

STEEL BARS, FORGINGS, AND TUBING
1.0Cr (0.98 - 1.10C) (SAE 51100)
Electroslag Remelted

UNS G51986

1. SCOPE:

1.1 Form: This specification covers a premium aircraft-quality, low-alloy steel in the form of bars, forgings, mechanical tubing, and forging stock.

1.2 Application: Primarily for bearing components, with thickness under 0.50 inch (12.7 mm), requiring a through-hardening steel, usually with hardness of approximately 60 HRC, and subject to very rigid inspection standards.

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 2806 - Identification, Bars, Wire, Mechanical Tubing, and Extrusions, Carbon and Alloy Steels and Corrosion and Heat Resistant Steels and Alloys
- AMS 2808 - Identification, Forgings

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 the Inclusion Content of Steel
- ASTM E350 - Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron

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 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, determined by wet chemical methods in accordance with ASTM E350, by spectrochemical methods or by other analytical methods acceptable to purchaser:

	min	max
Carbon	0.98	1.10
Manganese	0.25	0.45
Silicon	0.15	0.35
Phosphorus	--	0.015
Sulfur	--	0.015
Chromium	0.90	1.15
Nickel	--	0.25
Molybdenum	--	0.10
Copper	--	0.35

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

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

- 3.2.1.1 Bars 0.500 Inch (12.70 mm) and Under in Nominal Diameter or Distance Between Parallel Sides: Cold finished, with microstructure of spheroidized cementite in ferrite matrix, having tensile strength not higher than 120,000 psi (825 MPa).
- 3.2.1.2 Bars Over 0.500 Inch (12.70 mm) in Nominal Diameter or Distance Between Parallel Sides: Hot finished and annealed, with microstructure of spheroidized cementite in ferrite matrix, having hardness not higher than 207 HB, or equivalent, except that bars ordered cold finished may have hardness as high as 248 HB, or equivalent.
- 3.2.2 Forgings: As ordered.
- 3.2.3 Mechanical Tubing: Cold finished with microstructure of spheroidized cementite in ferrite matrix. Tubing ordered hot finished and annealed shall have hardness not higher than 95 HRB, or equivalent.
- 3.2.4 Forging Stock: As ordered by the forging manufacturer.

- 3.3 Properties: The product shall conform to the following requirements; hardness testing shall be performed in accordance with ASTM A370:

3.3.1 Inclusion Rating: Shall be as follows:

- 3.3.1.1 **Macrostructure:** Visual examination of transverse sections as in 4.3.3 from bars, billets, tube rounds or tubes, and forging stock, etched in accordance with ASTM A604, shall show no pipe or cracks. Except as specified in 3.3.1.1.1, porosity, segregation, inclusions, and other imperfections shall be no worse than the following macrographs of ASTM A604:

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

- 3.3.1.1.1 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.

- 3.3.1.2 **Micro-Inclusion Rating:** At least one specimen as in 4.3.4 from each ingot tested as well as two-thirds of the total number of specimens and the average of all specimens shall not exceed the following limits, determined in accordance with ASTM E45, Method D, except that the length of any inclusion shall be not greater than 0.015 inch (0.38 mm):

	A		B		C		D	
	Thin	Heavy	Thin	Heavy	Thin	Heavy	Thin	Heavy
Worst Field Severity	2.0	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

- 3.3.1.2.1 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.

3.3.2 Response to Heat Treatment: Specimens as in 4.3.5, protected by suitable means or treated in a neutral atmosphere to minimize scaling and prevent either carburization or decarburization, shall have substantially uniform hardness not lower than 63 HRC at any point below any permissible decarburization after being placed in a furnace which is at $1525^{\circ}\text{F} \pm 10$ ($829^{\circ}\text{C} \pm 6$), allowed to heat to $1525^{\circ}\text{F} \pm 10$ ($829^{\circ}\text{C} \pm 6$), held at heat for 20 minutes ± 2 , and quenched in commercial paraffin oil [100 SUS at 100°F (38°C)] at room temperature.

3.3.3 Decarburization:

3.3.3.1 Bars and tubing 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 3.3.3.4.

3.3.3.2 Allowable decarburization of bars, billets, and tube rounds ordered for redrawing or forging or to specified microstructural requirements other than spheroidized cementite in ferrite matrix shall be as agreed upon by purchaser and vendor.

3.3.3.3 Decarburization of bars for anti-friction balls and rollers to which 3.3.3.1 or 3.3.3.2 is not applicable shall be not greater than shown in Table I.

TABLE I

Nominal Diameter or Distance Between Parallel Sides Inch	Depth of Decarburization, Inch	
	Hot Finished	Cold Finished
Up to 0.250, incl	0.005	0.003
Over 0.250 to 0.500, incl	0.006	0.004
Over 0.500 to 0.750, incl	0.008	0.006
Over 0.750 to 1.000, incl	0.010	0.008

TABLE I (SI)

Nominal Diameter or Distance Between Parallel Sides Millimetres	Depth of Decarburization Millimetres	
	Hot Finished	Cold Finished
Up to 6.35, incl	0.13	0.08
Over 6.35 to 12.70, incl	0.15	0.10
Over 12.70 to 19.05, incl	0.20	0.15
Over 19.05 to 25.40, incl	0.25	0.20

- 3.3.3.4 Decarburization of bars and of the ID and OD of tubes to which 3.3.3.1, 3.3.3.2, or 3.3.3.3 is not applicable shall be not greater than shown in Table II.

TABLE II

Nominal Diameter or Distance Between Parallel Sides Inches	Depth of Decarburization, Inch				
	Bars		Tubes		
	Hot Finished	Annealed	Cold Finished	Annealed	Cold Finished
Up to 1.000, incl	0.012	0.015	0.012	0.012	0.010
Over 1.000 to 2.000, incl	0.017	0.022	0.015	0.020	0.014
Over 2.000 to 3.000, incl	0.025	0.030	0.025	0.030	0.019
Over 3.000 to 4.000, incl	0.035	0.045	0.035	0.035	0.024
Over 4.000 to 5.000, incl	0.055	0.065	0.055	0.040	0.028

TABLE II (SI)

Nominal Diameter or Distance Between Parallel Sides Millimetres	Depth of Decarburization, Millimetres				
	Bars		Tubes		
	Hot Finished	Annealed	Cold Finished	Annealed	Cold Finished
Up to 25.40, incl	0.30	0.38	0.30	0.30	0.25
Over 25.40 to 50.80, incl	0.43	0.56	0.38	0.51	0.36
Over 50.80 to 76.20, incl	0.64	0.76	0.64	0.76	0.48
Over 76.20 to 101.60, incl	0.89	1.14	0.89	0.89	0.61
Over 101.60 to 127.00, incl	1.40	1.65	1.40	1.02	0.71

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

- 3.3.3.5 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.

- 3.3.3.5.1 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 Quality:

- 3.4.1 Steel shall be premium aircraft-quality conforming to AMS 2300 or
Ø MAM 2300; it shall be multiple melted using electroslag remelting practice in the remelt cycle.
- 3.4.2 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.
- 3.4.2.1 Bars and tubing ordered ground, turned, or polished shall be free from seams, laps, tears, and cracks open to the ground, turned, or polished surfaces.
- 3.4.2.2 Product ordered to surface conditions other than ground, turned, or
Ø 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 AS1182.
- 3.4.2.3 Forgings shall have substantially uniform macrostructure. Standards for
Ø acceptance shall be as agreed upon by purchaser and vendor.
- 3.4.2.4 Grain flow of die forgings, except in areas which contain flash-line end
Ø grain, shall follow the general contour of the forgings showing no evidence of re-entrant grain flow.
- 3.5 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).

3.6 Tolerances: Shall conform to all applicable requirements of the following:

3.6.1 Bars: AMS 2251 or MAM 2251.

3.6.2 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 requirements for
Ø composition (3.1), condition (3.2), inclusion rating (3.3.1), response to heat treatment (3.3.2), decarburization (3.3.3), quality (3.4.2), and tolerances (3.6) are classified as acceptance tests and shall be performed on each heat or lot as applicable.

- 4.2.2 Periodic Tests: Tests to determine conformance to requirements for frequency-severity cleanliness rating (3.4.1) 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 of forgings, 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 electroslag remelted ingots produced from steel originally melted as a single furnace charge:
- 4.3.1 Bars and Mechanical Tubing: AMS 2370.
- 4.3.2 Forgings and Forging Stock: AMS 2372.
- 4.3.3 Samples for macrostructure rating (3.3.1.1) shall be full cross-sectional specimens obtained from the finished billet or suitable rerolled product representing the top and bottom of at least the first, middle, and last usable ingots of each heat. When ingot location is not available, the lot shall be sampled on at least one end of 10% of the bars or billets.
- 4.3.4 Samples for micro-inclusion rating (3.3.1.2) shall consist of not less than six specimens obtained from the full cross-section of billet stock representing the top and bottom of at least the first, middle, and last usable ingot from each heat.
- 4.3.5 Samples for response to heat treatment (3.3.2) shall be as follows:
- 4.3.5.1 Specimens from bars shall be full cross-sections of the bar, ground on both faces normal to the axis so that length is 0.30 inch $\pm$ 0.010 (7.6 mm $\pm$ 0.25).
- 4.3.5.2 Specimens from mechanical tubing shall be full cross-sections of the tubing, shall have wall thickness not over 0.625 inch (15.88 mm), with wall thicknesses over 0.625 inch (15.88 mm) being turned to 0.625 inch $\pm$ 0.010 (15.88 mm $\pm$ 0.25), and shall be ground on both faces so that length is 0.30 inch $\pm$ 0.010 (7.6 mm $\pm$ 0.25).
- 4.4 Approval: When specified, approval and control of forgings shall be in accordance with AMS 2375.