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Corrosion of metals and alloys — Guidelines for the corrosion testing of metals and alloys exposed in deep-sea water

Corrosion des métaux et alliages — Lignes directrices pour les essais de corrosion des métaux et alliages exposés en eau profonde

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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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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

With the developments of the offshore oil and gas industry, the activities of exploration and production of oil and gas have been extended into deep sea. Many subsea equipment and systems for oil/gas production have been deployed in deep-sea water. There are also some instruments placed in the subsea for environmental observation and scientific exploration. Corrosion is a crucial problem for these valuable installations because it seriously affects the performance, reliability and safety of these equipment and systems.

This document gives guidance on the corrosion testing of metals and alloys exposed in deep-sea water. The testing can be conducted based on the specified conditions and procedures, and meaningful comparisons may be made for different tests.

Corrosion of metals and alloys — Guidelines for the corrosion testing of metals and alloys exposed in deep-sea water

1 Scope

This document gives guidelines for the corrosion testing of metals and alloys exposed in deep-sea water, including the selection of the test site, components and assembly of the test system, specimen preparation, testing procedure, evaluation after the retrieval from exposure sites and test report.

This document is applicable to the general corrosion exposure testing of metals and alloys as well as localized corrosion tests such as stress corrosion cracking (SCC) testing, galvanic corrosion testing and crevice corrosion testing of specimens exposed in deep-sea water.

Testing with exposure in deep sea of other materials such as composites and elastomers can also be carried out with reference to these guidelines, but the evaluation of these materials after the retrieval is different from that of metals and alloys.

This document does not include the performance testing of sacrificial anodes for cathodic protection in the field of deep sea, which can be conducted using specified testing cells and equipment in the deep-sea exposure. However, this guidance can also provide useful information as reference for conducting performance testing of sacrificial anodes in deep-sea water.

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 terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
deep-sea water
sea water zone with a depth generally ranging from 200 meters to thousands of meters

Note 1 to entry: Deep-sea water has a corrosive environment with parameters such as temperature, salinity, dissolved oxygen content, microorganism and biofouling that are quite different from those in surface sea water.

3.2
test site
location where corrosion tests exposed in deep sea are performed

3.3
service environment
environment for which the corrosion data is required

3.4
test rack
structure within which the specimens or modules of specimens are housed

4   Selection of test site

The selection of test site is very important for corrosion tests exposed in deep-sea water because the environment can vary considerably at different test sites.

The selected test site should be suitable for conducting the testing. Generally, the test site should be selected with consideration of the following requirements.

a)   The environmental parameters of the test site should be representative of the service environment.

b)   The seabed at the test site should be generally flat without protruding rocks or deep traps, and the slope should be smaller than 3 %. The sediment at the seabed should be stable.

c)   The test site should be in an open area, where sea water can flow freely without being blocked in a valley or a basin.

d)   The test site should be in a place where the assembly will not be damaged by shipping, trawling or other foreseeable activities. Also, the as-set assembly at the test site should not affect the safety of foreseeable activities such as shipping and trawling.

e)   The test site should be selected in consideration of relevant rules and regulations. The risks of environmental impact and safety should be assessed prior to any activity is undertaken.

5   Assembly and components

5.1   Assembly

5.1.1   The assembly should have at least the following functions:

a)   carrying the specimens reliably during the test in deep sea;

b)   gathering the key environmental parameters related to corrosion at the test site;

c)   locating the assembly in deep sea;

d)   retrieving the assembly at the end of testing.

5.1.2   The assembly is mainly composed of the following parts:

a)   buoy(s);

b)   tension rope;

c)   test rack(s);

d)   release system;

e)   environmental parameter collection and storage unit;

f)   surface water location unit and under water location unit;

g)   anchor system.

5.1.3 The typical assembly of test system is shown in Figure 1. There may be a single test rack in the assembly. Alternatively, there may be several test racks deployed at different elevations on the assembly. This assembly with multiple test racks is longer and more complicated than the assembly with only one test rack.
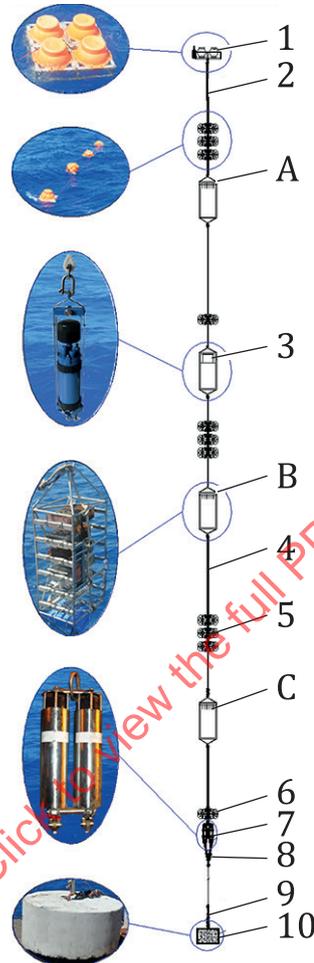
Key

1	top-of-string buoy	A	upper test rack
2	tension rope	B	middle test rack
3	environmental parameter collection and storage unit	C	lower test rack
4	tension rope		
5	buoy		
6	bottom-of-string buoy		
7	release system		
8	coupling between release system and anchor system		
9 & 10	anchor system		

Figure 1 — Diagram of a typical assembly of test system applied in deep-sea water

5.1.4 The assembly should be designed carefully to have high reliability and safety, and to be easy for the operation of deployment and retrieval. It should be fixed at the test site with an anchor system. The location of the test racks in the assembly should be determined according to the depth of sea water at which the specimens are expected to be exposed. The dimensions of the test racks should be able to contain all the specimens for the testing without interference. The buoys should be designed based on

the mass of the whole assembly to provide enough buoyancy to bring the assembly back to the surface when released from the anchor system. The design of the assembly should be carried out by a suitably qualified person.

5.1.5 The end user (and qualified personnel) is responsible for the test assembly installation, implementation and retrieval. Checks of the set up should be carried out once installed.

5.2   Test rack

5.2.1 Test rack may be made of corrosion resistant materials with proven performance in deep water environments. Alternatively, the test rack may be made of carbon steel provided it is protected from corrosion using coating and sacrificial anode cathodic protection, which should be carefully designed to avoid interference on specimens.

5.2.2 The test rack should have mechanical stability for the long-time service in deep-sea water. It should be suitable for the particular types of specimen to be deployed. Refer to 6.1 for guidance appropriate to different types of specimen.

5.3   Other parts and equipment

5.3.1   Equipment for environmental monitoring

Equipment for measuring environmental parameters should be located in or close to the test rack, so that environmental data collected is representative of the conditions to which the specimens are exposed.

Equipment is commercially available for the measurement of environmental parameters, such as oxygen concentration, temperature, conductivity of sea water, hydrostatic pressure, sea current velocity, pH value, etc., to characterize the local environment during the whole deployment period. Sensors to measure other parameters, such as SO_2 and H_2S concentration, may also be installed depending on the requirements of testing.

The equipment should be pressure-proof and have low electrical energy consumption. The data gathered will be stored automatically, so that they can be read out after the retrieval.

5.3.2   Release system

The controllable retrieval system is based on the release installed in the assembly, which can receive the signal from the surface vessel. When receiving the command for releasing, the system can automatically separate the test racks and buoys from the anchor system on the seabed. The buoys will bring the test rack and the equipment back to the surface. It is recommended that two release units in parallel configuration should be fixed in the assembly to enhance reliability for the retrieval.

5.3.3   Surface water location unit

Surface water location equipment (e.g. radio beacons) may be incorporated in the assembly to allow it to be located after returning to the surface with release from the anchor system.

5.3.4   Under water location unit

Under water location equipment (e.g. SONAR) should be incorporated in the assembly to allow it to be located *in situ*. The release system generally contains SONAR.

5.3.5   Buoys

Buoys should be suitable for the service environment. Note that glass floating spheres or syntactic foams comprising microspheres embedded in a plastic matrix are commercially available for deep

water application. Plastic shield housing should be applied to the glass floating sphere for protection from mechanical damage.

5.3.6 Connecting accessories

Connecting accessories such as shackles, swivels, fasteners, etc. should be resistant to corrosion in the deep-sea environment, and can be made from corrosion-resistant materials such as titanium and its alloys. Caution should be made to avoid galvanic action between the connecting parts.

5.3.7 Tension rope

The tension rope should be capable of withstanding the static and dynamic loads imposed during deployment, exposure and retrieval. The rope should be checked carefully. It cannot be used if defects or damages are found. Usually, high-modulus synthetic fibre ropes with proper sizes are used in the assembly.

5.3.8 Batteries

The instruments and the release installed in the assembly are powered by batteries in the containers. The batteries should have sufficient electrical capacity to conduct the tasks during the testing period of exposure in deep sea.

5.3.9 Anchor system

The anchor system is used to fix the assembly at the location of the testing site. It may be an anchor or a heavy mass (e.g. concrete block). The mass of the anchor system should be appropriate and well-considered during the design of the assembly. The anchor system is usually left on the seabed at the end of the test.

6 Specimens

6.1 Preparation of specimens

6.1.1   For the panel specimen in the exposure testing, the recommended sizes are 100 mm by 200 mm. To avoid perforation of samples during the exposure, sufficient thickness should be employed. Depending on the material and test period, the thickness can be from approximately 2 mm to 6 mm in general. Based on the practical test requirement, the specimen can also take other dimensions. For specimens having odd shapes, e.g. bolts, nuts and tubes, they should be prepared according to the requirements of the customers or the related standards. Welded specimens should be used when the welding effect is considered.

6.1.2   The specimen should be prepared using a machining approach. Caution should be taken with machining to avoid overheating and unnecessary cold working of the surface. The finish of the specimen is to be agreed with the end user. The surface state of the specimen should meet the testing requirements and the roughness, e.g. Ra should be recorded. Usually, a uniform finish should be applied to the surface of the specimen. If there are some defects such as pits or depressions left on the surface, they should be examined and recorded initially, avoiding confusion with the real corrosion attack at the completion of testing. Oil, grease and dirt on the surface should be cleaned with proper methods. Preparation of specimens is the same as that for exposure testing in surface sea water described in ISO 11306.

6.1.3   Specimens should be marked for identification during the life of the test. The marking methods should not influence the corrosion testing of specimens. Drilling holes, notches, tags or stamped codes may be used for the identification. The marks should be clear to be distinguished during the whole testing process without being faded by corrosion or other factors.

6.1.4   For tests evaluating localized corrosion, special specimen configurations may be used. The requirements of specimens for SCC tests, galvanic corrosion tests and crevice corrosion tests in the field should follow the guidelines of ASTM G71, ASTM G78, ISO 7539-2, ISO 7539-3, ISO 7539-5, ISO 7539-8, ISO 18070 and other related standards.

Galvanic corrosion may be tested with special devices that couple one specimen to another in electrical contact. However, it should be observed that galvanic corrosion will be greatly affected by the area ratio of the coupled specimens.

For stress corrosion tests, bent-beam specimens, U-bend specimens, C-ring specimens may be used for field exposure in deep sea.

6.1.5   The quantity of specimens should be determined according to the types of corrosion test, test materials or the requirements of the specific standards. Usually, the parallel samples should not be less than three in order to get reliable results.

6.1.6   The specimens should be weighed with the desired precision to determine the mass loss after test. Usually, the mass of the specimen should be accurate to ±1 mg. For measuring the dimension of the testing sample, usually the length and the width should be accurate to 0,05 mm, and the thickness should be accurate to 0,02 mm.

6.1.7   In some cases, control specimens may be used for comparisons. For example, control specimens should be tested to provide corrosion rates of the individual metals or alloys without coupling to demonstrate the galvanic corrosion effect. Control specimens without stress or strain at exposure can be used to indicate the influence of stress on the corrosion performance of materials.

6.1.8   Records should be kept of the inspection and measurement of the specimens before the exposure test. The contents should include materials to be tested, dimensions, mass and appearance of each specimen. Changes in the physical appearance and any corrosion losses of the specimen due to exposure in deep sea can then be determined.

6.2   Mount of specimens

6.2.1   It is recommended to fix the specimens into modules for easy transportation and installation. The modules can be mounted into the test racks before the deployment of the assembly. With specimens in odd shapes or mounted in special configurations for particular tests, it is essential to devise a suitable means to support them in the test racks.

6.2.2   The specimens should be supported by insulators and should not make electrical contact with each other or with the supporting test racks. The insulation sleeve can be made from nylon, polytetrafluoroethylene (PTFE) or other suitable materials.

6.2.3   Spacing of the mounted specimens is important for the tests. It is desirable to have enough space between the surfaces of specimens to ensure that adequate sea water flows through the space, and that the accumulated marine fouling and corrosion products will not block the space with long exposure. The

distance between the surfaces of the specimens can be from approximately 20 mm to 50 mm in general. The plate specimen can be fixed in series as shown in Figure 2.
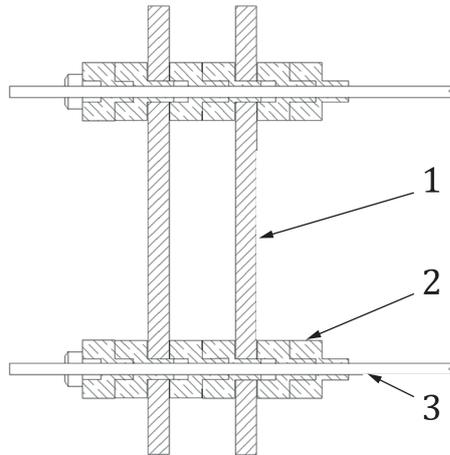
Key
1   specimen
2   insulated spacer
3   rod for fixing specimens

Figure 2 — Plate specimens mounted in the two parallel rods

6.2.4   The mounted specimens should be oriented vertically in the suspended test racks and subjected to the full effects of the sea water. Therefore, the sedimentation of silt and debris onto the specimen surface will be minimized. The specimens should be free of electrical contact with other specimens in the test racks.

6.2.5   It should be noted that the metallic ion from one specimen can influence the nearby others. For example, copper ion released from copper alloy specimen will accelerate the corrosion of aluminium specimens in the vicinity by copper deposition on aluminium. Therefore, copper coupons should be kept away as far as possible from aluminium specimens in the test racks. Shielding measures should be taken if necessary.

6.2.6   Test rack charts should be made illustrating the positions of all specimens and exposure data.

6.3   Packaging and transportation of specimens

6.3.1   The specimens should be handled carefully to avoid damage or pollution caused during packaging and transportation to the testing site.

6.3.2   Influence from humid air, splashing sea water and other corrosive media on the specimens should be avoided during transportation and storage. Proper protection should be taken for the specimens without changing the surface state. For example, the specimens and modules can be covered with plastic film to prevent corrosion from the atmosphere and sea-water splashing. Also, a desiccant can be used for scavenging humidity inside of the module.

NOTE   The protective coverage on the specimens is removed before deployment of the assembly into the sea.

7   Testing procedure

7.1   When arriving at the test site, all the parts and equipment should be checked to ensure they are in good condition without mechanical damage and malfunction. Then, the parts and equipment are assembled into a complete system. The assembly should be checked again carefully, especially the connecting parts and the joints. The instrument for measurement of water parameters should be set to work at the desired frequency of data gathering. The coverage on the specimens is removed. Any problem should not be left before the deployment.

7.2   The assembly is deployed into the sea using the lift on board the vessel. The depth and status of the assembly can be monitored with the equipment installed on the assembly and the equipment on board. When the assembly is deployed on the seabed, the final depth and the position of the test racks should be determined.

7.3   The recommended periods for the field test are 0,5, 1 and 2 years. For SCC tests, considerably shorter exposure times can be appropriate. Because the test is highly impacted by the sea conditions and the weather, the period can be adjusted according to the practical situation. Since the release and other equipment are generally powered by batteries, the test period should be within the life range of the batteries.

7.4   The test can be terminated when the scheduled test period arrives. If detections made during the test period show that the electrical energy working for the retrieval system is consumed too fast, then the test should be terminated before the schedule date.

7.5   Retrieval is normally triggered by sending a signal to the release system, causing the assembly to separate from the anchor system. This allows buoys to lift the assembly to the surface. It can take some time for this process depending on the depth of deployment and the buoyancy of the assembly.

7.6   The assembly floating on the sea is searched for and the test rack(s), equipment and other parts of the assembly are retrieved. The specimens or modules should be cleaned by dipping in fresh water and dried naturally. Attention should be paid to preventing changes in the surface conditions of the corroded specimens. The parts of the assembly should be dismantled and inspected. The connecting parts, ropes, buoys, release system and other devices that can be used again next time should be cleaned and reserved. The end user should have traceable cleaning procedures in place. The end user can decide where the assembly parts will be disposed of or where they will be stored in such conditions (if not damaged during the long-term exposure) that would allow their re-use.

7.7   The test racks, including specimens, should be stored under controlled conditions, up to the time of laboratory analysis, to prevent deterioration. Storage conditions can be different for different materials. It is highly recommended that the specimens are stored in a dry/inert environment until their examination and during their transportation to minimize as much as possible any post-test atmospheric exposure effect that could compromise the reliability of the data and surface condition of the test specimens. In no circumstances should they be stored in an open-air atmosphere near the sea or a coastal air atmosphere.

8   Evaluation of specimens

8.1   Using camera or video, the appearance and state of the test rack and the specimens should be recorded.

8.2   If there is marine biofouling on the surface of the specimen, a plastic or wooden scraper should be used to scrape off the marine growth without scratching the underneath substrate.

8.3   The specimen should be cleaned in accordance with the recommendations in ISO 8407. Then, the specimen should be reweighed to an appropriate degree of precision. For certain tests, corrosion