

AEROSPACE MATERIAL SPECIFICATION

Submitted for recognition as an American National Standard

AMS 6445E

Issued 7-15-63
Revised 1-1-89

Superseding AMS 6445D

STEEL BARS, FORGINGS, AND TUBING
1.05Cr - 1.1Mn (0.92 - 1.02C) (Modified 51100)
Consumable Electrode Vacuum Melted

UNS K22097

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 critical bearing components requiring a through-hardening steel, usually with hardness of approximately 60 HRC and section thicknesses of 0.40 to 0.80 inch (10.2 to 20.3 mm), 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.

SAE Technical Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any particular infringement arising therefrom, is the sole responsibility of the user."

AMS documents are protected under United States and international copyright laws. Reproduction of these documents by any means is strictly prohibited without the written consent of the publisher.

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 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

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

	min	max
Carbon	0.92	1.02
Manganese	0.95	1.25
Silicon	0.50	0.70
Phosphorus	--	0.015
Sulfur	--	0.015
Chromium	0.90	1.15
Nickel	--	0.25
Molybdenum	--	0.08
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. 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: Cold finished, with microstructure of spheroidized cementite in ferrite matrix, having tensile strength not higher than 120,000 psi (827 MPa).

- 3.2.1.2 Bars Over 0.500 Inch (12.70 mm) in Nominal Diameter or Distance Between Parallel Sides: Hot finished, 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. Heat treatment shall be in accordance with MIL-H-6875.

- 3.2.3 Mechanical Tubing: Cold finished with microstructure of spheroidized cementite in ferrite matrix and having hardness not higher than 24 HRC, or equivalent. Tubing ordered hot finished with microstructure of spheroidized cementite in ferrite matrix 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 for product 36 square inches (232 cm²) 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 cm²) 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

3.3.1.1.1 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: 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	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 No. 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 $1530^{\circ}\text{F} \pm 15$, ($832^{\circ}\text{C} \pm 8$), allowed to heat to $1530^{\circ}\text{F} \pm 15$, ($832^{\circ}\text{C} \pm 8$), held at heat for 30 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 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 Inches	Depth of Decarburization Inch
Up to 0.500, incl	0.015
Over 0.500 to 1.000, incl	0.020
Over 1.000 to 1.500, incl	0.025
Over 1.500 to 2.000, incl	0.030
Over 2.000 to 2.500, incl	0.035
Over 2.500 to 3.000, incl	0.040
Over 3.000	0.045

TABLE I (SI)

Nominal Diameter or Distance Between Parallel Sides Millimetres	Depth of Decarburization Millimetres
Up to 12.70, incl	0.38
Over 12.70 to 25.40, incl	0.51
Over 25.40 to 38.10, incl	0.64
Over 38.10 to 50.80, incl	0.76
Over 50.80 to 63.50, incl	0.89
Over 63.50 to 76.20, incl	1.02
Over 76.20	1.14

3.3.3.4 Decarburization on the ID and OD of all tubing to which 3.3.3.1 or 3.3.3.2 is not applicable shall be not greater than 0.025 inch (0.64 mm) on the ID and 0.025 inch (0.64 mm) on the outside diameter.

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 MAM 2300; it shall be multiple melted using consumable electrode vacuum process 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 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 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 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
Ø 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
Ø 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 is 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 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 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 ingot of each heat. If heat approval testing has not been accomplished, a suitable option shall be sampling the top and bottom of the applicable ingot.

- 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 taken from the top and bottom of at least the first, middle, and last usable ingots from each heat. If heat approval testing has not been accomplished, a suitable option shall be sampling the top and bottom of the applicable ingot.
- 4.3.5 Samples for response to heat treatment (3.3.2) shall be as follows:
- 4.3.5.1 Specimens from bars and billets shall be full cross-sections of the product, ground on both faces normal to the axis so that length is $0.75 \text{ inch} \pm 0.010$ ($19.0 \text{ mm} \pm 0.25$).
- 4.3.5.2 Specimens from mechanical tubing shall be full cross-sections of the tubing, shall have wall thickness not over 0.75 inch (19.0 mm) with wall thicknesses over 0.75 inch (19.0 mm) being turned to $0.75 \text{ inch} \pm 0.010$ ($19.0 \text{ mm} \pm 0.25$), and shall be ground on both faces so that length is $0.625 \text{ inch} \pm 0.010$ ($15.88 \text{ mm} \pm 0.25$).
- 4.4 Approval: When specified, approval and control of forgings shall be in accordance with AMS 2375.
- 4.5 Reports:
- 4.5.1 The vendor of bars, forgings, and mechanical tubing shall furnish with each shipment a report showing the results of tests for chemical composition, inclusion rating, of each heat and for response to heat treatment of each lot and, when performed, results of tests to determine conformance to the periodic test requirements. This report shall include the purchase order number, heat number, AMS 6445E, size, and quantity. If forgings are supplied, the part number and the size and melt source of stock used to make the forgings shall also be included.
- 4.5.2 The vendor of forging stock shall furnish with each shipment a report showing the results of tests for chemical composition and frequency-severity cleanliness rating of each heat. This report shall include the purchase order number, heat number, AMS 6445E, size, and quantity.
- 4.5.3 The vendor of finished or semi-finished parts shall furnish with each shipment a report showing the purchase order number, AMS 6445E, contractor or other direct supplier of product, part number, and quantity. When product for making parts is produced or purchased by the parts vendor, that vendor shall inspect each lot of product to determine conformance to the requirements of this specification and shall include in the report either a statement that the product conforms or copies of laboratory reports showing the results of tests to determine conformance.
- 4.6 Resampling and Retesting: Shall be in accordance with the following:
- 4.6.1 Bars and Mechanical Tubing: AMS 2370.
- 4.6.2 Forgings and Forging Stock: AMS 2372.