Designation: A 470 – 01

Standard Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts[1]

This standard is issued under the fixed designation A 470; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This specification covers vacuum-treated carbon and alloy steel forgings for turbine rotors and shafts.

1.2 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 Method for Magnetic Particle Examination of Steel Forgings[2]

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

A 418 Test Method for Ultrasonic Examination of Turbine and Generator Steel Rotor Forgings[2]

A 472 Test Method for Heat Stability of Steam Turbine Shafts and Rotor Forgings[2]

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

A 788 Specification for Steel Forgings, General Requirements[2]

E 139 Test Methods for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials[4]

3. Ordering Information and General Requirements

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

3.2 In addition to the ordering information required by Specification A 788, the purchaser shall include with the inquiry and order, the class of steel, alternative maximum for silicon content (see Table 1), the choice of yield strength offset (0.2 or 0.02 %) and any tests, supplementary requirements, and purchase options desired.

3.3 *Forging Drawing*—Each forging shall be manufactured in accordance with a drawing furnished by the purchaser showing the dimensions of the forging and bore hole, if any, and the location of mechanical test specimens.

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

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

4. Manufacture

4.1 *Melting Process*:

4.1.1 The steel shall be made by the basic electric-furnace process.

4.1.2 Provisions for subsequent secondary melting of the steel by the consumable electrode-electroslag or vacuum-arc remelting processes are included in Supplementary Requirement S7.

4.2 *Vacuum Treatment*—The vacuum degassing requirements of Specification A 788 are mandatory.

4.3 *Discard*—Sufficient discard shall be taken from each ingot to secure freedom from pipe and harmful segregation in the finished forging.

4.4 *Forging Process*—The forging shall receive its hot mechanical work under a press of ample power to adequately work the metal throughout the maximum section of the forging. It is important to maintain the axial center of the forging in common with the axial center of the ingot.

4.5 *Heat Treatment*:

4.5.1 After forging and before reheating for heat treatment for mechanical properties, the forging shall be allowed to cool in a manner designed to prevent injury and accomplish transformation.

4.5.2 The heat treatment for mechanical properties shall consist of double-normalizing and tempering for Classes 2, 3, 4, 8, and 9 and normalizing, quenching, and tempering for Classes 5, 6, and 7. In normalizing treatments, the forging may

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

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

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

TABLE 1 Chemical Requirements[A]

	Class 2	Classes 3 and 4	Classes 5, 6, and 7	Class 8	Class 9
Carbon	0.22–0.30	0.22–0.30	0.28	0.25–0.35	0.30
Manganese	0.20–0.60	0.20–0.60	0.20–0.60	1.00	0.70
Phosphorus	0.012	0.012	0.012	0.012	0.025
Sulfur	0.012	0.012	0.015	0.015	0.025
Silicon	[B]	[B]	[B,C]	[B]	[B]
Nickel	3.20–3.70	3.20–3.70	3.25–4.00	0.75	2.00
Chromium	0.75	0.75	1.25–2.00	1.05–1.50	0.75
Molybdenum[D]	0.40–0.60	0.40–0.60	0.25–0.60	1.00–1.50	0.25 min
Vanadium[E]	0.04–0.012	0.04–0.012	0.05–0.15	0.20–0.30	0.03–0.12
Antimony	[F]	[F]	[F]	[F]	[F]
Aluminum[G]	0.015	0.015	0.015	0.015	0.015
Equivalent Specification A 293 Grade Designation (replaced by Specification A 470)	...	...	...	Classes 2 and 3[H]	...

[A] Maximum or range, unless otherwise indicated.
[B] 0.10 % max, unless an alternative value, not in excess of 0.30 %, is specified in the purchase order.
[C] 0.15 to 0.30 % silicon is permitted for material that is subsequently VAR Processed.
[D] Supplementary Requirement, see S1.
[E] Vanadium addition optional for Class 1.
[F] To be reported for information only on Classes 2 through 9, incl.
[G] Total of soluble and insoluble.
[H] Phosphorus of 0.035 max and sulfur of 0.035 max were specified for Specification A 293.

be cooled in still air or in an air blast at the manufacturer's option. Faster cooling rates for Classes 2, 3, 4, 8, and 9 may be used if authorized by the purchaser. These rates are obtained by liquid quenching, or by the addition of water sprays of fog to the air blast.

4.5.2.1 The first normalizing treatment shall be from well above the transformation temperature range. At the manufacturer's option, this operation may be performed as a part of the preliminary treatment of the forging before preliminary machining (see 4.6.1).

4.5.2.2 The second normalizing or quenching treatment shall be from above the transformation range but below the first normalizing temperature described in 4.5.2.1. This treatment shall be performed after preliminary machining (see 4.6.1).

4.5.2.3 The final tempering temperature for Classes 2 to 7 and Class 9 shall be not less than 1075°F (580°C) and for Class 8 not less than 1200°F (650°C). With prior purchaser approval, a second tempering operation shall be performed prior to the operations described in 4.6.2 and 4.6.3 to complete the heat treatment cycle. This second temper will be in place of the stress relief specified in 4.5.2.4 and 4.5.2.5 and the temperatures applied to the second temper will meet the temperature limits in 4.5.2.4. However, with the prior approval of the purchaser, the second tempering temperature may approach, equal or slightly exceed the first tempering temperature as a means of adjusting final strength or toughness. The required tests for mechanical properties shall be made after the second tempering operation. Mechanical property tests after the first temper are optional with the manufacturer.

4.5.2.4 After heat treatment and subsequent rough machining and axial boring (see 4.6.2 and 4.6.3), the forging shall be stress-relieved at a temperature not more than 100°F (55°C) below the final tempering temperature, but not less than 1025°F (550°C).

4.5.2.5 With the prior approval of the purchaser, the stress-relief temperature may approach, equal, or slightly exceed the final tempering temperature as a means of adjusting final strength or toughness. If the stress-relief temperature is within 25°F (14°C) of the final tempering temperature, or higher, additional tension tests must be obtained (6.1.3).

4.6 *Machining*:

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

4.6.2 *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.

4.6.3 *Axial Bore*:

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

4.6.3.2 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 examination.

4.6.3.3 Unless otherwise specified by the purchaser, the manufacturer may bore the forging at any time prior to stress relief (see Supplementary Requirement S2).

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

5. Chemical Composition

5.1 The steel shall conform to the requirements for chemical composition prescribed in Table 1.

5.2 *Chemical Analysis*:

5.2.1 *Heat Analysis*—An analysis of each heat of steel shall be made by the manufacturer to determine the percentages of the elements specified in Table 1. This analysis shall be made from a test specimen preferably taken during the pouring of the heat. For forgings made from more than one heat, both individual heat analyses (when appropriate for the process) and

a weighted average analysis shall be reported. In this case, the weighted average analysis of the component heats shall conform to Table 1.

5.2.1.1 If the test specimen taken for the heat analysis is lost or declared inadequate for chemical determinations, the manufacturer may take alternative specimens from appropriate locations near the surface of the ingot or forging as necessary to establish the analysis of the heat in question. Location and depth of the alternative specimens shall be reported to the purchaser along with the chemical analysis.

5.2.2 *Product Analysis*—The manufacturer shall make a product analysis from each forging. The sample location and product analysis tolerances shall conform to Specification A 788.

5.3 *Referee Analysis*—Test Methods, Practices and Terminology A 751 shall be used for referee purposes.

6. Mechanical Properties

6.1 *Tension Test*:

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

6.1.2 The number and location of tension test specimens shall be as specified on the drawing furnished by the purchaser.

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

6.1.4 Testing shall be performed in accordance with the latest revision of Test Methods and Definitions A 370. Tension specimens shall be the standard 0.5-in. diameter by 2-in. gage length (or 12.5 by 50.0-mm type) as shown in Test Methods and Definitions A 370.

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

6.2 *Impact Test*:

6.2.1 The steel shall conform to the requirements for notch toughness (both transition temperature and room temperature impact values) prescribed in Table 2.

6.2.2 The impact specimens shall be machined from radial bars taken from the main body of the forging, as shown in the purchaser's drawing. The specimens shall be Charpy V-notch, as shown in Test Methods and Definitions A 370. The notch direction of the Charpy specimens shall be tangential.

6.2.3 The impact tests shall be performed in accordance with the section on Charpy impact testing of Test Methods and Definitions A 370.

6.3 The properties at the axial bore region may not necessarily be the same as those determined at the surface radial or axial prolongation regions. Slight variations in chemical homogeneity, different cooling rates, presence of non-metallics, and orientation of the test samples are some of the factors that can contribute to the difference. If axial bore properties are required, they can be obtained through Supplementary Requirement S2.

7. Dimensions, Tolerances, and Finish

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

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

8. Nondestructive Tests

8.1 *General Requirements*:

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

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

TABLE 2 Tensile and Notch Toughness Requirements

	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
Tensile strength, min, ksi (MPa)	80 (550)	90 (620)	105 (725)	90 to 110 (620–760)	105 to 125 (725–860)	120 to 135 (825–930)	105 to 125 (725–860)	95 (655)
Yield strength, min, ksi (MPa)	55 (380)	70 (483)	85 (585)	70 (483)	85 (585)	95 (655)	85 (585)	70 (485)
0.2 % offset	60 (415)	75 (520)	90 (620)	75 (520)	90 (620)	100 (690)	90 (620)	75 (520)
0.02 % offset	55 (380)	70 (485)	85 (585)	70 (485)	85 (585)	95 (655)	85 (585)	70 (485)
Elongation in 2 in. or 50 mm, min, %:								
Longitudinal prolongation	22	20	17	20	18	18	17	20
Radial body	20	17	16	18	17	17	14	15
Reduction of area, min, %:								
Longitudinal prolongation	50	48	45	52	52	52	43	40
Radial body	50	45	40	50	50	50	38	35
Transition temperature $FATT_{50}$max, °F(°C)	100 (38)	110 (43)	140 (60)	10 (−12)	20 (−7)	30 (−1)	250 (121)	175 (80)
Room temperature impact, min, ft·lbf (J)	28 (38.0)	25 (34.0)	20 (27.2)	50 (68.0)	45 (61.2)	40 (54.4)	6 (8.2)	12 (16)