
**Corrosion of metals and alloys —
Standard test method for particle-
free erosion corrosion of metallic
materials by jet-in-slit**

*Corrosion des métaux et alliages — Méthode d'essai normalisée de
corrosion-érosion en l'absence de particules par jet issu d'une fente*

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Contents

	Page
Foreword.....	iv
Introduction.....	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Principles	1
4.1 Schematic of jet-in-slit test.....	1
4.2 Hydrodynamic conditions on the specimen.....	2
4.3 Typical damage pattern.....	3
4.4 Material and solution.....	3
5 Apparatus	4
5.1 Nozzle and specimen.....	4
5.2 Test chamber.....	5
5.3 Test solution circuit.....	6
6 Test conditions and procedure	7
7 Test report	8
Annex A (informative) Recommended practice for copper alloys by jet-in-slit test	9
Bibliography	11

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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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This document was prepared by Technical Committee ISO/TC 156, *Corrosion of metals and alloys*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Particle-free erosion corrosion is a major problem in metallic materials of industries which handle liquids flowing rapidly that are corrosive. Specifically, the metallic materials include copper, copper alloys and steels, and the liquids are various types of liquids such as seawater, tap water, industrial water, chemical water (e.g. acid and alkali aqueous solution), waste water, etc. Particle-free erosion corrosion usually leads to rapid metal loss with possibly catastrophic consequences. In order to either prevent, mitigate or control, or all, the problems, it is important to determine the particle-free erosion corrosion behaviour of materials for plant construction. This can be achieved by standardizing the test methods which can reproduce the specific mode of corrosion in those materials. This test method can be applied to various types of metallic materials by choosing appropriate test solutions and conditions.

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Corrosion of metals and alloys — Standard test method for particle-free erosion corrosion of metallic materials by jet-in-slit

1 Scope

This document specifies a test method for particle-free erosion corrosion of metallic materials by use of jet-in-slit which is flow induced corrosion in single phase flowing liquids. The test method can be used for ranking materials performance, selecting candidate materials and testing the effects of corrosion inhibitors.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8044, *Corrosion of metals and alloys — Vocabulary*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

erosion

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

Note 1 to entry: For more details, see Reference [1].

3.2

erosion corrosion

process involving conjoint corrosion and *erosion* (3.1)

3.3

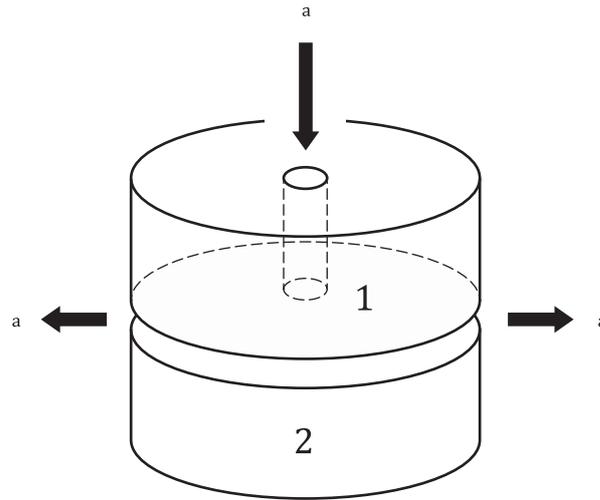
particle-free erosion corrosion

erosion corrosion (3.2) of metallic materials in single phase flowing liquids free of solid particles and gas bubbles

4 Principles

4.1 Schematic of jet-in-slit test

The schematic of jet-in-slit test can be seen in [Figure 1](#). Two circular discs with the same dimensions are set face-to-face to form a narrow gap (slit) between them. A bore hole is drilled-through at the centre of the upper disc to make a nozzle. A jet of test solution from the nozzle impinges at a right angle to the specimen and then to flow in a radial direction through the slit.



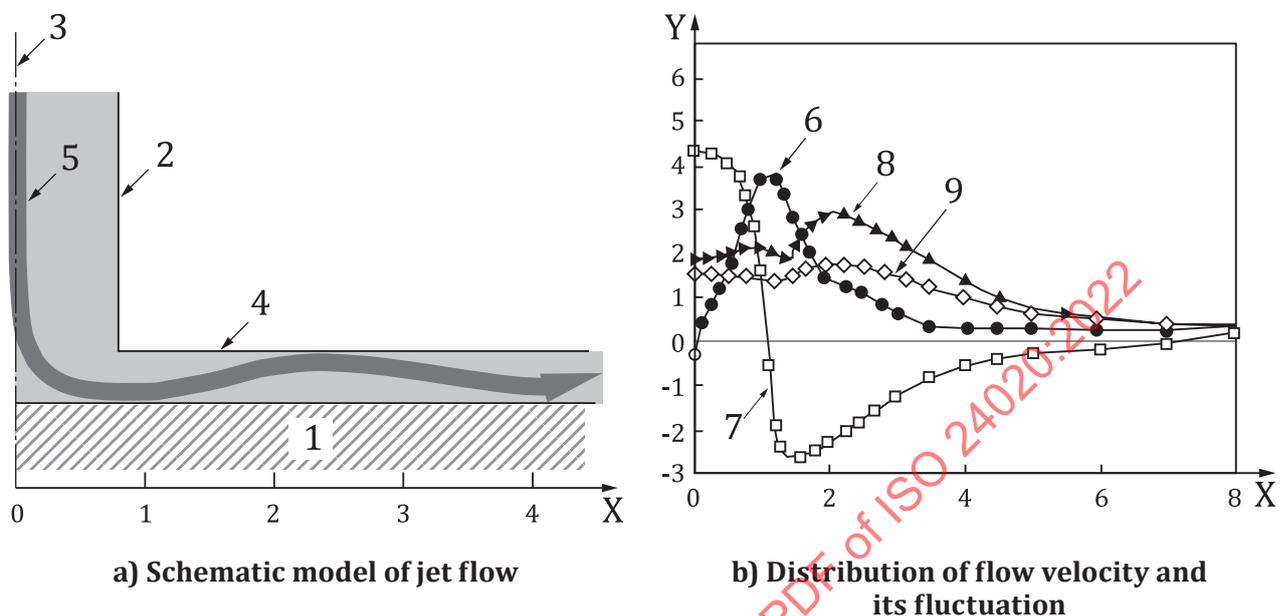
Key

- 1 nozzle
- 2 specimen
- a Solution flow.

Figure 1 — Schematic of jet-in-slit test

4.2 Hydrodynamic conditions on the specimen

The hydrodynamic conditions of jet flow on the specimen surface in the nozzle and slit are shown in [Figures 2 a\)](#) and [b\)](#)^[2]. The vertical flow velocity (see [Figure 2](#), Key 7) is highest at the centre (see [Figure 2](#), Key 3) of the nozzle (see [Figure 2](#), Key 2), or the specimen (see [Figure 2](#), Key 1), but is reciprocally the highest (reverse direction) at the location approximately 1,5 mm from the centre, in the jet flow (see [Figure 2](#), Key 5). The flow rebounds after impinging on the specimen surface and causes boundary layers peeling followed by flow fluctuation. The shear stress caused by fluid running over the surface of specimen is proportional to the velocity gradient normal to the surface and it is usually higher at higher flow velocity, as the shear stress in jet in impingement testing^[3]. The horizontal flow velocity (see [Figure 2](#), Key 6) shows a maximum at the location approximately 1 mm from the centre and gradually lowered as the circumference is approached. The fluctuation of horizontal (see [Figure 2](#), Key 8) and vertical (see [Figure 2](#), Key 9) flow velocities are highest at the location approximately 2 mm from the centre. In general, the fluctuation of flow velocity represents the intensity of turbulence in fluid flow.



Key

- X distance from the centre of the specimen, in mm
- Y flow velocity, in $\text{m}\cdot\text{s}^{-1}$
- 1 specimen (16 mm in diameter)
- 2 nozzle (1,6 mm in diameter)
- 3 centre of nozzle and specimen
- 4 slit (0,4 mm in width)
- 5 schematic model of jet flow
- 6 horizontal flow velocity (\rightarrow)
- 7 vertical flow velocity (\downarrow)
- 8 horizontal flow velocity fluctuation (\leftrightarrow)
- 9 vertical flow velocity fluctuation (\updownarrow)

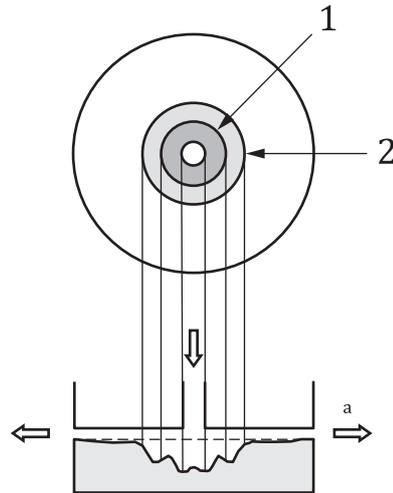
Figure 2 — Hydrodynamic condition of jet flow in nozzle and slit

4.3 Typical damage pattern

A typical damage pattern after jet-in slit test is shown in [Figure 3](#)^[4]. Damage ring 1 is formed by the separation of corrosion product film by the highly vertical and horizontal velocity, i.e. shear stress (see [Figure 2](#), Key 3 and Key 4), whereas damage ring 2 is formed due to that by turbulence in the flow (see [Figure 2](#), Key 5 and Key 6).

4.4 Material and solution

This document can be applied to various types of metallic materials by choosing appropriate test solutions and conditions. For copper and copper alloys, the solution examples are in seawater or industrial water environments. This test method has already been put to practical use in the industry. For steels and steel alloys, the solution examples are in various boiler water environments. This test method has been validated in the laboratory^{[5],[6]}.



Key

- 1 inner damage ring
- 2 outer damage ring
- a Solution flow.

Figure 3 — Surface and cross-section of a pure copper specimen after jet-in-slit test in 12,7 g (CuCl₂ · 2H₂O) /1 cupric chloride (II) solution^[4]

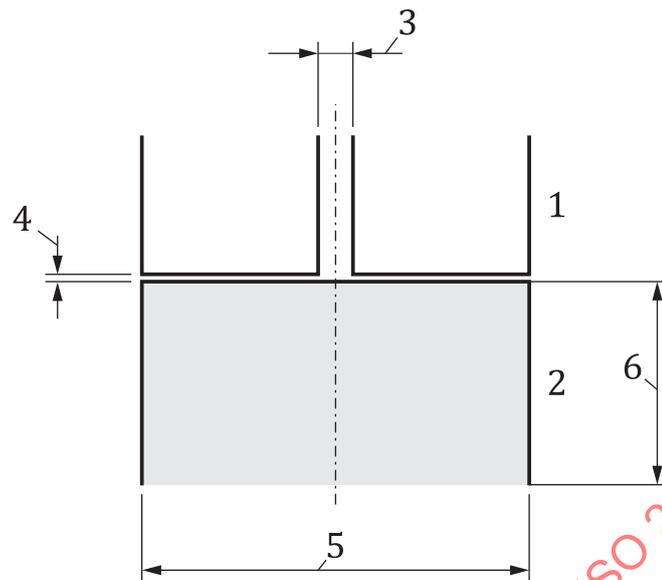
5 Apparatus

5.1 Nozzle and specimen

The required size and arrangement of nozzle and specimen is shown in [Figure 4](#). The specimen shall be set coaxially with nozzle. The meeting surfaces of nozzle and specimen shall be finished with JIS P600^[7] or finer abrasive cloth or paper after machining. The surfaces shall be polished to a maximum surface roughness of 0,8 µm. The circular edges of the specimen shall be smooth, but the chamfer or radius shall not exceed 0,15 mm.

NOTE The number of JIS P600^[7] corresponds to ISO P600^[8].

Dimensions in millimetres

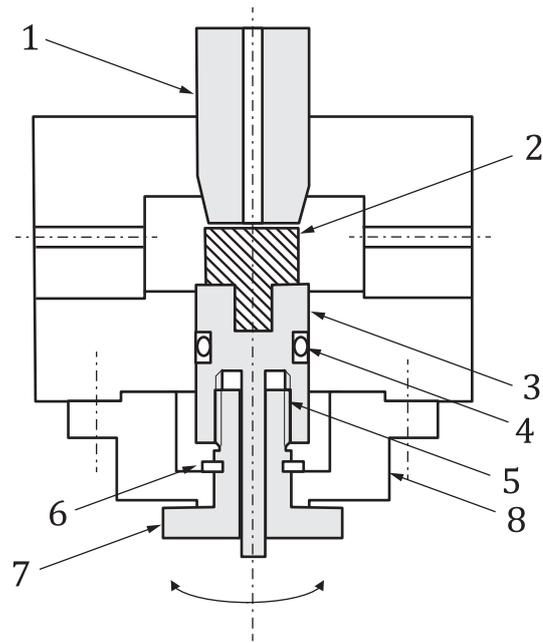
**Key**

- 1 nozzle
- 2 specimen
- 3 diameter of $1,6 \text{ mm} \pm 0,05 \text{ mm}$
- 4 width of $0,4 \text{ mm} \pm 0,01 \text{ mm}$
- 5 diameter of $16,0 \text{ mm} \pm 0,05 \text{ mm}$
- 6 given dimension

Figure 4 – Nozzle and specimen**5.2 Test chamber**

An example of test chamber is shown in [Figure 5](#). The specimen shall be mounted on the specimen holder. First press the specimen to the lower end of the nozzle, and then gradually lower it, by moving the slit adjuster (the slit adjuster can move up and down by rotation). The specimen holder height is adjusted to give the correct width of the slit using a dial gauge with needle to measure the position of the bottom face of the slit adjuster.

For testing, the testing apparatus should be made of an appropriate material for its corrosion resistance, easiness in assembling and high transparency to observe the inside of the chamber.



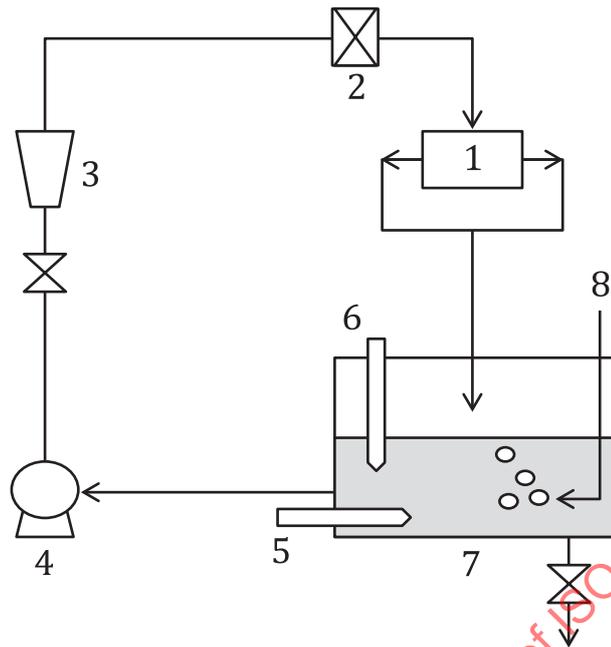
Key

- 1 nozzle (polymer)
- 2 specimen
- 3 specimen holder (polymer, vertical moving only, no rotation)
- 4 o-ring (rubber)
- 5 slit-adjusting screw (polymer)
- 6 c-ring (metal)
- 7 slit adjuster (polymer, rotation only, no vertical moving)
- 8 cover (polymer)

Figure 5 — Test chamber assembly

5.3 Test solution circuit

A test solution circuit is shown in [Figure 6](#). The test can be conducted in either an open or closed system. The open system uses the test solution supply with the discharge running to a suitable collection container, while in the closed system the test solution is recirculated. All system components shall be made of corrosion resistant material in the test solution. For a closed system, the reservoir solution volume shall be large enough to ensure that the concentration of dissolved species does not affect the test results.

**Key**

- 1 test section
- 2 filter
- 3 flow meter
- 4 pump
- 5 heater
- 6 thermometer
- 7 tank
- 8 air (where necessary)

Figure 6 — Test solution circuit**6 Test conditions and procedure**

- a) Prepare test specimens and a test solution (an example of test conditions is shown in [Annex A](#)).
- b) Preliminary tests shall be carried out in order to check the reproducibility of the test parameters and to determine optimum duration for which reliable and meaningful test results can be obtained with adequate accuracy.
- c) Measure the dimensions of the test specimen.
- d) The specimen surface shall be free of significant scratches and foreign matter. After washing the specimen with distilled water and ethanol, and dried with an air drier, it shall be cooled in a desiccator to room temperature.
- e) Measure the weight of the specimen by the balance with 0,1 mg accuracy, and mount the specimen in the test chamber within 10 min.
- f) Air should blow continuously for tests in a solution saturated with air.
- g) The test solution or single-phase solution shall not contain any gas bubbles and solid particles. The flow rate of test solution shall be varied from 0,01 l·min⁻¹ up to 1,0 l·min⁻¹. The flow rate shall be kept constant during the test.

- h) The temperature shall be maintained at $43\text{ °C} \pm 3\text{ °C}$ for the application (see [Annex A](#)). The temperature is controlled by the on/off button of the heater.
- i) After the test is completed, the specimen shall be quickly removed from the test chamber within 10 min. After washing with distilled water and ethanol, the specimen shall be dried in air, it shall be cooled in a desiccator to room temperature. The reason of quickly removing samples is to prevent the progress of corrosion after the test is over.
- j) The specimen shall be weighted and the topography shall be measured with a suitable contacting and non-contacting method. A photograph shall be taken.

7 Test report

The test report shall include the following information:

- a) a reference to this document (i.e. ISO 24020:2022),
- b) a full description of the test material; composition, method of manufacture of the specimen, details of the surface preparation and heat treatment,
- c) chemical composition, pH, temperature ($^{\circ}\text{C}$) and dissolved oxygen concentration (mg/l) of test solution with tolerances,
- d) flow rate ($\text{l}\cdot\text{min}^{-1}$) and test duration (h),
- e) sketch or photograph of the specimen surface morphology,
- f) maximum penetration depth (μm),
- g) mass loss (mg),
- h) cross-sectional surface profile before and after test,
- i) a microstructural evaluation to show the type of corrosion (e.g. second phase attack, de-alloying),
- j) the number of tested samples,
- k) any abnormality or incident occurring during the test procedure, and
- l) the date of the test.