Society of Automotive Engineers, Inc.
TWO PENNSYLVANIA PLAZA, NEW YORK, N.Y. 10001

AEROSPACE MATERIAL SPECIFICATION

AMS 6416A
Superseding AMS 6416
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STEEL BARS, FORGINGS, AND TUBING
1.62Si - 0.82Cr - 1.82Ni - 0.40Mo - 0.07V (0.41 - 0.46C)

1. SCOPE:

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

1.2 Application: Primarily for heat treated parts, such as pressure vessels, requiring through hardening to high strength levels. May be welded without undue difficulty.

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

2.1 SAE Publications: Available from Society of Automotive Engineers, Inc., Two Pennsylvania Plaza, New York, New York 10001.

2.1.1 Aerospace Material Specifications:

AMS 2251 - Tolerances, Alloy Steel Bars
AMS 2253 - Tolerances, Carbon and Alloy Steel Tubing
AMS 2259 - Chemical Check Analysis Limits, Wrought Low-Alloy and Carbon Steel
AMS 2301 - Aircraft Quality Steel Cleanliness, Magnetic Particle Inspection Procedure
AMS 2350 - Standards and Test Methods
AMS 2370 - Quality Assurance Sampling of Carbon and Low-Alloy Steels, Wrought Products Except Forgings
AMS 2372 - Quality Assurance Sampling of Carbon and Low-Alloy Steels, Forgings and Forging Stock
AMS 2375 - Approval and Control of Critical Forgings
AMS 2808 - Identification, Forgings

2.1.2 Aerospace Standards:

AS 1182 - 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, Pennsylvania, 19103.

ASTM A370 - Mechanical Testing of Steel Products
ASTM E45 - Determining the Inclusion Content of Steel
ASTM E112 - Estimating Average Grain Size of Metals
ASTM E350 - Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron
ASTM E381 - Rating Macroetched Steel

2.3 Government Publications: Available from Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania, 19120.

2.3.1 Federal Standards:

Federal Test Method Standard No. 151 - Metals, Test Methods

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 spectrographic methods in accordance with Federal Test Method Standard No. 151, Method 112, or by other approved analytical methods:

	min	max
Carbon	0.41	0.46
Manganese	0.60	0.90
Silicon	1.45	1.80
Phosphorus	--	0.015
Sulfur	--	0.015
Chromium	0.70	0.95
Nickel	1.65	2.00
Molybdenum	0.30	0.50
Vanadium	0.05	0.10
Copper	--	0.35

3.1.1 Check Analysis: Composition variations shall meet the requirements of AMS 2259, paragraph titled "Low Alloy Steels", except that check analysis limit for carbon shall be 0.01 under minimum or over maximum.

3.1.2 If size is over 100 sq in. (645 cm^2) in cross sectional area, the chemical composition and check analysis limits 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:

3.2.1 Bars:

3.2.1.1 Bars 0.500 In. (12.70 mm) and Under in Diameter or Distance Between Parallel Sides: Cold finished having tensile strength not higher than 130,000 psi (896 MPa) or equivalent hardness.

3.2.1.2 Bars Over 0.500 In. (12.70 mm) in Diameter or Distance Between Parallel Sides: Hot finished having hardness not higher than 241 HB or equivalent except that bars ordered cold finished may have hardness as high as 262 HB or equivalent.

3.2.2 Forgings: Normalized and tempered having hardness not higher than 248 HB or equivalent.

3.2.3 Mechanical Tubing: Cold finished having hardness not higher than 27 HRC or equivalent except that tubing ordered hot finished shall have hardness not higher than 23 HRC 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 and tensile testing shall be performed in accordance with ASTM A370:

3.3.1 Grain Size: Predominantly 5 or finer with occasional grains as large as 3 permissible, ASTM E112, McQuaid-Ehn test.

3.3.2 Macrostructure: Visual examination of transverse sections from bars, billets, tube rounds, and forging stock, etched in accordance with ASTM E381 in hot hydrochloric acid (1:1) at 160 - 180° F (71.1 - 82.2° C) for sufficient time to develop a well-defined macrostructure, shall show no injurious imperfections such as pipe, cracks, porosity, segregation, and inclusions detrimental to fabrication or to performance of parts. Macrostructure shall be equal to or better than the following macrographs of ASTM E381:

Section Size		
Square Inches	(Square Centimeters)	Macrographs
Up to 36, incl	(Up to 232, incl)	S2 - R1 - C2
Over 36 to 100, incl	(Over 232 to 645, incl)	S2 - R2 - C3
Over 100	(Over 645)	As agreed upon

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 Table II.

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

3.3.3.3 Decarburization of bars to which 3.3.3.1 or 3.3.3.2 is not applicable shall not be greater than shown in Table I.

TABLE I

Nominal Diameter or Distance Between Parallel Sides Inches	Depth of Decarburization Inches
Up to 0.375, incl	0.015
Over 0.375 to 0.500, incl	0.018
Over 0.500 to 0.625, incl	0.020
Over 0.625 to 1.000, incl	0.023
Over 1.000 to 1.500, incl	0.026
Over 1.500 to 2.000, incl	0.032
Over 2.000 to 2.500, incl	0.037
Over 2.500 to 3.000, incl	0.043
Over 3.000 to 4.000, incl	0.049

TABLE I (SI)

Nominal Diameter or Distance Between Parallel Sides Millimeters	Depth of Decarburization Millimeters
Up to 9.52, incl	0.38
Over 9.52 to 12.70, incl	0.46
Over 12.70 to 15.88, incl	0.51
Over 15.88 to 25.40, incl	0.58
Over 25.40 to 38.10, incl	0.66
Over 38.10 to 50.80, incl	0.81
Over 50.80 to 63.50, incl	0.94
Over 63.50 to 76.20, incl	1.09
Over 76.20 to 101.60, incl	1.24

3.3.3.3.1 Limits for depth of decarburization of bars over 4.000 in. (101.60 mm) in diameter or distance between parallel sides shall be as agreed upon by purchaser and vendor.

3.3.3.4 Decarburization of tubing to which 3.3.3.1 or 3.3.3.2 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 Millimeters	Depth of Decarburization, Millimeters	
	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

3.3.3.5 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 in. (0.13 mm) and the width is 0.065 in. (1.65 mm) or less.

3.3.4 Inclusion Rating: Two-thirds of all specimens, as well as the average of all specimens, shall not exceed the following limits, determined in accordance with ASTM E45, Method A:

Series	Type			
	A	B	C	D
Thin	2.0	2.0	2.0	2.0
Heavy	1.5	1.5	1.5	1.5

3.3.5 Response to Heat Treatment: Specimens, normalized by heating to 1700° F ± 10° (926.7° C ± 5.6°), holding at heat for approximately 1 hr and cooling in air; hardened by heating to 1600° F ± 10° (871.1° C ± 5.6°), holding at heat for approximately 1 hr, and quenching in oil; and then tempered by heating to 600° F ± 10° (315.6° C ± 5.6°), holding at heat for 2 - 3 hr, and cooling in air, shall have the following properties:

Tensile Strength, min	280,000 psi (1931 MPa)
Yield Strength at 0.2% Offset, min	230,000 psi (1586 MPa)
Elongation in 2 in (50.8 mm) or 4D, min	7%
Reduction of Area, min	
Parallel to Grain Flow	20%
Transverse to Grain Flow (at mid-radius)	8%

3.4 Quality: Steel shall be aircraft quality conforming to AMS 2301. The product shall be uniform in quality and condition, clean, sound, and free from foreign materials and from internal and external imperfections detrimental to fabrication or to performance of parts.

3.4.1 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 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 Sizes: Except when exact lengths or multiples of exact lengths are ordered, bars and tubing shall be acceptable in mill lengths of 6 - 20 ft (1.8 - 6.1 m) but not more than 10% of any shipment shall be supplied in lengths shorter than 10 ft (3 m).

3.6 Tolerances: Unless otherwise specified, tolerances shall conform to all applicable requirements of the following:

3.6.1 Bars: AMS 2251.

3.6.2 Mechanical Tubing: AMS 2253.

4. QUALITY ASSURANCE PROVISIONS:

4.1 Responsibility for Inspection: The vendor of the product shall supply all samples 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 perform such confirmatory testing as he deems necessary to assure that the product conforms to the requirements of this specification.

4.2 Classification of Tests: Tests to determine conformance to all technical requirements of this specification are classified as acceptance or routine control tests.

4.3 Sampling: Shall be in accordance with the following:

4.3.1 Bars and Mechanical Tubing: AMS 2370.

4.3.2 Forgings and Forging Stock: AMS 2372.

4.3.3 Macrostructure: Specimens for macrostructure (3.3.2) testing shall represent the full cross-section of stock taken from the top and bottom of at least the first, middle, and last usable ingots of each heat. Samples shall be full cross-sectional specimens obtained from the finished billet or a suitable rerolled product.