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Corrosion of metals and alloys — Evaluation of selective corrosion of Cu alloys and grey cast iron for power plant components by visual inspection and hardness measurement

Corrosion des métaux et alliages — Évaluation de la corrosion sélective des alliages de cuivre et des fontes grises dans les composants des centrales électriques par examen visuel et mesure de la dureté

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary Information

The committee responsible for this document is ISO/TC 156, *Corrosion of metals and alloys*.

Introduction

Selective corrosion occurs when some alloys such as brass, bronze, and cast iron come in contact with stagnant solutions for a long time. Materials suffering from selective corrosion may show various symptoms of deterioration such as localized porous areas (crumbly and fragile), discoloration, change in colour, and so on.

This kind of corrosion occurs when one of the alloying elements in alloys is dissolved from the matrix because of potential differences with other alloying elements. Most common types of selective corrosion are dezincification in brass and graphitization in grey cast iron. Selective corrosion is a very slow and inconspicuous process. Once it occurs, it may have an adverse effect on the integrity of components and structures in the industry. Therefore, it is needed to distinguish the symptoms of selective corrosion and roughly evaluate the soundness of components and structures in the field that are susceptible to selective corrosion before they are subjected to engineering evaluations.

This International Standard specifies the visual inspection and the hardness test for parts made of grey cast iron and uninhibited brass containing greater than 15 % zinc, etc. in systems and components that are sensitive to selective corrosion. Susceptible materials, high temperatures, stagnant flow conditions, and a corrosive environment, such as acidic solutions for brasses with high zinc content and dissolved oxygen, are the causes of selective corrosion. Components include piping, valve bodies and bonnets, pump casings, and heat exchanger components that are susceptible to selective corrosion. These components can be exposed to raw water, treated water, closed cooling water, ground water, water contaminated fuel oil, or water contaminated lube oil.

The criterion is suggested in this International Standard, whether the materials suffering from selective corrosion can be continuously used or should be subjected to engineering evaluation for further and exact examination. The determination of symptoms of selective corrosion and degree of deterioration can be made with the procedures as follows:

— selection of components sensitive to selective corrosion and components for the test (sampling);

— visual inspection for selective corrosion of alloys;

— hardness test for selective corrosion of alloys.

This International Standard provides examples of data sheets for descriptions and information of materials damaged by selective corrosion in the visual inspection. Provided reference photos of case histories can be used in comparing with the real damages of materials on sites. Examples of a description sheet and an evaluation sheet are also provided for the hardness test of selective corrosion.

Corrosion of metals and alloys — Evaluation of selective corrosion of Cu alloys and grey cast iron for power plant components by visual inspection and hardness measurement

1 Scope

This International Standard specifies procedures of on-site detection and evaluation in order to determine the effects of material deterioration such as material loss from the components and structures that are sensitive to selective corrosion in industrial facilities, including nuclear power plants.

The methodology involves visual inspection and hardness measurements in situ complemented by sample removal. These procedures include (a) representative sampling of components sensitive to selective corrosion, (b) the visual inspection, and (c) the hardness test, respectively. For an exact analysis, additional laboratory testing is recommended.

The methodology is most applicable to grey cast iron and copper alloy with more than 15 % zinc. Extension to other alloys requires supportive evidence of validation.

Assessment criteria orientated to the nuclear power plant application during the past five years before the end of extended operation define the necessity for further engineering evaluation and action like, for example, further sampling, higher frequency of inspection, and component repair or exchange.

This specification is not applicable for components used where the representative sampling of surfaces in contact to the fluid is not detectable optically or detected with the portable hardness tester. Also, in case of non-representative component selection like in HVAC or building service application, this specification is not applicable. For components not used in nuclear power plant, the assessment criteria have to be agreed by the parties. Assessment criteria of hardness test alone is not applicable to the evaluation of structural integrity of Al-bronze, NAB, and Cu-Ni.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
selective corrosion
corrosion of an alloy whereby the components react in proportions that differ from their proportions in the alloy

Note 1 to entry: It is a phenomenon in which one of the alloying elements is electrochemically active and sensitive to corrosion resulting in being selectively removed and the concentrations in other elements being relatively increased in alloys such as bronze, brass, and grey cast iron etc.

EXAMPLE Dezincification, graphitization

[SOURCE: ISO 8044:1999, 3.20]

2.1.1
dezincification
selective corrosion of brass resulting in preferential removal of zinc

Note 1 to entry: It is a phenomenon where the more electrochemically active zinc is preferentially dissolved from copper-zinc alloys with mass fraction of zinc greater than 15 % resulting in a porous copper layer with diminished mechanical properties.

[SOURCE: ISO 8044:1999, 3.21]

2.1.2
graphitization
selective corrosion of grey cast iron, resulting in partial removal of metallic constituents, leaving graphite

Note 1 to entry: It is a corrosion process in which iron is selectively dissolved from grey cast iron resulting in remaining vulnerable porous graphite.

[SOURCE: ISO 8044:1999, 3.22]

2.2
visual inspection
one of the non-destructive tests within condition monitoring in which the inspector observes directly the materials, productions, or structures with his own eyes to determine whether surface defects exist on the test bodies

2.3
hardness test
indentation test carried out using a hardness testing machine to measure the hardness of a material

Note 1 to entry: Hardness is local resistance of surface by pressing an indenter with specific load to designate solidness and softness of materials. There is the Brinell hardness which can be used as measuring method with the indenter. An informative calculation to other hardness types (Rockwell hardness, Vickers hardness, etc.) can be helpful.

3 Principle

The result of deterioration from the selective corrosion is the loss of materials followed by a loss of mechanical properties creating a failure.

The loss of materials, which may be the reason for failure, can be determined by the visual inspection and the hardness measurement. The visual inspection identifies corrosion, discoloration, change in colour and local porosity, and the hardness test reveals the change in mechanical properties from the corrosion process at the surface of the test material.

4 Procedures

4.1 Selection of components sensitive to selective corrosion and components for the test

Selection of candidate systems and components for the test and test samples are entirely site-specific considering operating characteristics, sensitivity of materials to degradation, and accessibility. It is recommended that components which are only present in small number in the installation are subjected to 100 % sampling, but that components in large number (e.g. small valves and flanges) are subject to random sampling. In this case, sampling ratio is recommended to be over 10 % of whole components.

NOTE “Large number” means the quantity that the inspectors cannot afford to handle in a limited inspection period such as an overhaul period or an in-service inspection period and vice versa for “small number”. Decision shall be made on responsibility of site engineers.

4.1.1 Components sensitive to selective corrosion of alloys

Components sensitive to selective corrosion are mainly made of copper alloys, aluminium-copper alloys, copper-nickel alloys, and grey cast irons, for example:

a) Heat exchangers in component cooling water systems, valves in component cooling seawater systems, pumps and valves in fire protection systems, and components in similar conditions thereof;

b) Buried pipes and fittings of grey cast iron;

c) Exemption for the test may be permitted for the components periodically subjected to non-destructive tests.

4.1.2 Selection of components subjected to the test for selective corrosion

4.1.2.1 In principle, components should be subjected to the 100 % sampling inspection for selective corrosion even though the components made of same materials are under the same environment and the same operating condition. The visual inspection and the hardness test should be performed for the surfaces of object components that have been in contact to corrosive media.

4.1.2.2 When it is impossible to perform 100 % sampling because there are numerous object components sensitive to selective corrosion, random sampling can be permitted for the object components. The selected sample components should be subjected to the visual inspection and the hardness test.

4.1.2.3 In case of selecting test samples from the whole object components, components that are representative among the classified material types such as brass and grey cast iron among others should be selected in advance.

4.1.2.4 In case of various components of same materials in the same system, the component should be selected first of all as a test sample which is exposed to the corrosive medium of lower flow rate, or shows severer damages, or is operated in hasher conditions such as higher pressure and higher temperature etc.(example of priority: older component than newer one, in seawater or in pure water, in stagnant medium than in flowing one, in higher pressure than in lower pressure, in higher temperature or in lower temperature).

4.1.2.5 Among the more than necessary samples selected upon above principles, test samples can be finally screened to components that are accessible in the field and are easily disassembled and assembled.

4.2 Visual inspection and hardness test for selective corrosion on alloys

4.2.1 After the visual inspection is fulfilled, the hardness test shall be performed for the test samples selected.

4.2.2 The visual inspection and hardness test shall be focused on the inside of the components such as a valve body and a pump casing that are in contact with the corrosive media.

4.3 Procedure of visual inspection for selective corrosion of alloys

4.3.1 Visual inspection for corrosion and porosity on the inside surface of the components shall be performed conforming to national regulations.

4.3.2 If symptoms of selective corrosion are found, it is recommended to compare the deteriorated area with photos in Annex E to determine whether the deterioration is similar to some of the case histories. The close-up photos of surface morphology on damaged area should be taken with a digital camera (over 600 dpi).

4.3.3 Results of visual inspection shall be documented on the basis of a sample form of Annex A. Furthermore, photos of damaged area shall be attached to the sample form of Annex B in which it is recommended to record the details of comparison with Annex E.

4.4 Procedure of hardness test for selective corrosion on alloys

4.4.1 Portable hardness testers shall be used and the results are indicated with the scale of Brinell hardness in principle.

4.4.2 Apparatus

4.4.2.1 Portable testers are designed in such a way that dead weights are not used in applying or limiting the indenting force so that they can be portable and so that the indenting forces can be applied in any direction.

4.4.2.2 The indenting force may be applied by means of a hydraulic cylinder with a pressure gauge to indicate the magnitude of the force. The hydraulic cylinder can also be equipped with a spring-forced relief valve to fix the magnitude of the force. Alternatively, the indenting force can be applied by means of a screw through a calibrated spring with a dial gauge or other means of measuring the deflection of the spring to indicate the magnitude of the force.

4.4.2.3 Portable hardness testers are generally provided with various means of holding the indenter in contact with the surface to be tested. The testers can be clamped to the object to be tested, attached to an adjacent fixed object, or attached to the surface to be tested by a magnet. For testing inside a cavity, the tester can be placed against one wall of the cavity to make a test on the opposite wall.

4.4.3 Whatever means is used to hold the tester to the piece being tested, make sure that there is no relative motion between the tester and the piece when the force is applied. This is particularly true for the portable Rockwell-type tester. Mount the tester in such a position that the axis of the indenter is normal to the surface to be tested.

4.4.4 Portable Brinell type test is principally applied for evaluating selective corrosion than any other hardness type test. Portable Brinell testers generally apply the force by means of a hydraulic cylinder equipped with both a pressure gage and a spring forced relief valve. With this arrangement, it is not possible to maintain the force at the point where the relief valve opens for any appreciable time. Therefore, bring up the force several times to the point where the pressure is released. It has been determined that for steel, when testing with an HBW 10/3 000, three times of force applications are equivalent to holding the force for 15 s, as required in the standard method. For other materials and forces, make comparing tests to determine the number of force applications required to give results equivalent to that of the standard method. Bring the force up gradually each time without jerking.

NOTE 1 The apparent hardness will depend on the applied force and the depth of surface porosity. A small load will be more sensitive to the early stages of degradation, whereas a large force with significant depth of indent will be less sensitive. However, small load creates a shallow indent leading to the dispersion of data due to local spatial variation of microstructure. In all testing, the applied force should be consistent and selected according to the degree of sensitivity required.

NOTE 2 It is recommended to use high test loads for less homogenous materials. For example, HBW × |3 000 should be used for cast iron, whereas HBW × |10 or HBW × |5 for brass (× = ball diameter).

4.4.5 Portable hardness testers shall be used only with applied forces at which the force measuring device has been calibrated.

4.4.6 Portable hardness testers shall also be checked for errors periodically by the comparison method or by test blocks as described in the manufacturer's manual.

4.4.7 Whole area or local area of test sample components shall have a ground finish with SiC paper (#600) in order to reduce the measurement errors caused by surface roughness before measuring. Oxides and contaminants including oil, especially lubricant, shall be removed with organic solvent such as methyl alcohol, acetone, etc. Finishing touches on the surface of test samples may be permitted for the indenter to be mounted properly on the tested surface. After cleaning other contaminants with distilled water and drying the surface, the testers shall be contacted and calibrated on it.

4.4.8 In case that the surface roughness is too high, the results of hardness have the tendency to show lower than the real values and the deviations can be varied with every each trial.

4.4.9 Measurement shall be performed in temperatures between 10 °C to 35 °C.

4.4.10 Materials composing the objects to be tested shall be identified.

4.4.11 Hardness scale and measuring orientation of objects to be tested shall be determined.

4.4.12 The tester shall be mounted in such a position that the axis of the indenter is normal to the surface to be tested.

4.4.13 At least five uniformly distributed measurements on the damaged area shall be made and the mean value of them shall be determined.

4.4.14 Measured data on the LCD panel of the portable hardness testers shall be ready for each damaged area on the sample components.

4.4.15 Evaluation results and data of measured hardness shall be recorded respectively in the form of Annex C and Annex D.

4.4.16 The measured Brinell hardness data can be converted into other scales of hardness according to ISO 18265 and they shall also be recorded.

HV: Vickers Hardness (ISO 6507), HR: Rockwell Hardness (ISO 6508)

4.4.17 Precision and bias

4.4.17.1 Precision

The precision of this test method has not been established because of the wide variety of portable hardness testers and metals for which it is used. When required, hardness tolerances for specific applications can be empirically established for a given portable hardness test using standardized reference hardness blocks. The precision of a given portable hardness test, whether involving a single operator, multiple operators, or multiple sites, can be established by employing statistical methods.

4.4.17.2 Bias

The bias of a portable hardness testing machine depends on the bias of the test force, indenter, and the device used to measure the indentation. Although standardized reference hardness blocks are available from hardness tester manufacturers, it is impractical to establish the bias of this test method because of the wide variety of portable hardness testers available, the many types of metallic materials tested by this method, and the variations possible within a test specimen. The bias of a given portable hardness tester can be established empirically using such standardized reference hardness blocks by employing statistical methods.

5 Responsibility

5.1 Visual inspectors should have the necessary competence.

5.2 Hardness tests should be performed by competent persons.

5.3 Work procedures, drawings, materials, and tools should be thoroughly prepared before testing.

5.4 Testers should be corrected and be workable in terms of validity.

5.5 Isolation of systems and components shall be controlled by the operators or competent persons.

5.6 Safety gears shall be worn by workers and safety devices shall be installed before tests. It should be cautioned not to lose or destroy the devices.

5.7 When workers are in the radioactive area, they shall obey the safety rules for radiation and shall thoroughly be equipped with protection gears.

5.8 While components such as pumps and valves are being opened and disassembled, testers must be cautious when sealing them so as to avoid impurities from penetrating inside. Impurities shall also be completely eliminated.

5.9 The supervisor shall have staff training for protection against impurities when opening the components before tests.

6 Assessment criteria and corrective actions

6.1 Assessment criteria

Assessment criteria for visual inspection and hardness test at the surface of components are indicated below.

6.1.1 Visual inspection.

6.1.1.1 Corrosion or porous area (crumbly and fragile) or discoloration/change in colour are the primary indicators of selective corrosion.

6.1.2 Hardness test.

6.1.2.1 After the implementation of hardness measurement, the results of the hardness value analysis shall be compared with hardness data on the mill sheet or the CMTR (Certified Material Test Report) or ISO codes of the original material. If the specifications of materials are uncertain, the comparison shall undergo with visually sound surface area or unwet area of the component. The trend curve should have uniform values throughout the representative surface of the component. However, if the plant engineer considers the reduction in hardness unacceptably low in some areas, reexamination shall be performed after expanding the size and range of examination samples.

NOTE The plant engineer shall decide reexamination from the field data of hardness referring to clauses in 4.4.

Hardness values from portable hardness testers can be affected by surface states of samples, temperature of metal surface, indenter angle, and characteristics of materials. Hardness values are proportionally decreased with the depth of selective corrosion, but the hardness change according to the depth of selective corrosion cannot be exactly quantified in various materials and environments. Therefore, assessment criteria for the hardness decrease shall depend on the engineering judgment of corrosion engineers in charge (plant specific).

6.2 Corrective actions for unsatisfactory results

6.2.1 If the loss of metal is detected as a result of visual inspection and hardness test, reexamination shall be performed after expanding the size and range of examination samples.

6.2.2 If the hardness from reexamination shows reduction of more than the specific criterion of compared hardness considering measurement errors, evaluations shall be performed for investigating the cause of the loss of hardness. The corrective action program shall ensure that the conditions adverse to functionality are promptly corrected. They should include (a) increasing of frequency of inspection, (b) repair of the component or cleaning from deposit, (c) correcting the materials and environmental factors causing selective corrosion, (d) using protective coating and cladding, (e) using materials that show high corrosion resistance, and (f) improving the water chemistry that the component comes in contact with.

6.2.3 When components cannot be used due to aging effects caused by selective corrosion, they shall be repaired or replaced based on the results of the integrity evaluation.

6.2.4 When it is confirmed that there is no aging effects caused by selective corrosion on the integrity of components, all tests and evaluations can be finished.

Annex A
(informative)

Data sheet of visual inspection for selective corrosion of alloys

System	Components		Criteria (loss of materials)	Results	Note
A	Valve a body inside	#1	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	
		#2	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	
B	Pump b casing inside	#1	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	
C	Pump c casing inside	#1	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	
	Pump d impeller	#2	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	
	Valve e body inside	#3	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	
	Valve f body inside	#4	Porous marks: □Yes □No Discoloration: □Yes □No	□Good □Poor □Good □Poor	

Comments:

Tester	Dep.		Name/Sign.	/	Date	20 . .
Checker	Dep.		Name/Sign.	/	Date	20 . .
Quality reviewer	Dep.		Name/Sign.	/	Date	20 . .

Annex B
(informative)

Description sheet for damaged area from selective corrosion of alloys

Attached photo of damaged area on the component (close-up digital picture taken within 10 cm distance, resolution of higher than 800×600 dpi)	
Comparison picture of similar case history in Annex E	

<Detailed description of damaged condition> (comparing with case histories in Annex E)

Tester	Dep.		Name/Sign.	/	Date	20 . .
Checker	Dep.		Name/Sign.	/	Date	20 . .
Quality reviewer	Dep.		Name/Sign.	/	Date	20 . .

Annex C
(informative)

Evaluation sheet of hardness test results for selective corrosion of alloys

System	Components		Criteria[1] average hardness value	Results	Note
A	Valve a body inside	#1		□Good □Poor	
		#2		□Good □Poor	
B	Pump b casing inside	#1		□Good □Poor	
C	Pump c casing inside	#1		□Good □Poor	
	Pump d impeller	#2		□Good □Poor	
	Valve e body inside	#3		□Good □Poor	
	Valve f body inside	#4		□Good □Poor	

[1] Criteria for judgment

1) If hardness values from five neighboring sites of the measured area show uniform consistency, the area is judged to be sound.

2) The mean value of hardness measured from the five neighboring sites of the area shall be calculated and recorded.

3) Measured data shall be recorded in Annex D.

4) Comments

Tester	Dep.		Name/Sign.	/	Date	20 . .
Checker	Dep.		Name/Sign.	/	Date	20 . .
Quality reviewer	Dep.		Name/Sign.	/	Date	20 . .

Annex D
(informative)

Data sheet of hardness test for selective corrosion of alloys (example)

Recording data form of hardness test

Component	

1. Model ID of hardness tester:

2. Mode of hardness: Brinnell (HB)

3. Materials specification of test objects: ______________________

4. Loads for test:

5. Indentation mode/diameter: ______/______ mm

6. Time of maintaining load: ____ sec

7. Results of hardness

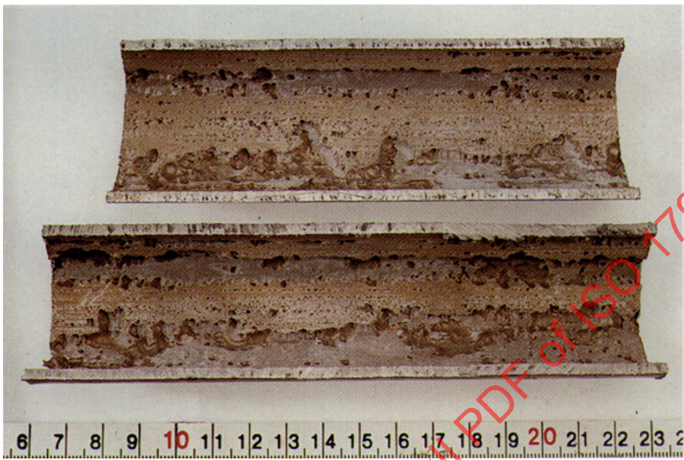
Sites \ Hardness		HB		HR	HV	Comparison
1						
2						
3						
4						
5						
Average Value						

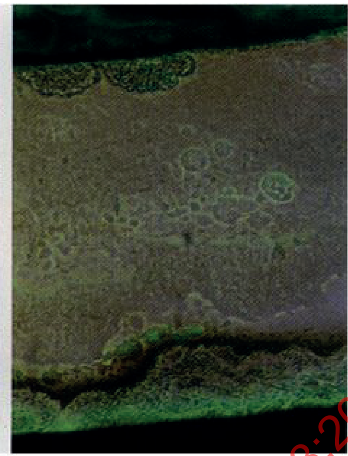
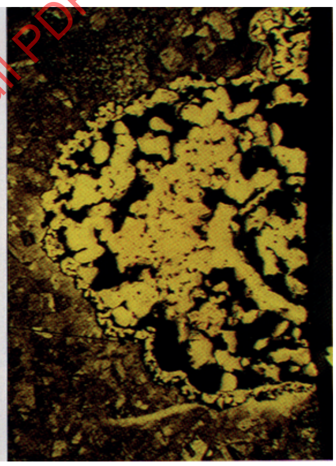
8. Outline drawing (locations, directions etc.)

Tester	Dep.		Name/Sign.	/	Date	20 . .
Checker	Dep.		Name/Sign.	/	Date	20 . .
Quality reviewer	Dep.		Name/Sign.	/	Date	20 . .

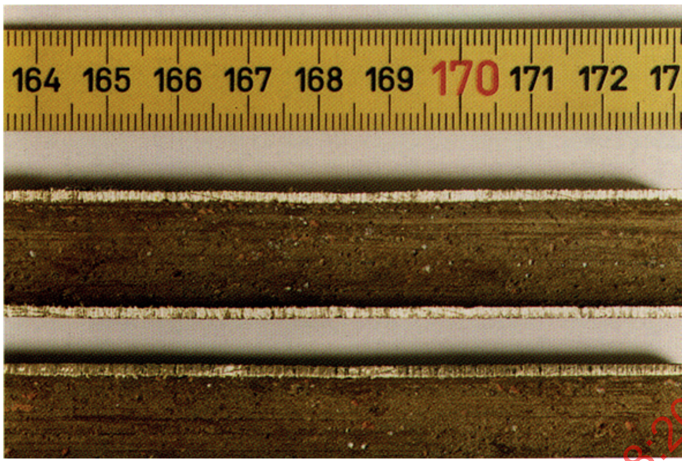
Annex E
(informative)

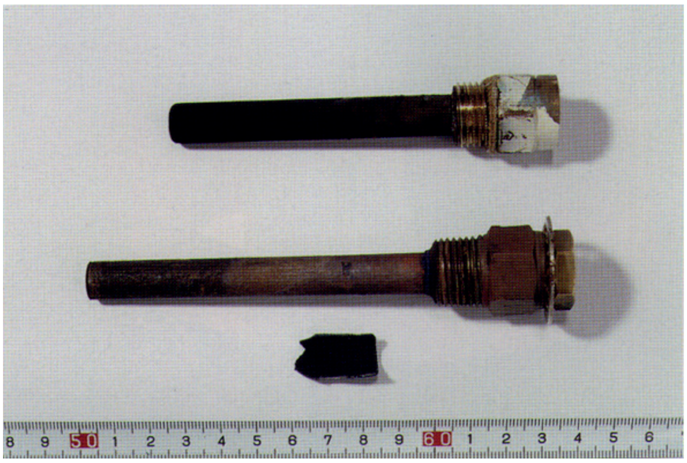
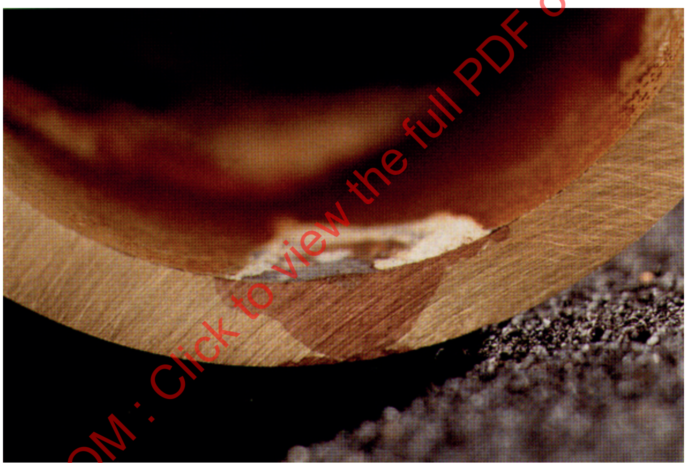
Photo samples of case histories for selective corrosion

#1		
	Material	Aluminium-zinc alloy(5~6 % zinc)
	System/Part	Glasshouse irrigation system
	Phenomenon	Dezincification
#2		
	Material	Brass
	System/Part	Automotive system/hose pillar of radiator
	Phenomenon	Layer-type dezincification

<table>
<tr><td rowspan="4">#3</td><td colspan="2"> </td></tr>
<tr><td>Material</td><td>Brass</td></tr>
<tr><td>System/Part</td><td>Copper-lined hot water storage boiler with copper tubes/ thermometer bulb</td></tr>
<tr><td>Phenomenon</td><td>Plug-type dezincification</td></tr>
<tr><td rowspan="4">#4</td><td colspan="2"> </td></tr>
<tr><td>Material</td><td>Brass</td></tr>
<tr><td>System/Part</td><td>Mains water system/tap component</td></tr>
<tr><td>Phenomenon</td><td>Plug-type dezincification</td></tr>
</table>

#5		
	Material	Brass
	System/Part	Hot tap water system/valve and pipe sections
	Phenomenon	Plug-type dezincification
#6		
	Material	Brass
	System/Part	Drinking water system/mixing tap orifice
	Phenomenon	Plug-type dezincification

#7		
	Material	Brass
	System/Part	150 kV plant transformer cooler/ cooling pipe
	Phenomenon	Plug-type dezincification
#8		
	Material	Brass
	System/Part	Circulating cooling water system/pipe
	Phenomenon	Plug-type dezincification

#9		
	Material	Brass (> 20 % Zn)
	System/Part	Central heating system/temperature sensor tube
	Phenomenon	Layer-type dezincification
#10		
	Material	Brass (35 % Zn-Cu)
	System/Part	Hot-water heating system in commercial building/horizontal pipe
	Phenomenon	Dezincification