



Standard Specification for Martensitic Stainless Steel Forgings and Forging Stock for High-Temperature Service¹

This standard is issued under the fixed designation A1021/A1021M; 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 martensitic chromium stainless steel forgings, forged bar, and forging stock for high temperature service. The mechanical properties are developed by suitable heat treatment, as indicated for each alloy.

1.2 This specification is expressed in both inch-pound units and in SI units; however, unless the purchase order or contract specifies the applicable M specification designation (SI units), the inch-pound units shall apply. 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 may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 Supplementary requirements of an optional nature are provided for use at the option of the purchaser. The supplementary requirements shall apply only when specified individually by the purchaser in the purchase order or contract.

1.4 *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

A275/A275M Practice for Magnetic Particle Examination of Steel Forgings

A370 Test Methods and Definitions for Mechanical Testing of Steel Products

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.

A788/A788M Specification for Steel Forgings, General Requirements

E112 Test Methods for Determining Average Grain Size

E292 Test Methods for Conducting Time-for-Rupture Notch Tension Tests of Materials

E381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings

E562 Test Method for Determining Volume Fraction by Systematic Manual Point Count

3. Ordering Information

3.1 In addition to the ordering information required by Specification **A788/A788M**, the purchaser shall specify the grade designation, heat treatment condition, class and finish, and include a sketch or written description of the forging with the inquiry and order.

4. General Requirements

4.1 Materials supplied to this specification shall conform to the requirements of Specification **A788/A788M**, including any supplementary requirements that are indicated in the purchase order. Failure to comply with the general requirements of Specification **A788/A788M** constitutes non-conformance with this specification. In case of conflict between the requirements of this specification and Specification **A788/A788M**, this specification shall prevail.

5. Manufacture

5.1 *Melting Process*—All melting processes of Specification **A788/A788M** are permitted unless the purchaser invokes Supplementary Requirement S1.

5.2 *Forging Process*—Either the closed impression die or the open die, including ring rolling, forging processes may be utilized unless the purchaser specifies a process.

5.3 *Heat Treatment*—Quenched and tempered classes shall be heat-treated in accordance with **Table 1**.

5.3.1 *Number of Heat Treatments*—Heat treatment as defined in **Table 1** shall consist of austenitizing, quenching, and tempering. Retempering is permitted but purchaser approval is required for more than one complete reheat treatment.

TABLE 1 Heat Treatment, °F [°C]

	Grade A	Grade B	Grade C		Grade D	Grade E		Grade F
	Class 1 & 2	Class 1	Class 1	Class 2	Class 1 & 2	Class 1	Class 2	
Austenitizing	1725-1775 [940-970]	1600-1750 [870-955]	1825-1875 [995-1025]	1725-1875 [940-1025]	1875-1925 [1025-1050]	2075-2125 [1135-1165]	1725-1775 [940-970]	2000-2050 [1095-1120]
Quenching	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Air or liquid	Rapid air or oil
Single Tempering	1050 min [565 min]	1050 min [565 min]	1050 min [565 min]	1050 min [565 min]	1150 min [620 min]	1250 min [675 min]	1100 min [595 min]	1185 min [640] min
Double Tempering	...	...	1025 min [550 min]	1025 min [550 min]	...	...	...	...
Stress Relieving	1025 min [550 min]	1025 min [550 min]	1000 min [540 min]	1000 min [540 min]	1100 min [595 min]	1200 min [650 min]	1050 min [565 min]	1135 min [610] min

5.4 *Stress Relief*—When heat treatment for mechanical properties is followed by straightening, a stress-relieving heat treatment is required in accordance with **Table 1**.

5.4.1 *Quenching after Stress Relief*—Liquid quenching of stress-relieved forgings is prohibited.

5.5 *Finish*—Forgings may be furnished in one of the following hot-finished conditions:

5.5.1 *Finish F*—As forged without descaling.

5.5.2 *Finish FD*—Forged and descaled.

5.5.3 *Finish RT*—Rough turned or rough machined to specified dimensions. Billets or blooms ordered as forging stock shall be furnished with a ground, machined, or descaled surface unless otherwise specified in the ordering document.

5.6 *Camber*—Camber shall not exceed ¼ in. [5 mm] in 5 ft [150 cm].

6. Chemical Composition

6.1 The steel shall conform to the requirements for chemical composition prescribed in **Table 2**.

7. Mechanical Properties

7.1 *Tension, Impact, Stress Rupture, and Hardness Tests*—All testing shall be performed after heat treatment and stress

relief, as applicable. The material and test specimens shall meet the requirements of **Table 3** if fully heat-treated or **Table 4** if annealed. Mechanical property requirements, including hardness, do not apply to forging stock when it is to be tested after forging and heat treatment.

7.2 *Test Specimens*—Forgings may be lot tested. Test specimens may be obtained from production forgings or from separately forged test blanks prepared from the stock used to make the finished part. Forgings that are lot tested shall be produced from the same heat of steel and heat treated at the same time. Separately forged test blanks shall receive essentially the same type of hot-working and forging reduction as the production forgings; however, a longitudinally forged bar with dimensions not less than T by T by $3T$ may be used to represent a ring forging. The dimension T shall be representative of the heaviest effective cross section of the forging.

7.3 *Test Specimen Orientation*—Mechanical property requirements are for samples oriented in the direction of grain flow. Unless otherwise specified in the purchase order, manufacturers may orient the samples in any direction provided the mechanical property requirements are met.

7.4 *Test Specimen Location*—When transverse or circumferential specimens are tested, they shall be taken from as close as

TABLE 2 Chemical Requirements^A

UNS Designation	Composition %					
	Grade A	Grade B	Grade C	Grade D	Grade E	Grade F
	403/410 SS UNS S41000	403/410 SS MOD.	XM-32 Mod	422 SS	UNS S41041	UNS S42226
Carbon	0.15	0.10-0.15	0.10-0.17	0.20-0.25	0.13-0.18	0.15-0.20
Manganese	1.00	0.25-0.80	0.65-1.05	0.50-1.00	0.40-0.60	0.50-0.80
Phosphorus	0.018	0.018	0.020	0.025	0.030	0.020
Sulfur	0.015	0.015	0.015	0.010	0.030	0.010
Silicon	1.00	0.50	0.35	0.50	0.50	0.20-0.60
Nickel	0.75	0.75	2.25-3.25	0.50-1.00	0.50	0.30-0.60
Chromium	11.5-13.5	11.5-13.0	11.25-12.75	11.0-12.5	11.5-13.0	10.0-11.5
Molybdenum	0.50	0.50	1.50-2.00	0.90-1.25	0.20	0.80-1.10
Vanadium	...	Report only	0.25-0.40	0.20-0.30	...	0.15-0.25
Tungsten	...	0.10	0.10	0.9-1.25	...	0.25
Nitrogen	...	0.08	0.020-0.045	Report only	...	0.04-0.08
Aluminum	...	0.025	0.025	0.025	0.050	0.05
Columbium	...	0.20	...	...	0.15-0.45	0.35-0.55
Cobalt	...	...	...	0.20	...	0.25
Titanium	...	0.05	0.05	0.025	...	0.05
Copper	...	0.50	0.50	0.50	...	...
Tin	...	0.05	0.05	0.02	...	0.04
Lead	...	...	...	...	...	0.005

^A Maximum or range unless otherwise specified.

TABLE 3 Mechanical Properties—Quenched & Tempered Classes

	Grade A		Grade B		Grade C		Grade D		Grade E		Grade F
	Class 1	Class 2	Class 1	Class 1	Class 2	Class 1	Class 2	Class 1	Class 2	Class 1	Class 1
Tensile strength, KSI min [MPa]	100 [690]	110 [760]	110 [760]	145 [1000]	160 [1105]	140 [965]	140 [965]	115 [795]	110 [760]	140 [965]	
Yield Strength min, KSI [MPa], 0.2 % Offset	70 [485]	80 [550]	90 [620]	115 [795]	120 [825]	90 [620]	100 [690]	75 [515]	80 [550]	100 [690]	
Elongation in 2 in., min %	20	18	18	15	16	13	13	15	18	15	
Reduction of area, min, %	60	50	50	30	50	30	35	50	55	45	
Impact Strength, min, avg., CV, RT, ft-lb [J]	30 [41]	25 [34]	30 [41]	30 [41]	40 [54]	8 [11]	13 [18]	20 [27]	25 [34]	8 [11]	
Impact Strength, min of one specimen per Test Methods A370 , CV, RT, ft-lb [J]	20 [27]	17 [23]	20 [27]	20 [27]	27 [36]	5 [7]	9 [12]	13 [18]	17 [23]	5 [7]	
Hardness, Brinell, max	255	269	269	352	375	331	331	277	262	321	
Hardness, Rockwell C, max	26	28	28	38	40	36	36	29	27	34	

TABLE 4 Mechanical Properties—Annealed Classes

	Grade A	Grade B	Grade C	Grade D	Grade E	Grade F
	Class 3	Class 2	Class 3	Class 3	Class 3	Class 2
Hardness, Brinell, max	248	248	311	248	248	302
Hardness, Rockwell C, max	24	24	33	24	24	32

possible to a mid-radius or mid-wall location of the forging. When longitudinal specimens are tested, they shall be taken from extensions. Extending the axial length of a larger section of a forging for a sufficient distance over a smaller section is also an acceptable location for transverse or circumferential specimens.

7.5 Number Of Tests—Where more than one location is designated on a forging drawing, tension tests shall be made from each location.

7.6 Hardness—The manufacturer shall perform Brinell or Rockwell hardness testing after final heat treatment and after machining to the forging drawing requirements.

7.7 Stress rupture testing of Grade F shall be conducted in accordance with **Table 5** using a combination test bar in

TABLE 5 Rupture Testing

		Grade F
Temperature, °F [°C]		1200 [650]
Stress, ksi [MPa], min		33 [230]
Time to rupture, h, min		25

accordance with Test Methods **E292**. Rupture must occur in the smooth section of each test specimen. The test may be discontinued after the time specified, provided notation in the certification. Stress rupture testing is not required on bars less than ½ in. in diameter or thickness.

8. Keywords

8.1 martensitic stainless steel; stainless steel billets; stainless steel forgings

SUPPLEMENTARY REQUIREMENTS

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

S1. Secondary Melting and Refining

S1.1 ESR or VAR is required. Use of either is permitted unless otherwise specified.

S2. Ingot Chemical Analysis

S2.1 If consumable electrode remelting is used, then chemical analyses of each remelted ingot shall meet the chemical composition requirements listed and shall be reported.

S3. Macrostructure

S3.1 Samples shall be taken from the top and bottom of the first and last ingot of each heat. The structure of the starting billets shall meet the criteria of Method **E381**, S-3, R-2, C-3 ≤ 36 in.² [0.84 m²] and S-3, R-3, C-3 > 36 in.² [0.84 m²].

S4. Magnetic Particle Inspection

S4.1 Each forging shall be magnetic particle inspected in accordance with Practice **A275/A275M**. The maximum acceptable indication size shall be ⅛ in. [3 mm] unless otherwise specified by the purchaser.

S5. Ultrasonic Inspection

S5.1 Ultrasonic inspection is required. The test method, location, and acceptance criteria shall be as agreed upon by the purchaser and producer.

S6. Microstructure

S6.1 The microstructure shall be tempered martensite with no more than 2 % delta ferrite.

S6.2 Metallographic inspection shall be performed at 100× magnification to determine the metallurgical structure, grain size, and delta ferrite content. Visual examination for the volume fraction of delta ferrite of various representative areas of examination is acceptable. When the visual estimation method indicates the delta ferrite content is greater than the allowed limit, the manufacturer may employ Test Method E562 for determining the acceptability of the lot.

S7. Stress Rupture Testing—Grade D

S7.1 Stress rupture testing shall be conducted at 1200°F [650°C] and 26 000 psi [180 MPa] using a combination test bar in accordance with Test Methods E292. Rupture must occur in the smooth section of each test specimen. The test may be discontinued after 25 h provided the certification so notes. Stress rupture testing is not required on bars less than ½ in. in diameter or thickness.

S8. Grain Size—Grade D and F

S8.1 The average grain size shall be 4 or finer. The maximum size of individual grains, distributed at random, shall be a 2. When the average grain size is 5 or finer, only the average size need be reported. Grain size determination shall be performed in accordance with Test Methods E112.

S9. Mechanical Properties

S9.1 Test samples shall be taken from an integral part of each forging whose drawing weight is over 500 lb [225 kg].

S10. Forging Temperature

S10.1 The maximum part temperature during forging is 2150°F [1175°C].

S11. Decarburization

S11.1 Surface decarburization of forgings shall not exceed 0.06 in. [1.5 mm].

S12. Forging Stock

S12.1 Forging stock shall be supplied in the annealed condition meeting the requirements of Table 4.

S13. Stress Relief

S13.1 Material shall be stress relieved in accordance with the requirements of Table 1.

S14. Microstructure-Grade F

S14.1 The microstructure shall be tempered martensite with no more than 1 % delta ferrite.

S14.2 Metallographic inspection shall be performed at 100× magnification to determine metallurgical structure, grain size, and delta ferrite content. Visual examination for the volume fraction of delta ferrite of various representative areas of examination is acceptable. When the visual estimation method indicates the delta ferrite content is greater than the allowed limit, the manufacturer may employ Test Method E562 for determining the acceptability of the lot.

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