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Standard Specification for Vacuum Treated Steel Forgings, Alloy, Differentially Heat Treated, for Turbine Rotors[1]

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1. Scope

1.1 This specification covers vacuum treated, alloy steel forgings, differentially heat treated for turbine rotors.

1.2 Differential heat treatment of a rotor forging involves subjecting two portions of the forging concurrently to two different austenitizing temperatures followed by two different cooling rates for normalizing and quenching, and then tempering, to achieve creep resistance in the high pressure (HP) portion and high toughness in the low pressure (LP) portion.[2]

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

2. Referenced Documents

2.1 *ASTM Standards:*

A 275/A 275M Test Methods for Magnetic Particle Examination of Steel Forgings[3]

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

A 418 Test Method of Ultrasonic Examination Inspection of Turbine and Generator Steel Rotor Forgings[3]

A 470 Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts[3]

A 472 Test Method for Heat Stability of Steam Turbine Shafts and Rotor Forgings[3]

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products[4]

A 788 Specification for Steel Forgings, General Requirements[3]

E 139 Practice for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[5]

3. Ordering Information

3.1 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order a detailed drawing, sketch, or written description of the forging, including the mechanical test locations, the portion of the forging to be included in the heating chamber during the stability test, and the minimum stability test temperature.

3.2 The purchaser shall specify if check tests for mechanical properties are required after stress relief or heat stability tests.

3.3 *Supplementary Requirements*—Supplementary requirements are provided. These requirements shall apply only when specified in the purchase order.

4. General Requirements

4.1 Material supplied to this specification shall conform to the requirements of Specification A 788, which outlines additional ordering information, manufacturing requirements, testing and retesting methods and procedures, marking, certification, product analysis variations, and additional supplementary requirements.

4.2 If the requirements of this specification are in conflict with the requirements of Specification A 788, the requirements of this specification shall prevail.

5. Manufacture

5.1 Melting processes of Specification A 788 shall be applicable, except that the open hearth or basic oxygen methods of primary melting shall not be used and the molten steel shall be vacuum treated during processing. When the ladle degassing process is used, the evacuation system shall be capable of reducing the system vacuum pressure to a low level (usually less than 1000 μm). The molten metal shall be stirred adequately for a sufficient length of time to maximize exposure to the evacuated atmosphere. When this process is used, hydrogen testing per Supplementary Requirement S4 is mandatory.

5.1.1 If the ESR process is used, the electrodes shall have been produced from vacuum treated primary heat(s), and Supplementary Requirement S4 is mandatory.

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[2] *Symposium on Steel Forgings, ASTM STP 903*, ASTM, Philadelphia, PA, 1984, pp. 59-86.

[3] *Annual Book of ASTM Standards*, Vol 01.05.

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

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

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5.2 In addition to the requirements of Specification A 788, it is important to maintain the axial center of the forging in common with the axial center of the original ingot.

5.3 *Differential Heat Treatment*—The heat treatment for mechanical properties shall consist of normalizing and tempering of the creep resistant portion, HP portion, and quenching and tempering of the high toughness portion, LP portion.

5.3.1 The preliminary heat treatment shall consist of normalizing well above the transformation temperature range.

5.3.2 The normalizing and quenching treatments shall be from above the transformation range but below the normalizing temperature described in 5.3.1. This treatment shall be performed after preliminary machining.

5.3.2.1 The heat treatment for the HP portion shall consist of normalizing, accelerated air cooling, and tempering.

5.3.2.2 For the high toughness LP portion, the heat treatment shall consist of water quenching (or water-spray quenching) and tempering.

5.3.3 The final tempering temperature for all zones shall not be below 1200°F (649°C).

5.3.4 After heat treatment and subsequent rough machining and boring, the forging shall be stress relieved at a temperature not more than 100°F (55°C) below the final tempering temperature, but not below 1100°F (593°C).

5.3.5 With the prior approval of the purchaser, the stress relieving temperature may approach, equal, or slightly exceed the final tempering temperature as a means of adjusting final strength or toughness. If the stress relieving temperature is within 25°F (14°C) of the final tempering temperature, or higher, acceptance tests shall be obtained after the stress relieving operation.

5.3.6 The method of cooling the HP and LP portions during the normalizing, quenching, tempering, and stress relieving heat treating cycles shall be reported.

5.4 *Machining*:

5.4.1 *Preliminary Rough Machining*—All exterior surfaces of the forging shall be machined prior to heat treatment for mechanical properties.

5.4.2 *Second Rough Machining*—After heat treatment for mechanical properties, all surfaces of the forging shall be rough machined prior to stress relief and the stability test.

5.4.3 *Boring*:

5.4.3.1 Forgings shall be bored to permissible bore size and tolerances when required by the purchaser's drawing.

5.4.3.2 Forgings may be bored to limits agreed to by the purchaser or indicated on the purchaser's drawing, to remove objectionable center conditions revealed by ultrasonic inspection.

5.4.3.3 Unless otherwise specified by the purchaser, the manufacturer may bore the forging at any time after quenching and prior to stress relief.

5.4.4 *Machining to Purchaser's Requirements for Shipment*—The forging, as shipped, shall conform to the finish and dimensions specified on the purchaser's drawing or order.

6. Chemical Composition

6.1 *Heat Analysis*—An analysis of each heat of steel shall be made by the manufacturer. This analysis shall be made from a test sample taken preferably during the pouring of the heat. The steel shall conform to the requirements for chemical composition prescribed in Table 1.

6.2 *Product Analysis*—The manufacturer shall make a product analysis from each forging. The chemical composition thus determined shall not vary from the requirements specified in Table 1 by more than the amounts prescribed in Specification A 788.

6.3 *Referee Analysis*—Test Methods, Practices, and Terminology A 751 shall be used.

7. Mechanical Properties

7.1 *Tension Test*:

7.1.1 The steel shall conform to the tensile requirements of Table 2.

7.1.2 The number and location of tension test specimens shall be as specified on the forging drawings furnished by the purchaser.

7.1.3 Final acceptance tests shall be performed after heat treatment of the forging for mechanical properties prior to stress relief. If the stress relief temperature is within 25°F (14°C) of the tempering temperature, or higher, check tests shall be made after the stress relief treatment and reported to the purchaser. The purchaser may require check tests after the completion of all heating cycles, including stress relief and the heat stability tests.

7.1.4 The yield strength prescribed in Table 2 shall be determined by the offset method of Test Methods and Definitions A 370.

7.2 *Impact Test*:

7.2.1 The steel shall conform to the requirements for notch toughness (both transition temperature and room temperature impact values) prescribed in Table 3.

7.2.2 The notch toughness specimens shall be machined from radial bars taken from the main body of the forging, as shown in the forging drawing. The specimens shall be Charpy V-notch, Type A, as shown in Test Methods and Definitions A 370. The notch direction of the Charpy bars shall be as prescribed in Specification A 470.

8. Nondestructive Tests

8.1 *General Requirements*:

8.1.1 The forgings shall be free of cracks, seams, laps, shrinkage, and other injurious imperfections.

8.1.2 The purchaser may request ultrasonic, magnetic particle, dye penetrant, etch, or other nondestructive inspections

TABLE 1 Chemical Composition

	Composition, % Grade 1
Carbon	0.23–0.31
Manganese	0.50–1.00
Phosphorus, max	0.012
Sulfur, max	0.015
Silicon, max	0.10
Nickel	0.80–1.10
Chromium	0.90–1.50
Molybdenum	1.10–1.50
Vanadium	0.20–0.30
Columbium (Niobium)	0.01–0.05
Aluminum	0.010 max

TABLE 2 Tensile Requirements

	Grade 1
Tensile strength, ksi (MPa)	105–125 (725–860)
Yield strength, min, ksi (MPa), 0.2 % offset	85 (585)
Elongation in 2 in. or 50 mm, min, %	17 longitudinal 14 radial
Reduction of area, min, %	43 longitudinal 38 radial

TABLE 3 Notch Toughness Requirements

Test Location	Grade 1	
	ft·lb (J), min	Transition Temperature, $FATT_{50}$°F (°C), max
HP	6 (8.2)	250 (121)
LP	25 (34)	36 (2)

necessary to evaluate imperfections and to ensure compliance with this requirement.

8.2 *Ultrasonic Inspection*:

8.2.1 An ultrasonic inspection shall be performed on the machined forging at the manufacturer's plant. This inspection shall be made in accordance with Test Method A 418 to demonstrate freedom from detrimental internal defects.

8.2.2 The ultrasonic inspection shall be conducted from all available surfaces prior to removal of the test specimens that would interfere with complete testing of the forging.

8.2.3 Forgings with reportable ultrasonic indications shall be referred to the purchaser for evaluation based on the nature, frequency, and location of the indications, both stationary and traveling. It shall be determined by conventional or mutually acceptable inspection procedures whether the forging will be rejected if the ultrasonic indications are considered objectionable.

8.3 *Internal Inspection*:

8.3.1 When specified for internal periscope inspection, boring shall be in accordance with the drawings furnished by the purchaser. The drawings shall specify the nominal dimensions of the bore hole.

8.3.2 If objectionable conditions are encountered during internal inspection of the bore hole, the manufacturer shall notify the purchaser of the location and nature of the condition. Further action shall be taken only after mutual agreement between the manufacturer and the purchaser.

9. Stability Test

9.1 Each forging shall be subjected to a heat stability test at the manufacturer's plant in accordance with the latest issue of Test Method A 472 to determine the stability or freedom from a tendency to distort during high-temperature operating conditions.

9.2 The stability test shall be conducted after the forging has been stress relieved.

9.2.1 The stress relief may be performed as part of the stability test if agreed to by the purchaser.

9.3 *Stability Test Requirements*:

9.3.1 The purchaser's drawings shall indicate the portion of the forging to be included within the heating chamber during the stability test.

9.3.2 The purchaser's drawings or order shall indicate the minimum stability test temperature.

10. Retreatment

10.1 If the results of the mechanical tests of any forging do not conform to the requirements specified, the manufacturer may retreat the entire forging one or more times, but not more than three additional times, without the approval of the purchaser.

10.2 If the bore core properties are specified under Supplementary Requirement S1 and retemper is necessary after boring, the remaining portions of the core shall be replaced in the bore during retemper. If the stress relief temperature is within 25°F (14°C) of the tempering temperature, the core bar shall be reinserted for the stress relief.

10.3 If complete retreatment, including differential heat treatment by normalizing and quenching, is necessary after boring, the feasibility of retreating portions of the bore core in the bore of the forging shall be discussed between the manufacturer and the purchaser and a procedure agreed upon before treatment.

11. Dimensions, Tolerances, and Finish

11.1 Each forging shall conform to the dimensions and tolerances specified on the purchaser's drawing or order.

11.2 The finish on each forging shall conform to the finish specified on the purchaser's drawing or order.

12. Certification and Reports

12.1 In addition to the certification requirements of Specification A 788, the following shall be reported:

12.1.1 Product analysis results, and

12.1.2 Location of the heat treatment transition point on the forging.

13. Package Marking, Packing, and Loading

13.1 Each forging shall be stamped legibly by the manufacturer with the manufacturer's name or symbol, the manufacturer's identification number, the ASTM designation, the appropriate grade number, and identification numbers specified by the purchaser on his drawing of the order.

13.2 The location of such identification marks may be specified by the purchaser on his drawing or order.

13.3 Test specimens shall be identified with numbers corresponding to the test location and type, if specified on the purchaser's drawings or order.

13.4 The axial bores of bored forgings shall be protected and plugged suitably to prevent damage or corrosion during shipment or storage.

14. Keywords

14.1 differential heat treatment; steel forgings; turbine rotor; vacuum treated steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the inquiry, contract, or order. Details of these supplementary requirements shall be agreed upon by the manufacturer and the purchaser.

S1. Bore Core Properties

S1.1 The purchaser may require the removal of a longitudinal bore core from the forging after heat treatment for mechanical properties and subsequent approval of the usual surface mechanical property tests.

S1.1.1 The diameter of the longitudinal bore core shall be subject to agreement between the manufacturer and the purchaser.

S1.1.2 The purchaser may require mechanical tests on tension or impact specimens from locations in the longitudinal bore core as specified on the forging drawings furnished by the purchaser.

S1.1.3 The acceptance level of the mechanical properties obtained from specimens from the longitudinal bore core shall be as agreed upon between the manufacturer and the purchaser.

S2. Stress Rupture Properties

S2.1 The purchaser may require that stress-rupture tests be made, by the manufacturer or by himself, on radial specimens taken from locations shown on the forging drawing.

S2.1.1 Stress-rupture tests shall be performed in accordance with Practice E 139.

S2.1.2 The size and shape of the test specimen and stress-rupture test requirements shall be mutually agreed upon between by the manufacturer and the purchaser.

S3. Vertical Heat Treatment

S3.1 Heat treatment for mechanical properties shall be performed with the forging in the vertical position.

S4. Hydrogen Determination

S4.1 A hydrogen determination shall be made. The acceptable hydrogen limit as well as the stage in processing when sampling, the sample preparation procedure, and the method of analysis shall be agreed upon between the manufacturer and the purchaser.

S5. Magnetic Particle Examination

S5.1 A magnetic particle examination of the complete exterior and bore surfaces of the machined forging shall be made at the forging manufacturer's plant. The examination shall be performed in accordance with the latest issue of Test Method A 275/A 275M.

S5.2 Forgings with either cracks or linear indications of any length are subject to rejection unless they can be removed to the purchaser's satisfaction.

S6. Heat Treatment After Machining of Disks or Wheels, or Both

S6.1 When agreed upon between the manufacturer and the purchaser, the heat treatment for mechanical properties shall be performed after additional machining of the material between the rotor discs or wheels, or both. This agreement should also address the following:

S6.1.1 Machining finish allowances, radii, and surface finish before and after the heat treatment for mechanical properties.

S6.1.2 Locations of the tension test specimens and the test direction.

S6.1.3 Locations of the impact test specimens and the notch direction.

S6.1.4 Impact energy and FATT requirements.

S6.1.5 Ultrasonic inspection of the cylindrical forging shapes following the preliminary heat treatment.

S6.1.6 Ultrasonic inspection of the discs or wheels, or both, and remaining shaft diameters after the heat treatment for mechanical properties.

S6.1.7 Magnetic particle inspection after the heat treatment for mechanical properties.

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