SAE Aerospace
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AEROSPACE MATERIAL SPECIFICATION

AMS 5441

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Nickel Alloy, Corrosion and Heat-Resistant, Bars, Forgings, and Rings
Ni - 18Cr - 2.8Mo - 5.5Cb(Nb) - 0.70Ti - 1.50Al - 10Fe - 9Co - 1W
Consumable Electrode Remelted or Vacuum Induction Melted
1775 °F (968 °C) Solution Heat Treated, Precipitation-Hardenable

(Composition similar to UNS N07818)

RATIONALE

AMS 5441 is a new specification to cover a nickel-based corrosion and heat-resistant alloy, and is supplied in the solution treated condition.

1. SCOPE

1.1 Form

This specification covers a corrosion and heat-resistant nickel alloy in the form of bars, forgings, flash welded rings, and stock for forging, flash welded rings, or heading.

1.2 Application

These products have been used typically for parts requiring high resistance to creep and stress-rupture up to 1400 °F (760 °C) and oxidation resistance up to 1800 °F (982 °C), particularly those parts which are formed or welded and then precipitation heat treated to develop required properties, but usage is not limited to such applications.

2. APPLICABLE DOCUMENTS

The issue of the following documents in effect on the date of the purchase order forms a part of this specification to the extent supplied herein. The supplier may work to a subsequent revision of a document unless a specific document issue is specified. When the referenced document has been cancelled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), or www.sae.org.

AMS 2261	Tolerances, Nickel, Nickel Alloy, and Cobalt Alloy Bars, Rods, and Wire
AMS 2269	Chemical Check Analysis Limits, Nickel, Nickel Alloys, and Cobalt Alloys
AMS 2371	Quality Assurance Sampling and Testing, Corrosion and Heat-Resistant Steels and Alloys, Wrought Products and Forging Stock
AMS 2374	Quality Assurance Sampling and Testing, Corrosion and Heat-Resistant Steel and Alloy Forgings
AMS 2750	Pyrometry
AMS 2806	Identification, Bars, Wire, Mechanical Tubing, and Extrusions, Carbon and Alloy Steels and Corrosion and Heat-Resistant Steels and Alloys
AMS 2808	Identification, Forgings

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: **http://www.sae.org**

AMS 7490 Rings, Flash Welded, Corrosion and Heat-Resistant Austenitic Steels, Austenitic-Type Iron, Nickel, or Cobalt Alloys, or Precipitation-Hardenable Alloys

ARP1313 Determination of Trace Elements in High-Temperature Alloys

2.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, or www.astm.org.

ASTM E 8/E 8M Tension Testing of Metallic Materials
ASTM E 10 Brinell Hardness of Metallic Materials
ASTM E 21 Elevated Temperature Tension Tests of Metallic Materials
ASTM E 103 Rapid Indentation Hardness Testing of Metallic Materials
ASTM E 112 Determining Average Grain Size
ASTM E 139 Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials
ASTM E 292 Conducting Time-for-Rupture Notch Tension Tests of Materials
ASTM E 354 Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt Alloys

3. TECHNICAL REQUIREMENTS

3.1 Composition

Shall conform to the percentages by weight shown in Table 1, determined by wet chemical methods in accordance with ASTM E 354, by spectrochemical methods, by the methods of ARP1313 for lead, bismuth, and selenium, or by other analytical methods acceptable to purchaser.

TABLE 1 - COMPOSITION

Element	min	max
Carbon	0.01	0.05
Manganese	--	0.35
Silicon	--	0.35
Phosphorus	0.004	0.020
Sulfur	--	0.0025
Chromium	17.00	21.00
Nickel	Remainder	
Molybdenum	2.50	3.10
Columbium (Niobium)	5.20	5.80
Titanium	0.50	1.00
Aluminum	1.20	1.70
Cobalt	8.00	10.00
Tungsten	0.80	1.40
Boron	0.003	0.008
Copper	--	0.30
Lead	--	0.0005 (5 ppm)
Bismuth	--	0.00003 (0.3 ppm)
Selenium	--	0.0003 (3 ppm)
Iron	8.00	10.00

3.1.1 Check Analysis

Composition variations shall meet the applicable requirements of AMS 2269.

3.2 Melting Practice

Alloy shall be multiple melted using consumable electrode practice in the remelt cycle or shall be induction melted under vacuum. If consumable electrode remelting is not performed in vacuum, electrodes which have been produced by vacuum induction melting shall be used for remelting.

3.3 Condition

The product shall be supplied in the following condition:

3.3.1 Bars

Hot or cold finished, solution heat treated, and descaled except as specified in 3.3.1.1 and 3.3.1.2.

3.3.1.1 Hot finished round bars shall be ground or turned; all other hot finished bars shall be as hot finished.

3.3.1.1.1 Cold finished round bars shall be ground or as cold finished; all other cold finished bars shall be as cold finished.

3.3.2 Forgings and Flash Welded Rings

Solution heat treated and descaled.

3.3.2.1.1 Flash welded rings shall not be supplied unless specified or permitted on purchaser's part drawing. When supplied, rings shall be manufactured in accordance with AMS 7490.

3.3.3 Stock for Forging, Flash Welded Rings, or Heading

As ordered by the forging, flash welded ring, or heading manufacturer.

3.4 Heat Treatment

Bars, forgings, and flash welded rings shall be solution heat treated by heating to a temperature within the range 1750 to 1800 °F (954 to 982 °C), holding at the selected temperature within ±25 °F (±14 °C) for one hour or a time commensurate with cross-sectional thickness, and cooling at a rate equivalent to an air cool or faster. Pyrometry shall be in accordance with AMS 2750.

3.4.1 If forgings are not to be machined all over, heat treatment shall be performed in a suitable protective atmosphere or, when permitted by purchaser, a suitable protective coating may be applied to the forgings in lieu of using a protective atmosphere.

3.5 Properties

The product shall conform to the following requirements:

3.5.1 Bars, Forgings, and Flash Welded Rings

3.5.1.1 As Solution Heat Treated

3.5.1.1.1 Hardness

Shall be not higher than 285 HB, or equivalent (See 8.2), determined in accordance with ASTM E 10 or ASTM E 103.

3.5.1.1.2 Average Grain Size

Shall be as follows, determined by the comparative method of ASTM E 112. In case of disagreement, the intercept (Heyn) procedure shall be used.

3.5.1.1.2.1 Bars and flash welded rings under 9 square inches (58 cm^2) in cross-sectional area shall exhibit an average grain size of ASTM No. 4 or finer. Due to the presence of nonrecrystallized grains, up to 20% of the cross section of the product may have an average grain size of ASTM No. 2 to 4, determined by the intercept method of ASTM E 112.

3.5.1.1.2.2 Bars and flash welded rings 9 to 50 square inches (58 to 323 cm^2), inclusive, in cross-sectional area and all forgings shall exhibit an average grain size of ASTM No. 4 or finer. Due to the presence of nonrecrystallized grains, up to 20% of the cross section of the product may have an average grain size of ASTM No. 1 to 3, determined by the intercept method of ASTM E 112.

3.5.1.1.3 Microstructure

Product shall be free of Laves phase. Banding of acicular phase and amount of acicular phase shall conform to standards acceptable to purchaser.

3.5.1.2 Response to Heat Treatment

Product, 5 inches (127 mm) and under in nominal diameter or least distance between parallel sides, shall meet the requirements of 3.5.1.2.1, 3.5.1.2.2, and 3.5.1.2.3 after being precipitation heat treated by heating to 1450 °F ± 15 (788 °C ± 8), hold at temperature for not less than eight hours, cool at a rate not less than 100 °F (56 °C) degrees per hour to 1300 °F ± 15 (704 °C ± 8), hold at 1300 °F ± 15 (704 °C ± 8) for not less than eight hours, and cool at a rate equivalent to air cool or faster.

3.5.1.2.1 Tensile Properties

3.5.1.2.1.1 At Room Temperature

Shall be as shown in Table 2, determined in accordance with ASTM E 8 or ASTM E 8M.

TABLE 2A - MINIMUM ROOM TEMPERATURE TENSILE PROPERTIES, INCH/POUND UNITS

Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 4D %	Reduction of Area %
194	139	15	15

TABLE 2B - MINIMUM ROOM TEMPERATURE TENSILE PROPERTIES, SI UNITS

Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Elongation in 4D %	Reduction of Area %
1338	958	15	15

3.5.1.2.1.2 At 1300 °F (704 °C)

Shall be as specified in Table 3, determined in accordance with ASTM E 21 on specimens heated to 1300 °F ± 5 (704 °C ± 3), held at heat for not less than 20 minutes before testing, and tested at 1300 °F ± 5 (704 °C ± 3).

TABLE 3A - MINIMUM TENSILE PROPERTIES AT 1300 °F, INCH/POUND UNITS

Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 4D %	Reduction of Area %
147	117	13	15

TABLE 3B - MINIMUM TENSILE PROPERTIES AT 704 °C, SI UNITS

Tensile Strength MPa	Yield Strength at 0.2% Offset MPa	Elongation in 4D %	Reduction of Area %
1014	807	13	15

3.5.1.2.1.3 Requirements of 3.5.1.2.1.1 and 3.5.1.2.1.2 apply to specimens taken with the axis approximately parallel to the grain flow, to specimens taken in the radial direction and in the tangential direction at the rim of disc forgings, and to specimens taken in the circumferential direction from flash welded rings.

3.5.1.2.1.4 Specific locations of specimens from forgings and flash welded rings shall be as agreed upon by purchaser and vendor.

3.5.1.2.2 Hardness

Shall be not lower than 331 HB, or equivalent (See 8.2), determined in accordance with ASTM E 10 or ASTM E 103. Product shall not be rejected on the basis of hardness if the tensile property requirements of 3.5.1.2.1.1 are acceptable, determined on specimens taken from the same sample as that with nonconforming hardness or from another sample with similar nonconforming hardness.

3.5.1.2.3 Stress-Rupture Properties at 1300 °F (704 °C)

Shall be as follows; testing of notched specimens and of combination smooth-and-notched specimens shall be performed in accordance with ASTM E 292 and testing of smooth specimens shall be performed in accordance with ASTM E 139:

3.5.1.2.3.1 A standard cylindrical combination smooth-and-notched specimen conforming to ASTM E 292, maintained at 1300 °F ± 3 (704 °C ± 2) while a load sufficient to produce an initial axial stress of 90 ksi (621 MPa) or higher is applied continuously, shall not rupture in less than 39 hours. The test shall be continued to rupture without change of load. Rupture shall occur in the smooth section and elongation of this section after rupture, measured at room temperature, shall be not less than 8% in 4D for product 5.0 inches (127 mm) and under in nominal diameter or distance between parallel sides.

3.5.1.2.3.2 As an alternate procedure, separate smooth and notched specimens, machined from adjacent sections of the same piece, with gage sections conforming to the respective dimensions shown in ASTM E 292 may be tested individually under the conditions of 3.5.1.2.3.1. The smooth specimen shall not rupture in less than 39 hours and elongation after rupture, measured at room temperature, shall be as specified in 3.5.1.2.3.1. The notched specimen shall not rupture in less time than the companion smooth specimen but need not be tested to rupture.

3.5.1.2.3.3 The tests of 3.5.1.2.3.1 and 3.5.1.2.3.2 may be conducted using incremental loading. In such case, the load required to produce an initial axial stress of 90 ksi (621 MPa) or higher shall be used to rupture or for 39 hours, whichever occurs first. After the 39 hours and at intervals of 8 hours minimum, thereafter, the stress shall be increased in increments of 5.0 ksi (34.5 MPa). Time to rupture, rupture location, and elongation requirements shall be as specified in 3.5.1.2.3.1.

3.5.2 Forging Stock

When a sample of stock is forged to a test coupon, heat treated as in 3.4 and 3.5.1.2, specimens taken from the heat treated coupon shall conform to the requirements of 3.5.1.2.1, 3.5.1.2.2, and 3.5.1.2.3. If specimens taken from the stock after heat treatment as in 3.4 and 3.5.1.2 conform to the requirements of 3.5.1.2.1, 3.5.1.2.2, and 3.5.1.2.3, the tests shall be accepted as equivalent to tests of a forged coupon.

3.5.3 Stock for Flash Welded Rings or Heading

Specimens taken from the stock after heat treatment as in 3.4 and 3.5.1.2 shall conform to the requirements of 3.5.1.2.1, 3.5.1.2.2, and 3.5.1.2.3.

3.6 Quality

The product, as received by purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from imperfections detrimental to usage of the product.

3.6.1 Grain flow of die forgings, except in areas which contain flash-line end grain, shall follow the general contour of the forgings showing no evidence of reentrant grain flow.

3.7 Tolerances

Bars shall conform to all applicable requirements of AMS 2261

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for Inspection

The vendor of the product shall supply all samples for vendor's tests and shall be responsible for the performance of all required tests. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to specified requirements.

4.2 Classification of Tests

4.2.1 Acceptance Tests

The following requirements are acceptance tests and shall be performed on each heat or lot as applicable.

4.2.1.1 Composition (3.1) of each heat.

4.2.1.2 Hardness (3.5.1.1.1) and average grain size (3.5.1.1.2) of each lot of bars, forgings, and flash welded rings as solution heat treated.

4.2.1.3 Room-temperature tensile properties (3.5.1.2.1.1), hardness (3.5.1.2.2), and stress-rupture properties (3.5.1.2.3) of each lot of bars, forgings, and flash welded rings after precipitation heat treatment.

4.2.1.4 Microstructure (3.5.1.1.3) of each lot.

4.2.1.5 Tolerances (3.7) of bars.

4.2.2 Periodic Tests

The following requirements are periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser:

4.2.2.1 Tensile properties at 1300 °F (704 °C) (3.5.1.2.1.2) of bars, forgings, and flash welded rings after precipitation heat treatment.

4.2.2.2 Ability of forging stock (3.5.2) and of stock for flash welded rings or heading (3.5.3) to develop required properties.

4.2.2.3 Grain flow (3.6.1) of die forgings.

4.3 Sampling and Testing

Shall be as follows:

4.3.1 Bars, Flash Welded Rings, and Stock for Forging, Flash Welded Rings, or Heading

In accordance with AMS 2371.

4.3.2 Forgings

In accordance with AMS 2374.