | SD | SE | SF | SG | SH | SI | SJ | SK | SL | SM | SN | SO | SP | SQ | SR | SS | ST | SU | SV | SW | SX | SY | SZ | TA | TB | TC | TD | TE | TF | TG | TH | TI | TJ | TK | TL | TM | TN | TO | TP | TQ | TR | TS | TT | TU | TV | TW | TX | TY | TZ | UA | UB | UC | UD | UE | UF | UG | UH | UI | UJ | UK | UL | UM | UN | UO | UP | UQ | UR | US | UT | UU | UV | UW | UX | UY | UZ | VA | VB | VC | VD | VE | VF | VG | VH | VI | VJ | VK | VL | VM | VN | VO | VP | VQ | VR | VS | VT | VU | VV | VW | VX | VY | VZ | WA | WB | WC | WD | WE | WF | WG | WH | WI | WJ | WK | WL | WM | WN | WO | WP | WQ | WR | WS | WT | WU | WV | WW | WX | WY | WZ | XA | XB | XC | XD | XE | XF | XG | XH | XI | XJ | XK | XL | XM | XN | XO | XP | XQ | XR | XS | XT | XU | XV | XW | XX | XY | XZ | YA | YB | YC | YD | YE | YF | YG | YH | YI | YJ | YK | YL | YM | YN | YO | YP | YQ | YR | YS | YT | YU | YV | YW | YX | YY | YZ | ZA | ZB | ZC | ZD | ZE | ZF | ZG | ZH | ZI | ZJ | ZK | ZL | ZM | ZN | ZO | ZP | ZQ | ZR | ZS | ZT | ZU | ZV | ZW | ZX | ZY | ZZ | | |

Note: This information has been drawn from a wide cross-section of sources and is intended to provide a generic indication of the properties of the different generic types of paint available. Variations will occur within each group, and some products are specifically formulated to provide exceptional resistance to certain chemicals or conditions. Always consult the paint manufacturer when any given paint is chosen for a particular application.

The main requirement for protective paint coatings is to provide protection against the type of environment to which it will be exposed. Other general requirements for paint coatings are ¹⁰⁰ possibility to be repaired; easy application; reasonable storage life and price; durability in the specified environment; formation of a coherent film with good adhesion; resistance to impact and mechanical damage, etc. In order to meet these requirements, suitable binders, pigments, and other additional constituents should be provided.

Protection of structure by painting is usually assumed by several coatings, forming a protective paint system. The different types of coating are ¹⁰⁰ the priming coat or primer; the undercoat; and the finishing coat.

The primer is applied to the substrate and there is no significant difference compared to other coatings. The main function of the primer is to "wet" the steel surface and to provide good adhesion with the steel substrate. Standard EN ISO 12944-5¹⁰⁰ defines 2 main categories of primer:

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