Designation: A 470/A 470M – 05$^{\epsilon 1}$

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/A 470M; 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.

ε[1] NOTE—Step-cooling temperatures in S4.1.2 editorially corrected in September 2006.

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 either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 275/A 275M Test Method for Magnetic Particle Examination of Steel Forgings

A 293 Specification for Steel Forgings, Carbon and Alloy, for Turbine Generator Rotors and Shafts[3]

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

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

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

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

A 788 Specification for Steel Forgings, General Requirements

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

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 grade and 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.

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.06 on Steel Forgings and Billets.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn.

***A Summary of Changes section appears at the end of this standard.**

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TABLE 1 Chemical Requirements[A]

	Grade A	Grade B	Grade C	Grade D	Grade E
	Ni-Mo-V	Ni-Mo-V	Ni-Cr-Mo-V	Cr-Mo-V	Ni-Mo-V
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 min.
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	0.04–0.12	0.04–0.12	0.05–0.15	0.20–0.30	0.03–0.12
Antimony	[E]	[E]	[E]	[E]	[E]
Aluminum[F]	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[G]	...

[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] To be reported for information only on all Grades.
[F] Total of soluble and insoluble.
[G] Phosphorus of 0.035 max and sulfur of 0.035 max were specified for Specification A 293.

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 The heat treatment for mechanical properties shall consist of double-normalizing and tempering for Grades A, B, D, and E and normalizing, quenching, and tempering for Grade C. In normalizing treatments, the forging may be cooled in still air or in an air blast at the manufacturer's option. Faster cooling rates for Grades A, B, D, and E 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.

4.5.1.1 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).

4.5.1.2 The second normalizing or quenching treatment shall be from above the transformation range but below the first normalizing temperature described in 4.5.1.1. This treatment shall be performed after preliminary machining (see 4.6.1).

4.5.1.3 The final tempering temperature for Grades A, B, C, and E shall be not less than 1075°F [580°C] and for Grade D 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 4.5.1.4 and 4.5.1.5 and the temperatures applied to the second temper will meet the temperature limits in 4.5.1.4. However, with the prior approval of the purchaser, the second tempering temperature may be 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.

4.5.1.4 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].

4.5.1.5 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).

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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 *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.

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.

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

8.2 *Ultrasonic Examination*:

TABLE 2 Tensile and Notch Toughness Requirements

	Grade A	Grade B		Grade C			Grade D	Grade E
	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 [485]	85 [585]	70 [485]	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]	25 [34]	20 [27]	50 [68]	45 [61]	40 [54]	6 [8]	12 [16]

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

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

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

8.3 *Internal Examination*:

8.3.1 Axial bore, when specified for internal visual examination, shall be in accordance with the drawing furnished by the purchaser. The drawing shall specify the nominal dimensions of the bore.

8.3.2 If objectionable conditions are encountered during the internal examination of the bore, 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 purchaser.

9. Stability Test

9.1 Each Grade D and E 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 tendency to distort during high-temperature operating conditions.

9.2 The stability test shall be conducted after the forging has been stress relieved in accordance with 4.5.1.4.

NOTE 1—If agreed upon between the manufacturer and the purchaser, the stress relief may be performed as part of the stability test.

9.3 *Stability Test Requirements*:

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

9.3.2 The purchaser's drawing 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 forging one or more times, but not more than three additional times, without the approval of the purchaser.

10.2 If bore core properties are specified under Supplementary Requirement S2 and retemper is necessary after boring, the remaining portions of the bore core shall be replaced in the bore during retemper.

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

11. Certification and Reports

11.1 The manufacturer shall furnish to the purchaser the number of properly certified test reports specified on the purchase order.

11.2 The following items shall be reported:

11.2.1 Purchaser order number,

11.2.2 Forging identification number,

11.2.3 Specification number, grade, and class,

11.2.4 Heat number (or numbers), heat chemical analysis (or analyses), and product, chemical analysis,

11.2.5 Results of all acceptance tests for mechanical properties and notch toughness,

11.2.6 Results of all nondestructive examinations plus sketches indicating the location and orientation of all recordable indications,

11.2.7 Final heat treatment cycle including austenitizing and tempering temperatures, holding times, and cooling methods, and

11.2.8 Results of any supplementary requirements that have been specified.

12. Packaging and Package Marking and Loading

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

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

13. Keywords

13.1 steel forgings; turbine rotors; turbine shafts; vacuum-treated steel

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SUPPLEMENTARY REQUIREMENTS

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

S1. Molybdenum Content

S1.1 If desirable because of operating temperatures, the purchaser may specify a molybdenum content of 0.40 % min for Grades A, B, C, and E.

S2. Axial Bore Core Properties

S2.1 The purchaser may require the removal of an axial bore core from the forging after heat treatment for mechanical properties and subsequent approval of the usual surface mechanical property tests.

S2.1.1 The diameter of the axial bore core shall be subject to agreement between manufacturer and purchaser.

S2.1.2 The purchaser may require mechanical tests on tension or impact specimens from locations in the axial bore core is specified on the forging drawings furnished by the purchaser.

S2.1.3 The acceptable level of mechanical properties obtained from specimens from the axial bore core shall be as agreed upon between manufacturer and purchaser.

S3. Stress-Rupture Properties

S3.1 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.

S3.1.1 Stress-rupture tests shall be performed in accordance with Practice E 139.

S3.1.2 The size and shape of the test specimen and stress-rupture test requirements shall be mutually agreed upon between manufacturer and purchaser.

S4. Special Requirements to Minimize Temper Embrittlement

S4.1 Forgings to Grade C for special application may be specified with restricted chemical composition and the additional notch toughness requirements noted below.

S4.1.1 *Heat Analysis:*

Element	Composition, %
Carbon	0.28 max
Manganese	0.40 max
Phosphorus	0.012 max
Sulfur	0.015 max
Silicon	0.10 max
Nickel	3.25–4.00
Chromium	1.25–2.00
Molybdenum	0.25–0.45
Vanadium	0.05–0.15
Antimony	[A]
Tin	[A]

[A] To be reported for information.

S4.1.2 A sufficient number of impact test specimens to determine the $FATT_{50}$ in the step-cooled condition shall be taken from locations specified in 6.2.2. Specimens, before testing, shall be step-cooled as follows:

1100°F [594°C], hold 1 h, furnace cool to
1000°F [538°C], hold 15 h, furnace cool to
975°F [524°C], hold 24 h, furnace cool to
925°F [496°C], hold 48 h, furnace cool to
875°F [468°C], hold 72 h, furnace cool to
600°F [316°C], or lower, air cool to room temperature.

S5. Vertical Heat Treatment

S5.1 Heat treatment for mechanical properties shall be performed with the forging in the vertical position.

S6. Vacuum Carbon Deoxidation of Grade D Material

S6.1 Grade D material shall be vacuum carbon deoxidized during processing, in which case silicon shall be 0.10 % maximum.

S7. Secondary Melting

S7.1 Steel to this specification shall be produced by a secondary consumable electrode remelting process such as electroslag remelting or vacuum-arc remelting, provided the material remelted is made by the basic electric-furnace process and receives vacuum treatment equivalent to that prescribed in 4.2 during subsequent processing.

S7.2 Material for consumable electrode-electroslag remelting shall be vacuum-treated prior to remelting. Material for

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consumable electrode vacuum-arc remelting may be vacuum-treated prior to remelting or air-poured and vacuum-treated during remelting, at the option of the producer.

S7.2.1 The level of objectionable dissolved gases, particularly hydrogen, in the remelted material shall be comparable to the levels achieved in vacuum-treated steels of the same grade. This should preferably be attained by appropriate controls during remelting and ingot solidification. Alternatively, this may be accomplished by subsequent thermal treatments to reduce the gas content to the desired level by diffusion.

S7.3 The heat analysis of a consumable electrode remelted ingot shall comply with the heat analysis requirements of the grade of material specified.

S7.3.1 When the ingot is produced by remelting electrodes from a common master heat, the heat analysis shall be determined by taking the average of analyses from the zone corresponding to the second and next to last electrodes remelted respectively.

S7.3.2 When the electrodes from different master heats are remelted sequentially to produce the ingot, an analysis shall be made in each zone of the remelted ingot corresponding to each electrode from each master heat represented. Each such analysis shall comply with the heat analysis requirements of the material grade specified. The zone analysis of the portion of the remelt ingot used in a forging shall be reported, and their average shall be the heat analysis of the forging.

S8. Hydrogen Determination

S8.1 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 as agreed upon between manufacturer and purchaser.

S9. Magnetic Particle Examination

S9.1 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.

S9.2 Forgings with either cracks or linear indications of any length are subject to rejection unless they can be removed to the purchaser's satisfaction.

S10. Heat Treatment After Machining of Disks or Wheels, or Both

S10.1 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:

S10.1.1 Machined finish allowances, radii, and surface finish before and after the heat treatment for mechanical properties.

S10.1.2 Locations of tension test specimens and test direction.

S10.1.3 Locations of impact test specimens and notch direction.

S10.1.4 Impact energy and FATT requirements.

S10.1.5 Ultrasonic examination of the cylindrical forging shapes following the preliminary heat treatment.

S10.1.6 Ultrasonic examination of the disc or wheels, or both, and remaining shaft diameters after the heat treatment for mechanical properties.

S10.1.7 Magnetic particle examination after the heat treatment for mechanical properties.

S11. Heat Stability Testing

S11.1 Each forging shall be subjected to a heat stability test in accordance with Section 9, regardless of grade.

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APPENDIXES

(Nonmandatory Information)

X1. HEAT STABILITY TESTING

X1.1 Heat stability testing provides assurance that the process controls utilized in the manufacture of a rotor forging have produced a thermally stable product. This test is optional for Grades A, B, and C in this specification. Customers ordering a Grade A, B, or C rotor forging, but lacking experience with rotor forgings produced by the current manufacturer, may obtain the desired assurance by invoking Supplementary Requirement S11.

X2. PREVIOUS A 470 AND CORRESPONDING CURRENT DESIGNATIONS

X2.1 Table X2.1 lists previous and corresponding current designations.

TABLE X2.1 Previous and Corresponding Current Designations

Previous Class	Corresponding Current Grade and Class
Class 2	Grade A, Class 2
Class 3	Grade B, Class 3
Class 4	Grade B, Class 4
Class 5	Grade C, Class 5
Class 6	Grade C, Class 6
Class 7	Grade C, Class 7
Class 8	Grade D, Class 8
Class 9	Grade E, Class 9

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 470 – 03) that may impact the use of this standard.

(1) Deleted several paragraphs that are already covered in the general requirements specification, A 788.

(2) Converted standard to dual unit format.

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