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Corrosion of metals and alloys — Guidelines for the selection of methods for particle-free erosion corrosion testing in flowing liquids

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National foreword

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Corrosion of metals and alloys — Guidelines for the selection of methods for particle-free erosion corrosion testing in flowing liquids

Corrosion des métaux et alliages — Lignes directrices pour la sélection des méthodes d'essai d'érosion-corrosion exempte de particule dans des liquides en mouvement

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Foreword

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

Introduction

Particle-free erosion corrosion is a major problem in industries handling liquids flowing rapidly that are corrosive especially at high temperatures and high pressures. This mode of corrosion usually leads to rapid metal loss with possibly catastrophic consequences. In order to prevent, mitigate and control the problems, it is important to determine the resistance to corrosion of materials accurately. This may be achieved by the use of test methods reproducing a specific mode of erosion corrosion.

Corrosion of metals and alloys — Guidelines for the selection of methods for particle-free erosion corrosion testing in flowing liquids

1 Scope

This Technical Report provides information on the erosion corrosion test of materials in single-phase flowing liquids and guidance for selection of test methods.

2 Normative references

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

ISO 8044, *Corrosion of metals and alloys — Basic terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 8044 and the following apply.

3.1
erosion
progressive loss of original material from a solid surface due to mechanical interaction between the surface and a fluid, a multicomponent fluid, or impinging liquid or solid particles

3.2
erosion corrosion
process involving conjoint corrosion and erosion

3.3
particle free erosion corrosion
corrosion of metallic materials in single phase flowing liquids

4 Principles

4.1 Erosion corrosion describes the mechanical removal of metals leading to enhanced corrosion. The process is synergistic in the sense that the localized loss of material can create additional turbulent flow that encourages further film removal or even prevents its formation. The conditions in which erosion corrosion occurs will be a sensitive function of the application but there are a range of laboratory test methods that have been developed to simulate typical service applications and can provide a basis for assessing the relative susceptibility of materials to damage development.

4.2 Erosion corrosion test is conducted either by setting up a uniform flow velocity distribution or by inducing different flow velocities or different rates of corrosion over the surface of test specimen. In the former, corrosion damage increases as the flow velocity of liquid increases, while in the latter, the damage increases as the difference in the corrosion rates becomes larger.

5 Test methods

5.1 Tests for uniform corrosion

5.1.1 Rotating cylinder test

This test uses a cylinder-shaped specimen insulated at the top and bottom end (see Figure 1). The cylindrical surface is the test surface. It is attached with a shaft at the top end with which it is rotated around the longitudinal axis in test solution. The radius of the cylinder may be chosen freely, but needs to be constant along the longitudinal distance, so that a uniform distribution of circumferential flow velocity over the entire surface of specimen is achieved. This test is widely used for elucidating the effect of flow velocity on the uniform corrosion.

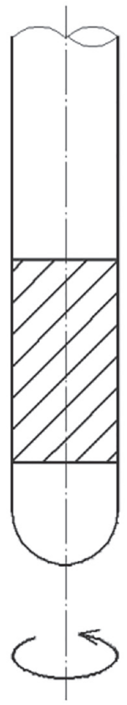


Figure 1 — Rotating cylinder test

5.1.2 Test in a pipe or channel

The flat plate specimen installed in the pipe line (the hatched part, upper in Figure 2) and the test specimens embedded in the wall of the duct (the hatched part, lower in Figure 2) are also used for investigating the effect of flow velocity on uniform corrosion. Because of the end effect, the specimen embedded in the wall of the duct is advantageous over the pipe. However, the former has some difficulties in setting the specimen precisely flat with the duct wall.

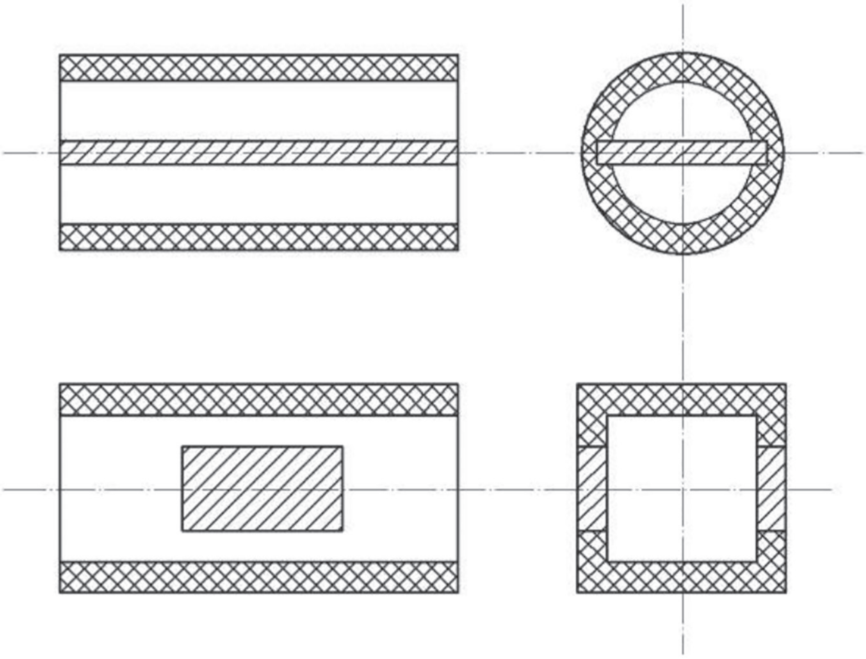


Figure 2 — Test in a pipe or channel with specimen surfaces parallel to the flow direction

5.2 Tests for localized corrosion

5.2.1 Rotating disc test

In this method, a circular disc with comparably smaller thickness is rotated horizontally around the vertical shaft which is attached vertically at the centre (see Figure 3). The test surface is the underside surface of the disc over which the flow velocity distribution is not uniform but distributed. This is the main reason why the localized corrosion of erosion corrosion type can be developed in the rotating disc unlike in the rotating cylinder test. However, the distribution of flow velocity may deviate from the theoretical calculation because the circumferential flow through the disc rotation is overlapped with the radial secondary flow as is shown in Figure 3 with the curved arrows.

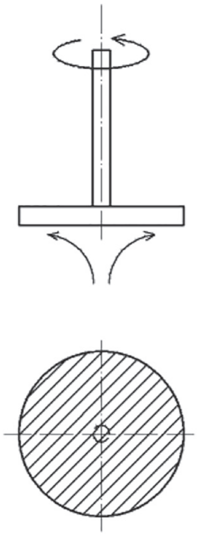


Figure 3 — Rotating disc test

5.2.2 Test in a pipe or channel with changes in flow cross section

A water tunnel with sudden convergence and divergence in the cross section of liquid flow (see Figure 4) is used to produce the localized corrosion of differential flow-velocity corrosion type on the inside surface of the tunnel wall, which is essentially the test surface. Stagnant volume of fluid or fixed vortexes may be built at the downstream of the boundary layer separation points, which are usually located at the corner tips where the cross section of flow changes suddenly (the thin hatched part in Figure 4). Therefore, the flow velocity distribution is not uniform along the flow axis, unlike that without change in the flow cross section, and localized corrosion occurs in this test.

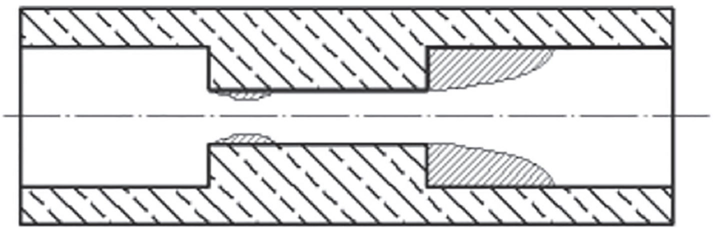
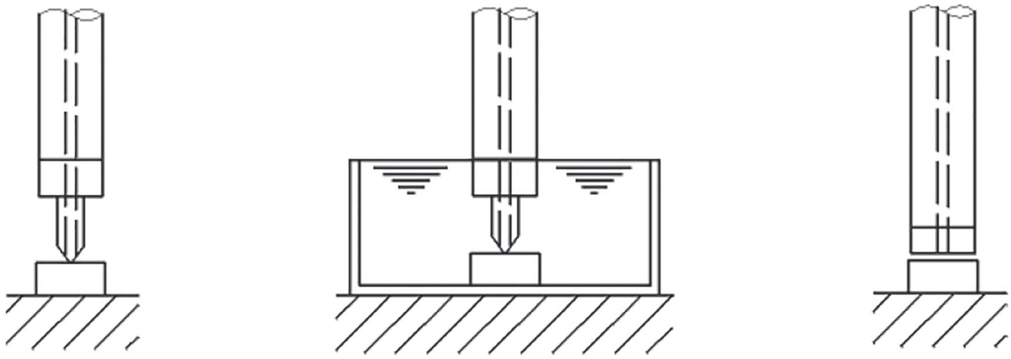


Figure 4 — Test in flow tunnel with sudden convergence and divergence

5.2.3 Jet impingement test

This test uses three types of jets: free jet; submerged jet; and jet-in-slit (see Figure 5). The free jet is used in conventional impingement tests, where the liquid jet strikes at a right angle to the specimen surface in the air. The submerged jet is a jet submerged in solution. The jet injected into a narrow gap has been named as jet-in-slit. Typically, the inside diameter of the nozzle is 1,6 mm; the gap between the nozzle top end and the specimen is 0,8 mm; and the flow rate of the test liquid is 0,4 l/min. At this flow rate, the fluid velocity at the nozzle outlet is around 3,3 m/s, and the Reynolds number at that point is 8 100.



(a) free jet **(b) submerged jet** **(c) jet-in slit**

Figure 5 — Impinging jets used to evaluate localized corrosion

6 Guidelines

6.1 General guidelines

6.1.1 In selecting test methods, it is necessary to decide which mode of corrosion is intended to be produced: uniform corrosion or localized corrosion. For the latter especially, factors should be chosen that produce the difference in corrosion rates over the specimen surface, i.e. shear force, turbulence in the flow, flow velocity difference, fixed vortex or active/passive states.

6.1.2 The flow conditions over the specimen surface should be clearly verified, irrespective of the test method chosen.

6.1.3 It is important to reproduce the wall shear stress in the practical applications at the specimen surface as closely as possible.

For the rotating disc method use Formula (1):

$$\sigma_{\text{ws}} = 6{,}302\mu\rho\omega\text{Re}^{\cdot 0.5} \qquad (1)$$

For the rotating cylinder method use Formula (2):

$$\sigma_{\text{ws}} = 0{,}079\ 1\rho\omega^2\ r^2\text{Re}^{-0.3} \qquad (2)$$

For the impinging jet method use Formula (3):

$$\sigma_{\text{ws}} = 0{,}044\ 7\rho u_0{}^2\text{Re}^{-0.182}\ (x/d_{\text{jet}})^{-2} \qquad (3)$$

For the flow channel method use Formula (4):

$$\sigma_{\text{ws}} = d(\Delta P/\Delta L)/4 \qquad (4)$$

where

σ_{ws} is wall shear stress, measured in Pa;

ω is angular velocity, measured in radian/sec;

ρ is the solution density, measured in kg m^{-3};

μ is the kinetic viscosity of the solution, measured in m^2 s^{-1};

Re is the Reynolds number;

r is the radius of rotating cylinder, measured in m;

d_{jet} is the inner diameter of the jet nozzle, measured in m;

u_0 is the fluid velocity at the front of the jet nozzle, measured in m s^{-1};

x is the radial distance from the jet nozzle centre line, measured in m;

ΔP is the pressure drop;

ΔL is the length of the pipe;

d is the diameter.

6.1.4 Specimens should be insulated from the holder to avoid galvanic corrosion.

6.1.5 The test set-up, which can accommodate multiple specimens in the same run, is conveniently used for comparative tests of materials. Specimen should be small in weight but large in surface area to determine the amount of damage so that even a small loss can be measured, and it is possible to shorten the testing time. A specimen with a flat surface is recommended not only for easy surface finishing before test but also for observations after test.

6.1.6 The rate of damage in wall thinning rate or in penetration rate with the dimension of (mm h^{-1}) is useful.

6.2 Applications and limitations of tests

Applications and limitations of each test methods for particle-free erosion corrosion in flowing liquids are listed in Table 1.

Table 1 — Applications and limitations of tests

Method	Applications	Limitations
Rotating cylinder	• Types of reproducible corrosion: – uniform corrosion • Corrosion damage information: – wall thinning or penetration rate – cumulative measurement of damage • Information on materials performance in the field: – qualitative evaluation or the order of merit of the materials tested	• Testing in single phase liquid only for the equations to apply • Maintaining good electrical contact with the rotating electrodes is difficult • Testing under high pressure is difficult
Rotating disc	• Types of reproducible localized corrosion: – erosion corrosion due to shear force – differential flow velocity corrosion • Corrosion damage information: – damage depth distribution over the specimen surface – cumulative measurement of damage • Information on materials performance in the field: – qualitative evaluation, or the order of merit of the materials tested	• Not applicable for gathering mechanistic and damage information on the localized corrosion of active/passive-cell types • Electrochemical measurements are difficult to conduct on a moving specimen
Flow channel	• Types of reproducible localized corrosion: – differential flow velocity corrosion – active/passive cell type • Information on the performance of materials in the field: – qualitative evaluation, or the order of merit of those materials tested	• Not applicable for gathering cumulative damage measurements • The capillary for electrochemical measurement is difficult to apply to the specimen surface
Jet-in-slit	• Types of reproducible localized corrosion: – erosion corrosion due to shear force and turbulence – differential flow velocity corrosion – active/passive cell type • Corrosion damage information: – distribution of damage depth over the specimen surface – cumulative measurement of damage • Electrochemical measurements: – potential as well as current density measurement on the specimen surface • Information on materials performance in the field: – qualitative evaluation or the order of merit of those materials tested	• Quantitative correlation is poor between the test results of specimen and the performance of the material in the field

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