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Standard Practice for Surveillance Testing of High-Temperature Nuclear Component Materials[1]

This standard is issued under the fixed designation E 531; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε1 NOTE—Keywords were added editorially in August 1996.

1. Scope

1.1 This practice covers procedures for specimen testing to establish changes occurring in the mechanical properties due to irradiation and thermal effects of nuclear component metallic materials where these materials are used for high temperature applications above 370°C (700°F).

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

E 3 Methods of Preparation of Metallographic Specimens[3]

E 8 Test Methods for Tension Testing of Metallic Materials[3]

E 21 Test Methods for Elevated Temperature Tension Tests of Metallic Materials[3]

E 23 Test Methods for Notched Bar Impact Testing of Metallic Materials[3]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[4]

E 45 Test Methods for Determining the Inclusion Content of Steel[3]

E 112 Test Methods for Determining the Average Grain Size[3]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[3]

E 184 Practice for Effects of High-Energy Neutron Radiation on the Mechanical Properties of Metallic Materials, E706 (IB)[5]

E 185 Practice for Conducting Surveillance Tests for Light Water-Cooled Nuclear Power Reactor Vessels, E706 (IF)[5]

E 206 Definitions of Terms Relating to Fatigue Testing and the Statistical Analysis of Fatigue Data[6]

E 261 Practice for Determining Neutron Fluence Rate, Fluence, and Spectra by Radioactivation Techniques[5]

E 399 Test Method for Plane-Strain Fracture Toughness of Metallic Materials[3]

E 453 Practice for Examination of Fuel Element Cladding Including the Determination of the Mechanical Properties[5]

E 482 Guide for Application of Neutron Transport Methods for Reactor Vessel Surveillance, E706 (IID)[5]

E 844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance, E706 (IIC)[5]

3. Significance and Use

3.1 The requirements contained herein can be used as a basis for establishing conditions for safe operation of critical components. The requirements provide for general plant assessment and verification that materials meet design criteria. The test specimens and procedures presented in this practice are for guidance when establishing a surveillance program.

3.2 This practice for high-temperature materials surveillance programs is used when nuclear reactor component materials are monitored by specimen testing. Periodic testing is performed through the service life of the components to assess changes in selected material properties that are caused by neutron irradiation and thermal effects. The properties are those used as design criteria for the respective nuclear components. The extent of material property change caused by neutron irradiation depends on the composition and structure of the initial material, its conditioning in component fabrication, as well as the nature of the irradiation exposure. The need for surveillance arises from a concern of specific material behavior under all irradiation conditions including spectrum and rate effects on material properties.

4. Description of Term

4.1 *test specimen*—a coupon or a piece of metal cut from a larger metal piece which is then formed to final size for testing to determine physical or mechanical properties.

5. Test Specimens

5.1 *Pre-Exposure Material Characterization*—It is important that test specimen materials be characterized prior to exposure and that the following should be considered as a minimum:

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[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] *Annual Book of ASTM Standards*, Vol 12.02.

[6] Discontinued—see *1986 Annual Book of ASTM Standards*, Vol 03.01.

5.1.1 Process history, material designation, manufacturer, heat number, weld and fabrication procedures used, and heat treatment,

5.1.2 Original location and orientation in the parent material,

5.1.3 Specimen weight and dimensions,

5.1.4 Metallographic characteristics (grain size, microstructure, and inclusion content established in accordance with Test Methods E 45 and E 112),

5.1.5 Chemical analysis results,

5.1.6 All specimens shall be taken from the specified location and orientation specified in Test Methods and Definitions A 370 and Test Methods E 8, and

5.1.7 Mechanical properties including yield strength, tensile strength, stress rupture life, creep strength, fatigue strength, and impact strength as a function of test temperature.

5.1.8 The information described in 5.1.1-5.1.7 should be reported in a single document.

5.2 *Post Exposure Material Characterization*—After exposure, the following should be reported:

5.2.1 Observations from visual examination,

5.2.2 Changes in specimen weight and dimensions,

5.2.3 Metallographic characteristics (grain size, microstructure, and inclusion content),

5.2.4 Results of chemical analysis,

5.2.5 Appropriate mechanical properties being surveyed including considerations of changes in tensile strength, stress-to-rupture strength, creep strength, fatigue strength, impact strength (control tests are recommended to be performed simultaneously with the tests of exposed specimens to ensure that deviations in test results can be attributed to the exposed specimen's environment and not to variations in testing methods), and

5.2.6 Optional quantitative examination of surface chemistry and subsequent changes.

5.2.7 Exposed test specimens should be cleaned in accordance with accepted cleaning procedures. (Refer to Subcommittee G01.08 for practices for preparing, cleaning, and evaluating test specimens.)

5.3 *Specimen Preparation*—Test specimens shall be standard recommended specimens where possible as described in Test Methods E 8, E 21 and E 23 and Practice E 139. The use of the word *specimen* or words *test specimen* as used in this practice is described in Section 4.

5.3.1 The test area of a specimen (for example, Charpy notch, reduced section of a fatigue specimen) may be left unfinished if further environmental exposure prior to testing is anticipated.

5.3.2 *Size*—In general, due to the limited space available in surveillance capsules the smaller sizes of test specimens are recommended. Where it is not possible to use specimens of the recommended size, the least deviation possible from recommended sizes should be adhered to. Non-standard specimens shall be evaluated prior to use as surveillance specimens to ensure that test results from the use of non-standard specimens can be correlated with test results from specimens of recommended size. In the event that non-standard specimens are used for surveillance specimens, the archive, base line, and thermal control specimens shall be identical with the surveillance specimens.

5.3.3 *Surface Condition*—Test specimens where surface condition is critical to the test results should not be finish machined in such critical areas (Charpy notch, fatigue specimen test area, surface of density change sample) until just prior to test. Specimens should be oversized to allow for removal of at least 0.1 mm of surface prior to test. Where possible, test specimens with the exception of weight change specimens shall be encapsulated in an inert environment so as to determine only the effect of neutron irradiation and temperature on mechanical or physical properties. It is recognized the integrity of the encapsulation may be breached in some cases during long exposure and an allowance for final machining even of the encapsulated specimens should be considered. This will ensure a meaningful comparison between baseline and exposed specimens.

5.3.4 *Number of Specimens*—The number of specimens employed for mechanical property testing should be selected so as to include each critical component that varies significantly in composition, processing, or in exposure conditions from similar components. Specific recommendations as to number of specimens will be found in the respective specimen sections. At least four sets of specimens shall be included in each surveillance program.

5.3.5 *Material*—Test specimens shall be taken from the material used in component fabrication. The material shall be processed at the same time as the component or processed in a fashion identical to the component surveyed. Weld and heat-affected zone test specimens shall be taken from equivalent material welded at the same time as the particular component or equivalent material welded with the same welding parameters. It is not necessary to include each heat or minor variation, but only to select those receiving the highest exposure or those previously found to be most sensitive to neutron irradiation and temperature or those that can restrict the operation of the reactor. Test specimens may be taken from components periodically removed from the reactor for other reasons. These specimens can be used to provide supplemental surveillance information. For this information to be meaningful a full characterization of the pre-exposure condition must be available along with measured exposure conditions.

5.4 *Tension Test Specimens*—The type and size of specimen to be used shall conform to the smaller sizes as recommended in Test Methods E 8 and E 21. Either threaded or button-head ends will be acceptable. For plate or sheet specimens, pin ends as described in Test Methods E 8 are recommended. The location and orientation of test specimens shall be as defined in Test Methods E 8 or Test Methods and Definitions A 370, or in Practice E 185. Both base metal and weld metal specimens will be taken. A set of tension specimens shall consist of three each base metal and weld metal.

5.5 *Creep and Stress-Rupture in Specimens*—The type and size of specimen to be used shall be the same as those used for tension specimens except that button-head or pinned-end specimens are recommended for high-temperature testing. Practice E 453 describes the attention that must be paid to specimen alignment and dimensional tolerances. One set of