Designation: A 471/A 471M – 09

Standard Specification for Vacuum-Treated Alloy Steel Forgings for Turbine Rotor Disks and Wheels[1]

This standard is issued under the fixed designation A 471/A 471M; 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.

1. Scope*

1.1 This specification covers vacuum-treated alloy steel forgings intended for use as turbine rotor disks and wheels.

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 Practice for Magnetic Particle Examination of Steel Forgings

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

A 388/A 388M Practice for Ultrasonic Examination of Steel Forgings

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

A 788/A 788M 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

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

3.2 The purchaser shall specify in the inquiry and order the class of steel desired and test and purchase options (see 4.5.5, 5.2.2, 6.1, 6.3, Section 7, and 15.1).

3.3 *Forging Drawing*—Each forging shall be manufactured in accordance with a purchaser-supplied drawing showing the finished dimensions and the locations of mechanical test specimens.

3.4 Supplementary requirements are provided and shall apply only when specified in the purchaser's order.

4. Materials and Manufacture

4.1 *Melting Process*:

4.1.1 The steel shall be made by the basic electric-furnace process, with additional ladle refining being optional.

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 S4.

4.2 The vacuum degassing requirements of Specification A 788/A 788M are mandatory.

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

4.4 *Forging Process*—The forgings shall receive their hot mechanical work under a press, hammer, or mill of sufficient power to work the metal throughout its section. The forgings shall be upset by forming from a block having an axial length before upsetting of at least two times the thickness of the forging after upsetting.

4.4.1 The as-forged dimensions of each forging shall be planned so the metal is shaped by forging as close as is practical to the dimensions shown on the purchaser's drawing so as to keep subsequent machining to a minimum.

4.4.2 The axial center of the forging shall be maintained in common with the axial center of the ingot.

4.5 *Heat Treatment*:

[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.

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

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4.5.1 *Cooling Prior to Heat Treatment*—After forging and before reheating for heat treatment, the forging shall be allowed to cool in a manner to prevent damage and to accomplish transformation.

4.5.2 *Preliminary Heat Treatment*—The forgings shall be given such preliminary heat treatment as is proper for the design and composition. The forgings shall be heated to a suitable temperature for a sufficient length of time for complete austenitization and shall be suitably cooled to bring about complete transformation.

4.5.3 *Heat Treatment for Mechanical Properties*—The forgings shall be reheated to a temperature above the upper critical temperature, held a sufficient length of time for complete austenitization, and liquid quenched.

4.5.4 *Tempering Temperature*—The forgings shall be tempered to develop the specified properties. The final tempering temperature for Class 1 to 6 and 11 through 14 shall be not less than 1100°F [595°C], and for Class 10 not less than 1200°F [650°C]. The forgings shall be cooled under suitable conditions from the tempering temperature.

4.5.5 *Stress Relief*—Unless otherwise specified by the purchaser, the forgings shall be stress relieved after machining (see 4.6.2) by heating slowly to a temperature within 100°F [55°C] below the final tempering temperature but in no case below 1025°F [550°C] for Classes 1 to 6 and 11 through 14 and 1150°F [620°C] for Class 10. They shall be held for a sufficient length of time and then cooled under suitable conditions. This stress-relief temperature may be omitted provided the metal removed in accordance with 4.6.2, excluding test metal, does not exceed 3⁄16 in. [5 mm] on any surface.

4.6 *Machining*:

4.6.1 *Preliminary Machining*—The forgings shall be preliminarily machined on all surfaces prior to heat treatment for mechanical properties (see 4.5.3).

4.6.2 *Machining to Purchaser's Requirements for Shipment*—After heat treatment for mechanical properties (see 4.5.3), the forgings shall be machined to the dimensions of the purchaser's forging drawing or instructions on the 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 those elements specified in Table 1. This analysis shall be made from a test ingot taken during the pouring of the heat.

5.2.1.1 If the test sample taken for the ladle analysis is lost or declared inadequate for chemical determinations, the manufacturer may take alternative samples from appropriate locations near the surface of the ingot or forging as necessary to establish the analysis of the heat in question.

5.2.2 *Product Analysis*—A product analysis may be made by the purchaser on each forging. Sample for an analysis may be taken from the forging at any point from the mid-radius to the outside diameter or from a full-size prolongation, or turnings may be taken from a test specimen. The chemical composition thus determined shall not vary from the requirements specified in Table 1 more than the amounts prescribed in Table 1 of Specification A 788/A 788M.

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

6. Mechanical Properties

6.1 *Tension Test*—The material shall conform to the requirement for tensile properties prescribed in Table 2 when tested in accordance with Test Methods and Definitions A 370. Tension test specimens shall be the standard round, ½-in. [12.5-mm] diameter, 2-in. [50-mm] gauge length as shown in Test Methods and Definitions A 370. The yield strength prescribed in Table 2 shall be determined by the 0.2 % offset method of Test Methods and Definitions A 370. The offset shall be 0.2 % unless 0.02 % is specified in the ordering information.

6.2 *Impact Test*—The material shall conform to the requirements for impact (both transition-temperature and room-temperature impact value) as prescribed in Table 2. The impact tests shall be performed in accordance with Test Methods and Definitions A 370 using standard full-size specimens.

6.3 *Hardness*—Forgings made from Classes 11 to 14 and subjected to group testing in accordance with 6.4.1 shall conform to the Brinell hardness requirements prescribed in Table 2 when tested in accordance with Test Methods and Definitions A 370.

TABLE 1 Chemical Requirements

	Composition, %			
	Classes 1 to 6, incl	Class 10	Classes 11 to 13, incl	Class 14
Carbon	0.28 max[A]	0.27–0.37	0.38–0.43	0.45 max
Manganese	0.70 max	0.70–1.00	0.60–1.00	0.60–1.00
Phosphorus	0.012 max	0.012 max	0.012 max	0.012 max
Sulfur	0.015 max	0.015 max	0.015 max	0.015 max
Silicon[B]	[B]	[B]	[B]	[B]
Nickel	2.00–4.00	0.50 max	0.50 max	1.65–3.50
Chromium	0.75–2.00	0.85–1.25	0.80–1.10	0.50–1.25
Molybdenum	0.20–0.70	1.00–1.50	0.15 min	0.20 min
Vanadium	0.05 min	0.20–0.30	0.06 max	optional
Antimony	[C]	[C]	[C]	[C]
Aluminum[D]	0.015 max	0.015 max	0.015 max	0.015 max

[A] 0.35 % C max for Classes 4 and 5; 0.40 % C, max, for Class 6.
[B] 0.10% max unless an alternative value, not in excess of 0.35%, is specified in the purchase order.
[C] To be reported for information only.
[D] Total of soluble and insoluble.

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TABLE 2 Tensile and Charpy Impact Requirements

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
Tensile strength, min, ksi [MPa]	100 [690]	105 [725]	110 [760]	120 [830]	130 [900]	140 [965]
Yield strength, ksi [MPa]						
0.2 % offset	80–100 [550–690]	90–110 [620–760]	100–120 [690–825]	110–130 [760–895]	120–140 [825–965]	130–150 [895–1035]
0.02 % offset	75–95 [520–655]	85–105 [585–725]	95–115 [655–790]	105–125 [725–860]	115–135 [790–930]	125–145 [860–1000]
Elongation in 2 in. or 50 mm, min, %	20	19	18	17	16	15
Reduction of area, min, %	50	50	47	45	43	43
Charpy V-notch impact, room temperature, ft·lbf [J], min	50 [68]	50 [68]	45 [61]	45 [61]	40 [54]	40 [54]
Transition temperature, $FATT_{50}$, °F [°C], max	0 [–18]	0 [–18]	0 [–18]	0 [–18]	10 [–12]	10 [–12]
Brinell hardness number	. . .	. . .	. . .	. . .	. . .	. . .
	Class 10	Class 11	Class 12	Class 13	Class 14	
Tensile strength, min, ksi [MPa]	105 [725]	100 [690]	110 [760]	125 [860]	125 [860]	
Yield strength, ksi [MPa]						
0.2 % offset	90–105 [620–725]	. . .	. . .	. . .	. . .	
			. . .	. . .	. . .	
		. . .	. . .	. . .	. . .	
0.02 % offset	85–100 [585–690]	75–95 [515–655]	85–105 [585–725]	105–125 [725–860]	105–125 [725–860]	
Elongation in 2 in. or 50 mm, min, %	15	20.0	18.0	16.0	18.0	
Reduction of area, min, %	30	50.0	48.0	45.0	45.0	
Charpy V-notch impact, room temperature, ft·lbf [J], min	10 [14]	15 [20] [A]	15 [20] [A]	15 [20] [A]	15 [20] [A]	
Transition temperature, $FATT_{50}$, °F [°C], max	200 [95]					
Brinell hardness number	. . .	207–255	229–269	255–302	255–302	

[A] Not required.

6.4 *Location and Number of Tests*—Classes 1 through 10 tension and impact test specimen shall be identified and taken from the locations as specified by the purchaser and agreed to by the producer. One tension test and a transition-temperature determination, including room-temperature impact strength shall be considered a minimum number of tests conducted on forgings made to this specification.

6.4.1 For Classes 11 through 14 unless otherwise specified by the purchaser, tests shall be made as follows:

6.4.1.1 Forgings 30 in. [750 mm] and under in diameter may be group tested. One tension test and one Charpy V-notch test shall be considered representative of each lot of forgings manufactured from the same heat of material and heat treated together. When group tested two Brinell tests, 180° apart, shall be made on the same face of each forging near the rim.

6.4.1.2 For forgings over 30 in. [750 mm] in diameter, at least one rim tension test and one Charpy V-notch test shall be made from each forging.

6.4.1.3 *Location*—Unless otherwise specified, tension and Charpy V-notch specimens shall be taken on full thickness prolongations on the forging periphery. The test specimen shall be taken as close as possible to the quarter thickness of the forging, with the axis of the specimen tangential.

6.5 *Removal of Test Specimens*—Removal of mechanical test specimens shall be done after all heat treatment, including the stress relief when required, has been completed. Test material shall not be separated from the forging until after the quench and temper cycles. If separated prior to a required stress relief cycle, test material sufficient to satisfy 6.4 and of the proper orientation shall be included with the stress relief cycle of the forgings and subsequently tested.

7. Nondestructive Test Requirements

7.1 *General Requirements*—The forgings shall be free from cracks, seams, laps, shrinkage, and other similar imperfections.

7.2 *Ultrasonic Inspection*—An ultrasonic inspection of the forgings shall be made on all available surfaces to demonstrate freedom from detrimental internal indications. In making the ultrasonic inspection, reference shall be made to Practice A 388/A 388M. Acceptance level shall be agreed upon between the purchaser and manufacturer.

7.3 Other nondestructive test methods such as dye penetrant, sulfur printing, or etching may be used upon request of the purchaser to evaluate the forging.

8. Dimensions and Tolerances

8.1 The forgings shall conform to the dimensions and tolerances specified on the purchaser's drawing or order.

9. Finish and Appearance

9.1 The forgings shall conform to the finish specified on the purchaser's drawing and shall have a good workmanlike appearance.

10. Retests

10.1 If the results of the mechanical tests do not conform to the requirements specified, retests are permitted as outlined in Test Methods and Definitions A 370 or as follows:

10.1.1 If the percentage of elongation of any tension test specimen is less than that specified because a flaw develops in the test specimen during testing, a retest shall be allowed if the flaw is not caused by ruptures, cracks, porosity, or flakes in the steel.

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10.1.2 Room temperature impact values lower than the minimum specified, but not less than 80 % of the minimum shall be cause for retest. In this event, two additional adjacent bars shall be broken to represent each failed bar. Both specimens shall have an impact strength above the minimum specified and the average for the three bars shall be above the minimum specified. Room temperature impact values less than 80 % of the specified value are not acceptable.

11. Retreatment

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

12. Inspection

12.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operation. All tests and inspections shall be made at the place of manufacture, unless otherwise agreed upon.

13. Rejection

13.1 Any forging having nonconforming conditions observed prior to or subsequent to acceptance at the manufacturer's plant shall be subject to rejection.

13.2 Any rejection based on tests made in accordance with 5.2.2 shall be reported to the manufacturer within 60 days from the receipt of the forgings by the purchaser, except in the case where it is obvious that a gross variation from specified chemical analysis exists. In this case there shall be no time limit for rejection.

14. Certification and Reports

14.1 The manufacturer shall furnish the required (on purchase order) number of test reports to the purchaser.

14.2 The following items shall be reported:

14.2.1 Heat and product (when specified by the purchaser) analyses,

14.2.2 Results of acceptance tests for mechanical properties,

14.2.3 Report of all nondestructive tests including sketches when necessary,

14.2.4 Final austenitizing, tempering, and stress relieving temperatures, holding times, and methods of cooling, and

14.2.5 The results of the supplementary requirement when required.

15. Packaging, Package Marking, and Loading

15.1 Each forging shall be legibly stamped by the manufacturer with the manufacturer's name or trademark, the manufacturer's serial number, the specification number (A 471), and the appropriate class number.

15.2 Packaging and loading shall be done so that the forging is not damaged during shipment to the purchaser.

16. Keywords

16.1 FATT requirement; steel forgings; turbine rotor disks; turbine rotor wheels; vacuum-treated low alloy steel

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser on the order.

S1. Creep Rupture

S1.1 In general, the procedure outlined in Test Methods E 139, shall be followed. A minimum of six test specimens shall be removed as instructed by the purchaser. The type test specimen and condition of the test shall be agreed upon between purchaser and manufacturer.

S2. Hydrogen Determination

S2.1 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 manufacturer and purchaser.

S3. Magnetic Particle Examination

S3.1 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 Practice A 275/A 275M.

S3.2 Forgings with cracks of any length or linear indications of ⅛ in. [3 mm] length or greater that are caused by nonmetallic inclusions are subject to rejection unless they can be removed to the purchaser's satisfaction.

S4. Secondary Melting

S4.1 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.

S4.2 Material for consumable electrode-electroslag remelting shall be vacuum-treated prior to remelting. Material for consumable electrode vacuum-arc remelting may by vacuum-treated prior to remelting or air-poured and vacuum-treated during remelting, at the option of the producer.

S4.2.1 The level of objectionable dissolved gases, particularly by 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. Alternately,

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this may be accomplished by subsequent thermal treatments to reduce gas content to the desired level by diffusion.

S4.3 The heat analysis of a consumable electrode remelted ingot shall comply with the heat analysis requirements of the specified grade and Specification A 788/A 788M.

SUMMARY OF CHANGES

Committee A01 has identified the location of selected changes to this standard since the last issue (A 471 – 08) that may impact the use of this standard. (Approved April 1, 2009.)

(*1*) Standard converted to dual units.
(*2*) Revised Section 3.
(*3*) Deleted 4.2.1 (details of product analysis requirements and vacuum degassing now included in Specification A 788/A 788M).
(*4*) Reference to secondary ladle refining added to 4.1.1.
(*5*) Deleted Table 2 and renumbered subsequent tables.

Committee A01 has identified the location of selected changes to this standard since the last issue (A 471 – 06) that may impact the use of this standard. (Approved Oct. 1, 2008.)

(*1*) Revised 3.1 and Table 1.

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