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Standard Specification for Seamless Austenitic and Martensitic Stainless Steel Duct Tubes for Liquid Metal-Cooled Reactor Core Components[1]

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1. Scope

1.1 This specification covers seamless, annealed or cold worked, austenitic or martensitic stainless steel duct tubes of 2 to 7-in. [51 to 178 mm] outside dimensions with wall thickness of 0.250 in. [6.35 mm] or less for use at high temperature in liquid metal-cooled reactor plants.

1.2 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.3 This specification and the applicable material specifications are expressed in both inch-pound and SI units. However, unless the order specifies the applicable "M" specification designation (SI units), the material shall be furnished in inch-pound units. [2]

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[3]

A 380 Practice for Cleaning and Descaling Stainless Steel Parts, Equipment and Systems[4]

A 450/A450M Specification for General Requirements for Carbon, Ferritic Alloy, and Austenitic Alloy Steel Tubes[5]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[3]

D 129 Test Method for Sulfur in Petroleum Products (General Bomb Method)[6]

D 808 Test Method for Chlorine in New and Used Petroleum Products (Bomb Method)[6]

E 3 Methods of Preparation of Metallographic Specimens[7]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[8]

E 45 Practice for Determining the Inclusion Content of Steel[7]

E 112 Test Methods for Determining the Average Grain Size[7]

E 165 Test Method for Liquid Penetrant Examination[9]

E 384 Test Method for Microhardness of Materials[7]

E 407 Test Methods for Microetching Metals and Alloys[7]

2.2 *ANSI Standard:*

ANSI B46.1 Surface Texture[10]

2.3 *ASME Standard:*

ASME NQA-1 Quality Assurance Program Requirements for Nuclear Facilities[10]

2.4 *ASNT Standard:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification[10]

3. Ordering Information

3.1 It is the responsibility of the purchaser to specify all requirements that are necessary for the safe and satisfactory performance of material ordered under this specification. Examples of such requirements include but are not limited to the following:

3.1.1 Quantity (feet, metres, or number of lengths),

3.1.2 Name of material (seamless duct tubes),

3.1.3 Grade (Table 1),

3.1.4 Melting process (5.1),

3.1.5 Approval of procedures for conversion of ingot to bar (5.2),

3.1.6 Thermomechanical treatment requirements (5.4),

3.1.7 Annealing and tempering requirements for martensitic grades (5.4),

3.1.8 Condition (annealed, cold-worked, or thermomechanical treatment) (5.6),

3.1.9 Percent of cold-work (5.7),

3.1.10 Sublotting requirements (5.8),

[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.10 on Steel Tubing.

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[2] Available from the American Society for Nondestructive Testing, 3200 Riverside Drive, Columbus, OH 43221.

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

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

[5] *Annual Book of ASTM Standards*, Vol 01.01.

[6] *Annual Book of ASTM Standards*, Vol 05.01.

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

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

[9] *Annual Book of ASTM Standards*, Vol 03.03.

[10] Available from American National Standards Institute, 11 West 42nd St., 13th Floor, New York, NY 10036.

TABLE 1 Chemical Requirements of Duct Tubes

Grade	TP 316	. . .	. . .
UNS Designation	S 31600	S38660	S42100
Carbon	0.040–0.060	0.030–0.050	0.17–0.23
Manganese	1.00–2.00	1.65–2.35	0.40–0.70
Phosphorus, max	0.040	0.040	0.040
Sulfur, max	0.010	0.010	0.010
Silicon	0.50–0.75	0.50–1.00	0.20–0.30
Nickel	13.0–14.0	14.5–16.5	0.30–0.80
Chromium	17.0–18.0	12.5–14.5	11.0–12.5
Molybdenum	2.00–3.00	1.50–2.50	0.80–1.20
Titanium	. . .	0.10–0.40[A]	. . .
Columbium	0.050 max	0.050 max	0.050 max
Tantalum, max	0.020	0.020	. . .
Tungsten	. . .	. . .	0.40–0.60
Nitrogen	0.010 max	0.005 max	. . .
Aluminum, max	0.050	0.050	0.050
Arsenic, max	0.030	0.030	. . .
Boron, max	0.0020	0.0020	. . .
Cobalt, max	0.050	0.050	. . .
Copper, max	0.04	0.04	. . .
Vanadium	0.05 max	0.05 max	0.25–0.35

[A] Aim for 0.25

3.1.11 Duct identification requirements (5.9),

3.1.12 Archive samples requirements (5.11),

3.1.13 Other chemical requirements (6.1),

3.1.14 Tensile property requirements and number of tests (7.1),

3.1.15 Microhardness measurement acceptance criteria, locations, and number of samples (7.2),

3.1.16 Dimensional data or applicable drawings (8.1),

3.1.17 Surface roughness limits (9.2),

3.1.18 Surface marring limits (9.3),

3.1.19 Cleaning procedures (9.4),

3.1.20 Grain size requirements for martensitic grades (10.1),

3.1.21 Carbide and carbonitride inclusion rating requirements (10.2),

3.1.22 Inclusion rating requirements for martensitic grades (10.2),

3.1.23 Penetrant examination requirements (11.1),

3.1.24 Lot qualification sampling levels (12.1),

3.1.25 Packaging (15.1), and

3.1.26 Quality assurance documentation (see Supplementary Requirements).

4. General Requirements for Delivery

4.1 Material supplied under this specification shall conform to the applicable requirements of Specification A 450/A 450M unless otherwise specified herein.

5. Manufacture

5.1 *Melting*—Unless an alternative melting process has been specified in the order, the process for austenitic grades shall consist of a vacuum induction melt followed by a consumable electrode vacuum-arc remelt. Additions of rare earths during melting are prohibited unless approved by the purchaser. The melting process for martensitic grades shall be as specified in the order.

5.2 *Ingot Processing*—Procedures for converting ingots to bars shall be approved by the purchaser prior to use if specified in the order. The parameters for the conversion of austenitic grades shall be selected to minimize the formation of complex carbides and carbonitrides.

5.3 *Tubemaking*—Duct tube fabrication shall be made by a seamless process that has been previously qualified as acceptable.

5.4 *Heat Treating*:

5.4.1 *Austenitic Grades*—Annealing times and temperatures shall be selected to ensure full carbide solution. Cooling shall be performed at a rate rapid enough to prevent carbide precipitation, unless a specific thermomechanical treatment is specified in the order.

5.4.2 *Martensitic Grades*—Martensitic grades shall be annealed and tempered as specified in the order.

5.5 *Cleanliness During Manufacture*—Before each heat treatment and after each cutting operation prior to any reduction, duct tubes shall be cleaned in accordance with the procedures of Recommended Practice A 380, and shall be visually inspected after cleaning in accordance with 7.2.1 of Recommended Practice A 380.

5.6 *Condition*—Duct tubes shall be furnished in the annealed, cold-worked, or thermomechanical condition as specified in the order.

5.7 *Cold Work*—Percent cold work shall be as specified in the order and shall be based upon the reduction in transverse area. Cold-worked duct tubes shall be cold worked to finished size and delivered without further heat treatment. The cold-working procedure shall be submitted to the purchaser for review and approval prior to use.

5.7.1 *Cold Work Determination*—Calculate percent cold work as follows:

$$CW = [A_1 - A_2/A_1] \times 100$$

where:

CW = percent cold work,

A_1 = duct tube cross-sectional area prior to final cold-work, and

A_2 = duct tube cross-sectional area after final cold-work.

5.8 *Lot Size*—Duct tubes shall be grouped into rational inspection lots that can be characterized by lot qualification sampling. This shall be done on the basis of items of the same nominal dimensions produced from the same heat, processed consecutively, and annealed under identical parameters. Any sublotting shall be as specified in the order.

5.9 *Identification*—Duct tubes shall be marked and processed in a manner that will ensure individual duct tube identity and traceability to both heat and lot numbers. Each duct tube shall be identified with the supplier code, lot code, heat number, alloy, purchase order number, and a sequential identification number as specified in the order. Duct tubes shall be marked using an electrolytic etching procedure approved by the purchaser.

5.10 *Repair and Rework*—Reworked duct tubes shall meet the requirements of this specification. Repair shall be permitted only after prior approval by the purchaser.

5.11 *Archive Samples*—Archive samples shall be supplied as specified in the order.

6. Chemical Composition

6.1 The material shall conform to the applicable chemical

requirements specified in Table 1, unless otherwise specified in the order.

6.2 An analysis of each heat of steel shall be made by the steel manufacturer in accordance with Methods, Practices, and Definitions A 751 to determine the percentages of the elements specified. If the secondary melting processes are employed, the heat analysis shall be obtained from one remelted ingot or the product of one remelted ingot of each primary melt. The chemical composition thus determined, or that determined from a product analysis made by the tubular product manufacturer, shall be reported to the purchaser or the purchaser's representative and shall conform to the requirements specified in 6.1.

6.3 An analysis shall be made on one finished duct tube fabricated from each heat of steel. The chemical composition thus determined, shall conform to the requirements specified in 6.1.

7. Mechanical Properties

7.1 *Tensile Properties*—Room temperature tensile properties of 20 % cold-worked Type 316 stainless steel duct tubes shall be determined in accordance with Specification A 450. Unless otherwise specified in the order, the requirements of Table 2 are for information only. Tensile properties of other grades and conditions and number of tests shall be specified in the order as required by the purchaser.

7.2 *Hardness*—The Vickers hardness shall be determined on samples of finished duct tubes in accordance with Test Method E 384 using a 500-g load. The acceptance criteria, number of samples, and measurement locations shall be as specified in the order.

8. Dimensions

8.1 Dimensional requirements shall be as specified in the order. The rounding-off method defined in Practice E 29 shall be used for determining conformance with these requirements.

8.2 *Equipment/Technique Accuracy* — Dimensional measurements shall be made with a device measuring in units no greater than 10 % of the specified tolerance range. For limits specified as minimum or maximum, use a device measuring in units to one decimal place beyond the character specified. Alternative measuring equipment shall require approval by the purchaser.

9. Surface Requirements

9.1 *Surface Condition*—The finished duct tubes shall be free of visible oxide, scale, splits, laps, cracks, seams, and inclusions.

9.2 *Surface Roughness*—All surfaces of finished duct tubes shall meet the limits specified in the order. Surfaces shall be examined visually and compared with roughness comparison specimens, or alternatively, measured with surface roughness measuring instruments. Roughness comparison specimens and roughness measurement instruments shall meet the requirements of ANSI B 46.1.

9.3 *Surface Marring*—Rejection criteria for surface imperfections, such as scratches, handling marks, light mandrel, and die or roll marks, shall be as specified in the order. The bottom of surface defects shall be visible, rounded, and well faired-in as confirmed by visual inspection. Removal of surface defects by grinding, buffing, or polishing is considered a repair subject to the requirements of 5.10.

9.4 *Cleaning*—All cleaning operations shall be conducted in accordance with the procedures meeting the requirements of Recommended Practice A 380 and shall be approved by the purchaser. Cleaned surfaces shall be inspected visually and by instrumental methods in accordance with Section 7 on Inspection After Cleaning of Recommended Practice A 380, as specified in the order. Measures to prevent the recontamination of cleaned surfaces shall be taken as soon as final cleaning is completed, and shall be maintained during all subsequent fabrication, inspection, storage, and shipping operations.

TABLE 2 Room Temperature Tensile Requirements for Duct Tubes

Alloy	Tensile Strength, min, ksi [MPa]	Yield Strength, min, ksi [MPa]	Minimum Total Elongation, %
TP 316	100 [689]	85 [586]	15
S38660[A]	100 [689]	85 [586]	15
S42100[B]	100 [689]	70 [483]	15

[A] 20 % cold-worked
[B] Tempered

10. Metallographic Test Requirements

10.1 *Grain Size*—The recrystallized average grain size of austenitic grade duct materials from any lot following final anneal and prior to cold working shall be 4 to 7, as determined in accordance with Methods E 112, Reference Plate II, and shall exhibit no evidence of a duplex structure. The grain size of martensitic grade duct materials shall be as specified in the order.

10.2 *Inclusions*—The inclusion rating of the austenitic grade starting bar, when determined in accordance with Microscopical Method D of Practice E 45, shall be limited to one for each of the following four types of inclusions: (*A*) Sulfide Type, (*B*) Alumina Type, (*C*) Silicate Type, and (*D*) Globular Oxide Type. The field of the samples shall be rated by comparison with Plate III of Practice E 45. A maximum of 10 % of the fields may show inclusions at the next higher density to that specified, and a maximum of 1 % of the fields may show inclusions at the second higher density. Complex carbide and carbonitride inclusion ratings shall be as specified in the order. The inclusion rating of martensitic grade starting bars shall be as specified in the order.

10.3 *Intergranular Attack*—Specimens from finished duct tubes shall be prepared in accordance with Methods E 3 and shall be metallographically examined at 100× to verify freedom from intergranular attack.

10.4 *Carbide Precipitation*—Specimens from finished austenitic grade duct tubes shall be mounted as transverse sections, polished, etched, and examined at 500×. Specimen preparation shall be as described in Methods E 3 using etching procedure 13 prescribed in Table 2 of Methods E 407. Specimens shall exhibit no visible carbide precipitation at the grain boundaries unless specific thermomechanical treatment has been specified in the order.

11. Nondestructive Examination

11.1 *Penetrant Examination of Finished Ducts*—Interior

and exterior surfaces of finished duct tubes shall be examined, if specified in the order, in accordance with the requirements of Procedures A-1, A-2, or B-2 of Table 1 of Practice E 165, and shall be free of indications as specified in the order. The penetrant materials shall be analyzed for sulfur and halogen in accordance with Test Method D 129 and Test Method D 808. The residual amount of sulfur and halogens shall not exceed 0.5 weight %.

12. Acceptance Criteria—Lot Basis Tests

12.1 *Lot Qualification*—Where lot qualification is listed, the lot shall be accepted only when all of the required number of samples meet the referenced requirement. Sampling levels shall be as specified in the order. Referenced test methods are the preferred method. Actual methods used shall be equal to or better than the methods referenced, and shall be approved by the purchaser prior to use.

13. Cleanliness

13.1 Finished duct tubes shall be free of residual iron, other metallic particles, oil, grease, lubricants, residual cleaning compounds, dirt, chips, and all other extraneous material.

13.2 Contact preservatives shall not be used.

14. Certification

14.1 The material manufacturer shall certify that the material was manufactured, tested, and examined in accordance with this specification and any added requirements of the purchase order. A copy of the certification shall be furnished at the time of shipment, together with a report of the results of all required tests and examinations. Certifications, test reports, and examination reports shall be positively traceable to individual tubes and their raw materials.

15. Packaging and Package Marking

15.1 *Packaging*—Duct tubes shall be individually packaged in polyethylene and placed in a container constructed to ensure delivery of clean, straight, and undamaged material. Packaging shall be in accordance with the requirements specified in the order.

15.2 *Shipping Containers*—A complete description of the shipping containers for duct tubes shall be submitted for approval before being used.

15.3 *Marking*—Each shipping container shall be legibly and conspicuously marked with the following data:

15.3.1 Purchase order number,
15.3.2 Name of supplier,
15.3.3 Alloy and heat,
15.3.4 Lot number,
15.3.5 Number of pieces in container,
15.3.6 Gross and net weights,
15.3.7 Applicable drawing,
15.3.8 Duct number(s), and
15.3.9 Specification designation.

16. Keywords

16.1 austenitic stainless steel; ferritic stainless steel; nuclear applications; stainless steel tubing; steel tubing

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order.

S1. Quality Assurance Program

S1.1 The materials manufacturer shall establish, maintain, and function in accordance with a quality verification program that will control the quality of the product during manufacture, testing, examination, repair, and treatment of the material, including subcontracted services, to ensure that all materials supplied by the manufacturer conform to the requirements of this specification. Compliance with ASME NQA-1 will be accepted as compliance with this section. The program shall be documented in a Quality System Manual that shall be implemented by procedures that are maintained by the materials manufacturer. The program shall be subject to audit and shall include the following:

S1.1.1 *Organization*—The authority and responsibilities of personnel in charge of the quality system program shall be clearly established and be independent of the individual or group performing the specific manufacturing activity.

S1.1.2 *Manufacturing Control*—The materials manufacturer shall operate under a controlled system using process sheets, shop procedures, check lists, travelers, or equivalent procedures.

S1.1.3 *Calibration of Measuring and Test Equipment*—Procedures shall be in effect to ensure that tools, gages, instruments, and other measuring, testing, and examination equipment and devices used to verify compliance of material with the basic material specification and this specification are calibrated, controlled, adjusted, and maintained to assure accuracy within the specified limits. Calibration shall be against measurement standards that have known valid relationships to national standards, where such standards exist. Corrective action is required when discrepancies which significantly affect the measurement of material specification properties are found at calibration. Methods for resolution of these discrepancies shall be part of the quality system program.

S1.1.4 *Control of Nondestructive Examination Procedures*—All nondestructive examinations required shall be performed in accordance with detailed written procedures that are capable of detecting and locating unacceptable discontinuities. Qualification of personnel performing or interpreting nondestructive examination, or both, shall be in accordance with SNT-TC-1A. Written procedures and records shall be made available to the purchaser on request. At least one copy of the procedure shall be available to nondestructive examination personnel for reference.

S1.1.5 *Procedure Control*—Procedural controls of heat treatment for all materials and materials test coupons shall be maintained and implemented.

S1.1.6 *Nonconforming Material* — Nonconforming material shall be identified and reviewed for acceptance, rejection, repair, or rework in accordance with documented procedures. The responsibility and authority for the disposition of nonconforming material shall be defined. Repaired and reworked material shall be reexamined in accordance with applicable procedures. Conditions adverse to final product quality (such as malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances) shall be promptly identified and reported to the appropriate levels of the materials manufacturer's management. The identification, cause, and corrective action taken on nonconformances shall be documented.

S1.1.7 *Audits*—Planned and periodic audits by personnel not having direct responsibility in the areas being audited shall be performed to assure compliance with the quality system program. Written procedures or checklists shall be used. Follow-up action, including reaudit of deficient areas, shall be taken where indicated.

S1.1.8 *Identification and Control of Materials*—Procedural controls for identification of materials, including partially processed materials, shall assure that identification is maintained either on the material or on records traceable to the material throughout manufacture.

S1.2 *Records*—The manufacturer is responsible for the preparation of all quality assurance documentation specified in this specification and in the order. Records of all tests and examinations shall be kept complete and available to the purchaser. Quality verification records shall be furnished with the delivered product and shall include:

S1.2.1 Identity of each duct tube as shown on the inspection/test and other quality records,

S1.2.2 Traceability of each duct tube lot to raw materials and heat numbers,

S1.2.3 Manufacturing plan which includes the number and type of forming operations, the sequence of such operations indicating the duct tube size at each stage, and the sequence of annealing operations detailing the time, temperature, and atmosphere of the annealing cycle,

S1.2.4 Reports showing the results of all inspections and tests on duct tubes and materials tests required by this specification and applicable material standards, and

S1.2.5 Other data which show the quality status of the delivered product.