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400 Commonwealth Dr., Warrendale, PA 15096-0001

AEROSPACE MATERIAL SPECIFICATION

Submitted for recognition as an American National Standard

AMS 6525A

Issued 1-15-76
Revised 1-1-89

Superseding AMS 6525

STEEL BARS, FORGINGS, TUBING, AND RINGS
0.75Cr - 9.0Ni - 4.5Co - 1.0Mo - 0.09V (0.17 - 0.23C)
Consumable Electrode Vacuum Melted

UNS K91283

1. SCOPE:

- 1.1 **Form:** This specification covers a premium aircraft-quality, low-alloy steel in the form of bars, forgings, mechanical tubing, flash welded rings, and stock for forging or flash welded rings.
- 1.2 **Application:** Primarily for heat-treated parts, such as pressure vessels, requiring toughness and through-hardening to high strength levels and where such parts may require welding during fabrication.

2. **APPLICABLE DOCUMENTS:** The following publications form a part of this specification to the extent specified herein. The latest issue of Aerospace Material Specifications and Aerospace Standards shall apply. The applicable issue of other documents shall be as specified in AMS 2350.

2.1 **SAE Publications:** Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096.

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2.1.1 Aerospace Material Specifications:

- AMS 2251 - Tolerances, Low-Alloy Steel Bars
- MAM 2251 - Tolerances, Metric, Low-Alloy Steel Bars
- AMS 2253 - Tolerances, Carbon and Alloy Steel Tubing
- MAM 2253 - Tolerances, Metric, Carbon and Alloy Steel Tubing
- AMS 2259 - Chemical Check Analysis Limits, Wrought Low-Alloy and Carbon Steels
- AMS 2300 - Premium Aircraft-Quality Steel Cleanliness, Magnetic Particle Inspection Procedure
- MAM 2300 - Premium Aircraft-Quality Steel Cleanliness, Magnetic Particle Inspection Procedure, Metric (SI) Measurement
- AMS 2350 - Standards and Test Methods
- AMS 2370 - Quality Assurance Sampling of Carbon and Low-Alloy Steels, Wrought Products Except Forgings and Forging Stock
- AMS 2372 - Quality Assurance Sampling of Carbon and Low-Alloy Steels, Forgings and Forging Stock
- AMS 2375 - Control of Forgings Requiring First Article Approval
- AMS 2630 - Ultrasonic Inspection
- AMS 2640 - Magnetic Particle Inspection
- 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
- AMS 7496 - Rings, Flash Welded, Carbon and Low-Alloy Steels

2.1.2 Aerospace Standards:

- AS1182 - Standard Machining Allowance, Aircraft Quality and Premium Quality Steel Products

2.2 ASTM Publications: Available from American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

- ASTM A370 - Mechanical Testing of Steel Products
- ASTM A604 - Macroetch Testing of Consumable Electrode Remelted Steel Bars and Billets
- ASTM E45 - Determining Inclusion Content of Steel
- ASTM E112 - Determining Average Grain Size
- ASTM E353 - Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
- ASTM E399 - Plane-Strain Fracture Toughness of Metallic Materials

2.3 U.S. Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120.2.3.1 Military Specifications:

- MIL-H-6875 - Heat Treatment of Steel, Process for

2.3.2 Military Standards:

MIL-STD-163 - Steel Mill Products, Preparation for Shipment and Storage

3. TECHNICAL REQUIREMENTS:

3.1 Composition: Shall conform to the following percentages by weight, \emptyset determined by wet chemical methods in accordance with ASTM E353, by spectrochemical methods, or by other analytical methods acceptable to purchaser:

	min	max
Carbon	0.17	0.23
Manganese	0.20	0.40
Silicon	--	0.20
Phosphorus	--	0.010
Sulfur	--	0.010
Chromium	0.65	0.85
Nickel	8.50	9.50
Cobalt	4.25	4.75
Molybdenum	0.90	1.10
Vanadium	0.06	0.12
Copper	--	0.35

3.1.1 Check Analysis: Composition variations shall meet the applicable requirements of AMS 2259.

3.1.2 For product over 200 square inches (1290 cm²) in cross-sectional area, the chemical composition and check analysis tolerances shall be as agreed upon by purchaser and vendor.

3.2 Condition: The product shall be supplied in the following condition; hardness and tensile strength shall be determined in accordance with ASTM A370. Pyrometry shall be in accordance with AMS 2750.

3.2.1 Bars:

3.2.1.1 Bars 0.500 Inch (12.70 mm) and Under in Nominal Diameter or Distance Between Parallel Sides: Annealed, or normalized and tempered, and cold finished having tensile strength not higher than 180,000 psi (1241 MPa).

3.2.1.2 Bars Over 0.500 Inch (12.70 mm) in Nominal Diameter or Distance Between Parallel Sides: Hot finished, annealed, or normalized and tempered, and descaled having hardness not higher than 341 HB, or equivalent, except that bars ordered annealed and cold finished may have hardness as high as 352 HB, or equivalent.

3.2.2 Forgings and Flash Welded Rings: Annealed, or normalized and tempered, and descaled having hardness not higher than 352 HB, or equivalent. Heat treatment of forging shall be in accordance with MIL-H-6875.

- 3.2.2.1 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 7496.
- 3.2.3 Mechanical Tubing: Annealed, or normalized and tempered, and cold finished having hardness not higher than 38 HRC, or equivalent, except that tubing ordered hot finished and annealed shall have hardness not higher than 36 HRC, or equivalent.
- 3.2.4 Stock for Forging or Flash Welded Rings: As ordered by the forging or flash welded ring manufacturer.
- 3.3 Annealing: Bars, mechanical tubing, and flash welded rings shall be annealed by heating to $1250^{\circ}\text{F} \pm 25$ ($677^{\circ}\text{C} \pm 14$), holding at heat for 4 hours ± 0.25 , air cooling to room temperature, reheating to $1150^{\circ}\text{F} \pm 25$ ($621^{\circ}\text{C} \pm 14$), holding at heat for 8 hours ± 0.25 , and cooling in air to room temperature.
- 3.3.1 When specified by purchaser, the product may be normalized prior to annealing by heating to $1650^{\circ}\text{F} \pm 25$ ($899^{\circ}\text{C} \pm 14$), holding at heat for not less than 1 hour per inch (25 mm) of maximum thickness but not less than 1 hour, and cooling in air to room temperature.
- 3.4 Properties: The product shall conform to the following requirements; hardness and tensile testing shall be performed in accordance with ASTM A370:
- 3.4.1 All Products:
- 3.4.1.1 Macrostructure: Visual examination of transverse sections as in 4.3.3 from bars, billets, tube rounds or tubes, and stock for forging or flash welded rings, etched in accordance with ASTM A604, shall show no pipe or cracks. Except as specified in 3.4.1.1.1, porosity, segregation, inclusions, and other imperfections for product 36 square inches (232 cm^2) and under in nominal cross-sectional area shall be no worse than the following macrographs of ASTM A604; macrostructure standards for product over 36 square inches (232 cm^2) in nominal cross-sectional area shall be as agreed upon by purchaser and vendor.

Class	Condition	Severity
1	Freckles	A
2	White Spots	A
3	Radial Segregation	B
4	Ring Pattern	B

3.4.1.1.1 If tubes are produced directly from ingots or large blooms, transverse sections may be taken from tubes rather than tube rounds. Macrostructure standards for such tubes shall be as agreed upon by purchaser and vendor.

3.4.1.2 Micro-Inclusion Rating: No specimen as in 4.3.4 shall exceed the following limits, determined in accordance with ASTM E45, Method D:

	A		B		C		D	
	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
Worst Field Severity	1.5	1.0	1.5	1.0	1.5	1.0	1.5	1.0
Worst Field Frequency, * maximum	1		*	1	*	1	3	1
Total Rateable Fields, Frequency, maximum	**	1	**	1	**	1	8	1

* Combined A+B+C, not more than 3 fields
 ** Combined A+B+C, not more than 8 fields

3.4.1.2.1 A rateable field is defined as one which has a type A, B, C, or D inclusion rating of at least 1.0 thin or heavy in accordance with the Jernkontoret Chart, Plate III, ASTM E45.

3.4.2 Bars, Forgings, Mechanical Tubing, and Flash Welded Rings:

3.4.2.1 Grain Size: Predominantly 5 or finer with occasional grains as large as 3 permissible, determined in accordance with ASTM E112.

3.4.2.2 Decarburization:

3.4.2.2.1 Bars, tubing, and flash welded rings ordered ground, turned, or polished shall be free from decarburization on the ground, turned, or polished surfaces. Decarburization on tubing ID shall not exceed the maximum depth specified in Table II.

3.4.2.2.2 Allowable decarburization of bars, billets, and tube rounds ordered for redrawing, forging, or flash welding or to specified microstructural requirements shall be as agreed upon by purchaser and vendor.

3.4.2.2.3 Decarburization of bars and flash welded rings to which 3.4.2.2.1 or 3.4.2.2.2 is not applicable shall be not greater than shown in Table I.

TABLE I

Nominal Diameter or Distance Between Parallel Sides Inches	Depth of Decarburization Inch
Up to 0.375, incl	0.010
Over 0.375 to 0.500, incl	0.012
Over 0.500 to 0.625, incl	0.014
Over 0.625 to 1.000, incl	0.017
Over 1.000 to 1.500, incl	0.020
Over 1.500 to 2.000, incl	0.025
Over 2.000 to 2.500, incl	0.030
Over 2.500 to 3.000, incl	0.035
Over 3.000 to 5.000, incl	0.045

TABLE I (SI)

Nominal Diameter or Distance Between Parallel Sides Millimetres	Depth of Decarburization Millimetres
Up to 9.52, incl	0.25
Over 9.52 to 12.70, incl	0.30
Over 12.70 to 15.88, incl	0.36
Over 15.88 to 25.40, incl	0.43
Over 25.40 to 38.10, incl	0.51
Over 38.10 to 50.80, incl	0.64
Over 50.80 to 63.50, incl	0.76
Over 63.50 to 76.20, incl	0.89
Over 76.20 to 127.00, incl	1.14

3.4.2.2.3.1 Limits for depth of decarburization of bars and ring cross-sections over 5.000 inches (127.00 mm) in nominal diameter or distance between parallel sides shall be as agreed upon by purchaser and vendor.

3.4.2.2.4 Decarburization of tubing to which 3.4.2.2.1 or 3.4.2.2.2 is not applicable shall be not greater than shown in Table II:

TABLE II

Nominal Wall Thickness Inches	Depth of Decarburization, Inch	
	ID	OD
Up to 0.109, incl	0.008	0.015
Over 0.109 to 0.203, incl	0.010	0.020
Over 0.203 to 0.400, incl	0.012	0.025
Over 0.400 to 0.600, incl	0.015	0.030
Over 0.600 to 1.000, incl	0.017	0.035
Over 1.000	0.020	0.040

TABLE II (SI)

Nominal Wall Thickness Millimetres	Depth of Decarburization, Millimetres	
	ID	OD
Up to 2.77, incl	0.20	0.38
Over 2.77 to 5.16, incl	0.25	0.51
Over 5.16 to 10.16, incl	0.30	0.64
Over 10.16 to 15.24, incl	0.38	0.76
Over 15.24 to 25.40, incl	0.43	0.89
Over 25.40	0.51	1.02

3.4.2.2.5 Depth of decarburization on forgings shall be not greater than \emptyset 0.060 inch (1.52 mm); forgings shall show no carburization.

3.4.2.2.6 Decarburization shall be measured by the microscopic method or by Rockwell Superficial 30-N scale or equivalent hardness testing method on hardened but untempered specimens protected during heat treatment to prevent changes in surface carbon content. Depth of decarburization, when measured by a hardness method, is defined as the perpendicular distance from the surface to the depth under that surface below which there is no further increase in hardness. Such measurements shall be far enough away from any adjacent surface to be uninfluenced by any decarburization or lack of decarburization thereon.

3.4.2.2.6.1 When determining the depth of decarburization, it is permissible to disregard local areas provided the decarburization of such areas does not exceed the above limits by more than 0.005 inch (0.13 mm) and the width is 0.065 inch (1.65 mm) or less.

3.4.2.3 Properties After Heat Treatment: Specimens as in 4.3.5, taken from product 100 square inches (645 cm²) and under in cross-sectional area after heat treatment as in 3.4.2.3.1, shall meet the requirements of 3.4.2.3.2, 3.4.2.3.3, and, when specified, 3.4.2.3.4. Heat treatment and resultant properties for product over 100 square inches (645 cm²) in cross-sectional area shall be as agreed upon by purchaser and vendor.

3.4.2.3.1 Heat Treatment:

3.4.2.3.1.1 Normalizing: Heat to 1650°F ± 25 (899°C ± 14), hold at heat for 1 hour per inch (25 mm) of maximum cross-section, and cool in air to room temperature.

3.4.2.3.1.1.1 Normalizing may be omitted if the product was supplied normalized and annealed.

- 3.4.2.3.1.2 Hardening: Heat to 1525°F ± 25 (829°C ± 14), hold at heat for 1 hour per inch (25 mm) of maximum section thickness but not less than 1 hour, and quench in oil at 60° to 150°F (16° to 66°C), cooling within 2 hours to -100°F ± 25 (-73°C ± 14), holding at -100°F ± 25 (-73°C ± 14) for not less than 1 hour, and warming to room temperature.
- 3.4.2.3.1.3 Tempering: Heat to 1025° - 1075°F (552° - 579°C), hold at heat for not less than 4 hours, and cool in air to room temperature.
- 3.4.2.3.2 Tensile Properties:
- | | |
|--|------------------------|
| Tensile Strength, minimum | 190,000 psi (1310 MPa) |
| Yield Strength at 0.2% Offset, minimum | 180,000 psi (1241 MPa) |
| Elongation in 4D, minimum | 12% |
| Reduction of Area, minimum | 45% |
- 3.4.2.3.3 Hardness: Should be 41 - 45 HRC, or equivalent but the product shall not be rejected on the basis of hardness if the tensile property requirements are met.
- 3.4.2.3.4 Fracture Toughness: Shall, when specified, be not lower than 110 ksi inch (121 MPa m) K_{IC} or K_{IQ}, determined in accordance with ASTM E399 on product not less than 1.50 inches (38.1 mm) in section thickness and not less than 4 inches (102 mm) wide.
- 3.4.3 Forging Stock: When a sample of stock is forged to a test coupon and heat treated as in 3.4.2.3.1, specimens taken from the heat treated coupon shall conform to the requirements of 3.4.2.3.2, 3.4.2.3.3, and, when specified, 3.4.2.3.4. If specimens taken from the stock after heat treatment as in 3.4.2.3.1 conform to the requirements of 3.4.2.3.2, 3.4.2.3.3, and, when specified, 3.4.2.3.4, the tests shall be accepted as equivalent to tests of a forged coupon.
- 3.4.3.1 Forging stock from a heat meeting the requirements of 3.4.3 in one size need not be retested for use in a smaller size.
- 3.4.4 Stock for Flash Welded Rings: Specimens taken from the stock after heat treatment as in 3.4.2.3.1 shall conform to the requirements of 3.4.2.3.2, 3.4.2.3.3, and, when specified, 3.4.2.3.4.
- 3.5 Quality:
- 3.5.1 Steel shall be premium aircraft-quality conforming to AMS 2300 or MAM 2300 except that a maximum average frequency (F) rating of 0.10 and a maximum average severity (S) rating of 0.20 shall apply. Steel shall be multiple melted using consumable electrode vacuum process in the remelt cycle; at least one of the melting cycles shall be under vacuum.
- 3.5.2 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.

- 3.5.2.1 Bars, tubing, and flash welded rings ordered ground, turned, or polished shall be free from seams, laps, tears, and cracks open to the ground, turned, or polished surfaces.
- 3.5.2.2 Product ordered to surface conditions other than ground, turned, or polished shall, after removal of the standard machining allowance, be free from seams, laps, tears, cracks, and other defects exposed to the machined surfaces. Standard machining allowance shall be in accordance with AS 1182.
- 3.5.2.3 When specified, the product shall be subjected to magnetic particle inspection in accordance with AMS 2640. Standards for acceptance shall be as agreed upon by purchaser and vendor.
- 3.5.2.4 When specified, the product shall be subjected to ultrasonic inspection in accordance with AMS 2630 and shall meet the requirements of Class A of that specification.
- 3.5.2.5 Forgings shall have substantially uniform macrostructure. Standards for acceptance shall be as agreed upon by purchaser and vendor.
- 3.5.2.6 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 re-entrant grain flow.
- 3.6 Sizes: Except when exact lengths or multiples of exact lengths are ordered, straight bars and tubing will be acceptable in mill lengths of 6 - 20 feet (1.8 - 6.1 m) but not more than 10% of any shipment shall be supplied in lengths shorter than 10 feet (3 m).
- 3.7 Tolerances: Shall conform to all applicable requirements of the following:
- 3.7.1 Bars: AMS 2251 or MAM 2251.
- 3.7.2 Mechanical Tubing: AMS 2253 or MAM 2253.
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 performing all required tests. Results of such tests shall be reported to the purchaser as required by 4.5. Purchaser reserves the right to sample and to perform any confirmatory testing deemed necessary to ensure that the product conforms to the requirements of this specification.
- 4.2 Classification of Tests:
- 4.2.1 Acceptance Tests: Tests to determine conformance to the following requirements are classified as acceptance tests and shall be performed on each heat or lot as applicable:

- 4.2.1.1 Composition (3.1), macrostructure (3.4.1.1), micro-inclusion rating (3.4.1.2), and frequency-severity cleanliness rating (3.5.1) of each heat.
- 4.2.1.2 Condition (3.2), grain size (3.4.2.1), and decarburization (3.4.2.2) of each lot of bars, forgings, mechanical tubing, and flash welded rings.
- 4.2.1.3 Tensile properties (3.4.2.3.2), hardness (3.4.2.3.3), and, when specified, fracture toughness (3.4.2.3.4) of each lot of bars, forgings, mechanical tubing, and flash welded rings after heat treatment.
- 4.2.1.4 Tolerances (3.7) of bars and mechanical tubing.
- 4.2.2 Periodic Tests: Tests of forging stock (3.4.3) and of stock for flash welded rings (3.4.4) to determine ability to develop required properties are classified as periodic tests and shall be performed at a frequency selected by the vendor unless frequency of testing is specified by purchaser.
- 4.2.3 Preproduction Tests: Tests of forgings to determine conformance to all applicable technical requirements of this specification when AMS 2375 is specified are classified as preproduction tests and shall be performed prior to or on the first article shipment of a forging to a purchaser, when a change in material and/or processing requires reapproval as in 4.4, and when purchaser deems confirmatory testing to be required.
- 4.2.3.1 For direct U.S. Military procurement, substantiating test data and, when requested, preproduction forgings shall be submitted to the cognizant agency as directed by the procuring activity, contracting officer, or request for procurement.
- 4.3 Sampling: Shall be in accordance with the following; a heat shall be the consumable electrode vacuum remelted ingots produced from steel originally melted as a single furnace charge:
- 4.3.1 Bars, Mechanical Tubing, Flash Welded Rings, and Stock for Flash Welded Rings: AMS 2370.
- 4.3.2 Forgings and Forging Stock: AMS 2372.
- 4.3.3 Samples for macrostructure rating (3.4.1.1) shall be full cross-sectional specimens obtained from the finished billet or suitable rerolled product representing the top and bottom of each ingot.
- 4.3.4 Samples for micro-inclusion rating (3.4.1.2) shall be obtained from the finished billet or suitable rerolled product and shall consist of not less than four specimens representing the top and bottom of the first and last ingot from a heat yielding ten or fewer ingots or not less than six specimens representing the top and bottom of the first, middle, and last usable ingot from a heat yielding more than ten ingots.