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Standard
Recommended Practice

Metallurgical and Inspection Requirements for Offshore Pipeline Bracelet Anodes

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Foreword

The purpose of this standard recommended practice is to set minimum physical quality and inspection requirements for cast galvanic anodes for offshore pipeline applications. The objectives are to standardize an industry-wide practice that can be used by consultants, manufacturers, and users to define the physical requirements of anodes; and to be sufficiently specific to assist inspection authorities in their task of confirming that anodes comply with the physical requirements. This standard is applicable to typical half-shell or segmented bracelet-type anodes.

This standard was originally prepared in 1992 by Task Group T-7L-9, a component of Unit Committee T-7L on Cathodic Protection. It was reaffirmed by T-7L in 1999 and is published under the auspices of Group Committee T-7 on Corrosion by Waters.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 3rd. ed., Paragraph 8.4.1.8. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state that which is considered good and is recommended but is not absolutely mandatory. *May* is used to state that which is considered optional.

NACE International
Standard
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Contents

Section 1: General

1.1 This standard defines minimum physical quality and inspection requirements for bracelet galvanic anodes for offshore pipeline applications, including risers and J-tubes.

1.2 This standard is applicable to the majority of bracelet-type anodes used on offshore pipelines, i.e., anodes of half-shell or segmented configurations. For other anode designs, such as semi-cylindrical segments with cast-in longitudinal notches, an experienced corrosion specialist should be responsible for defining the acceptance criteria.

1.3 This standard does not specify particular anode alloy compositions or define short- or long-term performance tests.

1.4 This standard does not specify particular anode or anode insert designs. An experienced corrosion specialist should be responsible for anode and anode insert design.

1.5 Although some aspects of this standard may be relevant to other types of galvanic anodes, it is not intended to apply to platform, hull, tank, or extruded-type anodes.

1.6 This standard does not address electrochemical or other anode performance test procedures. NACE Standard TM0190[1] gives a standardized short-term potential and capacity determination test procedure for quality control purposes in international laboratories.

1.7 The manufacturer is responsible for meeting the quality levels specified in this standard. The purchaser shall determine the extent of inspection to be conducted by the purchasing organization to prove compliance with the quality specified.

Section 2: Definitions

Bracelet Anodes: Anodes with geometry suitable for direct attachment around the circumference of a pipeline. These may be half-shell bracelets consisting of two semi-circular sections or segmented bracelets consisting of a large number of individual anodes.

Certificate of Conformity: A statement from the manufacturer's representative (executive) and endorsed by a representative of the purchaser affirming that the anodes listed comply with the requirements of the order.

Cold Lap: Horizontal discontinuity caused by solidification of the meniscus of a partially cast anode as a result of interrupted flow of the casting stream. The solidified meniscus is covered with metal when the flow resumes. Cold laps can occur along the length of an anode.

Cold Shut: Horizontal surface discontinuity caused by solidification of a portion of a meniscus during the progressive filling of a mold, which is later covered with more solidifying metal as the molten metal level rises. Cold shuts generally occur at corners remote from the point of pour.

Cracking: Fracture of metal along an irregular path producing a discontinuity similar to a ragged edge. It can occur during the solidification of the anode (hot cracking), during the contraction of the anode after solidification, or under externally applied loads. Hot cracking may be associated with the shrinkage depression that can occur in open-topped molds.

Dulling of Steels: Deterioration in the appearance of shot-blasted inserts due to oxidation that causes darkening of the surface but not rust discoloration (see *Rust Discoloration*).

Electrochemical Properties: Those properties of potential and current capacity that characterize a sacrificial anode and can be assessed by quantitative tests.

Gas Holes: Evidence of bubbles within the solidifying metal. The holes can indicate that moisture was on the mold or insert prior to casting or that the liquid metal contained a high level of hydrogen that formed bubbles during cooling of the metal.

Heat: Also called a *melt* or *cast*, it is the unit that defines molten metal and identifies the anodes cast from it. A heat is the product that is cast to a planned procedure in one melting operation in one furnace, without significant interruption. If the casting sequence is interrupted, the anodes produced before, between, and after the interruption constitute *batches*.

Insert: The form over which the anode is cast. This is sometimes referred to as a *core*.

Low-Carbon Steel: Steel having less than 0.30% carbon and no intentional alloying additions.

Nonmetallic Inclusions: Particles of oxides and other refractory materials entrapped in liquid metal during the melting or casting sequences.

Porosity: Uniformly distributed fine holes caused by gas bubbles, shrinkage (formed by the starvation of eutectic material within the dendrite arms during "unfed" solidification), or a combination of the two mechanisms when hydrogen in solution diffuses into the lower-pressure shrinkage voids.

Protrusion: Extraneous material on the anode surface that may interfere with the anode-to-structure fit, or may be a safety hazard. Protrusions can be formed by careless filling of the mold or the flash from imperfect fitting of mold sections.

Rimming (Rimmed) Steels: An incompletely deoxidized steel. (See *ASM*[1] *Handbook*, Desk Ed.,[2] for a detailed definition.)

Rust Discoloration: A brown bloom of iron oxide.

Sacrificial Anodes: The negative (reactive) components of a galvanic cell, designed to oxidize sacrificially and produce direct electrical current to protect a more electropositive (noble) metal operating in the same electrolyte and produced to a desired shape by the solidification of a molten alloy in a mold or die.

Sample: A representative specimen.

Shrinkage Depression: The natural concave surface produced when liquid metal is allowed to solidify in a container without the provision of extra liquid metal to compensate for the reduction in volume that occurs during the liquid-solid transformation. The term also applies to the concave surface produced when liquid metal is solidified in a closed mold in such a manner that the area is not "fed" by the liquid metal provided by the casting's riser.

Tap Sample: A specimen taken from a molten metal stream. Such samples may be taken at the commencement of pouring and then at regular intervals until a final sample is taken at the end of the pour.

Voids Adjacent to Insert: Visible spaces between anode and insert materials. These can be caused by surface evaporation of moisture from the insert, contraction of the insert, or movement of the insert during casting caused by uneven heating and expansion that distorts the insert and prevents it from returning to its original, desired position within the anode.

Section 3: Physical Requirements of Anodes

3.1 Samples for Chemical Analysis

3.1.1 Representative tap samples shall be taken at the beginning and end of each heat. All samples shall be hard stamped or engraved with the heat number and retained for the contract period.

3.1.2 The samples shall be analyzed to prove compliance with the agreed chemical composition limits of the alloy being produced.

3.2 Anode Identification

3.2.1 Each anode individual casting shall be marked with its unique heat number and the manufacturer's mark. For as-treated anodes, a heat-treatment batch number shall be provided on each anode.

3.3 Anode Weight

3.3.1 The net weight of individual anode castings shall be greater than 97% of the design net weight.

3.3.2 An agreed sample of anode castings shall be weighed, either individually or in small batches, to confirm general compliance with Paragraph 3.3.1.

3.3.3 The total supplied net weight shall not be below the nominal net contract weight.

3.4 Anode Dimensions and Straightness

3.4.1 Dimensions shall conform to the following:

3.4.1.1 The mean length of the anode casting shall be ±3% of nominal length or ±25 mm (1.0 in.), whichever is smaller.

3.4.1.2 Anode internal diameter shall conform to the following dimensional tolerances (for semi-cylindrical, see Paragraph 1.2):

(a) - 0 + 4 mm (0.16 in.) for pipeline diameters ≤30 cm (12 in.);

(b) - 0 + 6 mm (0.24 in.) for pipeline diameters >30 cm (12 in.) and ≤61 cm (24 in.); and

(c) - 0 + 1% for pipeline diameters >61 cm (24 in.).

3.4.1.3 The dimensional tolerance on the anode thickness shall be ±3 mm (0.12 in.).

[1] ASM International (ASM), 9639 Kinsman Rd., Materials Park, OH 44073-0002.

3.4.2 Anodes shall be free from excessive bowing or twisting. This shall be verified on a completely assembled bracelet by fitting to a full-length former or by another agreed method. The external diameter shall not exceed the summation of the tolerances given in Paragraphs 3.4.1.2 and 3.4.1.3.

3.4.3 For all anodes, the anode and anode insert dimensions shall be suitable for the proposed fitting requirements.

3.4.4 The number of samples to be measured to prove compliance with Paragraphs 3.4.1 and 3.4.2 shall be subject to agreement prior to manufacture.

3.5 Insert Dimensions and Position

3.5.1 Any special provisions needed to make the insert a suitable means of attachment shall predominate in the requirements of Paragraphs 3.4, 3.5, 3.6, and 3.7.

3.5.2 Anode insert cross-section dimensions shall comply with the appropriate specification for the insert material used.

3.5.3 Tolerances on insert position within the anode shall be subject to agreement prior to manufacture.

3.5.4 Anode insert protrusions, fixing centers, and any other critical dimensions specified in the contract pursuance of Paragraph 3.5.1 shall be measured on samples of all anodes of each type. The number of samples shall be agreed on prior to manufacture.

3.6 Insert Material

3.6.1 Inserts shall be fabricated from weldable structural steel plates or sections having physical properties required by the design.

3.6.2 Rimming steels shall not be used.

3.6.3 The carbon equivalent of insert materials shall not exceed 0.45%. The carbon equivalent value (C_{ev}) shall be calculated using Equation (1):

$$C_{ev} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \qquad (1)$$

where each element is expressed in weight percent (wt%).

3.6.3.1 Only elements that are included in the specified chemical composition of a given standard steel type shall be considered in the above formula.

3.6.4 Subject to meeting the requirements of Paragraphs 3.6.1, 3.6.2, and 3.6.3, the following types of specifications are acceptable:

Plate, bar sections:
BS[(2)] 4360[3] Grade 43A or 50D
ASTM[(3)] A 283[4] Grade C

3.6.5 For low-temperature applications, consideration shall be given to the notch toughness of the insert material—in particular, to the toughness of the insert material to be welded to the pipeline.

3.7 Fabrication of Inserts by Welding

3.7.1 All fabrication welding of steel inserts shall be in accordance with the relevant requirements of AWS[(4)] D1.1,[5] or an approved equivalent.

3.7.2 Qualification of welders and of welding procedures shall be in accordance with the requirements of AWS D1.1, or an approved equivalent.

3.7.3 All welds shall be visually inspected.

3.7.3.1 The level and type of other nondestructive testing inspection shall be agreed on prior to manufacture.

3.8 Insert Surface Preparation

3.8.1 For aluminum anodes, the steel fabrication to be inserted into the cast anode shall be prepared by a dry blast-cleaning process to a minimum quality complying with SIS[(5)] 05 5900[6] Sa 2-1/2 or its equivalent, i.e., NACE No. 2/SSPC-SP 10.[7]

3.8.2 At the time aluminum anodes are cast, “dulling” of the blast-cleaned surface of the insert shall be permitted. Rust discoloration and/or visible surface contamination of the blast-cleaned surface shall not be permitted.

3.8.3 For zinc anodes, the steel fabrication to be inserted into the cast anode shall be prepared by dry blast cleaning to SIS 05 5900 Sa 2-1/2, galvanizing to BS 729,[8] or zinc electroplating to BS 1706,[9] or equivalents.

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(2) British Standards Institution (BSI), 2 Park St., London, WIA 2BS, England.
(3) ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.
(4) American Welding Society (AWS), P.O. Box 251040, Miami, FL 33126.
(5) Swedish Standards Institution, Box 6455, 5-113, 82, Stockholm, Sweden.

3.8.4 At the time zinc anodes are cast, “dulling” of the blast-cleaned surface of the insert shall be permitted. Rust discoloration and/or visible surface contamination of the blast-cleaned or zinc-coated surface shall not be permitted.

3.9 Surface Irregularities on the Anode Casting

3.9.1 Shrinkage depressions shall not exceed 10% of the thickness of the anode as measured from the uppermost corner to the bottom of the depression. Shrinkage depressions that expose the insert are not acceptable.

3.9.2 Casting surface irregularities shall be fully bonded to the bulk anodic material.

3.9.3 Cold shuts or surface laps shall not exceed a depth of 10 mm (0.4 in.) or extend over a total length of 150 mm (5.9 in.).

3.9.4 All protrusions detrimental to the safety of personnel during handling of the anode(s) shall be removed. No further grinding or mechanical treatment of effective anode surface shall be permitted. The crack criteria of this standard apply to the as-cast condition. No treatment shall be applied to grind, peen, or in any manner dress cracks before inspection and checks are made against the criteria of Paragraphs 3.10.3 and 3.10.4.

3.9.5 Anodes shall be inspected visually to confirm compliance with Paragraphs 3.9.1 to 3.9.4.

3.10 Cracks in Cast Anodic Materials

3.10.1 Even with good foundry practice, particular compositions of anode alloy (notably aluminum-based) suffer a degree of cracking.

3.10.2 For sections of anodic material not completely supported by the anode insert, no visible cracks shall be permitted subject to the criteria defined in Paragraph 3.10.3.

3.10.3 The following cracks shall be allowed:

3.10.3.1 Longitudinal cracks of width ≤0.5 mm (0.02) in. and length <20% of the anode length.

3.10.3.2 Circumferential/transverse cracks of width ≤0.5 mm (0.02 in.) and length <50% of the internal anode diameter.

3.10.4 The following cracks are unacceptable:

(a) width >3 mm (0.12 in.), and either

(b) length >50% of the anode length for longitudinal cracks, or

(c) length >50% of the internal anode diameter for circumferential/transverse cracks, or

(d) depth >50% of the thickness of the anode material covering the insert.

3.10.5 Acceptance criteria for other cracks not defined in Paragraphs 3.10.3 and 3.10.4 depend on insert and anode design and shall be subject to agreement prior to manufacture.

3.10.6 A sample of anodes shall be inspected to confirm compliance with Paragraphs 3.10.3 and 3.10.4 and shall be agreed on prior to manufacture.

3.11 Anode Sections and Internal Defects

3.11.1 The number and method of selection of anodes to be sectioned during a contract should be determined based on insert and anode design. The number of anodes shall be agreed on prior to manufacture.

3.11.2 Anodes shall be sectioned transversely and/or longitudinally by single cuts at 25%, and 50% of nominal length, or at such other agreed-on locations for a particular anode design.

3.11.3 The cut faces, when examined visually without magnification, shall not have more than:

3.11.3.1 Two percent of the sum of the surface area, or more than 5% of any one surface as gas holes.

3.11.3.2 One percent of the sum of the surface area, or more than 2% of any one surface as nonmetallic inclusions.

3.11.3.3 Ten percent of the insert circumference-containing voids adjacent to the insert as an average of all sections, the maximum for any one section being 20%. The method of determining the above defect areas shall be subject to agreement prior to manufacture.

3.11.4 The insert position within the anode shall be confirmed by measurement on the cut faces.

3.12 Coating

3.12.1 When specified, coatings shall be applied only after inspection in accordance with Paragraphs 3.9 and 3.10.

3.12.2 Coatings shall be applied and inspected in accordance with the coating manufacturer’s instructions and/or a procedure agreed on prior to manufacture.

3.13 Heat Treatment

3.13.1 For anodic alloys for which post-casting heat treatment forms part of the specification for the materials manufacture, the heat-treatment history of each batch of anodes, i.e., each heat-treatment furnace charge, shall be recorded.

3.13.2 The temperature of the furnace and of a representative anode in each charge shall be recorded continuously throughout the heat treatment.

3.13.3 The manufacturer shall provide calibration records from a recognized national standards authority for the temperature-sensing and recording equipment and shall produce correlation between furnace temperature, anode surface temperatures, and anode center temperatures sufficient to demonstrate that all anodes in a particular charge are adequately heat treated.

3.14 Packing and Shipment

3.14.1 Anodes shall be bundled, strapped, placed on pallets, or individually loaded by an agreed-on procedure to facilitate unloading and minimize damage to anodes and inserts between the manufacturing plant and the installation site.

3.15 Repeat Measurements, Tests, Inspections, and Rejections

3.15.1 If in any instance the sample fails to meet the specified requirement in this standard, the manufacturer shall have the right to double the size of the sample to indicate general compliance with this standard.

3.15.2 If under Paragraph 3.15.1, the larger sample size results in more failures, the sample may be increased to include all of the anodes, and all anodes not complying with this standard may be rejected.

Section 4: Documentation of Inspection

4.1 General

4.1.1 Documentation shall be considered in two parts:

4.1.1.1 The retained documentation collected by the manufacturer during the normal quality control procedures, which shall be maintained by the manufacturer and made available for viewing or copying on request from the purchaser; and

4.1.1.2 The documentation that shall be provided to the purchaser by the manufacturer.

4.2 Retained Documentation

4.2.1 Retained documentation shall be available for the purchaser's inspection at the manufacturer's plant during the contract period and, subject to reasonable notice, for a period of two years thereafter.

4.2.2 Analysis results produced from Paragraphs 3.1.1 and 3.1.2 shall refer to individual heat numbers and shall form part of the retained documentation.

4.2.3 Heat-treatment records (when required) from Paragraph 3.13.1 shall refer to individual batch numbers and shall form part of the retained documentation.

4.2.4 Any electrochemical performance tests (not specified in this standard) undertaken by the manufacturer shall refer to individual heat numbers (and batch numbers, if applicable) and shall form part of the retained documentation.

4.2.5 All welding procedure qualification records, raw material certificates, and inspection records shall form part of the retained documentation.

4.3 Supplied Documentation

4.3.1 A certificate of conformity certifying that the anodes comply in all respects with this standard and the purchase order shall be supplied by the manufacturer.

4.3.2 Shipping documentation shall be provided to give evidence of compliance with Paragraph 3.3.

4.3.3 In addition to the certificate of conformity, the purchaser may require copies of any or all of the retained documentation. This shall be supplied by the manufacturer as required.

References

1. NACE Standard TM0190 (latest revision), “Impressed Current Test Method for Laboratory Testing of Aluminum Anodes” (Houston, TX: NACE International).
2. ASM Handbook, Desk Ed. (Materials Park, OH: ASM, 1985).

3. BS 4360 (latest revision), “Specification for Weldable Structural Steels” (London, England: BSI).

4. ASTM A 283 (latest revision), “Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates” (West Conshohocken, PA: ASTM).

5. AWS D1.1 (latest revision), “Structural Steel Welding Code-Steel” (Miami, FL: AWS).

6. SIS 05 5900 (latest revision), “Pictorial Surface Preparation Standards for Painting Steel Surfaces” (Stockholm, Sweden: SIS).

7. NACE No. 2/SSPC-SP 10 (latest revision), “Near-White Metal Blast Cleaning” (Houston, TX: NACE International, and Pittsburgh, PA: SSPC).

8. BS 729 (latest revision), “Hot Dip Galvanized Coatings on Iron and Steel Articles” (London, England: BSI).

9. BS 1706 (latest revision), “Electroplated Coatings of Cadmium and Zinc on Iron and Steel” (London, England: BSI).